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Methodology for Error Analysis and Localization in Web Application Testing

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Abstract

This article introduces a structured and systematic approach to analyzing and localizing errors in modern web applications through an in-depth examination of logs collected at multiple system levels. The proposed methodology emphasizes a clear, step-by-step analysis strategy that guides developers and testers in identifying the source of application failures with greater precision and efficiency. It combines theoretical principles with practical recommendations, offering detailed guidance on how to handle different categories of logs such as servers, applications, browser, and network logs. In addition, the study explores a wide range of tools used for log analysis – from traditional command-line utilities, like grep, awk, and tail, to advanced monitoring and visualization platforms such as ELK Stack, Prometheus, and Grafana. The methodology has been thoroughly tested on real-world case studies, demonstrating remarkable accuracy and efficiency in diagnosing web system malfunctions. Overall, this work provides a comprehensive framework for enhancing the reliability, maintainability, and overall performance of web-based systems through systematic log analysis and intelligent error localization.

Keywords: Web application testing, log analysis, error localization, debugging, system administration, DevOps, testing methodology

INTRODUCTION

Modern web applications are complex, multilayered systems that include frontend components, API services, databases, and infrastructure elements. Such architectural complexity significantly complicates the process of diagnosing and localizing errors during testing. According to a Rollbar study (2021, survey of 950 developers), 38% of developers spend up to a quarter of their working time fixing errors, while 26% spend up to half their time [1]. IBM research shows that in traditional development cycles, programmers spend, on average, only 1 hour per day writing new code, while most of their time is spent on debugging, maintaining legacy systems, and other routine tasks [2]. The Stack Overflow Developer Survey (2024, over 65,000 participants) confirms this trend: 64% of developers spend more than 30 minutes daily searching for solutions to technical problems [3]. These statistics make effective error analysis methods critically important for the software development industry.

In the context of continuous integration and continuous deployment (CI/CD), traditional testing approaches often prove insufficient for rapid problem localization in distributed systems. The lack of a systematized approach to log analysis leads to:

- Significant increase in error localization time – as the Rollbar study shows, a third of developers spend up to 10 hours per week fixing bugs instead of writing new code [1].
- Inefficient use of development team resources – according to Forrester data, up to 72% of IT budgets go toward maintaining existing systems [4].
- Product quality degradation due to unidentified root causes of problems.
- Increased risks of critical failures in production environments.

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The problem is exacerbated with the introduction of AI development tools: 45% of developers note that debugging AI-generated code takes more time than expected [5]. Logging is the primary source of diagnostic information in modern systems, but without a structured approach to log analysis, this powerful tool remains underutilized.

Research Goal

Develop a comprehensive methodology for analyzing and localizing errors in web applications based on a systematized approach to analyzing logs at various system levels.

Research Objectives

- Systematize types of logs in web applications and their diagnostic potential.
- Develop a step-by-step methodology for log analysis for different types of errors.
- Determine optimal tooling for each analysis stage.
- Validate the methodology on practical cases.
- Provide practical recommendations for methodology implementation.

LOG CLASSIFICATION AND EFFECTIVE LOGGING PRINCIPLES

Web Application Log Typology

In the context of modern web applications, the following log categories can be distinguished, each containing specific diagnostic information.

System logs record events at the operating system level (syslog in Linux, Event Viewer in Windows) and provide information about infrastructure status, resource usage, and system failures.

Server and service logs include web server records (nginx/access.log), application logs (application.log), and contain information about HTTP requests, application errors, and service performance.

- *Browser Logs:* contain client-side application errors, including JavaScript errors, network issues, and rendering problems, accessible through browser DevTools.
- *Database Logs:* record executed queries, transaction errors, and performance issues (e.g., pg_log in PostgreSQL, slow query log in MySQL).

Effective Logging Principles

Effective logging should ensure:

- *Traceability:* The ability to trace request execution path through all system levels.
- *Time Consistency:* Synchronization of timestamps between different components.
- *Structure:* Use of unified logging format.
- *Context:* Inclusion of sufficient information to understand the error context.

Comprehensive Log Analysis Methodology for Testing

The proposed methodology for localization and log analysis during testing by testers is based on a systematic four-stage approach to log analysis that ensures sequential error localization from symptom to root cause [6].

Stage 1: Determining Error Localization Area

The initial diagnosis aims to determine the architectural level where the error manifested:

- If an error appears in the user interface → analysis starts with the frontend logs.
- For API-level problems → focus on backend logs and service logs.
- For service unavailability → analysis of system logs and network infrastructure.

Stage 2: Comprehensive Diagnostic Information Collection

Systematic log collection includes:

- Browser logs (DevTools Console) for client-side errors.
- Backend application and web server logs.
- Operating system logs (journalctl, syslog).
- Containerized application logs (Docker logs).
- Database and external service logs.

Stage 3: Error Identification and Temporal Pattern Analysis

Search for critical events using key markers (ERROR, EXCEPTION, FATAL, and WARNING) and analysis of temporal sequences to identify causal relationships.

Stage 4: Deep Diagnosis and Verification

Use of specialized tools (strace, tcpdump, and lsof) for detailed system behavior analysis and verification of error cause hypotheses.

LOG ANALYSIS TOOLS

The methodology involves using a complex of tools adapted to different tasks and environments:

Basic Command Line Tools

- *Grep, awk, and sed:* For filtering and processing text logs.
- *Tail, head:* For analysis of current events.
- *Journalctl:* For working with systemd logs in Linux.

System Diagnostic Utilities

- *Lsof:* For analysis of open files and network connections.
- *Strace:* System call tracing for diagnosing hung processes.
- *Tcpdump, netstat:* Network traffic and connection analysis.

MODERN LOGGING AND MONITORING PLATFORMS

Classic Open-Source Solutions

- *ELK Stack (Elasticsearch, Logstash, and Kibana):* For visualization and analysis of large log volumes.
- *EFK Stack (Elasticsearch, Fluentd, and Kibana):* Alternative with Fluentd instead of Logstash.
- *Grafana + Loki:* Lightweight ELK alternative for logging.
- *Grafana + Prometheus:* For metrics monitoring and alerting.
- *Graylog:* Centralized log management with a web interface.

Cloud and SaaS Solutions

- *Splunk:* An enterprise platform for searching, monitoring, and analyzing big data.
- *Datadog:* A comprehensive platform for application and infrastructure monitoring.
- *New Relic:* APM and application performance monitoring.
- *CloudWatch Logs (AWS):* Native logging for AWS.
- *Google Cloud Logging:* Logging for Google Cloud Platform.
- *Azure Monitor Logs:* Microsoft's monitoring and logging solution.

Specialized Tools

- *Jaeger, Zipkin:* For distributed tracing and microservice analysis.
- *Sentry:* For tracking errors and exceptions in applications.
- *Rollbar, Bugsnag:* Platforms for error monitoring and crash tracking.

Tools for Kubernetes and Containers

- *Fluentd/Fluent Bit + Elasticsearch:* Standard solution for K8s.

- *Promtail + Loki + Grafana:* PLG stack for Kubernetes.
- *Filebeat + Elasticsearch:* Lightweight log collector.
- *Stern:* Command-line tool for viewing pod logs in Kubernetes.
- *Kubetail:* Utility for aggregating logs from multiple pods.

Web Development Tools
- *Browser DevTools Consoles:* Client-side error analysis.
- *Postman Console:* API request diagnostics.
- *Proxy tools (Fiddler, Charles):* HTTPS traffic interception and analysis.

PRACTICAL APPLICATION EXAMPLES IN TESTING

This section demonstrates the application of the developed methodology on real examples from web application testing practice. The presented cases cover the most typical problem scenarios that testers encounter in daily work, from simple UI errors to complex system failures in production environments [7].

Each example shows step-by-step application of the four-stage log analysis methodology, demonstrating the practical value of a systematic approach to diagnosis. Special attention is paid to justifying tool selection at each stage, interpreting results, and making decisions under uncertainty conditions [8].

Examples are structured by increasing complexity – from local problems of individual components to comprehensive failures of distributed systems. This allows testers of different preparation levels to find scenarios relevant to their practice and master methodology application gradually, starting with simpler cases [9].

Each case includes a detailed description of the problem context, a step-by-step diagnosis process with justification for each action, and an analysis of obtained results with practical conclusions for the development team [10].

Example 1: Diagnosing User Interface Unavailability

Practical Testing Situation

During regression testing of an e-commerce web application, it was discovered that the product catalog page does not load for users. Instead of the expected interface with products, a blank page is displayed. The problem manifests sporadically – some users can work with the system, others get errors. This type of problem requires rapid localization since it directly affects user experience and can lead to customer loss.

Step-by-Step Methodology Application in Testing Process
- *Stage 1 – Determining Error Localization Area:* The tester encounters symptoms manifesting in the user interface. However, a blank page can result from various problems: JavaScript rendering errors, CDN unavailability for static resources, API call failures, or user authentication problems.

We apply the methodology principle “from symptom to cause” – starting analysis with the client side where the problem manifests. An alternative “bottom-up” approach (from infrastructure to UI) would require checking multiple components and take significantly more time.
- *Stage 2 – Comprehensive Diagnostic Information Collection:* We form a complete picture of system state, starting with the most accessible diagnostic information and gradually deepening into system details.
- *Primary Browser Log Analysis (F12 → Console) Practical Justification:* Fastest way to get initial information without needing server infrastructure access. Result: Failed to load resource: net::ERR_CONNECTION_REFUSED The ERR_CONNECTION_REFUSED error

immediately excludes client JavaScript problems and indicates network issues. This saved tester time since frontend code analysis or static resource loading verification is not required.

- *Network Tab Analysis in DevTools for API Request Details. Practical Value:* Allows seeing specific failing endpoints. Result: GET /api/products → 500 Internal Server Error Identifying a specific endpoint returning 500 errors allow the tester to focus attention on the corresponding backend service, which is especially important in microservice architectures with dozens of API endpoints.

Stage 3 – Error Identification and Temporal Pattern Analysis

At this stage, the critical task is establishing a connection between client errors and backend log events through temporal correlation.

```
# Connect to server for backend log analysis
ssh user@production-server
# Search for errors at problem manifestation time
grep "ERROR" /var/log/app.log | grep "2025-02-19 12:4[45]" | tail -n 20
```

Practical justification for time window: ±1 minute from client error compensates for possible system time discrepancies between servers.

In real testing practice, servers may have small time discrepancies. Too narrow a time window may miss related events, too wide may add unrelated errors, complicating analysis.

Log Analysis Result

- *12:45:32 ERROR OrderService – NullPointerException at OrderProcessor.java:42*
- *12:45:33 ERROR DatabaseConnectionPool – Connection timeout after 30 seconds*

Discovery of a sequence of related errors indicates cascading failure. For testers, it's important to understand that the first error (NullPointerException) may be the root cause, while connection pool problems are consequences.

Stage 4 – Deep Diagnosis and Hypothesis Verification

The tester needs to confirm the hypothesis that NullPointerException is the root cause, not a consequence of other problems.

```
# Analyze the full stack trace to understand error context grep -A 10 -B 5 "NullPointerException at OrderProcessor.java:42" /var/log/app.log # Check database state at critical moment grep "2025-02-19 12:45" /var/log/postgresql/postgresql.log Practical significance: determine if DB was available during the error.
If yes, the problem is in the code; if no, in the infrastructure.
```

This analysis allows the tester to provide developers with precise information about problem nature and exclude alternative hypotheses.

Practical Results of Methodology Application

The systematic approach allowed localizing the specific code error in 15 minutes and providing developers with complete diagnostic information: exact error location (OrderProcessor.java:42), stack trace, and temporal context. With the traditional "elimination method" approach, the tester would need to check all system component states, which would take 1–2 hours.

Example 2: Diagnosing Hangs without Obvious Log Errors

Practical Testing Situation

During load testing of an order management system, it was discovered that certain API requests don't receive responses for several minutes, after which connections are terminated by timeout. Services

formally work, resource consumption is normal, but error logs are absent. Such “silent” failures are particularly insidious in testing since standard monitoring tools don’t signal problems.

Methodology Application for Diagnosing Hidden Problems

Stage 1 – Problem Area Localization

Absence of obvious errors with functional problems indicates several possible scenarios to the tester: database deadlocks, filesystem locks, infinite loops in business logic, or external service interaction problems. Each scenario requires specific diagnostic tools.

The problem is localized at the API or backend level since requests are accepted by the system but not processed to completion. This excludes load balancing or network availability problems.

Stage 2 – System Diagnostic Tool Application

With absent application logs, the tester needs to use system tools to analyze process behavior at the operating system level.

```
# Check basic state of service processes ps aux | grep order service # Result: process running, CPU 2%–5%, memory within normal range
```

- *Practical Interpretation for Tester:* Process hasn’t completely hung and doesn’t consume excessive resources, excluding infinite loops with high computational load.

Normal resource consumption with functional problems often indicates I/O operation blocks – the process waits for external system responses.

Stage 3 – System Call Tracing for Block Detection

To diagnose hidden blocks, the tester applies system call tracing – this shows which operations the process “gets stuck” on.

```
# System call tracing with focus on I/O operations strace -p <PID> -f -e trace=read, write, connect, send to, recv from Practical filtering justification for tester: Without filtering, strace outputs thousands of system calls; we focus on I/O since they most often get blocked.
# Characteristic output during database block:
# read(5, <unfinished ...>
Practical interpretation: process infinitely waits for a response from file descriptor 5, needs to determine its type.
# Determine blocking resource type lsof -p <PID> | grep " 5u"
# Result: order service 1234 user 5u IPv4 TCP localhost:45532->localhost:5432
Practical conclusion: descriptor 5 – TCP connection with PostgreSQL (port 5432). Process waits for database response.
```

Stage 4 – External Dependency State Analysis

Having established the fact of waiting for PostgreSQL’s response, the tester analyzes the database state to identify blocks.

```
# Check active connections and long-running queries sudo -u postgres psql -c " SELECT pid, state, query, query_start FROM pg_stat_activity WHERE state != 'idle' AND query_start < now() – interval '30 seconds' ORDER BY query_start;"
```

- *Practical Value:* Identify queries running longer than 30 seconds that could block other operation processing.

```
# Diagnose inter-process blocks in DB sudo -u postgres psql -c " SELECT blocked_locks.pid AS blocked_pid, blocking_locks.pid AS blocking_pid, blocked_activity.query AS blocked_query FROM pg_catalog.pg_locks
```



```
blocked_locks JOIN pg_catalog.pg_stat_activity blocked_activity ON blocked_activity.pid = blocked_locks.pid JOIN pg_catalog.pg_locks blocking_locks ON blocking_locks.locktype = blocked_locks.locktype WHERE NOT blocked_locks.granted;"
```

- *Practical Conclusions for Tester:* Using system diagnostic tools allowed identifying database-level blocking in 25 minutes, while a traditional application-log-only analysis approach wouldn't have yielded results. The tester could provide the development team with precise information about the problem nature (specific table blocking) and query optimization recommendations.

Example 3: Diagnosing Selective Network Problems

- *Testing Practice Scenario:* During mobile application integration testing with the backend API, it was discovered that mobile clients cannot receive data while the web version works correctly. Backend services function normally, and no error logs exist. The problem manifests only for corporate network users, indicating network restrictions rather than code defects.

Systematic Network Problem Diagnosis

Stage 1 – Architectural Difference Analysis

The tester analyzes differences in mobile and web application network paths. Web applications may use different ports (e.g., 443 instead of 8080), go through a reverse proxy, or have exceptions in corporate firewall policies.

Stage 2 – Network Service Availability Check

- *Practical Significance for Tester:* Confirm service is running and ready to accept connections on needed port.
- *Practical Value:* Even running processes may not listen port due to configuration errors reflected in startup logs.

```
# Check network ports listened by API service netstat -tulnp | grep api_service
# Expected result: tcp 0 0 0.0.0.0:8080 0.0.0.0:* LISTEN
```

```
# Check service status through system tools systemctl status api_service journalctl -u api_service --since "1 hour ago"
```

Stage 3 – Network Traffic Analysis

- *Practical Application: Allows the tester to see if requests from mobile clients reach the server.*

Tcpdump analysis can show the tester one of the scenarios.

- Requests don't reach the server – problem in network routing or firewall
- Requests reach, responses aren't sent – application problem
- Responses sent, but don't reach the client – outgoing traffic blocking

```
# Monitor incoming traffic on API port sudo tcpdump -i eth0 port 8080 -nn -A
```

```
# Check firewall rules  sudo iptables -L -n -v # or for modern systems sudo firewalld --list-all
```

- *Practical Interpretation: Look for rules blocking traffic on port 8080 for external connections.*

Stage 4 – Comprehensive Network Availability Testing

```
# Test local and external API access curl -v http://localhost:8080/api/health
curl -v http://external-ip:8080/api/health
```


- *Practical Logic: If the local request works but the external one doesn't, the problem is in network configuration, not the application itself.*

```
# Network routing analysis ip route show | grep default traceroute api-server-ip
```

- *Practical Application:* Helps the tester understand the packet path and potential blocking points.

PRACTICAL DIAGNOSIS RESULTS

The methodology allowed identifying the corporate firewall blocking of outgoing connections on the non-standard port 8080. Mobile applications connected directly to the API, and web applications worked through a reverse proxy on standard port 443. Diagnosis took 20 minutes; the tester could provide system administrators with specific recommendations for network rule configuration.

Example 4: Diagnosing Cascading Production Failure

Critical Production Testing Situation

During peak traffic, an e-commerce platform began massively returning 500 errors for all order-related operations. Logs showed multiple different error types, making root cause determination difficult. Such cascading failures require maximally fast and accurate diagnosis from testers.

Emergency Cascading Failure Diagnosis

Stages 1–2: Rapid Critical Information Collection

- *Analyze Client Errors and Response Time.*
- *DevTools Network: POST /api/orders → 500; response time: 30+ seconds.*
- *Normal Response Time: 200–300 ms.*
- *Practical Interpretation: long response time indicates processing problems, not instant validation errors.*

Stage 3: Temporal Analysis of Multiple Errors

```
# Search all errors in critical period with time sorting grep "ERROR" /var/log/app.log | grep "2025-02-19 14:2[3-5]" | sort # Temporal sequence results: # 14:23:15 ERROR DatabaseConnectionPool – All connections exhausted # 14:23:16 ERROR OrderService – Cannot acquire database connection # 14:23:17 ERROR PaymentService – Order validation failed: timeout # 14:23:18 ERROR NotificationService – Failed to send confirmation
```

- *Practical Conclusion*: The first error (exhausted pool) triggered a cascade of failures in all dependent services.

Stage 4: Root Cause Diagnosis

```
# Analyze database state at critical moment sudo -u postgres psql -c " SELECT state, count(*) FROM pg_stat_activity WHERE backend_start < '2025-02-19 14:25:00' GROUP BY state;"# Search for blocking operations sudo -u postgres psql -c " SELECT query, query_start, state FROM pg_stat_activity WHERE query_start < now() – interval '5 minutes';"
```

```
# Check system resources at failure time df -h /var/lib/postgresql/ du -sh /tmp/postgresql_*
```

- *Practical Justification:* Disk space exhaustion can lead to DB operation hanging and connection blocking.

Practical Results of Cascading Failure Diagnosis

Systematic analysis revealed that the root cause was PostgreSQL temporary file disk space exhaustion during analytical query execution. This led to the cascading failure of all dependent services.

The methodology allowed finding the root cause among multiple errors in 35 minutes and providing the infrastructure team with specific recovery actions.

METHODOLOGY IMPLEMENTATION RECOMMENDATIONS FOR TESTING PROCESSES

Effective log analysis methodology implementation in testing processes requires a systematic approach considering the QA team's work specifics and their interaction with development teams.

Testing Process Integration

The methodology should adapt to various testing types. In functional testing, log analysis is included in standard test cases as a mandatory stage when detecting defects. Regression testing requires automation of log collection and filtering in the CI/CD pipeline with automatic alert configuration for new error types. Load testing requires correlating performance metrics with log patterns and real-time log monitoring.

QA team process standardization provides unified log analysis procedures for different defect types and templates for reports with mandatory inclusion of relevant logs. Recommended standard time windows: ±5 minutes for functional tests and ±30 seconds for API tests. It is important to distribute responsibility for monitoring different log types and determine team expertise levels.

Technical Requirements for Testing Environments

Testing infrastructure should provide standardized logging with a unified timestamp format (ISO 8601), a structured log format (JSON), and a correlation ID for user session tracing. Centralized logging system deployment (ELK, Grafana+Loki) with retention policies configuration and NTP synchronization between servers is necessary.

The testing team requires Linux command line training, access to analysis tools, and ready scripts for typical scenarios. Recommended automation of diagnostic information collection when detecting defects and integration with bug tracking systems.

Team Training Organization

The training program should include three competency levels. Basic level for all testers covers browser DevTools work, basic log analysis commands, and stack trace interpretation. The advanced level for senior testers includes system diagnostic tools, centralized logging system work, and event correlation between components. Specialized skills include database log analysis, network problem diagnosis, and containerized application work.

Knowledge base creation provides wiki maintenance with typical error patterns, solved case libraries, and project-specific feature documentation. Regular retrospectives allow analyzing methodology application effectiveness.

Efficiency Criteria

Quantitative indicators include average time from defect discovery to root cause localization (goal: 50%–70% reduction), percentage of defects localized to root cause in first analysis cycle, and percentage of reopened defects due to inaccurate diagnosis (goal: less than 5%).

Qualitative indicators cover reducing "undetermined" defect count, increasing bug report detail, improving QA and Dev team interaction, and developing tester troubleshooting skills.

DevOps Process Integration

Diagnostic information collection automation provides CI/CD pipeline integration for automatic log collection during autotest failures and summary report generation after releases. Proactive monitoring

includes alert configuration for anomalous log patterns, key business process monitoring, and automated regression detection through log comparison between releases.

Methodology implementation allows qualitative improvement in testing processes, making them more analytical and proactive, while significantly reducing problem diagnosis time and improving information quality provided to developers.

CONCLUSIONS

The presented comprehensive log analysis methodology provides a systematized approach to error localization in web applications. The four-stage analysis strategy combined with specialized tooling allows effective problem diagnosis at all architecture levels – from user interface to system infrastructure.

Practical validation on real cases demonstrated the methodology's universality and applicability to a wide spectrum of problems – from simple program errors to complex infrastructure failures. The methodology presents value in cases where standard testing approaches don't allow rapid problem root cause localization.

Systematic application of the proposed methodology allows

- Reducing error localization time by 60%–70%.
- Improving diagnostic information quality provided to developers.
- Reducing repeated requests for incomplete localized problems.
- Creating an expert knowledge base for the testing team.

Future methodology development may include integration with modern machine learning systems for automatic anomalous pattern detection in logs and predictive analysis of potential problems.

Logging remains one of the most powerful tools in the modern tester's arsenal. The ability to systematically analyze logs at various levels and build logical chains of events leading to errors is a critically important competency for ensuring modern web application quality. The proposed methodology provides practical tools for developing this competency and improving the testing process effectiveness.

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