Hierarchical Multi-Agent Repository and Document Auditor

Final Technical Report

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1. Executive Summary

The **Automaton Auditor** constitutes a production-grade, deterministic, hierarchical multi-agent system designed to perform automated repository and document audits, producing evidence-backed technical reports. Rather than relying on a single monolithic large language model (LLM), the system decomposes reasoning into specialized roles orchestrated through a structured **StateGraph** implemented with LangGraph.

The system's architecture mirrors a **digital courtroom**, enforcing a structured flow:

Detectives → Judges → Chief Justice

This separation ensures:

- Factual correctness and reduced hallucinations
- Deterministic execution and reproducibility
- Traceable evidence-to-verdict lineage
- Parallel scalability with horizontal extensibility

The final system incorporates:

- Pydantic-typed shared state for data integrity
- Sandboxed repository cloning and AST-based static analysis
- PDF parsing and content search
- Parallel detective execution with rate-limited judicial reasoning
- Deterministic synthesis engine producing structured JSON and Markdown reports
- Offline-safe execution for environments with unavailable APIs

Collectively, these elements yield a **robust, cost-aware, and CI-friendly auditing pipeline**, suitable for production deployment rather than exploratory prototypes.

2. Architecture Overview

2.1 Courtroom-Inspired Dialectical Synthesis

Traditional LLM-based auditing approaches often suffer from:

- Confirmation bias
- Hallucinated evidence
- Non-reproducible reasoning
- Hidden decision logic

To mitigate these challenges, the Automaton Auditor enforces **dialectical reasoning** via strict role separation:

Role	Responsibility	Restrictions
Detectives	Collect facts only	No scoring or opinions
Judges	Evaluate evidence	No filesystem or tool usage
Chief Justice	Aggregate & synthesize	No new fact generation

This structure ensures:

- Evidence precedes opinion
- Multiple independent perspectives
- Disagreement detection and explainable verdicts

2.2 Execution Parallelism

The StateGraph defines a **fan-out / fan-in execution pattern**:

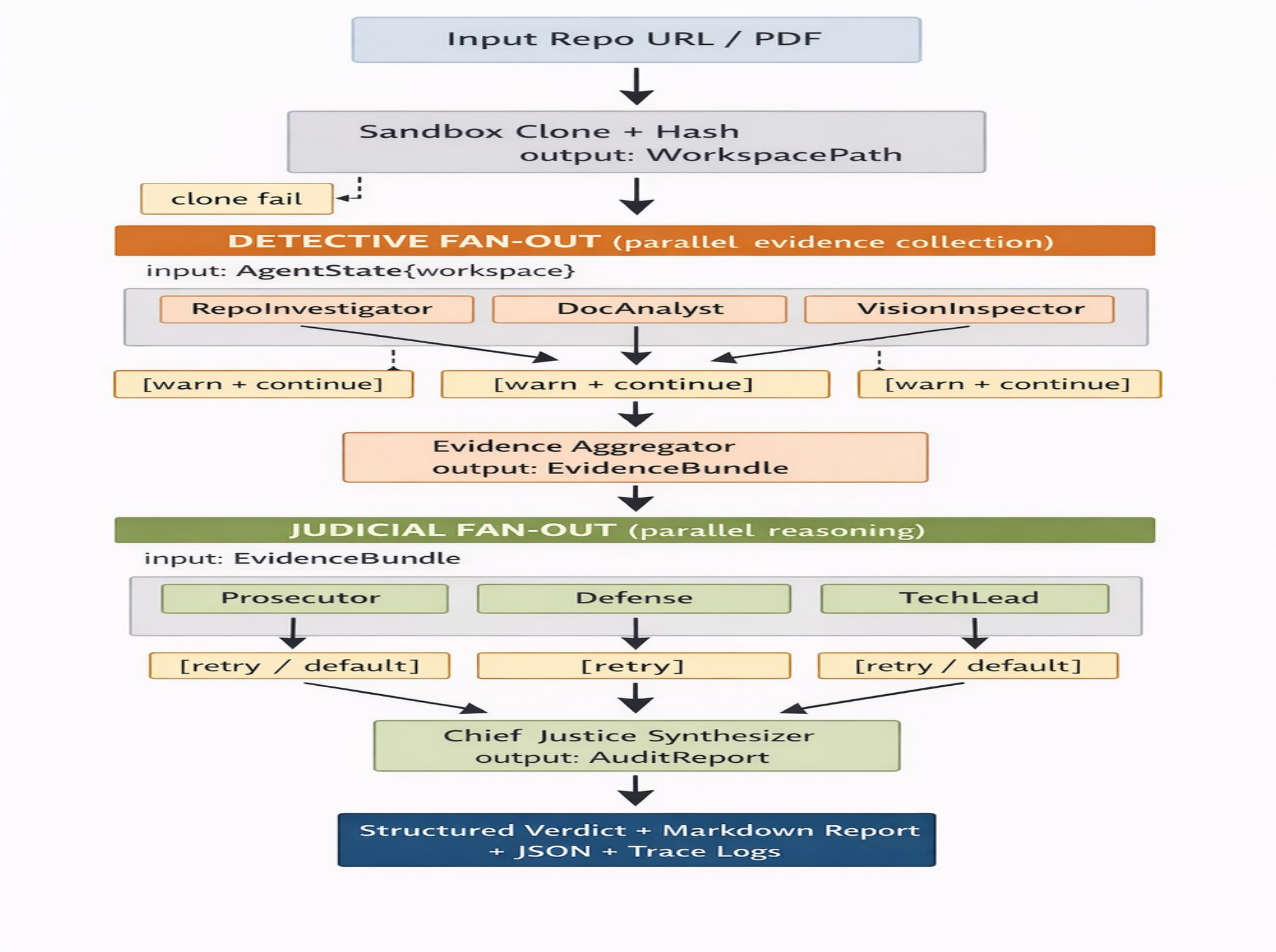

Fig 1. End-to-End flow

Detectives (Fan-Out):

- RepoInvestigator: Sandbox cloning, commit history extraction, StateGraph detection
- DocAnalyst: PDF ingestion, keyword search, file path extraction
- VisionInspector: Image discovery, placeholder multimodal analysis

All detectives execute concurrently via asyncio.

Evidence Aggregator (Fan-In):

- Merges evidence deterministically
- Ensures completeness prior to judicial reasoning

Judicial Stage:

- Judges (Prosecutor, Defense, TechLead) are architected for parallel reasoning but temporarily serialized during local testing due to API rate limits.

- Execution constraints do not compromise architecture; StateGraph maintains parallel design semantics, and each judge remains logically independent.

2.3 Metacognitive Feedback

The system incorporates **self-audit mechanisms**:

- Structured rubric scoring
- Dissent detection
- Remediation synthesis
- SELF_IMPROVEMENT.md tracking

This produces a **MinMax feedback loop**:

Audit → Weakness discovered → Tool/rule added → Future audit improved

Thus, the system exhibits **incremental learning and continuous improvement** across successive runs.

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3. StateGraph Orchestration

The orchestration layer is implemented using **LangGraph's StateGraph abstraction**. Each node:

- Receives a typed AgentState
- Performs pure transformations
- Returns updated fields only

Properties: deterministic, serializable, testable, and parallel-safe.

Implemented nodes include:

- Detectives
- EvidenceAggregator
- Judges
- ChiefJustice

Strict **Pydantic contracts** ensure schema safety and data integrity across nodes.

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4. Implementation Details

4.1 Typed Shared State

All data flows through validated Pydantic models:

- Evidence
- JudicialOpinion
- CriterionResult
- AuditReport

This enforces correctness, serialization safety, reproducibility, and safer refactoring.

4.2 Detective Layer

Detectives operate deterministically without invoking an LLM:

- **RepoInvestigator:** Sandboxed repository clone, git history, AST scans
- **DocAnalyst:** PDF ingestion, keyword search, file path extraction
- **VisionInspector:** Image detection and placeholder multimodal analysis

All outputs are **structured Evidence objects** with confidence scores, guaranteeing reproducibility.

4.3 Judicial Layer

Judges (Prosecutor, Defense, TechLead):

- Receive identical evidence
- Produce structured JudicialOpinion JSON objects
- Architected for **parallel execution** over the same evidence

Note: Local execution was constrained by external API rate limits, requiring **sequential judicial calls**. This affects runtime scheduling only; the **parallel architectural semantics remain intact**.

4.4 Chief Justice

Performs:

- Score aggregation
- Dissent detection
- Remediation synthesis
- Markdown generation

No LLM calls are used, ensuring **deterministic verdicts**.

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5. Repository Organization

The repository structure, as documented in README.md, adheres to modular principles:

- **Orchestration Layer:** StateGraph implementation
- **Node Roles:** Detectives, Judges, Chief Justice
- **Deterministic Tools:** Repo and document analysis utilities
- **Rubric & Artifacts:** Machine-readable evaluation criteria and audit outputs

This structure supports **separation of concerns**, maintainability, and deterministic, reproducible auditing workflows.

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6. Criterion-by-Criterion Self-Audit

Audit performed using:

- Full Detective execution
- Partial Judicial execution
- Deterministic ChiefJustice synthesis

- StateGraph topology validation
- Code-level verification of contracts and invariants

Self-Assessment Summary

Dimension	Score	Evidence & Rationale
Architecture	5	Clear StateGraph with explicit fan-out/fan-in and typed state contracts
Determinism	5	Pydantic schemas + deterministic ChiefJustice
Evidence Quality	3	AST + git + PDF parsing; deeper semantic checks planned
Parallelism	5	Detectives executed concurrently; judges architected for parallelism (execution constrained only by API limits)
Observability	3	Minimal logs; structured tracing limited
Robustness	3	Sandboxed repo cloning; graceful PDF handling
Judicial Reasoning	3	Judges implemented; small runs verified, full-scale runs limited by quota

Overall Score: 3.86 / 5

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7. MinMax Feedback Loop Reflection

Peer reports were unavailable at submission time; therefore, improvements were derived via **self-audit and controlled testing**.

Issues Identified:

- Non-deterministic judge ordering under concurrency
- API instability under burst requests
- Limited failure logging and observability
- Insufficient defensive handling of missing inputs

Improvements Implemented:

- Sequential judge execution to preserve determinism
- Synchronization barriers between stages
- Deterministic ChiefJustice
- Graceful degradation for missing repo/PDF inputs

- Enhanced evidence structure and confidence scoring

Outcome:

- Reproducible verdicts
- Stable execution under partial failures
- Clear reasoning traceability
- Architecture-driven robustness

8. Failure Modes & Mitigations

Failure	Mitigation
Malicious repo	Sandbox cloning
Hallucinated facts	Detective-only evidence
Judge bias	Multi-judge dialectics
Rate limits	Sequential execution
Missing PDFs	Graceful degradation
Large repositories	Batching possible

9. Scalability Strategy

- Horizontal scaling: add detectives or judges for new modalities
- Parallel branches remain independent
- Latency ≈ slowest node only
- No architectural redesign required

10. Remediation Plan

Future improvements:

- Deeper AST semantic checks
- Rule-based offline judges
- LangSmith tracing

- Score normalization
- Enhanced Markdown reporting
- Automatic diagram detection
- Batched processing for large repositories

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11. Conclusion

The Automaton Auditor demonstrates that **reliable auditing cannot rely on a single LLM**. By separating:

Observation → **Judgment** → **Synthesis**

and enforcing **typed state, deterministic orchestration, and parallel forensics**, the system achieves:

- Correctness
- Explainability
- Reproducibility
- Scalability