Systematic Engineering and Orchestration of Black Hole Architecture: A Specialized Technical Report on Gravity-Driven Multi-Agent Systems and Repository-Native Visualization

The evolution of software engineering through the integration of autonomous agents has necessitated the creation of novel architectural patterns that move beyond traditional human-centric management. Among the most promising of these is the Black Hole Architecture (BHA), a decentralized framework where the project vision acts as a gravitational center, pulling a codebase toward its final state through continuous agentic loops.[1] In such a system, orchestration is not a top-down mandate but an emergent property of the informational delta between the documented vision and the current implementation.[1] To manage the unprecedented velocity of BHA systems—which can generate upward of 1,500 pull requests in a period of ten days—a specialized visualization and orchestration platform is required.[3] This report details the theoretical underpinnings, diagnostic heuristics, and implementation requirements for such a platform, designed to monitor "software gravity" and orchestrate high-capacity agents including Google Jules, OpenAI Codex, and Anthropic's Claude Code.

Physics of Software: The Conceptual Framework of Black Hole Architecture

The Black Hole Architecture identifies the repository vision as the singularity of a project's development cycle.[5] By defining the end-state goals in a root-level file such as AGENTS.md or CLAUDE.md, the architecture creates a gradient of implementation work that autonomous agents are programmed to "fall" into.[1] The fundamental premise of this model is that no manager is required because the agents themselves read the gap between the vision and reality and pull toward it autonomously.[1]

Informational Curvature and Software Gravity

The strength of gravity within a BHA project is modeled on the Informational Curvature Equation, which measures the unity of causal structure against the dynamic throughput of

agentic activity.[7] Strong gravity occurs when the project vision is highly specific and the current codebase is sparse; this creates a high-energy gradient that accelerates the rate of pull request generation.[1] Conversely, "weak gravity" manifests when the vision is ambiguous or when the implementation has already matured to match the vision, leaving agents without a clear direction for further pulls.[1]

In a healthy BHA ecosystem, agents ship features autonomously with nearly zero human-in-the-loop interaction.[1] The architecture supports conflict-free development by ensuring each role owns specific files or partitions of the codebase.[1] This "no-overlap" rule means that even with 1,800 autonomous pull requests, merge conflicts remain virtually nonexistent because time acts as the primary mutex for implementations.[1] Planning happens in specialized directories, such as .sys/plans/{role}/, where written contracts are established before execution starts.[1]

Time as a Distributed Mutex

Unlike traditional systems that rely on complex locking logic, BHA treats the progression of the git history as the ultimate synchronizer.[1] The planning-execution cycle is designed as a serverless, conflict-free loop where the act of committing a plan to a repository serves as a temporal lock.[1] This approach relies on "asynchronous coding agents" that operate on a fire-and-forget basis, filing pull requests against the repository once the work is complete.[8]

Architectural Component	Function in Black Hole Model	Implementation Specifics
Singularity (Vision)	Central source of truth and direction.	AGENTS.md or root-level configuration.[1]
Event Horizon (Plan)	The point of implementational commitment.	.sys/plans/{role}/{task_id}.md.[1]
Accretion Disk (History)	The high-velocity stream of incoming PRs.	Clustered Git commit history.[10]
Software Gravity	The force pulling agents to implementation.	Informational delta between Vision and src/.[1]
Time Mutex	Temporal isolation of	Checkpoint-based planning

	role-based changes.	folders.[1]

Taxonomy of Weak Gravity and System Desynchronization

The primary challenge in managing a Black Hole Architecture is identifying anomalies in the gravitational field. Weak gravity leads to inefficiencies, redundant token spend, and implementational drift.[1] A specialized visualization tool must go beyond superficial commit counts to diagnose deep synchronization issues between planning and execution agents.

Planning-Execution Asynchrony

The most common failure mode in high-velocity BHA systems is when the planning phase becomes disconnected from the execution phase.[12] This typically manifests in two forms: planning getting ahead of executors or executors getting ahead of planners.

Planning overflow occurs when a planning agent, perhaps triggered by a high-frequency cron job, generates multiple distinct plans for the same feature or task before an executor has picked up the first one.[12] This results in a "noisy" planning directory where redundant implementation paths compete for token resources.[10] The platform must flag cases where the semantic distance between files in .sys/plans/{role}/ falls below a critical threshold, indicating duplicative efforts.

Implementational vacuum occurs when executors implement features without a corresponding plan or fail to find the plan associated with their current task.[12] This often happens after a failed plan run or when a previous agent session was interrupted without cleaning up the state.[13] The platform should alert users if a pull request touches code paths that have no active or completed plan in the planning directory, suggesting the agent is operating "out of bounds."

Scope Creep and Vision Saturation

Executor drift is a symptom of weak gravity where an agent, during the implementation of a specific plan, introduces extra scope or refactors code not defined in the original contract.[10] This weakens the system's predictability and increases the likelihood of breaking changes.[15] While exploration is often part of intelligent behavior, detection must focus on meaningful failures where the agent does something nonsensical or outside its intended boundaries.[16]

Vision saturation occurs when an agent role continues to attempt "pulls" for a feature that is already effectively implemented in the codebase.[1] This indicates that the vision doc for that role is stale or that the agent's ability to perceive implementations is failing.[17] The platform must use LLM-based scanning to compare the current state of the implementation against the vision and

flag roles that have "implementational overlap" or "saturated visions."

Heuristics for Detecting Anomalous Orbits

The visualization platform should implement the following heuristics to categorize repository health:

Diagnostic Metric	Detection Logic	Indicator of Weak Gravity
Plan-to-PR Ratio	Count of files in .sys/plans/ vs. associated PRs.	Ratio > 1 indicates planning overflow; < 1 indicates vacuum implementation.[1]
Path Integrity	Percentage of changes outside the role's defined directory.	High drift indicates the agent is failing to respect its boundaries.[1]
Semantic Redundancy	Vector distance between plans in the same role folder.	Low distance (high similarity) indicates duplicate planning.[10]
Vision Implementation Gap	Cosine similarity between AGENTS.md and src/.	High similarity indicates implementational saturation.[1]
Success-Turn Correlation	Number of comments/turns required for a successful PR.	High turns per PR indicate complex drift or poor task decomposition.[10]

Design of the Visualization Engine (V1)

Phase V1 of the platform is designed to provide a comprehensive, 3D visualization of the agentic ecosystem, treating each role as a planetary body in a gravity field.[20] The engine must be capable of processing the latest git history to provide a real-time view of project progress and gravitational health.

Auto-Detection of Agent Roles

A critical requirement is the ability to point the tool at any repository and have it automatically detect agent roles by parsing prompt definitions.[6] The tool should use recursive directory scanning to find folders such as docs/prompts/ (Helios style) or .github/agents/ (Copilot style).[6]

Once a prompt directory is identified, the parser must extract YAML frontmatter or Markdown headers to identify:

- **Role Identity**: The persona name (e.g., "The Architect," "The Frontend Developer").
- **Operating Boundaries**: The specific directories or file globs the role is permitted to modify.[1]
- **Tool Capabilities**: The specific skills or MCP servers allocated to the agent.[6]

By building a graph of these roles, the visualization engine can represent the "partitions" of the codebase as discrete gravitational domains.[1]

Force-Directed Graph Visualization

The platform should leverage 3D force-directed graphs to model the repository as a dynamic celestial system.[20] Nodes represent agent roles, and their "mass" in the graph is determined by the volume of code they own and the specificity of their vision doc.[20] Active pull requests are visualized as orbital paths between the vision (singularity) and the implementation (current state).

Weak gravity is represented through visual artifacts:

- **Planetary Drift**: Roles that are implementing features outside their boundaries drift away from their central orbit.
- **Orbital Decay**: Roles with saturated visions or implementational vacuums appear "faded" or stagnant.
- **Informational Hotspots**: Areas where multiple agents are generating plans for the same files glow with high-energy intensity, alerting the user to potential race conditions.

Git History Summarization and Accomplishment Tracking

With 1,500 PRs per week, humans cannot reasonably review every diff.[3] The tool must act as an automated "Mission Control" that transforms raw git activity into high-level status reports.[11] This involves a two-stage summarization pipeline:

The ingestion phase uses git log --pretty and git show --stat to fetch basic data, messages, hashes, and file change statistics.[25] An LLM then tagging each commit by type (Feature, Fix, Refactor, Docs) and intent.[26] For large pull requests, the agent selectively examines specific file diffs using specialized search tools to identify the core business logic change versus mechanical refactors.[25]

The aggregation phase clusters these summarized PRs using semantic embeddings to identify major milestones or "epics".[10] This allows the platform to provide a narrative summary of what has been accomplished recently, such as: "The Security Agent successfully refactored the OAuth flow across 24 files, while the UI Agent closed 42 tickets related to component polish."

Engineering the Orchestration Framework (V2)

Phase V2 transitions the platform from a diagnostic tool to an active "Command Center" for agents.[9] This layer is responsible for setting up the crons and background jobs that kick off API calls to the next-generation coding agents: Google Jules, OpenAI Codex, and Claude Code.[9]

Asynchronous Agent Lifecycle Management

The orchestration platform must manage the complex lifecycle of "asynchronous coding agents"—tools that run in isolated cloud containers and deliver work via pull requests.[8] This requires a specialized scheduler that optimizes for task completion and quota management.[32]

Orchestrating Google Jules

Google Jules is an autonomous, asynchronous coding agent that clones repositories into secure cloud VMs to perform end-to-end tasks like feature building and bug fixing.[30] The orchestration platform integrates with Jules via its alpha REST API.[34]

REST Resource	Method	Purpose in BHA Platform
v1alpha.sources	GET	List available GitHub repositories connected to the agent.[34]
v1alpha.sessions	POST	Create a new coding session with a task prompt and source context.[34]
v1alpha.sessions.approvePlan	POST	Approves a generated plan to begin implementation.[34]
v1alpha.sessions.activities	GET	Monitor real-time progress and event logs for the visualization graph.[35]

By default, the platform can set requirePlanApproval to true to allow the visualization layer (or a human reviewer) to vet architectural decisions before code is touched.[34]

OpenAI Codex and Multi-Agent Threads

The OpenAI Codex app serves as a command center for managing parallel agent workflows across projects.[9] The orchestration platform leverages Codex's "Skills" and "Automations" to run

tasks on a schedule in the background.[9]

The platform uses Codex's worktree-based version control to allow multiple agents to work on the same repository concurrently without merge conflicts.[29] By creating isolated copies of the codebase, Codex enables agents to explore alternative implementation strategies in parallel, which are then merged back into the main branch after validation.[29]

Claude Code and Agent Teams

Anthropic's Claude Code provides a terminal-based agent teams feature, allowing one lead session to coordinate multiple teammates working independently in their own context windows.[14] The platform orchestrates Claude Code using its TeammateTool and Task system.[38]

The lead agent breaks work into tasks and assigns them to teammates via JSON inboxes.[14] The platform can inject deterministic hooks, such as PreToolUse or PostToolUse, to run bash scripts that enforce BHA constraints—for example, blocking an agent from exiting its loop until its unit tests pass.[14]

Scheduling and the "Inception Strategy"

To maintain 24/7 autonomous operations, the platform implements an "inception strategy" where agents can spawn and manage other automated processes.[41] This requires a robust cron-based scheduling system (e.g., using Trigger.dev skills) that manages recurring agent loops.[41]

Advanced scheduler features include:

- **Run-if-idle**: Logic to only trigger an implementation "pull" when the agent's specific role-partition is currently unoccupied.[32]
- **Conflict Avoidance**: Batching low-priority maintenance tasks into catch-up windows during off-peak hours.[32]
- **Token-Aware Throttling**: Preventing "token blowout" by tracking the reasoning effort and session duration, hard-killing runaway agents that exceed a predefined budget.[32]

Large-Scale Data Handling and Summarization Patterns

Handling a week with 1,500 PRs requires an architecture that can digest massive amounts of code evolution without overwhelming the LLM's context window.[3] The platform utilizes a MapReduce summarization pattern and semantic clustering to maintain high-level situational awareness.[10]

The MapReduce Summarization Pipeline

Processing 1,000+ pull requests is handled through a recursive summarization loop:

- **Map Step**: Individual pull requests are chunked into logical groups. For each group, an LLM generates a concise, technical summary focusing on key findings, critical issues, and file modifications.[28]
- **Reduce Step**: These individual summaries are combined into bulleted "epics" or "themes." A final high-level report is reassembled using these summaries to provide the narrative "what we shipped this week" view.[28]

Semantic Clustering for Redundancy Detection

To detect "weak gravity" symptoms like multiple agents making plans for the same feature, the platform implements semantic clustering.[10] By converting plan descriptions and commit messages into high-dimensional vector representations, the tool can identify overlapping clusters.[10]

The clustering quality is assessed using a silhouette score; a low score indicate that the "boundaries" between agent roles have become blurred, and agents are essentially competing for the same implementational space.[10] This acts as a trigger for the user to refine the AGENTS.md vision to better separate concerns.

Summarization Metric	Value for High-Volume BHA	Implication
Commit Granularity	~500-1000 micro-changes hourly.	Requires operation-based version control (CRDTs) or extreme git log parsing.[46]
Token Consumption	~3,000-5,000 input tokens per PR review.	Requires local LLM backends (Ollama) or token-aware scheduling to manage costs.[32]
Context Overload	42 files avg. per complex task.	Requires "progressive disclosure" where agents load only the files they need.[10]
Success Rate	~69.2% overall for agentic tasks.	Requires automated failure handling and "CI Doctor" agents to fix broken runs.[10]

The Megaprompt: Design for the Coding Agent

To build the platform, a "megaprompt" is provided to a senior-level coding agent. This prompt is structured using a three-layer hierarchy: Layer 1 for universal rules, Layer 2 for workspace-specific context, and Layer 3 for the technical implementation requirements.[49]

Layer 1: Operational Constitution

"You are the Lead Systems Architect for the BHA Command Center. Your goal is to build a production-grade visualization and orchestration platform for autonomous engineering teams. Follow the Unix philosophy: write small, composable modules that do one thing well. Prefer high-performance TypeScript and React for the frontend, and a Node.js or Go backend for high-concurrency git operations. Every line of code must be written for agents to read, understand, and modify. Adhere to strict TDD practices, ensuring 90% test coverage.".[6]

Layer 2: Black Hole Workspace Context

"This application will operate on repositories following the Black Hole Architecture. Note that the source of truth for role definitions is always the docs/prompts/ directory. Planning happens in .sys/plans/{role}/. You must respect role-based file ownership. Use git worktrees for parallel agent execution to prevent merge conflicts. The vision of this app is to identify 'weak gravity'—informational hotspots where the vision-reality gap is not being closed efficiently.".[1]

Layer 3: Feature Implementation Matrix

"Implement the following features sequentially:

1. **Repository Parser**: Build a regex-based scanner to auto-detect roles and boundaries by parsing the provided folder structure. Map these to a 3D visualization graph.[6]
2. **Gravity Diagnostic Engine**: Develop heuristics to flag desyncs. Specifically, alert if multiple plans exist for the same task, or if executors implement features without a corresponding plan file.[12]
3. **Accomplishment Summarizer**: Implement a MapReduce pipeline to condense 1000+ PRs into narrative accomplishments using semantic clustering.[10]
4. **Orchestration Command Center**: Create API wrappers for Google Jules, OpenAI Codex, and Claude Code. Build a scheduler that manages crons, background jobs, and quota-aware session management.[14]
5. **Vision Overlap Alert**: Use an LLM to compare implementation against vision docs. If a role's vision is already implemented, flag it for the user to either expand the scope or retire the role.".[1]

Managing AI-Generated Debt and Attribution

In a system producing 1,500 pull requests per week, the accumulation of technical debt and

the tracking of provenance are paramount.[46] The platform must treat repository knowledge as the system of record, co-locating active plans, completed plans, and known technical debt within the codebase itself.[17]

Provenance Tracking and Attribution

The platform implements an AI-attribution schema to track exactly how much of the repository has been generated by agents versus humans.[52] Every pull request and commit must include an attribution footer:

- **Generated-by**: 67–100% agent implementation.
- **Co-authored-by**: 34–66% agent implementation.
- **Assisted-by**: Up to 33% agent implementation.[52]
- **Commit-generated-by**: AI summarized the commit message only; no code modification.[52]

This metadata allows for deep analysis of the repository's evolution and ensures that licensing and audit requirements are met.[46]

Doc-Gardening and Self-Annealing

To prevent "context rot," where documentation fails to reflect actual code behavior, the platform deploys dedicated "doc-gardening" agents.[17] These sub-agents scan for stale plans or architecture notes and open fix-up pull requests automatically.[17]

Furthermore, the platform incorporates "self-annealing" capabilities: when agents repeatedly fail a quality gate or produce broken code, a meta-agent is triggered to rewrite the skills and hooks that allowed the failure, ensuring that every mistake leads to a permanent architectural fix.[40]

Governance and Security in Autonomous Systems

As agents gain the ability to effect meaningful change in the environment, real-time failure detection becomes a safety-critical requirement.[16] The platform implements layered controls across the agent workflow to prevent irrecoverable or dangerous actions.[16]

Sandboxed Execution and Permissions

Agents operate within secure, isolated containers where internet access is often disabled after the initial bootstrap phase to prevent data exfiltration.[29] The platform enforces strict permission models:

- **Read-only analysis**: Agents use tools like Glob and Grep but are stripped of Edit or Write capabilities during the discovery phase.[19]
- **Role-based Access**: Coordinators can spawn sub-agents but cannot edit code; builders

can edit code but cannot delegate.[40]
- **Threat Detection Gating**: A separate job analyzes buffered implementation artifacts for secret leaks or policy violations before any write operation is executed.[55]

The Model Context Protocol (MCP) as an Integration Layer

The Model Context Protocol (MCP) serves as the universal interface between the orchestration platform and external tools.[24] By standardizing how agents interact with databases, file systems, and APIs, MCP enables the platform to scale its capabilities without modifying the underlying agent code.[56]

The platform utilizes MCP servers to:

- **Query Code Evolution**: Provide read-only access to git history so agents can reason about how and why code reached its current state.[46]
- **Search at Scale**: Use the Grep MCP server to retrieve patterns and regex matches across million-line codebases without loading them into memory.[56]
- **Context Persistence**: Bridge local coding sessions with remote knowledge bases to ensure agents maintain continuity across sessions.[56]

Second-Order Insights into the Future of Engineering

The transition to Black Hole Architecture represents a shift from authorship to orchestration.[60] The human developer's role is transformed from writing syntax to context engineering—managing the ecosystems of agents and ensuring that the project vision remains clear enough to maintain implementational gravity.[30]

The Feedback Loop Paradox

The analysis reveals a critical second-order insight: developer-provided context files (like a hand-written AGENTS.md) improve agent performance by roughly 4%, but LLM-generated context files can actually *decrease* performance by 3%.[1] This suggests that the "gravity" of a project is most effectively maintained through human-curated constraints. If a system relies too heavily on automated documentation, it induces context rot and noise, causing agents to struggle with obvious implementation details while missing deep architectural misalignments.[1]

Continuous AI as the Third Pillar

The Black Hole Architecture visualization platform positions "Continuous AI" (CAI) as the third leg of the DevOps trifecta, alongside Continuous Integration (CI) and Continuous Deployment (CD).[62] While traditional pipelines are deterministic, CAI is decision-driven and probabilistic. The platform acts as the observability layer for this paradigm, providing structured logs and distributed tracing to track what prompt triggered an action, what the agent "thought" at each

step, and what tools it used.[63]

Conclusions and Technical Outlook

The implementation of a visualization and orchestration platform for Black Hole Architecture is essential for managing the sheer scale and velocity of autonomous software development. By treating a codebase as a gravity field defined by a vision document, BHA allows for massive, conflict-free parallelization. The proposed tool addresses the critical need for situational awareness in systems where agents can generate thousands of pull requests in mere days.

V1 of the platform provides the visual telemetry required to detect "weak gravity," such as planning overflows and implementation vacuums. By auto-detecting agent roles and visualizing their implementational orbits, the platform enables engineers to maintain architectural integrity without manual oversight. V2 scales this capability by providing a command center for frontier coding agents, utilizing advanced scheduling logic and the Model Context Protocol to create self-evolving ecosystems.

Ultimately, the success of such a system depends on high-quality context engineering. The human role shifts to managing the "singularity" of the vision, while the platform ensures that the agentic loop remains synchronized and productive. As the industry moves toward this "Mission Control" model of development, tools that provide deep visibility into the temporal and semantic health of agentic systems will become the foundational infrastructure for the next generation of software engineering. The platform outlined in this report provides the blueprint for that future, turning the repository itself into a living, navigable history where every edit and decision is durably linked to the evolving goal.

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