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Building a Computing Infrastructure Digital Twin (CIDT) for Real-Time Monitoring, Log Analytics, and AI-Driven Anomaly Detection

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Challenges Taken

Can a CIDT combining real-time telemetry, Omniverse visualization, and AI-model log reasoning support the computational demands of next-generation ESDTs?

Background & Motivation

- Earth Science Digital Twins (ESDTs) require massive scalable computing infrastructure [1,2,3].
- These workloads place continuous demands on HPC systems, requiring sustained throughput, low latency, and coordinated data movement.
- Computing must support real-time ingest (***What Now***), forecasting (***What Next***), and simulation (***What If***) for a full end-to-end information DT system [4].
- There is a current literature gap in Computing Infrastructure Digital Twins (CIDTs) that support the real-time, HPC needs required by ESDTs.

CIDT Framework and Components

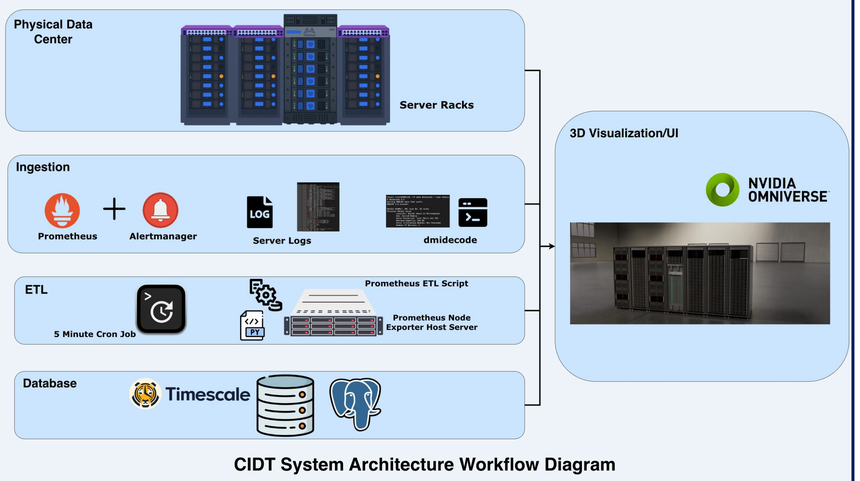
Operational Digital Twin for a 600-Machine Data Center:

- Prometheus metrics
- PostgreSQL log store
- Omniverse visualization
- Real-time alerting

Benchmarking Small LMs for Log Understanding in Digital Twin Operations:

- Logs are the "ground truth" of system health. Analyzing them allows the CIDT to detect silent failures and stop unhelpful simulations (e.g., non-converging AI models) to save computing resources
- Evaluated whether small AI models can support future CIDT log analytics and root-cause analysis by testing their understanding of real system logs
- Used syslog severity prediction (0–7) as a controlled benchmark, testing nine **0.6–4B models** on **46k** production journalctl logs from the operational environment using various prompting methods

System Architecture



CIDT System Architecture Workflow Diagram

Figure 1. CIDT architecture integrating real-time telemetry, centralized logs, and 3D visualization for AI-driven monitoring of a 600-machine data center.

Results

1. Implemented core CIDT infrastructure: Prometheus telemetry on all nodes, centralized metric scraping, and initial alerting rules for key system conditions
2. Built an interactive 3D data-center visualization in NVIDIA Omniverse to spatially explore node states and live system metrics
3. Benchmarked nine S(R)LMs (0.6–4B) on system logs across zero-shot, few-shot, and RAG settings; **Qwen3** models led all strategies, with RAG boosting accuracy up to **95.64%**, identifying strong candidates for real-time DT monitoring

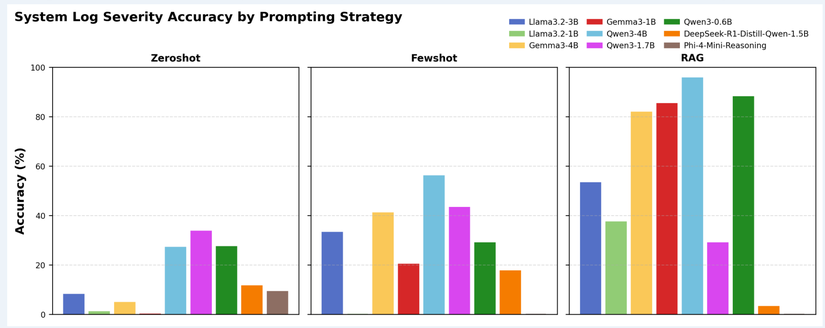


Figure 2. Accuracy of nine small LMs across zero-shot, few-shot, and RAG prompting. Qwen3 models lead all prompting modes, with Qwen3-4B + RAG achieving 95.64%.

Conclusion

- By improving infrastructure reliability and responsiveness, the CIDT directly supports ESDT workflows, as data volumes and system complexity continue to grow.
- Small Reasoning Language Models (SRLMs)—especially Qwen3 models—provide strong, low-latency performance for future CIDT-based RCA and anomaly detection.
- As AI and HPC demands increase, this CIDT framework provides a pathway toward efficient, resilient management of computationally intensive ESDT workflows.

Future Work

- Integrate top-performing AI models into the CIDT for real-time monitoring, alerting, and automated diagnosis.
- Apply CIDT insights to monitor AI/ML jobs, optimize resource scheduling, and stop non-converging simulations.
- Add adaptive retrieval and memory mechanisms to strengthen model robustness for evolving log patterns.
- Build a full digital-twin feedback loop connecting telemetry, log analytics, and AI-driven operational recommendations.

Abstract

GitHub

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