

Structured Context Engineering for File-Native Agentic Systems

Evaluating Schema Accuracy, Format Effectiveness, and Multi-File Navigation at Scale

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Abstract

Large Language Model agents increasingly operate external systems through programmatic interfaces, yet practitioners lack empirical guidance on how to structure the context these agents consume. Using SQL generation as a proxy for programmatic agent operations, we present a systematic study of context engineering for structured data, comprising 9,649 experiments across 11 models, 4 formats (YAML, Markdown, JSON, Token-Oriented Object Notation [TOON]), and schemas ranging from 10 to 10,000 tables.

Our findings challenge common assumptions. First, architecture choice is model-dependent: file-based context retrieval improves accuracy for frontier-tier models (Claude, GPT, Gemini; +2.7%, p=0.029) but shows mixed results for open source models (aggregate -7.7%, p<0.001), with deficits varying substantially by model. Second, format does not significantly affect aggregate accuracy ($\chi^2=2.45$, p=0.484), though individual models, particularly open source, exhibit format-specific sensitivities. Third, model capability is the dominant factor, with a 21 percentage point accuracy gap between frontier and open source tiers that dwarfs any format or architecture effect. Fourth, file-native agents scale to 10,000 tables through domain-partitioned schemas while maintaining high navigation accuracy. Fifth, file size does not predict runtime efficiency: compact formats can consume significantly more tokens at scale due to format-unfamiliar search patterns.

These findings provide practitioners with evidence-based guidance for deploying LLM agents on structured systems, demonstrating that architectural decisions should be tailored to model capability rather than assuming universal best practices.

Keywords: LLM agents, context engineering, file-native agents, schema representation, text-to-SQL, enterprise AI

1 Introduction

The emergence of Large Language Model (LLM) agents capable of operating external systems has created a fundamental question in AI systems design: how should agents understand the systems they actuate? Unlike information retrieval or question answering, agentic tasks require the LLM to comprehend schemas, relationships, constraints, and semantic meaning well enough to generate correct operations. This paper investigates structured context engineering for file-native agentic systems: the practice of organising persistent system knowledge to optimise agent performance when agents retrieve context through native file operations.

1.1 The Rise of File-Native Agent Context

A significant shift is occurring in how developers provide context to LLM agents. Rather than relying solely on retrieval-augmented approaches or embedding context directly in prompts, practitioners are increasingly adopting file-based semantic layers: structured documents that agents read through native file tools such as grep and read operations.

This pattern has emerged organically across the industry. CLAUDE.md and AGENTS.md files describe project conventions and architecture for coding agents. The llms.txt standard provides structured website descriptions optimised for LLM consumption. Cursor Rules and similar IDE configurations structure context for code-focused agents. Schema files in YAML, JSON,

or Markdown describe database structures and API specifications for data agents.

1.2 Research Questions

This paper investigates five research questions:

Table 1: Research Questions

RQ	Question
R1	Does file-native context engineering provide better accuracy than prompt engineering?
R2	Does format affect accuracy for file-native agents?
R3	How does model and model tier affect context engineering effectiveness?
R4	How does schema scale affect file-native agent effectiveness?
R5	Does format affect efficiency (tokens, cost, tool calls)?

1.3 Contributions

This paper makes the following contributions: (1) a systematic study with 9,649 experiments across 11 models, 4 formats, 2 architectures, and schemas from 10 to 10,000 tables; (2) demonstration that file-native architecture benefits frontier models but shows mixed results for open source models; (3) finding no significant aggregate format effect while identifying model-specific sensitivities; (4) validation of high navigation accuracy at 10,000 tables using partitioning; (5) identification of the 'grep tax' phenomenon where compact formats consume more runtime tokens.

2 Related Work

The evolution from single-turn LLM interactions to agentic systems has created new paradigms for how models interact with external systems. The ReAct framework [1] established the reasoning-plus-acting paradigm where models interleave chain-of-thought reasoning with tool invocations. Toolformer [11] demonstrated that language models can learn to use tools autonomously, while Gorilla [16] showed that LLMs can be connected with massive APIs for real-world actuation. ToolLLM [23] and ToolACE [25] have further advanced LLM function calling across thousands of real-world APIs. The Model Context Protocol and similar standards have formalised how agents access external resources [2]. Agent evaluation has advanced through benchmarks such as SWE-bench [14] for software engineering tasks and AgentBench [15] for evaluating LLMs across diverse agent environments.

Text-to-SQL translation has advanced significantly with large language models. The Spider benchmark [3] established cross-domain evaluation standards, followed by BIRD [17] which introduced large-scale, real-world databases with noisy schemas. DIN-SQL [4] achieved strong results by decomposing complex queries, while MAC-SQL [18] demonstrated multi-agent collaborative

approaches to text-to-SQL. Gao et al. [5] provided a comprehensive benchmark evaluation of LLM-based text-to-SQL approaches. Recent work has also questioned whether explicit schema linking remains necessary with capable models [24]. Our work differs by focusing on context engineering rather than prompt techniques, investigating how schema format and retrieval architecture affect generation accuracy.

Mohsenimofidi et al. [7] conducted the first empirical study of AI configuration files across 466 repositories, identifying a research gap: how content, structure, and style affect agent behaviour remains unevaluated. Our contribution directly addresses this gap.

Context engineering has recently been formalised as a discipline distinct from prompt engineering. A comprehensive survey [12] covering over 1,400 papers establishes context engineering as the systematic optimisation of information payloads for LLMs, encompassing retrieval, processing, and management. Chain-of-thought prompting [13] demonstrated that explicit reasoning steps improve performance on complex tasks, a finding relevant to our complexity tier analysis. StructGPT [21] proposed an iterative reading-then-reasoning framework for structured data including databases and knowledge graphs. Notably, the 'lost in the middle' phenomenon [6] demonstrates that LLMs struggle to use information positioned in context middles, motivating selective retrieval approaches like our file-native architecture.

Recent work has examined how serialisation format affects LLM comprehension of structured data. Sui et al. [19] benchmarked table serialisation formats (HTML, XML, JSON, YAML) and found that format choice significantly impacts structural understanding tasks. He et al. [20] reported up to 40% performance variation based on prompt formatting alone. Chain-of-Table [22] demonstrated that LLMs can iteratively transform tables during reasoning. Our work extends this line of inquiry to agent-consumed schema files in file-native architectures.

TOON (Token-Oriented Object Notation) [10] is a compact serialisation format designed specifically for LLM context efficiency. It achieves approximately 25% smaller file sizes than YAML through abbreviated keywords (TABLE, COL, FK) and minimal syntax. We include TOON in our evaluation to test whether file size optimisation translates to runtime efficiency.

3 Methodology

3.1 Experimental Overview

Table 2: Experimental Overview

Experiment	Focus	Evaluations	Key Variables
Core	SQL generation accuracy	8,401	Format, Model, Architecture, Tier
	Schema navigation	928	Format, Scale tier (S0-S5)
Partition	Enterprise navigation	320	Partitioning approach (S6-S9)

3.2 Format Conditions

We tested four schema representation formats: YAML (hierarchical structure, grep-friendly), Markdown (documentation-style with natural language), JSON (machine-parseable, verbose), and TOON (Token-Oriented Object Notation [10], a custom compact format ~25% smaller in file size). All formats received identical system prompts with generic grep guidance; no format-specific search patterns were provided. This tests native LLM comprehension of each format without optimisation. All formats include an identical navigator.md providing schema overview and table descriptions.

3.3 Architecture Conditions

We compared two context delivery architectures. File Agent: agents use grep and read tools to retrieve schema information from files on demand, selecting relevant sections based on query requirements. Prompt Baseline: the complete schema (~6,000 tokens for TPC-DS) is embedded in the system prompt alongside the query, with no tool access. Both conditions use identical schema content; only the delivery mechanism differs. This comparison isolates whether file-native retrieval provides advantages over direct context injection.

3.4 Model Conditions

We evaluated 11 models across three capability tiers.

Table 3: Model Conditions

Tier	Models	Characteristics
Frontier	claude-opus-4.5, gpt-5.2, gemini-2.5-pro	Highest capability
Frontier Lab	claude-haiku-4.5, gpt-5-mini, gemini-2.5-flash	Cost-optimised from frontier labs
Open Source	DeepSeek-V3.2, kimi-k2, llama-4-maverick, llama-4-scout, qwen3-32b	Publicly available

3.5 Complexity Tiers (L1-L5)

Table 4: Query Complexity Tiers

Tier	Type	Tables	SQL Features
L1	Direct lookup	1	SELECT, COUNT
L2	Single join	2	Basic JOIN, aggregation
L3	Multi-hop	3-4	Chained JOINs, GROUP BY
L4	Complex aggregation	4+	CTEs, window functions
L5	Multi-step reasoning	5+	Subqueries, nested logic

3.6 Scale Tiers (S0-S9)

Scale tiers range from S0 (10 tables, startup MVP) through S5 (500 tables, large enterprise) for single-file schemas. Partitioned tiers S6-S9 extend to 10,000 tables using domain-based partitioning with ~250 tables per domain. Scale experiments used Claude models only.

3.7 Evaluation

Queries were derived from the TPC-DS benchmark [8] query patterns and curated to ensure coverage across L1-L5 complexity tiers. We use Jaccard similarity over result sets: $J(A,G) = |A \cap G| / |A \cup G|$, where A is the agent-generated result set and G is the ground truth. Success threshold: Jaccard ≥ 0.9 . For multiple valid formulations, we credit any semantically correct approach. All models used temperature=0 for deterministic, reproducible outputs in a single-run design. The Claude Agent SDK, used for file-based Claude conditions, does not expose temperature control; OpenAI GPT-5 models enforce a minimum temperature of 1; all other conditions set temperature=0 explicitly via provider APIs. Statistical tests include independent t-tests, chi-square tests, and ANOVA with Benjamini-Hochberg correction [9].

4 Results

4.1 R1: File Agent vs Prompt Engineering

Finding: Architecture effectiveness depends on model tier.

Figure 1: File Agent vs Prompt Engineering by Model Tier

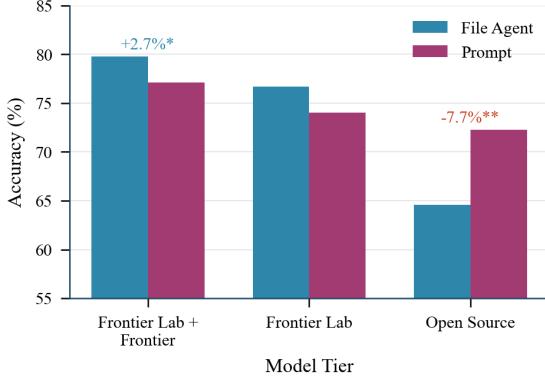


Table 5: File Agent vs Prompt Engineering by Tier

Model Tier	File Agent	Prompt	Diff	p-value	BH Sig
Frontier Lab + Frontier (excl. Opus)	79.8%	77.1%	+2.7%	0.029	Yes
Frontier Lab	76.7%	74.0%	+2.8%	0.107	No
Open Source	64.6%	72.3%	-7.7%	<0.001	Yes

The combined Frontier Lab + Frontier tier achieved significantly higher accuracy with file-native retrieval (+2.7%, p=0.029). Open source models showed mixed results: while the aggregate favoured prompt engineering by 7.7 percentage points (p<0.001), this was driven primarily by Qwen (-21.9%) and Llama Maverick (-13.9%), while Kimi (+0.3%) and Llama Scout (+0.5%) showed negligible differences.

Table 6: Individual Model File vs Prompt Comparison

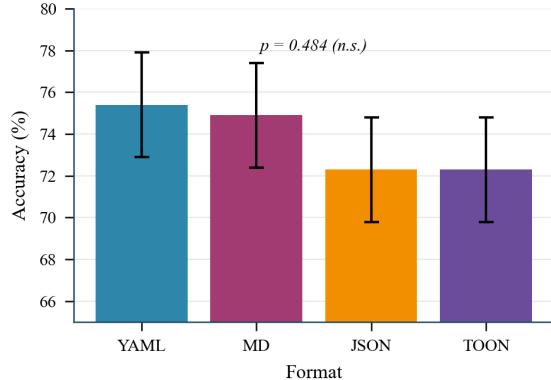
Model	Tier	File	Prompt	Diff	Winner
claude-opus-4.5	Frontier	89.0%	N/A	N/A	File only
gpt-5.2	Frontier	83.8%	82.0%	+1.8%	File
gemini-2.5-pro	Frontier	85.1%	81.4%	+3.7%	File
claude-haiku-4.5	Frontier Lab	76.1%	74.5%	+1.6%	File
gpt-5-mini	Frontier Lab	77.1%	69.4%	+7.7%	File
gemini-2.5-flash	Frontier Lab	77.0%	78.0%	-1.1%	Prompt
DeepSeek-V3.2	Open Source	75.3%	78.6%	-3.3%	Prompt
kimi-k2	Open Source	75.0%	74.7%	+0.3%	File
llama-4-maverick	Open Source	60.9%	74.8%	-13.9%	Prompt
llama-4-scout	Open Source	63.1%	62.6%	+0.5%	File
qwen3-32b	Open Source	48.9%	70.9%	-21.9%	Prompt

File agent performed better for 6 models while prompt engineering performed better for 4 models. The largest file agent advantages appeared in frontier and frontier lab models (GPT-5-mini +7.7%, Gemini Pro +3.7%), while the largest prompt advantages appeared in open source models (Qwen -21.9%, Llama Maverick -13.9%).

4.2 R2: Format Effects on Accuracy

Finding: Format did not significantly affect aggregate accuracy.

Figure 2: Accuracy by Format (File Agent)



Chi-squared test showed no significant format effect (p>0.05). YAML achieved 75.4%, MD 74.9%, JSON 72.3%, and TOON 72.3%. While aggregate results showed equivalence, individual models exhibited format sensitivities.

Table 7: Model × Format Accuracy (File Agent)

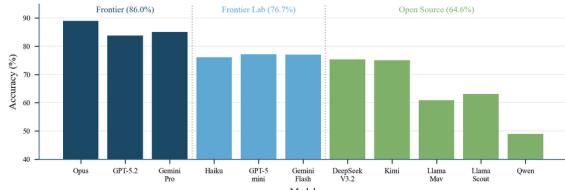
Model	Tier	YAML	MD	JSON	TOON	Best	Spread
claude-opus-4.5	Frontier	92%	86%	88%	90%	YAML	5.4%
gemini-2.5-pro	Frontier	86%	84%	88%	83%	JSON	5.1%
gpt-5.2	Frontier	84%	83%	85%	83%	JSON	1.8%
gpt-5-mini	Frontier Lab	78%	78%	76%	76%	MD	1.6%
gemini-2.5-flash	Frontier Lab	79%	79%	75%	74%	YAML	5.1%
claude-haiku-4.5	Frontier Lab	84%	72%	73%	75%	YAML	12.2%
DeepSeek-V3.2	Open Source	73%	80%	79%	70%	MD	10.2%
kimi-k2	Open Source	82%	71%	77%	71%	YAML	11.1%
llama-4-scout	Open Source	60%	72%	59%	61%	MD	13.2%
llama-4-maverick	Open Source	58%	71%	51%	63%	MD	20.1%
qwen3-32b	Open Source	54%	49%	45%	48%	YAML	9.8%

Format preference summary: YAML performed best for 5 models, MD for 4 models, JSON for 2 models, and TOON for 0 models. Open source models showed larger format sensitivities (spread 9.8-20.1%) than frontier models (spread 1.6-5.4%).

4.3 R3: Model Tier Effects

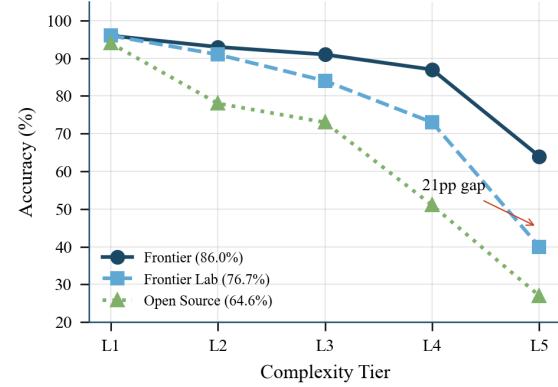
Finding: Model capability is the dominant factor.

Figure 3: Accuracy by Individual Model



One-way ANOVA: $F(10, 8390) = 30.55$, $p < 0.001$. Frontier tier achieved 86.0% accuracy, Frontier Lab 76.7%, and Open Source 64.6%. The 21 percentage point gap between frontier and open source tiers dwarfs any format or architecture effect.

Figure 4: Accuracy by Complexity and Model Tier



All tiers achieved similar accuracy at L1 (94-96%), but diverged sharply at higher complexity. Frontier models maintained 64% at L5 while open source dropped to 27%.

Table 8: Individual Model Performance by Complexity (File Agent)

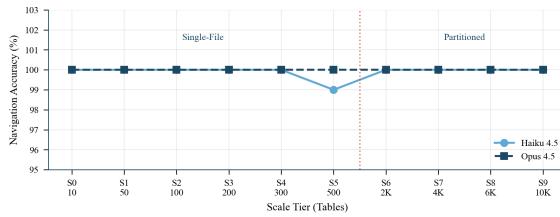
Model	Tier	L1	L2	L3	L4	L5	Overall
claude-opus-4.5	Frontier	100%	93%	94%	94%	64%	89.0%
gemini-2.5-pro	Frontier	94%	97%	81%	81%	74%	85.1%
gpt-5.2	Frontier	95%	89%	96%	85%	54%	83.8%
gpt-5-mini	Frontier Lab	95%	88%	82%	71%	49%	77.1%
gemini-2.5-flash	Frontier Lab	94%	92%	83%	75%	40%	77.0%
claude-haiku-4.5	Frontier Lab	100%	93%	87%	71%	29%	76.1%
DeepSeek-V3.2	Open Source	96%	92%	82%	67%	40%	75.3%
kimi-k2	Open Source	99%	89%	86%	64%	37%	75.0%
llama-4-scout	Open Source	94%	75%	79%	50%	18%	63.1%
llama-4-maverick	Open Source	90%	82%	73%	37%	23%	60.9%
qwen3-32b	Open Source	92%	53%	44%	37%	18%	48.9%

Notable observations: Gemini Pro achieved the highest L5 accuracy (74%) despite not having the highest overall score. Claude Opus maintained near-perfect L1-L3 performance. Qwen showed particularly steep degradation from L2 onwards.

4.4 R4: Navigation at Scale

Finding: File-native schema navigation scales to 10,000 tables with partitioning.

Figure 5: Navigation Accuracy at Scale

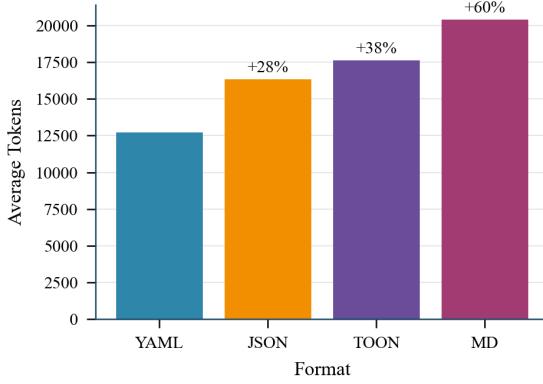


Single-file schemas maintained near-perfect accuracy up to 500 tables. Domain partitioning enabled high navigation accuracy at 10,000 tables. The partitioned architecture keeps per-query context bounded regardless of total schema size.

4.5 R5: Efficiency Effects

Finding: Token efficiency is model-dependent. Format efficiency varies significantly across models.

Figure 6: Token Efficiency by Format (TPC-DS, 11-Model Average)



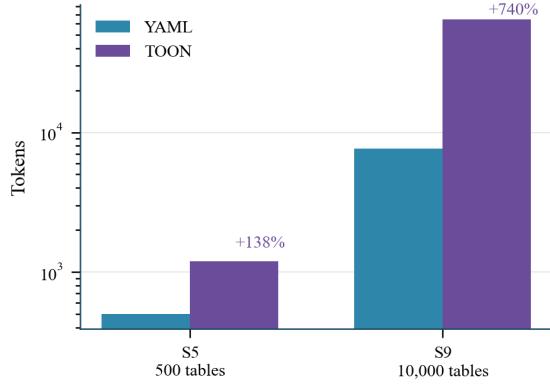
Averaged across all 11 models on the TPC-DS schema (24 tables), YAML was the most token-efficient format (12,729 tokens), followed by JSON (16,320, +28%), TOON (17,625, +38%), and MD (20,382, +60%). Token efficiency varied substantially by model: Claude models consumed 935-2,579 tokens while open source models ranged from 3,692 to 37,841 tokens, reflecting differences in tool-use efficiency.

Markdown's higher token consumption in file-based agents was not caused by grep inefficiency. Models matched Markdown heading patterns effectively on first attempt. Rather, each grep result returned more tokens due to Markdown's verbose pipe-table formatting (column separators, alignment dashes, repeated delimiters) compared to YAML's compact key-value pairs. This overhead varied by model, ranging from

+7% (Gemini Flash) to +105% (Claude Opus), with one outlier (Qwen 32B) where Markdown was actually 19% cheaper than YAML. Notably, this overhead was absent in prompt-based agents where the full schema was embedded directly, confirming the cause as retrieval verbosity rather than format comprehension.

As schema size increased, TOON showed dramatically increased token consumption for Claude models despite being ~25% smaller in file size. Scale experiments used Claude models only.

Figure 7: The 'Grep Tax' - TOON Token Overhead at Scale



The 'grep tax' emerged as schema size scaled. At S5 (500 tables), TOON consumed 138% more tokens than YAML; at S9 (10,000 tables), this grew to 740%. Root cause: models lacked familiarity with TOON's syntax and could not construct effective refinement patterns. When initial searches returned too many matches, agents cycled through patterns from known formats (DDL, JSON, YAML) before finding correct TOON patterns, each failed attempt adding to conversation context. This inefficiency was already present at the TPC-DS schema size (+38% vs YAML across all models) but compounded dramatically at scale.

5 Discussion

5.1 Architecture Choice is Model-Dependent

Our most significant finding challenges the assumption that file-native context retrieval universally improves agent performance. For frontier models, file-native retrieval provides measurable benefits (+2.7%, $p=0.029$). For open source models, results were mixed: some (Qwen, Llama Maverick) performed substantially worse with file-native retrieval, while others (Kimi, Llama Scout) showed no significant difference. We hypothesise this variation reflects differences in tool-use training across open source models, consistent with broader findings on capability gaps between open source and proprietary models [26].

5.2 Format Selection Should Be Operationally Driven

The absence of significant format effects on accuracy ($p=0.484$) suggests that format selection need not be driven by accuracy concerns. Instead, selection should be guided by: token efficiency (YAML consumed 28–60% fewer tokens across models), maintainability (YAML and JSON integrate with programmatic workflows), and grep-ability (formats with predictable patterns enable efficient retrieval).

5.3 The Grep Tax: Model and Scale Dependent

The grep tax is both model-dependent and scale-dependent. At the core experiment scale, models varied dramatically in TOON efficiency: DeepSeek consumed 10% fewer tokens with TOON than YAML, while Llama Scout consumed 38% more. This suggests different models have learned different grep patterns during training, with some effectively matching TOON’s compact syntax.

For models that do exhibit a grep tax (notably Claude), the effect compounds at scale. Using Claude Haiku: +20% at 24 tables, +138% at 500 tables, +386% at 2,000 tables, and +740% at 10,000 tables. As agents make more grep attempts in larger schemas, formats with non-standard keywords accumulate failed searches. Scale experiments used Claude models only; other models may show different scaling behaviour. Practitioners should evaluate format efficiency for their specific model before assuming YAML superiority.

5.4 Format Effects Are Model-Dependent

While format did not affect aggregate accuracy, we observed that formats influenced which valid interpretation models selected for semantically ambiguous queries. For queries about ‘customer state’, models took different join paths (home address via CUSTOMER vs transaction address via SS_ADDR_SK) depending on format. MD’s flat structure guided 72% of models to one path while YAML’s hierarchical structure guided only 33% to the same path. Notably, stronger models (Opus) navigated ambiguity correctly regardless of format, while weaker models followed format cues more readily. This suggests format structure subtly emphasises different relationships, but the effect only manifests where navigator guidance leaves room for interpretation. Practitioners should invest in navigator disambiguation rules rather than format optimisation.

5.5 Practical Recommendations

Table 9: Architecture Selection Guide

Model Tier	Recommended Architecture
Frontier	File Agent
Frontier Lab	File Agent (validate first)
Open Source	Prompt Engineering

Table 10: Format Selection Guide

Priority	Recommendation
Token efficiency	YAML
Human readability	Markdown
Programmatic generation	YAML or JSON
Custom formats	Ensure grep-friendly patterns

5.6 Limitations

The core experiment used a query bank of 100 queries (20 per tier); a larger query bank or different query construction methodology may yield different results. Scale experiments used Claude models only and tested schema navigation (metadata retrieval) rather than SQL reasoning at scale; SQL generation accuracy at 10,000 tables remains untested. All experiments used TPC-DS, a retail data warehouse benchmark. SQL generation serves as a proxy for programmatic operations but direct validation on non-SQL tasks would strengthen generalisability. TOON is a novel format largely absent from LLM training data; the observed grep tax may partly reflect format unfamiliarity rather than an inherent limitation of compact formats. Format-specific prompt guidance could mitigate this effect, but was outside our methodology which tested native LLM comprehension without format-specific optimisation. Not all conditions enforced temperature=0: the Claude Agent SDK does not expose temperature control for file-based conditions, and GPT-5 models enforce a minimum temperature of 1; these conditions may exhibit variance not captured by our single-run design. Single-shot evaluation may underestimate accuracy achievable with multi-turn correction.

6 Conclusion

This paper presented a systematic study of context engineering for structured data, comprising 9,649 experiments across 11 models, 4 formats, 2 architectures, and schemas ranging from 10 to 10,000 tables.

Our key findings: (R1) Architecture effectiveness is model-dependent: file-native retrieval improved accuracy for frontier models but showed mixed results for open source models. (R2) Format does not significantly affect accuracy at the aggregate level, but

individual models, particularly open source, show meaningful format sensitivities. (R3) Model capability is the dominant factor, with a 21 percentage point gap between tiers. (R4) File-native schema navigation scales to 10,000 tables with domain partitioning. (R5) Token efficiency is model-dependent; some models grep compact formats effectively while others incur a 'grep tax' that compounds at scale.

For practitioners: match architecture to model capability rather than assuming universal best practices. Invest in model capability before optimising format. Use YAML for token efficiency and grep-friendly patterns. Partition schemas by domain for enterprise scale.

Future work should extend experiments to non-SQL tasks, validate scale findings across providers, and investigate multi-turn evaluation. As LLM agents increasingly operate critical business systems, evidence-based guidance on context engineering becomes essential.

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