VectaDB: An Ontology-Native Vector and Graph Database for AI Systems *

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Abstract

Modern AI systems increasingly rely on vector similarity search, graph-structured data, and ontological knowledge representations. However, existing data management solutions treat these paradigms as separate concerns, resulting in fragmented architectures and limited reasoning capabilities.

This paper introduces **VectaDB**, an ontology-native database designed to unify vector embeddings, graph structures, and ontological semantics within a single data abstraction. VectaDB treats ontological entities as first-class citizens and supports hybrid queries that combine structural constraints, semantic similarity, and ontology-driven expansion.

We present the design principles, data model, and query semantics of VectaDB, along with a reference implementation intended for research and experimentation in AI-centric knowledge systems.

***K*eywords** Vector Databases · Graph Databases · Ontologies · Knowledge Representation · AI Systems

1 Introduction

Recent advances in large language models, autonomous agents, and reasoning-oriented AI systems have exposed fundamental limitations in current data management approaches. Vector databases excel at similarity search, graph databases capture relational structure, and ontologies provide formal semantics; yet these systems are typically deployed independently, forcing application-level orchestration.

This fragmentation complicates reasoning workflows, increases system complexity, and limits the expressive power available to AI systems. VectaDB is motivated by the need for a unified data layer in which vectors, graphs, and ontologies coexist as first-class primitives.

This paper makes the following contributions:

- A unified data model integrating vectors, graphs, and ontologies
- Ontology-native query semantics for AI-driven workloads
- A reference implementation designed for research and experimentation

2 Background and Related Work

2.1 Vector Databases

Vector databases such as FAISS, Milvus, and Pinecone focus on high-dimensional similarity search but lack structural and semantic reasoning capabilities.

*This paper describes ongoing research and an open-source reference implementation available at https://github.com/robertowilliams/VectaDB.

2.2 Graph Databases

Graph databases including Neo4j and JanusGraph provide expressive relationship modeling but treat embeddings and ontologies as external concerns.

2.3 Ontologies and Knowledge Graphs

Ontology frameworks (e.g., RDF, OWL) offer formal semantics and reasoning but are poorly integrated with modern embedding-based retrieval.

2.4 Cognitive and Memory-Oriented Systems

Systems such as Cognee explore cognitive data processing pipelines. VectaDB differs by adopting a database-centric abstraction rather than an application-level orchestration model.

3 System Design

VectaDB is designed around three core primitives:

- **Entities**: Ontological units with identity and type semantics
- **Relations**: Directed, typed edges forming a property graph
- **Embeddings**: Vector representations attached to entities or relations

Ontologies define allowable entity types, relations, and inheritance rules, enabling semantic constraints to guide data storage and retrieval.

4 Query Model

VectaDB supports hybrid queries combining:

- Structural constraints over the graph
- Vector similarity search
- Ontological expansion and filtering

Queries are evaluated through a staged execution model in which ontological rules guide graph traversal and vector search scopes.

5 Implementation

We provide an open-source reference implementation of VectaDB intended for experimentation. The current implementation emphasizes clarity and extensibility over performance and serves as a foundation for future optimization and distributed execution.

6 Use Cases

Potential applications include:

- Agent memory and long-term knowledge storage
- Ontology-guided retrieval for LLM systems
- Knowledge consolidation across heterogeneous data sources
- Graph-based reasoning augmented with semantic similarity

7 Limitations and Future Work

VectaDB is an early-stage research system. Open challenges include query optimization, scalability, distributed reasoning, and formal semantic guarantees.

8 Conclusion

VectaDB proposes a unified database abstraction for AI systems that integrates vectors, graphs, and ontologies. By elevating ontological semantics to first-class status, VectaDB aims to reduce architectural fragmentation and enable richer reasoning capabilities for next-generation AI applications.

Acknowledgments

The author thanks the open-source community for foundational work in vector search, graph databases, and knowledge representation.

References