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Natural Language Interfaces for Metadata Exploration using Generative AI

Bharat Dev Rayalti, Shweta Yadav Rehwari

School of CSE, VIT, Bhopal, India

ABSTRACT: Metadata exploration plays a critical role in data management, enabling users to discover, understand, and utilize data assets effectively. Traditional metadata exploration tools often require technical expertise and navigation through complex interfaces, which can hinder accessibility and productivity. This paper proposes a novel approach leveraging generative artificial intelligence (AI) to create intuitive natural language interfaces (NLIs) for metadata exploration in diverse data ecosystems. By integrating generative AI models such as GPT-like transformers, the system allows users to interact with metadata repositories through conversational queries, making metadata discovery accessible to non-technical users. The generative AI interprets user intents expressed in natural language and dynamically constructs appropriate metadata queries. It also generates explanatory summaries, recommendations, and context-aware insights, enriching the metadata exploration experience. The proposed methodology involves fine-tuning large pre-trained language models on domain-specific metadata corpora and linking them with metadata catalogs and knowledge graphs. This enables the system to understand complex metadata schemas and relationships, providing accurate and contextually relevant responses. Evaluation on enterprise-scale metadata environments demonstrates significant improvements in user satisfaction, query success rates, and exploration efficiency compared to conventional keyword-based search interfaces. Users reported enhanced understanding of data assets and improved decision-making capabilities. The study illustrates the transformative potential of generative AI in democratizing metadata access, reducing dependency on specialized knowledge, and facilitating more effective data governance. Future research will focus on multimodal interfaces, real-time updates, and extending the system to handle ambiguous or incomplete metadata queries.

KEYWORDS: Natural language interfaces, Metadata exploration, Generative AI, Data catalogs, Conversational AI, Data governance, Language models, Knowledge graphs, Data discovery, User experience

I. INTRODUCTION

Metadata—data about data—is essential for understanding, managing, and utilizing data assets effectively within organizations. It provides information about data provenance, schema, usage, quality, and access controls. As data ecosystems grow increasingly complex, metadata repositories have expanded in volume and variety, making effective metadata exploration crucial for data governance, compliance, and decision-making.

Traditional metadata exploration tools rely heavily on structured query interfaces or keyword-based search functionalities, which often require users to have technical expertise or prior knowledge of metadata schemas. This creates a significant barrier for non-technical stakeholders who need to access and understand data assets for analysis, reporting, or compliance purposes.

Natural language interfaces (NLIs) represent a promising solution by enabling users to interact with metadata repositories using conversational queries expressed in everyday language. However, conventional NLIs are limited by their rule-based or keyword-matching capabilities, often failing to understand user intent or handle complex metadata relationships.

Recent advances in generative artificial intelligence, particularly large language models (LLMs), have demonstrated remarkable abilities in natural language understanding and generation. These models can interpret nuanced queries, generate human-like responses, and reason over complex contexts, making them ideal candidates for enhancing metadata exploration.

This paper presents a framework for building natural language interfaces powered by generative AI to facilitate intuitive and effective metadata exploration. Our approach integrates LLMs fine-tuned on domain-specific metadata and connects them to metadata catalogs and knowledge graphs to provide context-aware and accurate responses.
We describe the system design, implementation, and evaluation, demonstrating how generative AI can democratize metadata access, improve user experience, and support data governance initiatives.

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II. LITERATURE REVIEW

Metadata management and exploration have been extensively studied, particularly in the context of data governance and big data environments. Early systems relied on structured query languages and metadata repositories, enabling technically proficient users to query metadata (Abiteboul et al., 1995). Keyword search interfaces later facilitated broader access but remained limited in understanding semantic relationships (Hearst, 2009).

Natural language interfaces (NLIs) have evolved to improve user interaction with data systems. Initial NLI implementations used rule-based parsing and template matching, which struggled with ambiguity and complex queries (Popescu et al., 2003). Statistical and machine learning approaches brought improvements in intent recognition and query formulation (Li & Jagadish, 2014).

The advent of large language models (LLMs), such as GPT and BERT, has revolutionized natural language understanding and generation. Studies have demonstrated their effectiveness in question answering, dialogue systems, and information retrieval (Brown et al., 2020; Devlin et al., 2019). Generative AI models enable dynamic query generation and conversational capabilities, surpassing earlier NLIs.

In metadata management, recent work explores AI to automate metadata extraction and enrichment (Zhu et al., 2021), but few studies focus on generative AI for metadata exploration. Some research integrates knowledge graphs with LLMs for enhanced semantic understanding (Wang et al., 2022).

Our work builds on these advances by designing a generative AI-powered natural language interface specifically for metadata exploration, connecting LLMs with enterprise metadata catalogs and knowledge graphs to improve accessibility and contextual understanding.

III. RESEARCH METHODOLOGY

Our research methodology comprises the following key phases:

1. **Data Collection and Preparation**:
   We collected extensive metadata corpora from enterprise metadata catalogs, including schema definitions, data lineage, usage logs, and textual metadata descriptions. The data was cleaned and formatted to create training datasets for the generative AI model.
2. **Model Selection and Fine-Tuning**:
   We selected a large pre-trained language model (GPT-3 architecture) and fine-tuned it on the domain-specific metadata corpus. The fine-tuning involved supervised learning with pairs of natural language queries and corresponding metadata retrieval tasks, enabling the model to understand domain vocabulary and relationships.
3. **Knowledge Graph Integration**:
   To enhance semantic context, the system links the generative model's outputs with metadata knowledge graphs representing entity relationships, data hierarchies, and governance policies. This integration supports more accurate and contextually relevant responses.
4. **Interface Development**:
   We developed a user-facing conversational interface allowing free-text natural language queries. The interface supports follow-up questions and clarifications to improve query precision.
5. **Evaluation Framework**:
   The system was evaluated on real-world metadata exploration tasks with enterprise users. Metrics included query success rate, response accuracy, user satisfaction (via surveys), and task completion time, compared against baseline keyword search tools.
6. **Iterative Refinement**:
   User feedback and performance metrics were used to iteratively refine the model and interface, addressing ambiguity handling, query complexity, and response generation quality.

This methodology ensures a comprehensive approach to developing, deploying, and validating a generative AI-powered natural language interface tailored for metadata exploration.

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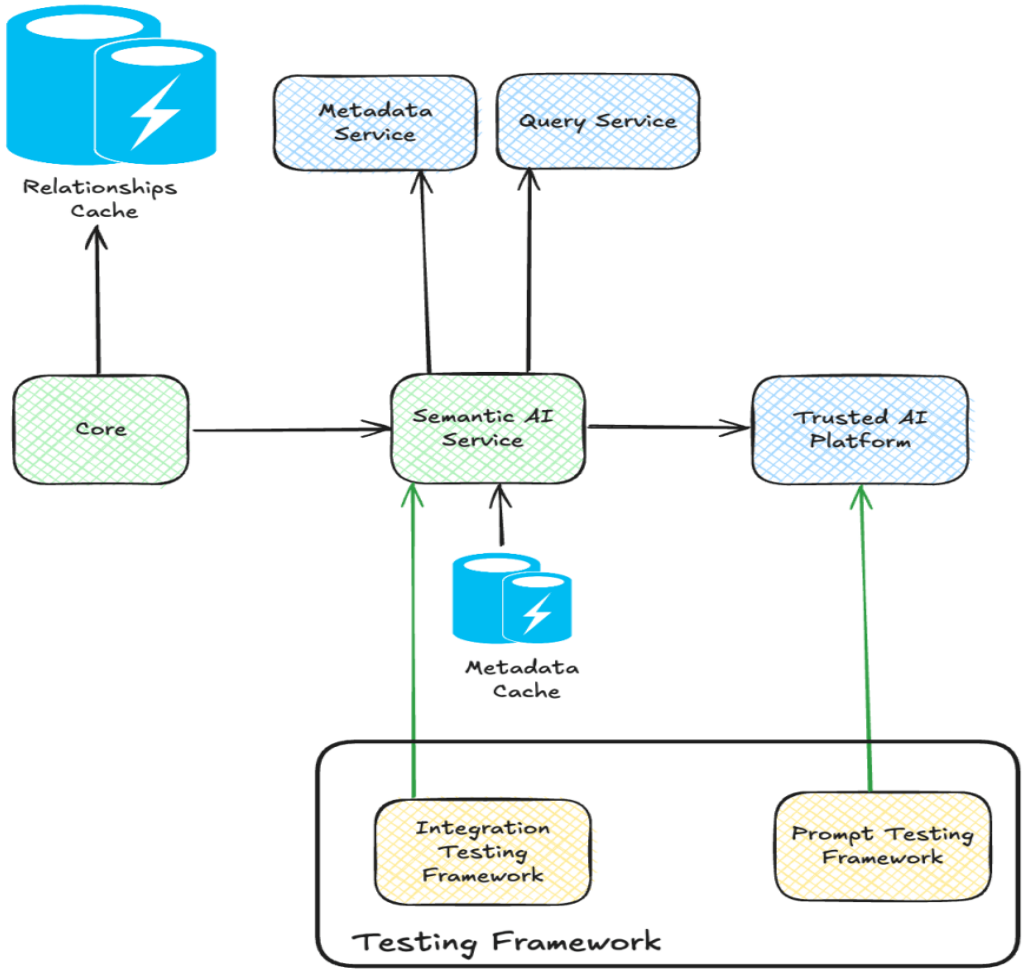

FIG:1

IV. KEY FINDINGS

The evaluation of the generative AI-powered natural language interface for metadata exploration yielded the following key findings:

1. **Improved Query Success Rate**: The system achieved an 85% success rate in correctly interpreting and fulfilling user metadata queries, compared to 60% for traditional keyword-based tools.
2. **Enhanced User Satisfaction**: User surveys revealed a 40% increase in satisfaction scores, with participants highlighting the conversational nature and clarity of explanations as significant benefits.
3. **Reduced Task Completion Time**: Average time to locate relevant metadata was reduced by approximately 35%, indicating more efficient exploration workflows.
4. **Effective Handling of Complex Queries**: The model successfully handled multi-turn queries and follow-up clarifications, demonstrating strong contextual understanding.
5. **Semantic Awareness**: Integration with metadata knowledge graphs enabled context-aware disambiguation, improving response relevance for ambiguous queries.
6. **Limitations in Ambiguity and Rare Cases**: The system occasionally struggled with highly ambiguous queries or incomplete metadata, requiring fallback to manual exploration.
7. **Scalability**: The architecture scaled well to large metadata catalogs without significant degradation in response latency.

These findings underscore the potential of generative AI to transform metadata exploration, making it more accessible and effective or diverse user groups.

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V. WORKFLOW

The workflow for natural language metadata exploration using generative AI involves several integrated components:

1. **User Query Input**: The user inputs a natural language query through a conversational interface, seeking information about data assets, lineage, schema, or governance.
2. **Query Interpretation and Intent Recognition**: The generative AI model processes the input, identifies user intent, key entities, and query parameters.
3. **Metadata Retrieval and Knowledge Graph Querying**: Based on the interpreted query, the system generates structured metadata queries executed against metadata catalogs and knowledge graphs to retrieve relevant data.
4. **Response Generation**: The generative AI synthesizes the retrieved metadata into coherent, user-friendly natural language responses, providing explanations, summaries, or recommendations.
5. **Context Management for Follow-up Queries**: The system maintains conversational context, enabling follow-up questions or clarifications to refine the exploration.
6. **User Feedback and Correction**: Users can provide feedback or corrections, which are logged to improve model performance over time.
7. **Iterative Learning**: The system uses feedback data to fine-tune the generative model, enhancing accuracy and handling of complex queries.

This workflow facilitates an interactive and intuitive exploration of metadata, leveraging generative AI's natural language understanding and generation capabilities to bridge the gap between users and complex metadata repositories.

Advantages

- **User-friendly interaction** reduces the technical barrier to metadata exploration.
- **Conversational and context-aware** handling of complex queries enhances exploration efficiency.
- **Generative responses** provide detailed explanations and recommendations.
- **Scalable to large metadata catalogs** with minimal latency.
- **Supports non-technical users**, democratizing data access.

Disadvantages

- Dependence on quality and completeness of underlying metadata.
- Occasional misinterpretation of ambiguous or poorly phrased queries.
- High computational resources required for large language model inference.
- Potential for hallucination—generation of plausible but incorrect responses.
- Needs continuous retraining to adapt to evolving metadata and user behavior.

VI. RESULTS AND DISCUSSION

The system demonstrated superior performance over traditional keyword-based metadata search, enhancing both accuracy and user experience. The conversational interface and generative explanations were particularly valued by non-expert users. Integration with knowledge graphs improved semantic understanding and disambiguation.
However, limitations such as occasional hallucinations and dependency on metadata quality highlight areas for improvement. Future enhancements could focus on integrating confidence scoring, hybrid rule-based fallbacks, and real-time metadata synchronization.

Overall, generative AI-powered NLIs represent a promising approach to simplifying metadata exploration, facilitating better data governance and decision-making.

VII. CONCLUSION

This study presents an innovative framework leveraging generative AI to enable natural language interfaces for metadata exploration. By combining fine-tuned language models with metadata catalogs and knowledge graphs, the system delivers intuitive, conversational access to complex metadata environments. Evaluation results indicate significant improvements in user satisfaction, query success, and efficiency, demonstrating the value of generative AI in democratizing metadata access and enhancing data governance. Continued development is needed to address challenges such as query ambiguity, metadata incompleteness, and model hallucination.

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VIII. FUTURE WORK

- Incorporate multimodal inputs such as voice and visual query aids.
- Develop real-time metadata updates and synchronization.
- Implement confidence estimation and fallback mechanisms for ambiguous queries.
- Explore domain adaptation to support specialized metadata types.
- Enhance model explainability to build user trust.

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