Natural Language Interfaces for Tabular Data Querying and Visualization: A Survey (Extended Abstract)

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***Abstract*—Natural Language Interfaces (NLIs) have transformed data interaction by enabling natural language querying and visualization of tabular data. Despite the growing importance of NLIs, prior research has examined querying and visualization tasks separately, lacking a unified perspective, especially in the era of Large Language Models (LLMs). To fill this gap, this survey provides a comprehensive analysis of NLIs for tabular data, examining their evolution and fundamental components: datasets, evaluation metrics, and architectural designs. By analyzing over 60 approaches and 38 datasets, we explore recent advancements in Text-to-SQL and Text-to-Vis tasks, focusing on semantic parsing techniques for natural language translation to SQL queries and visualization specifications. We evaluate the impact of LLMs on these systems, discussing their capabilities and limitations. Our systematic review serves as a roadmap for developing NLIs in the foundation model era.**

***Index Terms*—Natural Language Interface, Text-to-SQL, Text-to-Visualization, Semantic Parsing, Large Language Models**

I. Introduction

Tabular data forms the backbone of many fields in today's digital age, yet effectively interacting with tabular data remains challenging for users without technical expertise. The emergence of natural language processing technologies, particularly large language models, has enabled a shift toward more intuitive, language-based interfaces.

Natural Language Interfaces (NLIs) convert user's natural language questions (NLQs) for database queries into executable formats. Two typical NLIs are Text-to-SQL (which converts NLQ into SQL) and Text-to-Vis (which converts NLQ into specs for charting). While numerous surveys have examined Text-to-SQL systems or Text-to-Vis techniques independently, the relationship between these crucial aspects of data interaction remains unexplored, especially in the era of LLMs where new methodologies and challenges emerge. Our survey bridges this gap by providing the first unified analysis of both querying and visualization aspects, examining their evolution from rule-based approaches to sophisticated neural architectures and LLM-based systems. Fig. 1 illustrates the overall workflow of natural language interfaces for tabular data querying and visualization.

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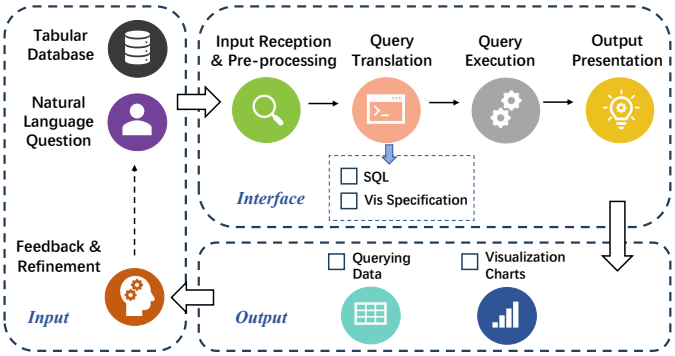

Fig. 1. Schematic representation of natural language interfaces for tabular data querying and visualization.

II. Framework and Components

This survey [1] summarizes recent developments on three essential components for effective data interaction through natural language.

A. Datasets

For Text-to-SQL tasks, datasets have evolved from single-domain collections to comprehensive cross-domain benchmarks, featuring diverse database schemas. The field has progressed through several stages: from simple single-table queries to complex multi-table scenarios, from single-turn to multi-turn dialogues, and from English-only to multilingual support. Recent benchmarks focus on real-world challenges requiring external knowledge.

Text-to-Vis datasets show similar trends, numbering only 8 major collections compared to over 30 Text-to-SQL datasets. Common benchmarks provide comprehensive coverage of chart types and analytical tasks, while recent additions support interactive visualization refinement and multilingual capabilities. Specialized collections address domain-specific applications and visualization types.

B. Evaluation Metrics

Evaluation methods comprise three main approaches, each addressing different aspects of system performance: *String-based metrics* (exact match, component match) evaluate the textual similarity between generated and reference outputs, being employed in more than 85% of studies and offering an efficient but sometimes rigid assessment. *Execution-based metrics* compare actual query results or visualization renderings, showing increasing adoption in recent publications and better capturing semantic equivalence, despite potentially missing logical errors. *Human evaluation* provides the most comprehensive assessment, examining aspects like query complexity, visualization effectiveness, and user experience, though used in less than 20% of published studies due to cost constraints.

C. System Design

NLIs employ four distinct architectural paradigms: *Rule-based systems* rely on predefined mappings, achieving high precision but struggling with linguistic variations. *Parsing-based systems* provide robust linguistic insights through grammatical understanding, while *multi-stage systems* decompose translation into specialized components for focused optimization. *End-to-end systems* directly map inputs to outputs through neural architectures, offering greater adaptability but often sacrificing interpretability.

III. Technical Approaches and Evolution

The development of NLIs has progressed through three distinct stages, each marking significant technological advances.

A. Traditional Stage

Before 2015, traditional approaches center on rule-based and template-based methods, establishing fundamental principles still relevant today. Rule-based systems employ carefully designed lexicons and mapping rules to translate natural language to SQL components, using intermediate logical representations and semantic coverage checking. For visualization tasks, these early systems introduce important innovations in ambiguity resolution through user interaction and attribute-based visualization recommendation, though they struggle with novel request patterns and domain adaptation.

B. Neural Network Stage

From 2015 to 2020, neural architectures bring transformative innovations in both encoder and decoder designs, improving accuracy by 30-40% over traditional approaches. Text-to-SQL systems evolve along two main paths: sequence-based approaches using recurrent and transformer architectures for natural language understanding, and graph-based methods that explicitly model database schema structure. Decoder architectures similarly diversify, from grammar-guided approaches ensuring syntactic correctness to skeleton-based methods combining templates with neural flexibility.

Text-to-Vis neural systems have developed specialized architectures for visualization-specific challenges. These include encoder-decoder frameworks for visualization specification, neural cache mechanisms for handling long-range dependencies, and graph neural networks for capturing relationships between visualization elements, demonstrating superior performance in complex visualization tasks.

C. Foundation Language Model Stage

Since 2020, the latest stage leverages large language models through two distinct approaches. Pre-trained language model-based methods (typically 100M-1B parameters) fine-tune models for specific tasks, demonstrating sophisticated schema grounding techniques and logical consistency through constrained decoding. Large language model-based approaches (typically 1B-100B parameters) leverage more extensive models through careful prompt engineering, achieving impressive zero-shot and few-shot performance across diverse domains.

Text-to-Vis approaches face unique challenges while achieving similar advances. Zero-shot methods leverage language models' broad knowledge for direct visualization generation, while few-shot approaches develop specialized prompting techniques. Hybrid solutions enhance reliability by combining language models with visualization-specific knowledge bases and constraint verification.

IV. Future Directions and Challenges

NLIs for tabular data present both challenges and opportunities. While neural models show promise in handling complex queries and sophisticated visualizations, they still require significant advancement in both architecture and training approaches. Large language models have emerged as a powerful solution, yet their effective deployment demands better tuning strategies and deeper integration with domain-specific knowledge. Future advances depend on diverse datasets, robust evaluation frameworks, and solutions to core challenges, such as input noise tolerance, cross-domain adaptation, and reasoning. The emergence of multimodal and interactive systems opens new possibilities for intuitive data exploration tools.

V. Conclusion

This survey has traced the evolution of natural language interfaces for tabular data querying and visualization from rule-based systems to modern LLM-based approaches, examining datasets, evaluation metrics, and architectures. Future advances will focus on overcoming current limitations while harnessing new technologies for powerful and user-friendly data exploration.

References

[1] W. Zhang, Y. Wang, Y. Song, V. J. Wei, Y. Tian, Y. Qi, J. H. Chan, R. C.-W. Wong, and H. Yang, "Natural language interfaces for tabular data querying and visualization: A survey," IEEE Trans. Knowl. Data Eng., vol. 36, no. 11, pp. 6699–6718, 2024.