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TransRAG for parallel transportation: toward reliable and trustworthy transportation systems via retrieval-augmented generation

Key words: Parallel transportation; Foundational models; Blockchain; Caching; Smart contracts; Retrieval-augmented generation

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Motivation

Recently, the advancement of foundation models has elevated the implementation of parallel transportation systems to a new level because of their exceptional understanding, generation, and reasoning abilities. However, the inherent flaws of foundational models (FMs) hinder their application in actual transportation systems and could even jeopardize the safety of passengers and drivers as follows:

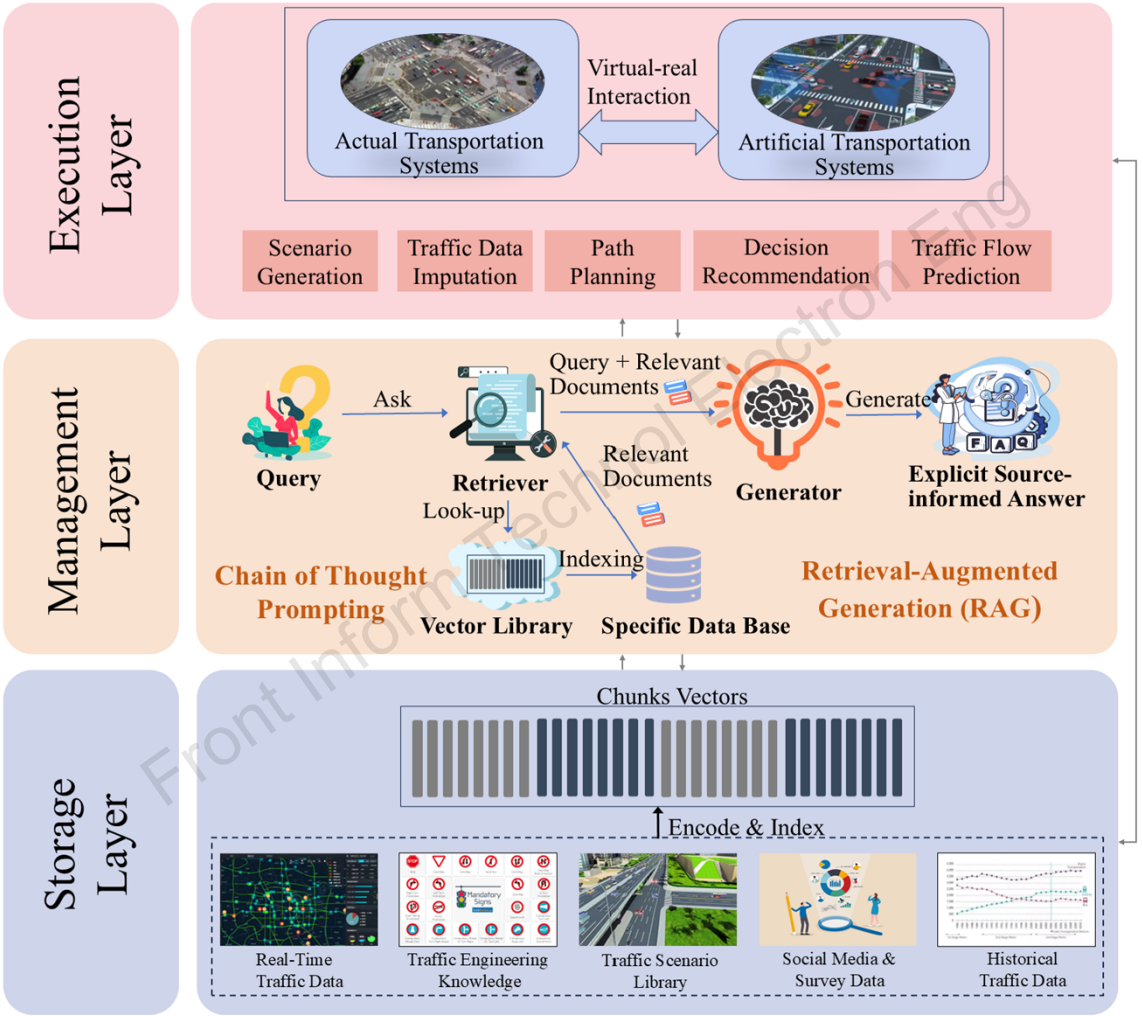
(1) “Hallucination” phenomena and outdated knowledge within FMs contribute to the unreliability of their inferences.

(2) The fact that FMs are neural network based “black-box” models makes their generation results inexplicable and untrustworthy.

Main idea

- We propose a unified TransRAG framework for parallel transportation to guarantee the dependability and trustworthiness of FMs' decision-making in different traffic scenarios and thus the safety of traffic system operations.
- Retrieval-augmented generation (RAG) and chain-of-thought (CoT) prompts are integrated into the framework to enable FMs to access real-time knowledge and information without the need for re-pretraining, steering them toward generating more accurate and interpretable outcomes.

Framework



Framework of TranRAG (RAG: retrieval-augmented generation)

Storage layer

- The storage layer is the lowest tier, primarily responsible for storing actual data and knowledge and supporting web-based retrieval functions.
- The stored data can be updated in real time, including real-time traffic data, traffic engineering knowledge, traffic scenario library, historical traffic data, and social media & survey data.
- To speed up retrieval and meet FMs' input token limits, all the texts in the database are broken down into several smaller and more approachable chunks. Subsequently, an embedding model is used to encode these chunks as corresponding vector representations, and thus an index is created where chunks are stored as values and vector representations as keys.

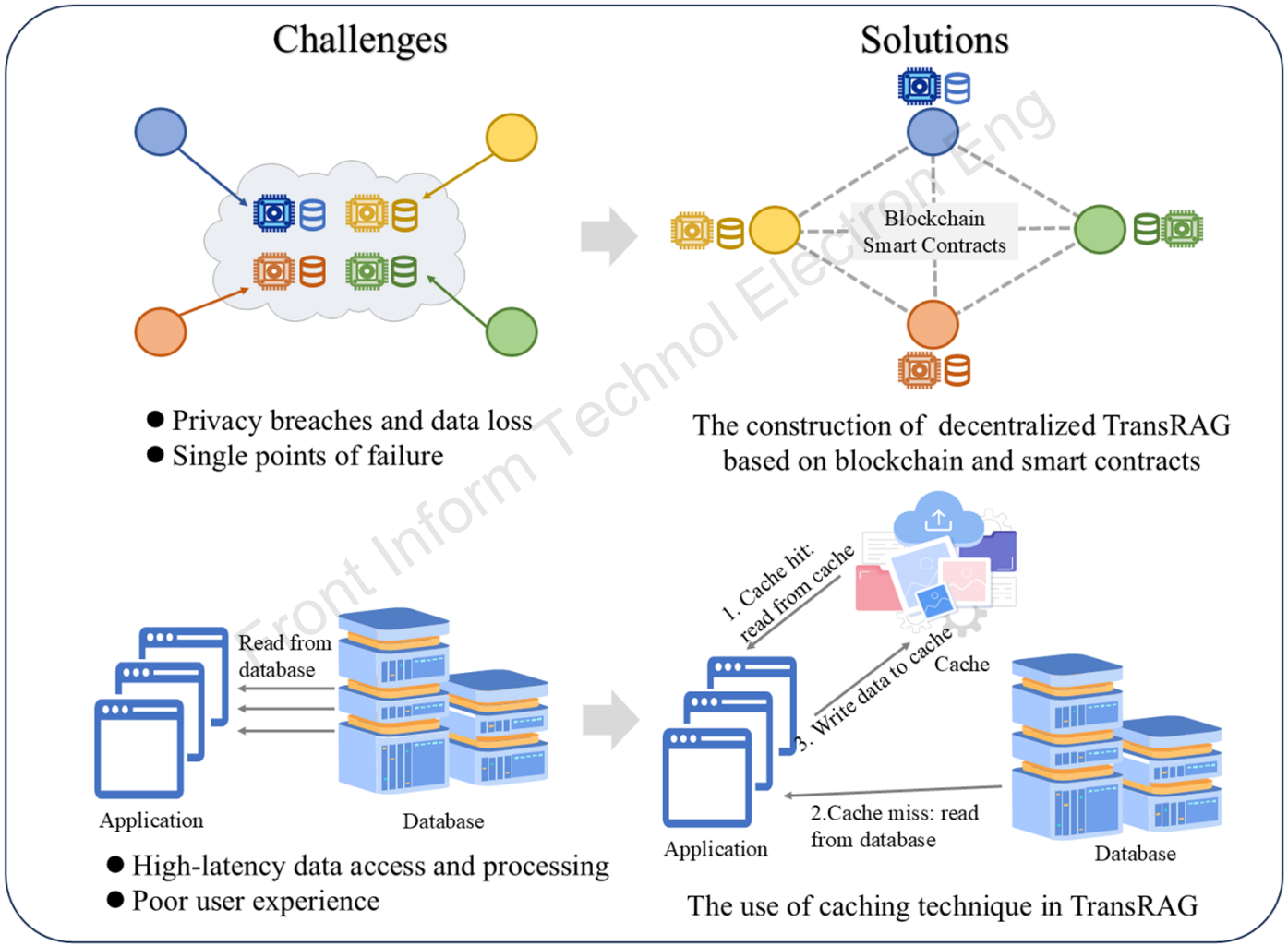
Management layer

- The management layer is the middle tier and leverages RAG and CoT to guide foundation models in making reliable and interpretable decisions through computational experiments.
- The entire decision-making process can be divided into two stages, retrieval and generation, so the layer includes at least one retriever and one generator.
- In the retrieval stage, after a query is asked, the same embedding model as the storage layer is leveraged to encode it as a query vector. The top-*K* most similar chunk vectors are identified and returned as relevant information by computing the similarity between the query vector and the chunk vectors.
- In the generation stage, the query, its relevant information, and task-specific prompts are combined as a coherent contextual prompt, fed into the generator to formulate a response.

Execution layer

- The execution layer is the highest tier, where the decisions from the management layer are executed in actual transportation systems in parallel with artificial transportation systems.
- A variety of artificial systems are built using scenario data from the storage layer, where computational experiments are performed by the management layer.
- During parallel execution, the differences between the two types of systems are fed back into the management layer to continuously optimize decision-making.
- Generated intermediate data and tested case studies are transmitted to the storage layer for storage, thereby accumulating experience for future strategy formulation.

Opportunities and challenges



Conclusions

- Transportation 4.0 to Transportation 5.0 requires a unified approach that seamlessly integrates all these elements, especially human and societal factors, instead of addressing them as separate issues.
- The proposed TransRAG for parallel transportation shows promise in advancing the shift toward Transportation 5.0 as a holistic framework.
- The shortcomings of TransRAG, such as privacy breaches, single point of failure, and delays in data access, are analyzed, and the corresponding solutions are offered, including the use of blockchain, smart contracts, and caching.

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