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Requirement Discovery Using Embedded Knowledge Graph with ChatGPT

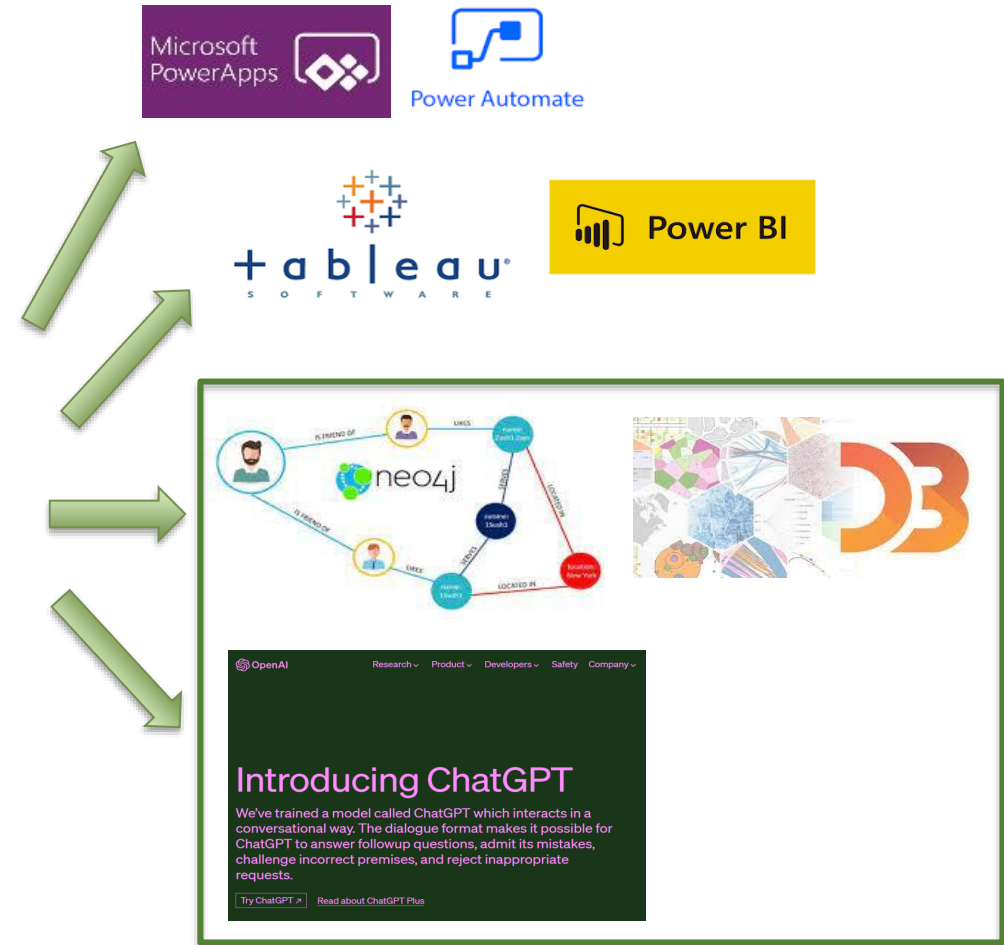
Use Case

- The field of Advanced Air Mobility (AAM) is witnessing a transformation with innovations such as electric aircraft and increasingly automated airspace operations. Within AAM, the Urban Air Mobility (UAM) concept focuses on providing air-taxi services in densely populated urban areas.
- This research introduces the utilization of Large Language Models (LLMs), such as OpenAI's GPT-4, to enhance the UAM Requirement discovery process.



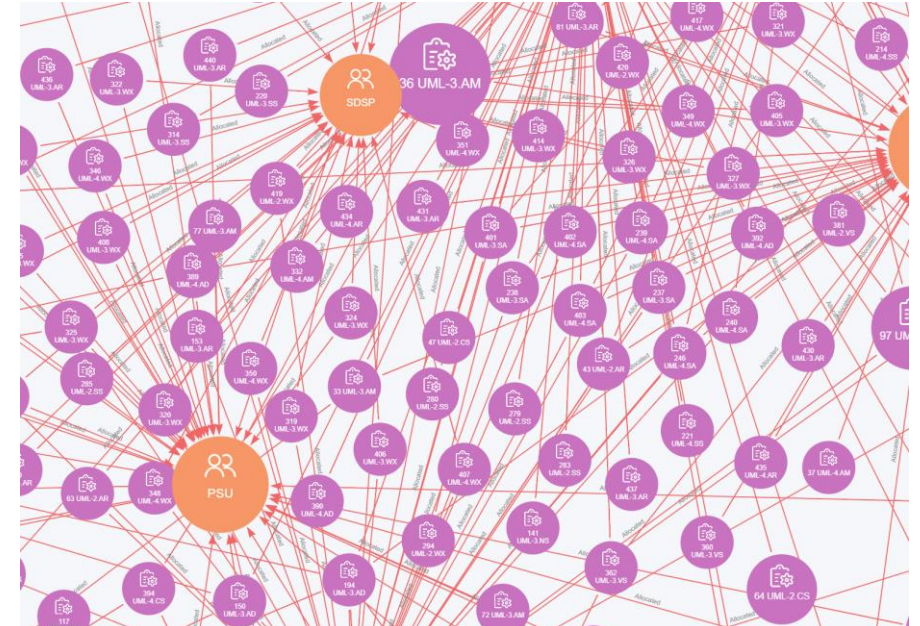
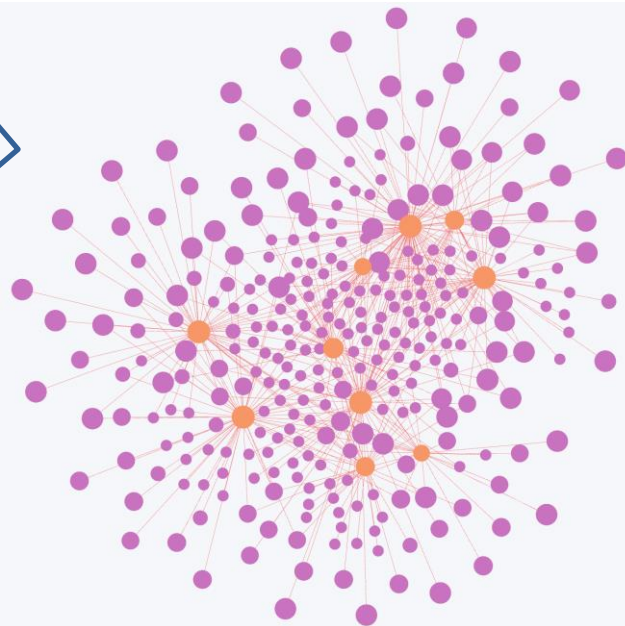
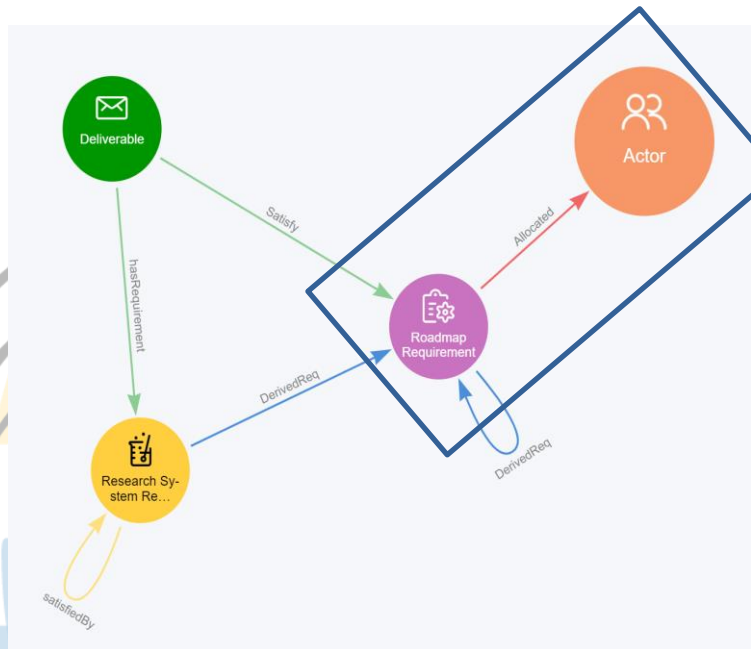
Workflow

Architecture, requirements, task deliverables, and traceability are captured in the **SysML models**, serving as the **single source of truth**.



Knowledge Graph for Roadmap Development

- Schema (left) showing graph structure between nodes.
 - Node represents the type of objects (e.g., Actor, Roadmap Requirement, etc.)
 - Link represents the relationship types.
- Due to the CUI nature of data, only focus on **Roadmap Requirement and Actor** for this study.
- Knowledge graph (middle and right) displays **complexity** beyond human user's ability to perform Roadmap's requirement discovery and analysis to identify potential missing requirements.



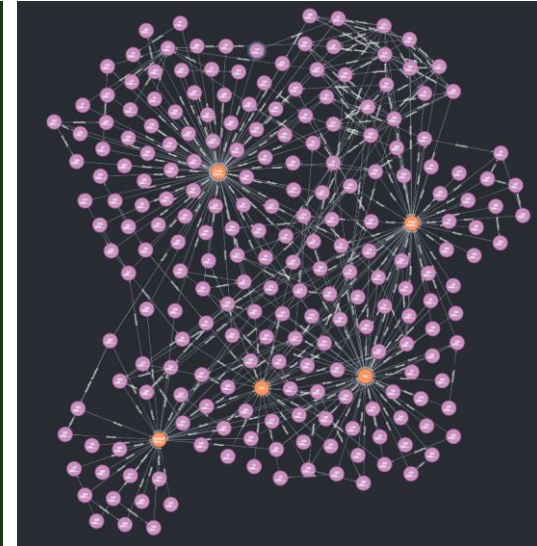
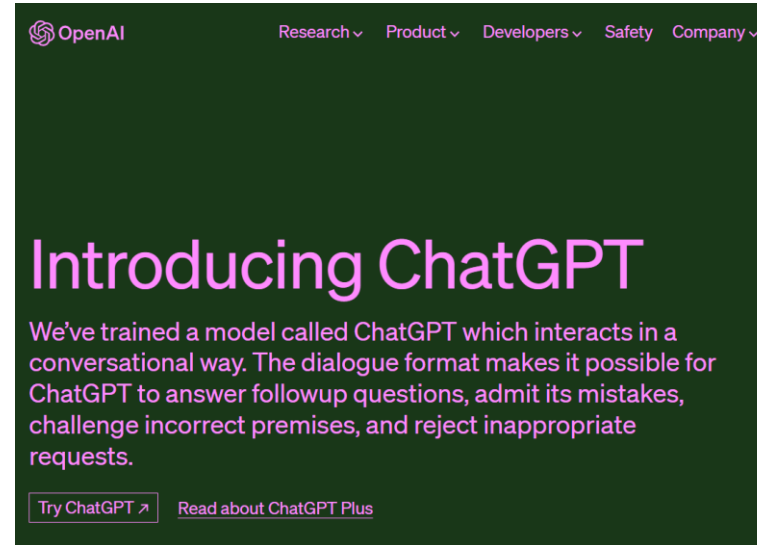
Knowledge Graph for Roadmap Development

Challenges:

- SE is worried that we might miss some requirements in the roadmap.
- SE has a limited bandwidth to perform requirement analysis.

Solution:

- Knowledge Graph:
 - (+) Accurate information based on database, readily available advanced analytics
 - (-) Complicated query command, queried results are not human readable
- ChatGPT / LLM (Large Language Model):
 - (+) Generate reasonable programming code, generate user friendly dialogue
 - (-) Hallucination (fake research)
- Using Knowledge Graph structure with ChatGPT capability

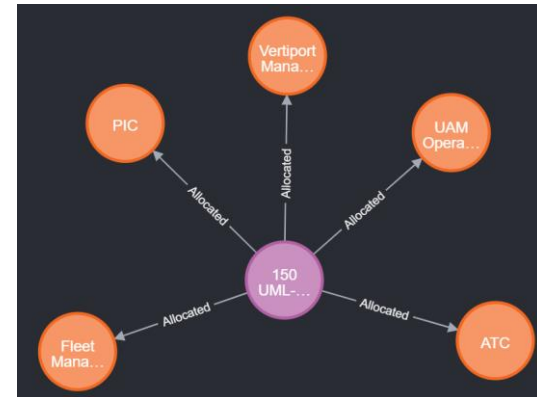


Off Nominal Procedures

For operations in controlled airspace, the FAA will approve off-nominal procedures that accommodate the appropriate aircraft performance characteristics. (268 UML-2.AD)

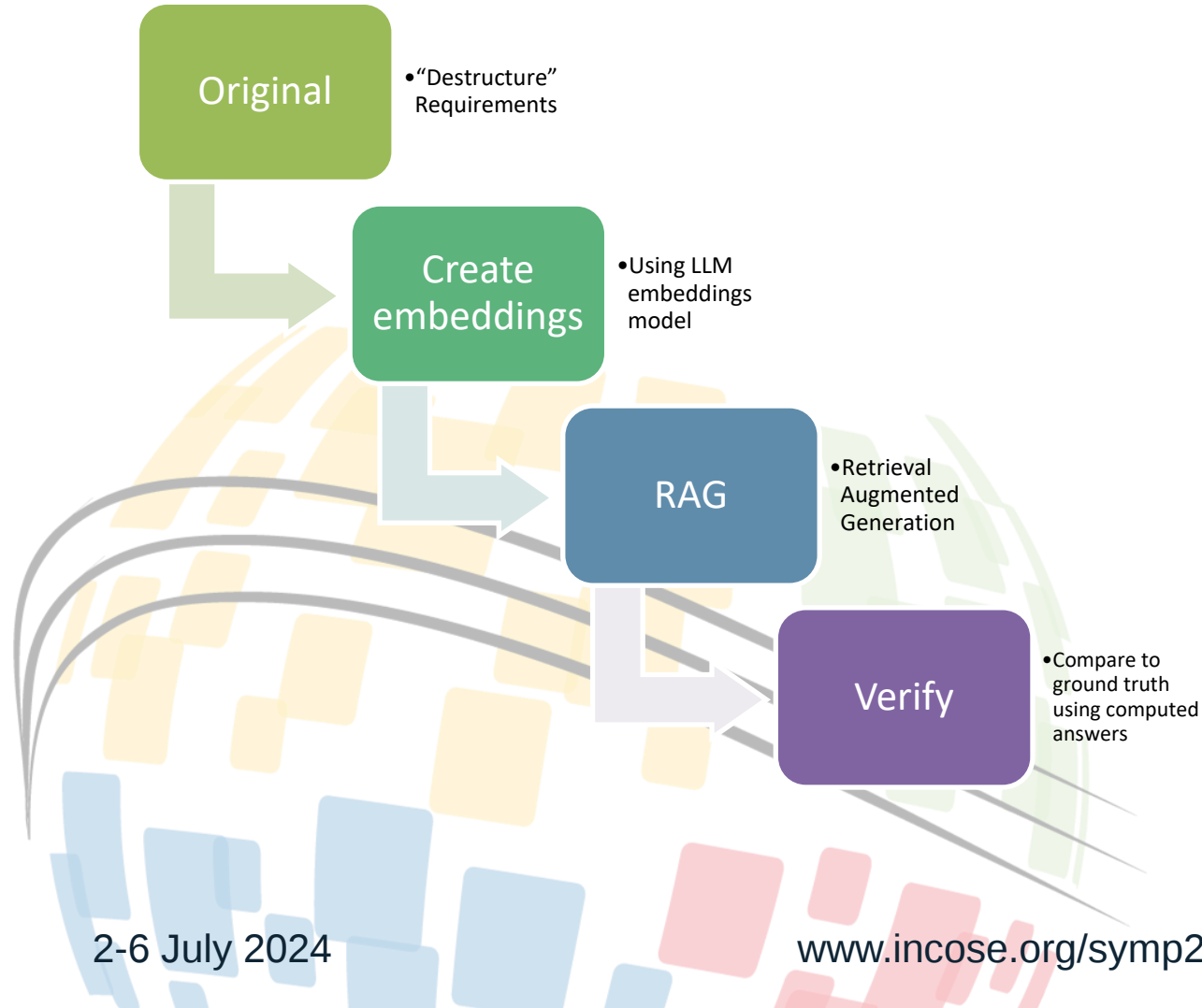
The UAM Operator shall establish a plan to resolve off-nominal conditions with the PIC, Fleet Manager, or Vertiport Manager, without ATC involvement. (150 UML-3.AD)

The PIC or RPIC will take any intervention during off-nominal conditions with the support of a sufficient autonomy level in the UAM vehicles. (329 UML-4.AD)

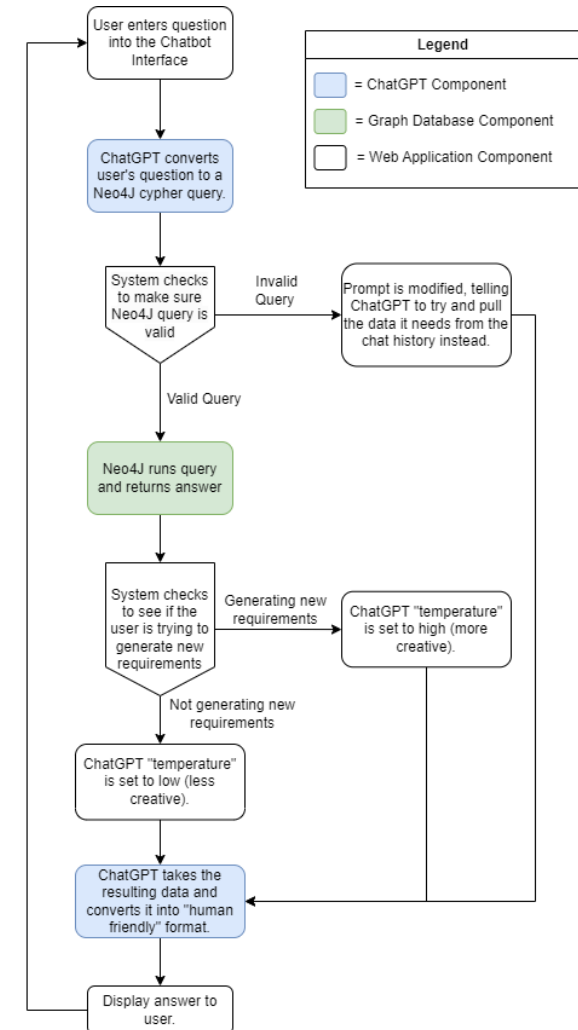


Approaches

ChatGPT + Document Embeddings (RAG)



Graph Database + ChatGPT



ChatGPT (Azure OpenAI GPT 3.5) Sample Questions

Applied Stereotype	ReqID	Actor	Requirement Text
Allocate [Abstraction]	19 UML-2.AM	ATC	When ATC is the designated separator; The Fleet Manager and PIC will receive services from ATC.

Requirement number "19 UML-2.AM" states "When ATC is the designated separator; The Fleet Manager and PIC will receive services from ATC." and has an Allocate relationship to the actor "ATC".

Query submitted to LLM after retrieval of relevant requirements information

How many unique requirements do we have for the System?

How many unique system actors do we have?

Please list the unique system actors

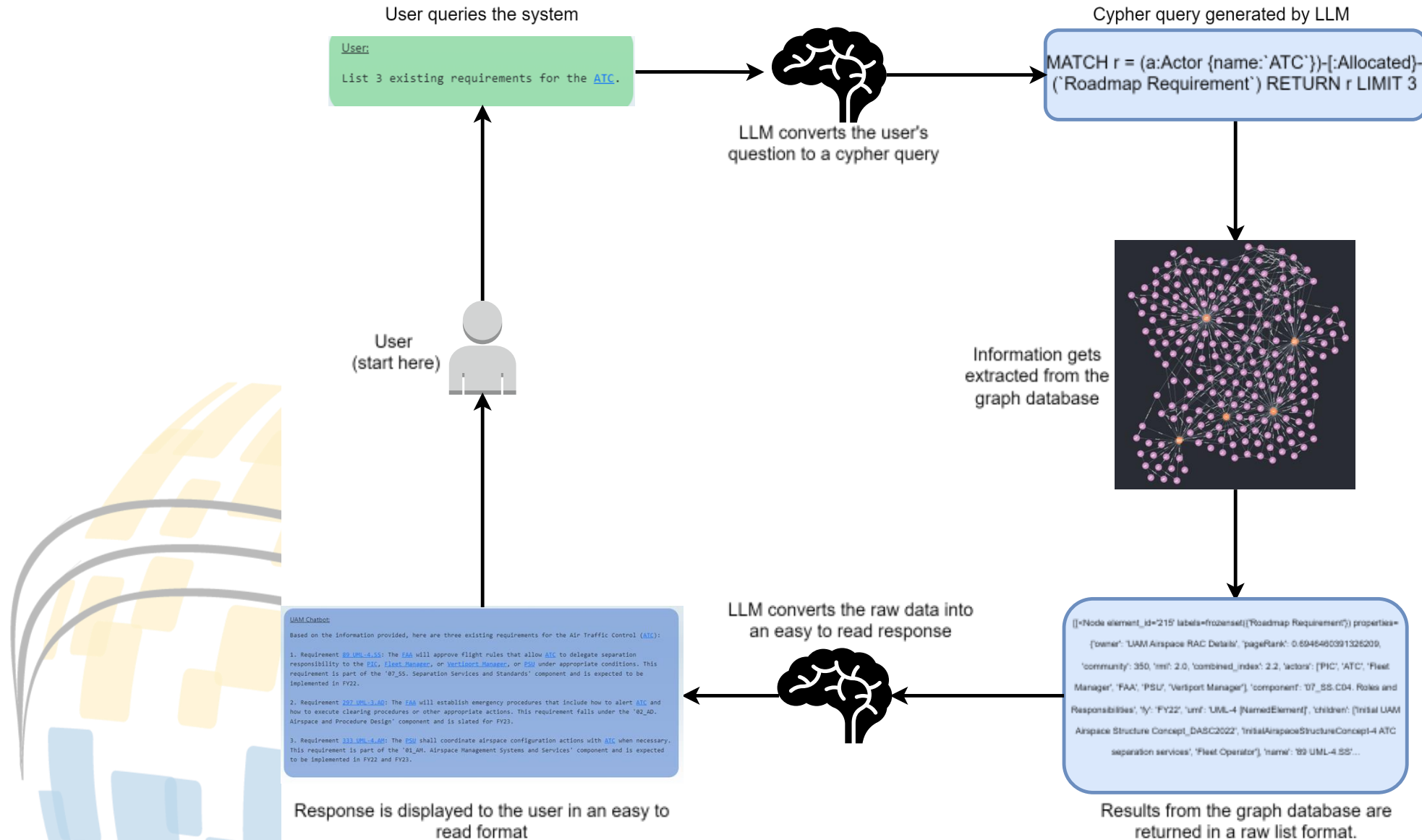
Give me 5 requirements with multiple actors. List them using a Python list of Requirement Numbers

List all existing requirements for UAM Aircraft

Predict five requirements for Urban Air Mobility systems that I may have missed

Create ten new requirements based on these predictions.

Graph Database + ChatGPT - Architecture



Graph Database + ChatGPT – Prompt Engineering

Prompt to Convert User's Question to a Cypher Query

Instructions

You are an assistant with an ability to generate Cypher queries based off example Cypher queries. Here is a list of example cypher queries:

Examples

User Question: What nodes are allocated to requirement 222 UML-2.SU?

Expected Cypher: `MATCH (n)-[r:Allocated]-(b)WHERE n.name="222 UML-2.SU" RETURN b`

User Question: Predict 10 requirements related to the System Actor actor FAA that I may have missed.

Expected Cypher: `MATCH (n{name:'FAA'}), (b:'Roadmap Requirement') where not (n)-[]-(b) with b.name as name, b.text as roadmap_requirement_description, gds.alpha.linkprediction.adamicAdar(n, b) as score where score > 0 return name, roadmap_requirement_description, score order by score desc LIMIT 10`

User Qustion: ...

Expected Cypher: ...

Prompt to Convert Database Responses to Structured English

Instructions

You are an assistant that helps to translate database responses to human readable answers. The latest prompt contains the information, and you need to generate a human readable response based on the given information. If the user asks to generate new requirements, use the examples provided below.

Examples

User: Generate 1 new requirements for the Actor ATC

Neo4j response: [{"input_name": "ATC", "input_description": "A service operated by appropriate authority to promote the safe, orderly, and expeditious flow of air traffic.", "predicted_roadmap_requirement_name": "411 UML-3.WX", "roadmap_requirement_description": "The SDSP shall publish forecasts that meets performance standards for weather parameters to all subscribers ..."}]

New requirement description to return to the user: New requirement based on 411 UML-3.WX: The ATC shall use weather forecasts provided by the SDSP to ensure the safe, orderly, and expeditious flow of UAM air traffic.

Graph Database + ChatGPT – Prediction Algorithms

- The system predicts requirements using Adamic-Adar link prediction provided by the Neo4J Graph Data Science Library. This measure looks at common neighbors and it attributes less significance to those common neighbors that have in turn too many neighbors.

User:

predict 3 requirements that may be related to the [ATC](#)

UAM Chatbot:

Based on the information provided, here are the three predicted requirements that may be related to the Air Traffic Control ([ATC](#)):

1. Requirement '[327 UML-3.WX](#)': The [SDSP](#) (System Data Service Provider) should use numerical weather prediction models that meet performance standards for estimating weather parameters. This requirement is relevant to the [ATC](#) as it relies on accurate weather predictions for managing air traffic.
2. Requirement '[411 UML-3.WX](#)': The [SDSP](#) should publish forecasts that meet performance standards for weather parameters to all subscribers. This requirement is also pertinent to the [ATC](#) as it uses these forecasts to ensure the safe and efficient flow of air traffic.
3. Requirement '[20 UML-2.CS](#)': The Pilot in Command ([PIC](#)) and [ATC](#) should have the ability to communicate by voice in all classes of airspace as required by regulation. This requirement is directly related to the [ATC](#) as it emphasizes the importance of clear communication between the [ATC](#) and pilots for maintaining air traffic safety.

Graph Database + ChatGPT – Prediction Algorithms

- The UAM Chatbot combines the information from the ATC and the predicted requirements to generate a whole new set of requirements catered towards the ATC.

User:

Using these predicted requirements, generate 3 new requirements for the [ATC](#)

UAM Chatbot:

Based on the predicted requirements, here are three new requirements for the Air Traffic Control ([ATC](#)):

1. New requirement based on '[411 UML-3.WX](#)': The [ATC](#) shall utilize the weather forecasts published by the [SDSP](#) to manage the safe, orderly, and expeditious flow of air traffic.
2. New requirement based on '[327 UML-3.WX](#)': The [ATC](#) shall rely on the numerical weather prediction models used by the [SDSP](#), which meet performance standards for estimating weather parameters, to aid in air traffic control decisions.
3. New requirement based on '[20 UML-2.CS](#)': The [ATC](#) shall maintain the ability to communicate by voice with the Pilot in Command ([PIC](#)) in all classes of airspace as required by regulation, ensuring effective coordination for air traffic safety.

Results

User Question	Approach 1: LLM with RAG (Azure OpenAI GPT-4)	Approach 2: Graph Database / Data Science + LLM (Azure OpenAI GPT-4)
How many unique requirements do we have for the System?	Capable of answering	Capable of answering
How many unique system actors do we have?	Capable of answering	Capable of answering
Please list the unique system actors	Capable of answering	Capable of answering
Give me 5 requirements with multiple actors.	Capable of answering	Capable of answering
Find all requirements where one actor is UAM Aircraft	Only Finds 4 of 6	Capable of answering
Predict five requirements for UAM Aircraft that I may have missed	Not able to answer	Capable of answering
Create five new requirements for UAM Aircraft	Capable of answering	Capable of answering
Summarize the responsibilities of the UAM Operator	Capable of answering	Capable of answering, requires two separate questions from the user.

Color Key: Acceptable Answer - ■ | Partially Acceptable Answer - ■ | Unacceptable Answer - ■

Results

Aspects	Approach 1: LLM with RAG (Azure OpenAI GPT-4)	Approach 2: Graph Database / Data Science + LLM (Azure OpenAI GPT-4)
Implementation	Moderate: Retrieval-augmented generation pattern using LLM and vector store	Difficult and more expensive, requires deployment of supporting infrastructure and curation of graph database.
Cost for cloud server and developer	OpenAI subscription	- Open AI subscription - Server for graph database - Server for web-application - Application / system administrator
Quality of solutions	Varies based on type of query and structure of embedding vector store: better on general open queries, worse on numerical counting	Using the graph database provides a ground truth, chances of hallucination are much lower (almost 0 but not quite since GPT-4 is a “black-box”). Capable of providing accurate answers for questions involving numerical counting. Provides advance graph algorithms to the user.
Lessons Learned	Controlled Unclassified Information (CUI) not permitted	- CUI not permitted - Difficult to get consistent, complex, cypher queries from GPT. Took many instances of trial and error to come up with a functional prompt.

Conclusion

- **Revolutionize** the way SE works
- Observed 7x improvement in the speed of which SEs navigate the UAM roadmap and in some cases the LLM exhibited more creativity than human user when generating requirements.
- Allows users to access powerful graph data algorithms, like link prediction, without having to know the complex cypher query language needed to access those methods traditionally.
- Reduces the likelihood of hallucinations from the LLM by coupling it with an authoritative data source (graph database).
- Technical Exchange with SERC community, potentially **inspire the SE community** on this innovative approach

UAM Chatbot

FOR PUBLIC DATA ONLY, DO NOT SEND ANY SENSITIVE NASA DATA THROUGH THIS SEARCH ENGINE

Selected Model: gpt-4-32k

ChatGPT Mode: ChatGPT + Knowledge Graph ChatGPT Standard

What would you like to ask me?

User:
Predict 3 requirements related to the [PIC](#) that I might have overlooked.

UAM Chatbot:
Based on the information provided, here are three requirements related to the [PIC](#) (Pilot in Command) that you might have overlooked:

1. Requirement '[411 UML-3.WX](#)': The [SDSP](#) (Service Delivery Platform) is required to publish forecasts that meet performance standards for weather parameters to all subscribers. This is crucial for the [PIC](#) as it aids in making informed decisions regarding flight operations.

2. Requirement '[327 UML-3.WX](#)': The [SDSP](#) should use numerical weather prediction models that meet performance standards for estimating weather parameters. This requirement is important for the [PIC](#) as it provides accurate weather predictions, ensuring the safety and efficiency of flight operations.

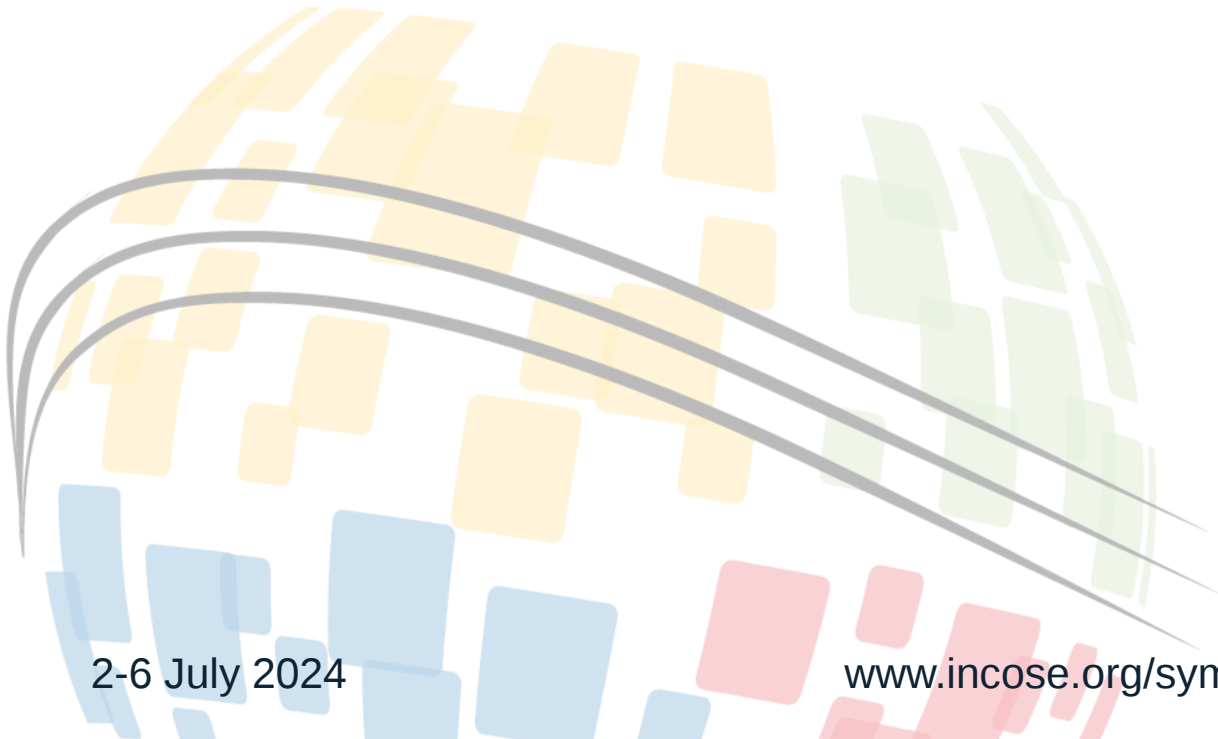
3. Requirement '[321 UML-3.WX](#)': The [SDSP](#) is required to collect and publish weather measurements meeting sensor and data performance standards for weather parameters to all subscribers. This requirement is relevant to the [PIC](#) as it provides real-time weather updates, which are essential for maintaining the safety and efficiency of flight operations.

Ask a question here!

Clear Chat History Ask Away!

Future Work

- Investigate fine-tuning open-source models that we can deploy in-house for use with CUI data.
- Look at potential to generate a dynamic system that can choose which data source it uses based off the user's question. I.e the model will select to pull data from a SQL database, vector store, or graph database.
- Find additional fields that may benefit from this approach. The approach can be applied to other fields with some modifications to the LLM prompt.





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