Document Management with Formal and Independent Knowledge Representation

NASA Space Apps Challenge 2023

October 8, 2023

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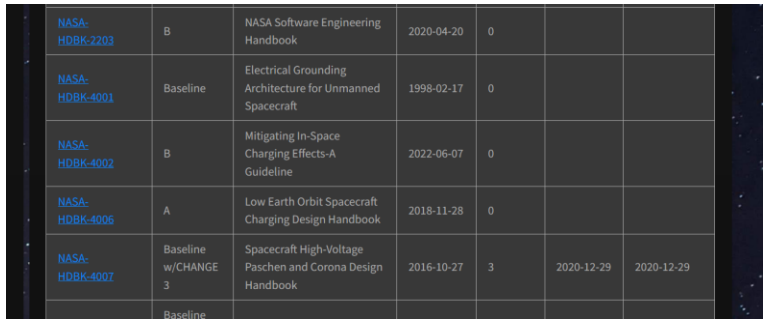
Background

- A large number of recommended practices (knowledge) are proposed in space development.
- This knowledge is scattered across various documents.
- Various documents are each added, modified, and deleted.
- In space development, it is important to follow these knowledge.



NASA-HDBK-2203	B	NASA Software Engineering Handbook	2020-04-20	0		
NASA-HDBK-4001	Baseline	Electrical Grounding Architecture for Unmanned Spacecraft	1998-02-17	0		
NASA-HDBK-4002	B	Mitigating In-Space Charging Effects-A Guideline	2022-06-07	0		
NASA-HDBK-4006	A	Low Earth Orbit Spacecraft Charging Design Handbook	2018-11-28	0		
NASA-HDBK-4007	Baseline w/CHANGE 3	Spacecraft High-Voltage Paschen and Corona Design Handbook	2016-10-27	3	2020-12-29	2020-12-29
	Baseline					

Over 80 documents are registered in NASA Standards.
(This is just a small part of the whole.)

Challenge

While AI is convenient, managing text with AI leads to the following problems:

1. Comprehensiveness Issue
2. Protection of Confidential Information

Comprehensiveness Issue

- AI operates on computational platforms, its computational capacity has limits.
- AI may ignore complex commands to huge sentences.
- It's challenging to determine if AI's observations are truly exhaustive.
- Comprehensiveness is important in space development because the slightest error can lead to a major accident.

Protection of Confidential Information

- Information required for space development includes confidential data.
- Controlling the output of LLM is challenging.
- Teaching LLM confidential information may result in potential data leaks.

Approach

1. Formalization of Knowledge
2. Independent Management of Knowledge

Formalization of Knowledge

- Manage knowledge with logical formulas (e.g., propositional logic, computational tree logic, linear temporal logic).
- With existing programs, one can manipulate knowledge or conduct comprehensive knowledge checks (e.g., SAT solvers, SPIN, NuSMV).

Independent Management of Knowledge

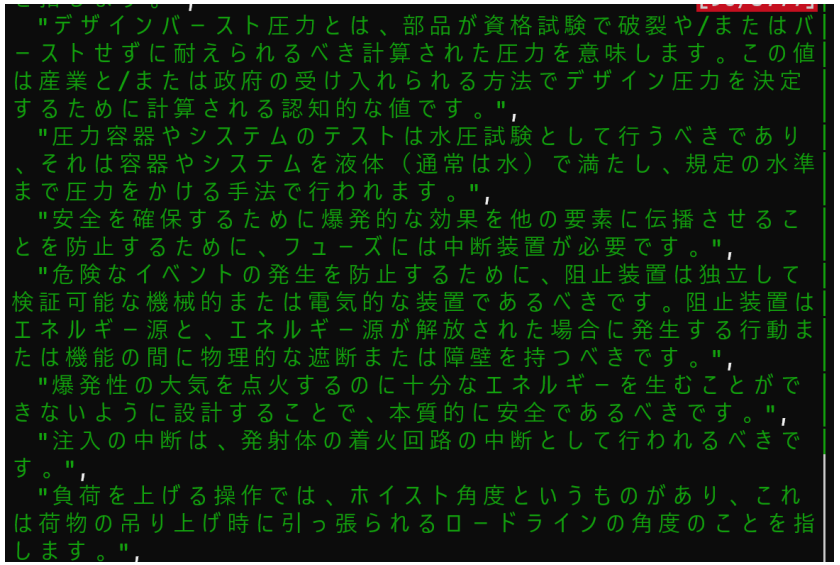
- We manage knowledge outside of the LLM model.
- We manipulate knowledge outside the LLM model using existing tools.
- Since there's no need to teach the LLM confidential information, it prevents potential leaks of confidential data.

Implementation

1. Knowledge Extraction
2. Knowledge Formalization
3. Document Review

Knowledge Extraction

- Input the document and extract recommendations in natural language.
- Utilize LLM.



Output (in Japanese)

- "Design burst pressure refers to the calculated pressure that a component should withstand during qualification tests without rupturing or bursting. This value is a recognized figure calculated in an industry and/or government accepted method to determine design pressure.“
- "Pressure vessel and system testing should be conducted as a hydrostatic test, which involves filling the vessel or system with a liquid (usually water) and applying pressure up to a specified level.“
- "To ensure safety and prevent propagating explosive effects to other elements, fuses must have an interrupt mechanism."

Output (in English)

Knowledge Formalization

- Formalizing natural language using LLM
- Expressing propositional logic formulas in S-expressions (formula)
- Maintaining a list of each atomic term and its description (atoms)


```
  {
    "prop": "A specific load project should create a mission-specific draft version o
f this document. The purpose is to eliminate all non-applicable requirements so that
only applicable requirements remain after detailed adjustments and waiting for the re
view of the PSWG and Range Safety.",
    "atoms": [
      {
        "id": "MissionSpecificDraft",
        "description": "A mission-specific draft is created"
      },
      {
        "id": "NonApplicableRequirementsEliminated",
        "description": "Non-applicable requirements are eliminated"
      },
      {
        "id": "WaitforPSWGRangeSafetyReview",
        "description": "Wait for PSWG and Range Safety review"
      }
    ],
    "formula": "(imply MissionSpecificDraft (and NonApplicableRequirementsEliminated
WaitforPSWGRangeSafetyReview))"
  },
```

Document Review

- Bottom-up approach
  - Identify atomic terms with similar meanings and ask humans.
  - If the meanings are similar, ask humans whether the propositional logic formulas constructed from those atomic terms hold true.
  - If those propositional logic formulas are valid, then they should be added to the document.


```
{
  "id_pair": [
    "RiskMitigation",
    "RiskManagement"
  ],
  "reason": "Both are involved in the process of planning and controlling for potential risks."
},
{
  "id_pair": [
    "RiskAssessment",
    "RiskAnalysis"
  ],
  "reason": "Both activities involve the identification and investigation of potential risks."
},
{
  "id_pair": [
    "SoftwareAssurance",
    "ProductVerification"
  ],
  "reason": "Both refer to processes that ensure the reliability and safety of software."
},
```

Document Review

- Topdown approach
  - Ask if a similar statement holds true.
  - If it does, then its content should be added to the document.

```
--->
[Question]
Are these properties same ?

(Property in KDB)
All pressure systems should have a pressure detection device that is marked to indicate the upper an
d lower limits of system pressure.

(Property in TARGET)
Inhibit is an independent and verifiable mechanical or electrical device that prevents the occurrenc
e of dangerous events and should have direct control.

[Answer]
=> Yes
<---
```

Management Strategy (Example)

- Prop: A => B
  - A, B : Atomic term
  - A => B: Analysis of another document shows that it holds. So, it may hold in the reviewing document.
  - A: Since the AI analysis determines that A is documented, A holds.

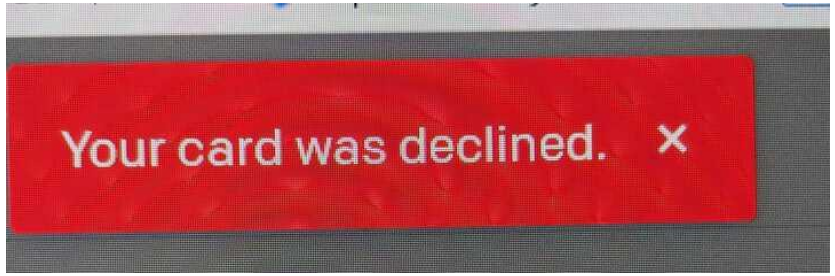
- Ask if B holds to user
  - A => B may hold.
  - A holds
  - B may hold
    - A => B == (not A) or B

      true false true? ⬅ Ask the user of it. If B holds, then ask the user about “A => B”.

Conclusion

- We have proposed a new document management method that manages and manipulates knowledge outside of the LLM.
- This allows for comprehensive knowledge checks and addresses potential leaks of confidential information.

Thanks!



Since my credit card was rejected by OpenAI and not available, much of the processing was implemented using scikit-learn instead of AI.Because of this, the accuracy is a bit poor.