Symbolic AI for Crew Assistance: Using Ontologies in the Cockpit

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Abstract: This paper presents the use of knowledge-based technologies, ontologies, as an interesting way to create a reasoning framework for the machine. Dassault Aviation is convinced that, for system automation, this technique is complementary with data-driven approaches and enhances performances: while deep learning algorithms and other machine learning techniques can provide "sensory services", such as understanding aural messages, understanding images, texts, interpreting low-level signals, etc., knowledge-based technologies can provide the system a framework to ensure "cognitive services", such as manipulating concepts and reasoning. From Dassault Aviation's perspective, both approaches are necessary to team the system and the crew in tomorrow's missions.

1 INTRODUCTION

Crew cockpits look more intuitive than before, for instance with large screens replacing several cockpit instruments in a « glass cockpit », but on the other hand they display more information than ever. The aircraft missions are becoming more complex too, with the crew assuming more activities in a dynamic environment, including many interconnected assets (Le Gleut, R., Conway-Mouret, H., 2020). In parallel, the automation of cockpits has led to a significant reduction of the amount of hazards and accidents within the past decades (Ministère chargé des transports, 2019). However, it created more complex design issues such as faulty human-system interactions due to human errors, and more generally human factors issues (Kharoufah, H. et al, 2018). The complexity of the missions and systems highlights the need for a human-centered approach in cockpit design, and the need to switch to a new paradigm for Human Machine Interaction: Human Machine Teaming.

The concept of Human Machine Teaming defines the relation between the crew and the system as a collaboration paradigm, instead of supervisory paradigm where the crew would be the only decision maker (Walliser et al., 2019). Within this framework, the crew and the system collaborate towards a common objective and are able to jointly allocate between them the tasks to be realized: the system is able to understand the situation and decide as a virtual team member (Madni et al., 2018). This approach is particularly suited for complex and dynamic environments with potentially high workload, such as aircraft, and represents the next step for future cockpits. In order to perform Human Machine Teaming, we need to give the machine the ability to understand the aircraft's data flow and reason on the associated concepts.

This paper presents the use of knowledge-based technologies, ontologies, as an interesting way to create a reasoning framework for the machine. Dassault Aviation is convinced that, for system automation, this technique is complementary with data-driven approaches and enhances performances: while deep learning algorithms and other machine learning techniques can provide "sensory services", such as understanding aural messages, understanding images, texts, interpreting low-level signals, etc., knowledge-based technologies can provide the system a framework to ensure "cognitive services", such as manipulating concepts and reasoning. From Dassault Aviation's perspective, both approaches are necessary to team the system and the crew in tomorrow's missions.

This paper presents three use cases for ontology technologies to assist the crew during a mission. This paper outlines the problematics and benefits for such technologies, identifies the incoming challenges and provides recommendations for future researches from Dassault Aviation's point of view..

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2 USE CASES

2.1 Using Ontologies to Enable Machine Reasoning

Ontologies are a computing concept, which model concepts and their relationships, therefore modeling the knowledge, which derive from these relations. Web Ontology Language (OWL) (RDF 1.1 XML Syntax - W3C Recommendation, 2014) is a family of languages, which formalize ontologies, also allowing to execute queries about the concepts that use the SPARQL language (SPARQL Query Language for RDF - W3C Recommendation, 2008). Ontologies may look like structured databases like SQL, but rather than monolithic structured database, they encourage and facilitate the segregation of the knowledge. This segregation simplifies how you must evolve the modelling of the structure of the ontology (the TBox) if you want to implement new concepts. For instance, OWL ontologies encourage to reuse Upper Ontologies in association with domain ontologies about a specific domain, because Semantic Web ontologies are built to easily allow interoperability between ontologies (Doan, A.H. and Halevy, A.Y., 2005). For example, if you use the concept of time in your ontology, you will be able to reuse the OWL Time ontology rather than implement time concepts in your own Ontology.

All these characteristics allow very easily reasoning using several ontologies « databases » with loose coupling. For example, it should be possible to associate an ontology about airports and runways, another dealing with waypoints, another dealing with ATM, and a specific ontology about the aircraft itself (Best project, 2016). Semantic reasoners engines (Bienvenu et al., 2020) can also be used in an ontology engine to infer logical consequences about facts, using first-order logics.

Building a general knowledge base that uses several loosely coupled ontologies should also allow to simplify the communication between the systems and the crew (Ferrer, B. R. et al, 2021). Suppose for example that the crew desires to find the nearest airport on which the aircraft could land, with a suitable weather condition. It would be possible to interrogate the airports ontology to detect the nearest airport, adding filters in the request to consider only airports that have a suitable landing runway. For example, the following diagram presents an OWL ontology with concepts about aircrafts, waypoints and weather information on a waypoint using the METAR format.

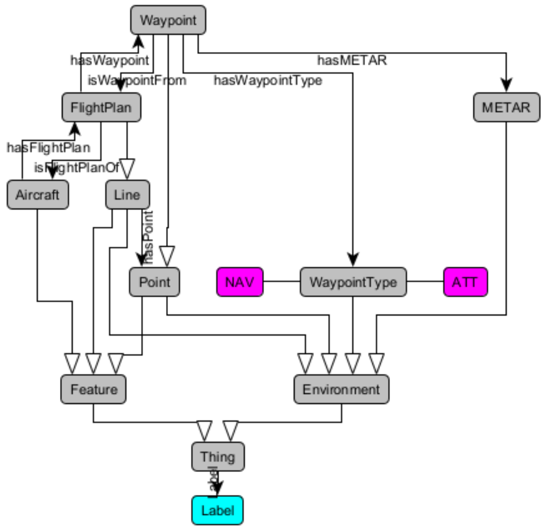

Figure 1: Example of a domain ontology in the context of an aircraft.

2.2 Using Ontologies to Enable Crew Machine Dialogue

Another usage of ontology technologies appears to be interesting for cockpit applications, in order to support the crew: the natural language understanding.

Future aircrafts will be integrated into more complex combined air operations or civilian air operations, including heterogeneous assets (unmanned aircrafts, heterogeneous manned aircrafts, aircraft controls, etc.), and linked to more networks and data (radio, transponders, satellite communications, datalink, etc.). We consider enabling natural language dialogue between the system and the crew as a key enabler to navigate and "dig" within these flows of data, and to allow the crew interacting in a more complex manner with their system.

Natural language processing technologies are also widespread for everyday usages, with the expansion of personal assistants. As these applications rely on everyday usages, these products' developers were able to gather huge labelled databases to train data-driven algorithms. However, for cockpit conversational assistants, the "natural" language relies on specific operational vocabulary and specific syntaxes, and fewer data is available for the training. Moreover, this vocabulary is dynamically updated during the different operational missions (for instance, waypoint names, cities, aircraft labels, mission code-names, etc.).

Knowledge based technologies, and especially ontologies, appear to be an interesting alternative to data-driven techniques for natural language understanding in aircraft operations:

- As expert-domain models, they require less data to train: using an ontology allows to quickly generate a knowledge base for the conversational engine without having to gather and label thousands of sentences.
- They are more versatile than other technologies (neural-network, decision trees, etc.): it is easy to update the elements of the ontology (intents, concepts, vocabulary) and thus to extend the dialogue perimeter of the embedded assistant without re-training the module.
- They are more robust to specific syntaxes used in aeronautic operations.

"EFA on waypoint Sierra Tango Bravo"
"Rolex + 2 min, Time on target 12:52"
"Activate 123.75 on radio 2"
"Bingo 2500 tons"

Figure 2: Crew requests examples using "aeronautical" language.

For instance, if a crew wants to address the following requests to their system: "Where is the closest runway?", then we would need to model the concepts: "airport", the parameter "closest" and the intents "retrieve".

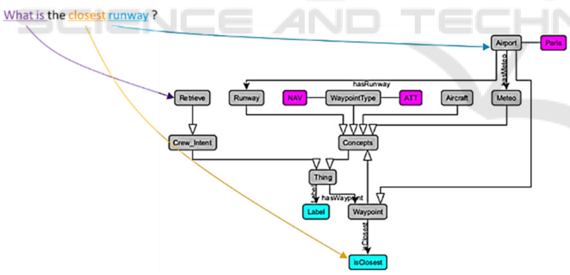

Figure 3: Extract of the mapping of one sentence on a dialogue ontology.

The ontology technologies are thus a very promising technology to assist the crew and enable crew-system dialogue, using natural language.

2.3 Mapping Heterogeneous Ontologies for Databases Interoperability

Ontology matching is a key subject for future aircraft implementation.

For instance, even if the ontology used for the crew dialog represents the same concepts as the domain ontology used for reasoning, these two ontologies might not be identical.

In this case, we therefore need to be able to convert the request issued from the dialog ontology to a request applied on the domain ontology.

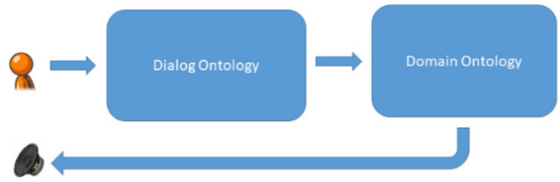

Figure 4: Mapping between a dialog ontology and a domain ontology.

This is a use case for ontology matching (also called ontology alignment): semantic integration research in the database community (Shvaiko and Euzenat, 2013). The general case for Ontology matching is complex, but in this case, the Dialog Ontology represents part of the concepts of the Domain Ontology, sometimes with a simplified relationships graph. Therefore, it is simpler to convert a query made on the first ontology to a query applied on the latter.

Furthermore, it can be possible to populate an ontology with the result of the communication between the system and the crew. For example, in the CAB project, the system should learn from the interactions with the user (CAB project – Cockpit et Assistant Bidirectionnel, 2021): it will both assist the user if he asks questions about the situation, but also will update its internal database depending on its interaction with the user.

3 DIRECTION FOR RESEARCH

Ontology, and all technologies related to "expert systems" and knowledge modeling are less "trending" these last years in regards of the exponential expansion of research on data-driven technologies. However, Dassault Aviation strongly believes that they are essential to the next generation of cockpits, where the machine will team with the crew (analyse and interprete the data, understand, reason and advise the crew, manage the tasks…) and not only execute the crew commands. The use cases described above are three examples of ontologies applications to assist the crew. They were studied during the Man Machine Teaming project (Direction Générale de l'Armement, 2019), and resulted in functional prototypes.

Many challenges remain:

- Increasing the technological maturity of these technologies for these applications, by prototyping these applications into more significant environments. Testing the entire loop in a representative environment is a key element in the future :
  - Enable the crew-system dialogue in natural language using a dialogue ontology
  - Enable machine reasoning on system data using an system ontology
  - Create the mechanisms to update these knowledge bases, by creating feedback loops with the user
- Generating ontologies that use existing databases (textual documentation, etc.): the processes and concepts manipulated during the operational missions are well documented. To harvest this huge data source could be an interesting way of creating or expanding the domain ontologies.
- Applying more robust and state-of-the-art techniques to match the dialogue and domain ontologies for aeronautical applications
- Creating a framework to modify manually the concepts and reasoning rules of the ontologies is also a key challenge, especially if we want to enable the end-user to update the dialogue ontologies.

More generally, one main challenge is to develop a hybrid system to assist the crew: couple data-driven technologies, enable “sensory” services for the system, with knowledge-based technologies, enable “cognitive” services for the system. The combination of these two types of technologies, as well as the ability to quickly orient and modify them, is an important step to creat a machine that can team with the crew during aeronautical missions.

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