An Ontology Based Single Source of Truth (SSOT) Construction Approach for Aircraft Modeling and Simulation

Yuchen Zhang, Chuangye Chang, Weijia Wang, and Gang Xiao

Abstract Single source of truth (SSOT) is a key element in the realization of digital engineering or model-based system engineering. During today's aircraft development, huge number of models are built and simulated for different design purposes at different development stages. This brings a crucial challenge for achieving and maintaining model consistency. The single source of truth is a solution to meet model consistency challenge. It emphasizes on building an authoritative data source and all other models shall refer back to it, so that no inconsistent duplicate exists and model consistency is ensured.

In this paper, an ontology based single source of truth construction approach is proposed. Ontology is brought out to provide a generic and language-independent description framework for aircraft and SSOT can be built based on this ontology. Then, with the model transformation mechanism introduced, which defines the matching relations between ontology and models, the reference ontology can be transformed into different kinds of aircraft design models and also support the transformation between different models. To confirm the usability of this approach, a practice of this approach on a fix wing unmanned aircraft system (UAS) development is introduced According to the practice, the ontology based single source of truth construction approach initially confirms its feasibility and usability.

Keywords Single source of truth · SSOT · Ontology · Aircraft · Modeling and simulation

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1 Introduction

Single source of truth (SSOT) is a key element in the realization of digital engineering or model-based system engineering. The goal of digital engineering is completing the paradigm shift from document-centric development to model-centric development, it raises model and data to an unprecedented high level in research and development process. In order to continuously transfer model and data across disciplines and through the whole life cycle, SSOT is proposed in digital engineering to support the management and usage of model and data.

SSOT is a collection of unified and authorized data. The idea of single source of truth is building an authoritative data source and all other usages of data shall refer back to the primary data source, so that no inconsistent duplicate exists and data consistency is ensured. Single source of truth is the single and authoritative data source for the analysis, design, implementation, verification and validation process in systems engineering, and is the key to guarantee the model and data consistency through all these processes.

Especially, during today's aircraft development, huge number of models are built and simulated for different design purposes at different development stages. From different levels, there are mission level models, engagement level models, engineering level models, and from different types, there are entity/structure models and behaviour models. According to our practice, these too many models bring a crucial challenge for achieving and maintaining model consistency. In this situation, the single source of truth comes up to our mind as a solution to meet model consistency challenge.

In this paper, an ontology based single source of truth construction approach is proposed. Ontology is brought out to provide a generic and language-independent description framework for aircraft modelling, defining and describing the basic information of aircraft. Ontology supports the construction of single source of truth and serves as the primary data source for all other aircraft models.

This paper firstly introduces how a SSOT is constructed based on a common and language-independent ontology description of aircraft. Then, it introduces how this ontology based SSOT solves our model consistency problem with model transformation mechanism. According to our practice, the ontology based single source of truth construction is feasible and several types of models in aircraft development are proved to be transformed and generated from this ontology based SSOT.

2 An Ontology Based SSOT Construction Approach

2.1 A Reference Ontology for Aircraft

Originating from philosophy, ontology is the study of being and existence. Ontology studies the formal description of existence and formal representation of knowledge.

An ontology describes the basic concepts in a certain domain, endeavoring to capture the essential meaning of concepts in a language-independent way [1].

In aircraft development, engineers from different disciplines build models from different aspects of aircraft to support their design and implementation. All these models describe the same aircraft, but from different aspects and in different modelling languages. This brings inconsistencies among models.

Since ontology is the study of essential concepts and describing concepts regardless of languages. It can be used to identify and describe model element which represent the same thing in different model representations. Thus, ontology naturally comes up to our mind as a solution to model inconsistency problem.

Referring to the models used in our aircraft development practices, mainly focusing on the mission analysis and concept design phase, we propose a reference ontology for aircraft. This ontology contains two parts: structural aspect shown in Fig. 1 and behaviour aspect shown in Fig. 2.

The figures below demonstrate the ontology in a UML way. Concepts are shown as rectangular annotations, and relationships are shown as different lines. Solid line means *Association*, line with filled diamond means *Composition*, line with hollow diamond means *Aggregation*, and line with hollow triangle means *Generalization.*

The core concept of this ontology is *Object*. An object is an active entity of system, such as aircraft or sub-system of aircraft. Object executes in its operational *Environment*. Each object owns *Properties* which represent its characteristics and owns *Interfaces* through which object interacts with outside.

For most ontology studies of aircraft [2–4], they only considered how to represent the structural aspect of aircraft, such as has-part and has-property relationships, while

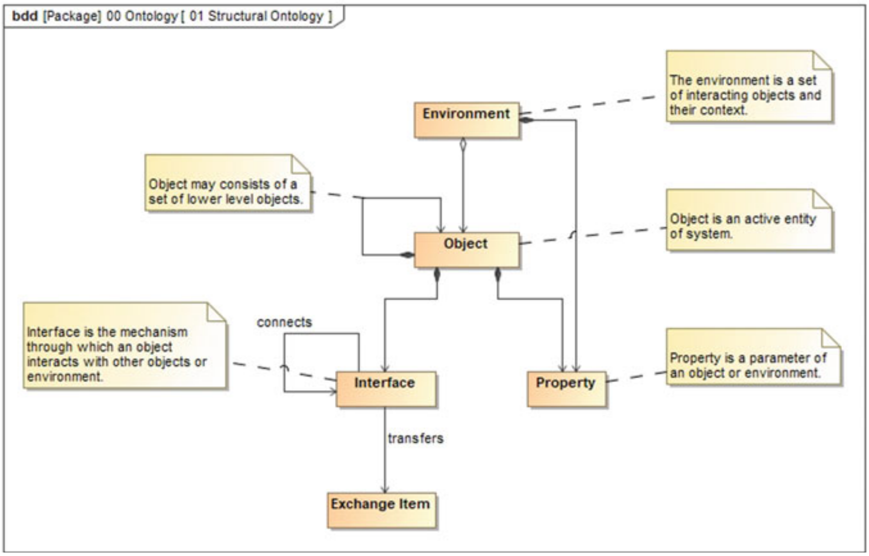

Fig. 1 Ontology from structural aspect

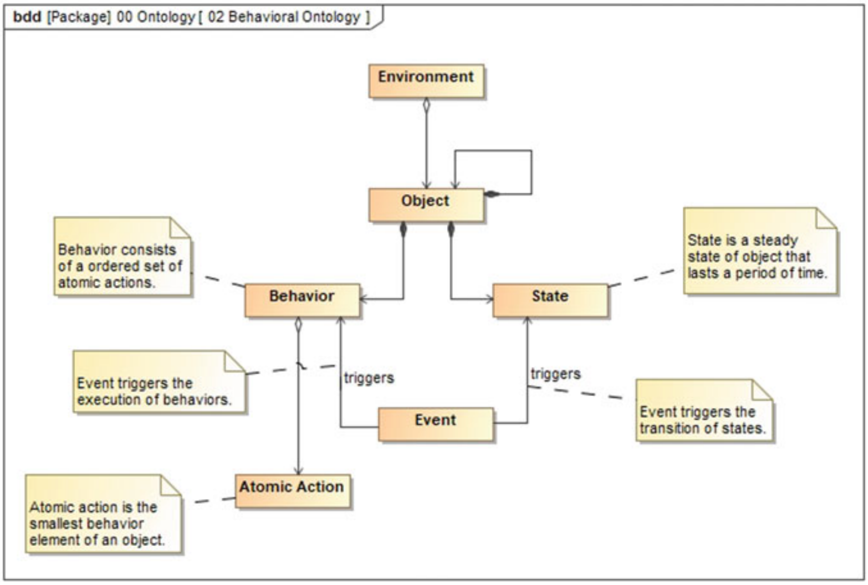

Fig. 2 Ontology from behavioral aspect

ignored the behavior aspect. In our case, because we need to ensure consistency of several behavior models, so we tried to propose an ontology also including behaviour aspect representation.

In this ontology, each object has its *Behaviors*. The behavior consists of an ordered set of atomic actions, and represent a process that object executes [5]. Besides of behaviors, each object has *States* as its dynamic properties. State describes the steady condition of object that lasts a period of time and can transit to other states. Each behavior executes in a state of object. The transition of states and the execution of behaviors are triggered by *Event*.

2.2 Construct SSOT Based on Ontology

Based on the reference ontology proposed above, single source of truth (SSOT) of aircrafts can be constructed. In our practice, a SSOT of a fix wing unmanned aircraft system (UAS) is built. Core concepts of this fix wing UAS, including system, subsystem, functions, measures, are all matched to the reference ontology.

In brief, this fix wing UAS consists of air vehicle and control station two parts. This three system and subsystem concepts are matched to *Object* in ontology and the whole-part relationship is represented with *Composition*. From behavior aspect, the behavior characteristics of aircraft are all represented using *State* and *Behavior*. While from structural aspect, the parameters and measures of aircraft are matched

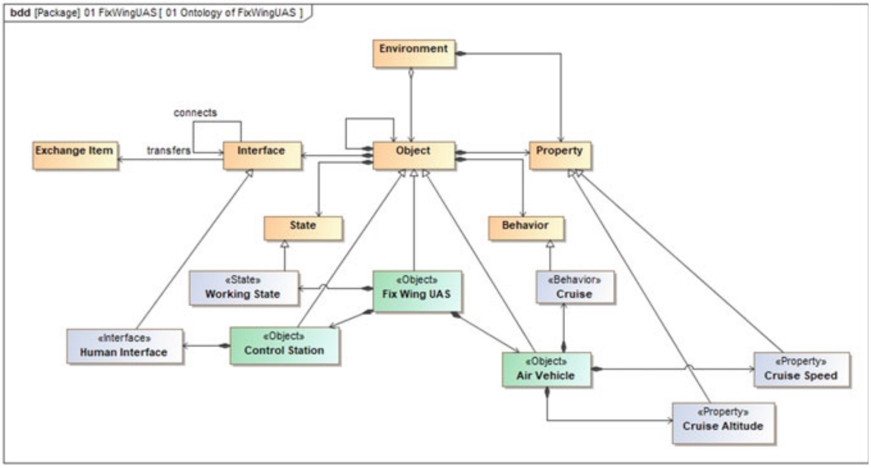

Fig. 3 Construct SSOT of fix wing UAS based on ontology

to *Property*, and the interaction mechanism of aircraft including ports and interface are mapped to *Interface* (Fig. 3).

With the approach above, most of the important concept of aircraft can be described using the reference ontology. And this unified description can serve as a SSOT for aircraft. It captures semantic from modelling languages, identifies core concepts of aircraft and represents these concepts by formal semantics. With this SSOT, all other representations of aircraft, namely other models, can be translated and transformed from this ontology based SSOT.

3 Model Transformation with Ontology Based SSOT

3.1 Behavior Model Transformation Example

With the ontology based SSOT, consistency of different models can be improved. Models can firstly transform to the ontology representation, then other kinds of models can be generated from the ontology. This process is automated or semi-automated, thus it avoids the repeated and redundant modeling and avoids the inconsistency occurring in the modeling process. Blow two examples of the model transformation is introduced. The transformation mechanism is mapping the semantics in different modeling languages to reference ontology, with the ontology based SSOT as medium, different models can be translated to each other.

The first example is a mission-level behavior model transformation example. Two models are DoDAF architecture description model and Maxsim wargame model. In our aircraft development process, for the fix wing UAS, its operational process is

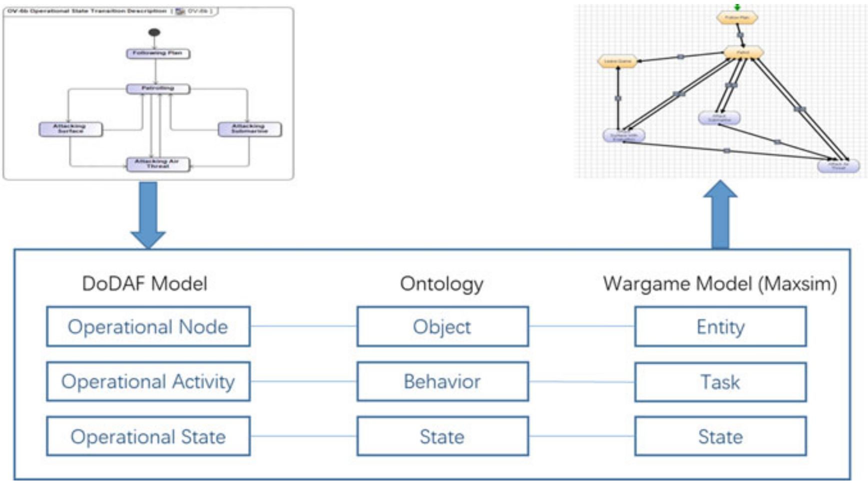

Fig. 4 Behavior model transformation example between DoDAF and Maxsim

firstly described with DoDAF model in operational view, then the operational process is simulated and evaluated with wargame model in Maxsim software. In the past, these two kinds of model were built respectively and the consistency was ensured by engineers. With the SSOT, the wargame model now can be transformed from DoDAF model automatically and the consistency is ensured by transformation mechanism (Fig. 4).

The semantics in two modeling languages are mapping to the semantics in ontology. As shown in the figure above, *Operational Node* in DoDAF and *Entity* in Maxsim are both represent entities, representing different kinds of organizations, systems, and materials. They are matched to *Object* in reference ontology. In a similar way, *Operational Activity* and *Task* both represent entity's behavior, thus matched to *Behavior* in ontology. With the ontology as medium, semantics in two modeling languages are mapped together, then the wargame model can be transformed from DoDAF model. There is no longer need to build model twice in different software and the less inconsistency mistakes will occur.

3.2 Structural Model Transformation Example

The second example is an engineering-level structural model transformation example. Two models are System concept model and Modelica analysis model. In our development practice, an aircraft is firstly described in SysML, analysing its requirements, functions and architecture, then takes multi-discipline simulation with Modelica model, analysing its design and performance.

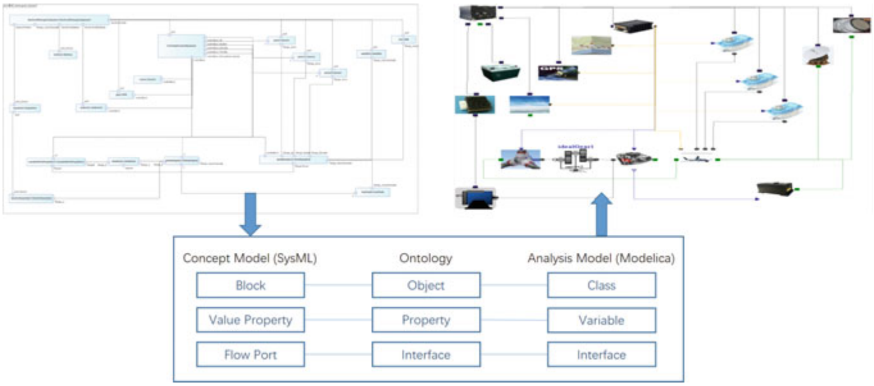

Fig. 5 Structural model transformation example between SysML and Modelica

Similar with above, semantics in SysML and Modelica are also mapped to the ontology [6, 7]. For example, in this time, *Block* in SysML and *Class* in Modelica both represent entity, thus these two semantics are matched to the *Object* in ontology. After the semantic mapping, model transformation can be realized (Fig. 5).

One question may be asked is that why don't we map the semantics of different languages directly and without the ontology as medium [8]. In fact, for two languages, directly mapping is more convenient. However, if there are many modeling languages, the directly mapping will be complex and redundant. For example, in our practice, *Operational Node* in DoDAF, *Entity* in Maxsim, *Block* in SysML, *Class* in Modelica are all represent entity. If we make pairs respectively, there will be six mappings. However, with a SSOT in the central, topological structure of mappings will be simple and clear.

4 Conclusion

In this paper, an ontology based SSOT construction approach is proposed. Firstly, a reference ontology for aircraft is introduced, capturing essential concepts of aircraft and providing generic description framework. A SSOT of fix wing UAS is constructed based on this ontology. Secondly, the model transformation mechanism is studied, demonstrating how different aircraft models are transformed by matching to the reference ontology. With the ontology based SSOT, several kinds of models of fix wing UAS are successfully transformed.

According to the practical results on fix wing UAS, the ontology based SSOT construction approach initially confirms its feasibility and usability. Ontology is an appropriate solution for SSOT construction and model transformation.

5 Discussion

At the end of the paper, we want to discuss some deficiencies of this work and put forward expectation of future work.

First, our primary motivation and goal of this work are ensuring the consistency of the models used in our aircraft development practice. The reference ontology in this paper is proposed for this purpose. So, when define the concepts of aircraft, we mainly refer to the modeling language involved in our practice, such as DoDAF, Maxsim, SysML, and Modelica. For this reason, the ontology proposed in this paper may be not complete and shall be further improved or extended. Our ontology can serve as a foundation for later work.

Second, the representation of the reference ontology is in a UML way. However, since ontology pursues to describe concepts language-independently, so there is actually no "right" language to represent ontology. So, the representation of ontology shall be more seriously considered, maybe in OWL or maybe in other ways.

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