An Ontological Analysis of Capability Modeling in Defense Enterprise Architecture Frameworks

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Abstract.

This paper presents an analysis of capability-related concepts in three enterprise architecture (EA) frameworks for the defense domain (DoDAF, MODAF and NAF). In this analysis, we adopt an ontological account for capabilities based on the notion of dispositions as endurants; a key aspect of this account is that it includes both disposition universals and individuals, in line with Aristotle's four-category ontology. We show how these foundations – which differ from the perdurantist foundations underlying the three defense frameworks – can serve to clarify semantic issues in the frameworks' support for capabilities.

1. Introduction

The importance of capabilities in the defense domain has been recognized in literature and practice [USA Department of Defense 2010] [British Ministry of Defence 2013] [NATO Architecture Framework 2013]. Capability-based theories have been commonly employed to identify existing and required capabilities, to support capability improvement, to enable the planning of acquisition of new capabilities and to facilitate portfolio management [USA Department of Defense 2010] [British Ministry of Defence 2013] [NATO Architecture Framework 2013].

In the management field, capability-based theories focus on "adapting, integrating, and re-configuring internal and external organizational skills, resources, and functional competences toward a changing environment" [Teece and Pisano 1994]. The notion of capabilities has been used to address rapidly changing environments (e.g. constant shifts in markets, competition, technology and regulations) [Kagut and Zander 1992], allowing organizations to plan the reconfiguration of their operations without focusing unnecessarily on the whole organizational structure [Azevedo et al. 2015] [Zdravkovic et al. 2013] [Danesh and Yu 2014].

In defense portfolio management, the importance of the notion of capability led to its inclusion in a number of Enterprise Architecture (EA) approaches for this domain, including DoDAF [USA Department of Defense 2010], MODAF [British Ministry of Defence 2013] and NAF [NATO Architecture Framework 2013]. These frameworks include a number of concepts and language constructs to describe capabilities and to describe the relations between capabilities and strategy as well as between capabilities and operations.

Despite the support for the representation of capabilities in these EA frameworks, the lack of a precise conceptualization for the capability notion may lead to some problems. In particular, the definitions for capabilities and capability-related constructs provided in these frameworks remain unclear and conflicting definitions arise. This paper presents an analysis of capability-related concepts in these frameworks, revealing issues in the underlying conceptualization and in the use of the capability concept. In this analysis, we adopt an ontological account for capabilities based on the notion of dispositions, derived from UFO [Guizzardi, 2005], [Guizzardi et al. 2013], [Guizzardi and Wagner 2013], which is strongly based on the notion of *powers* in, for example, [Molnar and Mumford 2003]; a key aspect of the UFO account of dispositions is that it includes both disposition universals and individuals, in line with the Aristotelian view of a four-category ontology [Lowe 2006]. We show how these foundations – which differ from the current foundations underlying three defense frameworks, namely, DoDAF, MODAF and NAF – can serve to clarify certain semantic issues that we have identified in the support for capabilities in these frameworks.

This paper is further structured as follows: Section 2 describes the ontological foundations we adopt in the ontological analysis; Section 3 describes the current support for capabilities in the EA frameworks for the defense domain; Section 4 discusses the support for capabilities in the light of the foundations we employ; Section 5 discusses related works and Section 6 presents concluding remarks and outlines future work.

2. Ontological Foundations

We adopt the *Unified Foundational Ontology* (UFO) as a semantic foundation, since it includes key concepts to deal with the notion of capability, following [Azevedo et al. 2015]. Here we describe a fragment of UFO that is relevant to the scope of this paper. Further details can be found in [Guizzardi, 2005], [Guizzardi et al. 2008], [Almeida and Guizzardi 2013], [Guizzardi et al. 2013], [Guizzardi and Wagner 2013], [Carvalho et al. 2015].

A fundamental distinction in this ontology is that between the categories of *individuals* and *universals;* theses are represented in conceptual modeling by the constructs of *types* (classes, classifiers) and their *instances*, respectively. *Universals* are patterns of features that are recurrent in a number of *individuals*, capturing their general aspects and *Individuals* are entities that instantiate one or more *universals.* For example, “John” and “Mary” are individuals that instantiate the universals “Man” and “Woman” respectively.

UFO includes a taxonomy of types of individuals and a taxonomy of types of universals. The topmost distinction in the taxonomy of individuals is between *endurants* and *events*. *Endurants* are *individuals* that persist in time while keeping their identity, in the sense that if we say that in circumstance *c1* an *endurant e* has a property *p1* and in circumstance *c2* a property *p2* (possibly incompatible with *p1*), *e* is the same *endurant* in each of these situations. Examples include physical and social persisting entities of everyday experience such as persons, balls, rocks, students and universities. *Events*, in contrast, are individuals that happen in time, in the sense that they extend in time and accumulate temporal parts. Examples include a kiss, a birthday party, a meeting, a conference or a particular execution of a business process.

Endurants are further classified into *substantials* and *moments*. A *substantial* (usually referred to by the common sense term “object”) does not depend existentially on any

other *individual* from which they are disjoint [Guizzardi 2005]. In contrast, a *moment* (also termed "trope", "individualized property" or "property particular") is existentially dependent on other individuals (their bearers) and can only exist in other individuals (e.g., an electrical charge can only exist in some conductor, a covalent bond can only exist if those connecting atoms exist, a headache can only exist if a person exists). Moments are said to *inhere in* their bearers, which may be other moments (e.g., think of the intensity of a headache, or the hue of a color).

Moments in UFO encompass both what are termed *qualities*, (e.g., the color of an eye, the atomic number of an atom) as well as what are termed *dispositions* (e.g., the fragility of a glass, the disposition of a magnet to attract metallic material) [Guizzardi et. al 2013]. *Dispositions* are moments that may be manifested through the occurrence of events. Take for example the disposition of a magnet *m* to attract metallic material. The object *m* has this disposition even if it is never manifested, for example, because it is never close to any metallic material. Nonetheless, *m* can certainly be said to possess that intrinsic (even essential, in this case) property, which it shares with other magnets. In its turn, a particular metallic material also has the disposition of being attracted by magnets. Given a situation in which *m* is in the presence of a particular metallic object (at a certain distance, of a certain mass, in a surface with a certain friction, etc.), the dispositions of these two entities (metallic object, magnet) can be manifested through the occurrence of a complex event, namely, the movement of that object towards the magnet.

Finally, the distinctions in the taxonomy of types of individuals discussed here are reflected in the taxonomy of types of universals. Thus, instances of *Moment Universal* (such as, e.g., Weight) are instantiated by specific moments (e.g., the weight of the Statue of Liberty is an instance of Weight), instances of *Substantial Universal* (such as, e.g., Person and Statue) are substantials (e.g., John, the Statue of Liberty). Figure 1 shows a fragment of UFO as a UML class diagram, focusing on these key distinctions.

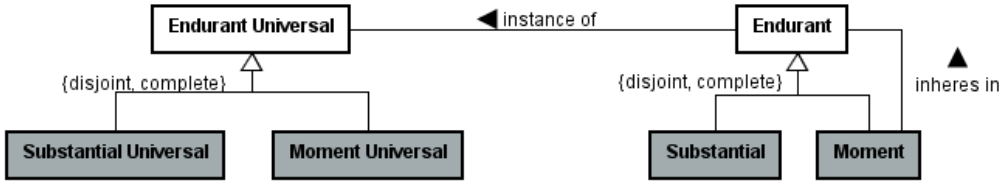

Figure 1. UFO Fragment about Endurants

The idea of an ontology centered on the four leaf categories highlighted in Figure 1 comes originally from the second chapter of Aristotle's Categories [Aristotle 1994], and has been termed in the literature as **four-category ontology** [Lowe 2006]. Such a system recognizes two fundamental categorical distinctions (*individuals* vs. *universals* and *substantials* vs. *moments*), which cut across each other to generate four fundamental ontological categories: substantial universals, substantial individuals (or simply substantials), moment universals, and moment individuals (or simply moments). Figure 2 illustrates the four core concepts of this ontology, forming the so-called Aristotelian Square.

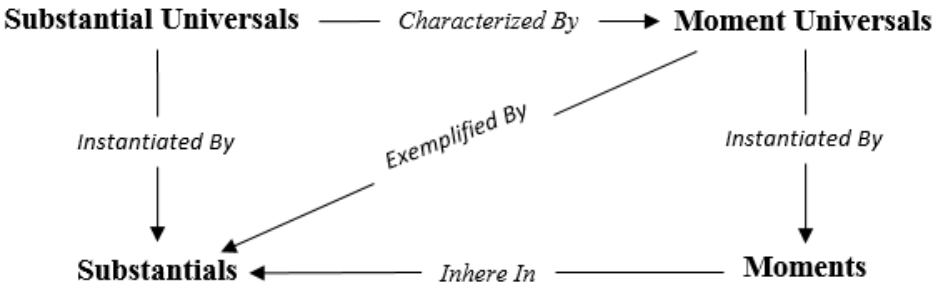

Figure 2. UFO concepts in the Aristotelian Square

As presented in Figure 2, substantial universals and moment universals are instantiated by substantials and moments respectively. The relation of characterization between substantial universals and moment universals indicates that categories of moments (e.g. "Weight", "Foreign Language Skill") can characterize categories of substantials, in the sense that their instances may bear moments of that particular category (e.g., the type person can be characterized by the types weight, and skill). Moreover, the relation of inherence between moments and substantials indicates that instances of moments (e.g., John's weight, John's singing skills, Mary's programming knowledge) inhere and, hence, are existentially dependent of instances of substantials (e.g., John, Mary) (even if indirectly through other moments). In such a four-category ontology, not only substantials but also moments may change qualitatively in time while keeping their identity [Guarino and Guizzardi 2015]. This allow us to account for statements such as "John's weight has changed significantly since last year", and "Mary's programming knowledge is always improving".

3. Capability Concept in Defense Architecture Frameworks

In this section, we briefly present the three defense architecture frameworks we analyze in this paper, namely, DoDAF, MODAF and NAF. We present fragments of their meta-models and provide their definitions for the notion of capability.

3.1. DoDAF

The Department of Defense Architecture Framework (DoDAF) is the overarching, comprehensive framework and conceptual model enabling the development of architectures for the US Department of Defense (DoD). It has been developed by the DoD to ensure a common basis for the definition of architectures of commands, military services and defense agencies. Although DoDAF is clearly oriented to military systems, it has broad applicability in architectures descriptions that are more general [USA Department of Defense 2010] [Cardoso 2010].

DoDAF 2.0 includes a Capability Viewpoint (CV), providing information on the collection and integration of activities that are combined to respond to specific requirements [Cardoso 2010]. The framework defines capability as "the ability to achieve a Desired Effect under specified (performance) standards and conditions through combinations of ways and means (activities and resources) to perform a set of activities" [USA Department of Defense 2010].

A fragment of the CV meta-model with the core concepts is depicted in Figure 3 (adapted from [DoD Architecture Framework 2011], following the representation conventions as in the original). The core of the CV meta-model is the *Capability*

concept. Note that *Capability* in DoDAF's metamodel is a second-order type, and thus its instances are themselves types.

DoDAF's metamodel also includes some support for representing information about the resources which may perform activities in the organization. Types capturing the general features of organizations, persons and objects that may participate in organizational activities are instances of *Performer*. Specific organizations, persons and objects are instances of *IndividualPerformer*. *IndividualPerformer* is related to *Performer* in a powertype pattern (instances of *Performer* are thus specializations of *IndividualPerformer*).

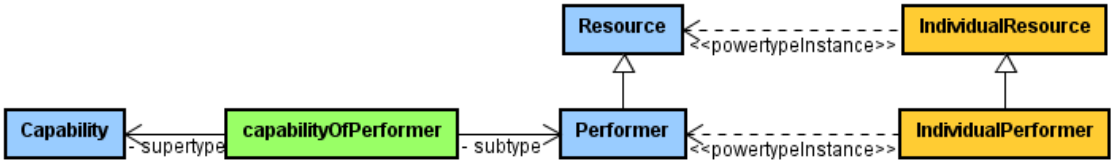

Figure 3. Fragment of Capability Viewpoint DoDAF

An instance of *Capability* may be related to an instance of *Performer* through the *capabilityOfPerformer* relation (reified as a class in the metamodel). This relation represents the specialization between two types. In other words, an instance of *Performer* may specialize an instance of *Capability*.

3.2. MODAF and NAF

The Ministry of Defence Architecture Framework (MODAF) is an enterprise architecture framework developed by the British Ministry of Defence (MOD) to support defense planning and change management activities [Cardoso 2010] [British Ministry of Defence 2013]. Since it shares a common metamodel with the North Atlantic Treaty Organization Architecture Framework (NAF) [NATO Architecture Framework 2013], we present these two frameworks together. A fragment of this common meta-model focusing on the elements of the so-called Capability Viewpoint is depicted in Figure 4.

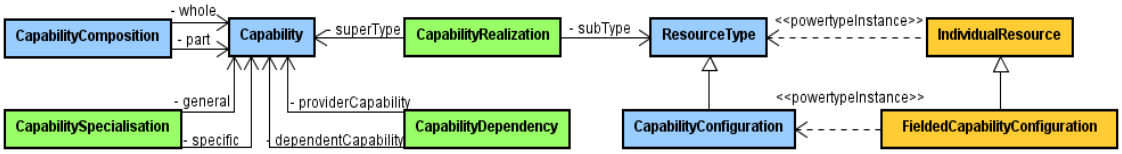

Figure 4. Fragment of MODAF and NAF meta-model

The core of the CV meta-model is the *Capability* concept, which is defined in MODAF as "a classification of some ability – and can be specified regardless of whether the enterprise is currently able to achieve it" [British Ministry of Defence 2009].

Differently from DoDAF, both MODAF and NAF are explicit about the relations between capabilities, including *CapabilitySpecialisation, CapabilityDependency* and *CapabilityComposition*. Moreover, MODAF and NAF include a notion of *CapabilityConfiguration*, which is a specialization of *ResourceType* and is defined as "a composite structure representing the physical and human resources (and their interactions) that when brought together provide one or more Capabilities" [NATO Architecture Framework 2013]. Both the *CapabilityConfiguration* concept and the *Performer* concept of DoDAF are entities that provide capabilities, while the MODAF construct is more expressive, as it can capture an arbitrary structure of elements that

interact to provide a capability. The notion of *ResourceType* in MODAF corresponds directly to the notion of *Resource* in DoDAF, despite the different naming convention (the MODAF naming convention seems more adequate as it clarifies that instances of *ResourceType* are types of resources).

3.3. Representation with UPDM

In order to exemplify the use of capability-related notions in the defense frameworks, we adopt the Unified Profile for DoDAF and MODAF (UPDM) specification [Object Management Group 2013]. It presents an abstract and concrete syntax, providing a modeling standard that supports both DoDAF, MODAF and NAF.

Figure 5 (adapted from [Object Management Group 2013]) presents an example of "Search and Rescue" (SAR) scenario. Capabilities and Capability Configurations are represented as classes marked with the stereotypes <<Capability>> and <<Capability Configuration>> respectively.

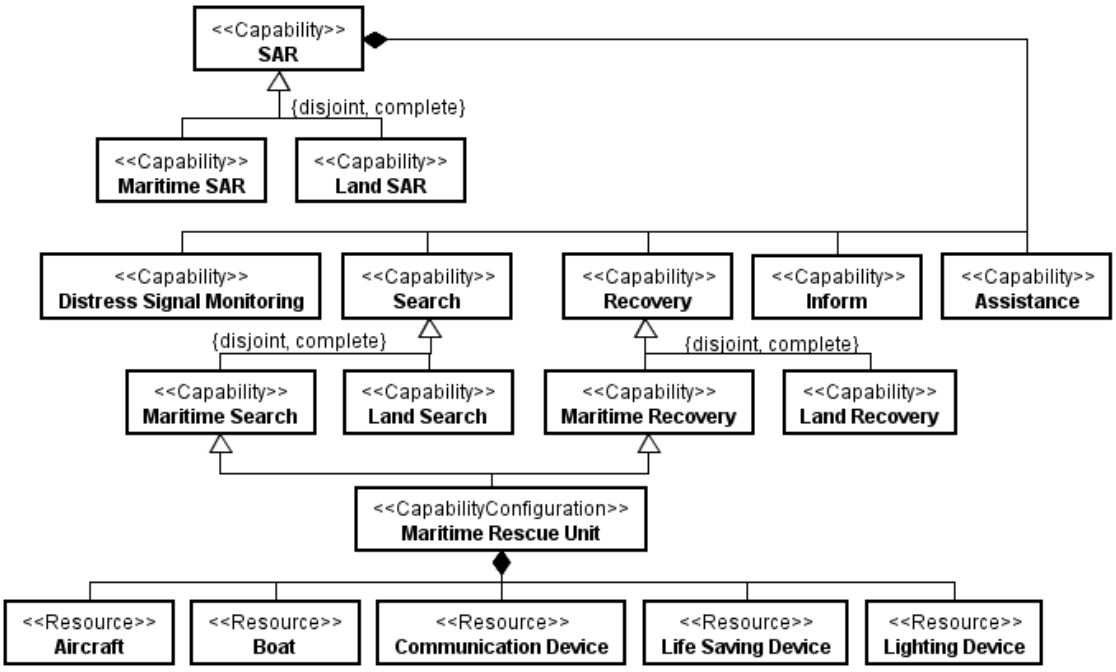

Figure 5. Example of SAR capability

As shown in Figure 5, the relationship between "Maritime SAR" and "SAR" and between "Land SAR" and "SAR" is a *specialization*. Moreover, the capabilities "Distress Signal Monitoring", "Search", "Recovery", "Inform", and "Assistance" support "SAR" capability (root) and its leaf capabilities through the composition relationship. Lastly, the Capability Configuration "Maritime Rescue Unit" provides the capabilities "Maritime Search" and "Maritime Recovery" (represented through specialization).

4. Ontological Analysis

The metamodels of the defense enterprise architecture frameworks presented in section 3 are anchored in the same underlying conceptualization, the International Defence Enterprise Architecture Specification (IDEAS) ontology [Ideas ontology metamodel 2012]. In order to proceed with the ontological analysis, we briefly present a relevant

fragment of the IDEAS ontology (section 4.1) and discuss how the framework's metamodels are anchored in this fragment (section 4.2). This leads to a diagnosis of the alignment of IDEAS with the definitions of capability in DoDAF, MODAF and NAF; we observe that there are some alignment issues, which seem to lead to inadequate models. Finally, in section 4.3, we show how the use of a four-category ontology such as UFO could have identified the issues currently present in the standard and would support more expressive capability representation.

4.1. IDEAS ontology

In this section, we focus primarily on the IDEAS notion of *Property*, which is later specialized by the various frameworks to account for capabilities [Ideas ontology metamodel 2012]. In IDEAS, instances of *Property* are types "whose members all exhibit a common trait or feature" [Ideas ontology metamodel 2012]. *Property* specializes the notion of *IndividualType,* which is the powertype of *Individual*. Thus, instances of instances of *Property* are individuals with a spatio-temporal extent. The type "Person" would be an example of an instance of *Property*, and specific persons, such as "John" and "Mary" would be examples of instances of "Person".

IDEAS, given its historical relations to Business Objects Reference Ontology (BORO) methodology [Ideas ontology metamodel 2012], is a perdurantist (or 4D) ontology, and as such, changes are explained via successive temporal parts. This means that when an object changes qualitatively, a new temporal part of this object is considered to appear, and this temporal part instantiates a different type (i.e., a different *Property*). For example, consider that we want to explain the fact that John sheds 10Kg after a heavy diet. According to IDEAS the following properties could be admitted in this scenario: "Weighing 80kg", "Weighing 70kg" and "Person" (instances of *Property*). John could thus be conceived as the sum of the temporal part "John weighing 80kg" (which instantiates both "Person" and "Weighing 80kg") and the temporal part that occurs later "John weighing 70kg" (which instantiates both "Person" and "Weighing 70kg").

Further, *Property* it specialized into: (i) *DispositionalProperty:* "a *Property* whose members are *Individuals* that are capable to manifest a *CategoricalProperty* under certain conditions", and (ii) *CategoricalProperty*: "a *Property* that is always exhibited by its instances (*Individuals*)". Figure 6 illustrates the fragment of IDEAS that is relevant for our purposes.

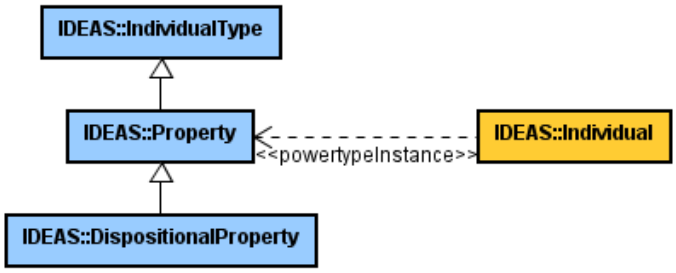

Figure 6. Key Concepts in the IDEAS Ontology

4.2. Alignment of DoDAF, MODAF, NAF and IDEAS

Figure 7 illustrates the relationship between the IDEAS concepts and the capability concepts of the aforementioned defense frameworks. We retain here the naming

convention of MODAF for *ResourceType*, and include MODAF's *Capability-Configuration* instead of DoDAF's *Performer*, as it is a more general notion.

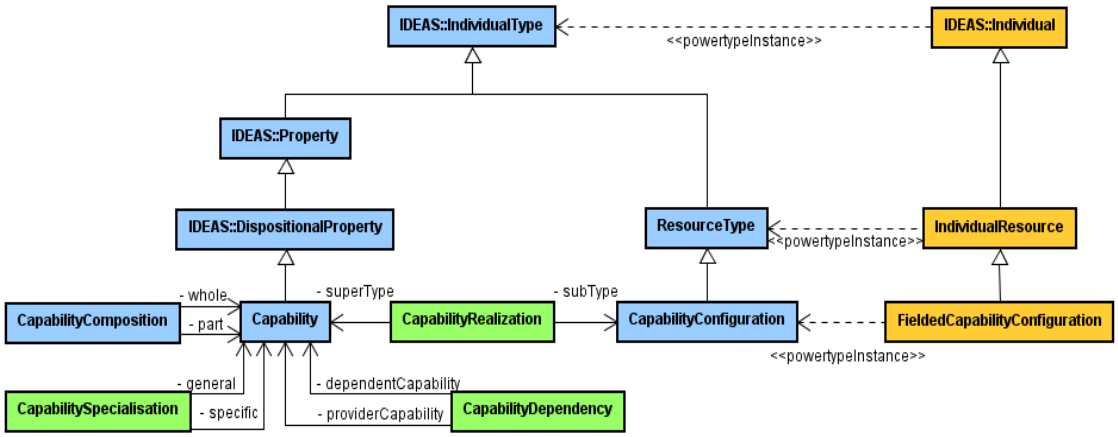

Figure 7. Capability concept related with IDEAS ontology

Note that all concepts of the frameworks specialize a more general concept of IDEAS. The *Capability* concept is a specialization of the *DispositionalProperty* concept of the IDEAS ontology. This means that the framework's designers have chosen to consider instances of *Capability* as (first-order) types. The instances of capabilities are individuals capable of manifesting certain categorical properties in certain conditions.

This formal notion of a capability as a *type of individual* that is capable seems at odds with our intuition when reading the definitions that are provided in the specifications. This is because the text does not refer to types, but rather defines capability in general as some "ability". This seems to affect also the naming conventions used by modelers to describe capabilities in the models produced. Take for example, Figure 5, which was derived from the official UPDM specification. The model represents instances of *Capability* named: "Search", "Maritime Search", "Recovery", "Maritime Recovery", etc. It also includes an instance of *Capability Configuration* named "Maritime Rescue Unit", which specializes "Maritime Search" and "Maritime Recovery". Specific instances of "Maritime Rescue Unit" (say maritime rescue unit X) are consequently also instances of "Search", "Maritime Search", "Recovery" and "Maritime Recovery". Intuitively, more adequate names for the capability elements could be "Capable of Search", "Capable of Maritime Search", "Capable of Recovery" and "Capable of Maritime Recovery".

4.3. A Four-Category Ontology to the Rescue

While this seems to be at first glance, a mere problem of naming convention, in fact, it reveals that in this framework, there is no support to represent what we usually refer to as a capability (only a type of capable things). In any case, even if these models were revisited with more adequate naming conventions, there would be expressiveness problems, as the *capabilities themselves* are never represented.

In this section, we discuss how a four-category ontology such as UFO can support the conceptualization of capabilities as endurants on their own, inhering in capable things.

Differently from IDEAS, UFO reifies moments and distinguishes substantial universals from moment universals. As we discussed in section 2, UFO includes the notion of

disposition, which can be used as a basis to conceptualize capabilities. Capabilities can be considered thus dispositions (moments) inhering in the substantials that are capable.

In order to account for the fact that a particular airplane is capable of flying, UFO would admit the existence of the airplane and of the airplane's capability of flying (an individual disposition inhering in the airplane). It would also distinguish between the substantial universal (whose instances are the airplanes capable of flying) and the moment universal. Thus, the modeler is able to represent the properties of a specific airplane's capability of flying, such as altitude and speed. Table 1 summarizes the difference between UFO and IDEAS ontology in four-category ontology approach.

Table 1. IDEAS ontology and UFO in Four-category approach

Ontology	*Distinctions*	Universal	Individual
IDEAS	Substantial	"Property" (a special "IndividualType")	"Individual"
	Moment		N/A
UFO	Substantial	"Substantial Universal"	"Substantial"
	Moment	"Moment Universal"	"Moment"

Reifying a capability explicitly is key to enabling activities such as capability measurement, representation of capability improvement over time and, especially, reconfiguration of resources while maintaining or improving a specific capability.

5. Related Work

Some approaches have addressed the use of capabilities in enterprise architecture and enterprise modeling.

In [Barroero et al. 2010] TOGAF has been extended to support modeling the capabilities a Business Component (BC) can perform. A BC is a business unit that encompasses a set of activities, supported by assets including people, processes and technology. The approach uses capabilities as "an idealized conceptual structure that describes what a BC can do to create value for customers".

Moreover, with respect to analysis of the capability concept and its usage in EA frameworks, [Azevedo et al. 2015] performed an ontological analysis of the concept at the *Business Strategy and Valuation Concepts* (BSVC) extension to ArchiMate. They identified issues about the original proposal conceptualization of resource, capability and competence concepts and proposed solutions to the identified problems. The capability conceptualization focused on explaining its properties, such that capabilities are only manifested in particular situations, can also fail to be manifested and that when manifested, they are manifested through the occurrence of events. The relations between capabilities and resources were also a focus of the work.

In recent years, a number of enterprise modeling approaches have been subject to ontology-based analysis. In [Santos Jr et al. 2010], the authors have defined the semantics of the ARIS framework concepts and relationships in terms of UFO. Problems regarding the ARIS Method were exposed and possible solutions to these problems were proposed. [Almeida and Guizzardi 2013] discuss the RM-ODP enterprise language, performing an ontological analysis to clarify the definitions of role-related and goal-related concepts. The analysis has supported the authors in identifying

certain ambiguities of the RM-ODP specification and allowed them to propose well-founded recommendations for clarifications and identify potential amendments to the standard.

6. Conclusions and Future Work

In this paper, we have presented an ontological analysis of capability-related concepts in three enterprise architecture (EA) frameworks for the defense domain (DODAF, MODAF and NAF). We have employed a comprehensive foundational ontology, which incorporates concepts to deal with objects, properties and relations. A key aspect of our ontological analysis is the endurantist view we apply, interpreting capabilities as dispositions in UFO, contrasting it with the perdurantist view employed by the IDEAS ontology.

Our main aim has been to clarify the concepts and relations presented in the defense EA frameworks and the IDEAS ontology. Our work allowed us to reveal inconsistences in the usage of the meta-model of the three defense EA frameworks. The issues identified can be summarized as follows: (i) the definitions of capability concept in defense frameworks become obscure when contrasted with the definition of *DispositionalProperty* in the IDEAS ontology; (ii) the terminology and naming conventions used in example diagrams differ from the formal account of capabilities as types of capable things in the meta-models and definitions of defense frameworks; (iii) capabilities themselves are never represented (only types of capable things). We believe that these issues could lead to problems in identifying and expressing important defense concerns, such as, capability measurement, capability improvement over time and, especially, reconfiguration of resources while maintaining or improving a specific capability.

In our future works, we intend to perform a more comprehensive ontological analysis in the defense frameworks, further investigating the consequences of the perdurantist view in the defense EA frameworks.

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