Final Report: Mapping UFO in DOLCE

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July 22, 2023

Abstract

In recent years, formal ontologies have played an important role in organizing data, but the models developed differ in scope, commitment, and formalization. A mapping is an alignment between foundational systems. This method allows determining which terms of one vocabulary can be integrated into another while maintaining the intended conceptualization. In this paper, I purpose a mapping between two fondational ontologies: DOLCE and UFO. After a brief introduction to the concept of formal ontologies and the general idea of mapping, I will present the list of predicates and axioms of both systems. In the last section, a partial mapping from UFO to DOLCE will be made, which will serve as a basis for further analysis in the future.

1 Introduction: throughout the concept of formal ontology

The aim of this paper is to provide a possible alignment between two different foundation ontologies: Unified Formal Ontologies (UFO) and Descriptive ontology for Linguistic and Cognitive Engineering (DOLCE). The present work summarizes the time I spent during my stage in the Laboratory of Applied Ontologies (LOA) in Trento under the supervision of C. Masolo. Throughout this time, we have focused on the concept of mapping and its application in foundational ontologies. In addition, we have explored the spectrum of UFO axioms from a temporal perspective to make the link reachable. Alignment between ontologies is, *in primis*, a work that involves a high degree of formalism, but it is nonetheless crucial for developing a correlative understanding of the informal commitment that motivates formal decisions.

It must be clear from the outset that DOLCE and UFO are very similar models, sharing in many respects a common conception of entities and their relations. Nevertheless, through a deep inquiry and comparison, both from a formal and informal point of view, some interesting points of divergence are drowned out. I hope that working out this knot by offering a feasible solution will form the basis for full alignment in the future.

In this introductory chapter, I will familiarise the reader with the concept of foundational ontologies and then introduce the key distinctions between the models. An introduction to the concept of mapping concludes the chapter. In 2 and 3 I will introduce respectively the source ontologies DOLCE and the target ontologies UFO. In the end, 5 is focused on syntactic alignment.

1.1 What is a foundational ontology

In recent years, the development of foundational ontologies has moved from the sphere of philosophy toward artificial intelligence, computational linguistics, and Database Theory. From a pragmatic point of view, this could be a direct consequence of the emergence of the Semantic Web because in the semantic environment data is described by ontologies. In fact, from the beginning, it has been thought that the main task is to provide a clear and enough descriptive structure by using a reliable foundational model. In this context, ontologies are structures that organize a discrete number of entities by means of *conceptialized* relations and are meant to facilitate mutual understanding between humans and data systems. Despite this, not every user shares the same metaphysical model. Over the years numerous systems have been developed and one might rightly wonder what kind of ontology we need. To answer this question we need to understand the different features that characterize each system.

To begin with, a basic understanding of the subject might help. We can divide a formal ontology system into two principal components:

I a certain interpretation of reality in metaphysical terms, the so-called *ontological commitment*, which is often expressed by the adoption of some traditional classes of philosophical stances, such as those from

Ontology (with capital letters). For example, mereological relations, endurantism and perdurantism arguments, topology aspects, concepts of social ontology, qualities and trope theories, etc. are often used;

II the second component is a particular *formal language* underlying the correct expression of such commitment. The chosen language may be less or more expressive, it may or may not include modal operators to increase accuracy [5](Section 2.3), or it may be non-classical like *Resource Description Framework* (RDF). The level of abstraction is also an important aspect: a formal language with a high level of generality can provide an explicit representation of the meaning of terms and reduce terminological ambiguity to promote negotiation between agents [14].

For this purpose, we are interested in axiomatic ontologies: "Given a language **L** with ontological commitment **K**, an ontology for **L** is a set of axioms designed in a way such that the set of its models approximates as best as possible the set of intended models of **L** according to **K**" [5] (section 2.2). In other terms, while the vocabulary contains the predicates and relations which arguably applied to the objects in our domain, the set of axioms provides information on the behaviour of those predicates and relations. As can be expected, both UFO and DOLCE have axiomatic structures.

1.2 Ontological commitment and domain

As said in [5] an ontology is a *partial* specification of a conceptualization, where the latter is a semantic structure which describes the backbone of a portion of reality. In other words, by a given domain we can organise the set of relations that are relevant to provide a description of the state of affairs. Moreover, these relations can be described not just in extensional terms: they preserve meaning through every possible configuration of objects in the domain.

A starting point for building ontology is the choice of conceptualization. In such an operation, we can adopt different strategies: I) a *reductionist approach* tries to minimise the number of entities admitted by a theory; II) conversely, a *multiplicative approach* consist in endorsing a very expressive system by means of a broad number of conceptualized relations. Notice that this aspect has mainly formal consequences in terms of loss of plainness and complexity. Furthermore, the domain described by a theory can often be remodelled and simplified over time.

From a metaphysical point of view, we can rightly ask how deep we should go in describing reality. Again, the answer lies in the adopted ontological commitment. If I think that a model should capture the ontological features that shape human cognition and languages, then I might have a *descriptive* attitude. According to this view (which is traced back to Strawson) the ability to recognize genuine metaphysical concepts under certain experiences is ontologically prior to the experiences themselves and thus more relevant [9]. In contrast, a *revisionist* stance that arises alongside scientific realism tends to regard perceptual and epistemic data as secondary sources of Ontology. As pointed out in [14](p.7), these approaches can entail significant differences in structure and semantic notion.

Linked to the previous point there is the matter of granularity regard to domain modelling. A coarse-grained system which adopts a highly general vocabulary, i.e., includes terms like 'object', 'event', 'propriety', etc., is called *Top-Level Ontology* (TLO). Those systems are often written in First-order logic (FOL) and tend to be richly axiomatized. In certain cases, a general vocabulary (without extensions) turns out to don't capture the relevant distinctions among objects in the domain. In fact, ontology systems can be also useful in organizing a very specific set of objects by extending TLO with a very specific conceptualization. This type of structure is called *application ontology* or *Domain-level Ontology* (DLO). At least, a system which is located halfway between TLO and DLO is called *Middle-level ontology* (MLO). Sometimes Its purpose is to organize and characterize the vocabulary used in wide disciplines like medicine, engineering, physics etc. [13].

Using those tree distinctions, i.e., *reductionist* vs *multiplicative*, *revisionary* vs *descriptive*, and *coarse* vs *fine*-grained, one can grasp the informal distinction between theories. It is essential, from the perspective of mapping, to have a reliable strategy for classifying ontologies. In what follows I will focus on describing the rules and methods for formal alignment, and then I'm going to briefly present the main aspects of DOLCE and UFO.

1.3 Mapping strategy

In the first place, taking two ontologies, a mapping is a description of one system (called *target* ontology) in terms of the vocabulary of the other system (called *source* ontology). Since the aim of the present work is to provide a description of the domain of UFO in terms of DOLCE, we will refer to them in the following as *source* and *target* ontology. Consequently, we will call the terms of DOLCE *definienes* and the terms of UFO *definendum*.

Generally speaking, a mapping consists in designing links between formulas; the links must cover the set of conceptualized relations that modelled the domain, with regard to their original intended meaning. As it may be arguable, the previous distinctions among commitment, domain capacity and formal language choices, are useful at least in providing an informal design of link, but it is not sufficient to state a reliable correspondence among individual concepts. Even though the two systems share a common vocabulary (e.g. both endorse the distinction between particulars and universals), only the preservation of axioms determines a reliable connection.

According to [11], an ontological conceptualization is a pair (S, A), where S stand for *signature* - the vocabulary which contains predicates and relations - and A stand for *axioms* - specifying the intended interpretation of vocabulary by means of a formal language. Therefore"a total ontology mapping from $O_1 = (S_1, A_1)$ to $O_2 = (S_2, A_2)$ is a morphism $f : S_1 \rightarrow S_2$ of ontological signature, such that $A_2 \vDash f(A_1)$, i.e., all interpretation that satisfy O_2's axioms also satisfy O_1's translated axioms" [11](p.3).

However, while this definition captures the idea of axioms preservation, it provides only a shallow notion of mapping:

I It could be possible that there is not a one-to-one correspondence to terms belongings to separate vocabulary. Most often $f(S_1)$ stand for a complex formula of the source ontology;

II In many cases, as in the present, the mapping cover only a subset of the vocabulary of the target ontology. Therefore it is a *partial* rather than *total mapping*.

Designing links between ontologies can turn into a very formal operation depending on the complexity of the systems involved. For this reason, one may look for a step-by-step procedure. [13] presents a list of three assumptions that justifies a well-driven mapping strategy:

M1 analyse the documentation in order to establish at least an informal connection between the presentations of the notions in the two ontologies;

M2 maximize the number of entities of the target ontology which are modelled in the terms of source ontology and enlight the number of axioms preserved in the mapping;

M3 Only links that can be expressed in the language of the source ontology (FOL in the case of DOLCE) may be considered. This assumption rules out meta-modelling techniques and second-order construction.

Of course, the importance of **M1** as a prerequisite to any mapping should be obvious by itself. **M2** and **M3** are more related points. While the former introduces the idea of extending the alignment as far as possible, the latter defines the formal boundaries and seems to require a high degree of simplicity.

I have only given a very brief description of mapping between ontologies here, and certainly there are other different approaches. Finally, in section 5, we will consider in detail the proposed mapping within the criticism that comes with it. But first, I would like to briefly introduce the source ontology.

2 DOLCE

The *Descriptive Ontologies for Linguistic and Cognitive Engineering* (or simply DOLCE) is the foundational ontology developed in the last twenty years at LOA. For the present introduction of the informal description, I will refer to [2] and [14], while for the formal definition I will refer to the version presented in [13]. To become familiar with this ontology, it is important to recall the concept of *deep background* proposed by Searle: "The Background is a set of nonrepresentational mental capacities that enable all representing to take place. Intentional states only have the conditions of satisfaction that they do, and thus only are the states that they are, against a Background of abilities that are not themselves Intentional states" [15] (p.143). Indeed, DOLCE was constituted to aid in modelling common sense concepts arising from natural language. Given what I said in Section 1, such a theory is a perfect candidate for a descriptive rather than a revisionary system. Moreover, it proposes a multiplicative approach by accepting co-located entities as a possible solution to problems of hylomorphism.

From a theoretical point of view, DOLCE is a model focused on the treatment of *particulars*. This means that anything that can be expressed in this model represents one or more individual entities rather than a universal.

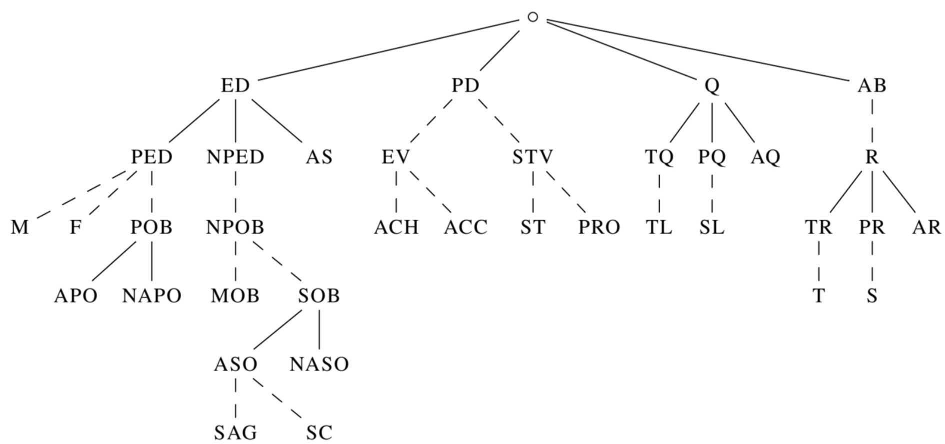

Figure 1: Taxonomy of DOLCE

An intuitive difference between particulars and universals is that the latter can have more than one *instantiation*, while the former do not (they exist as unique copies); moreover, one could say that universals exist across time and space, i.e. they are not in space-time as ordinary objects are. Technically, the predicates of DOLCE could be understood as *rigid* universals that apply to particulars, yet they only serve to organize the taxonomy and relations between objects in the domain. The rigidity of a property prevents any object it instantiates from passing into another property (e.g., events cannot become physical objects, etc.).

The major category (see Fig. 1) of DOLCE can be organized by means of the subsumption relation. The taxonomy goes from the most general property being an object to particularized leaf categories. The model integrates either *endurantism* and *perdurantism* theories. While *endurants* are characterized as entities that are 'in time', wholly present at any time of their existence, *perdurants* are entities that 'happens in time', they grew in time by accumulating temporal parts. Normally, one might associate endurant objects (physical or not) and perdurants with events or processes. This ontological commitment is reflected in the conceptualization of vocabulary: for instance, in DOLCE we can deal with two different part-relations (t*emporal parthood* and *parthood simpliciter*). In addition, the way an object deals with events is defined as a relation of *participation*.

Objects like *endurants* or *perdurants* in DOLCE are *bearers* for entities

AB	Abstract		PED	Physical Endurant
ACC	Accomplishment		POB	Physical Object
ACH	Achievement		PQ	Physical Quality
APO	Agentive Physical Object		PR	Physical Region
AQ	Abstract Quality		PRO	Process
AR	Abstract Region		Q	Quality
AS	Arbitrary Sum		R	Region
ASO	Agentive Social Object		S	Space Region
ED	Endurant		SAG	Social Agent
EV	Event		SC	Society
F	Feature		SOB	Social Object
M	Amount Of Matter		SL	Spatial Location
MOB	Mental Object		ST	State
NAPO	Non-agentive Physical Object		STV	Stative
NASO	Non-agentive Social Object		T	Time Interval
NPED	Non-physical Endurant		TQ	Temporal Quality
NPOB	Non-physical Object		TL	Temporal Location
PD	Perdurant		TR	Temporal Region

Figure 2: properties of DOLCE

whose names are *qualities*. This is the set of basic entities that can be perceived, measured, and projected in certain value spaces (colour, shape, size, weight, etc.). *Quality* existentially depends on the *bearer* (the object in which it is inherent) and each quality is associated with one and only one bearer. To be clear, the table that is under my hands has a particular colour, it acts as a carrier of that colour; on the other hand, the quality 'colour of the table' cannot pass to another object.

An individual quality expresses a specific *value* (e.g. the shape of the brown colour of my table) that is called *quale*. This describes the unique location of the quality in the conceptual space that organizes the set of all potential values (e.g., the chromatic space for colour, the spectrum of frequencies for sounds, etc.). The quality structure or region may include one or more dimensions. There is only one defined range of values for each quality. For some types of entities, we can specify certain properties directly, such as the spatial location of endurants or the temporal location of perdurants.

$\mathtt{DQT}(x,y)$	x is a direct quality of y
$\mathtt{EXD}(x,y,t)$	x is existentially dependent on y at time t
$\mathtt{K}(x,y,t)$	x constitutes y at time t
$\mathtt{P}(x,y)$	x is part of y
$\mathtt{PC}(x,y,t)$	x participates in y at time t
$\mathtt{QL}(x,y)$	x is the immediate quale of y
$\mathtt{SLC}(x,y,t)$	x is (exactly) located at space y at time t
$\mathtt{TLC}(x,t)$	x is (exactly) located at time t
$\mathtt{tP}(x,y,t)$	x is part of y at time t
$\mathtt{tQL}(x,y,t)$	x is the temporary quale of y at time t

Figure 3: primitive relation of DOLCE

2.1 DOLCE formalization

The latest version of DOLCE is formalized in FOL. A label precedes each formulas: $\mathbf{a}_d n$ stands for axioms, $\mathbf{t}_d n$ for theorems, and $\mathbf{d}_d n$ for syntactic definitions.

2.1.1 Mereology

$\mathbf{d}_d1$ $\mathtt{PP}(x,y) =_{df} \mathtt{P}(x,y) \wedge \neg\mathtt{P}(y,x)$

$\mathbf{d}_d2$ $\mathtt{O}(x,y) =_{df} \exists z(\mathtt{P}(z,x) \wedge \mathtt{P}(z,y))$

$\mathbf{d}_d3$ $\mathtt{AT}(x) =_{df} (\textsc{pd}(x) \vee \textsc{ab}(x)) \wedge \neg\exists y(\mathtt{PP}(y,x))$

$\mathbf{d}_d4$ $\mathtt{SUM}(s,x,y) =_{df} \forall z(\mathtt{O}(z,s) \leftrightarrow (\mathtt{O}(z,x) \vee \mathtt{O}(z,y)))$

$\mathbf{a}_d1$ $\mathtt{P}(x,y) \rightarrow (\textsc{ab}(x) \wedge \textsc{ab}(y)) \vee (\textsc{pd}(x) \wedge \textsc{pd}(y))$

$\mathbf{a}_d2$ $\mathtt{P}(x,y) \rightarrow (\textsc{t}(x) \leftrightarrow \textsc{t}(y))$

$\mathbf{a}_d3$ $\mathtt{P}(x,y) \rightarrow (\textsc{s}(x) \leftrightarrow \textsc{s}(y))$

$\mathbf{a}_d4$ $(\textsc{ab}(x) \vee \textsc{pd}(x)) \rightarrow \mathtt{P}(x,x)$

$\mathbf{a}_d5$ $\mathtt{P}(x,y) \wedge \mathtt{P}(y,x) \rightarrow x = y$

$\mathbf{a}_d6$ $\mathtt{P}(x,y) \wedge \mathtt{P}(y,z) \rightarrow \mathtt{P}(x,z)$

$\mathbf{a}_d7$ $(\textsc{ab}(x) \vee \textsc{pd}(x)) \wedge \neg\mathtt{P}(x,y) \rightarrow \exists z(\mathtt{P}(z,x) \wedge \neg\mathtt{O}(z,y))$

2.1.2 Direct Quality

$\mathbf{a}_d8$ $\mathtt{DQT}(x,y) \rightarrow (\textsc{tq}(x) \wedge \textsc{pd}(y)) \vee (\textsc{pq}(x) \wedge \textsc{ped}(y)) \vee (\textsc{aq}(x) \wedge \textsc{nped}(y))$

$\mathbf{a}_d9$ $\mathtt{DQT}(x,y) \wedge \mathtt{DQT}(x,z) \rightarrow y = z$

$\mathbf{a}_d10$ $\textsc{q}(x) \rightarrow \exists y(\mathtt{DQT}(x,y))$

$\mathbf{a}_d11$ $\textsc{pd}(x) \leftrightarrow \exists y(\mathtt{DQT}(y,x) \wedge \textsc{tl}(y))$

$\mathbf{a}_d12$ $\textsc{ped}(x) \leftrightarrow \exists y(\mathtt{DQT}(y,x) \wedge \textsc{sl}(y))$

$\mathbf{t}_d1$ $\mathtt{DQT}(x,y) \rightarrow x \neq y$

$\mathbf{t}_d2$ $\mathtt{DQT}(x,y) \wedge \textsc{aq}(x) \rightarrow \textsc{nped}(y)$

$\mathbf{t}_d3$ $\mathtt{DQT}(x,y) \wedge \textsc{pq}(x) \rightarrow \textsc{ped}(y)$

$\mathbf{t}_d4$ $\mathtt{DQT}(x,y) \wedge \textsc{tq}(x) \rightarrow \textsc{pd}(y)$

2.1.3 Immediate Quale

$\mathbf{a}_d13$ $\mathtt{QL}(x,y) \rightarrow \textsc{tr}(x) \wedge \textsc{tq}(y)$

$\mathbf{a}_d14$ $\textsc{tq}(x) \rightarrow \exists y(\mathtt{QL}(y,x))$

$\mathbf{a}_d15$ $\mathtt{QL}(x,y) \wedge \textsc{t}(x) \rightarrow \textsc{tl}(y)$

$\mathbf{a}_d16$ $\textsc{tl}(x) \rightarrow \exists y(\textsc{t}(y) \wedge \mathtt{QL}(y,x))$

$\mathbf{a}_d17$ $\mathtt{QL}(x,y) \wedge \mathtt{QL}(z,y) \wedge \textsc{t}(x) \wedge \textsc{t}(z) \rightarrow x = z$

2.1.4 Temporal Location and Present At

$\mathbf{d}_d5$ $\mathtt{PRE}(x,t) =_{df} \exists u(\mathtt{TLC}(x,u) \wedge \mathtt{P}(t,u))$

$\mathbf{d}_{d+}1$ [1] $\mathtt{TS}(x,y,t) =_{df} \mathtt{PRE}(x,t) \wedge \mathtt{PRE}(y,t) \wedge \forall s(\mathtt{PP}(t,s) \rightarrow \neg\mathtt{PRE}(x,s)) \wedge \mathtt{P}_d(x,y) \wedge \forall z(\mathtt{P}_d(z,y) \wedge \mathtt{PRE}(z,t) \rightarrow \mathtt{O}(z,x))$

$\mathbf{a}_d18$ $\mathtt{TLC}(x,t) \rightarrow (\textsc{ed}(x) \vee \textsc{pd}(x) \vee \textsc{q}(x)) \wedge \textsc{t}(t)$

$\mathbf{a}_d19$ $(\textsc{ed}(x) \vee \textsc{pd}(x) \vee \textsc{q}(x)) \rightarrow \exists t(\mathtt{TLC}(x,t))$

$\mathbf{a}_d20$ $\mathtt{TLC}(x,t) \wedge \mathtt{TLC}(x,u) \rightarrow t = u$

$\mathbf{a}_d21$ $\mathtt{P}(x,y) \wedge \mathtt{TLC}(x,t) \wedge \mathtt{TLC}(y,u) \rightarrow \mathtt{P}(t,u)$

[1] We added the definition of Temporal Slice, that is not present in the considered version of DOLCE [13], in order dealing with the parthood relation of UFO. Notice that the definition is well supported by the system.

$\mathbf{a}_d22$ $\mathtt{DQT}(x,y) \wedge \mathtt{TLC}(x,t) \wedge \mathtt{TLC}(y,u) \rightarrow \mathtt{P}(t,u)$

$\mathbf{a}_d23$ $\textsc{pd}(x) \rightarrow (\mathtt{TLC}(x,t) \leftrightarrow \exists y(\mathtt{DQT}(y,x) \wedge \mathtt{QL}(t,y) \wedge \textsc{t}(t)))$

$\mathbf{a}_d24$ $\textsc{sl}(x) \wedge \mathtt{DQT}(x,y) \wedge \mathtt{TLC}(x,t) \wedge \mathtt{TLC}(y,u) \rightarrow t = u$

$\mathbf{t}_d5$ $\mathtt{PRE}(x,t) \rightarrow (\textsc{ed}(x) \vee \textsc{pd}(x) \vee \textsc{q}(x)) \wedge \textsc{t}(t)$

$\mathbf{t}_d6$ $\mathtt{PRE}(x,t) \wedge \mathtt{P}(s,t) \rightarrow \mathtt{PRE}(x,s)$

$\mathbf{t}_d7$ $\mathtt{PRE}(x,t) \wedge \mathtt{P}(x,y) \rightarrow \mathtt{PRE}(y,t)$

$\mathbf{t}_d8$ $\mathtt{DQT}(x,y) \wedge \mathtt{PRE}(x,t) \rightarrow \mathtt{PRE}(y,t)$

$\mathbf{t}_d9$ $(\textsc{ed}(x) \vee \textsc{pd}(x) \vee \textsc{q}(x)) \rightarrow \exists t(\mathtt{PRE}(x,t))$

2.1.5 Temporary Quale

$\mathbf{a}_d25$ $\mathtt{tQL}(x,y,t) \rightarrow ((\textsc{pr}(x) \wedge \textsc{pq}(y)) \vee (\textsc{ar}(x) \wedge \textsc{aq}(y))) \wedge \textsc{t}(t)$

$\mathbf{a}_d26$ $\mathtt{tQL}(x,y,t) \rightarrow \mathtt{PRE}(y,t)$

$\mathbf{a}_d27$ $(\textsc{pq}(x) \vee \textsc{aq}(x)) \wedge \mathtt{PRE}(x,t) \rightarrow \exists y(\mathtt{tQL}(y,x,t))$

$\mathbf{a}_d28$ $\mathtt{tQL}(x,y,t) \wedge \mathtt{P}(u,t) \rightarrow \exists z(\mathtt{tQL}(z,y,u) \wedge \mathtt{P}(z,x))$

$\mathbf{a}_d29$ $\mathtt{tQL}(x,y,t) \wedge \textsc{s}(x) \rightarrow \textsc{sl}(y)$

$\mathbf{a}_d30$ $\textsc{sl}(x) \wedge \mathtt{PRE}(x,t) \rightarrow \exists y(\textsc{s}(y) \wedge \mathtt{tQL}(y,x,t))$

$\mathbf{a}_d31$ $\mathtt{tQL}(x,y,t) \wedge \mathtt{tQL}(z,y,t) \wedge \textsc{s}(x) \wedge \textsc{s}(z) \rightarrow x = z$

2.1.6 Temporary Mereology

$\mathbf{d}_d6$ $\mathtt{tO}(x,y,t) =_{df} \exists z(\mathtt{tP}(z,x,t) \wedge \mathtt{tP}(z,y,t))$

$\mathbf{d}_d7$ $\mathtt{tPP}(x,y,t) =_{df} \mathtt{tP}(x,y,t) \wedge \neg\mathtt{tP}(y,x,t)$

$\mathbf{a}_d32$ $\mathtt{tP}(x,y,t) \rightarrow \textsc{ed}(x) \wedge \textsc{ed}(y) \wedge \textsc{t}(t)$

$\mathbf{a}_d33$ $\mathtt{tP}(x,y,t) \rightarrow \mathtt{PRE}(x,t) \wedge \mathtt{PRE}(y,t)$

$\mathbf{a}_d34$ $\mathtt{tP}(x,y,t) \wedge \mathtt{P}(u,t) \rightarrow \mathtt{tP}(x,y,u)$

$\mathbf{a}_d35$ $\mathtt{tP}(x,y,t) \wedge \mathtt{tP}(x,y,u) \wedge \mathtt{SUM}(s,t,u) \rightarrow \mathtt{tP}(x,y,s)$

$\mathbf{a}_d36$ $\textsc{ed}(x) \wedge \mathtt{PRE}(x,t) \rightarrow \mathtt{tP}(x,x,t)$

$\mathbf{a}_d37$ $\mathtt{tP}(x,y,t) \wedge \mathtt{tP}(y,z,t) \rightarrow \mathtt{tP}(x,z,t)$

$\mathbf{a}_d$38 $\textsc{ed}(x) \wedge \textsc{ed}(y) \wedge \mathtt{PRE}(x,t) \wedge \mathtt{PRE}(y,t) \wedge \neg\mathtt{tP}(x,y,t) \rightarrow \exists z(\mathtt{tP}(z,x,t) \wedge \neg\mathtt{tO}(z,y,t))$

$\mathbf{a}_d$39 $\textsc{ped}(x) \leftrightarrow \exists yt(\mathtt{tP}(y,x,t)) \wedge \forall yt(\mathtt{tP}(y,x,t) \rightarrow \textsc{ped}(y))$

$\mathbf{a}_d$40 $\textsc{nped}(x) \leftrightarrow \exists yt(\mathtt{tP}(y,x,t)) \wedge \forall yt(\mathtt{tP}(y,x,t) \rightarrow \textsc{nped}(y))$

$\mathbf{a}_d$41 $\textsc{as}(x) \rightarrow \exists yzut(\mathtt{tP}(y,x,t) \wedge \textsc{ped}(y) \wedge \mathtt{tP}(z,x,u) \wedge \textsc{nped}(z))$

$\mathbf{a}_d$42 $\textsc{m}(x) \wedge \mathtt{tP}(y,x,t) \wedge \mathtt{PRE}(x,u) \rightarrow \mathtt{tP}(y,x,u)$

$\mathbf{t}_d$10 $\exists yzut(\mathtt{tP}(y,x,t) \wedge \textsc{ped}(y) \wedge \mathtt{tP}(z,x,u) \wedge \textsc{nped}(z)) \rightarrow \textsc{as}(x)$

2.1.7 Constitution

$\mathbf{a}_d$43 $\mathtt{K}(x,y,t) \rightarrow ((\textsc{ped}(x) \wedge \textsc{ped}(y)) \vee (\textsc{nped}(x) \wedge \textsc{nped}(y)) \vee (\textsc{pd}(x) \wedge \textsc{pd}(y))) \wedge \textsc{t}(t)$

$\mathbf{a}_d$44 $\mathtt{K}(x,y,t) \rightarrow \mathtt{PRE}(x,t) \wedge \mathtt{PRE}(y,t)$

$\mathbf{a}_d$45 $\mathtt{K}(x,y,t) \wedge \mathtt{P}(u,t) \rightarrow \mathtt{K}(x,y,u)$

$\mathbf{a}_d$46 $\mathtt{K}(x,y,t) \wedge \mathtt{K}(x,y,u) \wedge \mathtt{SUM}(s,t,u) \rightarrow \mathtt{K}(x,y,s)$

$\mathbf{a}_d$47 $\mathtt{K}(x,y,u) \wedge \mathtt{PRE}(y,t) \rightarrow \exists zv(\mathtt{P}(v,t) \wedge \mathtt{K}(z,y,v))$

$\mathbf{a}_d$48 $\mathtt{K}(x,y,t) \rightarrow \neg\mathtt{K}(y,x,t)$

$\mathbf{a}_d$49 $\mathtt{K}(x,y,t) \wedge \mathtt{K}(y,z,t) \rightarrow \mathtt{K}(x,z,t)$

$\mathbf{a}_d$50 $\mathtt{K}(x,y,t) \wedge \mathtt{tPP}(z,y,t) \rightarrow \exists w(\mathtt{tPP}(w,x,t) \wedge \mathtt{K}(w,z,t))$

$\mathbf{a}_d$51 $\mathtt{K}(x,y,t) \wedge \mathtt{K}(z,y,t) \rightarrow (x = z \vee \mathtt{K}(x,z,t) \vee \mathtt{K}(z,x,t))$

$\mathbf{t}_d$11 $\mathtt{K}(x,y,t) \rightarrow x \neq y$

$\mathbf{t}_d$12 $\mathtt{K}(x,y,u) \wedge \mathtt{PRE}(y,t) \wedge \mathtt{P}(v,t) \rightarrow \exists wz(\mathtt{P}(w,v) \wedge \mathtt{K}(z,y,w))$

2.1.8 Participation

$\mathbf{a}_d$52 $\mathtt{PC}(x,y,t) \rightarrow \textsc{ed}(x) \wedge \textsc{pd}(y) \wedge \textsc{t}(t)$

$\mathbf{a}_d$53 $\mathtt{PC}(x,y,t) \rightarrow \mathtt{PRE}(x,t) \wedge \mathtt{PRE}(y,t)$

$\mathbf{a}_d$54 $\mathtt{PC}(x,y,t) \wedge \mathtt{P}(u,t) \rightarrow \mathtt{PC}(x,y,u)$

$\mathbf{a}_d$55 $\mathtt{PC}(x,y,t) \wedge \mathtt{PC}(x,y,u) \wedge \mathtt{SUM}(s,t,u) \rightarrow \mathtt{PC}(x,y,s)$

$\mathbf{a}_d$56 $\textsc{pd}(x) \wedge \mathtt{PRE}(x,t) \rightarrow \exists yu(\mathtt{P}(u,t) \wedge \mathtt{PC}(y,x,u))$

$\mathbf{a}_d 57$ $\textsc{ed}(x) \wedge \texttt{PRE}(x,t) \rightarrow \exists yu(\texttt{P}(u,t) \wedge \texttt{PC}(x,y,u))$

$\mathbf{a}_d 58$ $\texttt{PC}(x,y,t) \wedge \texttt{P}(y,z) \rightarrow \texttt{PC}(x,z,t)$

$\mathbf{t}_d 13$ $\textsc{pd}(x) \wedge \texttt{PRE}(x,t) \wedge \texttt{P}(v,t) \rightarrow \exists yu(\texttt{P}(u,v) \wedge \texttt{PC}(y,x,u))$

$\mathbf{t}_d 14$ $\textsc{ed}(x) \wedge \texttt{PRE}(x,t) \wedge \texttt{P}(v,t) \rightarrow \exists yu(\texttt{P}(u,v) \wedge \texttt{PC}(x,y,u))$

$\mathbf{t}_d 15$ $\texttt{PC}(x,y,u) \wedge \texttt{PRE}(y,t) \rightarrow \exists zu(\texttt{P}(u,t) \wedge \texttt{PC}(z,y,u))$

$\mathbf{t}_d 16$ $\texttt{PC}(x,y,u) \wedge \texttt{PRE}(x,t) \rightarrow \exists zu(\texttt{P}(u,t) \wedge \texttt{PC}(x,z,u))$

$\mathbf{t}_d 17$ $\texttt{PC}(x,y,t) \rightarrow x \neq y$

2.1.9 Existential Dependence

$\mathbf{d}_d 8$ $\texttt{SD}(x,y) =_{df} \exists t(\texttt{PRE}(x,t)) \wedge \forall t(\texttt{PRE}(x,t) \rightarrow \texttt{EXD}(x,y,t))$

$\mathbf{a}_d 59$ $\texttt{EXD}(x,y,t) \rightarrow \texttt{PRE}(x,t) \wedge \texttt{PRE}(y,t)$

$\mathbf{a}_d 60$ $\texttt{EXD}(x,y,t) \wedge \texttt{P}(u,t) \rightarrow \texttt{EXD}(x,y,u)$

$\mathbf{a}_d 61$ $\texttt{EXD}(x,y,t) \wedge \texttt{EXD}(x,y,u) \wedge \texttt{SUM}(s,t,u) \rightarrow \texttt{EXD}(x,y,s)$

$\mathbf{a}_d 62$ $\texttt{EXD}(x,y,u) \wedge \texttt{PRE}(x,t) \rightarrow \exists zv(\texttt{P}(v,t) \wedge \texttt{EXD}(x,z,v))$

$\mathbf{a}_d 63$ $\texttt{K}(x,y,t) \rightarrow \texttt{EXD}(y,x,t)$

$\mathbf{a}_d 64$ $\texttt{PC}(x,y,t) \rightarrow \texttt{EXD}(x,y,t) \wedge \texttt{EXD}(y,x,t)$

$\mathbf{a}_d 65$ $\texttt{DQT}(x,y) \rightarrow \texttt{SD}(x,y)$

$\mathbf{a}_d 66$ $\textsc{nped}(x) \wedge \texttt{PRE}(x,t) \rightarrow \exists yu(\textsc{ped}(y) \wedge \texttt{P}(u,t) \wedge \texttt{EXD}(x,y,u))$

$\mathbf{a}_d 67$ $\textsc{mob}(x) \rightarrow \exists y(\textsc{apo}(y) \wedge \texttt{SD}(x,y))$

$\mathbf{a}_d 68$ $\textsc{naso}(x) \wedge \texttt{PRE}(x,t) \rightarrow \exists yu(\textsc{sc}(y) \wedge \texttt{P}(u,t) \wedge \texttt{EXD}(x,y,u))$

$\mathbf{a}_d 69$ $\textsc{sc}(x) \wedge \texttt{PRE}(x,t) \rightarrow \exists yu(\textsc{sag}(y) \wedge \texttt{P}(u,t) \wedge \texttt{K}(y,x,u))$

$\mathbf{a}_d 70$ $\textsc{sag}(x) \wedge \texttt{PRE}(x,t) \rightarrow \exists yu(\textsc{apo}(y) \wedge \texttt{P}(u,t) \wedge \texttt{EXD}(x,y,u))$

$\mathbf{a}_d 71$ $\textsc{f}(x) \wedge \texttt{PRE}(x,t) \rightarrow \exists yu(\textsc{napo}(y) \wedge \texttt{P}(u,t) \wedge \texttt{EXD}(x,y,u))$

$\mathbf{a}_d 72$ $\textsc{apo}(x) \wedge \texttt{PRE}(x,t) \rightarrow \exists yu(\textsc{napo}(y) \wedge \texttt{P}(u,t) \wedge \texttt{K}(y,x,u))$

$\mathbf{a}_d 73$ $\textsc{napo}(x) \wedge \texttt{PRE}(x,t) \rightarrow \exists yu(\textsc{m}(y) \wedge \texttt{P}(u,t) \wedge \texttt{K}(y,x,u))$

2.1.10 Spatial Location

$\mathbf{d}_d 9$ $\mathtt{sPRE}(x,s,t) =_{df} \exists r(\mathtt{SLC}(x,r,t) \wedge \mathtt{P}(s,r))$

$\mathbf{a}_d 74$ $\mathtt{SLC}(x,s,t) \rightarrow ((\textsc{ed}(x) \wedge \neg\textsc{as}(x)) \vee \textsc{pq}(x) \vee \textsc{pd}(x)) \wedge \textsc{s}(s)$

$\mathbf{a}_d 75$ $\mathtt{SLC}(x,s,t) \rightarrow \mathtt{PRE}(x,t)$

$\mathbf{a}_d 76$ $\mathtt{SLC}(x,s,t) \wedge \mathtt{SLC}(x,r,t) \rightarrow s = r$

$\mathbf{a}_d 77$ $\mathtt{SLC}(x,s,u) \wedge \mathtt{SLC}(x,r,t) \wedge \mathtt{P}(u,t) \rightarrow \mathtt{P}(s,r)$

$\mathbf{a}_d 78$ $\mathtt{SLC}(x,s,u) \wedge \mathtt{PRE}(x,t) \rightarrow \exists r(\mathtt{SLC}(x,r,t))$

$\mathbf{a}_d 79$ $\textsc{ped}(x) \rightarrow (\mathtt{SLC}(x,s,t) \leftrightarrow \exists y(\mathtt{DQT}(y,x) \wedge \textsc{sl}(y) \wedge \mathtt{tQL}(s,y,t)))$

$\mathbf{a}_d 80$ $\textsc{pq}(x) \rightarrow (\mathtt{SLC}(x,s,t) \leftrightarrow \exists y(\mathtt{DQT}(x,y) \wedge \mathtt{SLC}(y,s,t)))$

$\mathbf{a}_d 81$ $\textsc{nped}(x) \wedge \mathtt{SLC}(x,s,t) \rightarrow \exists y(\textsc{ped}(y) \wedge \mathtt{EXD}(x,y,t) \wedge \mathtt{SLC}(y,s,t))$

$\mathbf{a}_d 82$ $\mathtt{PC}(x,y,t) \wedge \mathtt{SLC}(x,s,t) \rightarrow \exists r(\mathtt{SLC}(y,r,t))$

$\mathbf{a}_d 83$ $\mathtt{PC}(x,y,t) \wedge \mathtt{SLC}(x,r,t) \wedge \mathtt{SLC}(y,s,t) \rightarrow \mathtt{P}(r,s)$

$\mathbf{a}_d 84$ $\mathtt{tP}(x,y,t) \wedge \mathtt{SLC}(x,s,t) \rightarrow \exists r(\mathtt{SLC}(y,r,t))$

$\mathbf{a}_d 85$ $\mathtt{tP}(x,y,t) \wedge \mathtt{SLC}(x,r,t) \wedge \mathtt{SLC}(y,s,t) \rightarrow \mathtt{P}(r,s)$

$\mathbf{a}_d 86$ $\mathtt{P}(x,y) \wedge \mathtt{SLC}(x,s,t) \rightarrow \exists r(\mathtt{SLC}(y,r,t))$

$\mathbf{a}_d 87$ $\mathtt{P}(x,y) \wedge \mathtt{SLC}(x,r,t) \wedge \mathtt{SLC}(y,s,t) \rightarrow \mathtt{P}(r,s)$

$\mathbf{a}_d 88$ $\mathtt{K}(x,y,t) \rightarrow \forall s(\mathtt{SLC}(x,s,t) \leftrightarrow \mathtt{SLC}(y,s,t))$

$\mathbf{t}_d 18$ $\textsc{ped}(x) \wedge \mathtt{PRE}(x,t) \rightarrow \exists s(\mathtt{SLC}(x,s,t))$

2.2 Taxonomy

2.2.1 Inclusions

$\mathbf{a}_d 89$ $\textsc{ab}(x) \vee \textsc{ed}(x) \vee \textsc{pd}(x) \vee \textsc{q}(x)$

$\mathbf{a}_d 90$ $(\textsc{as}(x) \vee \textsc{nped}(x) \vee \textsc{ped}(x)) \leftrightarrow \textsc{ed}(x)$

$\mathbf{a}_d 91$ $(\textsc{pro}(x) \vee \textsc{st}(x)) \rightarrow \textsc{stv}(x)$

$\mathbf{a}_d 92$ $(\textsc{ev}(x) \vee \textsc{stv}(x)) \rightarrow \textsc{pd}(x)$

$\mathbf{a}_d 93$ $(\textsc{aq}(x) \vee \textsc{pq}(x) \vee \textsc{tq}(x)) \leftrightarrow \textsc{q}(x)$

$\mathbf{a}_d 94$ $(\textsc{acc}(x) \vee \textsc{ach}(x)) \rightarrow \textsc{ev}(x)$

$\mathbf{a}_d95$ $(\textsc{apo}(x) \vee \textsc{napo}(x)) \leftrightarrow \textsc{pob}(x)$

$\mathbf{a}_d96$ $(\textsc{sag}(x) \vee \textsc{sc}(x)) \rightarrow \textsc{aso}(x)$

$\mathbf{a}_d97$ $(\textsc{aso}(x) \vee \textsc{naso}(x)) \leftrightarrow \textsc{sob}(x)$

$\mathbf{a}_d98$ $(\textsc{sob}(x) \vee \textsc{mob}(x)) \rightarrow \textsc{npob}(x)$

$\mathbf{a}_d99$ $(\textsc{ar}(x) \vee \textsc{pr}(x) \vee \textsc{tr}(x)) \leftrightarrow \textsc{r}(x)$

$\mathbf{a}_d100$ $\textsc{r}(x) \rightarrow \textsc{ab}(x)$

$\mathbf{a}_d101$ $(\textsc{f}(x) \vee \textsc{m}(x) \vee \textsc{pob}(x)) \rightarrow \textsc{ped}(x)$

$\mathbf{a}_d102$ $\textsc{npob}(x) \rightarrow \textsc{nped}(x)$

$\mathbf{a}_d103$ $\textsc{s}(x) \rightarrow \textsc{pr}(x)$

$\mathbf{a}_d104$ $\textsc{sl}(x) \rightarrow \textsc{pq}(x)$

$\mathbf{a}_d105$ $\textsc{t}(x) \rightarrow \textsc{tr}(x)$

$\mathbf{a}_d106$ $\textsc{tl}(x) \rightarrow \textsc{tq}(x)$

$\mathbf{a}_d107$ $\neg\exists x(\textsc{ab}(x) \wedge \textsc{ed}(x))$

$\mathbf{a}_d108$ $\neg\exists x(\textsc{ab}(x) \wedge \textsc{pd}(x))$

$\mathbf{a}_d109$ $\neg\exists x(\textsc{ab}(x) \wedge \textsc{q}(x))$

$\mathbf{a}_d110$ $\neg\exists x(\textsc{ed}(x) \wedge \textsc{pd}(x))$

$\mathbf{a}_d111$ $\neg\exists x(\textsc{pd}(x) \wedge \textsc{q}(x))$

$\mathbf{a}_d112$ $\neg\exists x(\textsc{ed}(x) \wedge \textsc{q}(x))$

$\mathbf{a}_d113$ $\neg\exists x(\textsc{ped}(x) \wedge \textsc{nped}(x))$

$\mathbf{a}_d114$ $\neg\exists x(\textsc{ped}(x) \wedge \textsc{as}(x))$

$\mathbf{a}_d115$ $\neg\exists x(\textsc{nped}(x) \wedge \textsc{as}(x))$

$\mathbf{a}_d116$ $\neg\exists x(\textsc{m}(x) \wedge \textsc{f}(x))$

$\mathbf{a}_d117$ $\neg\exists x(\textsc{f}(x) \wedge \textsc{pob}(x))$

$\mathbf{a}_d118$ $\neg\exists x(\textsc{m}(x) \wedge \textsc{pob}(x))$

$\mathbf{a}_d119$ $\neg\exists x(\textsc{mob}(x) \wedge \textsc{sob}(x))$

$\mathbf{a}_d120$ $\neg\exists x(\textsc{aso}(x) \wedge \textsc{naso}(x))$

$\mathbf{a}_d121$ $\neg\exists x(\textsc{sag}(x) \wedge \textsc{sc}(x))$

$\mathbf{a}_d122$ $\neg\exists x(\textsc{apo}(x) \wedge \textsc{napo}(x))$

$\mathbf{a}_d123$ $\neg\exists x(\textsc{ev}(x) \wedge \textsc{stv}(x))$

$\mathbf{a}_d124$ $\neg\exists x(\textsc{ach}(x) \wedge \textsc{acc}(x))$

$\mathbf{a}_d125$ $\neg\exists x(\textsc{st}(x) \wedge \textsc{pro}(x))$

$\mathbf{a}_d126$ $\neg\exists x(\textsc{tq}(x) \wedge \textsc{pq}(x))$

$\mathbf{a}_d127$ $\neg\exists x(\textsc{pq}(x) \wedge \textsc{aq}(x))$

$\mathbf{a}_d128$ $\neg\exists x(\textsc{tq}(x) \wedge \textsc{aq}(x))$

$\mathbf{a}_d129$ $\neg\exists x(\textsc{tr}(x) \wedge \textsc{pr}(x))$

$\mathbf{a}_d130$ $\neg\exists x(\textsc{pr}(x) \wedge \textsc{ar}(x))$

$\mathbf{a}_d131$ $\neg\exists x(\textsc{tr}(x) \wedge \textsc{ar}(x))$

3 UFO

Unified Foundational Ontology is a project born in 2005 from the work of G. Guizzardi which has promoted the development of OntoUML and other semantic-driven languages. As declared, the aim of this project is to provide an ontological foundation for *Conceptual Modeling* by uses of micro theory such as the theory of types, mereology, particularized properties, theory of roles and events, and so forth. For those who don't know what conceptual modelling is I will provide a brief but effective presentation from [3]: "Conceptual modelling is about describing the semantics of software applications at a high level of abstraction. Specifically, conceptual modellers (1) describe structure models in terms of entities, relationships, and constraints; (2) describe behaviour or functional models in terms of states, transitions among states, and actions performed in states and transitions; and (3) describe interactions and user interfaces in terms of messages sent and received and information exchanged. In their typical usage, conceptual-model diagrams are high-level abstractions that enable clients and analysts to understand one another, enable analysts to communicate successfully with application programmers, and in some cases automatically generate (parts of) the software application".

UFO adopt is split into three subsystems: While UFO-A is designed to deal with endurants, types of endurants, and their accidents, UFO-B and UFO-C were developed to describe perdurants and social events, respectively. In the present work, we will consider only the version of UFO-A included in [8], which is the broadest among the tree subsystems. The reasons for this choice will be explained in detail later (see 3.1).

An immediately obvious feature of UFO-A is that it contains both *individuals* and their *types*. We can view the latter entities as universals, i.e., entities that must be instantiated into individual things. This model represents a four-category ontology as presented in [12], and the choice is based on the necessity to make sense of language and cognition; moreover, this choice matches the description needs of Conceptual Modeling itself. The major categories of UFO-A are *types* and *individuals*; The latter is divided into *concreate* and *abstract* individuals. Dependent entities viz. *moments* are considered enduring objects but not *substantial*, i.e. they can be considered parasites which need to be held by a concrete being to exist. A *relator* is a moment which depends on more than one entity and is considered as the aggregation of *qua-individual* (for instance, the secret deal made

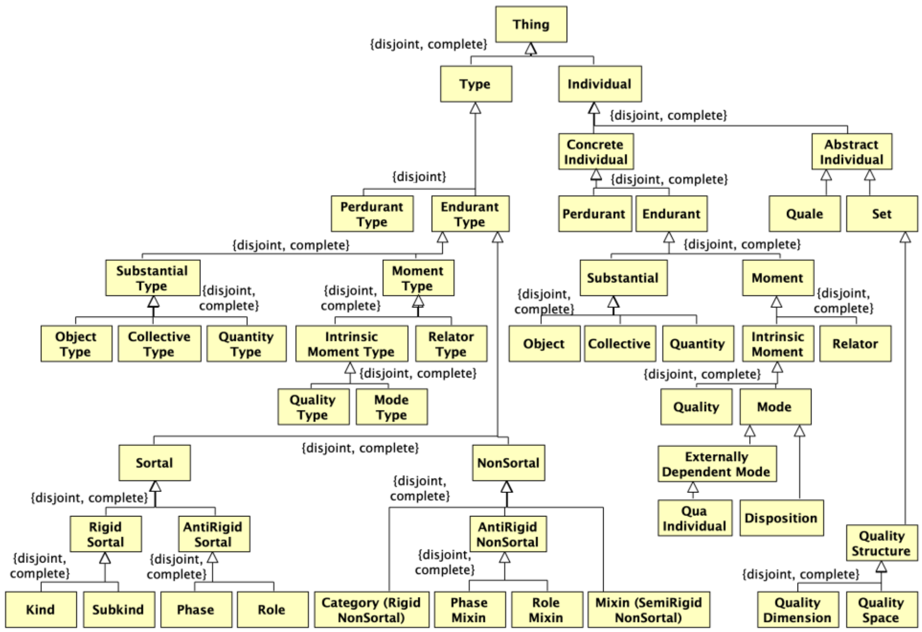

Figure 4: taxonomy of UFO-A

by some shady person). While *qualities* are directly projected in a certain value space *modes* can hold their qualities and be thought of as dispositions (e.g., function, vulnerability or capacities).

In UFO-A qualities have a specific value named *quale*. The qualia are associated with a *quality structures*, a range of possible values that can be built up of one or more dimensions. Finally, the branch of universal split off in *moment-types*, *substantial-types*, such as *sortals* and *non-sortals*; those last two can be rigid or non-rigid categories.

In what follows I will present the axioms listed in [8] but translate them into a different time structure. This, as I will explain, is a crucial step for aligning the target with the source ontology.

3.1 UFO-A's axioms in a temporal structure

As we have already seen, UFO-A is a foundational ontology that can deal with both individual and universal. From a temporal point of view, it describes an atomic slice of time, a single image of a momentary state [8](Section 2.8). For this reason, it seems hard for UFO-A to express genuine change through time, i.e. a stage of an object in t_1 which is different than t_2. On the other hand, UFO-A is expressed in modal language QS5, which means that a formula can be true (false), necessary (unnecessary), or possible (impossible) in a world. A derived notion of persistence through possible worlds can be derived from the use of aletic expressivity, which, in this particular case, enriches the distinction between endurants and perdurants: while the former retain their identity in different words, the letters are considered modally fragile. According to the point of view represented by UFO, an endurant can have different parts in different worlds, and an amount of matter can play different roles without losing its basic properties, but perdurants cannot (specific examples are in [8] Section 3). However, this distinction does not involve changing in time.

While the current axioms govern relations in a diachronic structure, we must consider them from a synchronic perspective. Since DOLCE is an ontology involved in the description of 3D entities along with 4D entities, a certain number of formulas are meant to define the relation between object and time structure. Therefore a diachronic lecture of UFO-A axioms is condition *sine qua non* a possible alignment can't be figured out.

In [1] the complexity of a translation from modality to temporal interpretation of UFO's axioms is pointed out. Even though UFO-A contains perdurants as an element of the domain, it cannot express the proper relation between events and time. UFO-B, on the other hand, which is an extension of the first with a foundational ontology of events, considers temporal aspects as essential. Its basic relations are designed to express the distinction between atomic and complex events, parts of events, participation, the length of events and so on [7]. But the main task in considering a unified ontology of endurants and perdurants is to provide an interpretation of UFO axioms in temporal terms. Since [1] adopts a translation from modality to branched time structure, which is not compatible with DOLCE, I and my tutor decided to purpose an alternative interpretation.

At first glance, necessity and contingency in linear time could be seen as immutability and mutability, but this could not prevent possibilistic counterfactuality. Suppose to interpret the formula $\Box$(Joshua is a bird) as $\forall t$(Joshua is a bird at time t); while we can intend the latter as "Joshua is actually a bird" or "Joshua will always be a bird", it does not capture the meaning of the former, i.e., "being a bird is an essential property of Joshua".

Orthogonally, there are several approaches to interpret alethic propositions in a temporal structure. One possible strategy is to retain the expressiveness of modality even in a temporalized structure, i.e., a proposition could be true at any moment or in some, in all worlds or only in certain ones. Consistent with this strategy, we have extended the meaning of the primitive relations of UFO-A and attempted to preserve the originally intended meaning. We have proceeded as follows:

1. first, we added the kind of entities Time that collect all times[2]. Moreover, we defined for all times the property of being *atomic*, i.e., if t is a time slice, then there is nothing that is its own proper part ($\mathrm{a}_{u+}0$).

2. Next, we isolated the list of primitive relations from UFO-A and considered for each of them a possible behaviour in temporal terms. For those relations R_n which could be subject to change in time, we created a list of relations R^1 with arity $n+1$; an additional place for a term that stands only for times[3]. Sometimes this strategy is called a *parameterist approach*, on which, e.g., in mereological cases, the primary parthood relation becomes logically three-placed (x is part of y at t), and objects may or may not have temporal parts [10].

3. For each of the temporalized primitives, we have added another axiom (denoted by $a_{+}n$). These axioms establish the existence of relata at the time when the relation holds. For example, the case where x is part of y at time t is sufficient to state either the existence of y and x at time t.

Against this line of argument, one could object that the assumed formalization has some unintended consequences. For example, an exotic case is axiom a_u48 which establishes the *antisymmetry* of parthood relation: if two things are mutual parts, they are identical. This axiom makes use of the identity relation. Whether it makes intuitive sense to say that $\mathsf{P}_u(x, y, t_1)$ and $\neg\mathsf{P}_u(x, y, t_2)$, it is not clear what it means to be identical at a given

[2]The position of Time into the taxonomy of UFO is not decided yet. Reasonably, time can be considered as a set or a structure, thus, as abstract individual.

[3]Since the predicates included in the taxonomy of UFO behave like rigid properties, we did not parameterize them with a temporal variable. It could be agreeable to say that being a *perdurant* is an immutable and innate property.

moment. As expected, one may reasonably rise some arguments to deny a possible temporalization of the identity relation. In [4](Section 7.3) is stated that being identical is a logical truth and if $x = y$ is true in a world, then $\Box x = y$. As a result, for two things which are part of each other at a given time, they are identical for necessity, i.e. in every possible world, and this goes beyond the original meaning of a_u48.

Either way, it seems difficult to avoid this unintended interpretation, especially when reflexivity is present (a_u47). This might depend on the behaviour of the cross-world relations, such as identity[4]. Nevertheless, we believe that this version is quite close to the original intended meaning of the axioms of UFO.

3.1.1 Times

$\mathrm{a}_{u+}0$ $\mathsf{Time}(x) \rightarrow \neg\exists yt(\mathsf{PP}_u(y, x, t))$

3.1.2 Existence

a_u62 $\mathsf{ex}(x, t) \rightarrow \mathsf{Thing}(x) \wedge \mathsf{Time}(t)$

a_u63 $\mathsf{ed}(x, y) \leftrightarrow \Diamond\exists t(\mathsf{ex}(x, t)) \wedge \Box\forall t(\mathsf{ex}(x, t) \rightarrow \mathsf{ex}(y, t))$

a_u64 $\mathsf{ind}(x, y) \leftrightarrow (\neg\mathsf{ed}(x, y) \wedge \neg\mathsf{ed}(y, x))$

3.1.3 Instantiation

$\mathrm{a}_{u+}1$ $x ::_t y \rightarrow \mathsf{ex}(x, t) \wedge \mathsf{ex}(y, t)$

a_u1 $\mathsf{Type}(x) \leftrightarrow \Diamond\exists yt(y ::_t x)$

a_u2 $\mathsf{Individual}(x) \leftrightarrow \Box\neg\exists yt(y ::_t x)$

a_u3 $x ::_t y \rightarrow (\mathsf{Type}(x) \vee \mathsf{Individual}(x))$

a_u4 $\neg\exists xyzt_1t_2(\mathsf{Type}(x) \wedge x ::_{t_1} y \wedge y ::_{t_2} z)$

a_u21 $\mathsf{Endurant}(x) \rightarrow \exists k(\mathsf{Kind}(k) \wedge \Box(x ::_t k))$

a_u22 $\mathsf{Kind}(k) \wedge x ::_t k \rightarrow \neg\Diamond(\exists z(\mathsf{Kind}(k) \wedge x ::_t z \wedge z \neq k))$

[4]Notice that even a less strong version of a_u48 might lead to unattended consequences within reflexivity: $P(a, b, s), P(b, a, s), \forall x\forall t[P(x, x, t)], \forall x\forall y[\exists t[P(x, y, t) \wedge P(y, x, t)] \rightarrow x = y], \vDash \forall t(P(a, b, t) \wedge P(b, a, t))$. I'm grateful to Daniele Porello, who has suggested this anomaly.

3.1.4 Mereology

$\mathrm{a}_{u+}2$ $\mathsf{P}_u(x,y,t) \rightarrow \mathsf{ex}(x,t) \wedge \mathsf{ex}(y,t)$

a_u47 $\mathsf{ex}(x,t) \rightarrow \mathsf{P}_u(x,x,t)$

a_u48 $\mathsf{P}_u(x,y,t) \wedge \mathsf{P}_u(y,x,t) \rightarrow x = y$

a_u49 $\mathsf{P}_u(x,y,t) \wedge \mathsf{P}_u(y,z,t) \rightarrow \mathsf{P}_u(x,z,t)$

a_u50 $\mathsf{O}(x,y,t) \leftrightarrow \exists z(\mathsf{P}_u(z,x,t) \wedge \mathsf{P}_u(z,y,t))$

a_u51 $\mathsf{ex}(x,t) \wedge \mathsf{ex}(y,t) \wedge \neg\mathsf{P}_u(x,y,t) \rightarrow \exists z(\mathsf{P}_u(z,y,t) \wedge \neg\mathsf{O}(z,x,t))$

a_u52 $\mathsf{P}_u\mathsf{P}_u(x,y,t) \leftrightarrow \mathsf{P}_u(x,y,t) \wedge \neg\mathsf{P}_u(y,x,t)$

3.1.5 Constitution

$\mathrm{a}_{u+}3$ $\mathsf{constituedBy}(x,y,t) \rightarrow \mathsf{ex}(x,t) \wedge \mathsf{ex}(y,t)$

a_u56 $\mathsf{constituedBy}(x,y,t) \rightarrow$
$$(\mathsf{Endurant}(x) \leftrightarrow \mathsf{Endurant}(y)) \wedge (\mathsf{Perdurant}(x) \leftrightarrow \mathsf{Perdurant}(y))$$

a_u57 $\mathsf{constituedBy}(x,y,t) \wedge x ::_t k \wedge y ::_t k' \wedge \mathsf{Kind}(k) \wedge \mathsf{Kind}(k') \rightarrow k \neq k'$

t_u27 $\neg\mathsf{constituedBy}(x,x,t)$

a_u58 $\mathsf{GCD}(k,k') \leftrightarrow \Box\forall xt(x ::_t k \rightarrow \exists y(y ::_t k' \wedge \mathsf{constituedBy}(x,y,t)))$

a_u59 $\mathsf{Constitution}(x,k,y,k') \leftrightarrow$
$$x ::_t k \wedge y ::_t k' \wedge \mathsf{GCD}(k,k') \wedge \mathsf{constituedBy}(x,y,t)$$

a_u60 $\mathsf{Perdurant}(x) \wedge \mathsf{constituedBy}(x,y,t) \rightarrow$
$$\Box(\mathsf{ex}(x,t) \rightarrow \mathsf{constituedBy}(x,y,t))$$

a_u61 $\mathsf{constituedBy}(x,y,t) \rightarrow \neg\mathsf{constituedBy}(y,x,t)$

3.1.6 Inherence

a_u65 $\mathsf{inheresIn}(x,y) \rightarrow \mathsf{ed}(x,y)$

a_u66 $\mathsf{inheresIn}(x,y) \rightarrow \mathsf{Moment}(x) \wedge (\mathsf{Type}(y) \vee \mathsf{ConcreteIndividual}(y))$

a_u67 $\mathsf{inheresIn}(x,y) \wedge \mathsf{inheresIn}(x,z) \rightarrow y = z$

3.1.7 Relators

a_u69 $\mathsf{externallyDependent}(x,y) \leftrightarrow \mathsf{ed}(x,y) \wedge \forall z(\mathsf{inheresIn}(x,z) \rightarrow \mathsf{ind}(y,z))$

a_u70 $\mathsf{ExternallyDependentMode}(x) \leftrightarrow$
$\mathsf{Mode}(x) \wedge \exists y(\mathsf{externallyDependent}(x,y))$

a_u71 $\mathsf{foundedBy}(x,y) \rightarrow$
$(\mathsf{ExternallyDependentMode}(x) \vee \mathsf{Relator}(x)) \wedge \mathsf{Perdurant}(y)$

a_u72 $\mathsf{ExternallyDependentMode}(x) \rightarrow \exists! y(\mathsf{foundedBy}(x,y))$

3.1.8 Quale

d_u5 $\mathsf{QualityStructure}(x) =_{df} \exists! y(\mathsf{QualityType}(y) \wedge \mathsf{associatedWith}(x,y))$

a_u86 $\mathsf{QualityStructure}(x) \rightarrow \mathsf{Set}(x) \wedge x \neq \emptyset$

a_u87 $\mathsf{Quality}(x) \leftrightarrow \exists! y(\mathsf{QualityStructure}(y) \wedge x \in y)$

a_u88 $\mathsf{QualityStructure}(x,y) \leftrightarrow \mathsf{QualityDomain}(x) \vee \mathsf{QualityDimension}(x)$

a_u89 $\mathsf{QualityDomain}(x) \rightarrow \neg\mathsf{QualityDimension}(x)$

a_u90 $\mathsf{associatedWith}(x,y) \wedge \mathsf{associatedWith}(x',y') \wedge y \sqsubset y' \rightarrow x \subset x'$

$\mathrm{a}_{u+}5$ $\mathsf{hasValue}(x,y,t) \rightarrow \mathsf{ex}(x,t) \wedge \mathsf{ex}(y,t)$

a_u92 $\mathsf{hasValue}(x,y,t) \rightarrow \mathsf{Quality}(x) \wedge \mathsf{Quale}(y)$

a_u93 $\mathsf{ex}(x,t) \wedge \mathsf{Quality}(x) \rightarrow \exists! y(\mathsf{ex}(y,t) \wedge \mathsf{hasValue}(x,y,t))$

a_u94 $\mathsf{hasValue}(x,y,t) \rightarrow \exists zs(x ::_t z \wedge \mathsf{associatedWith}(s,z) \wedge y \in s)$

d_u7 $\mathsf{SimpleQuality}(x) =_{df} \mathsf{Quality}(x) \wedge \neg\exists y(\mathsf{inheresIn}(y,x))$

d_u8 $\mathsf{ComplexQuality}(x) =_{df} \mathsf{Quality}(x) \wedge \neg\mathsf{SimpleQuality}(x)$

d_u9 $\mathsf{SimpleQualityType}(x) =_{df} \mathsf{QualityType}(x)$
$\wedge \forall yt(y ::_t x \rightarrow \mathsf{SimpleQuality}(y))$

d_u10 $\mathsf{ComplexQualityType}(x) =_{df} \mathsf{QualityType}(x)$
$\wedge \forall yt(y ::_t x \rightarrow \mathsf{ComplexQuality}(y))$

a_u95 $\mathsf{associatedWith}(x,y) \rightarrow (\mathsf{QualityDimension}(x) \leftrightarrow \mathsf{SimpleQualityType}(y))$

a_u96 $\mathsf{associatedWith}(x,y) \rightarrow (\mathsf{QualityDomain}(x) \leftrightarrow \mathsf{ComplexQualityType}(y))$

a_u97 $\mathsf{ComplexQuality}(x) \wedge y ::_t k \wedge z ::_t k' \wedge$
$\mathsf{inheresIn}(y,x) \wedge \mathsf{inheresIn}(z,x) \wedge k = k' \rightarrow y = z$

a_u98 $\mathsf{ComplexQuality}(x) \rightarrow \forall y(\mathsf{inheresIn}(y,x) \rightarrow \mathsf{SimpleQuality}(y))$

3.1.9 Perdurants

$\mathrm{a}_{u+}6$ $\mathsf{manifests}(x,y,t) \rightarrow \mathsf{ex}(x,t) \wedge \mathsf{ex}(y,t)$

$\mathrm{a}_{u}102$ $\mathsf{manifests}(x,y,t) \rightarrow \mathsf{Endurant}(x) \wedge \mathsf{Perdurant}(y)$

$\mathrm{a}_{u}103$ $\mathsf{lifeOf}(x,y) \leftrightarrow \mathsf{Perdurant}(x) \wedge \forall zt(\mathsf{O}(z,x,t) \leftrightarrow \mathsf{manifests}(z,y,t))$

$\mathrm{a}_{u}104$ $\mathsf{meet}(x,y) \rightarrow (\mathsf{Perdurant}(x) \wedge \mathsf{Perdurant}(y))$

4 Mapping UFO in DOLCE

In this section, I will purpose a possible mapping of the UFO-A's vocabulary into DOLCE. The links are reported in the form of syntactic definitions. The axioms of target ontology taken on board are those enriched with a time index described previously (3.1). The present mapping is not a total mapping but covers only partially the vocabulary of UFO-A. Links are noted with $\mathbf{d}_{ud}n$.

$\mathbf{d}_{ud}1$ $\mathsf{Perdurant}(x) =_{df} PD(x)$

Perdurants seem to be pretty much the same in both DOLCE and UFO. the concept of *perdurant* assumed in [8] involves a high degree of generality; indeed, it seems difficult to talk about events referring to a single slice of time. The detailed treatment of perdurants of UFO-B [7] is not considered in the present mapping.

$\mathbf{d}_{ud}2$ $\mathsf{manifests}(x, y, t) =_{df} \mathtt{PC}(x, y, t)$

The *manifest* relation specifies when a *endurants* participates in an event or process at a given time. Both the *relata* must be present at the time when the relation holds. In the version of UFO presented above, the time t is atomic, so we need not preserve constancy of participation (see $\mathbf{a}_d56$ and $\mathbf{a}_d57$).

$\mathbf{d}_{ud}3$ $\mathsf{ex}(x, t) =_{df} \mathtt{PRE}(x, t) \vee (T(x) \wedge \mathtt{P}_d(t, x)) \vee (AB(x) \wedge \neg T(x) \wedge T(t))$

According to a_u62, if x exists then it is either a *type* or a *individual.* In DOLCE only *perdurants*, *endurants* and *qualities* exists in time, yet not *abstracts* or *types* ($\mathbf{t}_d5$).

$\mathbf{d}_{ud}4$ $\mathsf{ed}(x, y) =_{df} \mathtt{SD}(x, y)$

According to a_u63, *existential dependence* involves modality: if x depends existentially on y, then there is not a world w in which x exists but not y. Conversely, the definition of special dependence of DOLCE is a form of constant dependence, but it does not involve modality.

$\mathbf{d}_{ud}5$ $\mathsf{Substantial}(x) =_{df} ED(x)$

A *substantial* in UFO denotes an entity that does not *inhere* to anything while *moments* necessarily (directly or via chain) are inherent in the former [6](p.215). As pointed out in au65, *inherence* is a form of *existential dependence*. From this perspective, *substantials* seem to benefit from a higher degree of *independence*, even though they may still be existentially dependent: For example, the statue (as a form) is existentially dependent on the material it is made of, despite any relation of inherence holds between them.

Objects unified by certain criteria, amounts of matter, and features (in the sense of DOLCE) are clearly classified as substantial. It is plausible that even *non-physical endurant*s can be considered substantial since we often refer to them as objects. A more exotic case is represented by *arbitrary sum*, which is not clear whether it can fit in UFO-A.

$\mathbf{d}_{ud}6$ $\mathsf{Moment}(x) =_{df} Q(x)$

Being a *moment* means to inhere to something necessarily. Both *intrinsic* and *Relators* are *moments*: while the former are dependent on a single individual, the latter depend on a plurality. *Intrinsic moment* are separate in *Qualities* and *Modes*. Qualities are parasitic entities which are directly connected to a certain value space, indeed they behave in a very similar way to that of DOLCE. Modes are intrinsic moments that are not *directly* related to *quality structures* or *domain*. Furthermore, they can have their own moments, i.e. qualities of second-degree [6](p.237). I will suggest two arguments in support for the inclusion of *modes* under DOLCE's qualities:

I there are *modes* that can be conceptualized in terms of *multiple separable quality structures*. Yet, this may increase the complexity of value spaces and required structured frame [6](ibid.);

II in the case of a *disposition*, e.g. being fragile, vulnerable, capable of etc., we may describe it in terms of having or not this nature by means of two-value quality space (1-0). We can visualise this as a switch that turns on (or off) a mode. It has to be said that this strategy performs if the disposition does not tolerate any change in degree. It is not clear how to describe proposition as "this house is *more* fragile than yesterday", and similar.

Beyond these dissimilarities, I think that the *Inheritance* of moments is sufficient to approximate them to DOLCE's qualities. If we deny this strategy, one alternative might be to compare modes to *non-physical endurant*s (NPED), i.e. entities that are existentially dependent on physics objects (e.g. thoughts). But this does not capture the meaning of inheritance which is a distinct form of dependence.

$\mathbf{d}_{ud}7$ $\mathsf{Endurant}(x) =_{df} \mathsf{Moment}(x) \vee \mathsf{Substantial}(x)$

$\mathbf{d}_{ud}8$ $\mathsf{ConcreteIndividual}(x) =_{df} \mathsf{Endurant}(x) \vee \mathsf{Perdurant}(x)$

$\mathbf{d}_{ud}9$ $\mathsf{inheresIn}(x,y) =_{df} (\mathtt{DQT}(x,y) \wedge (\mathsf{Moment}(x) \wedge (\mathsf{ConcreteIndividual}(y) \wedge \neg\mathsf{Moment}(y)))$

Inheritance is a relation that holds between a *moment* and its *bearer*. UFO consider moments as tropes, i.e. particularized qualities which inhere to a single entity during the whole career; this is preserved by DOLCE's axioms $\mathbf{a}_d9$ and $\mathbf{a}_d65$.

$\mathbf{d}_{ud}10$ $\mathsf{P}_u(x,y,t) =_{df} T(t) \wedge (\mathtt{P}_d(x,y) \wedge AB(x) \wedge AB(y)) \vee \mathtt{tP}_d(x,y,t) \vee (PD(x) \wedge \mathtt{PRE}(x,t) \wedge \mathtt{P}_d(x,y) \wedge \exists u \exists v(\mathtt{TS}(u,x,t) \wedge \mathtt{TS}(v,y,t) \wedge \mathtt{P}_d(u,v)))$

In the parthood relation of UFO presented above reflexivity (a_u47), antisymmetry (a_u48), transitivity (a_u49) and strong supplementation (a_u51) apply. Moreover, the relation is defined in the whole domain. The definition captures only partially the original meaning since in the present version of DOLCE we cannot express parts for qualities.

Notice that the temporalization of the parthood relation proposed can lead to some trivial situations. An exotic case is the one where x is part of y at t, and both x and y are *times*.

$\mathbf{d}_{ud}11$ $\mathsf{constituedBy}(x,y,t) =_{df} \mathtt{K}(x,y,t)$

Constitution in UFO is a relation defined both on *perdurants* and on *endurants* (that is, *moments* are also constituted or can constitute something). Moreover, the constitution involves *kinds*, i.e., rigid types. For this reason, the source ontology cannot express au57 indicating the inequality between kinds instantiated by the constitution's relata. In general, any category of DOLCE is a rigid property and functions as a *kind*, but we can express it exclusively by a second-order description.

In the case of *perdurants*, the constituents remain identical in all worlds (au60): since the last mentioned axiom involves modality to account for the fragility of eventive entities, it is not expressible in DOLCE.

$\mathbf{d}_{ud}12$ $\mathsf{Time}(x) =_{df} T(x) \wedge \mathtt{AT}(x)$

As mentioned, while in UFO time is an abstract entity which is atomic, i.e., instantaneous, in DOLCE we can encounter both time points and segments.

$\mathbf{d}_{ud}13$ $\mathsf{Abstractindividual}(x) =_{df} AB(x)$

In [14] *abstract entities* like mathematical objects are described as non-existing in time (or, at least, they don't have any causal power), and non-localized. Kinds of abstracts are intuitively organized in physical, temporal or abstract regions. On the other hand, UFO pays attention to set-theoretical features rather than physical or temporal distinctions (see Section 3.1.8). Nevertheless, from a metaphysical perspective, both source and target ontologies seem to describe a very similar entity: an *abstract* is a structure where *qualia* can exhibit specific values.

$\mathbf{d}_{ud}14$ $\mathsf{hasValue}(x, y, t) =_{df} \mathtt{PRE}(x, t) \wedge (\mathtt{tQL}(y, x, t) \vee \exists u \exists v \exists q(PD(u) \wedge \mathtt{DQT}(x, u) \wedge \mathtt{TS}(v, u, t) \wedge \mathtt{DQT}(q, v) \wedge \mathtt{QL}(y, q)))$

To have a *value* in UFO is to point to a specific spot in a *quality structure*. This relation holds between *qualities* and *qualia* (a_u92), and quality must have one and only one value at time t (a_u93). DOLCE includes two different relations (*immediate quale* and *temporary quale*) that hold between quality and its quale, depending on whether the bearer can change in time or not [14](Section 3.3.5).

$\mathbf{d}_{ud}15$ $\mathsf{associatedWith}(x, y) =_{df} (TQ(y) \wedge TR(x)) \vee (PQ(y) \wedge PR(x)) \vee (AQ(y) \wedge AR(x))$

Quality structures are associated with *quality types*, e.g. the colour of this chair is associated with chromatic space. Similarly, in DOLCE there are associations between physical, temporal and abstract qualities with physical, temporal or abstract regions.

$\mathbf{d}_{ud}16$ $\mathsf{Individual}(x) =_{df} \mathsf{Abstractindividual}(x) \vee \mathsf{ConcreteIndividual}(x)$

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