Formal Foundations of General System Modeling

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Abstract. We present an approach to the definition of an object-oriented modeling paradigm done in the scope of general system modeling. The paradigm includes a formally defined metamodel and its supporting philosophical and natural science foundations. The metamodel exhibits its internal consistency, supported by Russell's theory of types, and its consistency in interpretation of subjects of modeling, supported by Tarski's declarative semantics. We show a concrete example of the metamodel application, realized with the aid of concepts defined by RM-ODP (an ISO/ITU standard defining conceptual framework for modeling of distributed systems). This application was formalized in a computer-interpretable form, which allows for a computer-based verification of RM-ODP models. With the theoretical foundations of our metamodel, we deduce its defined structure and declarative semantics from the fundamentals of philosophy and natural science.

1. Introduction

Reality, whether it is physical or anything anyone could imagine, can be seen as an evolution of relations that are perceived between things of interest. The domain of general system modeling targets the development of adequate reality models. An ontology is one of the essential principles of general system modeling. It defines modeling terms by expressing relations between the reality being modeled and the model as well as relations between the model elements.

This work presents the results of our research on the development of a consistent object-oriented framework of modeling terms. Such a framework is necessary for the modeling of distributed systems within the IT research and development projects. Often in the software systems development community the notions for basic object-oriented terminology are understood from practical experience with programming languages. The basic terms like "object", "instance", "action", "state", etc. are rarely defined in a formal way. Our framework fills this gap by presenting formal theoretical foundations for the object-oriented terminology. The framework is expressed in a computer-interpretable form and preserves the generic nature of object-oriented terminology that supports the framework applications for heterogeneous contexts of general system modeling. Partial results of this research were previously presented in [9], [10], [11], [17].

The initial source of our inspiration for this work was the RM-ODP ISO/ITU standard [4]. From the very first time when we acquainted ourselves with the conceptual framework of RM-ODP, by analyzing its definitions, we understood that the definitions contain within themselves a considerable constructive potential from which there could emerge a modeling framework that would bring a positive difference compared to the existing frameworks used by people from the system modeling community (particularly, for the object-oriented systems analysis and design) in their everyday work. This potential could have been understood implicitly from the essence within the RM-ODP definitions and thus it was necessary to realize the potential in an explicit form, that is, to define this emerging modeling framework. This definition thus became the goal of our research.

To achieve the defined goal, we reinforced the RM-ODP standard reference model by adding strong logical and philosophical foundations as constraints for its interpretation. This allowed for a formalization of the resulting conceptual framework, thus we defined a formal ontology for system modeling featuring:

- an internally consistent metamodeling structure that is based on Russell's theory of types [13];
- an object-oriented kind of Tarski's declarative semantics for the standard terminology (e.g. for the terms like "object", "environment", "action", "state", etc);

- formal semantic relations for the modeling terms within the model.

The formalization was expressed with Alloy [10], the language for description of structural properties of a model [5]; thus the associated software tool (Alloy Constraint Analyzer) allows for the internal consistency check of models that use the formal object-oriented terminology of our ontology.

The metamodel that is realized by our ontology is internally consistent, introduces logical coherency of interpretation of a subject of modeling, defines formal semantics for the modeling concepts, its models are verifiable with the aid of computer tools and its conceptualization of a subject of modeling is supported by solid philosophical and natural science foundations. All these features make positive differences for the metamodel being compared with different other object-oriented metamodels that are used by modeling community nowadays. For example, as we showed in [8] the Unified Modeling language (UML) metamodel (that was designed by OMG with purposes and terminology that are similar to those of our metamodel) is destitute of all these described advantages.

In this paper we will present results of our research. In particular, Section 2 will define basic structure of the metamodel including its principal conceptual categories and their relations. Section 3 will explain the particularities of the basic modeling concepts category and define its concepts. Section 4 will discuss the role of the specification concepts category in our metamodel and present a particular example of specification concepts structure performed with the RM-ODP concepts. Thus sections 2, 3 and 4 will complete the definition of our metamodel. Section 5 has a special role in this paper: this section presents philosophical, logical (deductive) and natural science foundations of our metamodel, in the process of this presentation defining formally the domain of general system modeling where our metamodel can be applied.

2. Metamodel structure

In this section we will explain the structure of our metamodel. A metamodel structure should explicitly define the contexts of applications for different categories of modeling concepts that are introduced by the metamodel ontology. To define the structure of our metamodel we took the basic conceptual structure of RM-ODP [4] standard part 2: Foundations and reinforced it by means of the strong theoretical foundations of Russell's theory of types [13], as well as by means of the structural principles of Tarski's declarative semantics [15].

As it was proposed in RM-ODP part 2 clause 6 that defines "Basic Interpretation Concepts" conceptual category, we call the subject of modeling (which is the subject that has some modeling interest to a modeler) as "Universe of Discourse". In RM-ODP "Universe of Discourse" was constituted by entities (defined in [4] 2-6.1 as "*any concrete or abstract thing of interest*") and propositions that can be asserted or denied as being held for entities (defined [4] 2-6.2).

This notion of the "Universe of Discourse" organization is compatible with Russell's theory of types [13] defined by Bertrand Russell in 1908, that introduces individuals and propositions over individuals. Particularly, [13] explains:

"*We may define an individual as something destitute of complexity; it is then obviously not a proposition, since propositions are essentially complex. Hence in applying the process of generalization to individuals we run no risk of incurring reflexive fallacies.*

Elementary propositions together with such as contain only individuals as apparent variables we will call first-order propositions. We can thus form new propositions in which first-order propositions occur as apparent variables. These we will call second-order propositions; these form the third logical type. [while individuals form the 1st logical type and the first-order propositions form the 2nd logical type (note by A. Naumenko)] *Thus, for example, if Epimenides asserts "all first-order propositions affirmed by me are false," he asserts a second-order proposition; he may assert this truly, without asserting truly any first-order proposition, and thus no contradiction arises.*

The above process can be continued indefinitely. The (n + 1)th logical type will consist of propositions of order n, which will be such as contain propositions of order n - 1, but of no higher order, as apparent variables. "

Analogously, in our case we have "entity" corresponding to Russell's "*something destitute of complexity*", because the only intrinsic meaning of an entity in RM-ODP definition is to be "something" that can be qualified by means of propositions. An entity has no other meaning without the propositions associated with it. Thus, by mapping Russell's "individual" and "proposition" to our "entity" and "proposition", respectively, we can use Russell's suggestion in the context of our universe of discourse. This allows us to differentiate the propositions with regard to their subject of application:

- if a proposition is applied to an entity it is considered as the first-order proposition;
- if a proposition is applied to a proposition it is considered as the higher-order proposition.

Of course, in an application of these propositions there may be a situation when a higher-order proposition is applied on another higher-order proposition, which in its turn is applied on yet another higher-order proposition and so on, until the overall structure of the higher-order propositions is finally applied on the first-order proposition. Hence for simplification, we will refer to the combination of several higher-order propositions, which is applied on a first-order proposition, as a single higher-order proposition.

So we ordered the entities and propositions that constitute a universe of discourse in agreement with the Russell's theory of types. Now we can look at models that should represent an arbitrary universe of discourse. A model is the place where modeling language constructs should be applied. Thus it is for the model part of our metamodel that we should provide a useful structure of the categorization of concepts, which would explain the different contexts of practical applications for the concepts from different categories.

We suggest organizing the modeling concepts structure in such a way that there would be a straightforward correspondence between the model and the corresponding represented universe of discourse. That is, we suggest having a structure of concepts in the model constructed in agreement with Russell's theory of types, which would correspond directly to the universe of discourse organization we presented earlier.

According to our suggestion, within the model we will be able to identify "Model Elements" that will be analogous to the Russell's "*individuals*" defined "*as something destitute of complexity*". Also, under this assumption, in the model we will have some concepts that are analogous to the Russell's "*first-order propositions*" (we will call them "Basic Modeling Concepts"), and some concepts – analogs of the "*higher-order propositions*" (we will call them "Specification Concepts"). With this approach to the construction of a model it would be necessary to qualify "Model Elements" with the aid of "Basic Modeling Concepts", which in their turn could be qualified by means of "Specification Concepts".

Thus we are able to define the correspondence of the conceptual categories from within the model to the entities and propositions that form the universe of discourse that should be modeled. The correspondence was defined as following:

- *Entities* from the Universe of Discourse are modeled by *Model Elements* in the Model.
- *First-order Propositions* from the Universe of Discourse are modeled by *Basic Modeling Concepts* in the Model.
- *Higher-order Propositions* from the Universe of Discourse are modeled by *Specification Concepts* in the Model.

So, model elements are defined in the model as one to one counterparts to entities from the universe of discourse. Let us consider more closely the two other conceptual categories from within the model. As we showed, in correspondence with Russell's definitions, basic modeling concepts (essentially the first-order propositions) contain model elements as "*apparent variables*"; and specification concepts (the higher-order propositions) contain the basic modeling concepts as "*apparent variables*".

In fact, these two conceptual categories were introduced by RM-ODP specifications ([4] part 2, clauses 8 and 9); up to this point in our presentation we only reinforced logical justifications for this categorization with the support of Russell's theory of types and with explicit definitions of the application contexts for concepts from the two categories. For further explanation of difference between concepts from the two conceptual categories we will use the principal structure of relations between a universe of discourse from one side and its model from the other side; this structure was defined by Alfred Tarski in 1935 for the introduction of his formal declarative semantics [15].

The basic modeling concepts set, as it aims to model the first-order propositions from the universe of discourse, should contain the concepts expressing the qualities that are considered as primary and intrinsic for the universe of discourse entities. This fundamental nature of the primary qualities belonging to the universe of discourse doesn't allow their modeling representations to be defined exclusively within the model. Hence the only possibility for a definition of the basic modeling concepts is to define them using Tarski's declarative semantics [15]: the semantics that defines equivalence of an agreed conceptualization of the universe of discourse to a concrete concept in the model. The set of basic modeling concepts constructed in this way is the necessary, sufficient and limited set representing a limited amount of intrinsic qualities from the universe of discourse.

The set of specification concepts contains all the other concepts that can be found in models. These concepts aim to model the higher-order propositions from the universe of discourse; thus they do not represent the primary qualities of the universe of discourse entities and hence they do not need to have Tarski's declarative semantics for their definitions. So these concepts will be defined only in the relations between themselves and in the relations with the basic modeling concepts, but not in the relations with the universe of discourse. In a general case, the set of specification concepts is not limited because of the same quality of the higher-order propositions set. As new higher-order propositions can be constructed by applying one higher-order proposition on another, new specification concepts can similarly be constructed by applying one specification concept on another.

So it becomes clear that there is a significant semantic difference between the two conceptual categories. Basic modeling concepts are defined using Tarski's declarative semantics, but specification concepts are not. This is the consequence of difference in their design purposes, which explains the clear difference in their corresponding applications within a model.

Additional details on this categorization can be found in [9]. Here let us present a UML diagram explaining the structure of the introduced categorization (see Figure 1).

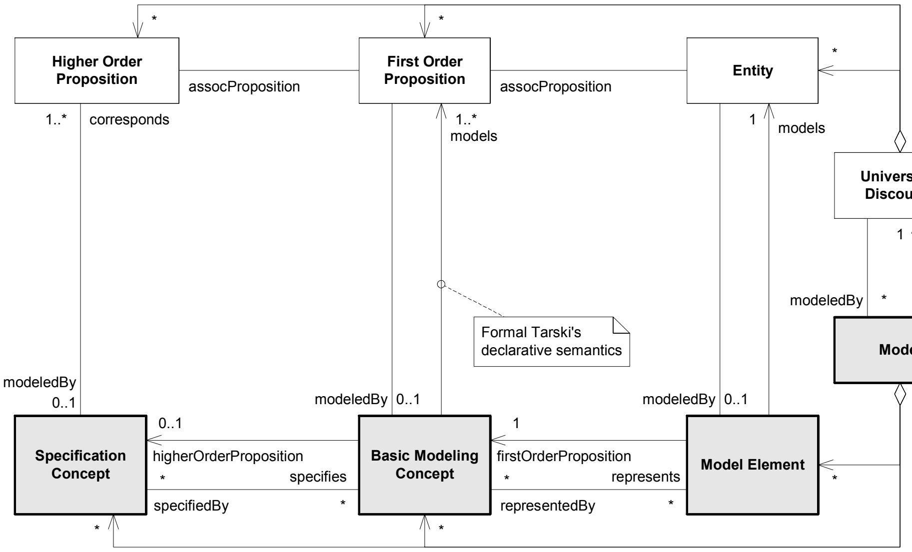

Figure 1. Categorization of concepts for the proposed metamodel (UML diagram)[1].

3. Basic Modeling Concepts

In this section we will introduce and define the concepts for the "Basic Modeling Concepts" conceptual category of our metamodel. As we already mentioned, the name of this conceptual category is the same as the name of a category from RM-ODP ([4] 2-8). And as we will see, the results of our definitions for the basic modeling concepts set will have a lot in common with the RM-ODP concepts from their basic modeling concepts category. However, in the part of basic modeling concepts there is a difference between our metamodel and RM-ODP. Our metamodel provides a systemic reasoning for the introduction of the basic modeling concepts set, as well as for the definition of the concepts semantics. And as it will be presented in the next section of the paper, the universe of discourse conceptualization that is needed for the semantics definition is supported by fundamental philosophical and natural science foundations; whereas

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[1] On the diagram from Figure 1, in addition to all the explained particularities of the categorization structure, we also showed that a specification concept can specify any of the basic modeling concepts, and a basic modeling concept can be specified by any of the specification concepts. In fact this is true only for the generic specification concepts – the subcategory of specification concepts that will be explained in Section 4.2 of the paper.

the RM-ODP standard doesn't provide any reasoning to support their defined basic modeling concepts set. This is an important difference that favors our metamodel compared to RM-ODP.

As we showed in the previous section, here our goal is to determine the necessary and sufficient set of concepts that should have Tarski's declarative semantics for their definitions. Recall that, we call these concepts "Basic Modeling Concepts", whereas all the other concepts in the model (those that will not have declarative semantics but will have their semantics defined in the relations with themselves as well as in the relations between themselves and the basic modeling concepts) we will call "Specification Concepts".

During the introduction of the basic modeling concepts we will need to understand a couple of general principles[2] that support conceptual reasoning (modeling). By conceptual reasoning (modeling) here we mean a framework of reasoning that results in construction of conceptual models.

One of the foundations of conceptual reasoning supports the possibility to localize a single concept in the overall conceptual multitude of a given scope and thus to differentiate concepts between themselves. We see the nature of this foundation in duality of two essences: continuum and discontinuity. Continuum as soon as it is introduced, automatically allows for discontinuity to appear. Discontinuity allows for definition of limiting points within a continuum, which consequently allows for definition of the interval between limiting points and of the space outside the interval within the continuum.

For instance, in plane geometry a line exhibits the continuum essence and allows for points to appear on it; a point exhibits the discontinuity essence, which allows for the definitions of a segment between two points on the line and of the corresponding space on the line outside the segment. This example illustrates the definition of discrete segment within the scope of the line continuum.

In fact, the continuum-discontinuity foundations fit the conceptual reasoning in a general case; this means that the mechanisms that were illustrated in the example of the plane geometry work as well for any conceptual domain. Indeed, we can consider any concept as something that is discrete within its conceptual scope. At the same time we can consider the conceptual scope to be continuum in which discrete concepts can exist. Thus we can define a concept as the discrete interval in the corresponding conceptual dimension.

The philosophical basis of the presented continuum-discontinuity foundations of conceptual reasoning will be discussed in the next section. Here we will just mention that application of these foundations can be considered as a natural modeling approach, as soon as the need to differentiate things in a given domain is considered natural. To use this approach we need to introduce definitions for the two basic essences, for Continuum and for Discontinuity:

def. 1. **Continuum** (in the model) is a conceptual extent representing a subject of modeling.

def. 2. **Discontinuity (also Point, Limit or Limiting Point)** in the model is a nil-extended conceptual entity that can be imagined within a **Continuum**.

Thus "Discontinuity" may serve as a reference within a conceptual continuum. And now, taking into account these foundations, we are ready to begin with introduction of the necessary and sufficient set of basic modeling concepts.

First we start by considering a notion of the space-time continuum. This notion is in correspondence with the conventional models of space-time in the universe that were proposed by natural science and mathematics (e.g. Minkowski's space-time and Galilean space-time). As explained, we can introduce a notion of a discrete interval within the space-time continuum as a space-time within some spatiotemporal limits in the continuum. Then, in the relation with the interval we can introduce the space-time outside the interval as a part of the space-time continuum that does not contain the interval. These notions of the space-time continuum, of the spatiotemporal limits, of the space-time interval and of the space-time outside the interval give us a possibility to define the four respective basic modeling concepts:

def. 3. **SpaceTime Continuum** (in the model) is a space-time (perceived in the subject of modeling).

def. 4. **Point in SpaceTime** (in the model) is a **Point** in **SpaceTime Continuum**.

Thus a "Point in SpaceTime" defines a spatiotemporal limit.

def. 5. **SpaceTime Interval** (in the model) is a space-time within some spatiotemporal limits (perceived in the subject of modeling).

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[2] A theoretical justification for these principles will be provided in Section 5 of this paper.

def. 6. **SpaceTime outside a SpaceTime Interval** (in the model) is a space-time outside some spatiotemporal limits (perceived in the subject of modeling).

By making reference to the perceived conceptualization of the subject that is being modeled (to the universe of discourse) definitions *def. 3,5,6* introduced Tarski's declarative semantics for the three respective concepts. To complete the definitions we need an additional semantic constraint that will insure an identity of the relations between the three concepts within a model and the relations that are perceived between their respective conceptualizations of the subject of modeling:

def. 7. **SpaceTime outside a SpaceTime Interval** is a complement of the corresponding **SpaceTime Interval** within the **SpaceTime Continuum**. That is: the union of the "SpaceTime outside a SpaceTime Interval" and of the corresponding "SpaceTime Interval" gives the "SpaceTime Continuum", while the intersection of the "SpaceTime outside a SpaceTime Interval" and of the corresponding "SpaceTime Interval" gives nil.

This semantic constraint defines that in the model a "SpaceTime outside a SpaceTime Interval" and the corresponding "SpaceTime Interval" are two disjoint (non-overlapping) parts complementing each other within the "SpaceTime Continuum".

We have introduced the four concepts whose purpose is to model spatiotemporal essence perceived in the subject of modeling. In natural science the spatiotemporal essence is traditionally considered as a primordial feature of the universe, - that's why we decided that for the general system modeling purposes it is also essential to distinguish the spatiotemporal part in the conceptualization of the universe of discourse (of the subject of modeling).

Naturally, as soon as we distinguished the spatiotemporal essence within the universe of subjects of modeling, its complement in this universe will be unambiguously the non-spatiotemporal essence. To represent the non-spatiotemporal essence in the model, we should have some concepts that, being considered without space-time, do not exhibit spatiotemporal characteristics. Thus essentially, the purpose of these non-spatiotemporal concepts will be to constitute the invariant to the space-time essence of the model. Because of this purpose we decided to refer to this non-spatiotemporal conceptual dimension of the model as "Model Constitution".

As we explained earlier in this section, we can consider any concept as something that is discrete within its conceptual scope. And we can consider the conceptual scope to be continuum in which discrete concepts can exist. Thus we can define a concept as the discrete interval in the corresponding conceptual dimension. Applying this mechanism to the model constitution, we will obtain a discrete constitution interval and its complement within the model constitution continuum. Traditionally in modern system modeling (particularly as defined in RM-ODP [4] 2-8.1 and 2-8.2) the principal piece constituting models is called "Object" and the constitutional part of the model that is not that "Object" is called as "Environment of the object". Hence for us there is no need to change terminology when introducing the constitution-related part of the basic modeling concepts. We can define:

def. 8. **Model Constitution Continuum** (in the model) is a conceptual scope (perceived in the subject of modeling) that is invariant with regard to space-time (perceived in the subject of modeling).

def. 9. **Point in Constitution** (in the model) is a **Point** in **Model Constitution Continuum**.

Thus a "Point in Constitution" defines a constitutional (non-spatiotemporal) limit.

def. 10. **Object** (in the model) is a constitutional entity (perceived in the subject of modeling) within some non-spatiotemporal conceptual limits.

def. 11. **Environment of an Object** (in the model) is a conceptual scope outside some non-spatiotemporal conceptual limits (perceived in the subject of modeling).

Analogously to the way it was defined in the case of spatiotemporal modeling, we can introduce a semantic constraint that will insure the adequateness of relations between the non-spatiotemporal basic modeling concepts inside models to the relations that are perceived between their respective conceptualizations of the subject of modeling:

def. 12. **Environment of an Object** is a complement of the corresponding **Object** within the **Model Constitution Continuum**. That is: the union of the "Environment of an Object" and of the corresponding “Object” gives the “Model Constitution Continuum”, while the intersection of the “Environment of an Object” and of the corresponding “Object” gives nil.

We would like to note here, that if considered exclusively under these definitions, “Object” and “Environment of an Object” have no relation to “SpaceTime Continuum”, which is natural because as *def. 12* explains, so far “Object” and “Environment of an Object” are only defined in the relation with each other within the “Model Constitution Continuum”, which does not imply any relation with the “SpaceTime Continuum”.

Now that we have introduced the two groups of basic modeling concepts (spatiotemporal and non-spatiotemporal concepts) we are ready to apply another foundation of conceptual reasoning (modeling), the one that explains the origins of emergent concepts.

Emergence is a well known property of systems that is closely considered in general system theory. Emergent concepts in the general case appear as a consequence of two conceptually different categories being put in the common scope of consideration, thus sharing a common context. For the emergent concept to appear, it is necessary that the two conceptually different categories are defined independently from each other and cannot be deductively reduced to (or derived from) a common conceptual category without loosing their defined essential features.

In our case we just defined the appropriate two conceptually different and mutually independent parts of basic modeling concepts, spatiotemporal concepts and non-spatiotemporal concepts, and because they were defined with the purpose to be considered in the common context (namely in the model) the third conceptual part of basic modeling concepts will, necessarily, emerge out of the first two being related with regard to each other.

So, now we will consider the space-time continuum and the model constitution continuum in the same context. This will give us a possibility to consider the constitution in the space-time and the space-time in the constitution. Essentially the third emergent conceptual part will represent the information about the second category with regard to the first, as well as the information about the first category with regard to the second. That is, we will get the spatiotemporal information about the non-spatiotemporal part of model and the non-spatiotemporal information about the spatiotemporal part of model. The former will describe how the model constitution evolves through the space-time continuum and the latter will indicate how the space-time evolves through the model constitution continuum.

Usually evolution of the space-time through the model constitution continuum is not considered in the general system modeling. Thus we also will exclude it from the scope of our consideration, nevertheless mentioning that modeling of the space-time evolution in the relation with the constitution is an interesting issue that can be positioned in the scope of consideration of the general theory of relativity in the theoretical physics.

So, let us concentrate on conceptualizing the information about model constitution in space-time. For the beginning, taking into account the above mentioned arguments, let us define the term of Information Continuum:

def. 13. **Information Continuum** (in the model) is a spatiotemporal information about the non-spatiotemporal conceptual scope (perceived in the subject of modeling).

Now we are able to apply the first of the previously described techniques of conceptual reasoning (modeling), which allows for a differentiation of an “Information Element” within the “Information Continuum”:

def. 14. **Information Element** (in the model) is a spatiotemporal information about a constitutional entity (perceived in the subject of modeling) within some non-spatiotemporal conceptual limits.

We see that for information-related concepts, contrary to what was done in cases of spatiotemporal and model constitution concepts, there was no need to define an explicit informational limit. This is because we construct information-related concepts as an emergent category and so for the definition of “Information Element” we can refer to the previously defined non-spatiotemporal limit.

Analyzing *def. 14* we can note that the declarative semantics for “Information Element” from the model make reference to the conceptualization of subject of modeling that corresponds to the “Object” concept (as it was defined in *def. 10*), also it refers to the spatiotemporal continuum in the subject of modeling (which participates in *def. 3*). Thus we can define the following semantic constraint:

def. 15. **Information Element** (in the model) is a **SpaceTime** information about an **Object** (in the model).

At this point we could have defined the concept corresponding to the complement of an "Information Element" within the "Information Continuum", - the same way as it was defined in the cases of the SpaceTime and the Model Constitution continuums. However, for the simplification we will omit this definition.

Thus we have defined a fundamental structure for basic modeling concepts that includes "SpaceTime", "Model Constitution" and "Information" about "Model Constitution" within "SpaceTime". The concept of "Information Element" crowns the structure presenting the information about spatiotemporal evolution of objects within models. For further exploration of the Information-related concepts, let us consider space and time separately, as two continuums within the space-time continuum[3]. Under this condition we may define the following concepts:

def. 16. **Space Continuum** (in the model) is a space (perceived in the subject of modeling).

def. 17. **Point in Space** (in the model) is a **Point** in **Space Continuum**.

Thus a "Point in Space" defines a spatial limit.

def. 18. **Space Interval** (in the model) is a space within some spatial limits (perceived in the subject of modeling).

def. 19. **Space outside a Space Interval** (in the model) is a space outside some spatial limits (perceived in the subject of modeling).

def. 20. **Space outside a Space Interval** is a complement of the corresponding **Space Interval** within the **Space Continuum**. That is: the union of the "Space outside a Space Interval" and of the corresponding "Space Interval" gives the "Space Continuum", while the intersection of the "Space outside a Space Interval" and of the corresponding "Space Interval" gives nil.

def. 21. **Space Information Element** (in the model) is space-dependent information about a constitutional entity perceived in the subject of modeling within some non-spatiotemporal conceptual limits.

def. 22. **Space Information Element** (in the model) is **Space**-dependent information about an **Object** (in the model).

def. 23. **Time Continuum** (in the model) is a time (perceived in the subject of modeling).

def. 24. **Point in Time** (in the model) is a **Point** in **Time Continuum**.

Thus a "Point in Time" defines a temporal limit.

def. 25. **Time Interval** (in the model) is a time within some temporal limits (perceived in the subject of modeling).

def. 26. **Time outside a Time Interval** (in the model) is a time outside some temporal limits (perceived in the subject of modeling).

def. 27. **Time outside a Time Interval** is a complement of the corresponding **Time Interval** within the **Time Continuum**. That is: the union of the "Time outside a Time Interval" and of the corresponding "Time Interval" gives the "Time Continuum", while the intersection of the "Time outside a Time Interval" and of the corresponding "Time Interval" gives nil.

def. 28. **Time Information Element** (in the model) is time-dependent information about a constitutional entity perceived in the subject of modeling within some non-spatiotemporal conceptual limits.

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[3] This assumption considering space and time as two entities doesn't impose any particular model for the properties of space and time interrelations. Different possible models (e.g. Minkowski's space-time, Galilean space-time) would be compatible with this assumption.

def. 29. **Time Information Element** (in the model) is **Time**-dependent information about an **Object** (in the model).

These definitions are straightforward analogs of *def. 3 – def. 7* and *def. 14 - def. 15* for the case when we consider space and time as two continuums within the space-time continuum.

Now let us explore the nature of "Information Element" within the three-dimensional framework where the dimensions are "Space Continuum", "Time Continuum" and "Model Constitution Continuum". This three-dimensional framework is presented on Figure 2.

As we saw, by considering an "Object" (the discrete part of "Model Constitution Continuum") in the relations with "Time Continuum" and with "Space Continuum" we are able to define "Time Information Element" (*def. 28, 29*) and "Space Information Element" (*def. 21, 22*) respectively. Further, for both of the information elements we can define two conceptually different parts: the information about an object related to a single point of the time (or space) continuum, and the information about an object related to an interval within the time (or space) continuum.

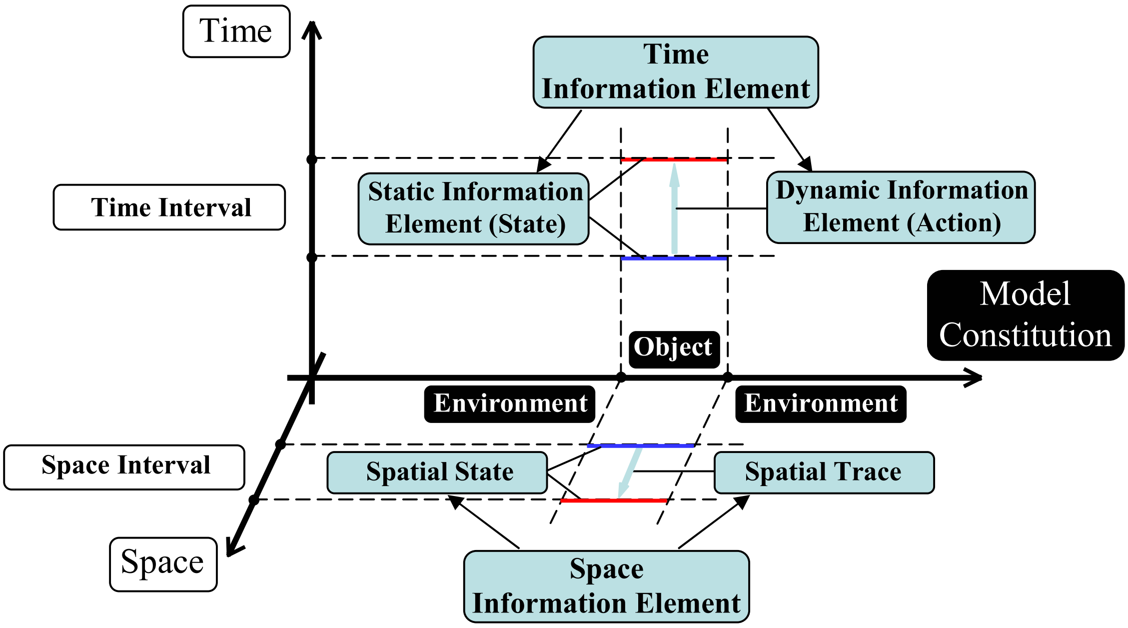

Figure 2. Three-dimensional framework with the dimensions of "Space Continuum", "Time Continuum" and "Model Constitution Continuum", which allows for the emergent "Information Continuum".

Thus in the case of "Time Continuum" we will have a specialization of "Time Information Element" giving the information about an "Object" related to a single point in time, and a specialization of "Time Information Element" giving the information about an "Object" related to an interval in time. Traditionally in system modeling the former information is called *static* (or sometimes *structural*), representing the *state* of an object at a point in time, while the latter information is called *dynamic* (or sometimes *behavioral*), representing the *behavior* (or the *action*) of an object in an interval in time. So, we can define another two basic modeling concepts as the specializations of "Time Information Element":

def. 30. **State (Static Information Element)** (in the model) is information about a constitutional entity perceived in the subject of modeling within some non-spatiotemporal conceptual limits at a point in time.

def. 31. **State (Static Information Element)** (in the model) is information about an **Object** (in the model) at a point in **Time Continuum** (in the model).

def. 32. **Action (Dynamic Information Element)** (in the model) is information about a constitutional entity perceived in the subject of modeling within some non-spatiotemporal conceptual limits in an interval in time.

def. 33. **Action (Dynamic Information Element)** (in the model) is information about an **Object** (in the model) in a **Time Interval** (in the model). That is: “Action” in the model is something that happens with a discrete constitutional part at a time interval in the subject of modeling.

Analogously in the case of “Space Continuum”, we will have a specialization of “Space Information Element” giving the information about an “Object” related to a single point in space, and a specialization of “Space Information Element” giving the information about an “Object” related to an interval in space. Thus we can define the information about a perceived spatial state of an object depending on a point in space and the information about a perceived spatial trace that an object follows within an interval in space:

def. 34. **Spatial State** (in the model) is information about a constitutional entity perceived in the subject of modeling within some non-spatiotemporal conceptual limits at a point in space.

def. 35. **Spatial State** (in the model) is information about an **Object** (in the model) at a point in **Space Continuum** (in the model).

def. 36. **Space Trace** (in the model) is information about a constitutional entity perceived in the subject of modeling within some non-spatiotemporal conceptual limits in an interval in space.

def. 37. **Space Trace** (in the model) is information about an **Object** (in the model) in a **Space Interval** (in the model). That is: “Space Trace” in the model is something that happens with a discrete constitutional part at a space interval in the subject of modeling.

This concludes the set of definitions of basic modeling concepts relevant in the general case. This set is necessary and sufficient for a specification of basic structure of any subject of interest in system modeling. Indeed, as it was constructed - it gives the possibility to represent any spatiotemporal or non-spatiotemporal entity, either discrete or continuum. The necessity of all the concepts in the set is justified by the need of modeling the mentioned scope. As for the sufficiency, if we assume that subjects that exhibit neither spatiotemporal nor non-spatiotemporal nature, and neither discrete nor continuum essence, are irrelevant for system modeling, then the sufficiency of the presented basic modeling concepts set is justified. We may consider this assumption as reasonable, because currently we are not aware of any presented system modeling example that wouldn’t be in agreement with the assumption.

Thus we don’t need other concepts for a representation of the basic essence of subjects of modeling. As we said in the beginning of this section, all the other concepts used in models will form the specification concepts category; since these concepts don’t represent the fundamental nature of subjects of modeling, they will not have declarative semantics in their definitions but will be defined in the relations with themselves as well as in the relations between themselves and the basic modeling concepts.

The defined structure of basic modeling concepts is presented in Figure 2. As we can see, regardless of the relatively big number of introduced definitions, the structure itself is quite simple. All the introduced definitions were necessary to support a rigorous logical method of the framework presentation, which included Tarski’s declarative semantics definitions, as well as definitions of semantic constraints that interrelate basic modeling concepts within a model. However for the practical applications of the framework a modeler should keep in mind the following essential set of 8 basic modeling concepts: “**Point in Space**”, “**Point in Time**”, “**Space Interval**”, “**Time Interval**”, “**Object**”, “**Environment**”, “**State**” and “**Action**”.

Indeed, traditionally, modeling tasks are concerned with the modeling of a concrete system, thus the consideration of overall continuums of space, of time and of information is not of primary importance. So we can consider the respective concepts of the continuums, and of parts outside intervals in the continuums, as relatively unimportant. The concepts of “Spatial State” and “Spatial Trace” are usually considered as constituent parts of “State” and “Action” respectively. This is not possible in the general case, but becomes possible with concrete space-time models where, for a given constitutional entity, a time interval is bound to a space interval and a point in time is bound to a point in space.

To conclude this section let us present the UML diagrams describing the introduced structures of basic modeling concepts. The diagram from Figure 3 presents the complete structure of definitions for basic modeling concepts under the assumption of concrete space-time models where, for a given constitutional entity, a time interval is bound to a space interval and a point in time is bound to a point in space (see the previous paragraph). Under the same assumption, the UML diagram from Figure 4 presents conceptual relations for the defined essential set of 8 basic modeling concepts.

The Figure 3 diagram shows how the definitions were constructed in this section. Here we demonstarte how the defined semantic constraints (*def. 7, 12, 20, 27*) relate the rest of the definitions between each other as composites with their component parts. The decompositions present the complete partitionings of their composites, and because the composites were introduced to represent the complete scope of the universe of discourse (subject of modeling), - we see again that the components of compositions, which are the mentioned 8 basic modeling concepts (marked as grey-filled rectangles), are necessary and sufficient for the complete representation of an arbitrary universe of discourse in general system modeling.

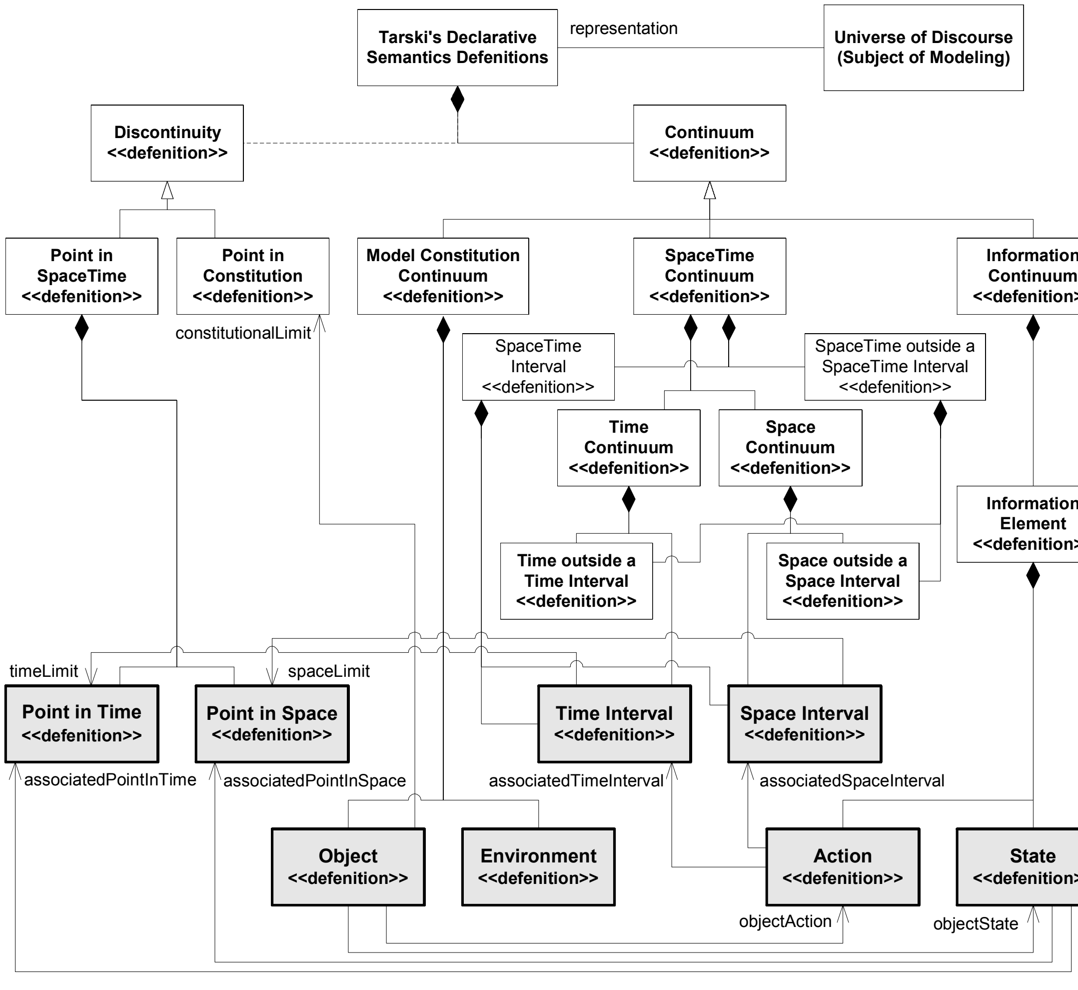

Figure 3. Basic Modeling Concepts: Definitions (UML diagram).

The Figure 4 diagram shows the resulting conceptual specialization of the basic modeling concepts set. The 8 concepts from the essential set of basic modeling concepts are again marked as grey-filled rectangles. As we can see, these are the most specific basic modeling concepts, which means that in the model these are the most specific concepts among all having their semantics defined as a kind of Tarski's declarative semantics (in the relation with the universe of discourse). Thus any further specialization of modeling constructs involving these 8 concepts can be done only with the aid of concepts from the specification concepts category.

Both of the diagrams present the introduced semantic relations for the essential set of 8 basic modeling concepts.

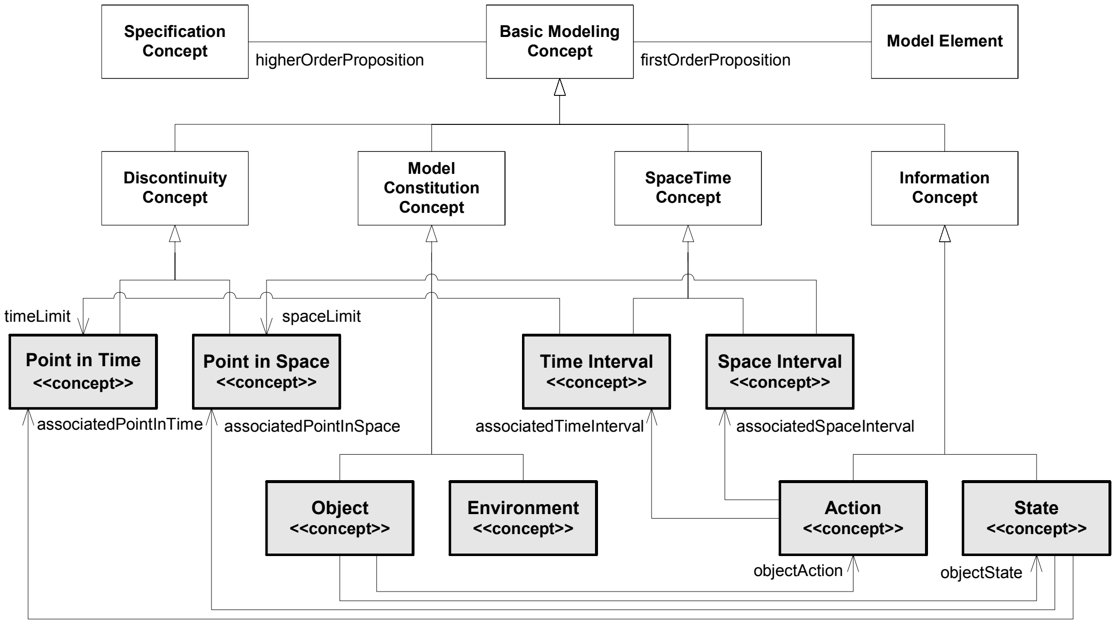

Figure 4. Basic Modeling Concepts: Conceptual Specialization (UML diagram).

4. Specification Concepts

In this section we will discuss the "Specification Concepts" conceptual category of our metamodel and present an example for the definition of the specification concepts that were taken from RM-ODP.

As we explained in Section 2 introducing our metamodel structure, the set of specification concepts contains all the concepts in the model that are neither basic modeling concepts nor model elements. This set of concepts in the model corresponds to the set of the higher-order propositions from the universe of discourse; thus in the general case the set of specification concepts is not limited (see Section 2).

We also explained that presenting the higher-order propositions from the universe of discourse, specification concepts do not represent primary qualities of the universe of discourse entities and hence they do not need to have Tarski's declarative semantics for their definitions. So these concepts will be defined only in the relations between themselves and in the relations with the basic modeling concepts, but not in the relations with the universe of discourse.

The basic design purpose of the specification concepts is to represent the set of higher-order propositions from the universe of discourse. Because in the general case the set of higher-order propositions is unlimited and destitute of any predefined structure, there are many different possible to define the specification concepts set. The only two requirements for the specification concepts definitions is that:

- they should present the structure of concepts that is internally consistent and destitute of self-contradictions;
- they should allow for a presentation of all the information that is included in the modeling scope of a concrete application of our metamodel.

This means that different existing object-oriented modeling frameworks can easily adapt our metamodel as soon as their conceptual frameworks are internally consistent and destitute of self-contradictions. Thus the different modeling frameworks of such kind have a possibility to use their concepts without redefining them as specification concepts in our metamodel.

Let us present an example of the specification concepts definition that is taken from RM-ODP standard. We were motivated to present the example of RM-ODP and not some other example particularly:

- by the internal consistency of the RM-ODP specification concepts structure and absence of self-contradictions introduced in the structure;
- by the fact that its terminology is conventional for the nowadays object-oriented modeling community (e.g. containing the terms like “type”, “instance”, “class”, “template”, etc.);
- by its possibility to represent successfully the information relevant to the modeling of IT systems by means of its defined specification concepts set accompanied by the conceptually rich extensions provided in the RM-ODP viewpoints definition.

4.1. Type and its related concepts

We will begin introducing the definitions with one of the most important specification concepts in the RM-ODP specification concepts structure, namely the concept called “Type”. RM-ODP defines:

def. [4] 2-9.7 ***Type (of an <X>)****: A predicate characterizing a collection of <X>s. An <X> is of the type, or satisfies the type, if the predicate holds for that <X>.*

This definition shows that “Type” specification concept has a primary importance in the RM-ODP models. Indeed, any predicate that can be found in models characterizes a collection of things (“*<X>s*”). Sometimes it is a collection with an unlimited number of things, sometimes – a collection of a concrete number of things, particularly it can be a collection of just one thing. Thus under this definition any predicate that can be found in models is “Type”.

This definition of “Type” if considered in the scope of our metamodel should be supplemented with the following restricting comment:

def. Supplement to [4] 2-9.7: Because of the special appointment of the modeling terms that are reserved for definitions on the level of the metamodel definition, none of these terms can be considered as the predicate that defines a “Type”.

These reserved terms include, in particular, the terms expressing basic modeling concepts, the terms expressing specification concepts, the term of “model element” and the terms expressing the universe of discourse (e.g. “entity”, “proposition”). Because these terms already have a concrete significance on the meta-modeling level, it would be unreasonable to appoint them in another context assuming a concrete significance on the modeling level.

Here we would like to present a brief example illustrating a couple of important features of “Type”. We are motivated for this presentation by our practical experience which shows that “Type” with its related concepts defined by the presented RM-ODP definition is very often the source of confusions in nowadays modelers’ practices.

In the relation with the “Type” concept RM-ODP defines the concepts of “Instance (of a type)” that allows, for example, for a differentiation of things characterized by the same “Type” predicate:

def. [4] 2-9.18 ***Instance (of a type):*** *An <X> that satisfies the type.*

Another RM-ODP definition introduces the terms of “Subtype” and “Supertype” for the types that have particular relations with other types:

def. [4] 2-9.9 ***Subtype/supertype:*** *A type A is a subtype of a type B, and B is a supertype of A, if every <X> which satisfies A also satisfies B.*

An instance of a type, as soon as it is named by some name within a model, necessarily expresses the predicate of this name. Thus, according to the definition [4] 2-9.7, in RM-ODP models an instance of a type necessarily expresses another type and, according to [4] 2-9.9, the latter type is a subtype of the former type, while the former type is a supertype of the latter one. In other words, a named instance of a type is the named subtype of this type. For example, instance A of type B is the subtype A of type B. The backward equivalence, that subtype A of type B is the instance A of type B, is also straightforward.

Thus in accordance with the three presented definitions, a named instance of a type and a named subtype of a type have essentially the same semantics. In addition, because an unnamed instance of a type in accordance with the three definitions makes the same sense as an unnamed subtype of a type, we can conclude that for RM-ODP models “instance of a type” and “subtype of a type” are two semantically identical concepts.

Also, in accordance with the three presented definitions, instance of a type (or, interchangeably, subtype of a type) is a specialization of the type in some context. The amount of different modeling contexts for the specialization is unlimited in general case (for example see Figure 5). So, since a definition of concrete modeling contexts is possible only in a limited modeling scope, the question of existence of the most concrete instance of a type (or, interchangeably, the most concrete subtype of a type) is irrelevant in the general case of an unlimited modeling scope.

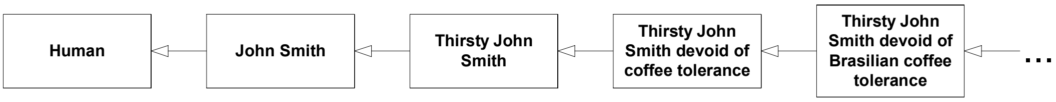

Figure 5. Illustration of the unlimited richness of modeling contexts leading to the irrelevance of question about existence of the most concrete instances of types in the general case (UML diagram).

Let us conclude the discussion about concrete specification concepts at this point. A detailed analysis of different specification concepts defined by RM-ODP, as well as their computer-interpretable formalization, can be found in [9]. In this section on example of RM-ODP specification concepts we would like to present some interesting particularities of conceptual organization of the specification concepts category that can play an important role on the level of metamodel definition.

4.2. Generic and specific specification concepts

The group of RM-ODP specification concepts that are defined in the relations with "Type" includes concepts like "Instance", "Class", "Template", "Instantiation", etc. This group together with the concepts of "Composition" and "Decomposition" presents *generic specification concepts*.

Generic specification concepts are those specification concepts that didn't need a reference to concrete basic modeling concepts for the definitions of their semantics. Instead for their semantics definitions we can refer to an <X> as did RM-ODP, where <X> is a variable that can be substituted by absolutely any of the basic modeling concepts. As a result, these concepts can specify any of the different basic modeling concepts.

For example, in the models "Type" can be applied to different basic modeling concepts, which would result in: "Type of Object", "Type of Action", "Type of Time Interval", etc. Analogously for the concept of "Composition" we would have "Composition of Objects", "Composition of Actions", "Composition of Time Intervals", etc.

Another group of concepts for the semantics definitions needed a reference to concrete basic modeling concepts. As a result, these concepts can specify only those concrete basic modeling concepts which were assumed in the definitions. Because of this specificity this group of concepts is called *specific specification concepts*.

For example "Internal Action", "Interaction", "Interface", "Role", etc. are specific specification concepts that should be related to the "Action" basic modeling concept; and "Precondition", "Postcondition" are specific specification concepts that are related with the "State" basic modeling concept.

As we defined them, generic specification concepts and specific specification concepts present a complete partitioning of the specification concepts category. Indeed, a specification concept can be either defined without using a reference to concrete basic modeling concepts or with a reference to concrete basic modeling concepts. Thus any specification concept is either generic or specific.

Figure 6 presents a UML diagram with the overall conceptual specialization of our metamodel, this conceptual structure includes the most important specification concepts of RM-ODP.

As we see from the Figure 6, specific specification concepts are in fact concrete specializations of "Type" for a particular basic modeling concept. For example, "Precondition" is a special "Type of State"; "Internal Action" is a special "Type of Action" etc.

We should also note that generic specification concepts are suitable not only for an application on the basic modeling concepts, but also for building more complex specification concepts by describing any of specification concepts themselves. Indeed, instead of <X> in the generic specification concepts definitions we can put any of specification concepts (generic or specific) to construct a more complex specification concept.

When we apply a generic specification concept on a generic specification concept, the possible applications of the resulting complex specification concept are defined by the latter generic specification concept, thus this complex specification concept will also be generic. For example, “type of type” and “composition of templates” are complex specification concepts that are generic.

When we apply a generic specification concept on a specific specification concept, obviously the resulting complex specification concept will be specific. For example “class of interaction” is a complex specification concept that is specific.

Of course, these complex specification concepts may have as many levels of complexity as it will be necessary; for instance: “type of composition of templates” or “type of composition of templates for types”. This corresponds to the unlimited in the general case complexity of higher-order propositions from the universe of discourse that should be modeled by means of the specification concepts.

But as we already explained in Section 2, if a specification concept of any level of complexity should be used in a model, then it will be applied to a basic modeling concept that, in its turn, will characterize a model element. And the statement constructed with the specification concept and the basic modeling concept, irrespectively of its complexity, will be a single assertion about the model element.

Thus, using RM-ODP concepts we have explained an example of the structure of specification concepts that can be used in our metamodel. The resulting conceptual specialization is presented in Figure 6.

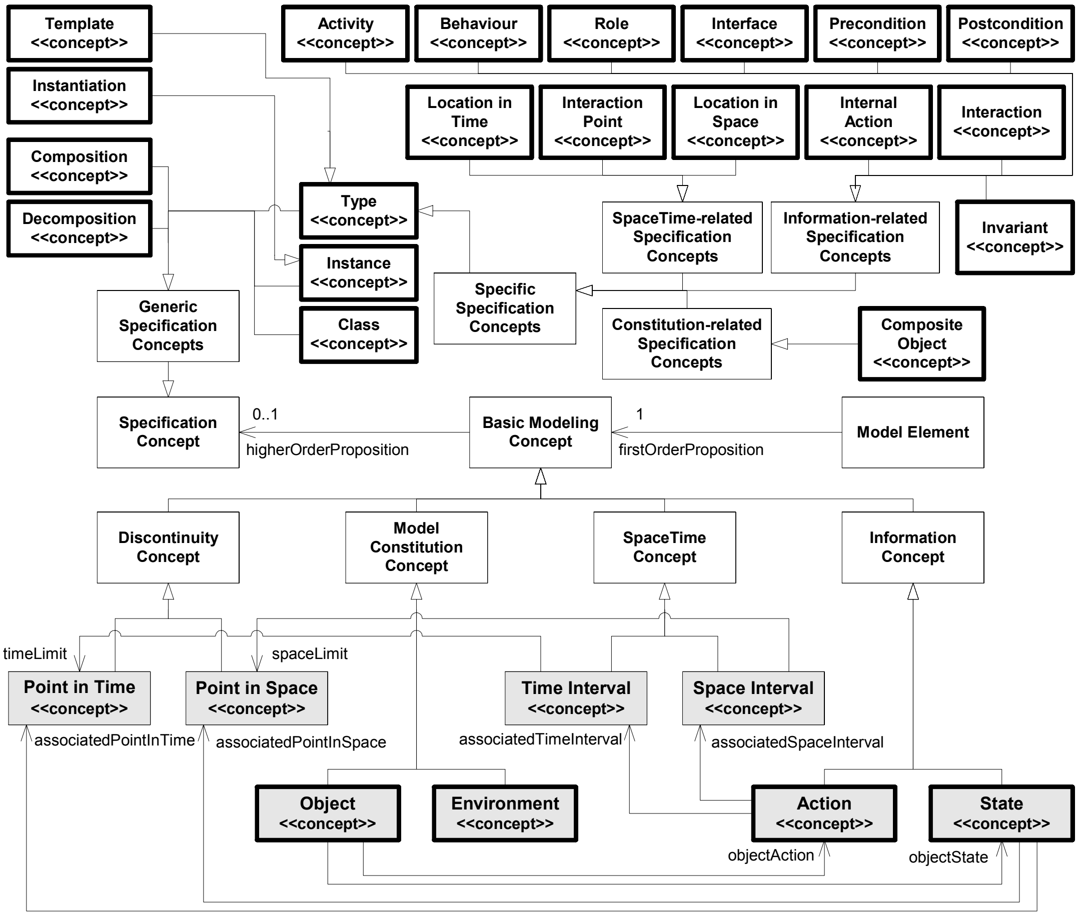

Figure 6. Example of RM-ODP conceptual framework presented using our defined metamodeling structure (UML diagram).

We would like to note again that the structure of specification concepts used in our metamodel is not reserved by a particular example and allows for many different ways for it to be defined. Thus our metamodel is flexible for adaptation by different object-oriented conceptual frameworks (assuming that such a framework obeys the requirements defined in the beginning of Section 4).

In the diagram from Figure 6, the original RM-ODP concepts are represented with the aid of rectangles with the thick-lined borders; our reserved basic modeling concepts are represented by gray rectangles. In Figure 6 we see how the internally consistent structure of our metamodel allowed us to formalize the overall presented conceptual framework of RM-ODP ([9], [10], [11]). Originally, the RM-ODP standard does not define an appropriate metamodel that would allow for such a formalization. And with the aid of our metamodel it is now possible to verify RM-ODP models with the aid of computer tools. This shows again the usefulness of the work that we did on the metamodel definition.

This concludes the discussion on definition of our metamodel.

5. Philosophical and Natural Science Foundations of Concepts Semantics in the Metamodel

A definition of formal ontology for system modeling is a general philosophical problem; its different solutions provided by humanity can be traced back to many centuries in the past. The book [12] gives a good review of those different solutions. Let us present here the philosophical foundations of our solution, which will allow for understanding of its particularities and for realization of the differences that our ontology brings in comparison with other existing ontologies.

5.1. Modeling

In the general case we can define "Modeling" as a relation between a subject of interest to a modeler and a model of this subject. Sometimes we refer to the subject of interest to a modeler as the universe of discourse, or as the subject of modeling, or as the subject being modeled, etc.

A model is under the responsibility and control of its modeler. The subject of a modeler's interest in the general case is not under the responsibility and control of the modeler. The specific case if the subject of a modeler's interest is also a model of some other universe of discourse, the model belonging to the same modeler, - is the only specific case when the subject of a modeler's interest is under the responsibility and control of the modeler.

Thus a model is impossible without its modeler. Obviously, the subject of a modeler's interest makes sense only in the scope of the modeler's consideration, thus it makes no sense without the modeler who would express this interest. The question whether the subject of a modeler's interest is possible or not without the modeler who would express the interest, is irrelevant for modeling because in this case:

- a model of this subject is impossible;
- the subject cannot make any sense to the modeler.

Clearly, in the general case, when there is no any concrete essence (in particular, spatiotemporal essence) implied neither at the modeling level (when establishing the modeling relation), nor on the metamodeling level (when defining the term of "Modeling"), we cannot refer to "Modeling" as anything more concrete then just a relation (e.g. as a process, or as a result of a process). Thus let us define:

def. 38. **Modeling** is a relation belonging to a modeler, the relation between a subject of the modeler's interest and a model of this subject.

5.2. To categorize or not to categorize? Continuum/Discontinuity foundations

As it is defined in [14]: "The subject of *ontology* is the study of the *categories* of things that exist or may exist in some domain." As we saw it in the Section 3, defining basic modeling concepts, in our solution prior to providing a particular study of general system modeling categories we have touched the very nature of categorization. We said that we see this nature in duality of two essences: continuum and discontinuity. Continuum as soon as it is introduced, automatically allows for discontinuity to appear. Discontinuity allows for a definition of limiting points within a continuum, which consequently allows for a definition of the interval between limiting points and of the space outside the interval within the continuum. Thus we were able to define a concept as a discrete interval within a continuous conceptual dimension.

def. 39. **Concept** is a discrete interval within a continuous conceptual dimension.

However, here we would like to note that the continuum/discontinuity vision allowing for a differentiation of things in a given domain (e.g. in time, in space, in some non-spatiotemporal conceptual domain) is by itself a modeling approach. And even if this modeling approach provides foundations not only for ontological studies, but for all the conventional science, nevertheless it was successfully challenged by Zeno, a pre-socratic Greek philosopher (490-425 BC), who formulated a set of paradoxes [1] proving that the continuum/discontinuity model is contradictory by its internal nature and hence cannot be an adequate model for a subject of modeling.

Moreover, the definitions for discontinuous terminology in the continuum/discontinuity modeling approach (terms like "point", "boundaries", "contact", etc) still remain an undetermined [16] topic of mereology, the branch of philosophy that investigates whole-part relationships. And it is exactly for this reason that our definition of point (*def. 2*) does not really introduce a Tarski's declarative semantics for the concept, instead it refers to an imaginary entity that can be positioned inside a model continuum. For the declarative semantics definition to exist, there are supposed to be some reasons originated in the subject of modeling that trigger this imagination, but while modern science is not able to conceptualize them, we are not able to define a kind of the declarative semantics in this case. This is also the reason why we have put in Figure 3 a dashed line for the discontinuity definition seen as a component in the overall declarative semantics definitions.

So, taking into account Zeno's paradoxes and problems with the definition of declarative semantics for the terminology of discontinuity, we see the continuum/discontinuity approach that allows for differentiation of things in a given domain, as a fair approximation, whose fairness is justified by practical reasons, namely by the fact that all the conventional modeling results are achieved neglecting Zeno's paradoxes. Indeed, if we choose the case of conventional reasoning where we would be able to differentiate things (which is obviously the case of this work), then we have no choice but to neglect the paradoxes. The alternative approach is formulated in [1] by reconstruction of Zeno's argument referring to the paradoxes as following: "*if you allow that reality can be successively divided into parts, you find yourself with the insupportable paradoxes; so you must think of reality as a single indivisible One*". This is a different approach, and it will not be investigated in this work. Thus in this work we are determined to stick to the continuum/discontinuity approach that gives us a possibility to define the term of concept and to have concepts grouped in the categories of concepts for a representation of a subject of modeling.

5.3. Conceptual modeling and general system modeling

The next step was to define the most fundamental conceptual categories for a representation of a subject of modeling. To accomplish this goal we needed first to understand the notion of conceptual modeling itself.

Clearly, conceptual modeling is a specific case of modeling, namely the specialization that is characterized by the modeling nature being conceptual. Thus we see that after we have defined the term of "modeling", the only step in defining the term of "conceptual modeling" was a realization that conceptual modeling is a modeling done with the aid of concepts. Here the importance of the previous subsection explaining the notion of "concept" becomes clear. We see that an explanation and a definition of the "concept" term was really necessary for us to advance further, because without the understanding of what "concept" is and why it is, we wouldn't be able to understand what would an alternative to the conceptual modeling (that is the modeling done without an aid of concepts) mean. And without understanding the alternative, the phrase "*conceptual modeling is a modeling done with the aid of concepts*" would be a trivial tautology destitute of any practical sense.

def. 40. **Conceptual Modeling** is a **Modeling** done with the aid of **Concepts**.

Having understood this very basic principle we are determined to construct a concrete framework of reasoning for conceptual modeling. Particularly, our interest was to define the "general system modeling" framework within conceptual modeling.

In fact, "general system modeling" (as well as "conceptual modeling") is one of those terms that are often used in practice without a concrete definition, assuming that their definitions are implicitly understood by the community. Thus, analogously to the case of "conceptual modeling", we thought it could be useful to provide an explicit definition for the term.

When defining the term of "conceptual modeling" we referred to the key word "concept" and thus to its definition that was previously constructed with the aid of continuum/discontinuity foundations. The same approach could have been taken for the "general system modeling", by referring to the general modeling of systems and trying to define the key word "system". This approach would lead us to the findings of general system theory introduced by Ludwig von Bertalanffy [2], where "system" is defined as a "*set of elements standing in interrelations*". We see that this definition can be positioned on the same level of specificity as the definition that we had for the term of "concept". Thus this approach will not help us to define the general system modeling framework as a particular specialization of conceptual modeling.

So we decided to take a different approach that was to analyze the numerous practical experiences referred nowadays as experiences of general system modeling. We found that these experiences assume (in most of the cases implicitly) for general system modeling a relevance of the basic natural science foundations (such as spatiotemporal consideration of different subjects). Thus, we considered it relevant to define general system modeling by positioning conceptual modeling in the relation with natural science.

Classical (Newtonian) mechanics presents a framework where space is relational depending on a particular frame of reference and time is absolute (invariant). A frame of reference is defined in the relation to a particular observer[4]. With such a model classical mechanics then studies material objects in space. In this mechanics Galilean transformations allow for passing from one frame of reference to another to study the events that happen with material objects from different observers' perspectives. Thus here material objects considered to be as invariant as time with regard to different observers' viewpoints (or different frames of reference).

Relativistic mechanics (the mechanics that is based on Einstein's principle of relativity) presents a framework where both space and time are relational depending on a particular frame of reference. Thus Minkowski's space-time is introduced, where, based on the invariance of the interval between events that happen with material objects in different frames of reference, Lorentz transformations are defined. As it was with Galilean transformations in classical mechanics, Lorentz transformations in relativistic mechanics allow for passing from one frame of reference to another to study the events that happen with material objects from different observers' perspectives. Thus in relativistic mechanics again it is assumed that material objects are considered to be invariant with regard to different observers' viewpoints (or different frames of reference).

In the case of conceptual modeling we don't pretend to study material objects as it is done in mechanics. Instead we study perceptions of different observers about a subject of modeling. A subject of modeling can be not only a material object but also a purely imaginary entity. Any entity, whether it is real or imaginary, can be modeled as soon as it is of interest to a modeler. Different perceptions about a subject of modeling result in different models. In conceptual modeling the perceptions are always subjective, that is: every modeler (observer) necessarily has an own perception about a subject of modeling, the perception which can be different from the perceptions of other modelers about the same subject. The existence of subjective viewpoints for each observer about any subject of modeling (including the laws of nature that are objective for natural science) and the extension of scope of modeling subjects with an imaginary area are two essential features that make difference between natural science and conceptual modeling.

Let us allocate a separate line for this quite important conclusion about the identified differences between conceptual modeling and natural science. So, the two differences between conceptual modeling and natural science are:

- the existence of subjective viewpoints for each observer about any subject of modeling in conceptual modeling from one side related with the invariance of laws of nature and subjects of study (e.g. material objects) for the different observers in natural science from the other side;
- the scope of the modeled subjects in conceptual modeling is different from the scope of the investigated subjects in natural science: the former can be seen as an extension of the later with the imaginary subjects of modeling.

Let us illustrate this difference with an extreme example: in conceptual modeling a modeler can build a model representing purely imaginary entities that are described by some laws having nothing in common with the laws of nature from natural science; and as soon as the model is internally consistent, it has its justified reason for existence presenting the subjective vision of the modeler with regard to the defined universe of discourse.

However, any of such subjective models is usually constructed to be used in a concrete practical context that has some kind of relation (e.g. motivating the modeling interest) with the identified universe of discourse. Thus, the modeler using a model in its assumed practical context depending on the outcome of the model use can consider this practical experience either as successful or as unsuccessful with regard to

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[4] When comparing modeling and natural science we consider the terms of «modeler» and of «observer» as interchangeable.

some set of criteria. Consequently, depending on the degree of success of this practical experience, the model is proved either to represent the identified universe of discourse adequately (in the case of successful practical experience), or inadequately (in the case of unsuccessful practical experience). The degree of adequateness may be compared for different models of the same universe of discourse, belonging to the same modeler (or on a bigger scale – belonging to the same modeling community) and being evaluated by the practical experiences judged with the same set of criteria. And if a model does not represent the universe of discourse adequately enough, then due to the model inefficiency in comparison with some other possible models, the model has a high chance to be discarded from practical applications of the modeler (or on a bigger scale - of the modeling community) in favor of more efficient models.

The judgment on the degree of success of practical experience of a model use including the selection of the set of criteria, in relation to which the experience should be judged, is under the responsibility and control of the modeler (or of the modeling community). Thus in modeling every modeler (every community) is naturally encouraged for the construction of adequate models for his/her (its) own benefit realized by the successful practical experiences.

Having concluded the analysis of this example of conceptual modeling let us return to the presented relations between natural science and conceptual modeling. With the performed analysis of these relations it becomes clear that all the results of natural science (and particularly of the classical mechanics and of the relativistic mechanics) are a straightforward example of a concrete modeling framework with the particular subject of modeling. Thus conceptual modeling can be seen as an extension of natural science with the two presented essential features.

This means that in a conceptual modeling framework we can use the framework definitions of natural science under the condition that they are adapted in flexibility to allow for a support of the two presented essential features of conceptual modeling. Of course, this vision of conceptual modeling having adopted the framework definitions of natural science that are adapted with regard to the two mentioned criteria is a specialization of the general vision of conceptual modeling that we defined previously as "*modeling done with the aid of concepts*".

Indeed, modeling done with the aid of concepts in the general case has no reason to be related with natural science; and it was our choice to establish this particular relation with natural science, the choice that we made because general system modeling practices imply this specialization. Thus now we can define "general system modeling" as a term expressing this particular specialization of conceptual modeling.

def. 41.1. **General System Modeling** is a kind of **Conceptual Modeling** that adopts for modeling the framework of natural science under the condition when the framework of natural science is adapted to support the following two essential features of Conceptual Modeling:

- the existence of subjective viewpoints about any subject of modeling for each observer (contrary to the invariance of laws of nature and subjects of study (e.g. material objects) for the different observers in natural science);

- the possibility to have any subject of potential interest to a modeler within the modeling scope (thus the scope of the investigated subjects of natural science should be extended with the imaginary subjects of modeling).

5.4. Adapting natural science foundations: Spatiotemporal and Non-spatiotemporal continuums presentation by means of a relational reference frame

As we defined in the previous section, to construct a conceptual framework for general system modeling we needed to adapt the basic foundations of natural science to support the two identified constraints of conceptual modeling:

- the existence of subjective viewpoints about any subject of modeling for each observer (contrary to the invariance of laws of nature and subjects of study (e.g. material objects) for the different observers in natural science);
- the possibility to have any subject of potential interest to a modeler within the modeling scope (thus the scope of the investigated subjects of natural science should be extended with the imaginary subjects of modeling).

The adaptation to the second of the two mentioned constraints was relatively straightforward. For this adaptation the basic scientific frameworks of natural science remain unchanged, only the subject of investigation of natural science, that can be referred in general case as material objects with their properties, is replaced by concepts which, as we know, are not necessarily material.

The adaptation to the first of the two mentioned constraints was a bit more creative and produced an original solution; but this solution also appears in a relatively straightforward way, as soon as we perform the following analysis of the problem.

As we explained in the previous section, in natural science the frame of reference is defined in the relation to an observer, and then, according to the laws of nature (such as Einstein's principle of relativity for the relativistic mechanics) some transformations are introduced for a transition from one frame of reference to another.

We mentioned that in classical (Newtonian) mechanics the observer-relational reference frames exhibit relational nature only in space, while time and material objects remain invariant for different observers.

Also we mentioned that in relativistic mechanics the observer-relational reference frames exhibit relational nature in space and in time, while material objects remain invariant for different observers.

From this experience the next possible step emerges naturally, this step will give us the necessary solution. To adapt the natural science foundations to the existence of subjective viewpoints about any subject of modeling for each observer, we need to consider the reference frames that include relational space, relational time and relational subjects of modeling. This can be presented as making material objects from relativistic mechanics relational instead of invariant and substituting them with concepts. In practice this solution is realized by the definition of an additional dimension for the observer-related reference frames (the dimension is additional in comparison with the relativistic mechanics that has only spatiotemporal dimensions).

This dimension should present concepts that constitute the content of models, the same way as material objects constituted the content of natural science models. That is the reason why we decided to call this dimension as "Model Constitution Continuum".

In agreement with these ideas we defined this continuum (*def. 8*) as presenting the non-spatiotemporal conceptual essence of the universe of discourse. Indeed, as we showed, the definition of "Object" (*def.10, 12*), which is the principal concept within the model constitution continuum, is done with the aid of defined non-spatiotemporal conceptual limits and in the relation with "Environment" that complements the object within the continuum. That is "Object" and "Environment of an Object" in their definitions do not have any reference to the spatiotemporal essence of the universe of discourse.

In such a way we defined for the model a reference frame representing two essences of the universe of discourse: the spatiotemporal essence and the non-spatiotemporal essence. The former is presented by "SpaceTime Continuum" in the reference frame while the latter is presented by "Model Constitution Continuum". For example, we can compare the conventional four-dimensional observer-relational model of reality (three spatial dimensions and one temporal) with our solution that if having the analogous outset will present the five-dimensional observer-relational model of reality (three spatial dimensions one temporal and one constitutional).

In accordance with its explained design goal, and in correspondence with the analogous roles of reference frames in natural science, our reference frame is defined for a given modeler. That is every modeler (and on a bigger scale – every modeling community) has his/her own reference frame where he/she constructs the models.

The possibility to introduce transformations that would allow for a transition from one frame of reference to another in the case of natural science assumed the existence of universal laws of nature (such as Einstein's principle of relativity in the case of relativistic mechanics).

In our case the vision of laws of nature is subjectively controlled by every concrete modeler as well as all the information within the modeler's frame of reference. Because of this it may seem that in general system modeling, as we defined it, there cannot be a universal transformation rule for the transition from one frame of reference to another. However, the absence of universal transformation rule can also be considered as a rule, which may seem to introduce a logical paradox. But in fact it doesn't introduce a paradox, because due to the defined intrinsic design features of conceptual modeling, in conceptual modeling any rule, be it a "universal transformation rule" or "the rule of absence of universal transformation" is valid or is not valid only in the *limited* scope of models belonging to a concrete modeler (or on a bigger scale – belonging to a concrete modeling community). Thus *the question of existence or non-existence of any rules or laws in the unlimited scope of models is irrelevant in conceptual modeling.*

That is, in these conditions the question doesn’t have logically justified reasons for existence and has concrete logically justified reasons for nonexistence.

However, for a limited scope of models this question indeed has logically justified reasons for existence, and in this case of the limited scope the question either can have or cannot have a concrete answer, depending on the concrete conditions of models from the limited scope. If the conditions are such that the question cannot have a concrete answer, then there is indeed a local paradox. But we should note again that this paradox is relevant only within this concrete limited scope of models under the concrete conditions, and on the unlimited scope of models that is considered by conceptual modeling in general case such paradox is impossible.

Let us conclude this section by summarizing its results. In this section based on the foundations of conceptual modeling and of natural science we have defined a modeler-relational frame of reference to be used for general system modeling. The frame of reference presents in models two essences of subjects of modeling: spatiotemporal essence is presented by means of SpaceTime Continuum, non-spatiotemporal essence is presented by means of Model Constitution Continuum.

5.5. Information continuum

By the definition of the modeler-relational frame of reference we introduced the first two basic conceptual categories that should exist in models done in general system modeling: the first is SpaceTime category which is defined by the SpaceTime Continuum dimension in the frame of reference; the second is Model Constitution category, which is defined by the Model Constitution Continuum dimension in the frame of reference.

As it we already demonstrated in the section that introduced basic modeling concepts, SpaceTime and Model Constitution necessarily give birth to the third conceptual category as soon as we positioned them in the same scope of consideration within our frame of reference. The fact of their positioning in the same reference frame by itself defines the possibility for existence of information about model constitution with regard to space-time in the models, as well as about space-time in the models with regard to model constitution. Thus our defined reference frame automatically introduces the third conceptual category emerging out of the first two. Because of its described informational nature, we call this conceptual category as “Information”; in the models it is presented by the corresponding “Information Continuum”.

It is impossible to overestimate the importance of this emerging information continuum for the general system modeling. Hermann Minkowski (1864-1909) when talking about his defined observer-relational space-time frame of reference that is used in relativistic mechanics, wrote: “*Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality.*” [3]. Analogously, for the models of general system modeling, with the support of our defined observer-relational space-time-constitution frame of reference we can say that in the models space-time by itself and model constitution by itself are introduced only for the convenience of presentation, but the only thing that really needs to be presented is the emergent information about model constitution within space-time and about space-time within model constitution.

Modelers nowadays traditionally concerned with representation of information about model constitution within space-time and practically neglect a representation of information about space-time within model constitution. That is the reason why in this work we defined the terminology representing the former part of information. However, we would like to note that a priori space-time and model constitution are equally balanced within our defined observer-relational frame of reference, thus the possibilities to investigate model constitution within space-time and space-time within model constitution are equally important.

Indeed, a priory both cases are equally interesting for the modeling consideration. The first case when model constitution, that is objects and their environments, is positioned within space-time is interesting for example if a modeler would like to present how information about a particular object is projected on different time intervals. The second case when space-time, including particularly time intervals and space intervals, is positioned within model constitution (objects and their environments) is interesting for example if a modeler would like to present how information about a particular time interval is projected on different objects.

Thus, as we don’t have any reason to favor space-time over model constitution or model constitution over space-time, we can consider them as two independent mutually assumed and mutually contained dimensions. That is model constitution assumed by and contained in space-time as well as space-time assumed by and contained in model constitution. This shows again that the only modeling interest is to present information about their mutual containment and not them individually.

It may seem that our reasoning for uniting space-time and constitution to produce information is the same as the reasoning that led Minkowski to unite space and time to produce a single space-time. In fact this is not true because in the latter case Einstein's principle of relativity was necessary to create the union. And in our case the things are different; we have the third conceptual dimension (information) naturally emerging out from the first two (from constitution and space-time) positioned in the same context.

In our case information is a real emergent concept in the sense of general systems theory and system sciences. That is, it is not equivalent and cannot be equivalent to its components with a composition rule. In natural science a composition rule is impossible to formulate when there is no means to reduce components to a common dimension (or to derive components from a common dimension, which is the inverse operation). This is exactly our case, when our two components (spatiotemporal conceptual essence and non-spatiotemporal conceptual essence) are introduced as complementary to each other. So in our case we have an emergence union of complements (space-time and constitution) producing the emergent (information).

In the case of Minkowski's space-time, the space-time is not an emergent concept, but just a simple union of space and time. That is, here the space-time is equivalent to the two components (space and time) with their composition rule. The composition rule in Minkowski's space-time is allowed by Einstein's principle of relativity, particularly by the speed of light constant, which makes it possible to reduce the spatial essence and the temporal essence to the common conceptual scope of spatiotemporal interval.

So, we see that the adaptation of the natural science foundations that was performed in the previous section led us to the realization of a new feature that from one side is essential for conceptual modeling and from the other side is not supported by natural science. This feature is emergence union of concepts leading to a new emergent concept. As we explained, in natural science there is no possibility to define a composition rule for the component concepts to be composed producing an emergent concept. Thus we can supplement our definition of "general system modeling" term with this third feature that is essential for conceptual modeling and that is not supported by natural science:

def. 41.2. **General System Modeling** is a kind of **Conceptual Modeling** that adopts for modeling the framework of natural science under the condition when the framework of natural science is adapted to support the following three essential features of Conceptual Modeling:

- the existence of subjective viewpoints about any subject of modeling for each observer (contrary to the invariance of laws of nature and subjects of study (e.g. material objects) for the different observers in natural science);
- the possibility to have any subject of potential interest to a modeler within the modeling scope (thus the scope of the investigated subjects of natural science should be extended with the imaginary subjects of modeling);
- the possibility to have emergence unions of concepts leading to new emergent concepts.

It is easy to note from our discussion that this definition by itself is an emergent definition. Indeed, before performing the adaptation of natural science foundations to the conceptual modeling needs we didn't have a reason defined in the scope of conceptual modeling consideration that would make it necessary for us to introduce the third supplement to the definition of general system modeling. But immediately after the adaptation such a reason has emerged which led us to the final form of general system modeling definition. This demonstrates that our means of argumentation in this discussion in their level of complexity correspond to the level of complexity of the discussed problems. A correspondence of the level of complexity of the methods and techniques used for modeling to the level of complexity of the modeling problems is an important requirement for the methods and techniques which is defined in the scope of system sciences [7].

Let us now return to the Information Continuum in the models. In the section introducing basic modeling concepts we defined principal concepts belonging to this continuum. These concepts were "Action" and "State", expressing respectively dynamic (behavioral) and static (structural) information about model constitution (e.g. objects) in space-time. As we explained when introducing the structure of our metamodel, in the models these two basic modeling concepts can be specified by means of specification concepts. We also explained that the set of specification concepts is an unlimited set. The unlimited amount of specification concepts that can be potentially applied to specify these two basic modeling concepts corresponds to the unlimited richness of information.

Thus taking our defined approach a modeler starting from an intention to create a *model* would be then confronted with the two complementary essences that are intrinsically assumed by the *model*, namely with *SpaceTime* and *Model Constitution*; and the two would necessarily produce the third emergent essence of *Information*, that can be *unlimitedly rich*.

We found an interesting philosophical supporting evidence that corresponds surprisingly well to the presented in the previous paragraph realization of our approach. The evidence was found in Taoist philosophy: in "Tao Te Ching" [6] an ancient book that is believed to have been written by Lao Tsu (604-531 BC) in the paragraph 42 we find:

> *The Tao begot one.*
> *One begot two.*
> *Two begot three.*
> *And three begot the ten thousand things.*

The analogy that our approach presents with regard to this quoted piece of "Tao Te Ching" is straightforward:

- "*The Tao begot one.*" – a *universe* allows for *modeling* (or a *modeler* intends to *model*), a choice between the passive or the active perspective doesn't influence the meaning;
- "*One begot two.*" – a *model* intrinsically assumes two essences: *space-time* and *model constitution*;
- "*Two begot three.*" – from *space-time* and *model constitution* necessarily emerges *information* about their mutual relation;
- "*And three begot the ten thousand things.*" – *information* about mutually related *space-time* and *model constitution* is *unlimitedly rich*.

At this point we would like to conclude the presentation of philosophical, logical (deductive) and natural science foundations of our metamodel.

6. Conclusions

We presented an approach to the definition of an object-oriented modeling paradigm made in the scope of general system modeling. The paradigm includes a formally defined metamodel and its supporting philosophical and natural science foundations. The metamodel exhibits the following important features:

- it is internally consistent (supported by Russell's theory of types [13]);
- it is coherent and unambiguous in the interpretations of subjects of modeling (supported by the defined kind of Tarski's declarative semantics [15] for the basic modeling concepts).
- it is applied on a concrete example of the RM-ODP conceptual framework that is formalized in a computer-interpretable form.

When presenting the philosophical and natural science foundations of our metamodel, we defined the domain of general system modeling where the metamodel can be used. These theoretical foundations provided justifications for the introduced conceptualization of the universe of discourse. The conceptualization was necessary for a definition of Tarski's declarative semantics for the basic modeling concepts. By justifying the conceptualization and by defining the semantics we showed that the set of basic modeling concepts is necessary and sufficient to represent the defined scope of the general system modeling interest.

Thus as a result of our research we defined an object-oriented paradigm that is based on the fundamentals of philosophy and natural science and that introduces formal definitions for the traditional object-oriented terminology. The fundamental foundations and formal presentation of our paradigm make a positive difference in favor of the paradigm being compared with the current state of the art in the object-oriented terminology. Traditionally, in the software development community, the object-oriented terminology semantics are considered to originate from modeling languages and rarely presented in a formal way. Thus our metamodel can have a constructive influence on the current programming practices by providing the software systems designers and developers with its logical rigor, its formal presentation and its solid theoretical foundations.

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