HOW TOP-LEVEL ONTOLOGY CAN HELP IN ANALYSES OF WORKFLOW MODELING LANGUAGES

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Abstract. A success of business process modeling depends on the level of formalization of the workflow modeling languages. However, the specification of the notations used for workflow modeling, does not include a formal semantics and syntax. This paper suggests defining semantics and syntax of workflow modeling languages using semiotic approach and mapping to concepts of top-level Bunge-Wand-Weber (BWW) ontology. Unfortunately, the BWW ontology has several shortcomings that limit its practical usage. We adapt the ontology in such a way that it becomes suitable for business processes modeling. We consider we are not allowed to introduce new concepts into BWW ontology, thus we give a new explanation to existing concepts in order to reflect necessary notions.

1. Introduction
A variety of languages and notations, namely: UML [1], BPMN [2], EPC [3], ebXML [4], BPEL [5], YAWL [6] are used in a workflow so the question emerges to carry out a comparative analysis to determine which is better suited for business process modeling [7]. These models are often transformed from one language to another; for example, EPC to BPMN and to BPEL, thus second query arises if these notations can equally represent a domain of a discourse? The semantics of these languages is determined in a text form and in some cases is ambiguous, thus formalization is required.

Y. Wand and R. Weber hypothesized: if a modeling language or notation is built on top of ontology [8], then the models created on this basis correctly reflect the surrounding world, and is easier to understand [9]. They applied an ontology presented by M. Bunge [10], [11] to a modeling of information systems and suggested a representation model defining a set of constructs that are thought by the Wand and Weber to be necessary and sufficient to describe the structure and behavior of the real world. Thus, they have defined a top-level ontology that underlies knowledge representation formalism in the field of IT development and business process modeling. The ontology is named after authors – Binge-Wand-Weber (BWW) [9]. Unfortunately, this ontology has some shortcomings that limit its practical implementation. Since this is a top-level ontology describing the most general categories, we cannot arbitrarily change the set of its concepts. Therefore, in this paper, we propose to reinterpret some concepts but staying in a context of original ontology by M. Bunge. Y. Wand and R. Weber supposed that a «good» modeling language could reflect all concepts of the top-level ontology [12]. However, we demonstrate that a big number of modeling languages are not capable to map all ontology’s concepts thus demonstrate a deficit of expressiveness. In this paper, we suggest a semiotic approach to analyses the workflow modeling languages. We limit observation to an artificial modeling notation, which sacrifices its beauty and imagery for the sake of accuracy and unambiguity.

2. Related works

We will regard the business process-modeling notation as an artificial language. Ch. Morris distinguished semantics defining a model meaning, syntax determining relations between signs, and pragmatics studying relations between signs and their users [13]. C. Peirce suggested differentiating between textual languages, whose alphabet consists of letters joined into words that convey the meaning, and iconic languages, where each sign denotes a separate notion and provokes the emergence of a sensory image [14]. D. Harel and B. Rumpe classed the visual business process modeling languages as iconic, whose alphabet consists of a finite number of graphic signs, each having its own semantic content [15]. They identified relations between the language components, showed that the semantics is defined by means of the semantic domain, which lists all the concepts of underlying domain, and the semantic mapping connecting the set of modeling language signs with the semantic domain (see Figure 1). Unfortunately, they did not identify the semantic domain scope and the properties of semantic mapping thus restricting the practical use of their approach.

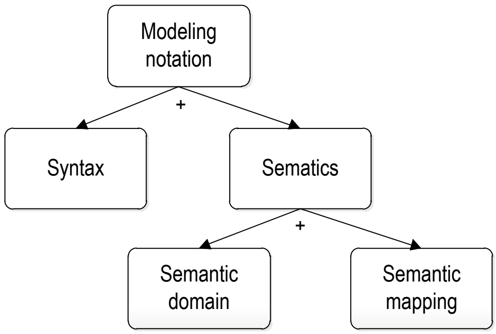

Figure 1. Modeling language semantics.

Y. Wand and R. Weber supposed that the expressiveness of a modeling language could be assessed as a semantic mapping property. They suggested that the ontological clarity of the modeling language could be evaluated by comparing the alphabet of this language with the constructs of the top-level ontology known as Bunge-Wand-Weber (BWW) [16]. They formalized the semantic domain for business process modeling language and studied semantic mapping.

A. Burton-Jones and R. Weber suggested two notions: ontological clarity and expressiveness. (See Figure 2) [17]. They suppose that modeling notation effectiveness and efficiency will be higher when a modeling grammar has higher levels of ontological expressiveness. The level of a grammar's ontological expressiveness will be higher when it has lower levels of ontological deficit and higher levels of ontological clarity. Its ontological clarity will be undermined when it has higher levels of construct redundancy, overload, and excess. They believe, whether a conceptual modeling grammar is deemed ontologically complete and/or clear depends on the particular "reference" ontology used to undertake the evaluation.

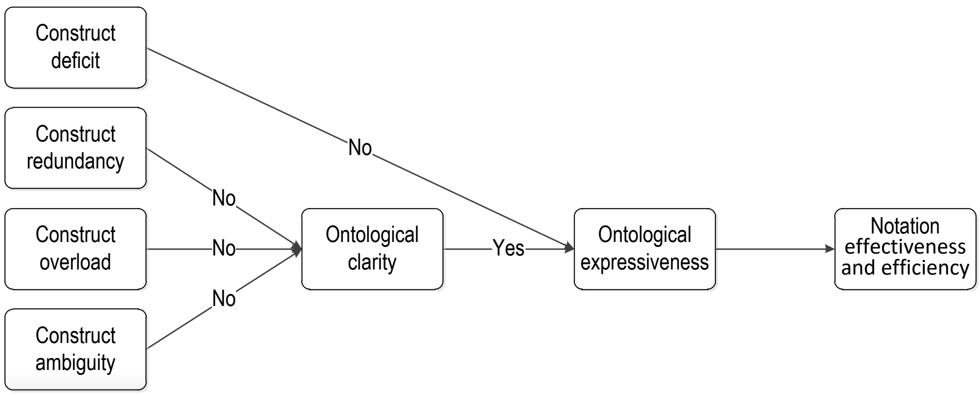

Figure 2. Modeling language semantics.

3. A semiotic approach to evaluating languages of a business process modeling

We base a semiotic approach on the G. Frege's triangle (see Figure 3) illustrating the principle of reality perception by the analyst. It connects the real world object, the respective language sign and the concept, abstracting the notion related to the sign. The universe of discourse that we are going to model is formed by objects aka denotatum, the aggregate of which is the subject area of modeling. A concept is a certain notion connected with the modeled real world object; it results from the conceptualization procedure. A total of all the concepts form the semantic domain. A sign is a logical name assigned to the respective concept. A set of all signs forms the language alphabet. A model is constructed from the alphabet. Thus, a modeling language sign denotes a real-world object if there is a concept associated with it, which in its turn abstracts this real-world object [18]. Frege's triangle sides can be interpreted as follows: the conceptualization mapping associates each denotatum with a certain concept, the semantic mapping relates the concept to the sign denoting it, the representation mapping relates a sign to a real-world's object, and it defines a consistency between the model and the original.

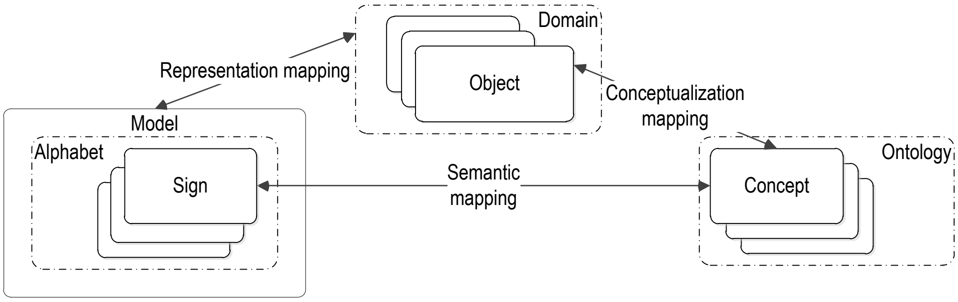

Figure 3. Frege's triangle.

Looking at this illustration, we can see that a quality of a modeling language can be evaluated by means of a semantic mapping analysis.

4. Semantic mapping

Y. Wand and R. Weber noted that a key success factor of using a given language is its ability to provide the users with a symbol set (modeling primitives), which can directly reflect appropriate ontology concepts (abstracts). They identify the following correspondence options between an alphabet of the modeling language and a set of ontology concepts (figure 4):

- construct equivalence: each symbol of an alphabet can be associated with exactly one concept;
- construct deficit: separate concepts have no corre-sponding symbol;
- construct excess: the ontology concept cannot be associated with any symbol;
- construct redundancy (synonymy): one concept can be represented directed in several symbols;
- uncertainty (homonymy): several concepts correspond to one symbol.

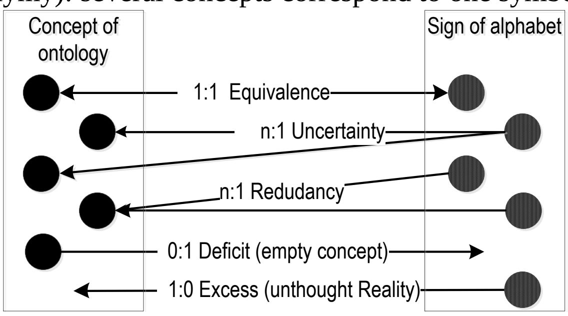

Figure 4. Semantic mapping.

The essence of the approach proposed by Y. Wand and R. Weber consist in checking an equivalence of two sets, i.e. symbols of an alphabet and ontology concepts. In the next section, we will present the ontology used for business process modeling languages analyses, demonstrate its shortcomings and suggest an extended version.

5. BWW ontological model

The model proposed by Y. Wand and R. Weber is the top-level ontology based on ideas developed by M. Bunge [10]. It contains the most general concepts that are not tied to any specific universe of discourse; on its basis lower-level ontologies relevant to a certain domain can be developed. Let us discuss this ontology.

M. Bunge calls a thing (aka concrete object) a substantial individual together with its properties. He supposes the world is made up of things. We will treat a thing as a «separate object of the tangible world with relative independence, objectivity, and stability of existence» [19], therefore, in what follows the term «object» will be used as a synonym of a thing. Any object has at least one property. A property is an attribute of an object; it cannot exist by themselves and must be attached to a thing. A property cannot have properties. The object state is defined as a set of all values of all its properties at a given time. Moreover, not all states are considered as acceptable and not all transitions between states are considered lawful [20]. The object state transits due to transformation, which is always implemented by a predetermined rule called the transformation law. Transformation can be interpreted as a work changing the object's properties, or an operation being performed on the object. An event is considered as a change of object's state. In this ontology only object change, and every change is an event that is characterized by a pair of initial and resulting states. A change of a state in the object under investigation is called an internal event, while a change happening in another object that belongs to the environment is considered an external event. Two objects are linked if one of them knows that the other has changed and can react accordingly. Summing up: a process is a history of an object changing its state as a result of a transformations initiated by an events. The strength of BWW ontology is in defining a few but really basic concepts; its weakness is in apparent simplicity, leaving a space for misinterpretation.

Here is an example of misconception [20]. State changes can happen either due to internal transformations in a thing (self-action of a thing) or due to interactions among different things. Initially, the object resides in the so-called stable state. Due to an action from an external event, the object leaves a stable state and traverses a sequence of unstable states until a new stable state is reached. A process is a sequence of unstable states leading to a stable state. We argue: there are no stable and unstable states as well as a self-actions. Being stable means be unchanging. However, there is no such property as being changing. We can make a proposition that an object change, but a proposition is not a property. In addition, a self- action is impossible because nothing acts upon itself. These misinterpretations had happened because the authors have departed from Bunge's original design

In our opinion BWW ontology has several shortcomings important for business process modeling:

- There is no concept for representing an actor participating in process execution. This seems strange and contradicts the established practice to start modeling with the identification of process participants.
- It remains unclear how to classify a logical operator that route the control flow but do not change a state of an object being processed. While a transformation always changes a state of an object.
- The ontology does not utilize the category of a time, although it is obvious that the temporal parameters of process execution are very important.

We adapt the ontology in such a way that it can be used to business processes modeling. We consider we are not allowed to introduce new concepts into BWW ontology, thus we give a new explanation to existing concepts in order to reflect necessary notions.

6. Enhanced BWW ontological model

Here and after we restrict our research to an information object only, and keep other types of objects out of a discussion. An informational object is a material one because it is stored on a physical medium and is recorded by means of physical principles. An informational object has attributes (aka properties), we associate them with state variables. Now we can say that a process is a trajectory of a phase point in a phase space. We also suppose an object to have a deterministic behaviour.

Transformation

According to M. Bunge, a transformation is the only cause of an object change. Wand and Weber consider a transformation by itself, with no connection to other concepts, so it remains unclear what is its origin. We explain a transformation keeping ideas of M. Bunge in mind. He distinguishes between a spontaneous change of an object, for example, due to radioactive decay, and induced one, resulting from the interaction between objects. We neglect a spontaneous change because information objects not subject to aging. Thus, a transformation is a result of an interaction between two or more objects. For the simplicity, but not losing a generality of reasoning, we consider one object acting upon another, and the latter does not react back. M. Bunge calls the former an agent and the latter a patient [11]. We will use a term an actor instead of an agent it can be a man or a machine doing a useful work that changes an information object. Thus, a transformation is a useful abstraction separating a unit of work from an actor performing it.

Y. Wand and R. Weber suppose that any transformation results in a change of an object's state. That is why remains unclear how classy logical operators (gateway) because they do not change a state of an information object. Let us pay attention to the fact that M. Bunge differentiates between the intrinsic object properties inherent thereto and distinguishing one entity instance from another one (for example, the color and shape characterize each object on an individual basis) and mutual properties, which characterize one object relative to another (for example, distance is a property of a pair of objects). Speaking about the transformation, Wand and Weber have in mind a change of intrinsic properties only. We will interpret the transformation in a more comprehensive sense, and consider a change of mutual properties. For example, an operation changes the intrinsic properties of the object, while the logical operator in a process diagram route the object along one of several processing paths, changing its relative position, whereas the intrinsic properties of the object remain unchanged. Therefore, by partitioning the transformations that change the intrinsic properties of the object and the transformations that modify the mutual properties, we complement the ontology with a capability to represent logical process operators [21].

Time

Y. Wand and R. Weber define an event as a fact of changing an object state, irrespective of the cause of the occurrence. Meanwhile, it remains unclear what is the difference between an event and a state. In the existing interpretation, the term «event» means a change of a state, it makes sense «for the reason of this» and reflects the cause-effect relationship – the next operation can start because of the completion of the previous one.

The interpretation of an event proposed by us is different from the interpretation suggested by M.Bunge. By the definition of E. Babkin, an event is something that is happening at some instant moment, step-wise and is considered as a state change of a certain object [22]. Yu. Pavlovsky interprets an event as an instant in time designating a change of the object states [23]. Therefore, we will link an event with a moment in time when a change of state of a certain object occurred; it has the meaning of «afterward» – later in the chronological order. Thus, an internal event establishes the fact and the moment in time when the object passed into the following state and is ready for execution of the next operation. The occurrence of an internal event is insufficient for the beginning of execution of the next operation. In case of an interactive operation the execution begins following the interference of an actor and the latter is treated as an external object relative to the system. If the operation is automatic, then it starts after a signal from an external control device. Therefore, the external event represents the fact and the moment in time of changing the state of the object outside of the system, which initiates the execution of the operation and records the moment when the transformation began. Thereby, the terms of temporal logic are added to the ontology: a moment in time and time interval between two consecutive events [21]. The time interval between the occurrence of an internal event indicating readiness for processing, and an external event indicating the real beginning of work will be interpreted as the waiting time, the time interval between the occurrence of an external event indicating the beginning of work and internal event indicating the end of processing will be interpreted as the execution time. An external event not only initiates the execution of the process operation but can also coordinate it. For example, a customer placed an order – this event initiates the process, and if the customer canceled the order, further processing may not be reasonable. The external event may imply the occurrence of an abnormal situation and require special processing.

Actor

The Bunge-Wanda-Weber ontology does not use the term "actor " (performer). We proposed to treat the actor as an external object belonging to an environment that generates external events initiating/completing the execution of transformations. The actor can suspend or terminate the execution, generate an external event that will cause the process operation to stop or to cancel execution.

It is important to note that the actor is an external entity in relation to the process model. Therefore, the process model should be mapped to the organizational and staff structure of the company. In this way, we can specify the performers for each of the operations included in the process model. To avoid the rigid binding of actors to posts or the organizational structure of a particular company, you should use the role model of access to the operations of the process [24].

Summing up

Figure 5 shows an object that changes its state after a current transformation. This state transition is considered an internal event, now the object is ready for the following transformation and is waiting for an external event. An external event reflects a change of a state in another object, belonging to the environment; it initiates transformation and a cycle repeat. We claim that for transformation the internal event is necessary but not sufficient, a next transformation starts only after an external event. A logical operator (a gateway) can start without an external event.

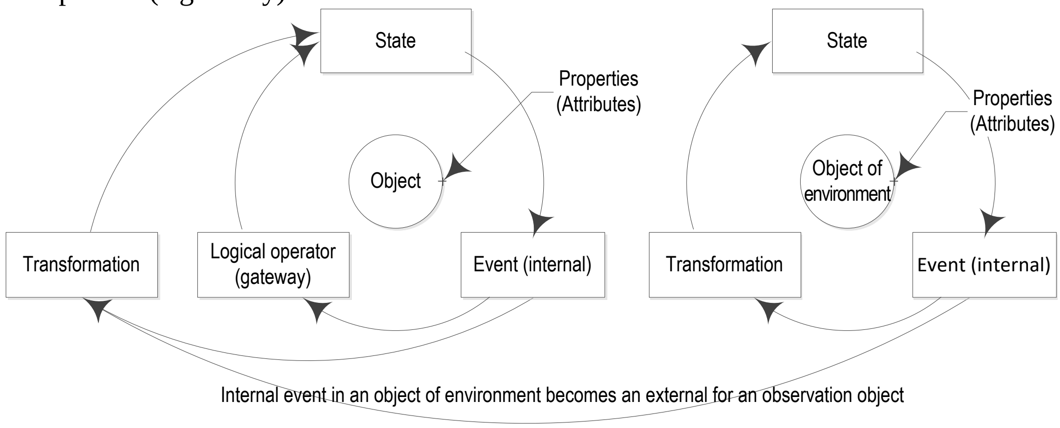

Figure 5. Linked objects.

The new concept of an event is treated in accordance with the representations of temporal logic. A time interval between an external event initiating a transformation and external event canceling a transformation is associated with duration of a transformation, while another time interval between an external event canceling a previous transformation and external event initiating the next transformation and is associated with a waiting time before it can start.

This approach allows us to explain, analyze and identify errors in business process models when an external event occurs earlier than an internal event associated with it. For example, in most cases the next possible error goes unnoticed: the external event occurs earlier than the object will go into the corresponding state and starts waiting for an event. Since the external event is not remembered, it will be lost. Therefore, an object achieving the desired state, will wait indefinitely for an event that has already happened in the past.

Thus, we enhanced the BWW ontology, added an actor – a man or a machine who perform a useful work; separated transformations: those changing intrinsic properties correspond to operations, others changing mutual properties correspond to logical operators; changed the interpretation of an event concept such that it designates a fact and a moment in time when the object state changes; we also demonstrated that the external events are related to each process operation. An important conclusion that can be made from the analysis of BWW enhanced ontology is in specifying a set of concepts:

- the object to be processed –has an internal structure describing a set of inherent object's properties;
- transformations changing intrinsic properties of the object that result in a change of its state, that are mapped to process operations;
- transformations changing relative properties and thus route the object are mapped to a gateways;
- internal events designate a moment in time when the object is ready for execution of the next operation;
- external events designate a moment in time when an external actor starts operation;
- a transformation can start only in case both preconditions fulfilled: a previous transformation is successfully finished and external event happen;
- time intervals between external and internal events characterize a duration of transformation and waiting time before it can start;
- any transformation must be mapped to an actor performing a useful work.

7. Evaluation of semantics by means of the BWW ontology

As an example, we consider the EPC notation. Methods ARIS 7.0 defines four main elements of notation: functions, events, connections and rules. A function is called a «subject-oriented task or an action performed on an object» [25]. Let's associate a function and a transformation. An event in the EPC is called «the fact that the information object has received the status associated with the business process». Events «switch functions» i.e. transfer control from one function to another [25]. That means we should associate an event and a state of the object being processed. This explanation is valid for intermediate and terminate events but is not legal for a start event. A start event represents a terminate state of the object that belongs to another process that was executed prior to the evaluated process. A connection «defines the logical links between the objects they connect». We can consider a connection both, as a trajectory of functions or as a history of object's states. There is no explicit definition of a tern «rule» but we can understand that a rule routes a process execution. Notation introduces two kinds of rules: function and event ones. A function rule selects next operation to be performed while an even rule can be considered as a condition on a state transition diagram that governs a permissible change of a state. We can see that EPC model is a combination of a state transition and data flow diagrams.

In a second example, we shortly consider a BPMN notation [26]. An official specification defines an activity as a work that is performed within a business process so we can associate it with a transformation. An activity can be atomic or compound a latter is called a process. Here we find inconsistency: according to BWW, a process is a trajectory of an object in its phase space while BPMN interprets a process as a sequence or flow of activities in an organization with the objective of carrying out work. A similar contradiction can be found in the definition of a sequence flow. To facilitate a discussion, BPMN specifications employ the concept of a token that traverses the sequence flows and passes through activities. A token is introduced as a theoretical concept that is used as an aid to defines the behaviour of a process that is being performed by describing how activities interact with a token. The only suitable BWW concept to represent a token would be an information object itself, but this consideration will require a total rethink of BNPM semantics. Last but not least, an event in BPMN is similar to an event in BWW, first it represents a transformation that listens for a notification coming from other object and after it arrives perform a useful work. Second, it represents a transformation that monitors an object and after it changes its state, it sends a notification to other objects.

This short example demonstrates only principles of using BWW ontology to evaluate semantics of a particular modeling notation and find contradictions or inconsistencies. BWW also helps to establish a mapping between several notations to simplify a port of a model. We found that semantics of signs having an equal name but belonging to different languages could be dissimilar which means we cannot directly map, for example, EPC event to BPMN events. It can be seen that both languages are capable to represent a different number of BWW concepts thus they have different expressive power. Let us investigate the expressiveness in detail.

8. The analysis of business processes modeling languages expressive power

A large body of research reveals that process modeling languages and notations are not capable of reflecting BWW ontological model concepts all at once, but only part of them. Moreover, the authors of investigations focus their attention on a percentage ratio of modeled and unmodeled concepts, calculate a relative degree of deficit, redundancy, excess and overload. Table 1 shows the results of similar research [27]. One is compelled to ask: to what extent a language having a 10% of the deficit is better than another language having a 15% expressiveness deficit.

Table 1. Analysis of notations expressiveness.

Notation	Relative level of			
	Deficit	Redundancy	Excess	Overload
BPMN 1.0	51%	35%	28%	25%
BPML 1.0	29%	65%	28%	3%
EPC	3%	62%	43%	28%
WSCI 1.0	29%	49%	18%	8%
ebXML 1.01	15%	13%	14%	5%
BPEL 1.1	32%	49%	13%	6%

Let us suggest that a requirement of equivalence of language symbols set and BWW ontology concepts is too strict, that the overload, redundancy and excess make the modeling language unsuitable for modeling. However, the expressiveness deficit of the language is acceptable, because it can be overcome. Table 2 shows a comparison of the EPC and BPMN expressive power in order to represent various perspectives of the process model. Both notations do not model the structure of information object; thus, they do not reflect the information perspective. The symbol ”event” in EPC notation reflects a state acquired by an object as a result of execution of the process operation. It makes it possible to show a sequence of state transitions and thus model objects behavior; however, no place for state mapping is foreseen in BPMN notation. Both notations represent names of the operations that transform the information object, but it is necessary to refine those using mini-specifications, to specify the properties to be changed in order to achieve a target state. The EPC diagram contains no means to indicate time intervals; therefore, it does not represent a temporal perspective, while this means are available in BPMN notation. Both diagrams enable us to reflect logical process statements.

Table 2. Comparative analyzes of BPMN vs. EPC.

Concept / **Notation**	Object	State	Activity	Time	Logic
EPC	-	+	+	-	+
BPMN	-	-	+	+	+

It can be seen that none of these modeling notations are able to represent all concepts at once, but only part of them – both have an expressiveness deficit. In other words, a model based on each notation rejects some important properties of an original, as a result, a model can become inadequate for the purposes of modeling. To overcome the deficit we proposed to model workflow in several agreed diagrams, so that each reveals separate perspectives of the model, and together they form an integrated description. For example, the EPC notation should be supplemented with an information model and a Gantt chart, and the model in BPMN notation should be supplemented with an information model and a state diagram. Diagrams depicting individual perspectives of the workflow should be well aligned. For example, the transformational perspective should describe the change only of those properties that characterize the corresponding target state of the object.

9. Conclusions

This research demonstrates that BWW ontology is a strong tool for analyses of a workflow modeling language. First, it serves to express modeling language semantics. By mapping a sign of a language on a concept of ontology, we are able to specify a precise and unified description that helps to avoid any kind of misunderstandings about its meaning. Second by evaluating the mapping of a set signs onto a set of ontology concepts, one can make a judgment on the overall quality of a modeling language.

The novelty of this research is manifested first in an adaptation of BWW ontology for process modeling languages analyses. Due to a specific of a task, we are not allowed to introduce any new concepts into top-level ontology, that is why we reinterpret some concepts, staying strictly in a context of original ontology by M. Bunge. The major achievement is in the introduction of notions of time, actor, and logical operator.

We found that the executor of the operations of the process (actor) is not included in the number of concepts of the process model. The actor generates external events that initiate/complete the execution of transformations. From this, it follows that the process model must be mapped to the organization's org chart. Thus, the process model proves to be invariant to changes in the organizational and staff structure. An important conclusion is made that the organizational model of the enterprise is not an immanent part of the process model. Both models are independent, and the executors on the process model must be mapped to the organizational model of the enterprise.

We propose to interpret the concept of transformation from the Bunge-Wanda-Weber ontology not only as a work that transforming an intrinsic property of an object but also its mutual property. Thus, the logical operators on the process model can be mapped into the concepts of the Bunge-Wanda-Weber ontology. We add a notion of time. For this, we give a different interpretation of an event. We will link an event with a moment in time when a change of state of a certain object occurred; it has the meaning of «afterward» – later in the chronological order. Thus, an internal event establishes the fact and the moment in time when the object passed into the following state and is ready for execution of the next operation. The external event represents the fact and the moment in time of changing the state of the object outside of the system, which initiates the execution of the operation and records the moment when the transformation began. The time interval between the occurrence of an internal event indicating readiness for processing, and an external event indicating the real beginning of work will be interpreted as the waiting time, the time interval between the occurrence of an external event indicating the beginning of work and internal event indicating the end of processing will be interpreted as the execution time.

Second, we propose a semiotic approach to evaluate business process modeling languages, thus proving a hypothetical assertion by Wand and Weber that a language can be evaluated by mapping on BWW ontology. In this paper, we apply this method to investigate language semantics, but it opens a new opportunity for evaluation of language grammar and pragmatics as well.

A practically important result is obtained, proving that none of the known business process modeling languages is capable to represent all BWW ontological concepts at once, but only part of them. Thus, all known modeling notations have an expressiveness deficit. This gives grounds to conclude that the process modeling should be carried out simultaneously in several notations, so that each particular model showed a limited set of properties of the simulated phenomenon, and all together, they gave a complete and comprehensive picture of the simulated reality.

The ideas and methods presented in this research can be also applied to improve axiomatic of the object-oriented programming. For example OOP terms: object, attribute, method, message are declared without precise explanation. Easy to see their direct correspondence to BWW concepts, which opens a way for rigorous specification of the semantics.

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