Semantic Technology in Business Process Modeling and Analysis. Part 1: Matching, Modeling Support, Correctness and Compliance

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Abstract: Conceptual modelling in Business Process Management (BPM) is one of the core research areas of Information Systems (IS). A variety of different strategies for modeling support and model analysis exists such as syntax-based auto-completion features, recommendation techniques, correctness and compliance checking, abstraction and matching, semantic and domain patterns, or AI-based planning approaches. These mechanisms increasingly gain attention in the BPM and conceptual modeling community. Due to the great variety of techniques and use cases of modeling support systems, research is scattered amongst different sub-communities of the large BPM and conceptual modeling communities and a common ground for discussion and research is not yet established. In order to bring together researchers working on different aspects of modeling support systems, a new working group *Semantic Technologies in Business Process Management* (SEMTECHBPM) has been established that is associated to the EMISA that in turn is a sub-group of the GERMAN INFORMATICS SOCIETY (GI).

The article at hand presents first results of the SEMTECHBPM working group in outlining different existing research streams engaged with semantic technologies in business process modeling and -analysis. Although we discussed all aspects in the working group and also invited non-members to contribute their knowledge prior to writing this article, we make no claim that the overview provided with this article is well-balanced or exhaustive. Rather, it should serve as a starting point to foster the collaboration between researchers engaged with semantic technologies in BPM and to promote their results. We are open to comments and welcome researchers who want to participate in the SEMTECHBPM working group.

In the first part of the article, we focus on model matching, modeling support as well as on correctness and compliance checking. The second part will cover the extraction and usage of domain patterns and (semantic) process model elicitation techniques. It will appear in a future issue of the EMISA FORUM.

1 Introduction

1.1 On the Definition of “Semantic Technology”

Semantic technologies have been developed and researched for over 25 years [NVCS11, p. 585]. Despite this long time, no single accepted definition has emerged. Common definitions of semantic technologies emphasize e.g. the goals or benefits of them. For example, BENJAMINS et al. state that “the value proposition of semantic technology is to enable applications and the Web to expose more intelligent behavior” [BRD+11, p. 623]. They further state that semantic technologies support this by “managing the meaning of data” [BRD+11, p. 638]. Similarly, DOMINGUE, FENSEL and HENDLER state that “Semantic Technology provide[s] machine-understandable (or better machine-processable) descriptions of data, programs, and infrastructure, enabling computers to reflect on these artifacts” [DFH11, p. 11]. Other definitions focus more on the problems that semantic technologies should help to solve. In this way, SURE and STUDER state that “a main goal is to enable interoperability, i.e. the ability to access, consistently and coherently, similar classes of digital objects and services, distributed across heterogeneous repositories” [SS05, p. 192].

Another common pattern of defining semantic technologies is to describe concrete standards, algorithms or IT artifacts associated with them. In this way, GRIMM et al. state that “the term Semantic Technologies or Semantic Web Technologies shall denote the whole range of Computer Science and Artificial Intelligence methods and tools typically used and typically playing together in applications that rely on a formal ontology (or several ontologies, respectively) and on explicit, ontology-based metadata for information items or information systems in order to enable better information search, integration, processing, or management, especially in distributed and open scenarios” [GAVS11, p. 538]. Additionally, NIXON et al. describe that it is expected by experts that in the future “core semantic technologies, such as semantic annotation, knowledge extraction, search, modeling, and reasoning, will interact with other emerging technologies to enable new applications and solve real-world problems” [NVCS11, p. 568].

Finally, a way of approaching a description of semantic technologies is also by enumerating application areas or presenting tool categories. In this regard, BENJAMINS et al. state that “at a high level, there are three main application areas for semantic technology: Information and Knowledge Management, Enterprise Application Integration, and Social Semantic Web” [BRD+11, p. 623]. The authors further report that todays most offered semantic tools fall in the categories of *search*, *modeling*, *data integration*, *information extraction* and *document tagging* [BRD+11, p. 635]. In more detail, VITVAR, PERISTERAS and TARABANIS list a set of concrete application areas such as “formal domain models expressed as content ontologies, formal service models expressed as service ontologies, semantic enhancements of business process models, semantic Service Oriented Architectures (SOAs) based on Semantic Web Services (SWS) frameworks, and ontology-based knowledge management” [VPT10, p. 2].

Due to the plethora of definitions and descriptions of what constitutes or what counts as a semantic technology, we opt for an an etymological approach to derive a working definition of the term. According to the OXFORD DICTIONARY, “semantics” may be defined as “the branch of linguistics and logic concerned with meaning” [Onla]. The other part of the compound term, “technology”, stems from the early 17th century Greek word “tekhnologia” meaning “systematic treatment” that in turn is derived from “tekhnē” meaning an art or craft in conjunction with “-logia” denoting a subject of study or interest such as in “psychology” [Onlb]. In the present, “technology” is defined as “the application of scientific knowledge for practical purposes, especially in industry” [Onlb]. We closely follow these definitions and the etymological considerations and define “semantic technology” as *the application of knowledge in conjunction with computer-supported procedures concerned with meaning for practical purposes*.

1.2 Semantics in Process Modeling and Analysis

The nature of semantics in business process modeling can best be understood by exploring the relationships between semantics, syntax and notation of modeling languages. Syntax “*relates the model to the modeling language by describing relations among language constructs without considering their meaning*” [LSS94]. A process model is constructed conforming to a syntax and using a notation. The notation defines a visualization for modeling language constructs. Semantics defines the meaning of the modeling language constructs and also describes the meaning of the modeling language syntax [KK02]. It may be specified in a formal way by e.g. using automata theory, Petri nets or set-based approaches. Since common business process modeling languages such as BPMN typically use labels that contain natural language descriptions of individual model elements, the resulting overall semantics is hence determined by both the modeling language dependent (formal) semantics and the semantics associated to individual model elements using descriptions in natural language [TF09]. In addition, since semantics also relates the model to the domain under investigation [LSS94], the domain of the model is relevant for its interpretation. In this regard, the semantics of a business process model can also be described in terms of statements that are used in the model and that correspond to statements about the domain [Moo98].

As an example for the above discussion of the trifold nature of process model semantics, consider a model element “Treatment completed” that is depicted in a process model using the notation construct of an end-event of the BPMN standard. First, this element is associated to the (formal) semantics of an end-event defined by the modeling language BPMN. This means that e.g. no outgoing sequence flow is possible and when the model is executed in a workflow engine, the execution either comes to an end or control is passed back to the super-process, if the model is embedded in a hierarchy. Second, this element has an additional, more specific meaning conveyed by the natural language label. The lexical semantics associated with the expression in the label is that a certain procedure has been (successfully) terminated. Third, since the model may be created to represent processes of a specific domain such as e.g. medicine, the interpretation is moreover dependent on domain knowledge. The completion of a treatment may carry a specific meaning in the medicine domain that is different from other domains such as e.g. chemistry.

On account of this combination of (formal) semantics, natural language-based semantics and domain dependent semantics, it is difficult to interpret process models automatically and to assist the user in common modeling and analysis tasks. Therefore, the application of semantic technologies geared explicitly towards the interpretation and processing of knowledge seems to be promising in order to provide new ways of process modeling and analysis.

In the remainder of this paper, we elicit different research directions concerning the integration of semantic technologies in business process modeling and analysis. In doing so, we do not confine ourselves to specific phases of the BPM life cycle such as analysis, modeling, enactment or execution. Further, we do not restrict ourselves to specific techniques of semantic processing such as natural language-related approaches or approaches related to formal semantics. Finally, we are open to any form of knowledge that is processed such as knowledge that is informal (e.g. natural language labels), formal (e.g. ontologies, taxonomies), domain-related (e.g. reference models for domains such as e-government), domain-independent (e.g. the PROCESS CLASSIFICATION FRAMEWORK), language-dependent (e.g. WORDNET as a lexical resource for English), language-independent (e.g. control flow patterns), prescriptive (e.g. process standards such as SCOR) or user-defined (e.g. custom vocabularies, recommendations of frequently executed modeling actions).

Owing to this wide focus, it should be clear that we do not aim at providing an exhaustive overview. Rather, our introduction should serve to establish a common ground amongst different sub-communities of the large BPM and conceptual modelling communities engaged with semantics in business process modeling. Although we strive to provide a balanced view on the subject, the contents of the paper are subjective and reflect the experiences and knowledge of the author team. All authors are member of the EMISA working group *"Semantic Technologies in Business Process Management"* (SEMTECHBPM). We welcome any feedback and participation in the working group in order to establish a lively discussion and research platform for semantic technologies in BPM.

2 State of the Art of Semantic Technology

2.1 Process Model Matching and Similarity

Process model matching is concerned with automatically identifying the correspondences between the activities of two process models. It represents the prerequisite for various advanced techniques such as automated modeling recommendation [KHO11], duplicate detection in process model repositories [UDGBLR11], and the merging of models [RDUD13]. The challenges in the context of process model matching include differing graph structures, the usage of heterogeneous terminology in the activity labels, and different levels of abstraction. To successfully deal with these challenges, semantic technology plays an important role. It, for instance, enables techniques to recognize that *invoice* and *bill* may refer to the same entity.

Approach	Authors
Probabilistic optimization of semantic process model matching	Leopold et al. [LNW+12]
Triple-S: A Matching Approach for Petri Nets on Syntactic, Semantic and Structural Level	Cayoglu et al. [COSU13]
RefMod-Mine/NSCM - N-Ary Semantic Cluster Matching	Thaler et al. [CDD+13]
RefMod-Mine/ESGM - Extended Semantic Greedy Matching	Hake et al. [CDD+13]
Predicting the quality of process model matching	Weidlich et al. [WSL+13]

Table 1: Overview of Process Model Matching Approaches Using Semantic Technology

In prior research, a variety of process model matching techniques has been introduced. They exploit different characteristics such as model structure, behavior, and natural language. However, only a few of them consider the usage of semantic technology. Table 1 gives an overview of existing approaches that build on semantic technology in order to compute the correspondences. An overview of current techniques can be also found in the report from the Process Model Matching Contest 2013 [CDD+13].

In general, it is interesting to note that all current matching techniques rely on the lexical database WORDNET. LEOPOLD et al. employ WORDNET for computing the Lin metric, which is then used for assessing the relatedness of activities [LNW+12]. The Triple-S approach by CAYOGLU et al. [COSU13] follows a similar strategy, but uses the Wu & Palmer metric instead of the Lin metric. The approach from THALER et al. and HAKE et al. use WORDNET to also take antonyms into account [CDD+13]. The approach from WEIDLICH et al. differs from the previously mentioned approaches as it uses WORDNET for assessing the likelihood of whether two process models can be successfully matched in the first place.

While WORDNET represents a manageable solution for integrating semantic technology into process model matching techniques, also its disadvantages need to be considered. WORDNET can only compute the similarity for words that are actually part of the WORDNET taxonomy. Hence, the similarity between specific yet related words often results in an erroneous value of zero. Here it might be worth to consider more sophisticated semantic techniques.

Process model similarity techniques are closely related to process model matching approaches. However, similarity techniques do not primarily aim at identifying the correspondences between process models, but rather aim at quantifying the similarity of two process models on a scale from 0 to 1. Consequently, the similarity techniques are less advanced when it comes to determining matches.

The number of process model similarity techniques is considerable (while Table 2 shows an overview of approaches mentioned in the following see [DDv+11] for further information). However, the potential of semantic technologies was only recognized quite recently. For instance, VAN DONGEN et al. consider synonyms in activity labels for determining a semantic similarity score [DDM08]. GACITUA-DECAR and PAHL use the structure of the WORDNET taxonomy to compute the similarity of words [GDP09]. As a result, they can also take hypernym and hyponym relations into account. GRIGORI et al. extend these approaches by adding further semantic label analyses through the usage of NGrams and a special abbreviation dictionary [GCBG10]. Another stream of approaches analyzes labels

Approach	Authors
Measuring Similarity between Process Models	Van Dongen, Dijkman, and Mendling [DDM08]
Automatic Business Process Pattern Matching for Enterprise Services Designs	Gacitua-Decar and Pahl [GDP09]
Ranking BPEL Processes for Service Discovery	Grigori et al. [GCBG10]
A Summary-Based Approach for Enhancing Process Model Matchmaking	Gater et al. [GGH+11]
Comparison and retrieval of process models using related cluster pairs	Niemann et al. [NSSS12]
Sprachbezogener Abgleich der Fachsemantik in heterogenen Geschftsprozessmodellen	Fengel and Reinking [FR12]
Measuring Similarity between Semantic Business Process Models	Ehrig, Koschmider, and Oberweis [EKO07]

Table 2: Overview of Process Model Similarity Techniques Using Semantic Technology

using information theoretic measures based on a lexical word corpus (e.g. [NSSS12]). Besides analyzing the labels of process models semantically, GATER et al. transform a model into a graph structure which they call *Semantic Process Graph* [GGH+11]. This graph is annotated with concepts from domain ontologies, which are used during the matching procedure. Hence, semantic technologies are not only used for label analysis but also applied to the control flow structure of a process model. EHRIG et al. [EKO07] as well as FENGEL and REINKING [FR12] transform a process model, too. But instead of using a newly developed format they use the standard ontology language OWL to represent models. Regarding the similarity analysis, the hierarchical ontology structure is utilized and approaches from ontology alignment are applied respectively.

This short review of process model similarity techniques demonstrated that mostly *traditional* text analysis techniques are applied. However, as for process model matching, these approaches face difficulties with determining similarity scores appropriately, especially for specific words. Hence, it could be worthwhile to develop specialized techniques. It might also be possible to adapt ontology alignment techniques and to include the structure of a process models into the semantic similarity analysis.

2.2 Modeling Support

To increase user productivity most of the currently available modeling tools focus on providing a repository of graphical symbols and advanced visualization techniques. However, there is room for improvement, when providing a modeling support function. Such modeling support spans from strict auto-completion of a business process model to suggesting closely matching recommendations. Process builders can request the modeling support on the modeling level or for the execution of the business process model. The support can be provided for labeling of process elements. It can be requested for the suggestion of a set of process elements suitable to complete an editing process model. Process builders can also request a complete process model and thus spare the design of a business process model from scratch. The chunks to be suggested might be extracted from a process model repository (in particular the "content" of process models is retrieved), based on user behavior or on the language syntax level. To suggest appropriate chunks to the user, her modeling intention has to be detected. This means that the statements that are used in the model and the domain to be modeled must be understand. Thus, semantics plays an important role for modeling support.

Related approaches that assist process builders in the labeling of process elements have been suggested by DELFMANN et al. [DHLS09], HAVEL et al. [HSDD14] and LEOPOLD et al. [LESM+13]. These approaches are able to detect naming conflicts already during the typing of a process element label using a domain specific vocabulary in the background. The assistance of labeling of process elements should be complemented with approaches that also consider metadata or objectives of the process model to be designed thus allowing for a more holistic modeling support.

The approach of CHAN, GAALOUL and TATA [CGT12] assists process modelers in the business process design through the suggestion of process activities matching the designed process. The suggestion of the complete business process model might be in some case too laborious for the process builder (she has to fully understand the process model before reusing it). The approach therefore suggests process activities through filtering process models available in a process repository.

Related approaches that suggest a set of prospective process activities (process model fragments) can also be found in literature [LCX+14, SWMW12, KHO11, CHSB13]. Process model fragments to be suggested are extracted from a repository (workspace). These approaches also consider the process model context (e.g., the purpose, view or complexity) in order to find appropriate process model fragments. Modeling support tools can also integrate the analysis of user behavior as proposed by DORN et al. [DBWD10] or social networks in order to recommend appropriate process model fragments that is investigated by KOSCHMIDER, SONG and REIJERS [KSR10].

Instead of creating a new process model from scratch, the process builder can request a new process model that is created from a process model repository using a linguistic analysis of the relationships between constructs of process descriptors which is proposed by LINCOLN, GOLANI and GAL [LGG10]. Further, a collaborative setting of business process modeling is supported based on the integration of multiple process reference models by WANG and WU [WW11]. Moreover, process modelers can also request suggestions for role assignment which is proposed by KOSCHMIDER, YINGBO and SCHUSTER [KYS12].

Modeling support can also be provided on the language syntax level. This is demonstrated by MAZANEK, MAIER and MINAS [MMM08]. In their approach, techniques of graph completion are used for the implementation of diagram completion. Such approaches should be used complementary to a content-based modeling support (suggesting process activities or process model fragments) since process builders use content-based recommendation to be inspired how to continue a process model being edited.

Another stream of modeling support is concerned with the execution level of business process models. For instance, MADHUSUDAN, ZHAO and MARSHALL use case-based reasoning (CBR) in order to leverage past process executions when specifying a new process model [MZM04]. Also, the interplay between processes of individual workers and

Approach	Literature
Assisting process builders in the labeling of process elements	Delfmann et al [DHLS09], Havel et al [HSDD14], Leopold et al [LESM+13]
Suggestion of activities through filtering process models	NguyenNgoc et al. [CGT12]
Suggestion of a set of prospective process activities	Li et al [LCX+14], Smirnov et al [SWMW12], Koschmider et al [KHO11, KSR10], Clever et al [CHSB13], Dorn et al [DBWD10]
Suggestion of a new process model using linguistic analysis	Lincoln et al [LGG10]
Modeling support in collaborative setting or role assignment	Wang & Wu [WW11], Koschmider et al [KYS12]
Modeling support on the language syntax level	Mazanek et al [MMM08]
Modeling support on the execution level	Madhusudan et al [MZM04], Barba et al [BWDJR13], Born et al [BHK+08, BBM+09], Smith & Bianchini [SB14]
Modeling support in related domains	Kuschke & Mäder [KM14], Sarnikar et al [SZ08], Chan et al [CGT11]

Table 3: Overview of Modeling Support Techniques using Semantic Technologies

organization-wide processes needs to be managed which is accomplished by the ontology-based system proposed by SCHERP, EISSING and STAAB [SES11]. A constraint-based approach for planning and scheduling of business process activities is suggested by IRENE et al. [BWDJR13]. This approach considers both the control-flow and the resource perspective. The semantic annotation of process model activities can also be used for an execution support of business process models [BHK+08, BBM+09, SB14]. These approaches use semantic annotations in order to find implementations for process activities.

Modeling support techniques have also been considered for different domains than business process management. Examples to mention are the auto-completion of UML modeling activities developed by KUSCHKE and MÄDER [KM14], the support for automation of knowledge flows across an organization developed by SARNIKAR and ZHAO [SZ08] or the recommendation of services that considers the process fragment surrounding developed by CHAN, GAALOUL and TATA [CGT11]. Table 3 summarizes related literature for business process modeling support techniques.

The effectiveness and efficiency of modeling support techniques highly depends on the number of process models in a repository. The repository must be populated with a sufficient number of process models (otherwise no appropriate suggestions can be given). Modeling support techniques usually base on techniques for similarity measurement. Lexical, syntactic and structural similarity measures are applied to make suggestions from existing model content. Techniques improving to understand the semantics of business process models are an integral part of an efficient modeling support.

2.3 Correctness and Compliance Checking

There is a long tradition in checking technical properties of business process models, such as the absence of deadlocks or the possibility to complete. In contrast, semantic compliance checking deals with the question whether the right process activities are executed in the right order and according to giving constraints on aspects such as timing, resource usage, data flow, security, or law in general. This means that process models or their execution logs are validated with respect to a set of rules, which can stem from laws, standards and regulations, from business contracts, or from process specifications [GMS06]. First papers on this topic were published at the end of the 90s (e.g [WWD+97, JMMS98]). In recent years, the process modeling community developed several approaches on checking process models against business process weaknesses and compliance with law and internal regulations. For sake of brevity, we do not name every approach here, but refer to recent literature surveys instead that are provided by AWAD [Awa10], BECKER et al. [BDES12] and FELLMANN and ZASADA [FZ14]. Corresponding approaches have in common that, based on a specification defining the structural and semantic properties of a weakness or compliance violation, process models are searched for occurrences of such a specification. If an occurrence is detected, this can show a flaw in the process, in the process model or in the specification. Formalisms for defining the specification are usually rooted in temporal logic or algorithmic graph theory, which restrains the comprehensibility of the specification for non-experts. Therefore, scholars developed specification formalisms based on patterns [SACO02, RFA12, TEvdHP12, DSDB15]. Declarative modeling approaches such as DECSERFLOW have been used as a graphical language for specifying constraints in a similar manner [MTA+08]. Related tools allow to create a model and to specify constraints by means of patterns or a graphical language. They either identify single problems by showing a counterexample in the model [LKRM+10, ASW09], or they highlight *every* occurrence of a potential problem in a process model [BDD+14]. In a similar way, process logs can be processed in order to locate compliance problems in executed model instances.

Special aspects of compliance (such as timing or security) have been considered in specialized tools. All approaches discussed so far consider the formal semantics of a diagram. For example, in order to verify whether for each execution of a process activity A is always followed by activity B, it is necessary to analyze the decisions in a model (where one of several alternatives can be chosen).

More sophisticated analysis is possible if the lexical semantics (i.e., the text of the labels of the modeling elements, in particular the activity labels) is taken into account. For example, both the activities *pay by cheque* and *pay by credit card* have in common that a certain state (*paid*) is reached. It is notable that hardly any existing compliance checking approach explicitly makes use of such lexical semantics processing. This is surprising, as semantic compliance checking nearly always has to take the labels of model elements into account. These can be ambiguous whenever standardization of lexical semantics is absent. Hence, compliance analysis results, regardless of which checking technique was used, can become useless. Most of the mentioned approaches apply simple string comparison or even do not make any statement to this end. Only few approaches address the problem of semantic ambiguity by utilizing predefined sets of possible labels (e.g. [MW06, Neo]).

Approach	Literature
Formal methods for compliance checking	see surveys in [Awa10, BDES12, FZ14]
Patterns for specifying compliance rules	Smith et al. [SACO02], Ramezani, Fahland, and van der Aalst [RFA12], Turetken et al. [TEvdHP12]
Weaknesses patterns	Becker et al. [BBR+10], Becker et al. [BBBR12], Bergener [Ber13]
Model query languages	see discussion of related work in [DSDB15]
Compliance for families of process models	Simidchieva and Osterweil [SO14]

Table 4: Range of Compliance Approaches

In this context, we see research potential concerning the processing of lexical semantics through compliance checking approaches in the near future. Here, approaches on lexical processing in conceptual models reusing concepts from computational linguistics could serve as a starting point (e.g., [BSPW08, SNEC07, DHL09]). Alternatively, approaches fixing the semantics of model elements through annotating ontologies could be reused (e.g., [Fel13]).

The key idea for including lexical semantics in compliance checking is to map the occurrence of events to states (e.g., [DLRvL09]). These facts (e.g., the state *paid* is a consequence of the execution of *pay by cheque*) need to be modeled as additional semantic annotations to process models. Formal ontologies have already been used for this purpose (e.g., [WHM10, FGR+09, GHSW08, FTB11]). Annotated models can be validated with respect to an ontology, which explains the meaning of the labels in the model. The fact that the ontology has to be modeled in addition to the diagram depicting the process obviously makes modeling more complex. Alternatively, natural language processing approaches can be exploited for reasoning about the meaning of element labels and for detecting modeling problems [HF12, GL11]. We see considerable research potential of involving lexical semantics processing into compliance checking while keeping the ease of use of the corresponding modeling method at the same time.

Table 4 summarizes the literature on compliance checking. Because of the large number of publications, we selected mainly sources that summarize the relating work.

3 Conclusion

In the first part of the paper, we focused on approaches making use of semantic technologies in the area of model similarity and matching, modeling support as well as on correctness and compliance checking. What we see in these areas is that a wide range of semantic technologies and techniques is in use. Although specialized approaches are developed inside the BPM research community, many approaches leverage technologies that originate from other research communities. Examples of these communities are natural language processing, recommender systems, software engineering and database technology. In order to avoid the situation that these communities and their advancements are disconnected to the BPM community, it would be beneficial to create a catalog of semantic technologies relevant for BPM. This catalog may contain knowledge regarding the application of the technologies in BPM settings and hence may serve to bridge the gap between the BPM community and other research communities engaged with semantic technologies.

In the second part of the paper, we will focus on the extraction and usage of domain patterns intended to support modeling and to foster the reuse of model content as well as on techniques to automatic model elicitation and documentation. The second part will appear in a future issue of the EMISA FORUM.

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