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Semantic Model Alignment for Business Process Integration

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ABSTRACT

Business process models describe an enterprise's way of conducting business and in this form the basis for shaping the organization and engineering the appropriate supporting or even enabling IT. Thereby, a major task in working with models is their analysis and comparison for the purpose of aligning them. As models can differ semantically not only concerning the modeling languages used, but even more so in the way in which the natural language for labeling the model elements has been applied, the correct identification of the intended meaning of a legacy model is a non-trivial task that thus far has only been solved by humans. In particular at the time of reorganizations, the set-up of B2B-collaborations or mergers and acquisitions the semantic analysis of models of different origin that need to be consolidated is a manual effort that is not only tedious and error-prone but also time consuming and costly and often even repetitive. For facilitating automation of this task by means of IT, in this thesis the new method of *Semantic Model Alignment* is presented. Its application enables to extract and formalize the semantics of models for relating them based on the modeling language used and determining similarities based on the natural language used in model element labels. The resulting alignment supports model-based semantic business process integration. The research conducted is based on a design-science oriented approach and the method developed has been created together with all its enabling artifacts. These results have been published as the research progressed and are presented here in this thesis based on a selection of peer reviewed publications comprehensively describing the various aspects.

DECLARATION

I certify that this thesis which I now submit for examination for the award of PhD, is entirely my own work and has not been taken from the work of others, save and to the extent that such work has been cited and acknowledged within the text of my work.

This thesis was prepared according to the regulations for postgraduate study by research of the Dublin Institute of Technology and has not been submitted in whole or in part for another award in any other third level institution.

The work reported on in this thesis conforms to the principles and requirements of the DIT's guidelines for ethics in research.

Signature ___________________________________ Date _______________

Janina Fengel

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LIST OF ABBREVIATIONS

API Application Programming Interface

B2B Business to Business

BPM Business Process Management

BPMN Business Process Model and Notation

EPC Event-driven Process Chain

ERP Enterprise Resource Planning

GUI Graphical User Interface

IT Information Technology

MCO Modeling Concepts Ontology

OWL Web Ontology Language

PN Petri Net

RDF Resource Description Framework

RDFS Resource Description Framework Schema

SKOS Simple Knowledge Organization System

UMCO Unifying Modeling Concepts Ontology

UML Unified Modeling Language

URI Uniform Resource Identifier

W3C World Wide Web Consortium

XML eXtensible Markup Language

XSLT eXtensible Stylesheet Language Transformation

Chapter 1 INTRODUCTION

Adopting *business process management* (BPM) provides an established holistic approach to managing organizational operations supported by information technology (IT) through structured methods and techniques (Brocke and Rosemann, 2010a, 2010b; Aalst, 2013). It facilitates a process oriented view of all business activities throughout an organization and across its boundaries that contribute to an added value for enabling business analyses and a corresponding alignment between business and IT for its realization. Hence, BPM is considered to be a key managerial approach to improving organizational performance (Gábor and Szabó, 2013).

1.1 Background

Business process management is concerned with realizing a business strategy by way of designing operational processes in a supporting manner through using all available resources in a reliable, repeatable and consistent way to achieve the business goals (Davenport and Short, 1990; Zairi, 1997). Thereby, a *business process* is a specific order of work activities across functional or even company boundaries with a defined start and end requiring inputs for obtaining outputs in order to create a value (Hammer and Champy, 2006, p. 35; Smirnov *et al.*, 2012, p. 64). In principle, business processes comprise all processes common to business management independently of the industry or type of business, e.g., industrial firms, service companies, public organizations or government agencies and institutions (Ko, 2009, p. 11; Vernadat, 2010, p. 139; Laguna and Marklund, 2013, pp. 16f).

With BPM the focus is at the conceptual level – on the “what is done” – considering organizational and operational aspects, even though for managing and controlling business processes the usage of information systems is of significant relevance (Aalst, 2013). Business processes are intended to provide input for the technical realization of their execution – the “how it is done” – which in turn may also be influenced by the possibilities that the employment of information technologies offers (Hammer, 2010, p. 8). Thereby, the benefit of standardizing business operations for quality assurance and optimization together with automating repetitive activities needs to be balanced against the need for allowing for flexibly reacting to unforeseen demands (Richter and Esswein, 2014). At the same time, clear functional confinement allows for specifying needs for the interfacing of processes (Mohapatra, 2013, p. 118).

Designing, managing and analyzing business processes requires their comprehensive and accurate description. For this, *business process models* provide a means for their representation and the use of models has become an accepted method for expressing the operation of an organizational system in a formalized manner (Morrison *et al.*, 2009, p. 30). Such models are considered to be key artifacts by which business processes can be explicitly described, documented, communicated, verified, simulated, analyzed, automated, evaluated, or improved (Smirnov *et al.*, 2012, p. 64). With the help of business process models, organizations can obtain a transparent overview of relevant business aspects as well as logical, organizational and technical dependencies and perform risk, compliance, security, and general business or performance analyses (Schmelzer and Sesselmann, 2013; Becker *et al.*, 2014, p. 187). The goals of the latter are in most cases the identification of potential efficiency, quality and performance improvements, e.g., in the context of globalization, mergers, business integration, enterprise resource planning (ERP) implementation or e-business integration (Hammer, 2010). Accordingly, *business process modeling* is considered fundamental to BPM (Aalst, 2013). It is one of the core elements of BPM and models are central to decision making (Rosemann and Brocke, 2010, p. 117; Becker *et al.*, 2010b, p. 187). Usually, business process model design requires personnel resources and is supported through the use of modeling software or business process management tools (Becker *et al.*, 2000, p. 31; Ko, 2009).

Generic descriptions of flows of business activities are possible with the help of *business process modeling languages*. In principle, these languages are artificial languages constructed for the purpose of describing existing or designing new processes (Hoyer *et al.*, 2008). Thereby, the behavior of an organization's related system elements for achieving a specific goal is depicted including possible concurrencies or alternative decision paths. The modeling constructs provided allow for the creation of models to describe interrelated business events, activities, and objects in a particular sequence (Schmelzer and Sesselmann, 2008). Upon modeling, the model elements are to be labeled in *natural language* for designating business objects and business activities. Thus, the element labels reflect the domain and business specific terminology and wording, the *business language*, for depicting the business statements.

As all business processes together conceptually describe an organization's way of working as a whole, they need to be coordinated and reconciled (Harmon, 2010,

p. 53). In order to organize an enterprise to enable it to achieve technical interoperability and most importantly business collaboration within and across its boundaries, it needs to be integrated from a business point of view focusing on its business processes as the overarching basis (Vernadat, 2002; Lam and Shankararaman, 2007, p. 2; Chen *et al.*, 2009). The basis for informed decision making regarding the shaping or reshaping of business operations in and between enterprises is the availability of a complete and correct description of all underlying business processes (Morrison *et al.*, 2009). This leads to the need for *business process alignment* and horizontal organizational thinking due to the complex nature of business processes, especially when crossing organizational or interorganizational boundaries (Hill *et al.*, 2006; Vernadat, 2010, p. 140). Thereby, *business process integration* encompasses the capability of coordinating business processes regardless of the modeling language they are expressed in (Castro *et al.*, 2014, p. 97). A holistic view of an enterprise's collection of business process models allows for an all-encompassing description for analyses and informed optimization decisions (Frank, 1994; Schmelzer and Sesselmann, 2013, pp. 7–10). In order to obtain transparency, interrelation and dependencies of the processes modeled need to be obvious (Dalal *et al.*, 2004; Weske, 2012, p. 373).

As a consequence, a major task in working with existing or *legacy business process models* is their analysis and comparison (Dumas *et al.*, 2009). Whilst over the past two decades business process management has been increasingly adopted, enterprises meanwhile can have acquired business process model collections of several hundreds of models (Zhiqiang *et al.*, 2012). These models have over time often been created by different people or in different teams, sometimes even according to different guidelines and rules. As a consequence, in particular in the case of organizational restructuring projects, reference model adoptions or company mergers huge numbers of legacy models from two parties are to be dealt with (Dijkman *et al.*, 2012). Thereby, even though the same business scenario may be modeled, the describing models can differ considerably regarding both the modeling and the business language (Damm, 2003, p. 147). Thus, models differ regarding their *semantics*, i.e., their intended meaning. However, semantic heterogeneity not only prevents human understanding and correct interpretation of models, but also any automated processing of the knowledge contained, process matching, alignment or integration (Becker *et al.*, 1996; Becker *et al.*, 2010b). Thus, next to handling model complexity, the problems in managing the language presently reduce the usefulness of models (Sarshar *et al.*, 2006). Hence, support by way of semantic model analysis is required for detecting possible conflicts and supporting the task of resolving semantic differences between business processes (Becker *et al.*, 2014).

1.2 Problem Definition

Even though business process models are the foundation of BPM, there is as yet no standard notation or architecture for their representation (Hammer, 2010). Over time, during the spreading adoption of BPM, a number of methods, techniques, languages, and standards for modeling conceptual business processes have been developed as well as supporting modeling tools (Aguilar-Savén, 2004; OMG, 2008, p. 13; Ko *et al.*, 2009; Aalst, 2013; La Rosa *et al.*, 2013). Presently, various different independent modeling techniques and general, universally applicable languages are common and actively in use (Thomas and Fellmann, 2009a; Recker *et al.*, 2009; Becker *et al.*, 2014, p. 188). They provide for specific language constructs for structuring activity sequences according to a certain set of rules but do not include explicit rules or guidelines for the application of the natural language to be used for labeling model elements. Thus, models can differ not only due to the use of different modeling languages, but even more so, they can differ significantly due to dissimilarly applied or inconsistently used natural language for labeling the models and their elements (Thomas and Fellmann, 2007). Furthermore, the model element labels are not backed with machine processable semantics and a shared understanding of the usage of terms or expressions is not trivially given (Fellmann *et al.*, 2010; Elias and Johannesson, 2013). Hence, the automation of matching element labels is being prevented (Fellmann *et al.*, 2010).

Thus, for enabling direct automated business interactions and integrations semantic model analysis for prior preparation is needed (Becker *et al.*, 2010b). Business processes need to be analyzed for identifying differences and commonalities such as overlaps or redundancies in order to achieve consolidation (Morrison *et al.*, 2009; La Rosa *et al.*, 2010b). The underlying business process models concerned need to be compared regarding their intended meaning, and as a first step the elements of the models to be compared need to be matched (Weidlich *et al.*, 2010). The reconciliation of the business language and disambiguation of naming conflicts is an absolute pre-requisite for any subsequent structure analysis (Simon and Mendling, 2007). Analyses of models' structure can only be performed after successful alignment of the domain language is accomplished (Becker and Laue, 2012b; Delfmann *et al.*, 2012, p. 127).

Accordingly, semantic alignment of business process models for finding similarities on the conceptual level needs to be performed before any meaningful model merging can be performed or business-IT alignment can be contemplated, as the development of information systems depends on prior alignment of the natural language present in models (Charaf and Rosenkranz, 2010).

So far, semantic analyses of this kind are mostly undertaken by domain experts, as comparing and matching conceptual models such as business process models for aligning them is still a purely intellectual task. In particular, in the case of naming conflicts or differences in phrasing in the element labels models cannot be matched directly, neither manually nor automatically (Thomas and Fellmann, 2007). Model comparisons require human labor for resolving language discrepancies, especially so if models are of different origin (Becker and Pfeiffer, 2007; Dijkman *et al.*, 2012). Hence, the task of comparing and aligning process models for deciding on possible consolidation, adaptation or merging is presently fulfilled by business analysts (Fan *et al.*, 2009; La Rosa *et al.*, 2013). This can lead to requiring substantial resources for resolving discrepancies, as such aligning of existing business process models is a non-trivial task (Thomas and Fellmann, 2009a). In consequence, semantic model analysis requires extensive intellectual efforts and time (La Rosa *et al.*, 2010b; Becker *et al.*, 2014, p. 189). Furthermore, often, this work is not only tedious, but also error-prone, as experts working manually may overlook details, especially with highly complex or visibly challenging graphical representations (Drumm *et al.*, 2008; Belhajjame and Brambilla, 2011; La Rosa *et al.*, 2013). To date, business process model analysis is mostly performed by humans, even though automation is deemed desirable, in particular upon having to match large numbers of models (Funk *et al.*, 2010; Becker *et al.*, 2013). For further advancing model matching, meaning-oriented analysis and comparison of the tacit domain knowledge contained in element labels needs to be enabled (Dijkman *et al.*, 2012).

1.3 Research Motivation

So far, the question of how to automatedly support semantically aligning heterogeneous legacy business process models on a horizontal level in a comprehensive manner has not been addressed exhaustively. Thus far, existing approaches in the literature either lack holism or practicability in that they focus on specific modeling areas or foresee manual involvement.

However, on the one hand, business process modeling offers a means for defining and describing the way business is organized and actually conducted in a semi-structured manner through encoding organizational and operational information. This knowledge can be used for supporting managerial and operational tasks by means of IT. On the other hand, the lack of computing support for working with legacy models when comparisons and alignments based on their meaning are required presently prohibits exploiting the business knowledge contained in them any further by means of IT.

Yet, with the advent of electronic data processing in general also the questions of how to structure information, manage semi-structured knowledge and determining and understanding the meaning of digital information by machines for integrating distributed knowledge needed to be addressed (Tochtermann and Maurer, 2006, p. 4). Semantics as the science of meaning of language has influenced the emergence of the fields of artificial intelligence and computer linguistics and led to methods and techniques for semantic processing, managing knowledge and achieving semantic interoperability (Blumauer and Pellegrini, 2006, p. 20). The fundamental function of semantic technologies is to provide access to knowledge for computers and enable machine processing based on their meaning (Dengel, 2012, p. 71). In this, they offer vast opportunities, as they advance computing onto a higher level by improving machine-understandability and computing capabilities of information (Frank, 2010b). Furthermore, they are often integrable into existing software ecosystems and improve life cycle economics through cost reductions, improved efficiencies, enhanced effectiveness, and new functionalities (Almeida *et al.*, 2013).

The desire for extending the usefulness of the structured information business process models supply by facilitating their semantic processing as well has driven the research presented here.

The motivation is to offer advancement to the present state of the art and existing practice of BPM by enabling the addition of the potential of semantic processing to the possibilities BPM is already offering and providing for meaningful support of human users. The intention is to assist business analysts who have to compare and align legacy business process models with regard to the business language contained in the model elements as a prior step to structural analysis. In this, subsequent decisions regarding potential redesign, adaptation or merging of models and holistic business analysis for organizational planning or business process integration could be prepared for. The research focus hereby lies on enabling horizontal alignments of legacy models irrespectively of the domain or industry, so that in business situations such as reorganizations or mergers a procedural instruction is available that can be of assistance for improving such business tasks, in particular alignments of semantically heterogeneous business process models. Thus the research aim is to develop a generic method to enable semantic business process model alignment based on the business meaning contained in the model elements in a systematic and automated manner independently of the modeling and natural languages used.

1.4 Research Question

In accordance with the research aim the main research question has been: "How does a method have to be designed for providing the application of semantic technologies for automatedly supporting the task of aligning legacy business process models based on the business meaning contained in their elements?".

This research question could be divided into four subquestions:

- (RQ1) "In what way can model semantics be captured, explicated and formalized for semantic processing?"
- (RQ2) "How can the extracted modeling languages semantics be exploited for alignment purposes?"
- (RQ3) "How can the extracted natural language in model element labels be matched and semantic similarity be measured between models?"
- (RQ4) "In what way can the thus determined semantic alignment be defined, formalized and preserved for further processing?"

For achieving this aim several research objectives were established:

- To examine current semantic technologies for applicability,
- To devise procedures for semantic extraction and matching,
- To develop formats for representing model semantics and alignments,

- To formulate the developments into a method.

The results could be evaluated and demonstrated through applying the results and subsequent publishing of the achievements.

1.5 Thesis Outline

This thesis is based on a selection of four prior publications, all of which are peer reviewed and the thesis author is either the first and main or the sole author. The publications included herein have been specifically chosen from the author's priorly published peer-reviewed publications. A complete list of all publications by the author can be found in the attached list of publications as of page 294. The rationale for selecting and sequencing the chosen publications was to provide a completive, coherent, and consistent presentation of the results developed for achieving the research aim.

In total this thesis contains nine chapters including the four chapters based on the relevant prior publications for presenting the resulting method called *Semantic Model Alignment* with individual focuses on its various aspects in answering the research questions.

Chapter 1 gives an introduction explaining the background and motivation for the research conducted together with the formulation of the research question.

Chapter 2 presents a review of the literature of the state of the art in the fields of business process model integration as well as semantic technologies for providing insights into the applicability of current approaches.

Chapter 3 describes the research methodology to report on the research conducted as a design-science based approach and reports on the individual steps for addressing the research questions and achieving the stated objectives.

Chapter 4 collectively introduces the result developed and provides a comprehensive overview of the proposed method named *Semantic Model Alignment* of which the details are presented in the subsequent four chapters.

Chapter 5 *Semantic Interoperability Enablement in E-Business* is based on a peer-reviewed book chapter which has been published in 2011 twice in two different reference collections intended for academicians, researchers, and practitioners. The chapter describes how model semantics be captured, explicated and formalized and the modeling languages semantics be exploited for matching the natural language in model element labels. The contribution hereby lies in the provision of answers to RQ1 and RQ2 of how to elicitate the model semantics and use the modeling languages semantics for alignment purposes.

Chapter 6 *Language-related Alignment of the Domain Semantics in Heterogeneous Business Process Models* is based on a peer-reviewed conference paper at “Modellierung” in 2012. This conference is organized by a special interest group of the German Informatics Society (Gesellschaft für Informatik e.V. (GI)). According to the ranking published by WKWI and GI the conference is ranked as B (WKWI & GI, 2008). The chapter presents the subsequent further research regarding the advancement of semantic matching that concentrates onto the challenge of matching the natural language in multi-term phrases as given in business process model elements. The chapter’s contribution lies in the provision of an answer to RQ3 of how to match natural language in model elements and determine semantic similarity between models.

Chapter 7 Business Semantics Alignment for Business Process Model Integration is based on a peer-reviewed book chapter published in 2013 in a reference source of a book series on e-business research intended for academicians, researchers, and practitioners. The chapter describes the combined application of the previous results developed to a real world business scenario. The chapter's contribution lies in the provision of an answer to RQ4 of how to join the developments together into a consistent method.

Chapter 8 Semantic Technologies for Aligning Heterogeneous Business Process Models is based on a peer-reviewed journal article that appeared in 2014 in the Business Process Management Journal. According to the ranking published by WKWI and GI this journal is ranked as B (WKWI & GI, 2008), in the German JourQUAL 2.1 ranked as C (Hennig-Thurau and Sattler, 2011) and in the British ABS ranked as Grade 1 (Harvey *et al.*, 2010), and has a SCJ rank of 0,841 (Scimago Lab, 2013). The chapter contains a holistic demonstration of the method developed showing the feasibility of applying semantic technologies for issues of business process integration as suggested and shows a proof of concept for alignments achieved. In this, therein the answer to the main research question of how to develop a suitable method is provided.

Chapter 9 contains a summary of the results achieved and discussion of the findings. The key contributions of the work are identified and the significance of the research results achieved is shown together with an outlook onto the potential for further research in the field.

Chapter 2 LITERATURE REVIEW

The management of business process models is an active field of research and different issues are of concern. Thereby, various aspects are relevant and reflect onto the research presented here. This chapter begins with addressing business process modeling and the integration of business process models. It then introduces semantic technologies and the different approaches of applying them to BPM for integration purposes. The literature review concludes with an analysis of the findings.

2.1 Business Process Modeling

A business process model reduces complexity through abstraction and captures the different ways in which a case, i.e., process instance, can be handled (Scheer, 2000; Aalst, 2013, p. 2). For constructing a business process model, a modeling language for structuring process flows and natural language for labeling model elements are required. Thereby, modeling languages are described by their metamodel, which can be understood as a model of a model describing its concepts and rules for creating models (Strahringer, 1998). The statement of conceptual models such as a business process models can be understood as a set of statements in a certain language and it can thus be analyzed regarding the semantics (Krogstie *et al.*, 2006, p. 92). The meaning of the statement a process model makes is contained in the blending of the semantics of the modeling and the natural language together (Leopold, 2013, p. VIII). Thereby, the information is communicated both visually by the graphical constructs of a modeling language and auditory by the textual element labels which in turn are crucial for the overall understanding of a process model (Leopold *et al.*, 2009).

2.1.1 Business Process Modeling Languages

Since the advent of BPM, a number of different notations for business process models have been suggested (Recker *et al.*, 2009). Modeling operational processes is mainly performed with general purpose modeling languages (Becker *et al.*, 2010b, p. 188). They allow for ordering activities in form of a control flow by describing causal dependencies and typically include descriptions of the activities, events, states, and control flow logic that constitute a business process (Aalst, 2013, p. 2). In addition, sometimes information about data, organizational, and IT resources can be included as well (Indulska *et al.*, 2009, p. 501).

The most prominent are Event-driven Process Chains (EPC), Activity Models of the Unified Modeling Language (UML) and Business Process Model and Notation (BPMN) (La Rosa *et al.*, 2013; Aalst, 2013). These languages are universal languages for generic process modeling independently of the domain (Becker *et al.*, 2014, p. 188). However, these conceptual languages are not suitable for automated process analysis, simulation or execution as given with Petri Nets (PN) or languages based on them as they are not directly executable due to their lower degree of expressivity (Recker *et al.*, 2009; Hoang *et al.*, 2010; Draheim, 2010, p. 49). Therefore, as a complement, mapping a semiformal business process modeling language to a formal language for checking process models for correctness with regard to their executability has been suggested, in detail the mapping of BPMN onto PN (Dijkman *et al.*, 2008).

Conceptual business process modeling languages are semiformal languages aiming for a compromise between mathematical precision and intuitive comprehensibility (Fellmann, 2013, p. 1) They provide for graph-oriented representations on a high level intended for human communication. The objective of using these languages is to avoid the ambiguity and high complexity of natural language. Thus, difficulties in retracing the way a certain situation has been depicted and thereby potential misinterpretations, contradictions or inconsistency should be prevented (Scheer, 2002, p. 1). Accordingly, the descriptions of these modeling languages include definitions regarding the syntax, i.e., notation of the language and its semantics, even though the semantics are not unambiguous (Harel and Rumpe, 2000, p. 2; Aalst, 2013, p. 24).

2.1.2 Natural Language Use for Model Element Labeling

For expressing the business statements the modeling languages provide modeling constructs that are to be labeled in natural language. These labels are key to human understanding of business process models (Leopold *et al.*, 2009; Mendling *et al.*, 2010b, p. 468). Nonetheless, the choice of words and phrasing of expressions are left to the modelers' discretion which is usually only influenced by linguistic conventions specific to the community the modeler belongs to and not governed by definitions within the scope of the modeling languages (Storey, 2005; Becker *et al.*, 2014, p. 190). Even though sometimes specific practical guides exist, they are informal or not definite enough, so that labeling is still predominantly done arbitrarily (Mendling *et al.*, 2010b, p. 468).

Hence, if the choice of words for model element labels representing the business semantics of a business process model has not been dominated by rules, terms have been chosen individually on a case-by-case-basis at the time of design. In consequence, identical facts could be named differently (Becker and Pfeiffer, 2008). Nevertheless, appropriate and consistent terminology is a major quality criterion regarding further model usage (Leopold *et al.*, 2009). Yet still, naming rules and even construction rules do not prevent the phrasing of multi-term expressions being carried out in different ways, so that the phrasing of element labels may vary even between team members (Delfmann *et al.*, 2009; Becker *et al.*, 2010a; Weissgerber, 2011, p. 15). Therefore, consistency in the grammatical style is considered to be another major quality criterion (Leopold *et al.*, 2009). However, a variety of styles for labeling activities can been found which strongly influences the user understandability, perceived ambiguity, and usefulness of models (Mendling *et al.*, 2010a; Mendling *et al.*, 2010b).

Thus, the richness and inherent complexity of natural language use is still to be addressed within the structured world of business process modeling. Even though human languages are systematic in that they are governed by rules with regards to phonology, graphics, morphology, syntax, lexicography and also their semantics, they are nevertheless essentially conventional, arbitrary and redundant in that information in a statement can be included more than once (Millward and Hayes, 2012). In general, language is volatile and inherently ambiguous (Charaf and Rosenkranz, 2010). But, above all, all natural languages are subject to change over time (Millward and Hayes, 2012, p. 6). As a consequence, a domain language has an informal, partially implicit semantics (Becker *et al.*, 2014, p. 190).

2.1.3 Model-based Business Process Integration

Recent global studies on key information technology and management issues show that BPM is of high importance, in particular the provision of holistic decision support and the integration of processes (Luftman *et al.*, 2012, 2013).

Interestingly, a study into the core issues of business process modeling shows that for supporting modeling activities model integration has been stated by practitioners as an unsolved issue, even though this seems not to be addressed by academics and software vendors (Indulska *et al.*, 2009). This finding, albeit in retrospective, is corroborated in a survey by the insight that process integration is an important concern to research in BPM and should have been included in the study (Aalst, 2013, p. 47).

In principle, upon working with business process models, the lack of a common conceptualization and consistent terminology can impede collaborative modeling, sharing, discovering, and reusing models and hinder automated transitions of models (Abramowicz *et al.*, 2010). Integrating business process models focuses on their integration on a horizontal level. This has been referred to as the creation of system models by successive enlargement, whereas in contrast vertical integration refers to the systematic, seamless process of refining conceptual models to running systems by providing for model execution through the coordination between business and IT (Schewe, 2013). The latter is often also referred to as Business/IT-Alignment (Teubner, 2006; Aier and Winter, 2009).

As business process models provide insights into the processes they document they can therefore in turn in retrospective be analyzed regarding this aspect (Aalst, 2013, p. 22). Information relevant to managerial issues such as integration can be obtained from business process models through semantic model analysis (Becker *et al.*, 2014). Such analysis concentrates on the intended meaning of models with the focus on the model semantics, whereby verification of model correctness or performance analysis of the execution of the individual model instantiations is not intended.

2.2 Semantic Technologies

Associating meaning with content facilitates machine processing of context-sensitive searches, analysis, and integration (Sheth *et al.*, 2002, p. 80). This can be accomplished by the application of techniques that support and exploit the semantics of information through structuring and encoding its meaning in order to describe and characterize the information for the purpose of enhancing its processing, the so called semantic technologies (Sheth and Ramakrishnan, 2003, p. 41). The goal is to enable sharing and reusing information in a reusable, scalable way without the need for any preordained knowledge about it for its integration (Gardner, 2005, p. 1004). Basically, semantic technologies are applicable to the two complementary demands of either supplementing information with describing attributes that carry the meaning or analyzing language for detecting meaning (Dengel, 2012, p. 13). They include various different technologies that allow for meaning-based classification, automated recognition and querying, e.g., natural language processing, artificial intelligence or semantic searches and semantic integration (Kalfoglou *et al.*, 2005a; Allemang and Hendler, 2008). Nowadays, various semantic technologies are realized based on the open standards of the World Wide Web Consortium (W3C) and are called Semantic Web technologies (Blumauer and Pellegrini, 2006, pp. 19–20; Feigenbaum, 2012). The Semantic Web extends the World Wide Web with intelligent applications for information exchange that can be understood by both humans and machines alike (Berners-Lee *et al.*, 2001). Thereby, the Web's capability is increased by the availability of machine-processable information (Davies *et al.*, 2009). The underlying principle of annotating information with metadata facilitates the representation of knowledge in structured, machine-processable form (Shadbolt *et al.*, 2006).

2.2.1 Semantic Modeling

Recently, the application of web-based ontologies has gained growing attention (Shadbolt *et al.*, 2006). Ontologies can be understood as semantic models that serve for capturing and formalizing meaning similar to a conceptual schema (Antoniou *et al.*, 2005). In principle, an ontology is a conceptualization of a domain of interest (Gruber, 1993; Daconta *et al.*, 2003). It formalizes a certain vocabulary and its meaning and describes the categories of things in the domain of interest and the terms used to name them (Sowa, 2002).

Basically, conceptual models such as folksonomies, glossaries, taxonomies, thesauri, database schemas, and data models can be regarded as ontologies with different degrees of formality and in this differing precision of their specification (Euzenat and Shvaiko, 2013, pp. 25–27). However, in contrast to those, ontologies describe semantics and are machine processable. They contain hierarchically organized terms and their relations expressed by logical statements, so that they can be used as conceptual frameworks for sharing and reusing the knowledge expressed (Devedžić *et al.*, 2009, p. 51).

For representing web-based ontologies ontology representation languages provide a structured way (Baader *et al.*, 2009). The common format building the foundation for these technologies is the Resource Description Framework (RDF) usable for representing information in the Web for data interchange (Schreiber and Raimond, 2014). It is a basic ontological schema language for depicting classes of objects and can be understood as a data model for describing graphs (Pan, 2009). The Resource Description Framework Schema (RDFS) extends RDF and allows to encode meaning through enabling the representation of the relationships behind the information expressed in RDF (Brickley and Guha, 2014). Also building on RDF, for organizing data and creating vocabularies, the Simple Knowledge Organization Systems (SKOS) allows for enriching data with meaning and thus describing controlled languages (Miles and Bechhofer, 2009).

The use of ontologies is a core element for knowledge engineering and semantic processing. Depending on the richness of their expressiveness and in this on their degree of semantic formalization, they are often distinguished in lightweight and heavyweight ontologies (Gómez-Pérez *et al.*, 2004, p. 8). Lightweight ontologies contain concepts, relationships between them, and properties that describe concepts. Heavyweight ontologies additionally contain axioms and constraints for further defining the concepts' intended meaning (Gómez-Pérez *et al.*, 2004, pp. 8–9). Heavyweight ontologies are more formal for the purpose of enabling logical reasoning and are therefore based on a logic formalism (Guarino *et al.*, 2009). For this, the Web Ontology Language (OWL) which is built on top of RDF and RDFS facilitates even greater machine interpretability than these by providing additional vocabulary along with a formal semantics (McGuinness and Harmelen, 2009; W3C, 2012). Its subset OWL DL is based on description logics and allows for representing the terminological knowledge defining the concepts and their properties in the so called terminological box, the TBox. To this, the assertional knowledge defining the individuals or instances of concepts, respectively, can be related as a set of facts in the so called assertional box, the ABox (Gómez-Pérez *et al.*, 2004, p. 17; Baader *et al.*, 2009). This view of separate levels correlates to the notion of business process models' instance and model levels.

2.2.2 Semantic Integration

As modeling is an activity gaining more and more importance for designing and managing business knowledge, semantic interoperability and integration becomes a key factor in working with models (Noy, 2004; Kalfoglou *et al.*, 2005c). In essence, drawing on several definitions that have appeared over the past years, semantic interoperability can be understood as denoting that differing information can be interconnected and exchanged in such a way that the precise meaning of the data is readily accessible without the need for manual analysis and mapping creation (Heflin and Hendler, 2000; Kalfoglou *et al.*, 2005c; European Commission, 2004). Finding, preserving and using mappings describing meaning-based relations provides for semantic integration based on the use of ontologies (Noy, 2004; Doan and Halevy, 2005; Schorlemmer and Kalfoglou, 2008).

For managing semantic heterogeneity among disparate ontologies, ontology matching provides an automated means for matching model entities and finding semantic correspondences between semantically related entities (Kalfoglou and Schorlemmer, 2005; Euzenat and Shvaiko, 2013). Upon matching, logical relations such as equivalence or similarity between the elements of ontologies are searched for. Thereby, both the terminology and the structure are of interest for determining similarity (Shvaiko and Euzenat, 2013). For finding such correspondences various matching techniques can be used for automating this process. Matching systems try to find pairs of entities from different ontologies with the same intended meaning (Euzenat *et al.*, 2008, p. 178). Basically, element-based and structure-based approaches can be distinguished. The former compare the individual elements from the input ontologies, while the latter additionally include information of those elements' neighborhoods, such as super- and sub-concepts, or attempt at structural matching of the graphs underlying the ontologies (Euzenat and Shvaiko, 2013, pp. 76–78). Semantic matching is a type of ontology matching technique that relies on semantic information encoded in lightweight ontologies to find mappings between the concepts of elements (Giunchiglia and Yatskevich, 2004).

Often, matching models is a crucial prerequisite for running heterogeneous information systems that need to communicate and requires database or XML schema integration, data warehouses or ontology integration through manual or semi-automatic analysis (Bellahsène *et al.*, 2011; Euzenat and Shvaiko, 2013). As matching large schemas or ontologies manually is time-consuming and error-prone, accordingly, automatic or semiautomatic approaches to find semantic correspondences are considered useful (Rahm, 2011; Shvaiko and Euzenat, 2013).

In general, the correspondences found through matching can be expressed as mappings and be used for various integration tasks, such as data translation or transformation, query answering, virtual integration, and merging (Noy, 2004; Shvaiko and Euzenat, 2013). Therefore, semantic mappings can been described as meaning preserving translations between two ontologies (Menzel, 2005). With this newly derived knowledge about semantic correspondence comparing and reconciling ontologies becomes possible and they can thus be aligned (Rahm, 2011). Thereby, an *alignment* can be understood as the set of *correspondences* expressed as *mappings* describing *semantic similarity* found through *matching* (Euzenat and Shvaiko, 2013, p. 39).

2.3 Use of Semantics for Model-based Business Process Integration

The suggestion of applying semantic technologies to business challenges in general has been made in the literature in different ways. As conceptual business process models are usually intended for documentation and business analysis purposes, and are not accessible for further machine processing, reasoning, querying or aligning, they do not allow for a high degree of automatic processing (Hoang *et al.*, 2010; Gábor and Szabó, 2013). Hence, applying semantic technologies is considered advantageous, especially in cases where intellectual work is too cost-intensive and continuous matching of existing knowledge needs to be performed for large amounts of heterogeneous information (Frank, 2010a). Here the application of semantic technologies is deemed useful, as they provide scalable methods for machine-readable representation of knowledge and posses the potential of integrating at the semantic level (Hoang *et al.*, 2010). Thereby, both vertical and horizontal integration issues can be addressed.

2.3.1 Integration of Modeling Languages

For providing alignments and even unification of models various approaches have been suggested based on meta-modeling as for example with the Model Driven Architecture (MDA) or in the fields of model management (Bernstein *et al.*, 2000; Melnik, 2004; Bézivin, 2005) and enterprise modeling (Lankhorst, 2009; Anaya *et al.*, 2010). Thereby, modeling languages are related based on their meaning as defined by their metamodel through the introduction of a meta-metamodel as a common model for several metamodels together for the purpose of enabling model transformations from one modeling language into another (Marschall, 2004; Brown, 2004). The goal is to dissolve semantic heterogeneity of the modeling languages and thus achieve model interoperability and enable model migrations, transformations, integrations, or even synchronization (Marschall, 2004; Jouault and Kurtev, 2006; Gehlert, 2007; Murzek and Kramler, 2007; Kensche *et al.*, 2007; Gašević *et al.*, 2007). As a means the use of an exchange format has been suggested (Grangel *et al.*, 2006).

For exploiting the capabilities of semantic technologies the use of ontologies for describing modeling languages in order to enable their further processing based on their meaning has been often suggested in the literature, e.g. in (Kappel *et al.*, 2005; Hepp *et al.*, 2005; Brockmans *et al.*, 2006; Thomas and Fellmann, 2009a; Elias *et al.*, 2010; Vernadat, 2010; Ayad *et al.*, 2012). Representing modeling languages' concepts in order to allow for semantic integration on a conceptual level has been suggested in the field of model-based software engineering for facilitating transparent exchange of models between modeling tools (Kappel *et al.*, 2006). Based on automated extraction of concepts and transformation into ontologies modeling languages can be semantically matched (Wimmer and Langer, 2013). Thus, semantic interoperability of business process models can be improved (Höfferer, 2007).

In the area of business/IT-alignment the use of process ontologies representing modeling languages can facilitate vertical model integration through semantic integration of models based on their modeling languages (Schewe, 2013). By the designation of semantic business process management (SBPM) the aim of optimizing business/IT-alignment through using semantic technologies for facilitating automated transformation of process models to executable applications is understood (Müller, 2011, p. 42; Gábor and Szabó, 2013). Using Semantic Web Service technologies as a complement to BPM has led to SBPM as a consolidated technology (Hepp *et al.*, 2005; Wetzstein, 2007; Becker *et al.*, 2010b). The resulting idea is an approach to manage the execution of IT-supported business operations from a business expert's view (Hepp *et al.*, 2005; Hoang *et al.*, 2010). Using the semantics enables the transformation of conceptual models into executable models (Belecheanu *et al.*, 2007; Wetzstein, 2007; Drumm *et al.*, 2008; Weber, 2009). Representing the knowledge of business process models in machine-readable form allows for relating them with Semantic Web Services which are discovered and composed for fulfilling the goals given by the business process models. In this, business process modeling languages' limited potential for automated execution due to their lack of formal representation is resolvable (Hoang *et al.*, 2010). Thereby, the focus lies on vertical integration and does not envisage horizontal integration at the business process level.

Modeling languages for a certain purpose such as business process modeling languages contain comparable concepts. Even though they differ in detail, they nevertheless resemble each other in intention (Söderström *et al.*, 2002; List and Korherr, 2006; Kensche *et al.*, 2007). Exploiting this fact enables to introduce an ontological meta-metamodel on top of a metamodel for the purpose of obtaining a common model for several metamodels with a corresponding notion. The development of a generic meta-metamodel in form of a common data model provides for mapping constructs of modeling languages with a similar purpose to a unifying construct of the meta-metamodel for defining such a relation between them (Shahzad *et al.*, 2009). Thereby, mappings can even express different degrees of correspondence between the constructs (Roque *et al.*, 2008; Anaya *et al.*, 2010). Through transforming process models into a unified representation syntactical differences can be resolved for integrating business process models on the conceptual level into a comprehensive model (Vanderhaeghen *et al.*, 2005). Such a model used as a canonical format can serve for common, normalized, and unambiguous representation (Mendling and Simon, 2006; La Rosa *et al.*, 2011).

2.3.2 Provision of Controlled Business Language

For supporting the labeling by model designers, sometimes glossaries or vocabularies are in place. The wish for unifying the labeling by modelers upon creating new models usually drives their development. With the emergence of information modeling, a need for using a normative language or controlled vocabulary for guiding the labeling of model elements has been stated (Ortner and Schienmann, 1996; Atkinson and Kühne, 2002; Saeki and Kaiya, 2006; Allemang, 2010, p. 8). Normative languages define terms and their meaning and are often seen as a mandatory preparation requirement (Rau, 2007, p. 34; Becker *et al.*, 2012a; Rosemann *et al.*, 2012; Becker *et al.*, 2012b).

Extending the ideas of controlled language provision and applying semantic technologies has led to postulating the use of domain ontologies as a means for capturing this knowledge. In the business domain, enterprise ontologies are applied for enterprise engineering and enterprise modeling, whereas domain or business ontologies try to capture the business specifics and provide their semantics (Rittgen, 2008). The objective of using enterprise or business ontologies within organizations or B2B-collaboration networks is to benefit from capturing and sharing the organizational knowledge for using and reusing it to solve business tasks, especially for supporting integration efforts within and across enterprise boundaries (Bruijn, 2004). Examples are the REA Ontology (Geerts and McCarthy, 1999) and TOVE or Enterprise Ontology (Uschold *et al.*, 1997; Fox and Gruninger, 1998; Dietz, 2006). Thereby, achieving the same understanding about information is intended, as the information exchanged in the course of business transactions needs to be unambiguous and carry the same meaning for both the sender and the recipient, regardless whether they are humans or computers, for facilitating uninterrupted business processing (Wigand, Picot, & Reichwald, 1997, pp. 60ff).

Nonetheless, analogous to controlled vocabularies, the development and maintenance of a domain or business ontology demands huge efforts with respect to time and cost and is an resource-intensive undertaking that companies are hesitant to start (Merdan *et al.*, 2010; Lucas *et al.*, 2012). Alternatively, automated creation of domain ontologies or ontologies representing the modeling language has been suggested (Hepp and Roman, 2007; Francescomarino *et al.*, 2008; Thomas and Fellmann, 2009a; Becker *et al.*, 2010a; Agt and Kutsche, 2013). Recently, automatic extraction of commonly used terms in business process model collections and building a knowledge base from them as the basis for generating suggestions for the creation of new models has been proposed (Delfmann *et al.*, 2009; Weissgerber, 2011).

In addition, the reuse of existing knowledge for creating new ontologies is deemed useful (Gómez-Pérez *et al.*, 2004). In the field of BPM the use of existing knowledge such as the MIT Process Handbook (Malone *et al.*, 1999), the SAP

Reference Model (Curran *et al.*, 1998), and the American Productivity & Quality Center (APQC) Process Classification Framework (APQC, 2014) has been suggested for designing processes (Fellmann, 2013). Alternatively, the utilization of e-business standards such as the Supply Chain Operations Reference-model (SCOR) (Supply-Chain Council, 2010) for naming activities or the United Nations Standard Products and Services Code (UNSPSC) (UNDP, 2009) or eclass (eclass, 2005) for naming products or services has been proposed (Hepp and Bruijn, 2007; Castro *et al.*, 2014, pp. 91–92). Similarly, existing business ontologies can be combined through defining mappings from them to a designated reference ontology (Andersson *et al.*, 2006). Furthermore, mining and extracting terms from unstructured data in text documents such as technical descriptions has been proposed for enhancing or extending business ontologies (Hesse *et al.*, 2014; Baer *et al.*, 2009).

2.3.3 Application of Ontologies for Model Design

To date, many approaches for applying semantic technologies to business process management, both intended for horizontal as well as vertical integration, concentrate on supporting the designing of new models (Koschmider, 2007; Ehrig *et al.*, 2007; Lin, 2008; Delfmann *et al.*, 2009; Becker *et al.*, 2010a; Ayad *et al.*, 2012). Thereby, in the suggestions given in the literature, the required ontologies are either created manually (Koschmider and Oberweis, 2007; Weske, 2012), by reusing existing ontologies (Cherfi *et al.*, 2013) or are automatically extracted (Becker *et al.*, 2010a) and need to be available in advance.

Upon creating a new model, an ontology representing the modeling language can be used at design time for checking for correct syntactical modeling according to the modeling language's specifications (Fellmann *et al.*, 2010; Francescomarino, 2011; Missikoff *et al.*, 2011). The purpose of utilizing a domain ontology for designing new models is to support modelers in applying correct labeling according to a preset terminology and solve word choice problems through providing suggestions or corrections (Filipowska *et al.*, 2009; Becker *et al.*, 2010a). This may encompass compliance checks and forced or auto correction (Francescomarino *et al.*, 2008; Leopold, 2013; Fellmann, 2013). A domain ontology may also further be used to support the determination and sequencing of all information associated with certain activities (Hua *et al.*, 2010). Thus, subsequent semantic support is provided for already at the time of modeling. The domain ontology is to be used as a guideline for creating model element labels in a uniform manner in order to prevent semantic differences (Weske, 2012). In this, in the future, incompatibilities when having to compare these models can be avoided (Becker *et al.*, 2013).

2.3.4 Ontologizing Legacy Business Process Models

Another suggestion for using ontologies is to semantically annotate existing business process models. Through annotation information is supplemented and in this enriched with describing attributes that carry the meaning, either at design time or sometime during its lifespan (Dengel, 2012). Annotated business process models are extended with metadata to share meaning (Jung, 2009; Furdík *et al.*, 2009; Bögl *et al.*, 2012; Castro *et al.*, 2014). Creating such semantic statements for expressing the meaning of resources and linking its describing terms to the concepts in an ontology can be seen as ontologizing the resources (Foxvog and Bussler, 2006; Pennacchiotti and Pantel, 2006). Semantic annotation offers the possibility of semantically enriching models gradually as needed without the need to change the model (Fill, 2011, p. 134).

Presently, the usages proposed in the literature for exploiting semantics for business process management seek to extend business process models with metadata for enabling their automated processing (Schönthaler *et al.*, 2012, p. 76; Smolnik *et al.*, 2012, p. viii). Semantic annotations have been suggested regarding the model structure or behavior with information about the modeling language (Francescomarino and Tonella, 2009; Fill, 2011) as well as regarding the meaning of entities thus focusing onto the element labels (Wang *et al.*, 2010; Fellmann, 2013; Elias and Johannesson, 2013; Vazquez *et al.*, 2013). The aim of semantically annotating business process model elements is to reduce the vagueness of the natural language in the element labels through relating the terms found therein to formalized ontology concepts (Funk *et al.*, 2010, p. 252).

In general, annotated models are usable for the purpose of analyzing or transforming them or resolving semantic heterogeneity between them (Vazquez *et al.*, 2013). Semantic annotations can furthermore provide the basis for facilitating their management in a repository (Ma *et al.*, 2007; Fauvet *et al.*, 2010; Elias and Johannesson, 2013; Aalst, 2013, pp. 45f). Thereby, annotating models provides for their discovery and reuse (Koschmider *et al.*, 2014; El Kharbili *et al.*, 2008).

The enrichment task of ontological or semantic lifting through annotating requires human intervention, so that models can be augmented into semantically richer constructs in accordance with the pre-defined semantic models (Hepp and Roman, 2007; Nicola *et al.*, 2008; Jung, 2009; Vazquez *et al.*, 2013). However, as manual annotation is inefficient, slow, and prone to errors and omissions, automatic annotation has been suggested (Born *et al.*, 2007; Francescomarino and Tonella, 2010; Belhajjame and Brambilla, 2011; Leopold, 2013) which can even be further enhanced by employing multiple ontologies containing background knowledge (Gómez-Berbís *et al.*, 2011). For annotating, the mentioned approaches assume that the applicable ontologies and annotation rules are readily available or need to be created separately.

2.4 Determining Semantic Similarity of Business Process Models

Automatic model comparison and detection of semantic similar business process models reduces the workload of having to analyze business process models manually at the time of having to manage and integrate them. The need for supporting conceptual modeling has only been addressed very recently by the idea of complementing the alignment between the business and the IT-perspective with aligning the business semantics of process models through annotating models at design time (Fellmann, 2013).

2.4.1 Searching Models

Managing large collections of business process models can be organized through using repositories for documenting and working with process models for their improvement (Dijkman *et al.*, 2009a). For managing large process model repositories effective search techniques are needed (Dijkman *et al.*, 2011). Querying process model collections enables the retrieval of similar models or model fragments (Dijkman *et al.*, 2009a). For querying text-based searches can be used for retrieving processes or fragments therefore containing the string of text queried for. Alternatively, searches can be formulated for finding specific key words (Kim and Suh, 2010). The approach of semantic business process management foresees key word matching based on predefined rules describing mappings to activities included in the SAP Reference Models (SUPER Integrated Project, 2013). Enhancement of such searches have been suggested for retrieval based on links model annotations may provide to the functional properties of concepts in a reference domain ontology (Missikoff *et al.*, 2011).

The literature shows various usage scenarios for searches based on the information provided by semantic annotations. Retrieval of models or model fragments is often used for supporting model design as described above. Alternatively, searching for similar process models elements is desired for the orchestration of web services as proposed by the notion of semantic business process management (Kim and Suh, 2010; SUPER Integrated Project, 2013). Consistency or compliance checks by querying for and comparing annotated business process models to normative rule specifications have been suggested (Governatori *et al.*, 2008; Ciuciu *et al.*, 2011). Reasoning over annotated models allows for their structural verification (Francescomarino *et al.*, 2008). In addition, reasoning allows for at least partly automating design adaptation support or unification of models through automatic adaptation or merging (Lin, 2008; Weber *et al.*, 2008; Hinge *et al.*, 2009; Missikoff *et al.*, 2010; Fellmann *et al.*, 2010). The intention hereby is to reduce the number of model variants (Breuker *et al.*, 2009) and resolve conflicts resulting thereof (Becker *et al.*, 2010b). Furthermore, retrieving processes provides for reusing modeled artifacts and redesign models as well as validating their compliance to given regulations (Markovic *et al.*, 2009; Weissgerber, 2011). Retrieving model fragments also enables automatic ontology creation based on the discovery of concepts from models that have priorly been manually annotated and related (Belhajjame and Brambilla, 2011).

2.4.2 Matching Models

In order to obtain more sophisticated results further means for assessing similarity between models or model fragments can be employed (Dijkman *et al.*, 2011). Measuring the similarity of business process models can be done through process model matching (Brockmans *et al.*, 2006; Ehrig *et al.*, 2007; Morrison *et al.*, 2009). Through such matching semantic similarity between the elements of pairs of models can be automatically established (Dijkman *et al.*, 2009a; Dijkman *et al.*, 2009c; Weidlich *et al.*, 2009). To date, the largest part of the approaches described in the literature take annotated process models as input (Dijkman, 2009). Abstracting from the models for matching them is suggested through using a canonical format (La Rosa *et al.*, 2011) or migration into an ontology (Jung, 2009). On the basis of a semantic description of models, semantic mappings can be produced (Arroyo *et al.*, 2007; Euzenat and Shvaiko, 2007). Such mappings express semantic similarity and describe how similar words or terms are (Agt and Kutsche, 2013), or in the case of business process models, phrases in model elements (Leopold, 2013).

In principle, the problem of process model matching for their alignment resembles that of data model or schema and ontology matching, even though there are structural differences between process models and ontologies. In particular, as ontologies provide for the formalization of semantic relationships between elements, those can be exploited for matching as well, even though on the other hand ontologies do not possess flow connector elements expressing logic relations with regard to the sequencing of elements (Dijkman *et al.*, 2009c).

Overall, business process models can differ in two areas, which are the structure through the sequence of their elements and the business statements contained in the model element labels. With regard to the business language, models can vary concerning their syntax, e.g. the labeled modeling language constructs expressing a fact or function, the degree of abstraction of models, the activities included, the availability of data or resource information and most importantly, in the phrasing of the labels of their elements (Weidlich *et al.*, 2009, p. 77; Becker *et al.*, 2010b, p. 193). Accordingly, the literature shows a variety of similarity measures. Such measures are functions that assign a real value between 0 and 1 to a pair of objects quantifying similarity, whereby 1 denotes maximum similarity and 0 maximum dissimilarity (Euzenat and Shvaiko, 2013, pp. 85–86). The computation can be done syntactically based on comparing character strings regarding their similarity (Euzenat and Shvaiko, 2013, pp. 87–96), semantically based on language aspects (Euzenat and Shvaiko, 2013, pp. 97–106) or based on the internal model structure (Euzenat and Shvaiko, 2013, p. 106). Depending on the focus in matching, they are of differing suitability (Dijkman *et al.*, 2011; Becker and Laue, 2012b). For comparing the labels of process model elements, either syntactic or semantic similarity measures, or a combination of both can be used (Dijkman *et al.*, 2009c; Becker and Laue, 2012b; Cayoglu *et al.*, 2014).

Recently, the need for automatically matching the activity labels of existing models has been identified in the literature and has been addressed (La Rosa *et al.*, 2010b; Leopold *et al.*, 2011; Smirnov *et al.*, 2011). However, even though the importance of events in business conduction has been stated (Luckham, 2008; Kong *et al.*, 2009), the matching of labels of other types of model elements, such as events or resources, is barely realized, only pointed out as being of importance (Francescomarino, 2011, pp. 108–111), even though they carry business knowledge as well.

2.4.3 Establishing Mappings

As a result of semantic matching directed relationships are determined between pairs of entities from two models. These semantic mappings produced through matching can be preserved so they may serve for semantic model integration on the conceptual level for overcoming differences between models (Kalfoglou and Schorlemmer, 2005). Representing mappings can be done in a knowledge representation language for enabling their sharing and reuse (Euzenat and Shvaiko, 2013, p. 322).

In principle, such mappings are usable for different purposes. In the context of managing process repositories this includes searches for related or similar models for the purpose of reuse, as well as assisting the design of new models and preventing duplication, model transformations or model mergers, as well as the measuring of conformance between models and reference models, normative guidelines or system specifications and identifying common or similar models in the context of organizational or company mergers (Dijkman, 2009; Weidlich *et al.*, 2009; Becker and Laue, 2012a). In this, semantic mappings obtained through matching serve for aligning models. The complete set of mappings found between pairs of models through matching can be collected in an alignment usable for establishing networks between ontologies (Euzenat and Shvaiko, 2013, pp. 39–40).

2.5 Discussion

Recently, as presented above, several works have presented approaches using semantics in business process modeling and utilizing ontologies as the core element for capturing and subsequently processing the knowledge contained in models for aligning them. In the following a summary is provided comparing the various contributions in the literature, followed by an identification of unanswered, open issues.

2.5.1 Summary of Findings

The literature shows a variety of suggestions for applying semantic technologies to BPM involving semantic comparisons and alignments of business process models and their elements either for aligning model elements to a given reference domain ontology or aligning pairs of models. These approaches have been developed in different research groups addressing various issues. Accordingly, they can be distinguished by their application focus. Table 2-1 provides a synoptic comparison considering different criteria:

- Purpose, stating the application focus,
- Issue, naming the problem to be solved through the application of semantic technologies,
- Ontologization, describing the procedure of providing semantic information,
- Semantic business process model (Semantic BP Model), providing details on the resulting semantic description that represents the ontologized

business process model, in particular if the business statement of a business process model is included as an ontology concept or as an ontology instance,

- Business modeling language ontology (BPML Ontology), listing the type of models represented by an ontology for representing the modeling language,
- Relating, stating if a generic metamodel for abstraction from the business process modeling language and the purpose of unification is given,
- Domain ontology, stating if a domain ontology is foreseen to be developed manually or in an automated manner in case it is required for reference,
- Element matching, detailing the extend of the semantic matching of business process model element labels,
- Mapping usage, describing the intended usage of mappings discovered.

Exemplary references	**Pur-pose**	**Issue**	**Ontologi-zation**	**Semantic BP Model**	**BPML Ontology**	**Relating**	**Domain Ontology**	**Element label matching**	**Mapping usage**
(Koschmider, 2007), (Koschmider *et al.*, 2011), (Ehrig *et al.*, 2007), (Brockmans *et al.*, 2006)	Design	Unified labeling	Transfor-mation	Business statements as OWL-instances	PN, extend-able to EPC	Equiva-lence definition	Manual creation	General English, string matching, stemming, stop word elimination, synonym resolution, structural neighborhood	Discovery at run time, suggestions for model element creation
(Lin, 2008), (Lin and Krogstie, 2010)	Design	Adaptation or merging	Manual annotation	Business statements as OWL-instances	UML AD, EEML, BPMN	Generic meta model	Assumed to be available, SCOR	Text-based search, English	Discovery at run time, suggestions for model adaptation
(Becker *et al.*, 2010a), (Becker *et al.*, 2010b), (Delfmann *et al.*, 2012), (Breuker *et al.*, 2009)	Design	Standardized labeling, variant reduction	Manual modeling	Own format (PICTURE)	Generic	Not intended	Pre-defined part of modeling language	General English, string matching, synonym resolution	Discovery at run time, suggestions for model element creation
(Ayad *et al.*, 2012), (Cherfi *et al.*, 2013)	Design and analysis	Verification	Not intended	Not intended	BPMN	Reference meta-model	Assumed to be available	General English, string matching, synonym and hyperonym resolution	Discovery at run time, suggestions for model adaptation
(Thomas and Fellmann, 2009a), (Fellmann *et al.*, 2010), (Fellmann, 2013)	Design and analysis	Verification	Manual annotation	Constructs, statements as OWL-instances	EPC	Not intended	Manual creation	Text-based search	Discovery at run time, terminological standardization, validation
(Francescomarino and Tonella, 2010), (Francescomarino, 2011)	Analysis	Verification, automatic adaptation	Semi-auto-matic annotation	Not intended	BPMN	Not intended	Manual creation and extension	General English, parsing, synonym resolution, corpus-based text similarity	Discovery at run-time, annotation suggestions
(Nicola *et al.*, 2007), (Missikoff *et al.*, 2011),	Analysis	Verification	Manual remodeling	Business statements as OWL-instances	BPMN	Generic meta model	Manual creation and reuse	Text-based search, graph matching	Discovery at run time
(Leopold *et al.*, 2012b), (Leopold, 2013)	Analysis	Unified labeling	Automatic annotation	Abstraction	BPMN, EPC	Canonical graph	WordNet	General English, parsing of activity phrases, term analysis	Discovery at run time, rephrasing
(Wang *et al.*, 2010), (Hoang *et al.*, 2013)	Analysis	Unified labeling	Manual annotation	Business statements as WSMO-instances	BPMN	SUPER ontologies	SCOR	General English, string matching, synonymy resolution, graph based structure	Discovery at run-time, annotation suggestions
(Belhajjame and Brambilla, 2011)	Compa-rison	Domain ontology creation	Manual annotation	Business statements as instances	BPMN	Generic meta model	Extracted	String matching, neighborhood	Discovery at run-time

Exemplary references	Pur-pose	Issue	Ontologi-zation	Semantic BP Model	BPML Ontology	Relating	Domain Ontology	Element label matching	Mapping usage
(Jung, 2009)	Compa-rison	Trans-formation	Manual annotation	Business statements as instances	BPMN	Ontolo-gies	Not foreseen	Manual, term extraction, string matching, structural matching	Discovery at run time, searches
(Elias *et al.*, 2010), (Elias and Johannesson, 2012)	Compa-rison	Management	Manual annotation	Business statements as instances	BPMN	Generic meta model	Not foreseen	Text-based search, mapped structural properties, English	Discovery at run time, searches
(Weidlich *et al.*, 2010), (Dijkman *et al.*, 2011), (La Rosa *et al.*, 2013)	Compa-rison	Similarity search	Extraction	Business statements as instances	BPMN, eEPC	Generic canonical graph	Not foreseen	Activity pairs: general English, string matching, stop word elimination, stemming, attributes (type, neighborhood), graph-based	Discovery at run time, automatic merging
(Cayoglu *et al.*, 2014)	Compa-rison	Similarity search	Not reported	Not intended	PN	Not intended	Not foreseen	Activity pairs: general English, string matching, stop word elimination, synonymy resolution, stemming, graph-based	Discovery at run time
(Kim and Suh, 2010)	Compa-rison	Similarity search	Manual annotation	Business statements as OWL-instances	EPC	Not intended	Manual creation	Text-based search	Discovery at run time
(Hepp *et al.*, 2005), (Hepp and Roman, 2007), (Markovic, 2010)	Compa-rison	Execution	Manual annotation	Business statements as WSMO instances	BPMN, EPC	Not intended	SAP Reference Model	Text-based search, key word matching	Discovery at run time
(Wang *et al.*, 2010), (Hoang *et al.*, 2013)	Compa-rison	Execution	Manual annotation	Business statements as WSMO-instances	BPMN	Not intended	SCOR	General English, string matching, synonymy resolution, graph based structure	Discovery at run-time, annotation suggestions
(Born *et al.*, 2007)	Compa-rison	Execution	Automatic annotation	Business statements as WSMO instances	BPMN	Not intended	Assumed to be available	String matching	Discovery at run time
(Weissgerber, 2011)	Compa-rison	Execution	Automatic annotation	Business statements as WSMO-instances	BPMN, EPC	ARIS	Assumed to be available	English, German localization	Discovery at run time, label auto correction

Table 2-1 Synoptic Comparison of Semantic Approaches to BPM

In general, all these approaches have in common that the business process modeling languages the business process models are described in are represented as semantic models that are to be developed in advance. In the cases where different modeling languages need to be related, a meta-metamodel for integration purposes is used, either for relating all constructs of modeling languages or for abstracting through normalization. For matching models, in the majority of the approaches it is foreseen to manually add semantic metadata as an enrichment for processing enablement. Furthermore, most of the proposals require a domain ontology as a reference point for matching model elements. Mostly, matches are searched for at run-time. The results are mainly used for improving models with regard to their labeling at the time of their creation or later in their lifetime at the time of optimization. In the area of managing a process repository matchings detected are used for variants reduction or automatic merging. For matching model elements with regard to their labels, the techniques applied range from basic methods such as text-based searches to more sophisticated like string matching and semantic analysis.

2.5.2 Research Gap Analysis

The review shows that the present suggestions in the literature can be drawn upon as a basic guideline for developing an answer to the research question this thesis examines.

Business process models supply graphical and textual information about the process they depict. Modeling languages provide for descriptions of their semantics, either as formal or as semiformal specifications as in the case of the most commonly used, universally applicable business process modeling languages. Analyzing business process models independently of their modeling language can be based on a uniform reference model for enabling comparability (Funk *et al.*, 2010). The works focusing on metamodel integration and Semantic BPM show the feasibility of relating modeling languages concepts based on their meaning for working with models expressed in different languages in an integrated manner for vertical integration. Integrating modeling languages on a horizontal level could be enabled in a comparable manner through applying semantic modeling. Especially, as even in the case of one modeling language becoming the standard, nevertheless legacy models can still be integrated even if they are described in different modeling languages. Furthermore, such a semantic model would allow for extending onto other kinds of models as well.

However, in the works focusing on vertical model migration or model execution, often the natural language contained in model element labels is not processed further but transferred as-is. As a result, the shortcoming of ignoring the natural language in the labels leaves the challenge of a comprehensive semantics-based alignment of models unanswered, as only part of the answer is provided and semantic heterogeneity of the domain language is disregarded. Also in practice, many present-day modeling tools provide functionalities for model migrations, but so far support for semantic processing of the business content is not given (Fellmann, 2013, p. 2).

Using ontologies for process integration in enterprises has been deemed useful (Grüninger *et al.*, 2000; Uschold and Grüninger, 2004). Ontological engineering works as a theory of content and in this provides a basis for analyzing the underlying background of real-world problems (Mizoguchi, 2014). Although at the time of developing ontologies, the same problems arise as when developing business process models regarding the choice of the modeling language and the labeling of the elements, ontologies can be further exploited, e.g., for automated matching or logical reasoning, since their semantics are formalized and thereby machine processable. Their strength lies in being a means of representing business knowledge, in particular to enable sharing it across domains and to facilitate logical reasoning over it.

Nevertheless, developing and engineering ontologies demands a lot of effort, discipline, and rigor (Devedžić *et al.*, 2009, p. 60). The definition of a jointly shared terminology is considered challenging and is one of the most important problems in information modeling (Sarshar *et al.*, 2006; Nkambou, 2010). For building ontologies, ontology engineering in particular needs to focus on knowledge acquisition as an important development step (Sure, 2003; Gómez-Pérez *et al.*, 2004). Acquiring knowledge is based on intensively working with domain experts, regardless of whether ontologies are built from scratch, by reusing existing ontologies as they are, or by reengineering ontological and non-ontological resources (García-Silva *et al.*, 2008; Devedžić *et al.*, 2009, p. 68; Gómez-Pérez and Ruiz, 2010).

Hence, the creation of ontologies is often hindered by the so called knowledge acquisition bottleneck (Hepp, 2007; Aquin *et al.*, 2008) and the need for their maintenance and curation (Pinto *et al.*, 2009; Curry *et al.*, 2010). Moreover, reusing and combining existing background knowledge of different origin can require reengineering in the case of a non-ontological resource and always requires its thorough analysis in order to be able to assess its usefulness for inclusion. This is comparable to the problem of semantically aligning legacy business process models to e-business standards in general. So far, this requires manual inspection and relating, whereby differences, ambiguities, inconsistencies, redundancies, vagueness and different granularities of information need to be dealt with by domain experts.

Moreover, even if construction rules and readily available controlled languages such as vocabularies, glossaries, thesauri or domain ontologies are in place, the adherence to naming rules upon designing business process models supports only their creation. Usually vocabularies or glossaries differ between teams, independent corporate units and almost always considerably between independent companies. Also the adherence to a company or domain ontology or even to industry-wide or global reference models or standards for business process model element labeling often only shifts the semantic problem onto a higher level at the time of aligning models, as there is presently no one single universal (business) standard in place (European Commission, 2013, p. 19; United Nations Economic Commission for Europe, 2013, p. 33f). Accordingly, unified labeling and semantic standardization cannot answer the question of how to align models of different origin, as in the majority of cases legacy models from different origin have been modeled according to dissimilar guidelines.

In labels, synonymy, homonymy, vagueness, incorrect labeling, as well as differing modeling styles result in uncertainty, ambiguity, and misunderstandings (Leopold *et al.*, 2012b; Becker *et al.*, 2014). In general, these differences arise over time, in decentralized teams, different corporate units and most obviously in independent enterprises especially when several modelers or decentralized teams have been involved (Hadar and Soffer, 2006; Scheer and Klueckmann, 2009). Yet, for aligning models, even for humans, creating mappings is a labor-intensive and error prone and therefore many ontology matching tools are semi-automated, helping humans in an interactive manner (Uschold and Grüninger, 2004).

Consequently, the usage of various matching techniques has been suggested. Presently, the works in the field of aligning existing business process models mostly concentrate on matching models expressed in the same modeling language. Hereby, the comparison of the business semantics is predominately based on string matching. In a few approaches, also the possibility of having to resolve synonymy of terms or eliminating stop words is considered. Hitherto, suggested matching approaches for process matching include determining syntactic similarity, whereby only the syntax of the labels is considered, semantic similarity, where the semantics of the words within the labels is considered and structural or contextual similarity, where also the neighborhood and context in which these elements occur is looked at or combinations thereof. This leads to matching elements comparing the neighborhood of entities before resolving any potential ambiguity of their meaning. However, as previously stated, for obtaining meaningful matching results, structural analysis of process models has to build on prior semantic analysis, as otherwise matchings could be incomplete and automatically merged model may not always be desirable, as they again require visual analysis and comparison. Furthermore, as expressed by the need for including goals into processes, other influences may dictate the formation outcome of a process (Belecheanu *et al.*, 2007; Cardoso *et al.*, 2010) or keeping processes separate is of the essence. Therefore, using automatically obtained mappings for automated mergings of process models could potentially lead to the emergence of undesired processes from a business point of view. Overall, in all approaches the particularity of business process model element labels in general, which is the occurrence of phrases that carry the meaning through their specific composition of several terms, is not addressed and inclusion of linguistic analysis is not foreseen.

Likewise, the interest seems to be the determination of similarity in general without further specification of the strength or grounding of a mapping created as recently became obvious in the first process matching contest offered in the area of BPM (Cayoglu *et al.*, 2014). Furthermore, all approaches foresee the measuring of semantic similarity between model element pairs describing activities. Measures for assessing the semantic similarity of other labeled model elements models such as events or model similarity overall are not given, but even though activities are the largest part, the other labeled constructs are also important (Leopold *et al.*, 2009). Moreover, the overwhelming majority of works to date in this field tend to be concentrated only on modeling element labels in English, even though a need for another language has been recognized, though not answered, as for example in (Dijkman *et al.*, 2009c; Becker *et al.*, 2010a). Furthermore, the given approaches are using WordNet (Fellbaum, 1998) as background knowledge, even though this is a general thesaurus for the English language and by nature does not include specific business or industry terminology as well. In addition, a need for an overall inclusion of more aspects of business modeling has been stated (Kindler *et al.*, 2006; Rosemann *et al.*, 2012), for example documents and factual data (Samaranayake, 2009), although this also remains unanswered.

It has been found that semantic analysis of labels presents the biggest challenge in process model matching, especially with large or numerous models, and the involvement of humans for judging the quality of computed mappings or decisions regarding further work is deemed mandatory (La Rosa *et al.*, 2010b; Becker *et al.*, 2013; Cayoglu *et al.*, 2014). This is comparable to ontology alignment, where fully automatic methods presently produce imperfect mappings, so that involving human experts in the alignment process is necessary for refining the matching results for providing alignments usable in practice (Shvaiko and Euzenat, 2008; Granitzer *et al.*, 2010; Scharffe *et al.*, 2014). For preserving the knowledge about process model alignments, hitherto it has been suggested to store mappings in a wiki (Fellmann, 2013) or to generate textual documentation (Leopold, 2013). On the other hand, in the field of ontology matching it has been shown that a suitable presentation can enhance alignment through active user involvement and user input (Granitzer *et al.*, 2010).

Overall, comparing the present suggestions for business process integration through semantic analysis and model matching reveals several remaining issues as listed in Table 2-2.

Comparison criterion	**Issue identified**	**Cause**
Ontologi-zation	Lack of automation	Knowledge contained in models is not reused directly, but instead business process models are to be manually annotated
	Lack of interoperability	Semantic models are not expressed in a standard format
Semantic BP Model	Lack of extendability	Inclusion of business statements as instances prevents adding business process model instance information in the ontology

Comparison criterion	Issue identified	Cause
		at a later stage
BPML Ontology	Lack of transferability	Focus lies on single process models and does not also assume other types of models
Relating	Lack of independency of modeling language	Focus lies on a single business process modeling language with its specifics
Domain ontology	Lack of automation	Upfront creation of a domain ontology for comparisons is foreseen requiring efforts that are mainly assumed to be human labor
Element label matching	Lack of independency of natural language	Semantic analysis only given for general English
	Lack of including linguistic analysis	No language specific linguistic analysis capabilities included for analyzing phrases
	Lack of specific semantic similarity measures	Measures for element (activities) pair similarity provided, but not for phrases and overall model similarity
Mapping usage	Lack of knowledge sustaining	Preservation or export from tool of the knowledge derived for further application not included or reported
	Lack of user support for matching evaluation	Provision of explanation for mapping rationale not included or reported

Table 2-2 List of Open Issues Identified

The comparison of approaches to using semantics in BPM shows that even though the suggested approaches include a heterogeneous mix of methods and techniques, none of them addresses all the identified criteria as presented in Table 2-1.

2.5.3 Conclusion

The literature review demonstrates that to date there are no comprehensive suggestions for methods for semantically aligning business process models in differing modeling languages and incorporating the business semantics in full independently of the natural language used in an automated manner. So far, individual aspects have been considered, even though the open issues identified show that present approaches lack in practicability as they mostly require considerable preparation for developing ontologies upfront and manual annotation efforts. Furthermore, many approaches lack in holism, as they focus on single languages and are not easily extendable or do not fully enable long-term interoperability. Moreover, the potential of semantic processing for alignment purposes seems to be under-utilized and not provided for more than the English language alone. The problem of having to analyze the phrases in element labels that are mostly not complete sentences but more than an unsorted collection of terms is not yet solved and a holistic measuring of model similarity is not yet available.

This challenge has motivated the work presented here. For closing the research gap and developing a comprehensive, practicable, and holistic solution the research has concentrated onto engineering an applicable method for the usage of semantics for model-based business process integration answering the open issues identified.

The provision of a generic integration of modeling languages in a standard ontology format could answer the need for dealing with legacy models in different languages on a horizontal level, possibly even in case in the future one of them emerges as the standard notion.

Although the proposed provision of controlled business language through the usage of domain ontologies for achieving unified element labeling at the time of creating new models can help in preventing ambiguity in the future, the required manual creation and curation incurs high costs. Furthermore, this does not prevent the encounter of heterogeneous legacy models in the future outside the closed world in which the normative language has been applied. Instead, thereby the need of having to compare models of different origin and resolve heterogeneous language in model labels is still to be dealt with. Accordingly, for matching model elements the requirement of having to create a domain ontology or pre-define mappings should be refrained from.

As for ontologizing legacy business process models semantic annotation for enabling semantic matching as suggested in the literature is mostly to be performed manually according to a pre-defined domain ontology, the requirement of human involvement leads to incurring high costs for applying the suggestions. Alternatively, automating the process through a transformation of models into ontologies prevents the annotation efforts for preparing matchings for aligning them.

Furthermore, the existing suggestions for semantic annotation turn the business statements expressed by the element labels into ontology instances, as thereby the focus is either onto the design or the verification of new models through employing reasoning mechanisms. Instead, future ontology population with data from process execution should be possible or the extension of interlinked models into an enterprise ontology for further usage.

Finally, the semantic heterogeneity stemming from the given arbitrariness in labeling the elements in business process models needs to be resolved through further semantic processing enablement for linguistically analyzing the natural language in the phrases encountered and for further natural languages besides English. Mappings found should be preserved in a format foreseeing an explanation to users regarding the rationale and allow for supporting business analysis tasks regarding the question of business process integration.

The following chapter outlines the chosen research methodology to achieve the research aims and objectives identified to address the gap in the existing knowledge within the field.

Chapter 3 RESEARCH METHODOLOGY

The research presented belongs to the discipline of business informatics in that it combines subject areas in business administration and management, information and knowledge management, and computer science. Its purpose is the development of systematic procedure guidelines by engineering a method together with its supporting artifacts and the design of a supporting information system for providing an answer to the problem of how to semantically align business process models in an automated manner based on the meaning of their elements.

3.1 Design-Science Based Research

The research described is a constructivist, design-science oriented approach. Design science is concerned with the process of design as it is common in the field of engineering, architecture, business, education, law, and medicine (Simon, 1996, p. 111). Design science research systematizes design as a science in information systems research and provides for the construction of novel, innovative, and viable artifacts, such as languages, symbols, or models, usable as abstractions or representations, practical instantiations or methods in order to increase knowledge for solving organizational problems of general interest (March and Smith, 1995; Hevner *et al.*, 2004). Thereby, a designer provides an answer to a problem by developing an innovative artifact and in this contributes new knowledge how it can solve the problem being addressed. Such an artifact is constructed by humans and therefore by nature artificial, not naturally occurring (Hevner and Chatterjee, 2010, pp. 5–6). The results are of interest for management and technology audiences, whereby the latter need further information about the construction and usage (Hevner and Chatterjee, 2010, p. 19).

Accordingly, the design and development of a method is considered novel research (Ortner, 2002, p. 39; Österle *et al.*, 2010). The contribution to knowledge lies in the novelty of a viable method (March and Smith, 1995, p. 260). Thus, the focus is application-oriented in that guidance for action in practice is intended to be provided by the results (Gregor, 2007). A method is to be understood as a planned, result-oriented approach for systematically solving a task (Sarshar, 2008). Method engineering provides for new principles for systematically reaching a goal (Gutzwiller, 1994). This includes the design, construction and adaption of methods, techniques and tools (Brinkkemper, 1996).

For developing a solution to the problem identified here, the research is concentrated on engineering a suitable method. The overall epistemic interest is the creation of an IT-supported action enablement for solving a general class of business problems. Thereby, a resolution to a problem in the field of process modeling is created by combining and employing techniques from the field of knowledge engineering, in particular semantic modeling and matching. The resulting method is intended to be a repeatable operational guideline offering directions for systematically solving a task (Brinkkemper, 1996; Becker *et al.*, 2001; Sarshar, 2008; Aier and Fischer, 2009). In this, it is to serve as prescriptive action knowledge explication (Henderson-Sellers *et al.*, 2014, p. 54). Herein the approach follows the notion of engineering that concerns both people and artifacts where the results of scientific research become applicable (Gregor, 2007, p. 14).

This work's contribution lies in the resulting method description and its supporting artifacts that define a practice for innovatively improving information technologies application in the field of business process modeling and semantic processing.

3.2 Research Design

As the foundation for conducting this research, the design science research guidelines as described by Hevner are applied (Hevner and Chatterjee, 2010, pp. 12, 20). Accordingly, novel, utile, and relevant artifacts are to be developed in an iterative manner, evaluated and disseminated. For engineering the method, the Design Science Research Methodology as suggested in (Hevner and Chatterjee, 2010, pp. 28–31) has been used as a guideline in devising a suitable specific research design and research process. The development of the method and its supporting artifacts follows the suggested activities of problem identification and motivation, definition of the objectives for a solution, design and development, demonstration, evaluation and communication.

For realizing the various process steps different design-oriented methods as common in the field of business informatics have been used (Wilde and Hess, 2007). Multiple methods have been applied in accordance with the specifics of the individual actions required for realizing each activity.

Thereby, the activities of designing and developing and the demonstration and evaluation are envisaged to be performed in iterations. In this, the incorporation of the evaluation outcomes and feedback received from communication upon publishing the results as they became available was provided for. Thus, the results could be optimized and completed accordingly. Based on the process designed for researching, all activities have been completed in succession through applying the methods envisaged. Figure 3-1 shows in which sequence the activities are performed in and which methods are utilized, whereby the numbers indicate the respective chapters in this thesis.

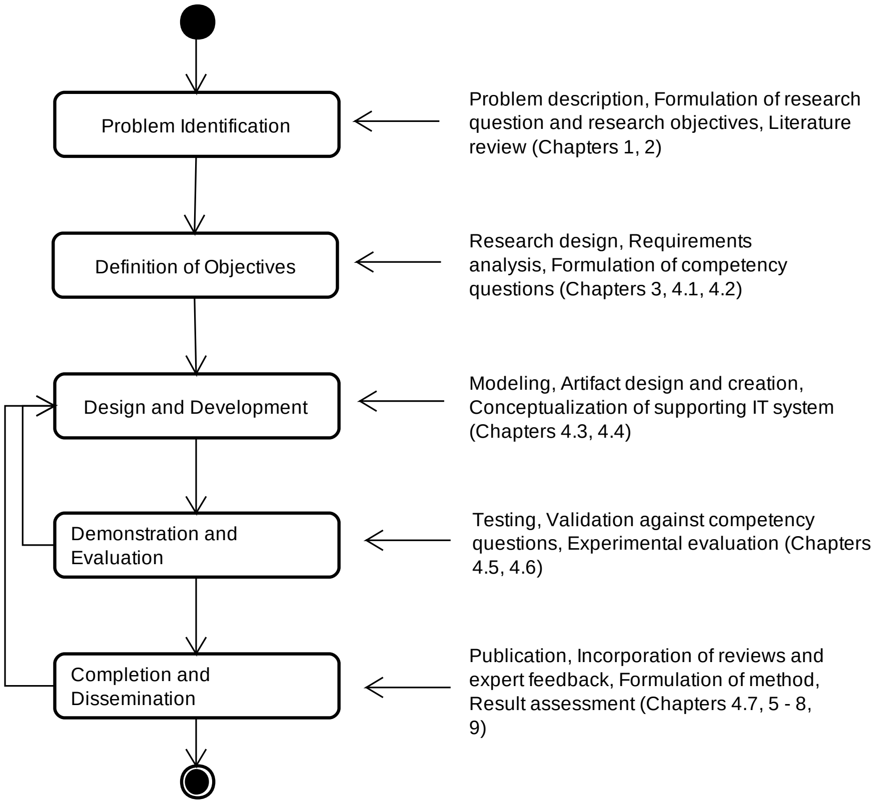

Figure 3-1 Overview of the Research Process

Thereby, each activity contains several tasks and builds on the results achieved in the previous activity. In the following each activity is described in detail.

3.2.1 Problem Identification

The awareness about a need for and the challenges involved in having to analyze and compare legacy business process models stems from insights and expertise gained by working as a research associate in research projects concerning issues of business integration which correlates with previous professional experience. The identified problem of the need of having to semantically align legacy business process models is described and the motivation for conducting relevant research is presented in Chapter 1. Subsequently, the research question is formulated together with the research objectives for developing an answer through engineering a suitable method.

For exactly defining a problem knowledge of the state of the problem and the importance and viability of its potential solution are required (Hevner and Chatterjee, 2010, p. 28). Accordingly, the identified need for automated support for aligning business process models based on their semantics and possibility of applying semantic technologies is reinforced and supported with a comprehensive, systematic literature review as presented in Chapter 2. Based on a concept-centric synthesis the state of the art and knowledge gaps become identifiable that provide the motivation for closing them (Webster and Watson, 2002). This includes the identification, analysis and critical assessment of the literature relevant to the topics concerned and the formulation of a design-science based research approach in accordance with the decision for the construction of a method as presented in Section 3.1.

3.2.2 Definition of Objectives

As a next step, based on the problem definition, the course of action for fulfilling the research objectives as presented in Chapter 1 could be defined. The first research objective is to examine current semantic technologies for applicability. This is achieved through the presentation of the identification of the research gap and conclusion about the findings from the literature review as described in Section 2.5.3.

For deriving a solution to a problem its qualities should be inferred together with understanding about its feasibility based on knowledge of the state of the art and current solutions, if any, and their efficacy (Hevner and Chatterjee, 2010, p. 29).

Accordingly, in order to achieve the second research objective of devising procedures for semantic extraction and matching, the requirements and the desired outcome are specified as presented in Section 4.1. As the basis for the method development, requirements elicitation and analysis as described in the area of software engineering is conducted (Abran, 2004, pp. 2-4ff). Such systematic elicitation, analysis and documentation of the requirements for enabling the evaluation of the results as common in this area is considered to also be of support in other engineering disciplines (Smith *et al.*, 2007). Accordingly, the requirements elicitation for developing the method here included interviews with in total thirteen domain experts from industry and five project partners from academia for obtaining input with regard to the issues identified in the literature. Thereby, narrative expert interviews in open form guided by the central question of how model alignments are perceived and separate group discussions conducted as conference room meetings provided the means to elicitate collective experience (Bortz and Döring, 2006, p. 243; Nohl, 2012, pp. 8f; 14f).

In order to determine the scope of support to be expected through the application of the resulting method, competency questions have been derived based on real-world needs as expressed by the domain experts and project partners. With the emergence of ontologies formulating competency questions has been suggested, as with their help the scope and later the validation of the intended development can be assessed (Grüninger and Fox, 1995). Thereby, a set of informal questions is specifically formulated for leading the development. This approach has become an accepted means in various design methodologies and such questions serve as requirement definitions as well as for result evaluation (Fernández-López and Gómez-Pérez, 2002; Fernandes *et al.*, 2011). As here the resulting method is a semantic solution and consequently ontology-based, for defining the scope and enabling the assessment of the results achievable by its application competency questions derived from the needs specified are formulated.

Analyzing the elicitated requirements facilitated the conceptualization of the method to be developed as presented in Section 4.2. In this, the second research objective was achieved.

3.2.3 Design and Development

To achieve the third research objective of developing formats for representing model semantics and alignments and the fourth research objective of formulating the developments into a method, the desired result was designed and developed as presented in Sections 4.3 and 4.4.

Upon designing, the desired functionality of the artifact to be developed is determined and created (Hevner and Chatterjee, 2010, p. 29). Thereby, the design and subsequent creation is based on the prior conceptualization (Hevner and Chatterjee, 2010, p. 26). Engineering a method encompasses two levels analogously to software engineering. These are the architectural design describing the overall method with its components and the detailed design describing them (Abran, 2004, pp. 3-1f).

Subsequently, as the method here describes an IT-supported procedure, for modeling a UML activity diagram for its description has been chosen. As the UML also provides data models, these have been chosen for modeling the supporting ontology artifacts designed for enabling the application of the method. Modeling in UML also provides for visual notation for expressing an ontology in OWL (Brockmans *et al.*, 2004). Based thereon, the implementation in OWL has been realized using the open source ontology editor Protégé (Horridge *et al.*, 2004).

For developing the design of the procedure and subsequent tool support for matching the natural language the same steps of requirement analysis and conceptual modeling have been performed. For elicitating the requirements, next to studying business process models from reference models, standards and examples from the literature, there was furthermore a possibility to analyze and work with real-world models of an industry partner, a large enterprise with its global headquarter in Germany. In-depth analysis of modeling habits and differences in style and labeling was possible and provided valuable insights. Furthermore, for analyzing the requirements for developing the procedure of matching models, systematic, open, non-participative observations were conducted (Bortz and Döring, 2006, pp. 263f). Through observing the approach taken by seven domain experts with different levels of modeling experience in combination with self-observation a general course of action for matching models became evident.

This input led to the creation of the matching procedure for supporting human users in a heuristic manner. The documentation includes a UML activity diagram for the high-level description together with a textual description of the tool requirements. For a detailed description of the computational process to be realized pseudocode was developed as an informal, programming language independent specification of the matching algorithm designed (Abran, 2004, pp. 3–5; Roy, 2006). After implementing all artifacts the matching tool was prototypically realized. It has been programmed by the co-author of the publication presented in Chapter 6 in accordance with the design developed in the research presented here. As software prototyping provides for realizing the core of an application in full for testing the proposed solution (Guida *et al.*, 1999, pp. 3–4), it could be validated for fulfilling the requirements accordingly (Abran, 2004, pp. 2–9).

3.2.4 Demonstration and Evaluation

Following development, a demonstration shows the use of an artifact developed to solve a problem, e.g., in experimentation, simulation, case study, or proof (Hevner and Chatterjee, 2010, p. 30). Accordingly, demonstration allowed for verifying the method through testing. All developments and tests have been done on the same IT-equipment for comparability. All artifacts developed have been tested as they became available which in turn allowed for error detection and fine tuning.

For formulating and assessing the comprehensive application of the resulting method its capability in answering the competency questions was validated. Applying the method in form of a preliminary study on a small scale enabled to determine its feasibility. For its conduction, business process models from the SAP Reference Model Collection together with example models from the literature have been utilized. The testing was performed by members of the project team where this research originated from in form of a laboratory experiment for assessing the resulting alignments. The matching system itself was tested for its functionality with sets of ontologies of different sizes derived from models from the literature and from industry partners. The purpose was to examine the result achievable by using the algorithm, not the implementation done for testing it. Accordingly, the similarities computed have been assessed regarding their correctness.

For evaluation, the objectives of a solution to actual observed results from the use of the artifact in the demonstration is observed (Hevner and Chatterjee, 2010, p. 30). Hence, as a next step, an experimental evaluation was prepared as a proof-of-concept evaluation by a representative group of the domain experts who were also interviewed for the requirement analysis. In principle, a proof of concept aims at demonstrating the achievability of the goals and feasibility of the IT-support designed (Shaw, 2003). Using prototypes and implementation results provides for proving that a method's application and artifacts can successfully result in the desired outcome (Yang, 2005). Furthermore, with a proof of concept through assessing the important aspects the deliverability of the desired outcome can be demonstrated (Hudson and Mankoff, 2014, p. 78). Applying the method developed here for transformation and semantic processing provided the semantic formats for matching and producing an alignment. For the proof of concept, all individual aspects of the method together have been applied to a random sample of business process models from a large model collection. Firstly, the method was tested and validated regarding its capability of answering the competency questions and assessed by intellectually appraising the correctness of the answers provided. For evaluating the matching results and publication purposes the creation of a reference benchmark for assessing the matching results of publicly available models aligned was foreseen, so that results obtainable are judged against the common measures called precision and recall from information retrieval by using such a gold standard created by the domain experts (Euzenat and Shvaiko, 2013, p. 65). Precision is a measure for the proportion of correct correspondences out of the total number of correspondences found and in this expresses correctness. Recall is a measure for the proportion of the correspondences found in comparison to the total number of all existing correspondences and in this expresses completeness. Thereby it was found that creating a reference alignment poses the same challenge as manual process model matching itself with regards to reaching a common understanding about the intended meaning of model elements as well as about the intended usage of a matching and required degree of recall. Accordingly, measuring precision and recall allows only for an approximation of correctness and completeness (Euzenat and Shvaiko, 2013, p. 65). Nevertheless, as these measures are common in the literature, for the purpose of comparability, they have been used here.

3.2.5 Completion and Dissemination

A further important activity is communication about the problem and the artifact developed for its solution and its novelty, utility, and effectiveness (Hevner and Chatterjee, 2010, p. 30). Thus, throughout the research process results were published. Thereby, comments and peer reviews provided helpful expert feedback for iterative development and result refining. For demonstrating the results achieved and subsequent publication, however, it was not possible to use the real world models of the industry partner due to reasons of confidentiality. Therefore, for illustration purposes freely available models have been used. As a practical example, models from the literature depicting the process of booking travel services have been chosen, as this is an activity that is given in all industries alike. This universal applicability was thought to make the individual business activities generally known and comprehensible without requiring industry-specific domain knowledge. Hence, the flow and naming of activities could be assumed to be familiar. Moreover, this provided for preventing any bias as well and allowed for showing the strength of the approach in actually working with models of independent origins.

The publications chosen for presenting the results achieved are included herein as individual chapters whereby each chapter is preceded with its bibliographic information and abstract. Together the publications form a consistent description of the results achieved. They have built on each other and in this show the iterative development of the resulting method. However, as each of the publications has been written as a self-contained contribution, inevitably the background and motivation for the research works had to be given in each publication. Nevertheless, the trade-off of a certain redundancy given by the unavoidable repetition of foundational concepts as the basis for presenting a certain aspect was balanced by the advantage of publishing while the research was ongoing. Thus, the work was validated by its continual assessment when results were made available for discussion in the scientific community, as the feedback and input could be used for further progress and improvement. Hence, even though there is a certain overlap in this respect, the main focus and contributions clearly differ. The publications are presented verbatim without modifications, except to ease reading, the headlines and figures are numbered for inclusion herein and all citations appear only once cumulatively at the end of this thesis. Furthermore, as the publications have been written in American English in accordance with the applicable publishing requirements, for the purpose of consistency the other parts of this thesis are written in American English as well.

Chapter 4 SEMANTIC MODEL ALIGNMENT DEVELOPMENT

In this chapter the development of the method called *Semantic Model Alignment* is presented comprehensively showing its details and application.

4.1 Requirements Analysis

Following the recognition of the lack of a holistic method for solving semantic heterogeneity in legacy business process models as a research gap, the need for automating their semantic alignment was identified. As a first step for defining the corresponding method development, the terminology to be used within the research was defined as documented in the attached glossary as of page 291. As a second step, based on the issues identified in the state of the art through the literature review and supported by discussions with the domain experts the needs for developing a solution could be elicitated, assessed and formulated as requirements. An overview of these requirements as they have been derived based on the open issues as presented in Table 2-2 is given here in Table 4-1.

Issue identified	**Requirement derived**
Lack of automation	Automated reuse of the information contained in business process models through reengineering for avoidance of preparatory efforts for upfront ontology creation or manual annotation efforts
Lack of interoperability	Use of open standards by W3C and reuse of freely available resources as-is
Lack of extendability	Reengineering of business process models into ontologies capturing model information at model level
Lack of transferability	Generic design for extendability onto further modeling languages and different model types
Lack of independency of modeling language	Comparability through semantic abstraction as the basis providing independence of tools at the same time

Issue identified	Requirement derived
Lack of independency of natural language	Facilitate semantic analysis of English and further natural languages including business and industry terminologies
Lack of including linguistic analysis	Inclusion of information linguistics for semantic matching and procedure for phrase sense disambiguation
Lack of specific semantic similarity measures	Development of configurable similarity computation for phrases and overall model similarity
Lack of knowledge sustaining	Preservation of the knowledge derived for further application in an interoperable format
Lack of user support for matching evaluation	Inclusion of explanation for mapping rationale

Table 4-1 Overview of Method Requirements

The method development is based on the premise that within enterprises and B2B-collaborations meaningful vertical alignment of the strategic, business and technical levels cannot be achieved unless each level is horizontally aligned. It is assumed that holistic, horizontally integrated overviews of business operations need to be established for deciding on operational shaping and any subsequent technical execution, especially as the designing of business processes is not only governed by economically justifiable considerations but also by legal, fiscal and cultural-based regulations as well. Accordingly, automated process merging or adaptations for performance improvements cannot be performed without the risk of erroneous decisions. Instead, ambiguity of model element semantics needs to be resolved so that models' structure and element neighborhood can be meaningfully compared. As expressed by the research question the research here concentrates onto the application of semantic technologies for fulfilling the requirements for automatedly supporting the task of aligning legacy business process models based on the business meaning contained in their elements. In the course of the research it became apparent that some of the global players headquartered in Germany use the local language also as their first language for modeling. As a consequence, any provision of semantic matching needs to be language-specific as well.

For describing and assessing the results achievable through the application of the method of Semantic Model Alignment a list of competency questions was developed. The returned answers should satisfy humans judging the degree of correctness. The complete list of these questions and their expected answers and their answer type is shown in Table 4-2.

Business task	**Competency question**	**Expected answer**
Semantic relating of models of different origin	Which business process models match?	Alphanumerical list of semantic correspondences between models from interlinked models
	Do models A and B describe the same or similar business operations?	Numerical degree of model aboutness between two models
Determining semantic model similarity	How similar are the elements included in models A and B?	Alphanumerical list of semantic correspondences between the model elements
Language consistency analysis for linked models	Does term X / phrase XYZ appear in different variants?	Alphanumerical list of occurrences to a model element from interlinked models
	How is a certain concept designated in models?	Alphanumerical list of semantic correspondences to a model element from interlinked models
Search for entities with the same intended meaning	Are there semantic correspondences to a certain model element?	Alphanumerical list of semantic correspondences of interlinked models from interlinked models
Retrieval of a certain element	Where can a certain model element be found?	Alphanumerical list of occurrences of a model element from interlinked models
Exploration of linked models	Derivation and analysis of semantic landscapes	Ontology-based integration of model ontologies, meta-metamodel and mapping ontologies

Table 4-2 List of Competency Questions

Based on this requirement analysis and this list of competency questions the method is engineered.

4.2 Method Conceptualization

As the research aims at further automation of the model alignment task, it is based on the consideration that the manual workload of having to create an accompanying ontology and remodeling or annotating business process models is not feasible. Furthermore, semantic analysis is deemed to have to be linguistically motivated and the results need to be presented to users in an intuitive manner. To address the four research subquestions formulated for detailing the main research question and taking into account these considerations, four method phases have been devised as shown in Figure 4-1.

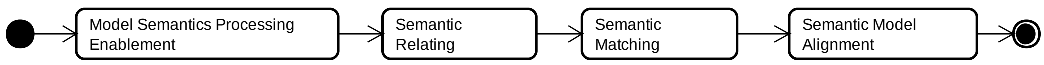

Figure 4-1 The Method of Semantic Model Alignment

Each of the method's phases is a step of the process for its realization:

- Enabling the processing of the model semantics provides the answer to RQ1 of how to capture, explicate and formalize them for semantic processing;
- Semantic Relating provides the answer to RQ2 of how to exploit the extracted modeling languages semantics for alignment purposes;
- Semantic Matching provides the answer to RQ3 of how to match the extracted natural language in model element labels and determine semantic similarity determined between models;
- Semantic Model Alignment provides the answer to RQ4 of how to determine, collect, and formalize semantic alignments for preserving them for further processing.

Applying the method as a whole enables semantic model alignments which can be utilized by business analysts for model-based integration decisions concerning business processes.

4.3 Method Design

For realizing the method phases adequate procedures are created. Figure 4-2 gives an overview of the design.

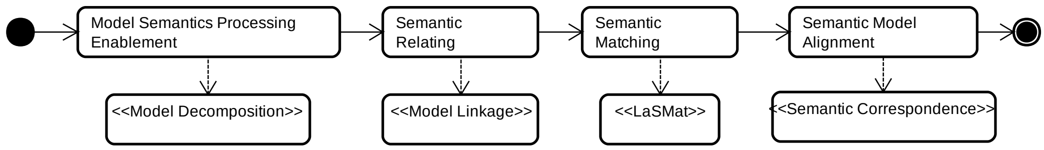

Figure 4-2 Realization of the Semantic Model Alignment Method

In order to facilitate the processing of the model semantics and to gain access to the semantics contained in business process models, a procedure for reengineering these non-ontological resources is designed that has been named *Model Decomposition*. It is based on abstracting from the models to be aligned, so that they could remain actively in use. For capturing the knowledge elicited the use of web-based ontologies is decided upon. In this, the semantics could be stored separately in a "semantics warehouse" and worked on directly without the need for ontology creation in advance for comparison purposes or any manual annotations. By employing ontologies the potential for semantic processing is provided for in full.

For semantically relating models the modeling language semantics provide a means for unambiguously recognizing the intended meaning of an element's function. This fact has been exploited for designing a linking mechanism based thereon, which is named *Model Linkage*. Following the idea of meta-

metamodeling, an ontology-based representation of modeling languages' concepts has been designed for supplying the concepts' representation and the definition of semantic relations between them, in particular equivalence. Through this generic approach potential future inclusion of further types of models, such as models describing business objects, documents, value chains or organizational structures, is enabled. In this, extended semantics-based business analysis capabilities are facilitated as mismatches or overlaps due to errors in the in- or output of a business process may potentially also be searched for.

For semantically matching the ontologies obtained, the procedure devised here is named *LaSMat* (Language-aware Semantic Matching). Basically, ontology matching methods facilitate the search for ontology elements which are semantically related on the conceptual level. The literature shows various types of techniques for determining semantic similarity between concepts. However, for the development described here, special attention had to be given to enable semantic matching of the natural language of the model element labels as captured in the model ontologies. The element labels in business process models do not only contain one or two nouns. Instead, they often contain phrases composed of several terms which can be understood as multi-word combinations of verbs and nouns. Yet, these expressions are not full grammatically complete sentences. Following the first application of model decomposition and model linkage as presented in Chapter 5 with using an existing matcher system, it had become evident that semantic matching needed to be further developed beyond the matching of terms to include linguistic analysis for disambiguating phrase senses as well and for more than general English alone. Experiments were conducted with the free available ontology matchers with the objective of finding suitable matchers for matching a given sample set of element labels representing typical and often occurring phrases in business process models. The correctness of the automatically obtained semantic similarity was assessed by domain experts. It was observed that none of the available matchers could provide satisfactory results. Furthermore, upon using available ontology matchers scalability problems occurred as for example the anatomy ontologies used later on in this research for evaluating the LaSMat procedure (c.f. Section 4.6) could not be matched with those.

The extensive model analysis conducted with models from the literature and with real-world models from the industry revealed various issues concerning the linguistic analysis of phrases. These observations together with their origin recognized and effect caused are shown in an overview in Table 4-3.

Observation	**Origin**	**Effect**
Synonymy	Incoherent choice of terminology, Anglicism (in German)	Ambiguity disadvantage
Variations in phrasing	Non-availability or non-adherence to guidelines	Prevention of direct comparison
Homonymy	Missing expression of context information or lack of specificity	Ambiguity disadvantage
Generality of terms	Choice of unspecific terms	Ambiguity disadvantage
Use of meta-information in labels	Perceived lack of specificity of model language	Falsification of business statement
Incorrect label types for the chosen element types	Perceived lack of specificity of model language or inexperience in modeling	Non-usableness of element type information for comparison
Varying style of grammatical structuring	Use of auxiliary and modal verbs or compounds and nouns or nominalizations	Prevention of direct comparison

Observation	Origin	Effect
Differing expression style of negation	Negation not expressed by stop word "not", but terms with contrary meaning	Prevention of direct comparison
Aggregations in designations	List of activities in one activity element, use of slashes, hyphens	Assumed relatedness of one label to multiple more precise labels
Inconsistent or unclear abbreviations	Space restrictions caused by modeling tool, wish for saving time at modeling	Ambiguity disadvantage
Use of mathematical operators	Wish for abbreviating or expression of rules	Ambiguity disadvantage, non-usableness of element type information for comparison
Uncommon acronyms	Use of domain or company specific expressions	Ambiguity disadvantage
Spelling, grammatical and typing errors	Lack of validation	Prevention of direct comparison

Table 4-3 Observation of Linguistic Differences in Phrases of Business Process Model Element Labels

The outcome of this analysis has been corroborated to findings in the literature for avoiding potentially biased conclusions due to the industry specifics given in the real-world models. Notwithstanding, the findings here correlate to reports on real-world models in the literature (Delfmann *et al.*, 2009; Weissgerber, 2011; Leopold, 2013). At the same time, as expected, irony, sentiment expression or colloquial language have not been found, so that treatment of ambiguities caused thereof do not have to be included. However, it became evident that the phrasing style in models can vary considerably and part-of-speech analysis does not lead to meaningful results, as such phrases are not complete sentences and thus not allow for clearly inferring the semantic categorization of terms used. These findings correlate with similar findings in the literature for the English language (Francescomarino and Tonella, 2010; Leopold *et al.*, 2012b). Furthermore, even business process models belonging to a confined model collection assumed to having been guided by universal guidelines for labeling differ significantly. For example, 60% of the models of the SAP Reference Model contain labels of function elements using a verb for designating the activity depicted, whereas 34% use nouns, even though the recommendation for using verbs is widely advocated (Mendling *et al.*, 2010b). However, other collections can show different distributions (Leopold *et al.*, 2012b, p. 451). As a consequence, suggestions for adding a fixed expression to given activity labels for turning phrases into full sentences for enabling part-of-speech-analysis, e.g. adding the prefix "you have to" to phrases of activity labels (Leopold *et al.*, 2009) need to be refrained from, as this leads to results of reduced quality for labels with nouns.

Based on the results obtainable by performing language-aware semantic matching, in the next method phase their further use is provided for. This procedure is named *Semantic Correspondence* and builds the foundation for semantic model alignments that are directly usable for supporting business process integrations. The semantic similarity computed includes an explanation for users about its rationale. The set of results for matching pairs of models is expressed in a mapping ontology format specifically developed here for this purpose. Choosing an ontology for capturing the knowledge about semantic similarity in this manner also provides for its potential enhancement by users editing, adding or deleting relations established directly. In this, implicit user knowledge and subject matter expertise can be explicated and integrated into the ontology. Furthermore, the aligned ontologies together with the semantic correspondence may provide the skeleton for a semantic enterprise model or even a business or domain ontology.

4.4 Development of Supporting Artifacts

In a subsequent step the artifacts required for enabling the method's application have been designed and created. Figure 4-3 shows the results for each phase of the method.

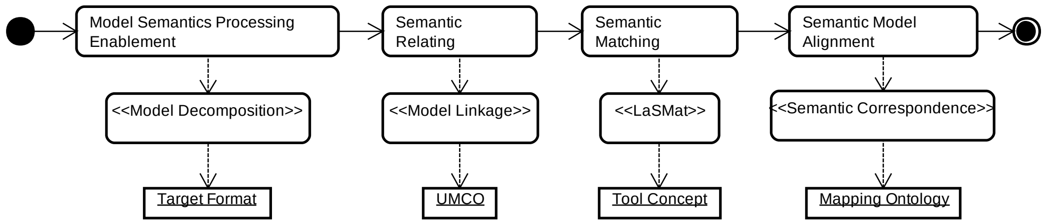

Figure 4-3 Supporting Artifacts for the Semantic Model Alignment Method

In the following the results are presented in detail.

4.4.1 Target Format Development for Model Decomposition

For enabling the model decomposition the translation rules and target format were created. As most business process modeling tools provide for an export based on the eXtensible Markup Language (XML), transformation by Extensible Stylesheet Language Transformations (XSLT) can be applied and processed by standard XSLT-processors. Thereby, a business process model is decomposed into a model ontology representing the model element labels and containing connections into a modeling constructs ontology representing the modeling language used.

In general, business process models contain nodes with or without labels and edges, i.e., flows. For creating model ontologies the element labels and the model name are of interest. However, semantic attributes such as disjointness etc. cannot be safely assumed. The label information available is comparable to textual descriptions as business process modeling languages are semiformal and unequivocal labeling cannot be assumed. Each model element label is transferred as-is into a class in a corresponding model ontology. Transferring the labels as-is allows for their processing as given without the risk of any bias incurred through alterations done by preparation or pre-processing. Thus, alignment based on the given facts is provided for. The flows and connectors the model elements are tied with are transferred as object properties with restrictions for preserving the information regarding the element sequencing within the process model. In the course of the research the relating of the classes by object properties has been refined. Instead of relating classes only with a property called “associated with” for expressing a logical connection as initially supplied, properties for representing the control and information flows within business process models have been created representing from which node to which node the flow is modeled. Thereby further semantic knowledge is transferred as well for enabling queries and inferences regarding the neighborhood of elements. The format template developed for such reengineering is shown in Appendix A .

For knowledge representation OWL was selected, so that by using this web-based open standard by W3C long-term interoperability is provided for. In particular, the resulting model ontologies are expressed in OWL DL. This subset of OWL is based on description logic and provides maximum expressiveness without losing computational completeness in case future reasoning over it should become necessary. In order to also avoid preventing further usage of the thus derived model ontologies, the reengineering does not cross the levels of models and instances. OWL DL provides for representing the terminological knowledge defining the concepts and their properties derived from the business process models in the TBox. To this, any assertional knowledge defining the instances of these concepts can potentially be related in the ABox if needed. This view of separate levels correlates to the notion of business process models' instance and model levels. Accordingly, all concepts of a model are preserved in the ontology's TBox, thus leaving the ABox open for potential inclusion of factual knowledge on instance level in future application scenarios, e.g. data from process logs or document management, etc. for potential process analysis.

Transforming business process models as described allows for automatedly creating ontologies even though once for each model type a modeling tool supports a sheet needs to be developed. As there is as yet no semantically unambiguous, standard exchange format for business process models, these XSLT-sheets need to be created individually according to given tool specifics so that model ontologies as required here can be created. To assess the quality of a transformation sheet, correct availability of a representation of all labeled elements of a model needs to be validated.

The resulting model ontology is an abstraction from the business process model for representing the business semantics without the need for details about the process behavior. Thereby, it is not intended to migrate or transform models, but to support the analysis of semantic models of the business language of models.

4.4.2 Format Development of a Modeling Concepts Ontology

For capturing the semantics of the modeling language constructs of the model elements of which the labels have been elicitated, a Modeling Concepts Ontology (MCO) can be created. Appendix B shows a template and an illustrating data model of an MCO. An MCO is a small, lightweight ontology intended to represent the modeling language constructs of the model elements that carry labels. Once an MCO is established, it can be used for semantically relating all decomposed models of the same type. The connection between a class of a model ontology and the applicable class of the applicable MCO can be established by a property called “occurs as”. This principle is illustrated in Appendix C . As the result of a decomposition, a model ontology is created with links into its applicable MCO. In this manner the business statement of a process model is preserved.

4.4.3 Format Development of the Unifying Modeling Concepts Ontology

The model ontologies obtained can be linked based on the MCO they are connected with. Even in cases where model ontologies link into different MCOs, they can be semantically related as well. For this purpose the Unifying Modeling Concepts Ontology (UMCO) developed here serves as a small bridge ontology. It is a lightweight ontology consisting of concepts and their relations without formal axioms or constraints. It is intended to solely serve as a semantic collection of constructs of modeling languages. Its classes represent generalized modeling language constructs as shown in Appendix D as a consolidation point for individual MCOs. The integration is based on the declaration of these classes being equivalent to the classes with a similar intended meaning in the various MCOs. MCOs are intended to be parts of the UMCO, so that integration independently of the modeling languages used for given business process models is provided. Further constructs can be added in the same manner as necessary for including more MCOs and for model types other than business process models. For example, ebusiness standards can be decomposed in the same manner and thus reengineered into ontologies for matching them to legacy business process models. In case of including data models or any other static models decomposed in the same manner, subsumption and aggregation constructs can be added as well as an exploitable basis for their semantic matching, even though such structural information cannot support their semantic matching to dynamic models such as business process models.

The UMCO works in the sense of an upper ontology in that it describes very general concepts and allows for linking concepts from other ontologies. For aligning all concepts into a correct hierarchy, both the MCOs and the UMCO contain an element “domain entity” as a linkage point. However, the UMCO is not intended to serve as an exclusively applicable, universal ontology. Instead, through the class “domain entity” it can be connected if needed to generally available upper ontologies such as SUMO (IEEE, 2009) or DOLCE (Laboratory for Applied Ontology, 2009). Ultimately, the resulting model ontologies together with the MCOs and the UMCO can form an initial core skeleton of a business or even domain ontology. In order to test and evaluate the method created here, the UMCO has been prototypically developed containing the mainly used constructs of EPC, eEPC, UML Activity Models, and BPMN models as well as UML Class Models. This is shown in Appendix E

4.4.4 Development of Language-aware Semantic Matching

Due to the nature of the model ontologies and the style of the element labels matching with existing element-based ontology matchers does not return satisfactory results. In the course of the research it became evident that the reuse of freely available ontology matchers does not fulfill the task of matching the model ontology entities sufficiently. The model ontologies do not possess a hierarchical structure or OWL semantics such as a hierarchy, disjointness or functional properties etc. Hence, ontology matchers relying on this information are unsuitable. Furthermore, the phrases used as model element labels which are transferred into the model ontologies entities could not be resolved adequately by using string matching and synonymy resolution based on WordNet alone. Also, as mentioned, part-of-speech-analysis for disambiguating word categories to support word sense disambiguation or lemmatization could not improve the matching results. Including context information into the matching detection such as comparing element neighbors leads to weakening semantic similarities detected between elements in case of semantic heterogeneity between the element neighbors. These findings provided the basis for developing the LaSMat semantic matching method, choosing the suitable techniques, and sequencing them for computing semantic similarities of phrases. Table 4-4 shows an overview which technique is selected for addressing a phenomenon observed as reported in Table 4-3.

Observation	**Approach**	**Solution**
Synonymy	Inclusion of thesauri	Resolution of ambiguity through provision of terms with same intended meaning
Variations in phrasing	Phrase splitting, decomposition, stop word weighting, term disorder weighting	Enablement of direct comparison term by term and phrase composition
Homonymy	Phrase splitting, decomposition, inclusion of model name in model ontologies as context information	Disambiguation through low correspondence rate for the whole phrase and context information for users
Generality of terms	Phrase splitting, term disorder weight	Disambiguation through low correspondence rate for the whole phrase
Use of meta-information in labels	Phrase splitting, term disorder weighting	Disambiguation through low correspondence rate for the whole phrase
Incorrect label types for the chosen	Phrase splitting, stemming	Provision of comparability of terms in phrases

Observation	Approach	Solution
element types		
Varying style of grammatical structuring	Stemming, term disorder weighting	Provision of comparability of terms in phrases
Differing expression style of negation	Stop word weighting, stemming, string matching	Provision of comparability of terms in phrases
Aggregations in designations	Full matching procedure	Provision of lists of correspondences without preselection
Inconsistent or unclear abbreviations	String matching	Provision of comparability of terms in phrases
Use of mathematical operators	Extension or addition of thesaurus, string matching	Provision of comparability of terms in phrases
Uncommon acronyms	Extension or addition of thesaurus, string matching	Provision of comparability of terms in phrases
Spelling, grammatical and typing errors	String matching	Provision of comparability of terms in phrases

Table 4-4 Linguistic Procedures within Language-aware Semantic Matching

The LaSMat procedure foresees that after comparing phrases as a whole, the steps of splitting phrases in terms, decomposition, pair wise matching, stop word matching, synonymy resolution, stemming, and string matching for determining semantic correspondences are performed successively. The detailed succession of these steps is given in Chapter 7. This sequencing of activities was set as the result of observing humans' course of action approaching the task of semantic matching. However, the techniques of decomposition, stop word treatment, and stemming are specific to a natural language as well as the selection of thesauri as background knowledge for synonymy resolution and the disambiguation of acronyms or uncommon abbreviations.

The procedure of language-aware semantic matching outlined enables to match phrases in differing modeling styles in both English and German and works over pairs of ontologies. The algorithm specifically developed in the work presented here for fulfilling this task compares all elements to all by a breadth-first search as therewith the search for corresponding elements is uninformed and complete (Russell and Norvig, 2003, pp. 73–74). Even though this leads to exponential complexity, this type of search is generally suitable in case small numbers of nodes are to be compared as given here in the case of matching business process models. Accordingly, the required space for processing does not pose a problem due to the low number of nodes, whereas the required time for processing is not critical due to matching being performed at design-time once, not repeatedly at run-time or as a mission-critical application. Instead, it is part of the overall method of semantic model alignment. The pseudocode for the semantic matching developed shown in Appendix F illustrates the procedure foreseen. The computation of semantic similarity is based on aggregating the individual results of the various steps of the matching procedure according to the formulas specifically developed for this purpose. They are presented in detail in Chapter 7.

Upon testing the matching of phrases against the gold standard created, it became evident that users perceive correctness und usefulness differently according to their individual needs. Even though in general high precision and recall are required, the degree demanded for both differ. High recall entails a large number of correspondences with a low precision and high precision entails a low number of correspondences found (Ehrig and Sure, 2005, p. 3). The degree for qualifying as a high or satisfying measure depends on user needs (Euzenat and Shvaiko, 2013, p. 65). As a consequence, for computing the aggregate results by language-aware semantic matching, the procedure is designed to be adaptive in accordance to the demand so that either a large set of correspondences with an average precision is obtainable or a small set with high precision. Furthermore, the procedure foresees the inclusion of arbitrary thesauri and the setting of weights for synonymy resolution, stop word treatment, and string matching result inclusion together with setting a weight for the determination of the position of terms in phrases through the creation of the term disorder weight specifically developed here. As a general overall measure, a similarity measure for model aboutness has been created. These details of the matching are reported in Chapter 6 .

The result of language-aware matching is an alignment consisting of semantic correspondences describing semantic similarity between pairs of entities of the ontologies compared and allows for statements as "A from Ontology X corresponds to B from Ontology Y to a certain degree". Thereby, A and B stand for the entities of the two ontologies. Semantic similarity is a measure for the degree of likeliness and thereby equivalence of the intended meaning. The strength of a certain degree is a fuzzy value as a confidence measure for the semantic similarity, whereby a degree of 1 describes full similarity, i.e., equality, a degree between 0.99 to 0.01 semantic similarity of a certain strength, and a degree of 0 no likeliness.

4.4.5 Design of the LaSMat Semantic Matching Tool

Based on the idea of language-aware semantic matching a supporting matching tool has been designed. It is conceptualized to be usable as a matcher for ontologies in general, so that model ontologies resulting from model decomposition may potentially also be matched to arbitrary ontologies as well. For enabling the matching of basic ontologies in RDFS as well as more expressive ontologies in OWL, the semantic matcher is conceptualized for matching classes, instances, and annotation property labels in RDFS taking as input the element labels, or if there are none, their Uniform Resource Identifier (URI) fragments. This matching tool also called LaSMat in accordance with the procedure it implements works as an extended RDFS-matcher including linguistic analysis for English and German.

The matcher's design foresees its usage by an application programming interface (API) and also by a graphical user interface (GUI), so that the matching system can be coupled or used in stand-alone form. For the interaction several functional requirements have been specified for guiding the programming. They are shown in Appendix G . The design foresees for users to include arbitrary thesauri in SKOS, choose a string matching procedure, set the weights for synonymy resolution, stop word treatment, string matching result inclusion, and term disorder weight as well as thresholds for the result presentation.

4.4.6 Migration of a German Thesaurus

Upon developing the system it became evident that for synonymy resolution the inclusion of WordNet for the English language is not sufficient for the business domain, as it is a general language resource. The addition of the thesaurus STW containing terms from the field of business improved the results, as it contains vocabulary on economic subjects in English and German (ZBW, 2010). Due to the non-availability of a free general German thesaurus, for testing the freely available OpenThesaurus for German was migrated to Simple Knowledge Organization System (SKOS). Appendix H shows the format of the concepts obtained through the migration and an example extract.

4.4.7 Format Development of the LaSMat Mapping Ontology

For persisting the computed semantic correspondences a generic format for a mapping ontology was created. It is included in Appendix I . The ontology is populated with the computation results of matchings in the form of instance information. This representation allows users to assess semantic correspondence pointing from the source phrase to the destination phrase and its degree of strength together with the underlying rationale for this match. For more intuitive understandability the results are also available in a fuzzyficated form. For this, a presentation in five equidistant intervals has been chosen, so a verbal description with a higher level of detailing illustrates the meaning of the confidence computed. The details are presented in Chapter 6 in Section 6.3.3.

Mapping ontologies can provide the basis for interlinking the model ontologies based on the business semantic with semantic correspondences expressing similarity while at the same time being designed for potential extension with other types of relations. For representation OWL is chosen, so that any manual post-editing deemed necessary by users can be processed by using any ontology editor. The obtained knowledge base allows for being used similar to a dictionary and answering questions such as the competency questions developed. Furthermore, the interlinked alignments may also be used similarly to an automatically derived thesaurus.

4.5 Completion

All artifacts developed for model decomposition, model linkage, language-aware semantic matching and alignment expression have been formulated comprehensively into the method of semantic model alignment. The fulfillment of the requirements through the method's application has been validated as shown in Table 4-5 in an overview.

Requirement	Fulfillment
Automated reuse of the information contained in business process models through reengineering for avoidance of preparatory efforts for upfront ontology creation or manual annotation efforts	Transforming models in XML or XMI via XSLT by way of model decomposition into ontologies in OWL; the bridge ontology UMCO including MCOs for common modeling languages is available
Use of open standards by W3C and reuse of freely available resources as-is	Based on W3C standards OWL and SKOS; arbitrary open or proprietary thesauri can be used
Reengineering of business process models into ontologies capturing model information at model level	Transformation of elicitated semantics into ontologies in OWL DL provides for full semantic processability and further usage
Generic design for extendability onto further modeling languages and different model types	The UMCO allows for adding further MCOs for arbitrary types of models of any kind
Comparability through semantic abstraction as the basis providing independence of tools at the same time	Through deriving semantic models directly usable business process models may remain actively in use
Facilitate semantic analysis of English and further natural languages including business and industry terminologies	Support for English and German including business and industry terminologies are given; the concept allows for supporting further European languages
Inclusion of information linguistics for semantic matching and procedure for phrase sense disambiguation	Combination of various information linguistics procedures included
Development of configurable similarity computation for phrases and overall model similarity	Parameterizable computing of semantic similarity and model aboutness developed
Preservation of the knowledge derived for further application in an interoperable format	Definition of a mapping format in OWL for interlinking matched ontologies
Inclusion of explanation for mapping rationale	Mapping format provides for intuitive comprehensibility and description of matching result rationale and overall model similarity

Table 4-5 Fulfillment of Method Requirements

Applying the method and utilizing the supporting artifacts supplies ontology creation from models in an automated manner through transformation, ontology mapping through the UMCO and ontology matching including specific linguistic techniques for phrase sense disambiguation. The competency questions have been found to be all fully answerable. The resulting mapping ontology describing the alignment is capable of further manual post editing and usage as a seed for evolving into an enterprise ontology.

Even though the literature shows various different approaches to constructing methods, they all have in common that the availability of an activity or procedure model for its description is seen as a fundamental element (Braun *et al.*, 2005, p. 1297). Therefore, for an overall presentation of the method of Semantic Model Alignment application guidelines are included in Appendix J , serving at the same time as a throughgoing example.

4.6 Evaluation

After their completion, testing and validation of all artifacts have been performed as foreseen (c.f. section 3.2.4). The matching system was tested on a standard 32-bit windows-operated laptop computer with a 2.4 GHz Intel Dual Core processor and 4 GB RAM. For testing, ontologized business process models from the literature and the SAP reference model with sizes between 8 to 64 labeled elements have been used. As described in Section 3.2.4, the results were to be assessed with regard to their probability by domain experts, in particular regarding the usage possibilities for the parameterization foreseen.

For testing the scalability of the matching operator, also tests with large ontologies describing the human anatomy from the Ontology Alignment Evaluation Initiative (OAEI) requiring matching 2,744 to 3,304 classes (Euzenat, 2014) have been performed. As was expected due to its nature as a semantic matcher it cannot exploit the formal ontological semantics included in more heavyweight ontologies than the model ontologies derivable here. With regard to the complexity of the matching algorithm it was found that matching also large sets is possible to completion and scalability seems not to be an issue.

After completion and the formulation of the method as a whole, a proof-of-concept has been performed for measuring precision and recall against a gold standard. This is reported in detail in Chapter 8 . Furthermore, in the course of the evaluation, with respect to time, it was found useful that model ontologies are automatedly obtained and that matching them with the LaSMat system lasted between 290 ms to maximum 3,100 ms per pair while humans needed between one to several hours. For an evaluation with respect to the utility of the method and support offered it was assessed regarding the usefulness of the answers obtainable to the competency questions upon matching a legacy business process model to a model of an ontologized e-business standard in a case demonstration as reported in (Fengel, 2012):

- Semantic correspondences with a high confidence are helpful in detecting linking points in previously unrelated models, as mostly the aligned elements are actually related regarding their intended meaning.
- Semantic correspondences with confidences of medium range are helpful for pointing out potential consolidation points in cases of differences in the scope and granularity of models as well as offering a cluster possibility regarding terms considerable as key words for types of activities or object treatment.
- Semantic correspondences with low confidence can be helpful as indications that the aligned elements are actually rather highly related

regarding their intended meaning when their naming or phrasing impedes the detection of the appropriate confidence value in cases of abbreviations, the use of nouns instead or verbs or vice versa or disparately used hyphens or plus signs.

As the results achieved have been demonstrated and evaluated throughout the method's design and development iterative improvement and completion was possible, in particular by incorporating the feedback and input received through the continuous publishing of the results.

4.7 Publication of Results

For presenting the research work conducted in detail, out of the author's total list of peer-reviewed publications in the field four have been selected exclusively for comprehensively describing the results achieved here. In Figure 4-4 the individual publications are related to the method phase they focus.

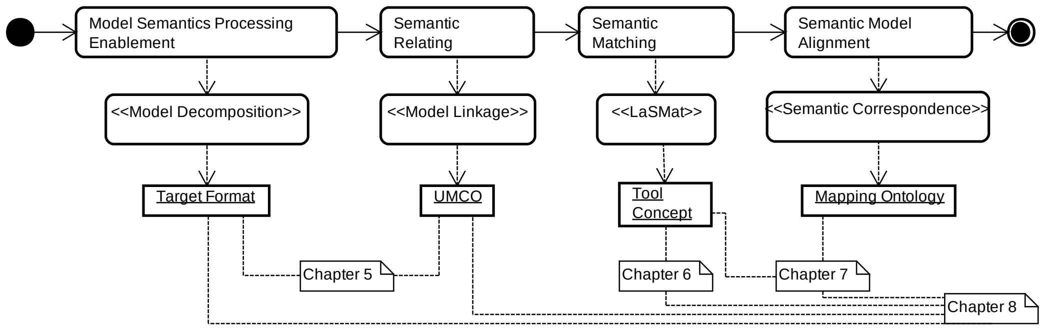

Figure 4-4 Publications presenting Semantic Model Alignment for Business Process Integration

The benefit of combining model decomposition and model linkage could be initially demonstrated by means of a web-based tool called MODI that has been developed using the open source Semantic Web Framework Jena for programming the working with the ontologies. This tool includes a freely available ontology matcher system as reported in Chapter 5 . Based on ontologies obtained through model decomposition, automated determination of semantic correspondence of similar class and process models is performed by the coupled ontology matcher system. Thereby the focus lies on finding semantic references that express semantic similarity between model elements indicating the strength of the similarity computed and enhancing this with a user ranking for rating the perceived correctness of the automatically determined similarity measure in form of a value called acceptance. Here is the special interest on the social component of user involvement through the manual assigning of such rating values to the results. These rated results are stored in a knowledge basis from which a list of correspondences is obtainable.

However, as the common ontology matchers do not fulfill the requirements for phrase sense disambiguation in the case of matching ontologized business process models, the novel procedure of language-aware semantic matching has been created. Chapter 6 reports in detail how it supplies flexible computation enablement of semantic similarity by phrase sense disambiguation and an intuitive representation format of the resulting alignment for further usage. Its application to the question of aligning business process models with a special focus on the linguistics analysis is reported in detail in Chapter 7. A comprehensive application of the method of Semantic Model Alignment together with its evaluation is shown in Chapter 8 .

THE ORIGINAL PUBLICATIONS ARE NOT INCLUDED IN THIS VERSION.

Chapter 5 SEMANTIC INTEROPERABILITY ENABLEMENT IN E-BUSINESS MODELING

This chapter represents a peer-reviewed book chapter that has been published twice:

(1) Fengel, Janina (2011): Semantic Interoperability Enablement in E-Business Modeling. In: Kajan, E. (ed.): Electronic Business Interoperability: Concepts, Opportunities and Challenges. IGI Global Business Science Reference, Hershey, pp. 331-361. DOI 10.4018/978-1-60960-485-1.ch014

and

(2) Fengel, Janina (2011). Semantic Interoperability Enablement in E-Business Modeling. In: International Management Association, USA (eds.): Global Business: Concepts, Methodologies, Tools and Applications. IGI Global, Hershey. S. 373-402. DOI 10.4018/978-1-60960-587-2.ch209

Abstract

Businesses all over the world are faced with the challenge of having to flexibly react to change and to dynamically work with varying business partners. For establishing electronic business, the underlying processes and subsequent IT-support need to be described clearly. For doing so, conceptual modeling has become an indispensable means. Models describe interrelated business objects and activities, expressed in a certain modeling language with elements labeled in natural language. If the decision for the labels is not dominated by rules, models are semantically heterogeneous not only concerning their modeling language, but

more importantly concerning their domain language, making their comparison or integration a non-trivial task. For its alleviation we apply Semantic-Web technologies. Transforming legacy models of different types into ontologies allows for reusing and connecting the domain facts modeled. We here describe our novel method of semantic model referencing developed for this task and show how it can provide the basis for semantic integration.

Chapter 6 LANGUAGE-RELATED ALIGNMENT OF THE DOMAIN SEMANTICS IN HETEROGENEOUS BUSINESS PROCESS MODELS

This chapter has been published in German as a peer-reviewed conference paper:

Fengel, Janina; Reinking, Kerstin (2012): Sprachbezogener Abgleich der Fachsemantik in heterogenen Geschäftsprozessmodellen (*Language-related Alignment of the Domain Semantics in Heterogeneous Business Process Models*). In: Sinz, E.; Schürr, A. (eds.): Modellierung 2012. GI-Edition - Lecture Notes in Informatics (LNI) P-201. Köllen, Bonn, pp. 43-58. URL http://subs.emis.de/LNI/Proceedings/Proceedings201/32.pdf.

Abstract

Within enterprises, over time business process modeling produces collections of differing models. When they are to be merged, semantic differences hinder content-related matching, even though this is the pre-condition for model integration as for example in cases of analyses, enterprise reorganizations, company mergers or standard adoptions. Next to semantic heterogeneity caused by the usage of different modeling languages, a main obstacle for automated matching of models is the manner in which the natural language chosen for the designation of models and their elements is used as well as differently applied domain languages. In this contribution a method is introduced of how a combination of ontology matching procedures can offer heuristic support.

6.1 Background and Motivation

Business process modeling for describing and designing business operations has significantly gained importance over the past decades. Therefore in business practice often the need for aligning existing models arises in cases of projects of architecture, data and process integration, semantic consolidation projects, company mergers and B2B integrations as well as at the time of adopting standards or standard software. For consolidating business process models the existing models have to be compared regarding the meaning of their elements for detecting correspondences, consolidation points, interfaces or even overlaps and redundancies. However, comparing and linking is a non-trivial task, because even models of the same type often differ semantically (Becker and Pfeiffer, 2008). Indeed, semantic heterogeneity occurs not only in the area of the modeling languages, but typically in the choice of the technical and domain specific terms in the natural language used for labeling the model elements (Thomas and Fellmann, 2007).

Notably the arbitrarily chosen professional terminology impedes the integration of models and in this of the underlying data and processes, even more so in case of different origin of the models, be it from decentralized teams, different departments or enterprise divisions or other independents companies. The designations of the labels phrased in natural language reflect the passed down company specific business language next to the domain terminology common in the particular industry. If no general bindingly defined vocabulary or rules for the application exist, models can differ considerably in this respect. Comparisons are difficult not only due to different meaning of designations used and the understanding about them, but also due to differently chosen terms or term combinations for labeling model elements. If naming conflicts are at hand due to synonymy or homonymy, models are not directly comparable and are thereby neither manually integrable nor automatedly (Becker *et al.*, 1996; Thomas and Fellmann, 2006). Especially in large companies a multitude of models already exists, which have been created over time by different persons or decentralized in teams with several persons, often also according to different guidelines, in different modeling languages or by using differing domain terminologies. Even if the same situation is modeled, models that have been created in a collaborative manner can differ substantially regarding their labels, so that the comparability necessary for their usage cannot be generally presumed (Becker *et al.*, 2010a). This applies to an even greater extend in cases where models from previously independently acting companies or company divisions are encountered. Therefore, it is imperative to analyze the actual semantic as-is-status prior to beginning any further works. Semantic ambiguity needs to be resolved for relating and matching models' statements with regard to the content, because it is only the alignment of the domain language that allows for identifying models and model elements that are similar and correspond to each other with regard to their meaning and based thereon potential further structural comparisons (Simon and Mendling, 2007). As yet, such analysis tasks are mostly achievable only manually. The matching required and the integration of conceptual models such as business process models as being in the focus here are purely intellectual work. In case a lot of and large models are given, without automated support these tasks can only by fulfilled by extensive resources allocation.

For closing this gap and utilizing the potential of computing power for automated processing, in the following an IT-supported heuristic method to that effect is presented. The approach focuses onto the usage phase following the creation of models, in particular on issues of collaborative utilization. For reducing the workload on the users' side for meaning-based matching, the application of Semantic-Web-Technologies, in particular ontology engineering, and a combination of procedures for natural language processing onto the question of determining semantic similarity of business process models is described in section 6.2. This is followed by the presentation of the method for capturing and formalizing the semantic information contained in business process models and the required ontologies for this, and furtheron in Section 6.3 by the applicable prototypical implementation. Based on this prototype the application of the method is shown in Section 6.4. The contribution closes in Section 6.5 with the presentation of related work and a short conclusion together with an outlook onto future work.

6.2 Semantic Analysis

Models usually represent agreed-upon specialized knowledge. This is knowledge about the description of business situations in representation or modeling languages as well as the subject knowledge about the modeled sequence of activities described by the organizational or business semantics. The exploitation and description of this knowledge can be done by semantic analysis (Liu, 2000). Thereby the relations between objects of both domains can be captured and depicted. In general, the representation and automated processing of knowledge can contribute to further developing information processing. In daily business operations the ubiquity of the Internet as a global infrastructure has contributed to the high acceptance of web-based support of electronic business conduction. The development of the idea of the Semantic Web and its specific technologies now further offers the possibility of using web-based ontologies in their capacity as explicit specifications as a means for structuring knowledge and the provision of semantic interoperability based on open standards. The principle of annotating information with metadata allows for the representation of knowledge in structured, machine-accessible form based on Internet technologies, readable both for machines and for humans (Shadbolt *et al.*, 2006). Especially in cases where intellectual work is too costly and in particular matchings need to be performed recurrently for large and heterogeneous amounts of data and information, the usage of these technologies may be beneficial (Frank, 2010a). The aim of a domain-language related alignment of business process models is to support the preparatory work for structural model comparisons, which are in turn influenced by the modeling language used.

6.2.1 Ontology Creation and Ontology Matching

Ontologies are core elements of the Semantic Web. They are IT-artifacts and can be understood as conceptual schematas (Antoniou *et al.*, 2005). In principle ontologies are collections of definitions of elements and their relations and contain an agreed-upon vocabulary (Daconta *et al.*, 2003). They formalize the meaning of terms. Although the same problems arises as when developing ontologies at the same time when models are developed, namely the occurrence of semantic heterogeneity due to the choice of the modeling language and the domain language for the designations for classes or concepts, respectively, as well as the relations, ontologies in turn are further usable for automated alignments. The research in the field of ontology matching concentrates on the questions of matching and resolving semantic ambiguities (Euzenat and Shvaiko, 2007).

Ontology matching procedures support the clarification of the meaning of designations used and in this serve for detecting the meaning of statements about facts and their descriptions, respectively. The goal is the discovery of semantic relations, which can be expressed as ontology mappings. Applied onto the question of determining the similarity of the content meaning of models and their elements these can serve as semantic correspondences. This enables statements such as “A in ontology X corresponds to B in ontology “, which are describable as functions

$$SemCorr\ (e_1) = \{\{e_2 \in O_2 | e_2\}, e_1 \in\ O_1\ \} \in\ [0,1] \qquad (6\text{-}1).$$

These semantic correspondences express equivalency or similarity. For aligning the domain or business semantics in business process models element-based ontology matching procedure are useful. An extensive overview can be found in (Euzenat and Shvaiko, 2007). Correspondences can be persisted for further usage. Thereby the related ontologies can remain without the need of having to be merged. This is especially useful with regard to the fact that the underlying models cannot be amended readily as they are actively in use. Instead, preserved correspondences offer the possibility of a virtual semantic integration.

6.2.2 Capture and Formalization of Model Semantics

Existing business process models are non-ontological resources from which the meaning of the model statement may be extracted through reengineering and semantically formalized. Such a reuse of models and their conversion into ontologies provides for their further usage while they remain unchanged for active usage. Through automated decomposition and transformation into ontologies machine access to the knowledge contained is established. The starting point for tapping the knowledge contained is the consideration that models contain facts from two knowledge areas. From the ontological space of the domain language concepts have been taken for denoting models and their elements, while the concepts of the modeling language have been used for a description in the sense of classifying and ordering these domain concepts. By reverting this process models can be deconstructed for extracting the concepts of each language space and capture these in models as described in (Fengel and Rebstock, 2010a). Thereby the existent model information is accessed without any manual or additional intellectual efforts at this time. The ontologies for the description of the metamodel are already available in OWL and can be used for processing model decomposition. Hence, for the actual matching no preparatory efforts are required. Upon decomposition the models are converted by means of XSLT in two ontologies in OWL DL. These are the model ontology with the labels of the model name and the model elements and the model type ontology with the model type and the model element types. Together they describe the model with its name and model type and the model elements with their names and their model element types. Upon converting, all model names and model element labels are transferred as-is without any further treatment. Thus complete expressions can be taken for further processing, as the subject expertise knowledge at the time of modeling often only becomes available through the combination of terms into often used phrases. Likewise it is preserved that potentially conventions have guided the assigning of the element labels just as the natural language used and differing language usage are preserved together with any domain characteristics. For the designation of the events and actions in business process models mostly expressions or phrases, respectively, are used which contain multiple terms that rarely constitute a complete sentence. Hence, for a semantic alignment each term needs to be looked at by itself and also in its function as a part of the given combination, as the phrases carry their intended meaning only in their entirety. The most obvious difference noted upon analyzing the models aligned with the method presented here was the differentiation between models in the German and English language. However, it came evident, that mostly no colloquial language is applied and the expression of emotions such as irony or embellishment do not occur. Furthermore, describing adjectives, adverbs or modifying expressions have been hardly found. Thereby it also became obvious that different designations for the same concept can be found not only due to a different language usage on the part of the modelers, but also on account of the requirements and constraints of the particular modeling language (Becker *et al.*, 2010a).

6.2.3 Semantic Alignment of the Natural Language of Designators

For automatedly relating the models ontologies created which contain the domain semantics of the converted models ontology matching procedures can be applied. Thereby automated support can be provided for model comparisons that otherwise need to be performed manually and the model elements that reflect the domain semantics can be compared independently of the originally used modeling language. Thus is was shown that the designation of elements with multiple terms in one phrase as described above and commonly given in process models causes results of minor value when applying name-matching techniques such as string comparisons or string matching metrics alone. This holds especially true in case synonyms are encountered as well as in cases where the same or similar terms are at different positions within the phrases to be compared. Hence it was necessary to fulfill different requirements. As described, differing language usage by modelers leads to the application of differing designations. Hence, it is to be expected that synonyms are present in the models to be compared, and it cannot be detected that they correspond if solely string metrics are used. Instead, the resolution of synonyms is essential. Furthermore, it is to be expected that designators in semantically similar models can appear in different languages. Accordingly, processing models in multiple languages and using information linguistic procedures depending on the respective language used is required. But in that the designators in models are phrases which are not grammatically complete sentences or even less texts, some information linguistic procedures are not directly applicable. For example, such phrases cannot be examined meaningfully by part-of-speech analysis. For providing suitable treatment for this kind of designators here several different methods have been combined, which are presented in detail in the following.

6.2.4 Information Linguistic Procedures

In the past decades different natural language processing and information linguistic procedures became available that enable the processing of natural language in and for information systems (Harms and Luckhardt, 2009). Thus they are suitable for ontology matching at element level (Euzenat and Shvaiko, 2007).

6.2.4.1 *Decomposition of Compounds*

Terms in natural language can be of different complexity, either consisting of a single term or in form of a combination of terms. Thereby a single term usually consists of the word and a term combination comprises several terminological components. In English these are often multiple word terms, while in contrast in German these are compound terms, i.e., the combination of at least two individually existing words into one composite word (Bertram, 2005). For languages foreseeing the creation of compounds such as the German language their decomposition and subsequent comparison of the individual components is considered to be meaningful (Stock, 2007). Thereby, upon decomposing it is of importance to generate conceptually meaningful terminological component parts for finding all occurrence of a search term. For avoiding meaningless decompositions of compounds or undesired decomposition of proper names appropriate dictionaries can offer support (Bertram, 2005).

6.2.4.2 *Disambiguation through Resolving Synonymy*

Synonyms are differing designations for the same concept. The differences occur in form of differing inflection, spelling variants, abbreviations or full forms as well as alternatively used designations (Weiss, 2001). Resolving synonyms ensures that semantic correspondence of concepts can be detected, even if they are designated differently so that matching results are optimized (Stock, 2007). Such synonymy resolution or word sense disambiguation can be performed through employing a thesaurus as a synonym dictionary for support (Stock, 2007). A thesaurus links terms to conceptual entities with or without listing preferred labels and relates them to other concepts. Such systems mostly capture semantic relations such as synonymy and ambiguity, hyponymy and hyperonymy, and antonymy as well as association (Stock and Stock, 2008). For creating web-based thesauri the W3C provides SKOS, the Simple Knowledge Organization System (Miles and Bechhofer, 2009). The use of SKOS allows for the reuse of freely available resources, such as for example WordNet (Fellbaum, 1998) or the STW Thesaurus for Economics (ZBW, 2010).

6.2.4.3 Treatment of Stopwords

In information retrieval words that are not considered upon indexing are called stop words. Mostly they have syntactical functions and are therefore not relevant for drawing conclusions about the content of a document. In German as well as in English these are articles, conjunctions, prepositions or pronouns and negation (Bertram, 2005). Nevertheless, they are essential for understanding meaning (Bertram, 2005). The number of stop words may vary depending on the domain, since also words can be included which, even though they carry meaning, are not to be used for analysis purposes, since they occur in most documents and are therefore not useful for differentiating content. Accordingly, applied onto the issue of the business semantics in process models it seems advantageous to not eliminating them in general as suggested in (Koschmider, 2007), but domain specifically. Depending on the type of searches refraining from elimination allows for better results when searching in word combinations (Beus, 2008). Furthermore, in the case of business processes often the existence of negation within decisions is of importance when searching for semantically similar elements. Especially when short phrases are given in which a stop word common to the given language constitutes a significant difference in meaning, stop word elimination can lead to incorrect results, as for example with negations (Stock, 2007).

6.2.4.4 *Stemming*

For morphological analysis information retrieval methods for determining the basic form of a word or lemmatization as well as for determining the stem of a word or stemming can be used (Stock, 2007). Through lemmatization the grammatical base or principal form is determined by attributing the concrete form to a dictionary entry. Through stemming the morphological variants of a word are traced back to their common stem by deleting inflectional endings and derivation suffixes, though this is not necessarily a lexical term. In the given case of matching process models this way semantic similarity between activities can be detected more precisely, regardless if named with a substantiated verb or a combination of a verb and a noun, and objects, as here only the stems are compared. Furthermore, undesired matching of suffixes is prevented, as they are deleted prior to matching.

6.2.4.5 *String Matching*

A sequence of characters out of a defined character set is called a string. Strings may be character sequences of arbitrary length from a predefined set (Euzenat and Shvaiko, 2007). String matching algorithms search for matching character sequences. This task needs to be addressed in various domains and has over time led to different approaches (Cohen *et al.*, 2003). String metrics allow for measuring the similarity of character sequences (Stoilos *et al.*, 2005). The Levenshtein distance of two strings expresses the minimally required number of insertions or deletions for converting the first onto the second string (Levenshtein, 1966). The Jaccard metric compares the similarity of words within an expression (Jaccard, 1912). The Jaro metric compares characters and their position within the string, even when they are a few positions apart (Jaro, 1989). N-Grams can be used for fragmenting words or character sequences (Stock, 2007). On this basis the Q-Grams algorithm counts the common set of tri-grams in the strings to be compared and is therefore applicable for so called approximate string matching (Sutinen and Tarhio, 1995). As the results returned by the different methods can be very different, a suitable metric needs to be chosen depending on the language and the function of the terms (Stoilos *et al.*, 2005). Even though string metrics alone cannot fulfill all requirements for finding semantic similarity of designators, they proved nevertheless useful in this field (Stoilos *et al.*, 2005). They can be used for determining semantic similarity based on the matching of strings in case synonymy of terms is not given. Prior stemming can further increase the result precision, as by reducing onto the word stem for example matchings of suffixes are not computed.

6.3 Implementation

For applying the described method a prototypical system called LaSMat has been implemented, which stands for Language-aware Semantic Matching.

6.3.1 Technical Realization

The implementation of the components has been realized in Java. The system can be linked through as a Java API or be used by a prototypical graphical user interface. Figure 6-1 shows the process for matching model ontologies in form of a sequence diagram. For a request as the first step a comparison of both phrases is being done. This alignment is processed unidirectionally. If a complete matching exists, a value of 1 is returned as the confidence value and in this as the assumed strength of the semantic correspondence found. If this is not the case, the phrases are split into the individual terms which in turn are compared. Thereby all of the above methods are applied, although the decomposition of compounds is presently only performed for German.

For all methods the user has the possibility to parameterize by assigning weights to the results. The weights for matchings of terms which have been identified as stop words are configurable. For resolving synonyms thesauri in SKOS-format can be imported at runtime. By default WordNet (Fellbaum, 1998) in SKOS (W3C, 2010) is included as a general lexical resource for English and as a business specific resource the STW which contains terms in German and English (ZBW, 2010). Furthermore, generally for German a version of the OpenThesaurus (Naber, 2005) created by us in SKOS is in use.

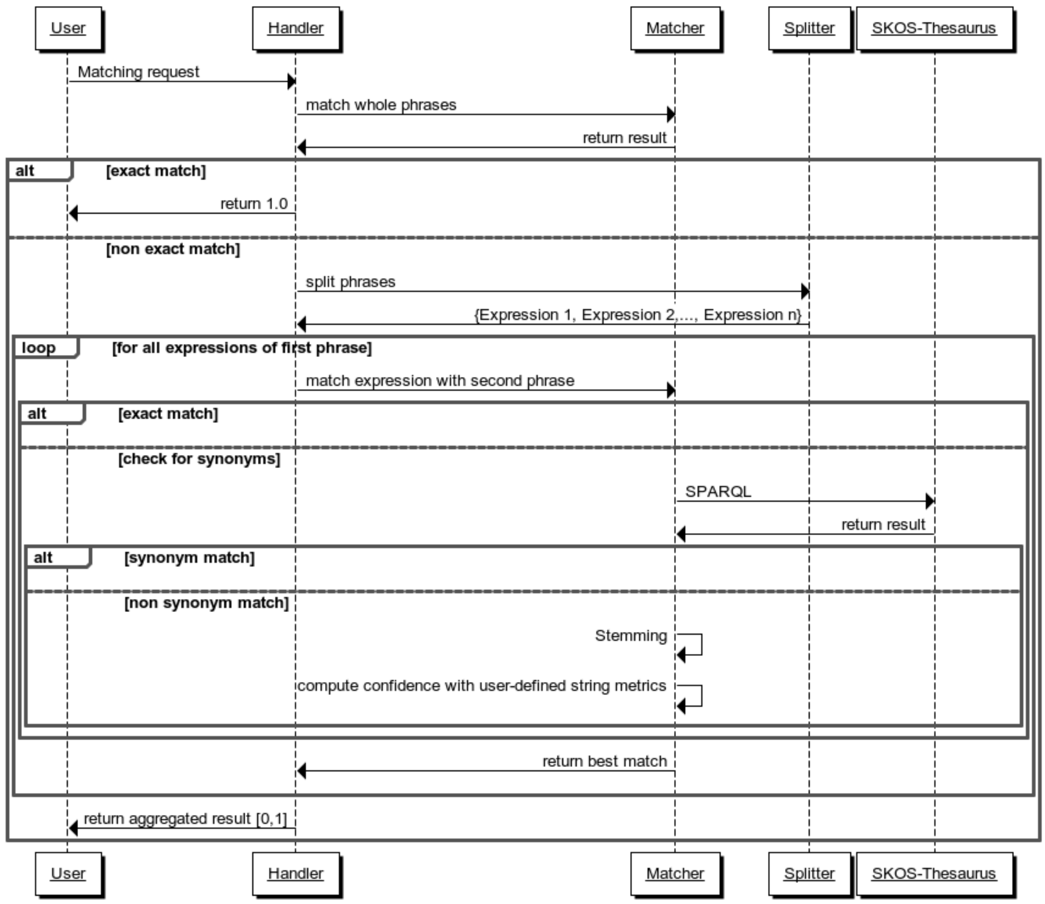

Figure 6-1 Sequence Diagram of the Language-aware Semantic Matcher

Thereby the weighting of synonym matches for the result aggregation can be configured through the parameter s $\in$ [0,1] as the synonymy measure. For stemming the libraries of the Snowball Project for German and English are used (Porter and Boulton, 2011). For string matching a selection of different string metrics is available. For this the JAVA API SimMetrics is used (Chapman, 2006). For weighting the results for the aggregation of the overall result an applicable value can be set. For computing the overall result from confidences of the correspondences found the best results from all methods are aggregated. The results are alignment information for each phrase. These may be stored in the INRIA format (Euzenat, 2006) as well as in an alignment ontology in a format developed by us. The prototypical graphical user interface provides a tabular visualization of the results, whereby for filtering a threshold for the confidence of the correspondences found can be set.

6.3.2 Computing Semantic Similarity

Correspondences found are described a tuples in the form

$$\langle (e_1, m_1), (e_2, m_2), c \rangle \tag{6-2}$$

whereby

- (e_k, m_k) is the label of an element of a model ontology,
- c as the confidence represents the assumed strength of the relation, expressed as a numerical value between 0 and 1.

The algorithm developed determines a fuzzy value for the similarity between two element designators or labels, respectively, whereby 1 expresses equivalency and 0 denotes no correspondence. We define the similarity between two labels as the arithmetic mean of all similarities in relation to the number of term in both labels with

$$Sim(e_1, e_2) = \frac{\frac{OverallTermSim(e_1, e_2)}{length(e_1)} + \frac{OverallTermSim(e_1, e_2)}{length(e_2)}}{2} \tag{6-3}$$

whereby

- $length(e_k)$ is the number of terms of label e_k, expressed as $length(e_k) = Num(t_{e_k})$,
- $OverallTermSim(e_1, e_2)$ is the overall similarity of all terms of two labels.

For computing the overall similarity in each case the highest similarity measure between the applicable term and all terms of the second label are used with

$$OverallTermSim(e_1, e_2) = \sum_{k=1}^{length(e_1)} \max\left(Sim\left(t_{k_{e_1}}, t_{1 \dots n_{e_2}}\right)\right) \quad (6\text{-}4)$$

whereby

- $Sim(t_k, t_n)$ is the similarity measure of two terms.

The calculation of this similarity measure is based on the inclusion of different values. In case of an exact match the similarity measure is

$$Sim(t_k, t_n) = 1 \quad (6\text{-}5).$$

However, in case thereby two equivalent, i.e., totally similar terms are stop words instead of the value of 1 the configurable stop word measure is used. In case of (k ≠ n) the result of the distance measure would be that similarity is not given or that a separate treatment due to the distance between the individual characters, here terms, is required (Jaro, 1989). Thereby it needs to be considered that differently as with pure character sequences such as gene codes, the distance between two terms does not in all cases induce modifications in meaning, but that nonetheless semantic similarity exists. This can be illustrated with the example of the two labels „check invoice“ und „invoice check“ for which semantic similarity is presumable. However, the different positioning of the terms in the labels suggests the presence of different word types. Thus the distance between terms allows for concluding a difference, but a lesser distance than the one between characters in a string (Porter and Winkler, 1997). Therefore, in our approach here for (k ≠ n) this is further developed to

$$\frac{Sim(t_k, t_n)}{td} \quad (6\text{-}6)$$

whereby

- *td* is introduced as „term disorder weight” with a value ≥ 1.

This follows the idea by McLaughlin for treating “disagreeing characters” in string matching as applied in (Porter and Winkler, 1997), even though the actual distance of the two terms is disregarded for above mentioned reason. This value is configurable. A high value lowers the similarity measure between two terms that are at different positions within a phrase.

6.3.3 Interpretation of Results

The matching results describe the strength of a correspondence determined as a confidence value between 0 and 1. However, at the time of the result analysis by domain experts it became apparent that the results are not intuitively comprehensive in this form. Therefore fuzzyfication is carried out and beginning with 1 for $c = 1$ the statement “exactMatch”, for $1 < c > 0.745$ the statement “closeMatch”, for $0.745 < c > 0.495$ the statement “relatedMatch“ are presented to users. This supports them for deciding about further alignment or analysis works.

6.4 Application

The prototype has been used for demonstrating its feasibility and usefulness for a collection of totally 1,380 business process models with equal parts with German or English element labels. These are models from the SAP Reference Model, different models from the literature as well as reference models from e-business standards.

6.4.1 Empirical Evaluation

From this collection randomly eight models pairs have been chosen between which similarity has been assumed. Thereby models of different type have been arbitrarily selected from EPC, BPMN model and UML activity models. Additionally, the configurable values as shown in the screen shot in Figure 6-2 have been set.

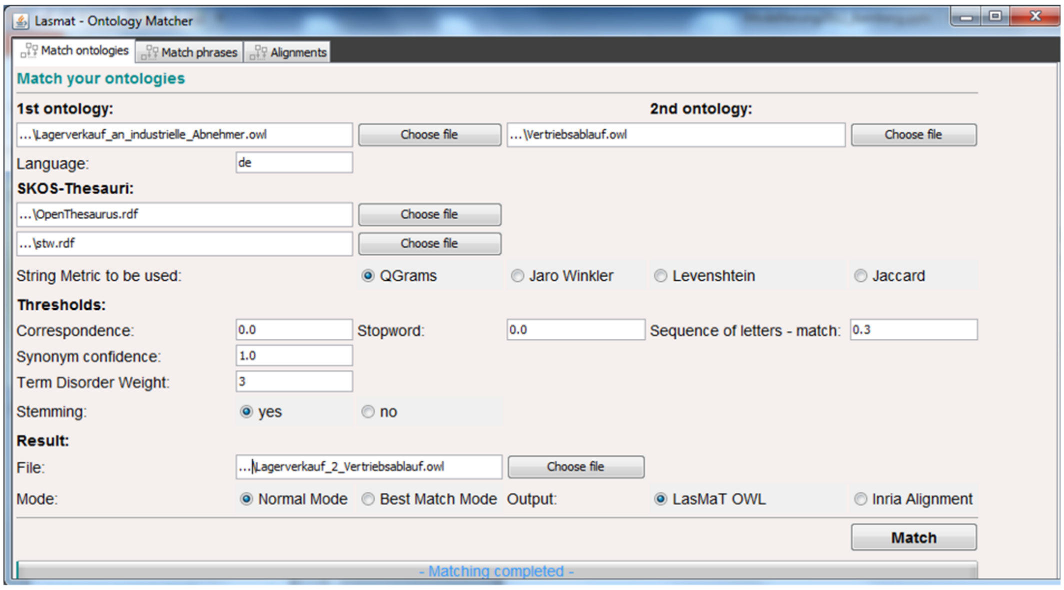

Figure 6-2 LaSMat Screenshot

For evaluating the results of the matchings performed of the model ontologies which represent the business semantics, the correspondences found with a confidence above 0.5 have been compared with correspondences manually created by domain experts for reference. Most evident was the expenditure of time. While human efforts for matching all chosen model pairs ranges between one to several hours, the matching by the LaSMat system lasted between 290 ms to maximum 3.100 ms per pair. For assessing the quality of the results measures from information retrieval have been applied (Stock, 2007). These are precision (*P*), recall (*R*) and F-measure (*F*) expressed as a value between 0 and 1. *P* denotes the correctness as the relation of the number of all correctly found correspondences to the number of all correspondences found in total. *R* denotes the completeness as the relation of all correctly found correspondences to the number of all correspondences expected to be found. For an overall assessment *F* shows the weighted harmonic mean of these two values. The application of our method yielded for P a mean value of 0.89, for R a mean value of 0.9 and for F a mean value of 0.89. As an indicator for the method's feasibility the mean values of the sample could suggest a precision between 0.8 and 0.98 and a recall between 0.83 and 0.97 for the population with a 5% probability of error, whereby the maximum value is always 1.

6.4.2 Detailed Analysis of the Method Combination

For evaluating the effects of parameterizing the various procedures used a detailed assessment of individual examples has been done. Through the decomposition of compounds the results have been enhanced as expected, for example for the similarity between "Rechnungsprüfung" and "Rechnung prüfen" a value of 0.54 was returned without decomposition and a value of 0.74 with decomposition. Synonym matches can be weighted differently. This seems useful for cases where the meaning is shifted due to the presence of quasi-synonyms. While matching without synonymy resolution does not find similarity between labels with the same intended meaning, these similarities are found by synonymy resolution. Thereby a value of 0 results in a matching without synonymy resolution, whereas all values greater than 0 weight the results. An exact match found between stop words significantly influences the overall result in phrase matching due to the low number of terms in comparison to full texts. Our approach with weighting stop word matches with 0.0 so that stop word matches are not included in the weighting for the overall result returns similar results as with stop word elimination, but still considers the cases where a stop word constitutes a difference in meaning. Through stemming matchings could be supported, whereby the results for the German languages with its heavy use of inflections could only be improved less than for the English language. For matching strings for the evaluation Q-Grams was used with, in accordance with McLaughlin as described above, a term disorder weight of 3. This improved the recall through considering the position of a term within a phrase.

6.5 Related Work

Due to the importance of modeling for describing and designing business operations consequently model matching and model integration are becoming increasingly more important for the optimization of processes and IT and in this ultimately for an enterprise's competitiveness. However, despite this importance presently there exist no methods or tools suitable for application within enterprises. Some of the works presented in the literature about model integration concentrate onto the area of the modeling languages and the possibility of migrating or integrating based on the conversion of models from one modeling language onto another (Gehlert, 2007; Murzek and Kramler, 2007). Thereby the aspect of heterogeneously used domain language is not considered, instead the model element labels remain unchanged in use. Even though the usage of ontologies is seen in the long term as a possibility for creating a unified, common, continuously up-to-date and collaboratively evolving digital model of enterprises in their entirety (Frank, 2010a), so far no suggestions exist concerning their application for model alignments after their creation or their integrations or consolidations. Presently suggestions for the integration of process models mostly concentrate onto the phase of developing models. Thereby the existence of a separately developed domain models for labeling model elements or for aligning them is assumed (Brockmans *et al.*, 2006; Weske, 2007). In contrast, our method does not additionally require such preparatory works. Other approaches require manual annotation efforts for enabling semantic processing (Hepp *et al.*, 2005; Thomas and Fellmann, 2009b; Becker *et al.*, 2010a). Presently there are no approaches for semantic alignments of existing models that take into account both the modeling and the domain terminology used together with the different natural languages. Here our approach can be a complement.

6.6 Conclusion

In this contribution a method for semantically aligning existing business process models by means of Semantic Web technologies, in particular ontology matching, has been introduced. Thus the domain semantics in models become computer processable and automatedly comparable by language related choosing and combining various suitable language processing procedures as well as parameterizable result aggregation. The results computed can serve as starting points for further structural matching and based thereon further processing such as consolidations or model modifications. To this end the system proposed here has been prototypically implemented and used for a proof-of-concept of the method conceived. Thereby it could be shown that the chosen combination of individual procedures can offer automated support to users. As the system provides for parameterizing weights further evaluation as to their efficiency are planned for finding domain specifically suitable combinations. Furthermore, (so far) ontology matching does not produce perfect results. In particular, for cases where phrases contain numerical, cryptic or terms in mixed languages additional research is need. In the long term, further research regarding the requirement for block matching for detecting taxonomic or mereological relations could be beneficial. Overall, with our proposition we hope to have been showing the usefulness of applying Semantic Web technologies for supporting alignments of business process models.

Chapter 7 BUSINESS SEMANTICS ALIGNMENT FOR BUSINESS PROCESS MODEL INTEGRATION

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Abstract

Business process modeling has become an accepted means for designing and describing business operations. However, due to dissimilar utilization of modeling languages and, even more importantly, the natural language for labeling model elements, models can differ. As a result, comparisons are a non-trivial task that is presently to be performed manually. Thereby, one of the major challenges is the alignment of the business semantics contained, which is an indispensible pre-requisite for structural comparisons. For easing this workload, we here present a novel approach for aligning business process models semantically in an automated manner. Semantic matching is enabled through a combination of ontology matching and information linguistics processing techniques. This provides for a heuristic to support domain experts in identifying similarities or discrepancies.

Chapter 8 SEMANTIC TECHNOLOGIES FOR ALIGNING HETEROGENEOUS BUSINESS PROCESS MODELS

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Abstract

Purpose

In this paper a solution is proposed for automating the task of matching business process models and searching for correspondences with regard to the model semantics, thus improving the efficiency of such works.

Methodology

A method is proposed based on combining several semantic technologies. The research follows a design-science oriented approach in that a method together with its supporting artifacts has been engineered. It application allows for reusing legacy models and automatedly determining semantic similarity.

Findings

The method has been applied and the first findings suggest the effectiveness of the approach. The results of applying the method show its feasibility and significance.

The suggested heuristic computing of semantic correspondences between semantically heterogeneous business process models is flexible and can support domain users.

Research limitations/implications

Even though a solution can be offered that is directly usable, so far the full complexity of the natural language as given in model element labels is not yet completely resolvable. Here further research could contribute to the potential optimizations and refinement of automatic matching and linguistic procedures. However, an open research question could be solved.

Practical implications

The method presented is aimed at adding to the methods in the field of business process management and could extend the possibilities of automating support for business analysis.

Originality/value

The suggested combination of semantic technologies is innovative and addresses the aspect of semantic heterogeneity in a holistic, which is novel to the field.

Chapter 9 CONCLUSION

In this thesis the new method of *Semantic Model Alignment* and its development is presented. In this concluding chapter a summary of the results is given, the key findings presented and the contribution and limits discussed. Furthermore, an outlook is given onto potential for future research.

9.1 Summary of Results

This research answers the question of how semantic technologies can be applied for automatedly supporting the task of aligning legacy business process models based on the business meaning contained in their elements. For achieving this aim the research objectives established have been accomplished as defined. In order to examine current semantic technologies for applicability as per the first research objective the findings from a systematic literature review were combined with insights gained from domain expertise. These provided the grounds for achieving the second and third research objectives of devising procedures for semantic extraction and matching and developing formats for representing model semantics and alignments as per the fourth research objective. Thereby, the research subquestions were answered in full:

- Answer to RQ1: Model semantics can be captured, explicated and formalized for semantic processing by model decomposition for ontologizing business process models.
- Answer to RQ2: The modeling languages semantics can be exploited for alignment purposes by model linkage through using the UMCO for mapping the ontologized business process models.

– Answer to RQ3: The natural language in model element labels can be matched and semantic similarity can determined between models through phrase sense disambiguation by language-aware semantic matching.
– Answer to RQ4: Semantic alignments can be determined, formalized and preserved for further processing by means of the LaSMat mapping ontology.

In completion, the developments were brought together and formulated into a method. The resulting comprehensive solution has been conceptualized, designed, realized, prototypically applied and published. The method developed is created as a generic ontology-based enablement for automated alignment of semantically heterogeneous business process models. The supporting artifacts have been conceived by foreseeing the use of W3C-standards. Applicable IT-support by means of a semantic matcher was designed and carried through to its implementation for exemplary application for proof-of-concept. The method was evaluated and demonstrated through applying the results and subsequent publishing of the results. The achievement encompasses the creation of a new method suitable for providing IT-support together with its supporting artifacts for semantically analyzing and matching legacy business process models focusing on the business semantics and thereby closing the research gap identified.

9.2 Key Findings and Contribution to Knowledge

The results present a new approach for achieving automation for business tasks that hitherto needed to be performed by humans. Its application supports human users by establishing meaning-oriented relations between business process models through automated disambiguation and mapping, thus allowing for the identification of occurrences, similarities and potential consolidation points of the models for supporting decisions concerning the integration of business processes.

9.2.1 Key Findings

Due to the generality achieved by method's extendable design and foundation on Semantic Web technologies by using open standards the method's application does not depend on certain tools or proprietary formats. During the research it became evident that providing for directly working with the automatically extracted and formalized business process model semantics provides the key to preventing manual preparation efforts and avoiding incurring costs and annotation errors. Furthermore, the method is robust, as also incorrect or unsound models can be ontologized and analyzed and the method application is not affected.

For enabling the usage of the method conceived, all supporting artifacts such as the necessary upper-level ontology and ontology formats as well as the procedure and tool for matching have been created. As a result, no efforts are needed for ontology creation or annotating. The benefit thereby lies in being enabled to obtain model ontologies that are directly usable without any modifications as-is and in any arbitrary ontology editor. The method has the form of a documented procedure containing details for working with the business knowledge contained in business process models and is therefore directly deployable.

Applying the method provides a means for automatedly reusing models, extracting the semantic knowledge contained through model decomposition, and interlinking them for further processing by use of the UMCO. Through the approach of language-aware semantic matching especially developed here for the task of semantically matching phrases in business process model elements, heterogeneous and ambiguous semantics can be resolved and aligned in a heuristic manner. These solutions are novel suggestions for solving these tasks.

The LaSMat mapping ontology format provides the basis for preserving the knowledge as it is given in business process models and extending it by knowledge about links and similarities it can build the basis for the derivation of a semantic model or business ontology, respectively, representing a semantic process map for meaning-based business analysis. This enables unambiguously working on business process integration decisions. The combination of ontology matching techniques with information linguistic methods has proven advantageous for improving the results of phrases in English and furthermore also tackling the challenge of including semantic analysis for other natural languages.

As the method foresees the reuse of existing information and avoids the manual workload of having to create an ontology or remodel or annotate large collections of business process models, it is of high usability. As it is also easily extendable to further model types as well as natural languages due to its foundation on semantically abstracting from models, it can complement present proprietary approaches. The provision of flexibly computing semantic similarity between models and their elements and the consequent use of ontologies as the foundation further differentiate this approach. At the same time it offers users well-grounded alignments and enables the derivation of a comprehensive interrelated semantic model for further analysis.

Overall, by applying the method to the various business scenarios, its usefulness could be demonstrated. It is a holistic and practicable solution for aligning legacy business process models based on their meaning. The results achievable by its application support business analysis and business process integration in an automatic manner.

9.2.2 Contribution to Knowledge

The method developed closes a gap and provides innovative answers to identified issues in this area. Using the method of Semantic Model Alignment supports business process management concerning essential issues involved in integrating processes by aligning the underlying business process models in a new way.

9.2.3 Scientific Contribution

The scientific contribution lies in the development of a novel method for semantically aligning legacy business process models and the design of subsequent support by information technology and the supporting ontology formats. The results provide answers to the open issues identified. The work shows how combining metamodeling with semantic technologies and information linguistics can be beneficially achieved and applied. Through the concept of model decomposition and model linkage together with the development of language-aware semantic matching and the flexible computation of semantic similarity and model aboutness new means have come available in this field.

The solution presented differs from approaches postulated in the literature by its focus on semantic alignment as the basis for resolving disambiguity before including structural model information or performing any structural alignment. It addresses the challenges involved in aligning legacy models, in particular in automatically aligning business process models of different origin in different languages based on their intended meaning as captured in the phrases in their element labels.

The proposed solution is holistic and generic so that it can be applied arbitrarily to any type of model and is based on open standards. Through the creation of a format for result presentation in the standards of the Semantic Web, longevity, interoperability, and reusability of the results are assured. Furthermore, it is a practicable solution in that it does not rely on extensive employment of manual labor. Upfront creation of an ontology or manual annotation of business process models is not required. Instead, the knowledge contained in business process models is automatically extracted and transformed for further semantic processing.

9.2.4 Contribution to Practice

For practice, the method can serve as a readily available solution for using semantic technologies to support meaning-based process model matching.

The experiments demonstrate the feasibility of the approach and that it can serve as a blueprint for ontology-based business process model integration. In addition, the evaluation showed that the information provided support for the fulfillment of business tasks concerning the alignment of legacy business process models, as the semantic correspondences found can be taken by domain experts as a basis for analysis tasks. The requirement of finding elements with the same or a similar intended meaning upon comparing and aligning models can be fulfilled in an automated manner, thus freeing the human users from the error-prone checking process in favor of being able to decide how to proceed further.

Using the method improves and eases the accomplishment of business analysis tasks. The construction of the supporting artifacts, i.e., the ontology formats created and the prototype system developed for the semantic matching task provides for direct application. Overall, the method application provides for automation of a highly challenging demand. In particular, in the case of mergers and acquisitions and the establishing of business collaborations where the models to be integrated originate from different independent sources and can differ significantly, the method developed provides an answer for resolving semantic heterogeneity and ease alignments. Presently the individual model phases are to be processed using openly available software. Notwithstanding, any potential development of one single software tool comprising all single actions is conceivable, as all necessary ontology formats are provided for.

9.3 Limitations

In this thesis a new method is introduced that contributes to the advancement of business process management issues. Nevertheless, a few limitations can be observed.

For reengineering models by XSLT for each model type a sheet is required. However, as most business process modeling tool favour their individual XML-based export format, no generally applicable sheet can be offered. Instead, the creation of suitable XSLT-sheets for the model decomposition needs to be prepared in advance for each model type for processing all the models in this format.

The procedure of language-aware semantic matching is based on European languages and is therefore not directly transferable to non-European languages without further research. Furthermore, it became evident that in cases of more informal or relaxed labelling quality or uncommon abbreviating there is as yet no fully satisfactory correspondence determination possible. To solve this question, potential further research is thought to be beneficial.

Upon evaluating the method application, for objectivity examples from the literature have been used, even though the group of domain experts involved included professionals and academics together. Extending evaluations of the method onto larger collections or including a larger number of experts might be useful once a more adequate possibility for benchmarking results becomes available without manual reference standard creation and the vagueness incurred through using precision and recall for measuring.

9.4 Recommendations for Future Research

The work presented not only provides answers, but potentially also leads to areas for future research. It became obvious in the course of the research that to date semantic matching and information linguistic procedures do not always provide perfect and universally distinct results. Up to now, full automation is not yet achievable due to the liveliness of natural language and its flexibility with regards to how wording and phrasing is possible. To overcome this limitation, starting points for future research could concentrate on issues where ambiguous language is encountered in the form of abbreviations, numeric or cryptic labels or mixes of natural languages, and labels with unclear or inexpert phrasing. Optimizing the matching of natural language and extending ontology matching by the possibility of finding complex mappings and detecting taxonomical or also mereological relations could be of further benefit. This could support alignments of models that greatly differ in scope and granularity.

Alternatively, as an extension of the research presented here, analysis with regard to matching multi-lingual ontologies could potentially provide answers for not only achieving not solely translation, but considering different cultural specifics and legal regulations that may have influenced or even constrained the business processes expressed through their models. Additionally, further research regarding the design of the ontology format developed could in future provide for enhancements leading towards holistic enterprise modeling by exploiting the method's capabilities for automation.

For practice, the method presented here could be used further on for incorporation into a business process management suite. Hence, for advancing further research and development, the development of an open, universal interchange format for business process models that is even extendable to further model types could potentially resolve lock-in situations and isolated process collections that depend on the usage of a certain tool.

Overall, as has been shown here, the potential of semantic processing offers a way to advance the concept of meaningful automation that underlies the field of business informatics to the area of working with legacy models and integration issues within enterprises. Thereby, semantic model alignment has been used for aligning business processes. Yet, the application of the method to other areas such as e-government, scientific processes or production processes might be fruitful and provide new insights. In so doing, another potential area for further research could be the question of how to evaluate matching results more precisely and more user-oriented as by the need of having to manually create a benchmark as gold standard and using only approximative measures.

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GLOSSARY

Business Process Management: Holistic approach providing structuring methods for managing and optimizing an organization's processes for improving the corporate performance

Business Process Model: Specification and representation of a business process in a certain business process modeling language. Often business process models are graphically visualized.

Business Semantics: Business language and specific terminology in natural language, used in the domain of an enterprise or business management

Conceptual Model: An abstracted representation of reality, expressed in a certain modeling language with elements labeled in the natural language as applicable in the respective domain. It is a description by denoting the general ideas and their relations within a certain domain of discourse. In business its purpose is to describe business objects, business activities and events from a business-oriented point-of-view independent from technical and implementation specific details.

Domain Semantics: Specific terminology used in a certain domain

E-Business: Conduction of business supported by information technology through support of communication, information exchange and business processes through electronic communication services in potentially all functional business areas within and across company boundaries.

E-Business Standard: Specification of business related terminology and issues intended as a framework and guideline by providing a common understanding and a means of structuring and ordering. These may be official rules as well as non-official specifications or guidelines developed by companies, users, vendors or consortiums. E-business standards contain pre-defined rules for formatting data such as the descriptions of products, documents, transactions, processes, services, objects or conditions.

Model Aboutness: Overall similarity of the intended meaning of a model to another to a certain degree

Ontology: A formal specification of a conceptualization, usually depicting a certain problem domain serving as a semantic model capturing and describing knowledge for the purpose of under-standing and sharing in an unambiguous manner. Ontologies may have different scopes and degrees of formality, depending on their purpose.

Ontology Mapping: Description and representation of a semantic relation found as the result of ontology matching

Ontology Matching: Process of reconciling two ontologies for searching for equivalences between the ontologies' elements

Semantic Alignment: Determination and collection of relations between concepts with the same or a similar intended meaning

Semantic Analysis: Exploration of intention and study of meaning

Semantic Correspondence: Relation on the conceptual level expressing semantic equivalence or similarity usable as a reference or mapping

Semantic Heterogeneity: Differences in expression and thereby of meaning leading to diversity, therefore in consequence comparisons are hindered.

Semantic Interoperability: Enablement to share and reuse business knowledge upon integrating heterogeneous sources of information concerning their intended meaning, thus making this knowledge compatible.

Semantic Model Alignment: Determination and collection of relations between models and their elements with the same or a similar intended meaning

Semantic Model Referencing: Method for semantically integrating heterogeneous models of different kinds and types concerning their modeling and domain languages

Semantic Reference: Relation on the conceptual level expressing semantic equivalence or similarity usable as a reference or mapping including an acceptance rating regarding the perceived usefulness or correctness

Semantic Similarity: Equivalence in terms of likeliness of the intended meaning of a concept to another to a certain degree

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3. Tag der Forschung der Hochschule Darmstadt (Research Day) 2008

4. Tag der Forschung der Hochschule Darmstadt (Research Day) 2007

5. Tag der Informatik 2007, Hochschule Darmstadt (Informatics Day)

6. Tag der Forschung der Hochschule Darmstadt (Research Day) 2006

7. Tag der Forschung der Hochschule Darmstadt (Research Day) 2005

8. Tag der Forschung der Hochschule Darmstadt (Research Day) 2004

STATEMENT OF AUTHORSHIP

The published book chapters and journal article contained herein have been authored solely by Janina Fengel. The research presented as in the coauthored conference paper titled “Sprachbezogener Abgleich der Fachsemantik in heterogenen Geschäftsprozessmodellen” included in Chapter 6 has principally been developed, executed and written by Janina Fengel as the first author. The co-author contributed to the research works by implementing a software prototype according to the design given by the first author.

Signature ___________________________________ Date _______________

Janina Fengel

Signature ___________________________________ Date _______________

Kerstin Diwisch, née Reinking

Appendix A Format Template of a Model Ontology

Placeholders are shown in *italics*.

Synoptic Overview

Ontology		
	Model.owl	
Classes		
	DomainEntity	appears once; serves as linkage point
	Model_Name	appears once; can serve as context information
	X	each class represents an element label; ontology contains as many as needed
Object Properties		
	`is_associated_with`	connects the class representing the model name with all classes representing the element labels
	`follows`	for preserving the information about the element sequencing; flow connectors in the model indicating a split, regardless if an inclusive OR or an exclusive XOR, require the value constraint `owl:someValuesFrom` and a joint requires the value constraint `owl:allValuesFrom`
	`is_followed_by`	inverse to `"follows";`
	`occurs_as`	creates the connection into the applicable Modeling Concepts Ontology (MCO)

Representation in OWL

Classes of a Model Ontology

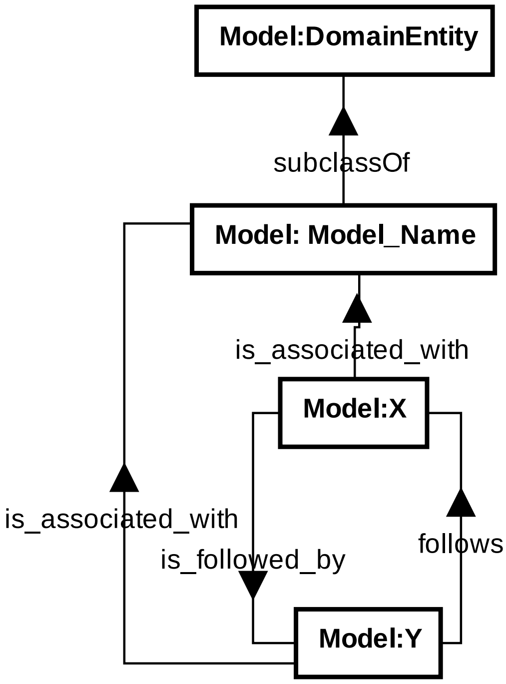
```
<owl:Class rdf:about="&MODEL;DomainEntity">
 <rdfs:comment xml:lang="en">Linkage point for the MCO</rdfs:comment>
</owl:Class>

<owl:Class rdf:about="&MODEL;Model_Name">
 <rdfs:label rdf:datatype="&xsd;string">Model Name</rdfs:label>
 <rdfs:subClassOf rdf:resource="&MODEL;DomainEntity"/>
</owl:Class>

<owl:Class rdf:about="&MODEL;X">
 <rdfs:label rdf:datatype="&xsd;string">X</rdfs:label>
 <rdfs:subClassOf rdf:resource="&MODEL;DomainEntity"/>
</owl:Class>
```

Object Properties of a Model Ontology

```
<owl:ObjectProperty rdf:about="&MODEL;is_associated_with">
 <rdf:type rdf:resource="&owl;SymmetricProperty"/>
</owl:ObjectProperty>

<owl:ObjectProperty rdf:about="&MODEL;follows"/>

<owl:ObjectProperty rdf:about="&MODEL;is_followed_by">
```

```
 <owl:inverseOf rdf:resource="&MODEL;follows"/>

</owl:ObjectProperty>
<owl:ObjectProperty rdf:about="&MODEL;occurs_as"/>
```

Simplified Representation of Conceptual Idea as a Data Model



Appendix B Format Template of a Modeling Concepts Ontology (MCO)

Placeholders are shown in *italics*. “ML” stands for the abbreviation of the modeling language’s name, “Model_Type” for the type of model and “Language_Construct” for a modeling language’s element.

Synoptic Overview

Ontology		
	*ML*_MCO.owl	
Classes		
	DomainEntity	appears once; serves as linkage point
	Model_Type	appears once
	Language_Construct	each class represents a construct; ontology contains as many as needed
Object Properties		
	`is_part_of`	connects the class representing the model type with all classes representing the constructs
	`has_part`	inverse to “`is_part_of`”;

Representation in OWL

Classes of a MCO

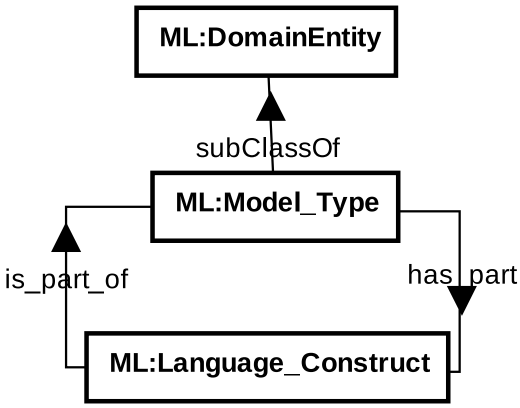
```
<owl:Class rdf:about="&ML;DomainEntity">
 <rdfs:comment xml:lang="en">Linkage point for the UMCO</rdfs:comment>
</owl:Class>

<owl:Class rdf:about="&ML;Model_Type">
 <rdfs:label rdf:datatype="&xsd;string">ML</rdfs:label>
 <rdfs:subClassOf rdf:resource="&ML;DomainEntity"/>
</owl:Class>

<owl:Class rdf:about="&ML;Language_Construct">
 <rdfs:label rdf:datatype="&xsd;string">Language_Construct</rdfs:label>
 <rdfs:subClassOf>
  <owl:Restriction>
   <owl:onProperty rdf:resource="&ML;is_part_of"/>
   <owl:allValuesFrom rdf:resource="&ML;ModelType"/>
  </owl:Restriction>
 </rdfs:subClassOf>
 <owl:disjointWith rdf:resource="&ML;A"/>
 <owl:disjointWith rdf:resource="&ML;B"/>
</owl:Class>
```

Object Properties of a MCO

```
<owl:ObjectProperty rdf:about="&ML;is_part_of">
```

```
 <rdfs:label xml:lang="en">is part of</rdfs:label>
</owl:ObjectProperty>

<owl:ObjectProperty rdf:about="&ML;has_part">
 <rdfs:label xml:lang="en">has part</rdfs:label>
 <owl:inverseOf rdf:resource="&ML;is_part_of"/>
</owl:ObjectProperty>
```

Simplified Representation of Conceptual Idea as a Data Model

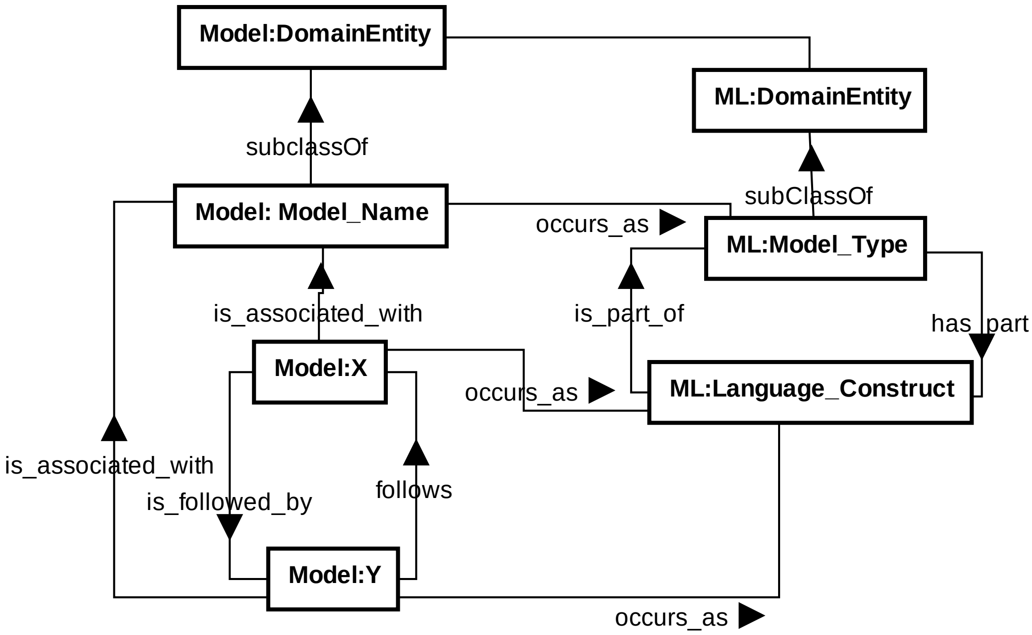


Appendix C Usage of the Object Property "occurs as"

Object Property of the MCO

```
<rdfs:subClassOf>
 <owl:Restriction>
  <owl:onProperty rdf:resource="&MODEL.owl#occurs_as"/>
  <owl:allValuesFrom rdf:resource="&ML;Language_Construct"/>
 </owl:Restriction>
```

Simplified Representation of Conceptual Idea as a Data Model



Appendix D Format of the Unifying Modeling Concepts Ontology (UMCO)

Synoptic Overview

Ontology		
	UMCO.owl	
Classes		
	DomainEntity	appears once; serves as linkage point
	Business_Process	appears once
	Action	appears once
	X	each class represents a construct; ontology contains as many as needed; classes are disjoint
Object Properties		
	`is_part_of`	connects the class representing the model type with all classes representing the constructs
	`has_part`	inverse to `"is_part_of";`

Representation in OWL

Classes of the UMCO

```
<owl:Class rdf:about="&UMCO;DomainEntity">
 <rdfs:label xml:lang="en">Domain Entity</rdfs:label>
 <dc:description xml:lang="en">import interface for MCOs</dc:description>
</owl:Class>

<owl:Class rdf:about="&UMCO;Business_Process">
 <rdfs:label xml:lang="en">Business Process</rdfs:label>
 <rdfs:subClassOf rdf:resource="&UMCO;DomainEntity"/>
 <dc:description xml:lang="en">Abstraction for behavioural models
describing dynamic flows of activities</dc:description>
</owl:Class>

<owl:Class rdf:about="&UMCO;Action">
 <rdfs:label xml:lang="en">Action</rdfs:label>
 <rdfs:subClassOf rdf:resource="&UMCO;DomainEntity"/>
 <owl:disjointWith rdf:resource="&UMCO;Event"/>
</owl:Class>

<owl:Class …
```

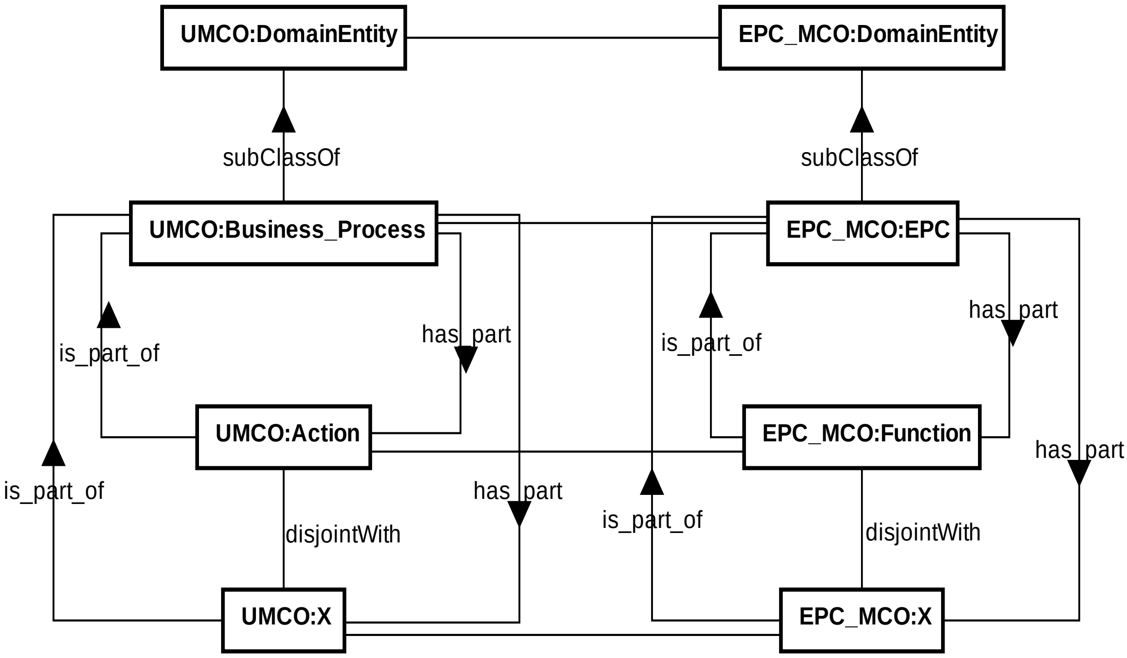
Object Properties of the UMCO

```
<owl:ObjectProperty rdf:about="&UMCO;is_part_of">
 <rdfs:label xml:lang="en">is part of</rdfs:label>
</owl:ObjectProperty>

<owl:ObjectProperty rdf:about="&UMCO;has_part">
 <rdfs:label xml:lang="en">has part</rdfs:label>
 <owl:inverseOf rdf:resource="&UMCO;is_part_of"/>
</owl:ObjectProperty>
```

Setting of Equivalency in the UMCO

```
<owl:Class rdf:about="&UMCO;DomainEntity">
 <rdfs:label xml:lang="en">Domain Entity</rdfs:label>
 <owl:equivalentClass rdf:resource="&UML_AM_MCO;DomainEntity"/>
 <owl:equivalentClass rdf:resource="&EPC_MCO;DomainEntity"/>
 <dc:description xml:lang="en">import interface for MCOs</dc:description>
 </owl:Class>

<owl:Class rdf:about="&UMCO;Business_Process">
 <rdfs:label xml:lang="en">Business Process</rdfs:label>
 <owl:equivalentClass rdf:resource="&UML_AM_MCO;Activity_Model"/>
 <rdfs:subClassOf rdf:resource="&UMCO;DomainEntity"/>
 <dc:description xml:lang="en">Abstraction for behavioural models
describing dynamic flows of activities</dc:description>
    </owl:Class>

<owl:Class …
```

Simplified Representation of Conceptual Idea as a Data Model



Appendix E Elements of the UMCO Prototype

Overview of MCOs and Equivalency Defined

UMCO	Sub-class	**EPC_ MCO**	**eEPC_ MCO**	**UML_AD _MCO**	**BPMN_ MCO**	**UML_CM _MCO**
Business Process	–	EPC	eEPC	Activity Model	BPMN Model	–
Business Process	–	–	Process Interface	–	Subprocess	–
Action	–	Function	Function	Action	Task	–
State	–	Event	Event	–	Event	–
Agent	Role		Group / Role	–	–	–
Agent	Unit	–	Organiza-tional Unit	Partition	Pool	–
Agent	Actor	–	Participant	–	Lane	–
Agent	Actor	–	Person	–	Lane	–
Agent	Appli-cation	–	Applica-tion / IT System	–	–	–
Infor-mation	–	–	Data / Informa-tion	–	–	Class Model
Object	–	–	–	Object	Data Object	Class
Object	–	–	–	–	–	Role
Object	Product	–	Product	–	–	
Object	Docu-ment		Document	–	–	–
Object	–	–	–	–	–	Attribute
Action	–	–	–	–	–	Operation
State	–	–	–	State	Annotation	Constraint

Appendix F Pseudocode for Language-aware Semantic Matching

```
matchOntologies(Ontology ont1, Ontology ont2){
  ont1ExpressionList = extractExpression(ont1);
  ont2ExpressionList = extractExpression(ont2);
  (iterate over ont1ExpressionList){
    (compare current ont1's expression with all elements of
     ont2ExpressionList){
      matchExpressions(expr1, expr2, language);
      generate ResultItem;}
  }
  computeAboutness(Ontology ont1, Ontology ont2);
  return Result;
 }

extractExpression(ont){
  (iterate over ont's classes and individuals){
        if label exists:
          add annotation to return list;
        else:
          add URI fragment to return list,}
  return list;
}

 matchExpressions(expr1, expr2, language){
  if exactMatch:
    return 1.0f;
  else:
    extractTerms(expr1);
    extractTerms(expr2);
    (matchAllTerms){
      case exactMatch:
        if term = stopword: STOPWORD_CONFIDENCE;
        else:
          1.0f
      case synonymMatch via SKOSThesaurus:
        SYNONYM_CONFIDENCE;
      case stringMatch:
        if stemming enabled:
          stemTerms(expr1);
          stemTerms(expr2);
        (matchAllTerms){
          if TERM_DISORDER_WEIGHT > 1:
            computedConfidence / TERM_DISORDER_WEIGHT;
          if computedConfidence > STRING_MATCH_THRESHOLD:
            computedConfidence;
          else:
            0.0f;
          storeBestResults;}
  }
```

Appendix G Functional Requirements for LaSMat

Function	**Requirement**
Input	Possibility to load and match a pair of ontologies
	Possibility to load and match a pair of single phrases
	Possibility to load and match bundles of ontologies
Language setting	Selection of natural language
Background	Inclusion of several arbitrary thesauri in SKOS-format
Stemming	Selection of inclusion
String Matching	Selection of string matcher (edit-distance, distance measuring, sequence of lettering, set comparison)
Computation	Computation of semantic similarity with confidence
Parameterization	Threshold for confidence for result computing
	Confidence of synonym matches
	Weight for stopword matches
	Threshold for string matches
	Term Disorder Weight for result computing
	Threshold for model aboutness
Mode	Choice between normal and best mode (only the mapping with the highest confidence for each element)
Format Generation	Choice between INRIA Alignment and LaSMat Mapping Ontology
Output	Preservation in OWL-file
	List view for analysis
Assessment	Evaluation and computing of P, R, F

Appendix H SKOS-Format of the OpenThesaurus in German

Representation in SKOS

Concepts

```
<skos:Concept rdf:about="OTH:n">
   <skos:altLabel xml:lang="de">X</skos:altLabel>
   <skos:altLabel xml:lang="de">Y</skos:altLabel>
</skos:Concept>
```

Example Extract

```
<?xml version="1.0" encoding="ISO-8859-1"?>
<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
xmlns:skos="http://www.w3.org/2004/02/skos/core#"
xmlns:dc="http://purl.org/dc/terms#"
xmlns:OTH="http://www.project.org/thesauri/OpenThesaurus.rdf#">
<rdf:Description>
<dc:title>OpenThesaurus</dc:title>
<dc:description xml:lang="en">A thesaurus describing synonymy in the
German language</dc:description>
<dc:description>Ein Thesaurus zu Synonymie in der deutschen
Sprache</dc:description>
<dc:creator>Janina Fengel</dc:creator>
<dc:date>October 2012</dc:date>
<dc:language>de</dc:language>
<dc:hasVersion>1.0</dc:hasVersion>
</rdf:Description>
<!--
Creator: Janina Fengel
Email: J_Fengel at web de
migrated into SKOS-format by omitting the given explanations in brackets
from OpenThesaurus - German Thesaurus in text format
as has been published as automatically generated 2010-07-12 00:01
under http://www.openthesaurus.de
Copyright (C) 2003-2009 Daniel Naber (naber at danielnaber de)

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You should have received a copy of the GNU Lesser General Public
License along with this library; if not, write to the Free Software
Foundation, Inc., 51 Franklin St, Fifth Floor, Boston, MA  02110-1301 USA
-->

…

<skos:Concept rdf:about="OTH:6035"><skos:altLabel
xml:lang="de">Verdienstnachweis</skos:altLabel><skos:altLabel
xml:lang="de">Entgeltnachweis</skos:altLabel><skos:altLabel
xml:lang="de">Lohnstreifen</skos:altLabel><skos:altLabel
xml:lang="de">Verdienstabrechnung</skos:altLabel><skos:altLabel
xml:lang="de">Gehaltsabrechnung</skos:altLabel></skos:Concept>

…
```

Appendix I LaSMat Mapping Ontology

Synoptic Overview

Ontology		
	Mapping.owl	
Classes		
	Aboutness	appears once; represents the overall model similarity
	Destination	each class represents a model entity to the ontology to which the matching was performed; ontology contains as many as needed
	Rationale	each class epresents the explanation for a semantic correspondence computed; ontology contains as many as needed
	SemanticCorrespondence	each class represents the semantic similarity unidirectionally computed between “Source” and “Destination” ; ontology contains as many as needed
	Source	each class represents a model entity from the ontology from which the matching was performed; ontology contains as many as needed
	Term	each class represents the individual terms of an element name forming the phrase; ontology contains as many as needed
Object Properties		
	basedOn	connects the class representing the Rationale with the class representing the term
	closeMatch	subproperty for fuzzyfication
	containsTerm	connects the class representing a source or a destination with the class representing a term contained in the phrase
	exactMatch	subproperty for fuzzyfication
	fromSource	connects the class representing the source with the classerepresenting the semantic correspondence
	looseMatch	subproperty for fuzzyfication
	match	represents the match determined
	predicatedOn	connects the class representing the Rationale with the class representing the semantic correspondence
	relatedMatch	subproperty for fuzzyfication
	toDestination	connects the class representing the destination with the class representing the semantic correspondence
Datatype Properties		
	confidence	expresses the confidence of a semantic correspondences
	relation	expresses the type of relation found, i.e. semantic similarity
	value	expresses the aboutness value

Representation in OWL

Classes of the LaSMat Mapping Ontology

```
<owl:Class rdf:about="&lasmat;Aboutness">
 <rdfs:subClassOf>
  <owl:Restriction>
   <owl:onProperty rdf:resource="&lasmat;value"/>
   <owl:someValuesFrom rdf:resource="&xsd;float"/>
   </owl:Restriction>
 </rdfs:subClassOf>
</owl:Class>

<owl:Class rdf:about="&lasmat;Destination">
 <rdfs:subClassOf>
  <owl:Restriction>
   <owl:onProperty rdf:resource="&lasmat;containsTerm"/>
   <owl:allValuesFrom rdf:resource="&lasmat;Term"/>
  </owl:Restriction>
 </rdfs:subClassOf>
</owl:Class>

<owl:Class rdf:about="&lasmat;Rationale">
 <rdfs:subClassOf>
  <owl:Restriction>
   <owl:onProperty rdf:resource="&lasmat;basedOn"/>
   <owl:someValuesFrom rdf:resource="&lasmat;Term"/>
  </owl:Restriction>
 </rdfs:subClassOf>
</owl:Class>

<owl:Class rdf:about="&lasmat;SemanticCorrespondence">
 <rdfs:label>Semantic Correspondence</rdfs:label>
 <rdfs:subClassOf>
  <owl:Restriction>
   <owl:onProperty rdf:resource="&lasmat;toDestination"/>
   <owl:allValuesFrom rdf:resource="&lasmat;Destination"/>
  </owl:Restriction>
 </rdfs:subClassOf>
 <rdfs:subClassOf>
  <owl:Restriction>
   <owl:onProperty rdf:resource="&lasmat;fromSource"/>
   <owl:allValuesFrom rdf:resource="&lasmat;Source"/>
  </owl:Restriction>
 </rdfs:subClassOf>
 <rdfs:subClassOf>
  <owl:Restriction>
   <owl:onProperty rdf:resource="&lasmat;predicatedOn"/>
   <owl:allValuesFrom rdf:resource="&lasmat;Rationale"/>
  </owl:Restriction>
 </rdfs:subClassOf>
</owl:Class>

<owl:Class rdf:about="&lasmat;Source">
 <rdfs:subClassOf>
  <owl:Restriction>
   <owl:onProperty rdf:resource="&lasmat;containsTerm"/>
   <owl:allValuesFrom rdf:resource="&lasmat;Term"/>
  </owl:Restriction>
 </rdfs:subClassOf>
</owl:Class>

<owl:Class rdf:about="&lasmat;Term">
 <rdfs:label>Term</rdfs:label>
```

```
</owl:Class>
```

Object Properties of the LaSMat Mapping Ontology

```
<owl:ObjectProperty rdf:about="&lasmat;basedOn"/>

<owl:ObjectProperty rdf:about="&lasmat;closeMatch">
 <rdfs:subPropertyOf rdf:resource="&lasmat;match"/>
</owl:ObjectProperty>

<owl:ObjectProperty rdf:about="&lasmat;containsTerm">
 <rdfs:range rdf:resource="&lasmat;Term"/>
</owl:ObjectProperty>

<owl:ObjectProperty rdf:about="&lasmat;exactMatch">
 <rdfs:subPropertyOf rdf:resource="&lasmat;match"/>
</owl:ObjectProperty>

<owl:ObjectProperty rdf:about="&lasmat;fromSource">
 <rdfs:domain rdf:resource="&lasmat;SemanticCorrespondence"/>
 <rdfs:range rdf:resource="&lasmat;Source"/>
</owl:ObjectProperty>

<owl:ObjectProperty rdf:about="&lasmat;looseMatch">
 <rdfs:subPropertyOf rdf:resource="&lasmat;match"/>
</owl:ObjectProperty>

<owl:ObjectProperty rdf:about="&lasmat;match"/>

<owl:ObjectProperty rdf:about="&lasmat;predicatedOn"/>

<owl:ObjectProperty rdf:about="&lasmat;relatedMatch">
 <rdfs:subPropertyOf rdf:resource="&lasmat;match"/>
</owl:ObjectProperty>

<owl:ObjectProperty rdf:about="&lasmat;toDestination">
 <rdfs:range rdf:resource="&lasmat;Destination"/>
 <rdfs:domain rdf:resource="&lasmat;SemanticCorrespondence"/>
</owl:ObjectProperty>
```

Datatype Properties of the LaSMat Mapping Ontology

```
<owl:DatatypeProperty rdf:about="&lasmat;confidence">
        <rdfs:range rdf:resource="&xsd;float"/>
    </owl:DatatypeProperty>

<owl:DatatypeProperty rdf:about="&lasmat;relation">
        <rdfs:range rdf:resource="&xsd;string"/>
    </owl:DatatypeProperty>

<owl:DatatypeProperty rdf:about="&lasmat;value">
        <rdfs:range rdf:resource="&xsd;float"/>
    </owl:DatatypeProperty>
```

Appendix J Application Guideline

Representation as an Activity Model