Wirtschaftsinformatik Proceedings 2009 Wirtschaftsinformatik

2009

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Abstract
In process-driven organizations, process models are the basis on which their supporting process-aware information systems are built. Process modeling today is a highly complex, time consuming and error-prone task. In this paper, we define the abstraction levels of process modeling and extract the business knowledge required for modeling a process. Further, we present a process-oriented enterprise ontology framework for capturing all relevant aspects of process models. Finally, we provide a set of application scenarios to illustrate the usage of the ontology framework. In this way, we reduce the complexity of process modeling, enable improved enterprise transparency and help ensuring the quality of designed process models.

1. Introduction

In the 1990s, process orientation was introduced [4] to achieve a holistic view on an enterprise, with business processes as the main instrument for organizing the operations of an enterprise [10]. The innumerable benefits of investing in business process techniques were demonstrated in efficiency, productivity, cost reduction, quality, faster results, standardization, and, above all, in the encouragement of innovation, leading to competitive advantage and client satisfaction [3]. This followed with the introduction of process-aware information systems (PAIS) [9] as means to support the information workers in performing business processes. PAIS are driven by explicit process models, which enable a better understanding of business processes, facilitate communication between business analysts and IT experts and serve as a basis for the management and execution of business processes. However, the sources of business knowledge that describe the processes of an organization are diverse and scattered in IT-supported processes, business documents, presentations and the heads of business people. Currently, there is no agreed upon meta-model which covers the representation of all relevant aspects of process models. On the other hand, Semantic Web (SW) technologies have shown the potential in integrating the knowledge coming from various sources by means of ontologies. In addition, SW provides concepts and tools for automated inference on the represented knowledge, which enables the provision of some additional services based on existing process knowledge.

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The goal of this paper is to show how semantic technologies can facilitate structuring and modeling the knowledge related to business processes and to illustrate the benefits of evaluation on different levels of process modeling. To achieve this, we contribute with i) defining the abstraction levels of process modeling and process information in models, ii) presenting a formal model for capturing all relevant aspects of process models and iii) describing a set of application scenarios.

The paper is structured as follows. Section 2 gives an overview of related work and identifies some open issues. In section 3, we discuss the notion of the process in more detail and provide a layering from high-level business concepts down to process models. Section 4 presents our formal model for capturing the knowledge related to business process design. We discuss the application scenarios of our formal model in section 5. Finally, section 6 summarizes our contribution and indicates the areas for future work.

2. Related work

In this section we give an overview of the related work. We start with the conventional approaches and continue with the semantic-based ones.

ARIS (Architecture of Integrated Information Systems) is a method for analyzing processes and taking a holistic view of process design, management, workflow, and application processing [2]. ARIS consists of five views: organizational view, data view, control view, function view, and product/service view. However, the conceptual model of ARIS does not provide formal semantics which allows only for syntax-based analysis of models.

The Object Management Group (OMG) has been developing a set of business modeling standards for enabling business flexibility. Business Process Modeling Notation (BPMN)[3] specification aims to define a standard modeling notation for business process models. Business Motivation Model (BMM) [11] standard provides a schema for modeling business plans. However, these standards do not cover all the relevant aspects and do not define the formal semantics of the concepts, attributes and relations defined in the specifications. This makes it impossible to perform automated inference on models created using these specifications.

One of the earliest initiatives within the enterprise ontology approaches was the TOVE project [12] that aimed at development of a set of integrated ontologies for enterprise modeling. TOVE Common Sense Model of Enterprise included three levels: reference model with typical business functions (finance, sales, distribution, and administration), generic model (with such concepts as time, causality, space, resources), and concept model (e.g. role, property, structure). However, the granularity of developed ontologies may be perceived inconsistent what hampers their potential application. Enterprise Ontology (EO) [13] is a collection of terms and definitions relevant to business enterprises. It was developed as part of the Enterprise Project, with the aim to provide a framework for enterprise modeling. EO is divided into five parts: i) terms related to processes and planning, ii) terms related to organizational structure, iii) terms related to high-level planning for an enterprise, iv) terms relating to marketing and sales of goods and services and v) terms used to define the terms of the ontology together with a few terms related to time. It was first completed in natural language format and afterwards ported to Ontolingua [13]. Finally, in [6], a set of ontologies for Semantic Business Process Management [5] is proposed. This work gives a rather high-level overview of an ontology stack covering the full BPM lifecycle, based on the ARIS [2]

[3] Object Management Group. Business Process Modeling Notation – BPMN 1.0. http://www.bpmn.org/, 2006.

methodology. However, in order to make use of it, the stack needs to be refined and enriched and some application scenarios need to be defined.

The conventional approaches do not cover all aspects of process description (e.g. business motivation) and do not define formal semantics for the models, while enterprise ontology works fail to provide a process-centric view on the organization. Enterprise ontologies are also not available in any contemporarily recognized ontology language standard for which an efficient reasoner exists. Common weakness of all the works is that they do not provide process abstraction levels to reduce modeling complexity.

3. Process hierarchy and process information in models

In this section we provide two viewpoints for structuring of process knowledge with the purpose of managing process complexity. In subsection 3.1 we present a way to deal with a company's process landscape, starting from a motivational (strategic) level, by gradually enriching the process descriptions with more details (scenario level) until the level of concrete activities have been reached (operational level). Another method to deal with the aforementioned complexity is, to have a clear understanding what sorts of information an organization deals with. We therefore present a process-centric view on the organization in subsection 3.2.

3.1. Levels of abstraction

Enterprise processes are highly complicated as they span across many functional areas, involve many actors, governed by enterprise policies, government regulations, etc. To model such a process with all information is highly complex and would also defy the principle of modeling itself. Hence enterprise processes are modeled with various levels of abstraction. Each level of abstraction models a viewpoint of the enterprise process with a certain level of details for a specific purpose (artifacts associated using dotted arrows in Figure 1). The topmost level usually gives a conceptual view and one can gradually drill down from it to more concrete and detailed processes, as indicated with bold arrows in Figure 1. There is no limit on the number of levels but modeling usually stops at the smallest business relevant activity which has no further process level below. Inspired by *SAP Business Maps*[4] we visualize the levels of abstraction with a pyramid-like structure, as shown in the Figure 1. We have found six different abstraction layers which we are describing in the following.

Business Motivation forms the top most layer of the pyramid. It models the various driving forces (i.e. goals, strategies, metrics, etc.) of the enterprise and the relationships between them (cf. top left of Figure 1). The business motivation model is then structured along the *industry-specific value chain*. The value chain is composed of a sequence of value-creating functional areas - so called value chain elements. It starts from a supplier and ends in a consumer. The top right of Figure 1 shows the telecommunication industry value chain with its value chain elements. A *Business Scenario Group* is a collection of business scenarios with the same business goals. It can span across several functional areas (cf. center of Figure 1) and sometimes also integrates consumers and suppliers delimitating a value chain. A *Business Scenario* is a set of logically related business processes performed to achieve defined and measurable business objectives. Each Business scenario is associated with metrics (key performance indicators) as efficiency benchmarks as shown for *Lead and Opportunity Management* scenario in center right of Figure 1. A *Business Process* is a

[4] SAP Business Maps comprise the content delivered with the SAP Solution Composer, which is a modeling tool freely provided by SAP for creating and browsing business-related diagrams. As a result of evolutionary adoptions and alignments of their content, the Business Maps offer a representative snapshot of the concepts and terminology perceived and applied in every-day business. http://www.sap.com/solutions/businessmaps/index.epx.

set of operations within a business scenario. All Business processes follow a well defined flow in order to achieve the business objectives of its scenario. A *Business Process Step* represents an operation of a business process that performs a defined function. The bottom right part of Figure 1 shows the process steps of the *Lead Processing* process. All business process steps are connected in a business logical flow in order to fulfill the purpose of the business process.

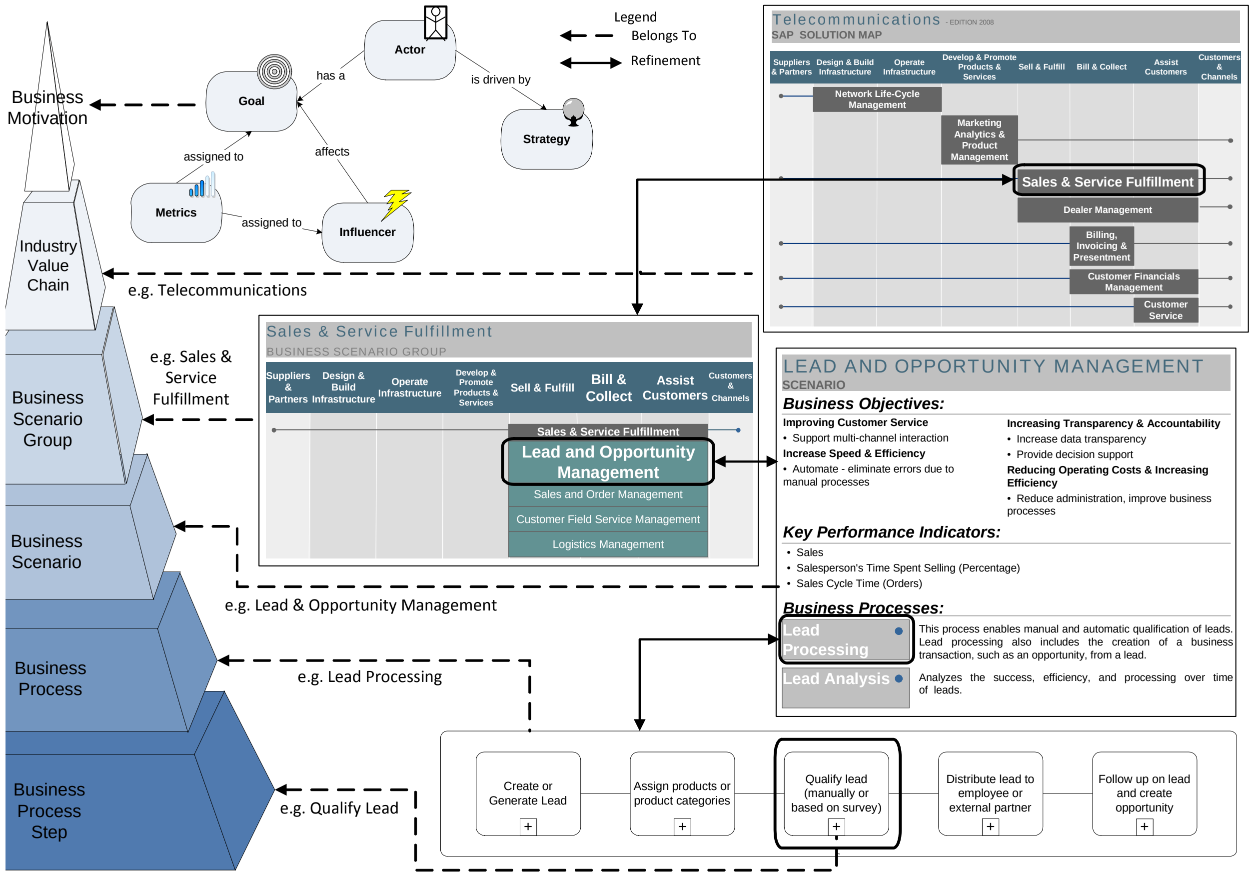

Figure 1: Processes at different levels of abstraction

Business Process Frameworks[5], which are becoming popular in companies, serve the similar purpose. They provide a common language, a set of high level processes and its associated metrics which one can use as a template to quickly and easily define new processes or evaluate and improve existing ones based on the provided metrics. Some of the best known examples are Supply Chain Council's *SCOR (Supply Chain Operation Reference model)*, TeleManagement Forum's *eTOM* framework and the Value Chain Group's *VRM (Value Reference Model)*. Business Process Frameworks correspond to *Business Scenario Group*, *Business Scenario* and *Business Process* levels within our abstraction levels.

3.2. Process information in models

In this section, we give an overview on the different information artifacts depicted in Figure 2 from a process-centric perspective.

The *process flow* could be seen as the core of a process representation and means the business logical sequence of activities and their dependencies from end to end. As processes essentially are

5 http://www.bptrends.com/publicationfiles/spotlight_052008.pdf

transformations that manipulate *objects* (e.g. create, change or delete) it is relevant for the process to capture information on these and the states they take on during the transformation. From a systems perspective objects might form the source for system data. *Technology* can be seen as an enabler for certain steps in the process in terms of persistency and efficiency. Also, in a tight connection to the questions on objects and data are the *media* used in a process. This is especially interesting since often a medium forms a process differentiating characteristic. A process could be quite different, depending on the medium used, e.g. providing the customer of a telecommunication service with either an electronic or paper bill. To the collection of objects, technology and media we refer to as *resources*. A similar grouping under the label of *stakeholders* could be done for organizational units, roles and process owners. Given the end-to-end process perspective described in the first chapter, it is important to stress that processes run across one or more organizational units within a functional or divisional hierarchy. We define a *role* as task and responsibility bundle which is clearly distinguished from the person that is performing the role. It can be held by different persons and one person can hold several roles. Talking about roles and processes allows to easily talk about the tasks that should belong together or should be separated from a process perspective before mapping them to the organizational structure. The *process owner* as an accountable manager for the process end-to-end execution can be seen as a special role in the context of processes.

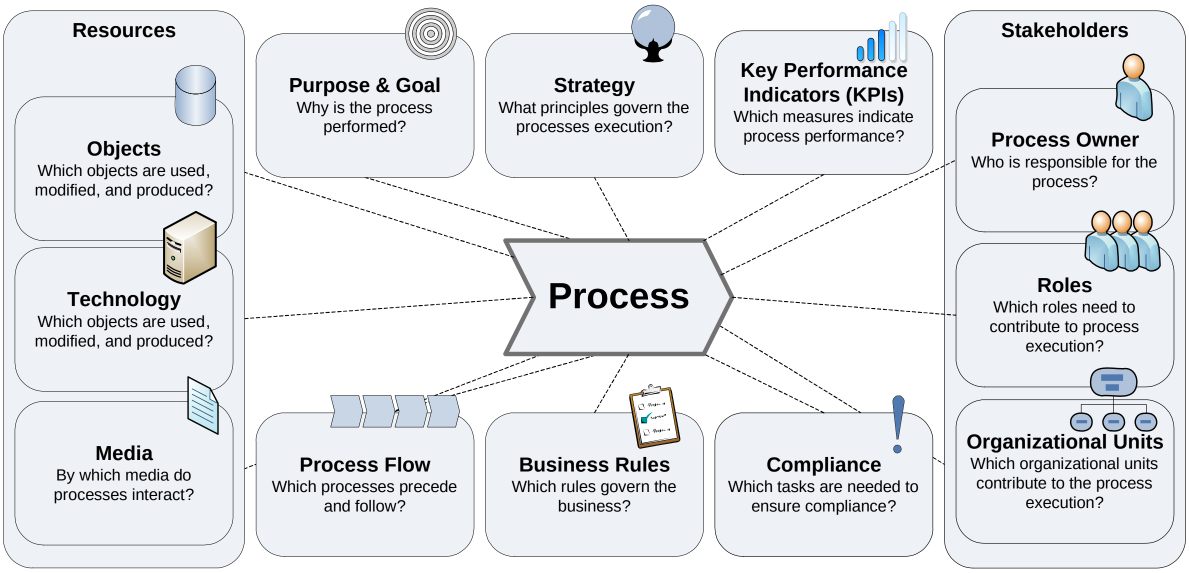

Figure 2: Process information in models

Compliance is of high importance to nowadays businesses. These regulations especially impact processes as specific tasks in processes are required in order to fulfill regulatory requirements. Thus, in process design it is important to capture and explicitly mark these tasks. The process *goal* is the ultimate reason for the process existence and the purpose it serves. When formulating a process goal it is useful to already think about quantifiable results. The way to do this is to define appropriate *key performance indicators* along e.g. the dimensions time, cost or quality that measure the process and then determine corresponding values. A goal makes explicit where to go, a *strategy* shapes the way reaching a goal i.e. it channels efforts towards a goal. Business policies and business rules exist to control, guide and shape strategies. They define what can be done and what must not be done. For example, a decision rule for a specific business situation states which alternative should be chosen according to predefined decision criteria. A prioritizing rule applies when reserving resources. Business Policies differ from business rules in that they are less formally-structured [11]. Business rules are in practice not necessarily stated explicitly, but likely incorporated into the process design [7]. The information associated to processes described in this chapter could be thought of as the answers to the questions illustrated in Figure 2.

We can think of the process-centric knowledge depicted in Figure 2 as being present on each layer of the pyramid from Figure 1 in smaller or greater detail. Some parts of this knowledge tend to grow stronger as we move down the pyramid, e.g. process flow. Of course, high level knowledge such as strategic goals and core strategy plans do not vanish as we reach a level of higher detail. They get refined and superimposed by a more concrete view. Strategic goals grow to measurable and timed operational goals, strategic directions to detailed plans, etc. Viewing the pyramid from a bird's eye view gives the full perspective of a process in all its complexity.

4. Process-oriented enterprise ontology framework

In section 3 we gave two viewpoints on process-oriented enterprise knowledge. Much of this knowledge can be captured with the help of modeling approaches such as ARIS [2] using Value Chain Diagrams (VCD), Event-driven Process Chain (EPC), as well as standard office software. These methods fail however, to capture the information's fit in the abstraction hierarchy (see Figure 1) as well as to describe their interrelation in a formal way. There is no way to retrieve any knowledge from classical enterprise modeling, which is not explicitly stated. Therefore, we propose an integrated model which allows for a machine-accessible description of enterprise knowledge using an ontology framework[6] (see Figure 3). In the following we describe the main components.

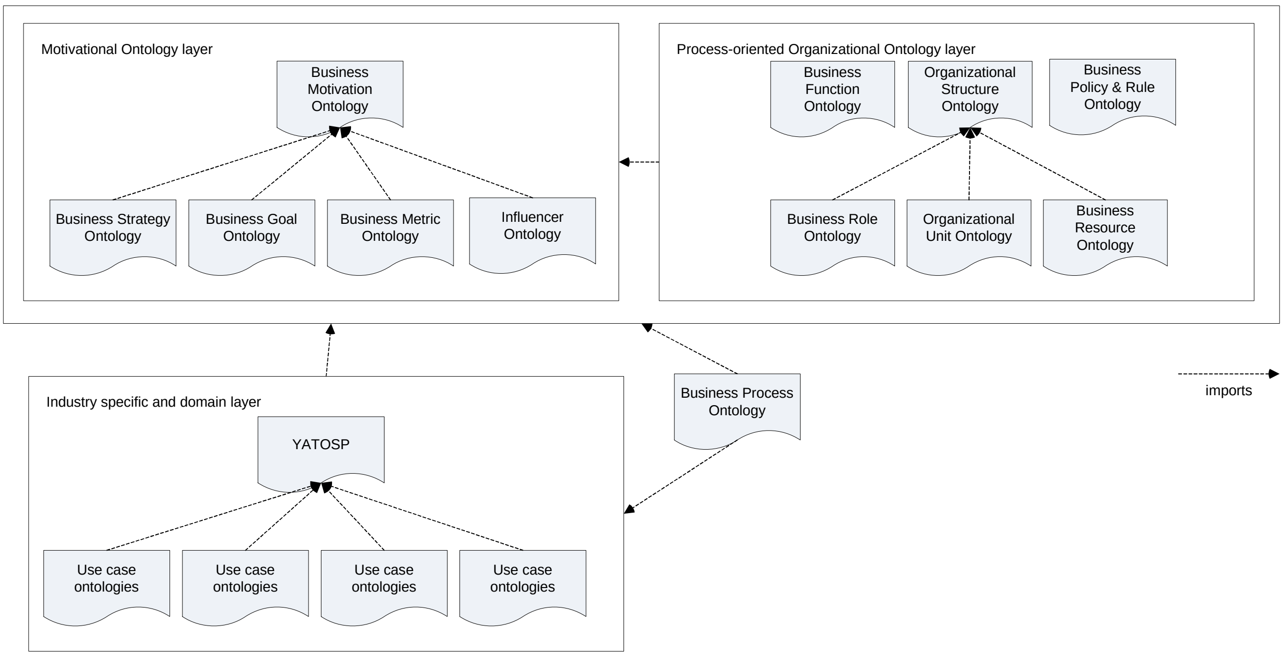

Figure 3: Ontology framework

Business Motivation Ontology: This acts as an umbrella ontology to capture the concepts from the uppermost level in the hierarchy given by Figure 1. There are two fundamental questions, we believe are to be captured separately from the perspectives 'what to reach' and 'how to reach it'. First, what is needed to achieve what the business wants to achieve? And second, why does each element of a company's business plan exist? [11]. Since business modeling in the end is about cognition and action in order to create value, we establish the concept of an actor at the topmost

[6] The ontologies can be found at http://www.ip-super.org/ontologies

level of the motivation ontology. Actors are the source of all business artifacts captured in the ontologies which import the business motivation ontology. For example, the motivation for setting up a goal is not there for itself but by the cognition of an actor. The sub-ontologies are as follows:

Business Goal Ontology (BGO): Goals may explain why the processes exist in the organization; examples include customer satisfaction, growth, etc. BGO models a hierarchy of business goals and provides a set of relations between them to enable goal-based reasoning [7]. We distinguish between a strategic goal, which tend to be long term and defined qualitatively rather than quantitatively, and an operational goal which is a step along the way (a milestone) towards a strategic goal. Goals can conflict with each other (if they cannot be satisfied simultaneously) and can positively or negatively influence other goals. There can be different levels of influence between goals.

Business Strategy Ontology: We think of a strategy as a plan to achieve a goal. Thus, a strategy channels effort towards a goal [11]. As for the goals set up by the company for achievement the plans how to achieve goals can be refined into sub-plans. A high level strategy usually channels effort towards a high level, most likely strategic (i.e. qualitative) goal and a more detailed plan channels effort towards an operational goal. This gives a coupling between strategy and goals by a means-end relationship, although is not necessarily 1:1 nor does it always connect strategies and goals on equal levels in a decomposition tree.

Influencer Ontology: Following [11], we see an *influencer* as something that can cause changes that affect the enterprise in the employment of its means or achievement of its ends. Influencers may be internal or external. For example, external influencers could be a customer or a competitor, internal influencers could be habits or management prerogatives. Actions by market rivals will most likely have some sort of impact on an enterprise. An influence itself nevertheless, and therefore the change caused by an influencer, is neutral. Assessment is needed to judge how an enterprise reacts to change caused by influencers. Assessment would be an application of the presented ontology stack. The bases for judgments are metrics.

Business Metric Ontology: This ontology models business metrics, in particular Key Performance Indicators (KPIs) as key metrics for getting information on the performance of a company. Metrics are assigned to goals (in order to monitor the achievement of goals) and to influencers (with the purpose to evaluate their impact on the organization). Business metrics (similar to goals) can be defined on multiple levels: strategic, operational and process level. Metrics assigned to goals are modeled in a hierarchical way, coupled with the goal hierarchy.

Process-oriented Organizational Ontology: It aims at describing the environment in which process is carried out from the organization's perspective. Therefore following [6], the process-oriented organizational ontology should provide a basic vocabulary and structure for describing organizations, description of artifacts, define common types of divisions, roles, business resources, business policies and business functions that are utilized or involved in the process. The organizational ontologies provide a high level view of the organization and process-related space. Since this space is quite complex the organizational ontologies layer has been further logically divided into sub-ontologies, as depicted in the Figure 3, each of them describes different part of the process space. The sub-ontologies are as follows:

Organizational Structure Ontology (OSO) (cf. top right of Figure 3) describes organizational structure (hierarchy) of a company in a domain independent way by providing the main structure and relations between them. *Organizational Unit Ontology (OUO)* provides specification of typical units that may be found in a company. Along with Business Roles and Business Resources Ontologies, it provides extensions to OSO which is shown by the imports arrow in Figure 3. *Business Role Ontology (BROnt)* defines common roles that are found in an organization e.g. Designer, Process Modeler, IT Expert, CEO etc. *Business Resource Ontology (BRO)* describes applications and resources that should be spent when carrying out certain processes or that may be results of certain task in a process. *Business Function Ontology (BFO)* (cf. top right of Figure 3) provides hierarchy of different functions that may be carried out within the company. It is supposed to enable vendor and domain independent classification of company processes. *Business Policy and Rule Ontology (BPRO)* (cf. top right of Figure 3) allows modeling constraints/guidelines that govern the behavior of the process. It is designed in a generic way to support modeling constraints from a variety of internal and external regulations.

Business Process Ontology (BPO): For describing the behavioral (dynamic) perspective of a process model we use a process algebra, the π-calculus. By using the π-calculus for representing the process behavior, we are also able to integrate existing tools and techniques for verification and simulation of processes in our framework. The dynamic perspective of a process model stands for process control- and dataflow, and we model it using the ontologized π-calculus. For more details on this ontology, we refer the reader to [8].

Note that our framework maps to the process-centric knowledge depicted in Figure 2 and hence correspond to the layers in the pyramid from Figure 1, as motivated in the last section. In order to demonstrate the applicability of our process-oriented enterprise ontology framework, within the SUPER[7] project, we have applied our framework in the telecommunication domain. The bottom left part of Figure 3 shows the *Industry specific and domain layer* which imports (is specialization of) the framework. In our case, this layer consists of the telco industry-specific YATOSP [1] ontology and a set of domain-specific use case ontologies, used in describing various telco business scenarios. YATOSP ontology is based on the aforementioned eTOM business process framework.

5. Applications of the ontology framework

Formal representation of process-oriented enterprise knowledge provides many advantages. We illustrate the benefits of using our ontology framework for business modeling in the following application scenarios.

5.1. Evaluation of Motivation Models

Use case 1 – Check for completeness. When checking for completeness of the motivation model we are interested in whether necessary links between the modeling elements are actually specified. For example, a strategy brings an enterprise towards a goal and a goal is set up by an actor, e.g. an organizational unit. Therefore, for example, we check if for any goal g_1 an actor is given as a stakeholder and a strategy is given which supports the goal.

Use case 2 – Checking for conflicts and redundancy. Goal models are an important feature of our motivation modeling. Using properties and relations of the goal ontology we can specify the priority of goals g_1 and g_2 as well as the degree in which goal g_1 supports or hinders goal g_2. We say two goals are in *conflict* with one another if g_1 is of lower priority than g_2 and g_1 hinders g_2. A goal g_1 subsumes another goal g_2, if g_2 is achieved when g_1 is achieved. If both g_1 and g_2 are subgoals of a goal g, then g_2 is *redundant* [7].

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[7] http://www.ip-super.org

Use case 3 – Propagation of goal contribution. When analyzing motivation models, we might be interested in how entities in the model affect each other. We illustrate this on the example of business goal modeling. Each goal has a priority attached, reflecting its importance for the business. There can be multiple levels of priorities. Goals can be decomposed into subgoals, where priority tends to decrease within the lower levels of a goal tree. Besides decomposition we can state if either a goal g_1 supports or hinders a goal g_2, i.e. if it has a positive or negative influence. The degree of influence is quantified in percentages. Consider that we change the degree of influence of a goal g_1 to another goal or its priority level. This will not only influence its direct neighboring goals, but also other goals in the model. We would like to see how this change propagates further in the goal tree and influences goal g_2. By taking into account and accumulating the influence and priority levels of the goals which connect g_1 with g_2 in the goal tree, we are able to recompute the influence of g_1 on g_2. This is very convenient for what-if scenario analysis where we can see how a change in one part of the model influences the other.

5.2. Evaluation of Business Process Models

Use case 1 – Check for consistency across models. The diverse nature of process information (see Figure 2) can result in inconsistency as this information is captured across various parts of the enterprise model. The ontology framework (see Figure 3) not only links different models by providing a common, structured and formalized vocabulary but also helps to detect inconsistency arising from information resulting by incorrect model usage. For example, the definition of relations such as assigning a business function to an organizational unit, roles that an employee is allowed to play, resources required for carrying out a business activity, involves concepts defined in multiple ontologies within the framework. Consistency check ensures that a business process model is annotated consistently with respect to the constraints modeled within the ontology framework

Use case 2 – Behavioral checks on process models. Behavioral checks, such as ensuring certain order of execution between activities; can also be performed on process models as BPO is based on π-calculus process algebra. For example, the activity *Quality check* is to be performed only after the activity *Produce product* and before the activity *Product delivery*.

Use case 3 – Checks on process model based on its context. Explicit capturing of contextual information about a process (business function, goal, resources used, etc.) can be used to recommend relevant business policies to be enforced on a given process. BPRO is used to capture contextual information related to policies like policy scope, goal, its applicability criteria, etc. By matching the contextual annotations of policies to the ones of processes, we can retrieve all relevant policies for enforcement. Business policies usually contain one or more business and/or information system rules which implement them. These rules can then be checked against the matching processes in order to ensure the compliance of processes to internal and external regulations.

5.3. Navigation through the process levels

By creating a common model which integrates all relevant aspects of process representation (cf. Figure 3), we are able to browse through different levels of process hierarchy. This enables the top-down linkage and bottom-up traceability between business motivation concepts on the one and detailed process models on the other side. In order to illustrate the benefits which such an integrated view provides, we list some example queries that can be answered using our ontology framework:

- Query 1: Show me all processes that support a specific goal
- Query 2: Show me all metrics associated to a process/goal

- Query 3: Filter goals on the basis of a given deadline and/or priority
- Query 4: Which organizational units are involved in a specific process?
- Query 5: Which processes use a specific resource?
- Query 6: Which processes is a specific business policy enforced on?
- Query 7: What processes are currently performed in a specific business function?
- Query 8: What influencers affect the employment of a specific strategy?

Ability to pose such queries creates better enterprise transparency and enables improved change management when regulations or market situation alter.

6. Conclusions & Outlook

In this paper, we have presented a process-oriented approach to business modeling supported by semantic technologies. First, we reduced the complexity of process modeling by proposing process abstraction layers and identifying the relevant aspects of process description. Further, we presented a process-oriented enterprise ontology framework which we validated in the telecommunication domain. The application scenarios of the framework described in section 5 show, how introducing formal semantics enables us to perform various types of evaluation on each level of process modeling in order to detect errors/inconsistencies early in the design. In section 5, we also demonstrate how an integrated process-centric view on an organization allows us to navigate its process space, improving enterprise transparency and change management. As our next step, we plan to implement the presented application scenarios in the SAP Research Maestro process modeling tool. In the long term, we aim to evaluate the benefits of our approach within a real-world industrial setting.

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