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Martin Hepp

University of Innsbruck, mhepp@computer.org

Dumitru Roman

University of Innsbruck, dumitru.roman@deri.org

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An Ontology Framework for Semantic Business Process Management

Martin Hepp, Dumitru Roman

Semantics in Business Information Systems (SEBIS), DERI Innsbruck
University of Innsbruck, A-6020 Innsbruck, Austria
mhepp@computer.org, dimitru.roman@deri.org

Abstract

A core challenge in Business Process Management is the continuous, bi-directional translation between (1) a business requirements view on the process space of an enterprise and (2) the actual process space of this enterprise, constituted by the multiplicity of IT systems, resources, and human labor. Semantic Business Process Management (SBPM) [HeLD'05]¹ is a novel approach of increasing the level of automation in the translation between these two spheres, and is currently driven by major players from the ERP, BPM, and Semantic Web Services domain, namely SAP². One core paradigm of SPBM is to represent the two spheres and their parts using ontology languages and to employ machine reasoning for the automated or semi-automated translation. In this paper, we (1) outline the representational requirements of SBPM, (2) propose a set of ontologies and formalisms, and (3) define the scope of these ontologies by giving competency questions, which is a common technique in the ontology engineering process.

1 Introduction

Business Process Management (BPM) is the approach of managing the execution of IT-supported business operations *from a managerial process view* rather than from a technical perspective [SmiFi'02]. However, the degree of automation in BPM is still unsatisfying. Also, BPM does not provide a uniform representation of an organization's process space at a semantic level, which would be accessible to intelligent queries or for compliance checks. BPM often includes the modeling of processes in some form. While process modeling is a traditional and well-established topic in Information Systems research, the various possible motivations for modeling a process, the various sources of models, and the resulting variety of requirements on

¹ In order to make this paper self-contained, we include a summary of some materials already presented there in here.

² The most prominent example of this approach is the research project „SUPER“, lead by SAP, with a total project volume of more than 16 Million euro; see <http://www.ip-super.org>

the formalisms used for representing processes are often not considered. This contributes to the dominance of a simplified, workflow-centric view on business processes, i.e. business processes are reduced to the sequencing of activities. Evidence of this workflow-minded notion of processes is that languages and tools for modeling business processes focus on control flow patterns. This is in particular true for BPEL [cf. ACGD'03]. It is only recently that the weaknesses of a merely workflow-centric representation were pointed out by van der Aalst and Pesic [AaPe'06]. In parallel, there has been substantial work on a more comprehensive and richer conceptual model of enterprises and their processes in the “enterprise ontology” research community, see e.g. [FoGr'98], [FBGL'98], [GrAF'00], or recently [Diet'06]. However, process models that could also be executed in production systems were not at the core of this community’s interest. As a consequence, workflow-centric process representations and work on enterprise ontologies are largely unconnected, which contributes to two current shortcomings: Firstly, workflow-centric process representations are not very suitable for accessing the business process space at knowledge level (e.g. for the discovery of processes or process fragments that can serve a particular purpose). Secondly, models created by the “enterprise ontology” community cannot be used with current, workflow-centric BPM tools and infrastructure.

With regard to combining a comprehensive conceptual model of an enterprise with the actual production system and executable workflows, the ARIS methodology [Sche'98] and respective tooling support was a major step. ARIS includes not only the control flow perspective, but also the organizational, data, and functional dimensions of enterprises [Sche'98]. While ARIS is based on such a comprehensive conceptual framework, it has two weaknesses: (1) the expressiveness and degree of formality in the various models is rather limited and (2) the links between the various models are quite weak. This limits the degree of automation in ARIS-based BPM; it also makes access to the enterprise as a whole on a semantic level impossible. With the latter, we mean for instance querying the process space using logical expressions and machine reasoning.

Semantic Business Process Management [HeLD'05] is a novel approach of increasing the level of automation of BPM by representing the various spheres of an enterprise using ontology languages and Semantic Web Services frameworks. The goal is to be able to apply machine reasoning for the translation between these two spheres, in particular for the discovery of processes and process fragments and for process composition. The gain in automation can be because (1) tasks can actually be performed by machines or (2) because SBPM allows for more

intelligent tooling support in BPM, e.g. by detecting conflicts or constraint violations in composite process models assembled by humans. The general vision of Semantic Business Process Management has already been presented in [HeLD'05], and a large group of academic and industrial partners is working on the respective research challenges. However, there does not yet exist a common understanding of the representational requirements of SBPM, i.e. which ontologies and formalisms will be needed, what they shall be used for, and how existing standards, namely BPEL and EPCs, can be integrated into that framework. In particular, there exists no comprehensive stack of respective ontologies available in popular ontology formalisms, e.g. OWL [W3C'04] or WSML [dBLK'05].

1.1 Our Contribution

In this paper, we (1) outline the representational requirements of Semantic Business Process Management, (2) propose a set of ontologies and formalisms, and (3) define the scope of these ontologies by giving competency questions [cf. UsGr'96], which is a common approach in the ontology engineering process. This is an important step in actually building these ontologies.

1.2 Related Work

A substantial part of Information Systems literature deals with aspects of modeling business processes. Thus, a full survey of related literature is obviously outside the scope of this paper. The most important streams of work closely related to ours can be classified as follows:

Enterprise Ontology: Wand and Weber have proposed to use the philosophical discipline of Ontology for building and maintaining information systems. Based on the work by Bunge, they provided a set of “Bunge-Wand-Weber” models for the analysis of IS modeling tasks; see [Webe'97] and [RIRG'06]. As part of the “Toronto Virtual Enterprise (TOVE)” project, Gruninger, Fox, and several others have developed formal ontologies for various aspects of an enterprise, see e.g. [FoGr'98], [FBGL'98], and [GrAF'00]. While much of their work can likely be reused for SBPM, their ontologies are to our knowledge not available in current ontology languages. Recently, Dietz has provided a comprehensive ontological approach to enterprise modeling [Diet'06]. Since his work is not directly linked to common ontology languages and Semantic Web services frameworks, however, the contribution to process composition in Services-oriented Architectures (SOAs) and intelligent queries to the process space is limited.

Business Process Modeling Languages and Standardization Initiatives: The BPM and Web Services communities have yielded a wealth of languages and standardization approaches that

aim at describing business processes, especially from the perspective of Web Services orchestration. The most prominent example is now BPEL4WS [ACGD'03], but other activities covering a varying scope are around, e.g. BPML [Arki'02], BPMN as a complementing graphical notation [BPMI'04a], XLANG [That'01], WSCI [AAFJ'02], and WS-CAF [BCHL'03]. In short, all those focus only on the representation of a part of the process space, mainly the patterns of message exchange (choreography) and the control and data flow in the combination of multiple Web services (orchestration). They were not designed as fully-fledged languages for knowledge representation, but rather for defining process models that can be executed or for abstract processes that can be refined and turned into executable processes later. The shortcomings of a procedural modeling style for the representation of business processes has been recently pointed out by van der Aalst and Pesic; they also proposed a “Declarative Service Flow Language” (DecSerFlow) as a cure [AaPe'06].

Semantic Web Services (SWS): OWL-S [MBDH'04] is a framework and ontology for adding semantics to Web service descriptions. WSMF is a more comprehensive framework [FeBu'02], which has been further developed to the Web Service Modeling Ontology (WSMO). The core specification of WSMO can be found in [RLKB'05], a brief introduction is given in [FeDo'05]. WSML [dBLK'05] is a family of fully-fledged ontology representation languages that supports WSMO. SWS are currently subject to intense research, especially in the DIP project³. The very recent work by Oberle [Ober'06] is very related to our approach, as it is to our knowledge the first approach to combine Semantic Web Services and the management of enterprise IT landscapes.

Workflow management: For an overview of production workflow management including the role of business processes and their modeling, see for example [LeRo'00]. [Leym'96] discusses the impact of using workflow technology on the creation of applications. [LeRo'97] describes an overall environment for modeling, testing, deployment, running, analyzing applications based on business processes (i.e. the lifecycle).

2 Semantic Business Process Management

The basic “semantic bottleneck” in Business Process Management can be described as follows (see also [HeLD'05]): Although a significant part of an enterprise and its process space is already stored in computer systems (e.g. in the form of process models, code fragments as

³ <http://dip.semanticweb.org>

activity implementations, data structures, data, system links, etc.), both *querying* and *manipulating* the process space regularly requires human intervention. When we need a list of processes or enterprise resources that meet a particular definition, we have to ask a business analyst to compose such a document manually, taking into account a lot of implicit knowledge. This implicit knowledge includes in particular generalization and specialization relationships. Modifying the process space, in turn, requires programmers or system engineers to modify program code, change ERP customizing data, or extend database structures in order to materialize a change request in the actual process space. Obviously, there is a functional bottleneck between (1) the *business perspective* on operations and (2) the *actual execution* of operations [cf. BPMI'04b]. In other words, *the fundamental problem is that traversing from one sphere to the other requires manual labor in any of the two directions, i.e. both for querying and manipulating the process space*: If a manager needs to know all billing processes, systems analysts have to try to create an inventory of any such processes; and if a manager needs a new billing process for a new product or service, software engineers have to transform the management requirements into an IT implementation. This leads to the situation that business-process-related activities are, amidst a wealth of IT, surprisingly centric to human labor, and thus slow, costly, and imperfect.

This gap has been already targeted by the emerging field of Business Process Management (BPM) [SmiFi'02]. BPM modeling tools usually put a strong emphasis on the graphical representation of processes, augmented with middleware for workflow and, often, Enterprise Application Integration (EAI) functionality. However, current BPM does not overcome the underlying limitation that *the business process space inside the organization as a whole is not accessible at a semantic level*, especially because business process modeling languages like BPEL4WS [ACGD'03] are an insufficient means of capturing and representing such a domain of discourse.

2.1 Vision

It can be expected that Business Process Management will only come closer to its promise if it allows for a better automation of the bi-directional translation between the business and the systems spheres. The basic idea of Semantic Business Process Management is to combine Semantic Web Services frameworks, ontology infrastructure, and Business Process Management methodologies and tools, namely ARIS, and to develop one consolidated technology. The fundamental approach is to represent both the business perspective and the

systems perspective of enterprises using a set of ontologies, and to use machine reasoning for carrying out or supporting the translation tasks between the two spheres. This principle is shown in Figure 1.

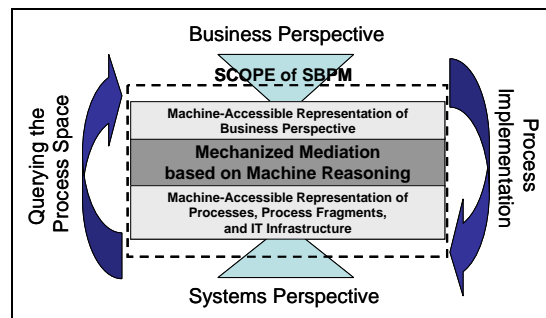


Figure 1. Semantic Business Process Management: Capturing business and IT spheres using ontologies [HeLD'05]

One paradigm of current SBPM research is to provide as much compatibility to existing tools and standards as possible. In particular, processes represented in BPEL or as EPCs should be usable inside an SBPM environment. Also, it should be possible to export processes configured inside an SBPM environment to BPEL so that standard BPEL engines could be used for their execution.

2.2 SUPER Overall Architecture

Currently, the following structure for Semantic Business Process Management emerges as part of the SUPER research project [Leym'06]: First, a **Semantic Service Bus**. This is the foundational layer that deals with brokering service requests from the upper layers. Second, a **Semantic Process Engine**. This is a process engine that instantiates and executes business process models and handles the related service requests from the service bus. Third, the **Semantic Process Modeling Layer**. This layer stores models of business processes plus all additionally relevant spheres of the enterprise, e.g. regarding the organization, resources, etc.

Making SBPM a reality includes a plethora of theoretical and practical challenges. In this paper, we focus on the ontologies and formalisms that constitute the conceptual framework.

2.3 Origins of Process Models

Prior to defining the conceptual framework for SBPM, it is crucial to stress that there are at least three distinct types of sources for business process models that need to be dealt with.

Tools-based, Manual Modeling: The most obvious source of process models are modeling tools used by humans for modeling either existing processes (documenting the “as-is”) or target processes (defining the “should-be”). Typical notations are EPCs [KeNS'91], various

formalisms related to Petri nets, UML activity diagrams, or, more recently, BPMN [BPMI'04a; RIRG'06].

Reference Process Libraries: The gain in spending substantial effort in manually modeling the current status (“as-is”) has been questioned, in particular in ERP-centric corporate environments; instead, Thome and Hufgard have called for dedicating more attention to the implicit process library contained in large Common-of-the-Shelf software packages [ThHu'96]. As a matter of fact, there exists large bodies of process specifications that can be regarded as libraries of best practice; they are an important source of process models for enterprises. Besides reference process models in ERP packages, this includes standards (e.g. RosettaNet PIPs⁴) or the MIT Process Handbook [MaCH'03].

Reconstruction: Process Mining and Reverse Business Engineering: The third source of process models are tools that reconstruct processes from log files and from the customizing data of existing systems. An early description of the fundamental idea of process mining was given by Agrawal, Gunopulos, and Leymann [AgGL'98]. A comprehensive description of challenges in process mining is given in [AaDH'03]. [GrGM'05] describes algorithms for mining workflow management systems for frequent patterns of workflow execution. Very recent work by Jansen-Fullers, van der Aalst, and Rosemann describes work on process mining in the context of ERP solutions [JaAR'06]. Reverse Business Engineering [Ibis'05] is a methodology and family of toolsets that extract and interpret transactional data and program module usage in ERP systems, namely SAP R/3 and mySAP, in order to analyze the process space of an organization. While the main goal of RBE is not the creation of process models, it can be used to select from the ERP reference processes those variants that are in use in the given environment. Process Mining and Reverse Business Engineering can be both the source of process models and at the same time also benefit from richer representations in SBPM environments.

2.4 Process Lifecycle in Semantic Business Process Management

In this section, we describe the process lifecycle in a minimal SBPM environment. It takes into account market structures (e.g. the dominance of EPC- and BPEL-centric tools and BPEL execution engines) and aims at combining the essence of the vision with a realistic scenario. Figure 2 shows the respective lifecycle.

Primary input to an SBPM environment are process models coming from modeling tools, standards, reference process libraries given by ERP vendors, reverse business engineering and

⁴ <http://www.rosettanel.org/>

process mining tools (shown on the left side). These process specifications come in two major types of formalisms: (1) Standardized, control-flow-centric (“procedural”) process notations, e.g. BPEL or EPC, and (2) proprietary representations.

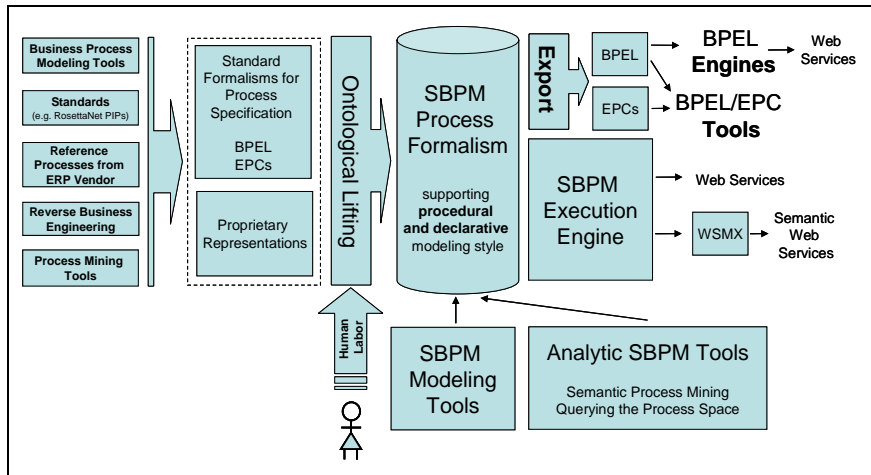


Figure 2. Process Lifecycle in Semantic Business Process Management

All this input must be ontologically lifted, i.e. all data must be augmented by references to ontologies used in the framework. In the case of BPEL processes, this may mean converting a BPEL file to a semantically enriched process specification. Ontological lifting requires almost always human intervention, since the formal semantics of input data must be augmented by annotations or expressed using richer constructs, provided by the target ontologies. A typical example is that the name of the resource is to be replaced by the unique identifier of this resource in the domain ontology.

Once the process specifications are ontologically lifted, they can be stored in the process repository. For this, a rich process formalism is being used that allows both preserving “rigid” control flows of existing workflows, as well as adding declarative specifications, references to resources, and in general any kind of relations to other elements in the SBPM enterprise ontology. This rich SBPM process representation can be accessed by native SBPM modeling tools to create or modify such models directly. It can also be used by native SBPM analytic tools, which may be used to inspect the process space on the basis of this formalism. From the SBPM process formalism, one may export abstract or executable BPEL processes for the use with existing BPEL tooling. These will be procedural reductions of the SBPM process representations that include a defined control flow.

Additionally, the SBPM execution engine can be used to directly execute such SBPM process models. For process models that include the definition of a control flow (e.g. imported BPEL processes), this control flow may be used. For declaratively specified processes, several options

exist: A specific reasoner can be used to create a valid control flow from an existing declarative process. Alternatively, an SBPM tool can be used to guide the user in creating a control flow that meets all constraints. The same two options can also be used for exporting “rigid” control flows in the form of BPEL from SBPM models, in order to have them executed by existing workflow engines. Subsets of SBPM models can also be exported as EPCs for the use in existing EPC-based tooling environments.

3 The SUPER Set of Ontologies for Business Process Management

In this section, we describe a set of ontologies for Semantic Business Process Management that is compatible with the SUPER approach while providing backward compatibility to the ARIS methodology, EPC tools, and BPEL engines and tooling support.

3.1 Methodology

We take the ARIS model of integrated business information systems [Sche'98] as a starting point. ARIS defines the following four views on enterprises: (1) Organization, (2) Data, (3) Control, and (4) Function. For each of these views, we identify suitable ontology sets. Then, we complement the four views by additional spheres, which we assume to be relevant for SBPM tasks. Inside these sets, we try to determine suitable upper ontologies that can be used to ground various more detailed ontologies. It should be stressed that the upper ontologies will have a crucial impact on the degree of automation and interoperability, for they define the common subsets between data from various sources.

3.2 Spheres Relevant for Modeling

In this section, we describe the spheres that contribute to the process space of an enterprise and which need to be represented in a SBPM framework. Figure 3 summarizes these spheres.

Processes: With this we mean the chains of activities that are actually executed, e.g. explicitly designed processes as well as ad-hoc processes.

Process Models: With process models we mean explicit *specifications* of processes, which can be abstract definitions or executable specifications; they may be expressed in a declarative or procedural style. Such models will usually come from past modeling done by humans, software packages in use, or be brought in as requirements from outside the enterprise, e.g. process standards which must be supported in order to participate in a particular value chain.

Organization: Actors in enterprises are bound by the inner structure of the enterprise, e.g. the roles performed by the actors and the line of authority and reporting. Also, all tangible and

intangible resources (e.g. machinery, intellectual property, ...) are part of the organization of an enterprise.

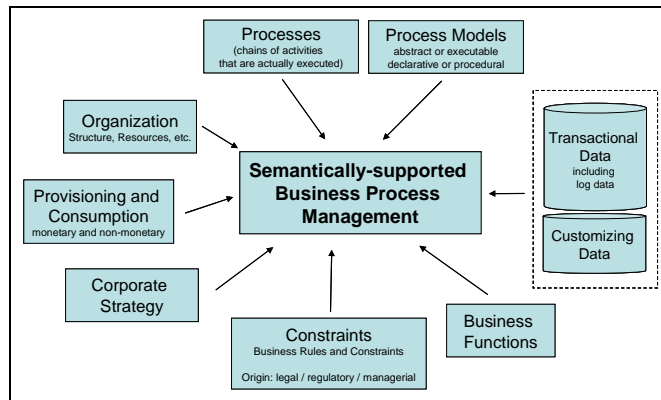


Figure 3. Contributing Spheres

Corporate Strategy: Strategic goals of an enterprise do also influence the process space; in particular, they should be available for ranking alternative process compositions.

Constraints: The process space is further influenced by constraints caused by legal, regulatory, or managerial rules. For instance, if an enterprise has declared to use only organic food in all corporate restaurants or if there if the law of the state prohibits that pregnant employees operate a particular class of machinery, this must be represented for SBPM.

Business Functions: The functional sphere of an enterprise, e.g. typical business functions like Accounting or Human Resources.

Transactional and Customizing Data: The enterprise data stored in corporate databases should also be represented in a SBPM framework. This includes the transactional data and the customizing data, i.e. the settings and process parameters of extensively configurable ERP systems.

In addition to these spheres, there are obviously additional, domain-specific spheres that may need to be included in particular SBPM settings.

3.3 Proposed Ontologies and Formalisms

In this section, we propose a set of ontologies and formalisms for the spheres identified above.

3.3.1 Core Process Modeling: Orchestration

The weaknesses of a workflow-centric representation were recently pointed out by van der Aalst and Pesic [AaPe'06], in particular that capturing a particular sequencing of activities is an over-specification of a business process, since it introduces unnecessary constraints on the execution of this process. If for example, a technical process requires that at least two other tasks are carried out between washing an item and painting it, this is usually expressed in a

workflow-centric modeling language by giving a sequence of activities that meets this constraint (i.e. by putting two other tasks in between), but not by actually capturing this constraint. This has several disadvantages. First, it is much harder to determine whether one process can substitute another, since there is no declaration of the *cause* of this particular ordering. Second, the particular process is bound to a particular set of resources. For instance, if there are additional workstations available, one does not immediately know whether it is valid to perform two tasks in parallel that are modeled as a sequence in the original process. While some of such problems may be solved by avoiding modeling pitfalls, it is quite obvious that a workflow-minded modeling style for processes puts more emphasis on *how* a process is actually executed than necessary. Third, workflow-centric modeling does not clearly distinguish between the constraints of a process (i.e. what must be met) and the actual execution of a process (i.e. how the process is carried out). Fourth, additional knowledge about the process space, e.g. generalization and specialization relationships between activities is not represented. SBPM aims at accessing the process space of an enterprise at a knowledge level, e.g. we want to be able to reason about process composition and substitution and about whether there exists a valid order of execution so that a particular set of Web services with explicit constraints can be employed to constitute a given business process. We may also want to specify processes in a declarative manner. This means that a process ontology that is mainly built around workflow patterns will not be sufficient. On the other hand, we agree that there is sometimes a need to represent rigid workflow patterns.

As a consequence, we propose to define a set of four ontologies for representing processes in SBPM: First, an *Upper Process Ontology* that captures the very basic notions of processes, in particular “activity” and “pre-/post-condition”. This ontology shall also be able to capture existing workflow specifications for a process. Thus, it should also include elements for the most important workflow patterns. Additionally, we propose ontological representations of the three most popular formalisms and notations for processes, i.e. BPEL, BPMN, and EPCs. With “ontological representation”, we mean that we create ontology elements (e.g. concepts and relations) for all (or a subset) of the elements of the respective language and *ground them in the Upper Process Ontology*.

In the following, we give *Competency Questions* [UsGr'96] for the **Upper Process Ontology**:

1. Which is the set of activities constituting a particular process?
2. Which are the pre-conditions, post-conditions, assumptions, and effects of a particular process?

3. For each activity in a particular process, what are the pre-conditions, post-conditions, assumptions, and effects?
4. What is a valid execution order of the activities in a particular process?
5. If the process includes a procedural specification, what is the specified order of execution (i.e.: by which workflow patterns are the activities connected)?
6. If the process includes a procedural specification, is activity 1 {always | sometimes | never} executed {before | directly before | after | directly after | in parallel to} activity 2?

With *pre-conditions*, we mean the information space of an activity or process prior to its execution. With *assumptions*, we mean the necessary state of the world prior to the execution of the activity or process. With *post-conditions*, we mean the information space an activity or process after its execution. With *effects*, we mean the state of the world after the execution of the activity or process. These definitions are taken from [RLKB'05; FeDo'05].

Elements of this ontology will be e.g. *Process*, *Activity*, *Assumption*, *Pre-condition*, *Post-condition*, *Effect*, and typical workflow patterns (e.g. *follows (activity1, activity2)*, *loop (activity1, exit condition)*). For these patterns, we will likely draw on the rich literature on workflow patterns.

It is important to note that these two ways of modeling a process in the Upper Process Ontology are complementing each other; there may even be conflicts such that the specified execution order and the pre-conditions do not match. However, this is something that needs to be dealt with on the operational level. The aim of this foundational ontology is to provide one common point of reference for procedural and declarative process specifications.

The three other ontologies will be ontology variants of popular process modeling formalisms, which will be grounded by references to the Upper Process Ontology. In detail, we will develop **sBPEL**, an ontology version of BPEL [ACGD'03] or a reasonable subset of BPEL; **sBPMN**, i.e. an ontology version of BPMN [BPMI'04a] or a reasonable subset of BPMN; and **sEPC**, an ontology version of EPCs [KeNS'91] or a reasonable subset of EPCs.

3.3.2 Organization and Resources

For the ontological representation of the organizational sphere of enterprises, we can draw upon the rich work done as part of the TOVE project by Fox, Gruninger, and others; see e.g. [FoGr'98], [FBGL'98], or [GrAF'00]. They consider an organization “to be a set of constraints on the activities performed by agents” [FBGL'98]. This ontology provides the vocabulary and constraints for describing the environment in which processes are being carried out. For example, this ontology may be used to describe the actors and the machinery that are being referred to in the process definitions. We propose three major building blocks: First, an *Upper Organizational Ontology* that provides the basic vocabulary and structure for describing

organizations and resources. Second, a *Business Organization Ontology* that defines common types of divisions, roles, and tasks; and third, a *Business Resources Ontology* that defines common types of business resources.

In the following, we give *Competency Questions* for the **Upper Organizational Ontology**:

1. Which employees are members of {the organization | a particular division | a particular subdivision}?
2. Which employees perform a particular role?
3. Which roles does a particular employee perform?
4. Which are the skills of a particular employee?
5. Which are the capabilities of a particular {machine | intangible resource}?
6. Which skills or capabilities are required for a particular role?
7. Who supervises a particular employee?
8. Whom does a particular employee report to?
9. Whom does a particular {employee | system} communicate with?
10. Which resources exist in the enterprise?
11. Which resources are required for a particular task?

These may be extended by aspects of authority and empowerment, e.g. “what resources does an actor have authority to assign?” [FBGL'98].

Elements of this ontology will be e.g. the concepts *Organization*, *Role*, *Task*, *Division*, *Resource*, *Employee*, *MachineOrSystem*, *IntangibleResource*, *SkillCapability*, and the relations *subordinateRoleOf* (*a,b*), *generalizedRoleOf* (*a,b*), *specializedRoleOf* (*a,b*), *reportsTo* (*a,b*), *communicatesWith* (*a,b*), and *supervises* (*a,b*).

The **Business Organization Ontology** will refine the concepts *Role*, *Task*, *Division*, *Employee*, and *SkillCapability* by common types, e.g. *StaffMember*, *Manager*, *CEO*, etc.

The **Business Resources Ontology** will refine the concepts *Resource*, *MachineOrSystem*, and *IntangibleResource* by common types of such things, e.g. *WeldingStation*, *Galvanization-Vessel*, etc. Note that this ontology will just describe the static aspect of resources, not their consumption.

3.3.3 Functions

The processes and process models (and the other elements listed in here) must be regarded in the context of the underlying business functions, i.e. the functional perspective on a enterprise. This includes typical functional groups (e.g. “accounting”) and typical tasks (e.g. “print paycheck”). It is important to note that this is a perspective of its own right, even though there seems to be overlap with the process model and organization sphere. For this, we propose a **Business Functions Upper Ontology** which represents common business functions (e.g. *Marketing*, *Human Resources*, *Operations*, ...) and typical tasks (i.e. activity types). This can

be used as the basis for an enterprise-specific functional ontology. Such grounding will ease several tasks, e.g. benchmarking or systems integration after Mergers & Acquisitions.

3.3.4 Data

The transactional data, usually kept in a relational database management system, is also part of the process space of an enterprise. It is desirable that such data can be included into the unified view on the enterprise. This will likely happen by representing (1) the data structures and (2) the events that create or consume instance data. In ERP-centric IT landscapes, (3) the customizing data of the system must also be regarded, since from this, the set of processes from the process library which are actually enabled can be derived. Also, for processes that can be configured in more detail, the process parameters can be determined.

We propose three ontologies for capturing the data sphere: First, an *Enterprise Data Upper Ontology* that can be used for describing the available data sources and recipients in an enterprise, all metadata, and all events that generate or consume data. (It must be decided on a business level later on whether all such events should be actually annotated; however, a respective vocabulary should be available). Second, a *Transactional Data Ontology* that describes the relational schemas (and their business meaning) of all relevant data sources, and third a *Customizing Data Ontology* that represents the customizing data of ERP systems.

In the following, we give *Competency Questions* for the **Enterprise Data Upper Ontology**:

1. Which database management systems exist in the enterprise?
2. Which databases are in use in the enterprise and on which systems are they located?
3. Which tables (relations) belong to a particular database?
4. Which {business function | task | event | role | machine or system} {writes to | reads from} a particular {data base | table} ?

Elements of this ontology will be e.g. the concepts *DBMS*, *Database*, *DatabaseTable*, and the relations *writesTo* (*a,b*) or *readsFrom* (*a,b*).

3.3.5 Provisioning and Consumption

So far, we have not catered for the fact that the main aspect of business operations is the consumption and production of scarce resources. For the comparison of process alternatives or for activity-based costing, it is necessary to represent the sphere of consumption and provisioning, both of monetary and non-monetary amounts. As a first approximation, we propose a minimal **Provisioning and Consumption Ontology** and define it using the following *Competency Questions*:

1. Which activity {consumes | occupies} [which amount of] which resource at which location at which point in time [for which duration]?

2. Which activity {provides | creates} [which amount of] which resource at which location at which point in time [for which duration]?

3.3.6 *Business Logics: Rules and Constraints*

The process space of an enterprise is also influenced by legal and regulatory constraints and corporate rules based on managerial decisions. Examples of such constraints are that “pregnant employees are not allowed to operate X-ray equipment” or that “machinery used for handling food may not be used for handling non-food materials”. Some of such rules may also be stored in the constraints of the processes themselves. However, in order to avoid redundancy and to ease the maintenance of such constraints, they should be stored separately. For this purpose, we propose an **Enterprise Rules and Constraints Ontology**. In the following, we give preliminary *Competency Questions* for this ontology:

1. Which {states | sequence of activities} {must not occur | should be avoided | should be preferred [over this {state | sequence of activities}]?}
2. What is the reason for any such constraint?
3. Is the reason for the existence of a particular constraint a legal one, a regulatory one, or a managerial decision?

3.3.7 *Strategy*

When composing business processes or monitoring their execution, we also need access to the corporate strategy, for only this will allow us comparing choices. In the following, we give preliminary *Competency Questions* for an **Enterprise Strategy Upper Ontology**:

1. Which are the business goals of the organization?
2. Which are the sub-goals of a particular goal of the organization?
3. Does a particular activity contribute to or conflict with a particular goal or subgoal?

Elements of this ontology will be e.g. the concepts *Goal*, *SubGoal* and the relations *contributesTo* (*Activity*, *Goal*) and *conflictsWith* (*Activity*, *Goal*).

3.3.8 *Domain Ontologies*

It will usually be necessary to complement the ontologies described by specific domain ontologies, which will refine and extend the standard ontologies. For example, the telecommunications domain will require a very detailed ontology of industry-specific concepts, e.g. “router”, “leased line”, “modem” as resources etc. Quite naturally, defining such domain ontologies is outside the scope of this paper.

4 **Evaluation and Discussion**

In the previous section, we have identified the relevant spheres that must be taken into account when building an ontology framework for SBPM. For this, we took the widely accepted ARIS methodology and framework [Sche'98] as a starting point and proposed suitable ontologies.

Since ontologies are agreements between communities and thus include subjective judgments, evaluating them in a meaningful way is difficult and in fact an open research field; for an introduction, see e.g. [FBGL'98] and [GRUB'95]. A practically relevant evaluation of our approach is possible only by coding the respective ontologies and using them in a prototypical SBPM application. Our conceptual framework is based on (1) the ARIS approach as a popular methodology and widely used tooling environment and (2) the process notion of the Web Service Modeling Ontology (WSMO) [RLKB'05] as one leading framework for Semantic Web Services. We take this as two important aspects of a successful representational framework for Semantic Business Process Management, since it will contribute to bridging the respective two research communities.

Two additional aspects require a bit of discussion. First of all, in ERP-centric environments, many facts described by these ontologies will be readily available in the conceptual model of the ERP system. For example, resources and organizational constraints are already stored in the relational databases of the ERP system. This is rather a benefit than a problem, since it will allow us using this large amount of structured data at little cost; it just requires ontology mappings between the various upper level ontologies described in this paper and the database structure of the ERP system.

A second aspect of SBPM that is still open is whether the cost of formalizing the domain of discourse is justified by the business gain in monetary terms. A substantiation of this claim is still lacking from the proponents of SBPM as such. However, in ERP-centric environments, the large amount of structured and semi-structured information in the transactional and customizing data in combination with the vendor-specific process models lets us believe that, at least within the scope of ERP systems, SBPM can be made a reality at reasonable cost. It is also noteworthy that e.g. the ARIS toolset already provides standardized terminology and conceptual models that may be reused.

5 Conclusion

In this paper, we have discussed the representational requirements of Semantic Business Process Management. We proposed a set of ontologies and formalisms and defined the scope of these ontologies by giving competency questions, which is a common approach in the ontology engineering process. In particular, we have shown that a control flow-centric, procedural representation of business processes is often an over-specification of the actual process and should thus not be made the core of an ontological framework for Semantic Business Process

Management. We are currently in the process of a detailed domain capture for the proposed ontologies. Next, we will formalize the ontologies in WSMML and validate their competency by trying to answer the competency questions using our ontologies.

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