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AN ONTOLOGICAL FRAMEWORK FOR CONTEXT-AWARE COLLABORATIVE BUSINESS PROCESS FORMULATION

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Abstract. In cross-enterprise collaborative environment, we have dealt with challenges in business process integration for common business goals. Research directions in this domain range from business to business integration (B2Bi) to service-oriented augmentation. Ontologies are used in Business Process Management (BPM) to reduce the gap between the business world and information technology (IT), especially in the context of cross enterprise collaboration. For a dynamic collaboration, virtual enterprises need to establish collaborative processes with appropriate matching levels of tasks. However, the problem of solving the semantics mismatching is still not tackled or even harder in case of querying space between different enterprise profiles as considered as ontologies. This article presents a framework based on the ontological and context awareness during the task integration and

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matching in order to form collaborative processes in the manner of cross enterprise collaboration.

Keywords: Cross-enterprise collaboration, semantic business process management, collaborative works, ontology engineering, ontological information systems

1 INTRODUCTION

Cross enterprise collaboration has become one of the main course of semantic Business Process Management (BPM) research recently [1, 24, 12]. There are several approaches for this issue with different perspectives which have been surveyed in [8]. State-of-the-art research trends have been focused on two issues for this problem:

1. forming *collaborative business process* (CBP) dynamically using ontologies or existing BPM standards;
2. Solving the semantics conflicts or mismatching during the process integration and mapping into the execution level.

Both issues have been studied in our previous work [7, 8], in which we choose to move our focal research into the second issue by proposing a conceptual architecture based on business processes ontologies. One of our recent works [9] has focused more on the mapping into the execution level with the semantic web services composition approach based on an ontological hierarchical task networking (O-HTN) for the CBP formulation.

In the other hand, the second issue has not been discussed in more detail in recent research efforts. Approaches often ignore this crucial issue in this challenging problem of semantic B2B. The main point, according to our survey in [8], is the heterogeneity of used ontologies in several different forms and domains. This makes the querying space for needed processes becomes huge and the matching process faces a real challenge for finding matched patterns.

The context-aware approach proposed in this paper is about introducing a solution to scope down the querying space for processes in the matching process for CBP formulation. This paper uses BizKB Ontology (BO) as "context ontology" (or the context in short) with our O-HTN solution to achieve the goal. The rest of this article is organized as follows: Section 2 presents an overview of BizKB Framework, while Section 3 describes the O-HTN methodology for the main component of BizKB Framework. Main points of the article are introduced in Sections 4 and 5. Then the related work to this research is discussed in Section 6. Section 7 gives discussions and the conclusion.

2 BIZKB FRAMEWORK

2.1 Ontological Enterprise Profiles

According to [20], the Enterprise Architecture refers to a comprehensive description of all of the key elements and relationships that make up an organization. Through the Enterprise Architecture, enterprises can implement enterprise integration to cope with dynamically changing business environment.

Existing Enterprise Architectures, however, lack semantics for humans and systems to understand them exactly and commonly, which causes communication problems between humans or between systems or between human and system. These communication problems keep enterprises from implementing integration and collaborating with other enterprises.

In order to solve this problem, an ontology-based Enterprise Architecture is proposed [20, 13] and depicted in Figure 1. The Enterprise Architecture ontology is composed of ontologies in three levels. Ontologies of business terms are in the first level, ontologies of Enterprise Architecture components are in the second level, and ontologies of relationships among Enterprise Architecture components are in the top level (Figure 1).

In the scope of this article, we focus on ontologies for business processes that are used for the CBP formulation in the B2B integration problem (level 1 and 2-processes). We call those enterprise profiles which are modeled and stored in BizKB framework as a knowledge base. As depicted in Figure 2, the overall conceptual architecture of the BizKB framework consists of two main parts: the BizKB and the Process Formulator. The output of BizKB framework is CBP with semantic web services profiles attached to the CBP. BizKB is the core part of BizKB Framework containing the business knowledge in the form of BPMO-based collaborative business processes with different levels of the abstraction [7, 14].

2.2 BizKB

The ultimate goal of our BizKB framework [7] is to build a platform for BP discovery and integration based-on Semantic Web technologies, which supports the process of cross-enterprise collaboration. Many initiatives restrict the range of standards they deal with for political, practical or technical reasons. For companies exposed to different national, industry or enterprise-specific standards – as is practically every business if all of its communications are addressed – this approach is clearly of low practical value. A universally usable methodology will avoid the predefinition of a range of manageable standards [23, 15].

As depicted in Figure 2, the overall conceptual architecture of the BizKB framework consists of two main parts: the BizKB and the Process Formulator. The output of BizKB framework is CBP with Semantic Web Services profiles attached to the CBP. BizKB is the heart of the BizKB Framework which contains the knowledge of the businesses in the form of Business Process Modeling Ontology

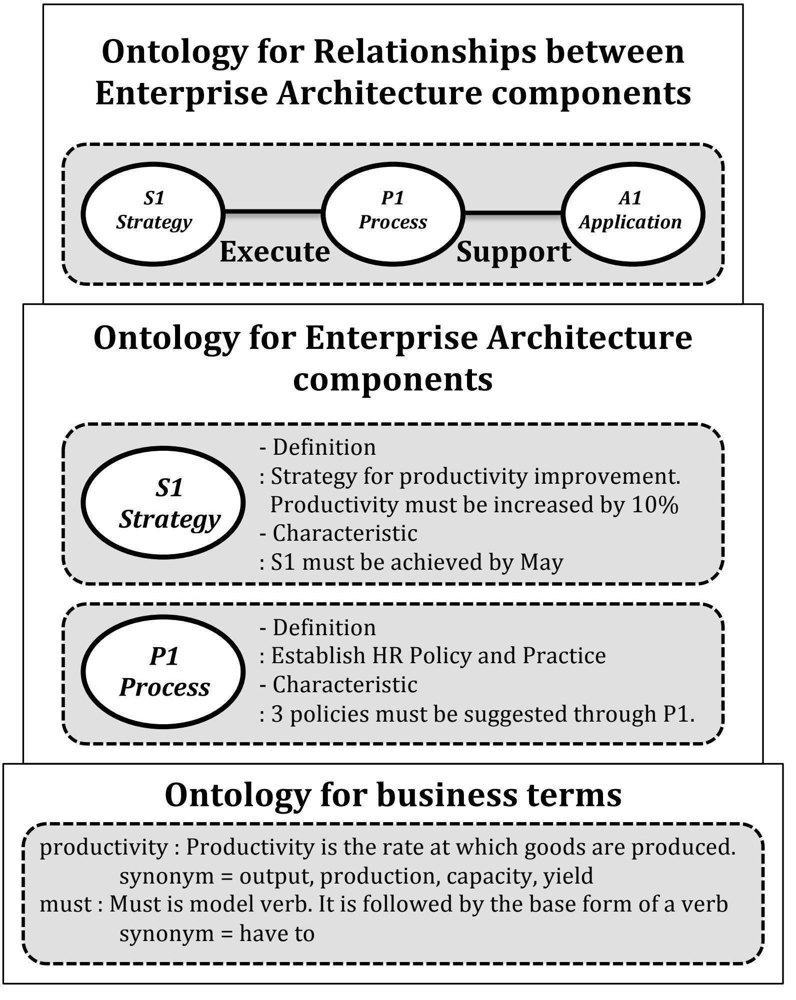

Figure 1. Levels of Enterprise Architecture ontology

(BPMO)-based collaborative business processes with different levels of the abstraction [7].

In order to formulate these BPMO-based processes to store in the BizKB, the BP analysts are required as an important human factor of the system. Based on the analysis on the BPs, the found CBP patterns, level of the abstraction and associate business rules are also extracted and realized.

As shown in Figure 2, extracted artifacts of BPs are modeled using BPMO according to specific domains and kept in the BizKB. This repository is considered

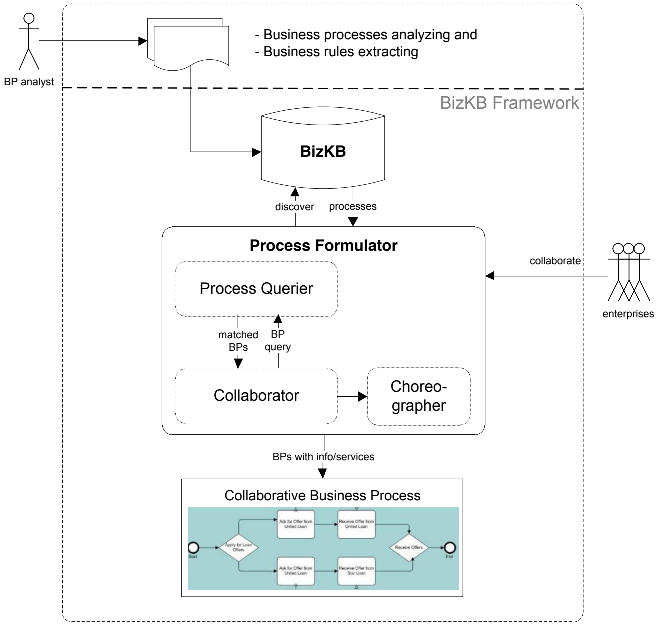

Figure 2. BizKB Framework architecture

as the process feeder for the later stage of the CBP pattern discovery and CBPs formulation.

Establishing a complete reference collection as a knowledge base beforehand is very unlikely due to the number of standards, their evolution speed and the cost a complete analysis would create, if it were possible at all. Thus the knowledge base has to be flexible, in the sense that its evolutionary growth is not only possible but also a substantial building criterion. Clearly, an approach that does not start with a fully developed knowledge base shows weaknesses in the starting phase. Due to its initially small knowledge base, references supplied by the system might be erroneous and incomplete; but with the growth of the knowledge base, quality improvement occurs quickly [23, 16].

2.3 BizKB Ontology for CBP

From the above three B2B collaboration phases, a comprehensive list of CBP tasks can be modeled in BizKB Ontology (BO). First, the sequences and hierarchies of granular tasks were synthesized into the three B2B collaboration phases.

BO is a set of ordered compound or primitive task and methods. Compound tasks have one more *"hasMethod"* property since they can be decomposed into primitive tasks that can be performed directly using O-HTN. Each method has a prescription for how to decompose some task into a set of subtasks, with different restrictions that must be satisfied so that a method would be applicable and also with respect to various constraints of the subtask and relationship among them.

2.4 Process Formulator

The interactive part of the BizKB framework is the *Process Formulator* component which consists of two main subparts – *Process Querier* and *Collaborator*. These parts are interacted by the demanding enterprise to find out the appropriate CBP patterns to form a collaborative business process with the help of the third subpart – *Choreographer*.

The Process Querier helps to find the appropriate process patterns at a certain abstraction level. Due to the enterprise discovery into the BizKB, the detailed level will be matched to the need. For example, in the Order Management process, one participant wants to identify the process of "Buy" products, however the participant cannot clearly identify parts of the process and related information; the Process Querier can help to identify the basic patterns, sample processes, and even the generalization levels of the needed process. After matched processes returned, the Choreographer will coordinate to finalize the output collaborative business process to fulfill the B2B integration demand.

The new formed CBP is attached with services profiles for specific Semantic Web Services. This process is serialized using WSMO standard which conforms the unification of the framework's BPMO standard – based on WSMO, and benefits from Semantic Web Services advantages.

3 O-HTN PROCESS FORMULATOR

3.1 HTN in Brief

In artificial intelligence, the *hierarchical task network*, or HTN, is an approach to automated planning in which the dependency among actions can be given in the form of networks. Planning problems are specified in the hierarchical task network approach by providing a set of tasks, which can be: primitive tasks, compound tasks, goal tasks [2, 17].

In HTN planning, a goal to a problem is realized via a plan of simple steps generated by the dynamic decomposition of a hierarchical network of compound tasks into sub-tasks in a domain. The lowest level task is a primitive task. To decompose and chain a task, the HTN planning algorithm matches the constraints with the criteria of the appropriate method.

For instance in travel problem as depicted in Figure 3, consider two methods of travel planning for the compound task travel(x, y). The choice whether to travel by taxi or by air depends on the distance between x and y. If the distance (i.e. the constraint) is large, travel(x, y) will be decomposed into sub-tasks via the method "travel by air"; if the distance is short, the travel(x, y) task will be decomposed into

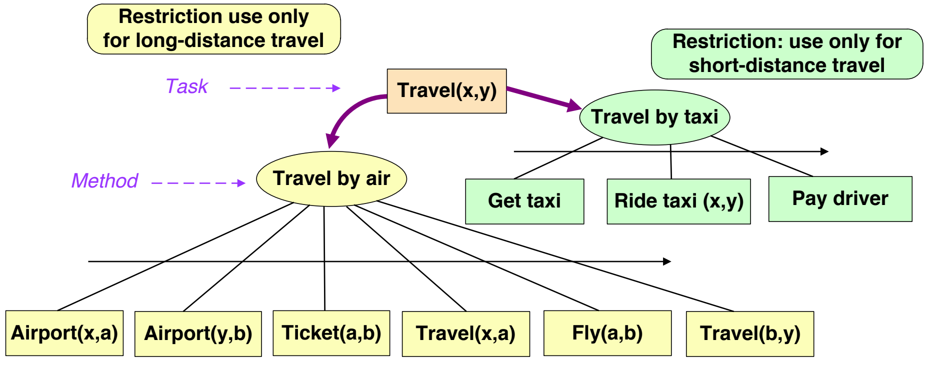

Figure 3. A travel problem represented as an HTN

sub-tasks "travel by taxi". All tasks are represented in a network of parent-child relationships.

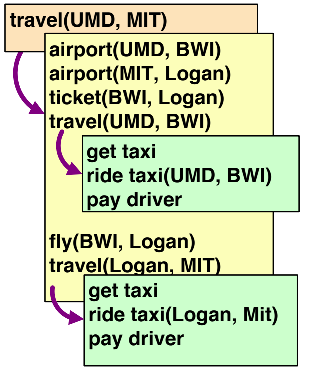

Figure 4. A plan generated by the HTN algorithm

After the HTN planning algorithm traverses through the HTN recursively decomposing tasks according to the matching methods, a result (or plan) is generated for "traveling from University of Maryland (UMD) to Massachusetts Institute of Technology (MIT)" (Figure 4). Thus, it can be seen that HTN planning decomposes and sequences tasks (e.g. travel(UMD, MIT)).

3.2 Ontological HTN for CBP Formulation

We have ontologized HTN tasks, or Ontological HTN – O-HTN, for dynamic collaborative B2B using Web Service Modeling Ontology (WSMO) as the modeling foundation. WSMO is a flexible ontology language with dynamic reasoning features, and supports execution based-on Web services as well [25, 17]. BizKB Ontologies

(BO) describe the hierarchical relationships between compound and primitive B2B collaboration tasks, and methods for task decompositions, and relevant planning criteria (e.g. cost, quantity ordered, type of collaboration) embedded in the methods. Different criteria input by the user result in different permutations of sub-tasks.

Main reasons for the creation of O-HTN: O-HTN is feasible for dynamically creating CBP task sequences ideal for direct Web service execution. As mentioned above, *Choreographer* will coordinate to finalize the output collaborative business process to fulfill the B2B integration goal. Here, we use O-HTN algorithm as described in the following sub-section for this phase.

3.3 O-HTN Algorithm

Starting with an initial high-level task, the algorithm decomposes the task into subtasks, until primitive tasks are found that can be performed directly with web services. The O-HTN algorithm originates from [21, 18] and we have done improvements shown as follows.

```
Input: Task to be decomposed
Output: Decomposed Tree, primitive actions

Procedure HTNPlanning()
Create empty tree
/* decompose for three hierarchies of
tasks for each collaboration phase */
Create three thread
/* save Task when decompose in BO */
Each thread
  Decompose (nameTask, listMethod, listTask, criteria)
  Return tree
End HTNPlanning

Procedure Decompose (nameTask,listMethod,listTask,criteria)
  Count number of methods in nameTask
  If there are no methods
     Mark task nameTask as primitive task for service execution
     Extract actor of task nameTask
     Write nameTask in tree
  Else
     While there are methods for nameTask not processed
       Select the next method nameMethod of nameTask
       Check supervised criteria of nameMethod with user
                                                   criteria
       If supervised criteria matches user criteria
          /* subtasks will be chained in control flows */
          Check number of control flows in nameMethod
          While there are still control flows in nameMethod
```

```
        Read the outermost control flow cf
        Write the start of the cf in tree
        For each subtask st in cf
            Decompose(st,"","",criteria)
        Write the end of cf in tree
            End While
          End If
     End While
   End If
End Decompose
```

4 BIZKB CBP FORMULATION

In BizKB, we do not focus on research for new approaches for ontology matching algorithm. We use existing ontology matching and alignment algorithms mentioned in [11] and [5] to build an ontology matching framework by integrating matching techniques to create a new effective matching results [5, 19]. The following framework describes the matching mechanism for CBP:

Matching Repository is the repository of ontology matching (OM) artifacts that could be reused and metadata describing their properties. Ontology Repository is used to manage input data of the OM process described by ontology metadata. Rule Repository is considered as associations of ontologies and matching properties, and used to identify appropriate OM rules for input ontologies.

Matching Engine is responsible of the selection (through rules) and the execution of the OM algorithms according specific input ontologies.

Metadata (Matching metadata, Ontology metadata) are used to represent the semantics of OM algorithms' properties and ontologies. Based on these metadata, the Matching Engine will automatically compare input value's metadata to constraints of given algorithms along with rule sets built by experts that eliminate the applying inappropriate OM algorithms, and the algorithms not satisfied with attributes of ontologies to be applied for the OM.

For BizKB framework, the Ontology Repository is the BizKB that contains the ontological enterprise profiles modeled in BPMO. However, the OM-based querying mechanism for CBP formulation in a dynamic manner could have very large querying space, especially when finding web services to be fitted into the CBP with service profiles. We cannot limit the scope of domain in on-the-fly CBP formulation attached with web services. The context-awareness could help narrow down the scope for querying relevant concepts according to the application domain.

5 CONTEXT-AWARE SEMANTIC WEB SERVICES DISCOVERY

The formed CBP with service profiles has its own semantics described by BizKB artifacts. Concepts for a new CBP generated from BizKB are organized as an onto-

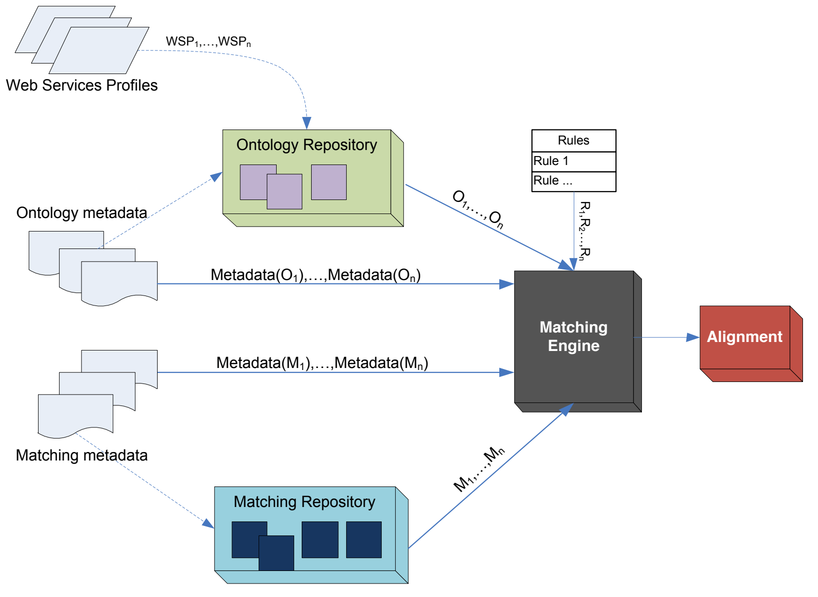

Figure 5. Ontology matching framework

logy. The next step is the discovery phase for appropriate web services that match CBP's service profiles. In order to do so, we have to do a mapping from different ontologies into the CBP ontology – called context ontology. We call this process the contextualization of web services into the CBP's conceptual space.

5.1 Concept Contextualization

Definition 1 (Concept contextualization)**.** (Con) is a mapping of classes C of service ontology O_1 to the context ontology O_2. The relationship between C and other concepts in O_2 will be reformed.

$$Con : \langle C, O_1 \rangle \longmapsto \langle C, O_2 \rangle$$

The concepts in the CBP context ontology, or *context ontology* in short, is still associated to the BizKB artifacts. The contextualization is realized by applying the mapping mechanism mentioned above.

5.2 Context-Aware Service Discovery Framework

5.2.1 O-HTN Service Context

Definition 2. The BizKB Enterprise Context (BizKB-EC) is a set of concepts from the context ontology linked to the enterprise profiles and associated resources, as well as the properties are in querying action. Let U be called a BizKB-EC; then we have:

$$U = \langle C, R, P \rangle$$

where C is the set of the underlying concepts, R is a set of associated resources, and P is a set of queried properties.

The O-HTN based architecture [9] for the Process Formulator is shown in Figure 6. Users' request is presented in WSMO ontologies and a WSMO Goal. The context-aware mapping process for the goal G with n enterprise profiles is described as follows:

$$G = OntoMap(Con(P_i, U), U), i = \overline{1, n}$$

where $OntoMap$ is the used ontology matching algorithm mentioned above.

5.2.2 O-HTN Context-Aware Service Discovery Framework

Based on [9], in this framework (Figure 6), the WSMX component uses the discovery component to find web services profiles which have semantic descriptions registered through their capabilities and interfaces. A set of properties strictly belonging to a goal is defined as non-functional properties of a WSMO goal. A goal may be defined by reusing one or several already existing goals by means of goal mediators.

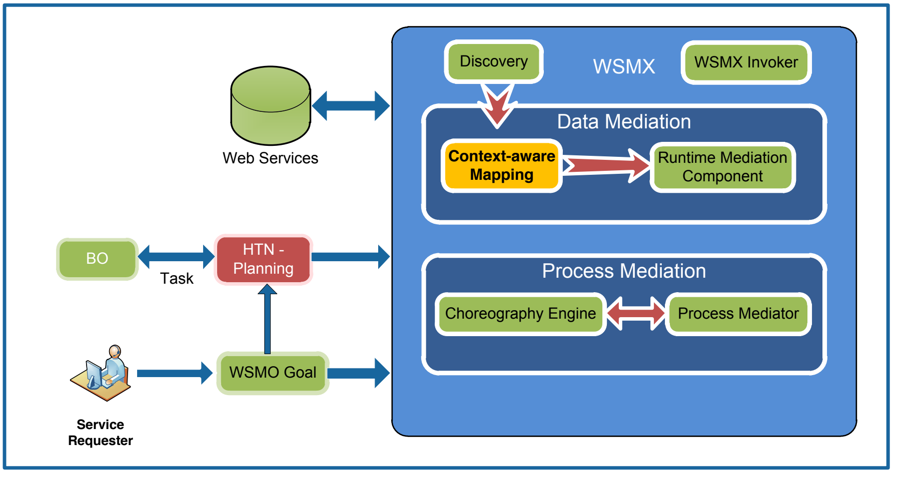

Figure 6. The O-HTN-based context-aware process formulator

During the discovery process the users' goal and the web services description may use different ontologies. If this occurs, *Data Mediation* is needed to resolve heterogeneity issues. Once these mappings are registered with WSMX, the runtime data mediation component can perform automatic mediation between the two ontologies. We apply the contextualization process here to make the service matching more efficient and to reduce the mapping and matching spaces according to the enterprise's description model in its profiles. The context-aware approach is the matching process with the target for comparison on the context ontology, that is CBP's service profiles and ontological enterprise profiles.

Every Semantic Web service has a specific choreography that describes the way in which the user should interact with it. This choreography describes semantically the control and data flow of messages the Web Service can exchange. In cases where the choreography of the user and the choreography of the Web Service do not match, process mediation is required. The process mediation component WSMX is responsible for resolving mismatches between the choreographies of the user and web service. If there is no single web service that satisfies the request then the request will be offered to the planner.

The planner then tries to combine existing Semantic Web services and generate the process model. In the proposed framework, the Process Formulator is based on O-HTN with the ontological context-awareness methods. To tackle the problems of heterogeneous ontologies and choreography, the Process Formulator uses discovery component of WSMX. Thus, via this component, the process generator will be able to discover the appropriate semantic web services for the dynamic cross-enterprise collaboration. Finally the process model with matched services will be transferred to the WSMX for its execution. The stages for execution of Web services as a process model are like single web services.

5.3 BizKB Service Caching

We optimize the Web service discovery at runtime. Therefore, we perform the Web services discovery through the way of manipulating the relations between ontologies and based on the functional and non-functional properties, and constraints specified by the user as a goal at process run-time. An example of this process can be seen in Figure 7.

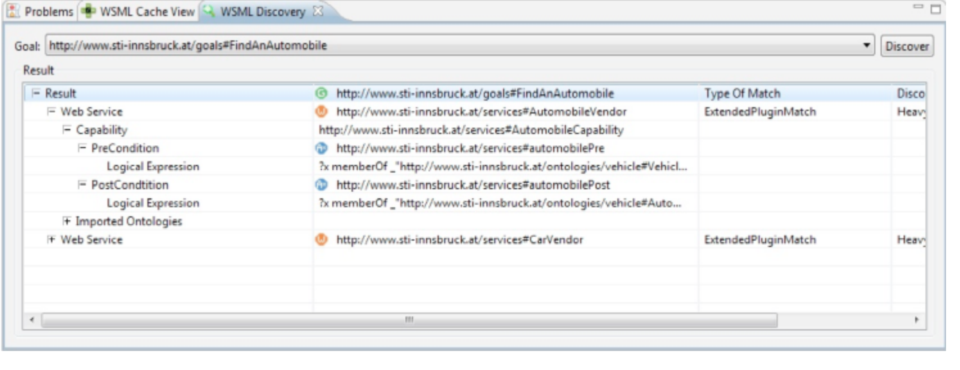

Figure 7. Discovery process using WSMT

Primitive tasks in BO are used for discovering appropriate Web services, and those services are matched to the goal. We do address that process using Web Service Modeling Toolkit (WSMT) and each primitive task can invoke an appropriate web service. This is saved in storage that captures relevant knowledge of design time. The discovery results will be effectively used for enhancing the computational performance of runtime discovery operations. This approach adopts the concept of caching to the context of Web service discovery.

6 RELATED WORK

Since the failure of the non-semantic approaches mentioned above, research efforts have emerged from the motivation of knowledge management and applying Semantic Web technologies into BPM researches to bring the administrative side and IT side together.

Jenz's BPM Ontology approach [10] argued that the third generation business process management is different in that it provides an integrated view on business processes. According to Jenz, the business-oriented view has a counterpiece in the form of the IT view, and both must be on an equal footing. The business view can be segmented into three layers: core business ontology layer; industry-specific ontology layer; and organization-specific ontology layer. The IT view is not segmented into layers and is completely organization-specific.

SUPER [1, 4] addresses the ever enduring need of new weaponry in struggle for survival in optimistic business environment where profit margins dramatically drop while competitiveness reaches the new sky-high limits. The major objective of the SUPER project is to raise BPM to the business level, where it belongs, from the IT level where it mostly resides now [1]. This objective requires that BPM is accessible at the level of semantics of business experts. SUPER's approach has tried to transform existing BPMN and BPEL standards into a semantics-enriched form, called sBPMN (so-called BPMO – Business Process Modeling Ontology) and sBPEL, respectively in the attempt to realize their goals.

At the same line, the SemBiz project (`http://sembiz.org`) aims at bridging the gap between the business level perspective and the technical implementation level in Business Process Management (BPM) by semantic descriptions of business processes along with respective tool support. This approach takes emerging frameworks for Semantic Web Services, namely the Web Service Modeling Ontology (WSMO) as a basis for defining an exhaustive semantic description framework for business processes. On the basis of this, novel functionalities for BPM on the business level can be supported by inference-based techniques that work on semantic process descriptions.

Haller in [3] extended the multi metamodel process ontology (*m3po*) introduced with concepts for a full formalization of the meta-model of XPDL. In the context of their approach, to deal with collaborative processes (choreographies) these internal workflow models are aligned to the external behavior advertised through web services interfaces. The *m3po* ontology presented explicitly models the complete semantics of XPDL. The integrated *m3po* is used as shared representation to perform the integration. The advantage of this approach is that authors use a web ontology language to formalize proposed model into linked data with established business document standards.

One of recent efforts in cross-enterprise collaboration research is the Genesis approach based on its ontology called Business-OWL (BOWL) [21]. The core of the approach is about BOWL that is a hierarchical task networking modeled in OWL describing the hierarchical relations between tasks of collaborative business processes consist of compound tasks, primitive tasks and task decomposition methods. HTN keeps hierarchical relations of compound and primitive tasks; however, HTN's typical techniques store the knowledge and the specification domain in text files and they could not be processed in the Web environment and are not suitable for current dynamic e-commerce today. Therefore, the knowledge described by HTN needs to be modeled in forms of OWL ontologies proposed in this approach.

Through the evaluation and comparison of these approaches, we can see that the fusion of BPM and the Semantic Web or ontology-based techniques is becoming a promising research direction in the domain. This research approach can bring new opportunities, new prospects and useful tools for e-business and B2B integration especially. The effort following this line is Jung's work [11] which focuses on basic problems of applying ontology aligning for business process integration. However, there is still room for the two issues mentioned above. Thus, our BizKB framework is based on combining O-HTN for high level CBP, ontological profiles with the context in the information retrieval [6] for a complete solution.

7 CONCLUDING REMARKS AND FUTURE WORK

In this paper we have proposed an ontological context-aware approach using Ontological-HTN as 'context' ontology and WSMO for forming collaborative business processes in the dynamic cross-enterprise collaboration and service discovery in the process enactment. The approach is motivated by the semantic web approach in efforts of bridging business perspective and IT world together, and provides an architecture that supports the dynamic semantics-based collaborative business process management in a new e-business environment.

This new approach reduces the querying space and helps discover the most appropriate services according the formed CBP and enterprises' profiles in BizKB framework. For the future work, we plan to improve the algorithm and implement some experiments for benchmarking, especially for the web services discovery with new approach to ontology mapping mechanism and carry out experiments with mapping of attached web services into the execution level with practical examples.

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