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Research-in-Progress

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Abstract

Business process modeling is a critical area of business application as business processes increase in complexity and become more automated. However, little attention has been paid to the fact that business process modelers often misunderstand domain concepts or relationships due to a lack of precise domain knowledge. This semantic ambiguity problem often affects the efficiency and quality of business process modeling. To address this problem, we propose a domain ontology based approach (DOBA) to supporting business process design by capturing domain semantics with a meta model of process ontologies. DOBA provides a means to capture rich, semantic information on complex business processes, which enables the incorporation of domain specific ontologies to facilitate modeling of business processes. The validity of DOBA is demonstrated via a business case in electronic auctions. The DOBA approach represents a first step towards developing a formal methodology for ontology-based modeling and analysis in business process management.

Keywords: Ontologies, business process modeling, conceptual modeling, semantic modeling

Introduction

Business process modeling has long been recognized as an important and challenging issue by academic and business practitioners. Many formal methodologies and business solutions have been proposed to model business processes from various perspectives (Basu et al. 2000; Howard et al. 2003; Lee et al. 2008; Sun et al. 2006; Van der Aalst 1998). However, most current business process models are designed manually by business analysts or system designers with limited quality control measures (Jenz 2003).

Business process modeling techniques lie in the center of business process management. As the underlying business domains become larger and more complex, the model quality tends to decrease because of a lack of familiarity with the modeling domains results in greater semantic ambiguity in the mind of process modelers. Meanwhile, domain ontologies, as formal representations of domain-specific knowledge, are effective tools for eliminating the semantic obstacles that hinder our further understanding of specific domains. An appropriate research question is "Is it possible to utilize domain ontologies to support business process modeling?"

The objective of this research, therefore, is to *develop a formal approach to facilitating the modeling of business processes with an ontological method.* Domain ontologies, at the conceptual level, can provide semantically rich information on real-world phenomena. Our modeling approach incorporates domain ontological information to support the modeling of business processes. The contribution of this research is to complete the first step towards developing a systematic methodology for ontology based modeling and analysis in business process management.

The remainder of this paper proceeds as follows: First, we present background information on business process modeling and ontology-based business process modeling. Then, we present our domain ontology-based approach (DOBA) to business process modeling in detail, which includes a meta model for domain ontology construction and a procedure for ontology-based business process design. We then illustrate the DOBA approach with an example from the auction domain. The final section summarizes the contributions, limitations and future research directions.

Literature Review

Business process modeling plays a key role in the business process management discipline (Davenport et al. 1990). Business process modeling may be generally defined as an activity of representing and analyzing the processes of enterprises with various modeling methodologies and supporting tools (Howard et al. 2003). High-quality business process models help enterprises reduce organizational costs and improve operational efficiency (Davenport et al. 1990; Howard et al. 2003). Since the 1990s, significant progress has been achieved on the formal analysis of business process modeling. Workflow technology has developed as a standard solution for business process management because a workflow can represent a business process from functional, behavioral, informational, operational, and organizational perspectives (Sun et al. 2006). Petri nets are applied to the workflow analysis and verification from a control-flow perspective (Van der Aalst 1998). Another important workflow analysis technique is metagraphs (Basu et al. 2000; Basu et al. 2003). Although these methods offer means of analysis on business processes, they do not address problems in business process design directly for many reasons (Howard et al. 2003). One of the main difficulties is the semantic gap between the understanding of business process modelers and the real world phenomena (Jenz 2003).

An ontology conceptually represents real-world phenomena with formal *constructs* (Sugumaran et al. 2002). Domain ontologies describe specific domains with terms, definitions, and axioms related to the domains of discourse (Sugumaran et al. 2006). Wand and Weber (1990) have developed an ontology-based theory of representation and the Bunge-Wand-Weber (BWW) representation model to evaluate the representational capabilities (Recker et al. 2009; Wand et al. 1999). Recker et al. (2007; 2009) apply the BWW model to assess the ontological expressiveness of different process modeling techniques. These analyses and empirical assessments reveal the need for work on an ontologically complete and clear method and supporting tool for business process modeling. Sugumaran et al. (2006) present an ontology-based methodology and develop a prototype supporting Entity-Relationship modeling. Domain ontologies are shown to effectively improve the quality of database design results. Ram et al. (2004) propose a conflict resolution ontology to solve both data-level and schema-level conflicts in database management and to enable semantic interoperability among heterogeneous databases.

Jenz (2003) proposes to use business process ontologies to speed up business process implementation by eliminating the semantic gap between business analysts and software developers. Höfferer et al. discuss the possiblility of

achieving semantic interoperability of business process models with the combined use of metamodel and ontologies (Höfferer et al. 2007). In (Koschmider et al. 2005), the authors propose to combine Petri nets and Web Ontology Language (OWL) to make more flexible representations and integration of business processes. However, these meta ontologies or meta models are not domain knowledge oriented, which means that the necessary domain knowledge to support business process design can not be integrated into the modeling process. Consequently, closing the semantic gap between the modeling requirements and the perception of process modelers requires more research.

A Meta Model of Domain Ontologies for Business Process Modeling

Domain ontologies consist of terms, relationships among terms, and rules/constraints applied to the terms and relationships (Sugumaran et al. 2006). For business processes, terms might include the roles/actors, activities/tasks, products/services, information, data, etc. For the purposes of this research, terms are classified into three main categories: role nouns, non-role nouns, and activity verb phrases. Rule nouns refer to the actors or performers of specific business activities. Non-role nouns include names of products, services, data, etc, most of which are used for information transmission among roles. Activity verb phrases describe the activities to be performed by various business roles.

Figure 1 formally defines the terms. TID is the unique identification number of a term. Terms consist of strings attached to a corresponding classification identifier such as "RT", "NRT" or "AT", which refer to "role term", "non-role term" and "activity term" respectively. For example, the concept of "seller" can be represented as: *(1,"seller","RT")*.

<term>::=(<TID>, <role term>|<non-role term>|<activity term>);
<role term>::=<role nouns>, "RT";
<non-role term>::=<non-role nouns>, "NRT";
<activity term>::=<activity verb phrase>, "AT"

Figure 1. Term definition in business process ontologies

Relationships in conceptual modeling are always complicated. Some are common and universal across different domains (e.g., is_a, synonymic, etc), and are called basic relationships. Others may be domain-specific, and are referred to as domain relationships (Storey 2005; Sugumaran et al. 2006).

<basic relationship>::=(<RID>, <term>, <basic relation name>, <term>)
<activity-performing relationship>::=(<RID>, <role term>, <activity term>, <role term>, <non-role term>);
<temporal relationship>::=(<RID>, <role term>, <activity term>, <temporal_relation>, <activity term>);
<temporal_relation>**::=**"prior to"|"at the same time"|"mutually exclusive";
<conditional relationship>::=(<RID>, <role term>, <activity term>, "conditioned on", <non-role term>).

Figure 2. Definition of basic relationships and domain relationships in business process modeling

A basic relationship is defined on the top of Figure 2, in which RID, similar to TID, is the unique identification number of a relationship. Suppose the terms "cash" and "payment" exist in the term repository. A typical example of a basic relationship might be: *(5, <cash>, "is_a", <payment>)*, which represents the fact that cash is one kind of payment. For business process modeling, we define three major types of domain relationships:

- *Activity-performing relationship*: One role performs some activity to another role with some information, data, etc, that can be represented with non-role terms. Basically, an activity-performing relationship describes the connection of two roles involved in an activity to be performed by one of them.
- *Temporal relationship*: A temporal relationship in the business process domain describes the sequence of activities to be performed by one role. In this research, we define three kinds of temporal relationships: "prior to" "at the same time" and "mutually exclusive". A "prior to" relationship refers to the scenario where one activity needs to be performed before another. "At the same time" means two activities can be performed concurrently. "Mutually exclusive" describes a scenario where, at a given time, one and only one, of the two activities can be performed by the role.
- *Conditional relationship*: a conditional relationship differs from a temporal relationship which determines the sequence of activities. This relationship describes the conditions (such as information, data, etc) needed to

perform one specific activity for a role. For example, in the auction domain, a bidder needs to pay the money conditioned on his/her successful bid on the item. Such conditions in conceptual modeling are often represented as messages and/or events.

All of the three domain relationships in business process modeling are defined in Figure 2. These three relationships are sufficient to capture the relationships in most business processes.

A Domain Ontology Based Procedure

This section presents a domain ontology based approach (DOBA) for business process modeling which takes a top-down approach and consists of 6 steps (see Table 1):

Table 1. Main Steps of Ontology Based Business Process Modeling

Step No.	Description	Domain Knowledge Involved	The Role of Ontology	Artifacts Produced
Step 1)	Building the domain ontology for the targeted business field	Entities and relationships among entities	NA	Domain ontology for the targeted business field
Step 2)	Identifying the key roles of who performs activities in the targeted business process	Role terms	Help with the identification of roles in the process	Business roles identified
Step 3)	Constructing major activities for specific roles	Activity-performing relationships, terms	Select major activities for each role	Major activities identified but not ordered
Step 4)	Generating the basic sequence of major activities	Temporal relationships, terms	Help sequence the activities	Basic order among activities
Step 5)	Placing the information delivery between roles	Activity-performing relationships, terms	Help construct information flow	Data flow among roles identified
Step 6)	Refining information flow connections	Conditional and temporal relationships, terms	Help verify the logic connection within the process	Final business process model

Step 1) Building the domain ontology for a targeted business field

This step involves ontology building for a specific business domain. Ontology design is difficult. Although researchers on the Semantic Web and knowledge management have attempted to create ontology libraries (e.g., www.daml.org), most ontologies are developed manually. Research on ontology development automation and ontology integration is progressing (Embley et al. 2005; Sugumaran et al. 2002). The creation of ontologies requires both domain expertise and heuristics (Pinto et al. 2004).

Ontology construction for the business process modeling can be achieved via several approaches. The general principle is to follow the meta model defined in a previous section, which provides categories and relationship classifications as the hints for the identification of entities and relationships. It is worth noting that there are more and more available ontology libraries or other knowledge repositories (Sugumaran et al. 2002); however, the retrieved ontologies need to be adapted and enriched to fulfill the modeling requirements. It is feasible to build the domain ontologies from scratch by combing the meta model with general ontological engineering approaches (Gruber 1995; Holsapple et al. 2002).

After the availability of the ontology has been established, the terms may be classified as *role nouns, non-role nouns, activity verb phrases,* and relationships explicitly specified among the terms in the domain. The resulting ontology from this step can then be stored into an ontology repository and used in the following steps.

Step 2) Identifying the key roles of who perform activities in the targeted business process

This step helps the process modeler identify the necessary roles that will be in the resulting process model. In most cases, there are several different roles in a business process, although it might not be appropriate to model all of the roles. For example, a "buyer" is a "bidder" in an auction ontology. There is no need to model both of them because a bidder becomes a buyer when he or she successfully bids on the item. Some roles might be excluded simply because the modeler does not want to represent the whole business process. The following procedure can be applied to identify the key roles to be included in the targeted process.

-Search the ontology repository and display all the "role noun" terms to the modeler; -Let the modeler select the necessary roles to be modeled; -For the selected roles: **If** term *A* has a "*is_a*" or "*synonymic*" relationship with term *B* **Then** indicate the modeler to refine the selection.
Figure 3. Procedure 1: Identify the key roles

Step 3) Constructing major activities for specific roles

After specifying the key roles to be modeled in the business process, the ontology knowledge can be used to identify the corresponding activities performed by those roles. Procedure 2 helps to check the relevant activities to be performed by some role by searching the activity-performing relationship in the ontology repository:

-Search the activity-performing relationship in the knowledge base: **If** a role *A* and an activity term *B* exist in a relationship: *(RID, A, B, "role term C", "non-role term D")*, and role *A* was selected in Step 2) **Then** add activity term *B* into *A*'s activities
Figure 4. Procedure 2: Constructing major activities for specific roles

Step 4) Generating the basic sequence of major activities

One of the key challenges in business process design is to arrange the sequence of activities. Domain ontologies can aid the process of generating a basic sequence of major activities (see Procedure 3). This is done by searching the temporal relationship in the ontology repository:

-For each selected role, -Search temporal relationship which involves the role in the ontology repository, -Generate a basic sequence among the activities of the role according to the "*prior to*", "*at the same time*" or "*mutually exclusive*" relationships.
Figure 5. Procedure 3: Generating the basic sequence of major activities

Step 5) Placing the information delivery between roles

Information and data are delivered for communication among the roles. Domain ontologies can assist the business process modeler to connect the information source and information destination by exploring the activity-performing relationship in the ontology repository. Formally, it can be carried out as in Procedure 4:

- Search the activity-performing relationship in the ontology repository: **If** a role *A* and a role *B* exist in a relationship: *(RID, A, "activity C", B, "non-role term D")*, **Then** add one information flow from *A* to *B* with information *D* on the flow.
Figure 6. Procedure 4: Placing the information delivery between roles

Step 6) Refining information flow connections

An activity is performed by a role based on certain conditions. Such conditions include the temporal relationship discussed in Step 4). Other conditions may include the arrival of information flow or the content of the information. Combining these conditions, we can connect the activities or business process components together and finally form the final business process model (Procedure 5).

-For each activity, search the temporal relationship and conditional relationship -Connect and generate all the conditions for this activity.
Figure 7. Procedure 5: Refining information flow connections

An Illustrative Example

To illustrate the work, an online auction process is modeled using the approach. We first construct the ontology for the auction process with the meta model and then follow the remaining steps in DOBA to incrementally construct the business process with BPMN notations (OMG 2009). This example is simple, yet illustrates the concepts and framework of our research. The auction domain is easy to understand and has been investigated previously as a research example (e.g., (Sugumaran et al. 2006)). For simplicity, consider the major part of an online auction.

Consider a single item, English auction. Generally, the seller starts the auction of one item with a relatively low starting price, and then all the bidders compete openly with each other by bidding an increasingly higher price. The auction host maintains the whole bidding process and the item will be sold to the highest bidder. The key steps of an online auction process are shown below, including the major activities of each participants/roles, business decision making, message flow, etc. Obviously, not all of the information and knowledge of an auction are incorporated in this example. Instead, this case captures and demonstrates the essence of our research.

- The seller sends a request to the auction host with relevant information (such as seller identification information, item description, and starting biding price, etc) to start an auction.
- The auction host receives the auction request and creates an auction for the item based on some principles. At the same time, it sends messages to the seller and potential bidders to announce the start of the auction.
- The bidders interested in this auction send requests to the auction host to join in it.
- The auction host receives the requests from potential bidders and decides whether to allow or deny the requests based upon some auction criteria.
- The bidders either begin to bid the item with an increasingly higher price if they are allowed to join in the auction; or, otherwise, they end their processes.
- The auction host constantly receives the biddings from bidders and processes them appropriately.
- The auction host ends the auction if no other bidders ask for a higher price on the item, and then send relevant information to the seller and bidders.
- The seller sends the payment information to the winner and prepares to send off the item.
- The winner of the auction sends payment to the seller and ends his/her auction process.

Ontology construction of the auction domain

From the above information, we first build up the ontological description of the auction domain with the meta model. The domain ontology can be stored in a knowledge repository. First, relevant terms in the auction domain are identified and classified. For demonstration purposes, assume we do not plan to create an exhaustive ontological representation of an auction, so we simply list the core terms that are most relevant. In real applications, the representation granularity of domain ontologies primarily depends on the corresponding modeling requirements of the business processes. The following are the core terms used in the auction domain corresponding to the classification in the meta model:

- Role terms: *seller, auction host, bidder, buyer, winner, shipper*.
- Non-role terms: *product, item, start price, seller info, bidder info, admission info, auction status, bid info, payment, cash*.
- Activity terms: *request auction, create auction, request to join in auction, allow bidder's join, deny bidder's join, bid, process bids, end auction, send payment info, send item, send payment*.

All of these terms can be coded and stored in a knowledge repository. For example, a record of "(1, seller, "RT")" specifies term "seller" as a role term in the knowledge repository. The relationships among the terms in the domain ontology are more complicated. Using the meta model, we focus on four types of relationships for business process modeling: the basic relationship, activity-performing relationship, temporal relationship, and conditional relationship. The basic relationships in the auction domain include: *(1, buyer, synonymic, bidder); (2, winner, is-a, bidder); (3, shipper, is-a, seller); (4, item, synonymic, product)...*

Note that both the terms and their relationships are highly dependent on the domains which provide the semantic contexts for them. In this example, a shipper is a seller, which assumes that the seller will send the item of the auction directly to the auction winner. In other cases, there may be an independent shipper responsible for the item shipping. Similarly, we specify the other three kinds of relationships for the auction domain (Table 2):

Table 2. Domain relationships in the auction domain

Activity-performing relationship	Temporal relationship	Conditional relationship
(1, seller, request auction, auction host, seller info); *(2, auction host, create auction, seller, auction status);* *(3, auction host, create auction, bidder, auction status);* *(4, bidder, request to join in auction, auction host, bidder info);* *(5, auction host, allow bidder's join, bidder, admission info);* *(6, auction host, deny bidder's join, bidder, admission info)…*	*(1, seller, request auction, "priori to", send item);* *(2, seller, request auction, "priori to", send payment info);* *(3, auction host, allow bidder's join, "mutually exclusive", deny bidder's join);* *(4, seller, send item "at the same time", send payment info);* *(5, bidder, bid, "priori to", send payment)…*	*(1, auction host, create auction, "conditioned on", seller info);* *(2, bidder, request to join in auction, "conditioned on", auction status);* *(3, bidder, bid, "conditioned on", admission info);* *(4, auction host, process bids, "conditioned on", bidder info);* *(5, bidder, send payment, "conditioned on", auction status);* *(6, bidder, send payment, "conditioned on", payment)…*

Business process modeling for the auction domain

Once the construction of the domain ontology of an online auction is complete, a top-down approach is taken to focus on the process design of the domain. First, the key roles in the domain must be identified. Although simple, this step is of great importance.

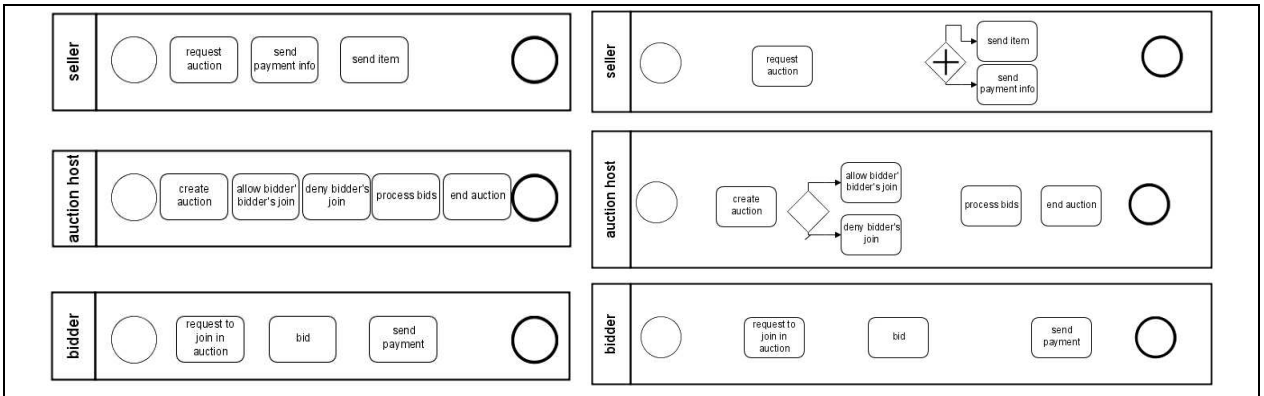

Figure 8. Constructing major activities for the identified roles and generating the basic sequences

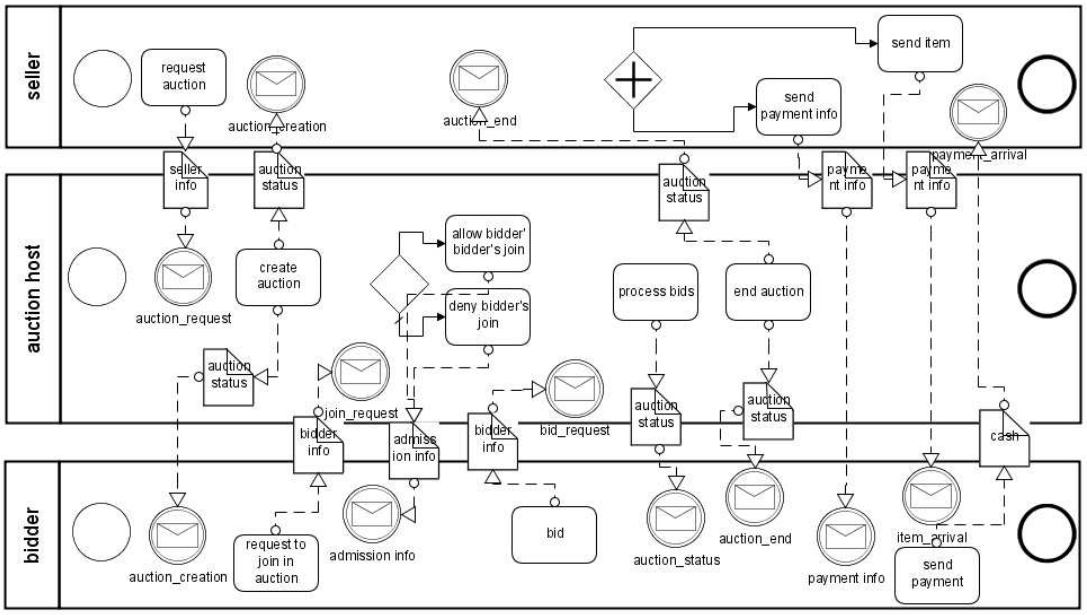

Figure 9. Placing the information delivery between roles

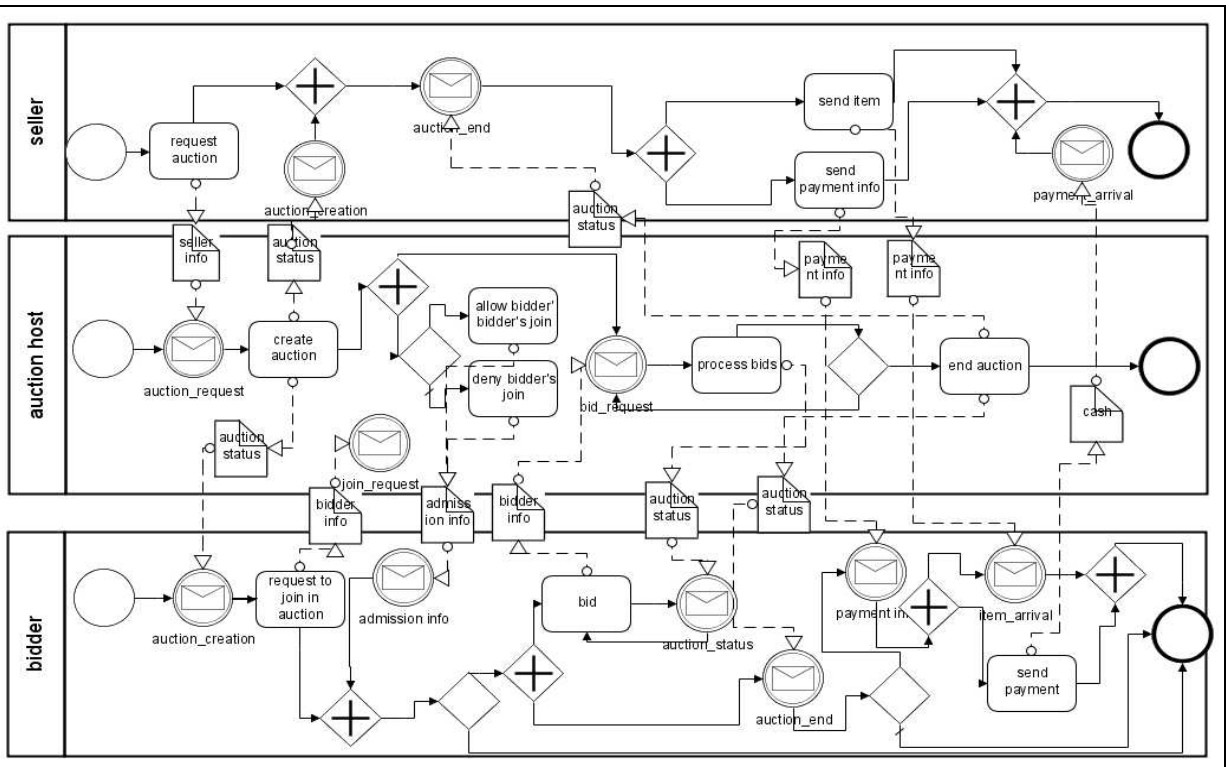

Figure 10. Refining information flow connections

In the example, we have three roles to be modeled: *seller*, *auction host*, and *bidder*. Then, in Step 3) we construct the major activities for the specific roles selected in the Step 2). Applying Procedure 2 of Step 3 results in an

identification of the major activities to be performed by specific roles. In Step 4, we generate the basic sequence of these activities. Following Procedure 3, we search the temporal relationships and generate some basic sequences among the activities. See Figure 8 for the outcome of above three steps.

In Step 5), the information delivery is appropriately placed between roles. During this step, the activity-performing relationship in the domain ontology is applied. See Figure 9. Finally, we refine information flow connections and the whole model. During this step, all of the activities are connected and the messages are delivered to the correct place. The result is shown in Figure 10.

Concluding Remarks

This research proposes a domain ontology based approach (DOBA) to support the business process modeling by capturing the domain semantics. DOBA includes a meta model for domain ontology construction and a domain ontology based procedure for business process design. To the best of our knowledge, this work is the first attempt to apply domain ontologies to support the modeling of business processes. Our preliminary analysis shows the effectiveness and feasibility of the DOBA approach. Our work also confirms the usefulness of domain ontologies as a new perspective to research in business process modeling.

Our future research will refine the DOBA approach and apply it to real world applications. We will also further investigate the validity of DOBA via a proof-of-concept implementation and related empirical studies. In addition, we will extend the ontological perspective into other areas of business process management, such as business process integration, process interoperability, and business process mining.

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