A Metagraph View-Based Approach to Multi-firm Process Coordination

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Abstract

The structural details of a firm's business processes are traditionally inaccessible to entities outside the firm. However, as firms move towards tighter coordination of processes with business partners, and system-level coupling between the processes of interacting firms, it is useful to share some features of the processes. In this paper, we show how the representation of business processes using metagraphs supports a hierarchical view that facilitates such information sharing. We show how each process owner can designate appropriate elements of process structure to be shared, while keeping other details private. We also show how business rules can be specified for shared processes. A bank loan process example is used to illustrate the approach.

Introduction

Business process modeling and analysis has traditionally focused on processes within firms. There are several reasons for this. First, most businesses, and particularly vertically integrated firms, have devoted much of their management attention on internal processes, preferring to deal with external service providers and business partners at arm's length. Second, most firms have traditionally had very few levers of influence over the operational performance of the business processes owned by their business partners. Third, the level of information available to process modelers is obviously much larger for internal processes, and thus the investment in formal tools for process modeling has appeared far more justifiable for these internal processes.

Today, firms are increasingly participating in collaborative networks. This allows more tightly focused business capabilities that more effectively leverage each firm's core competencies. A major factor driving this trend has been the increased capabilities for online inter-firm coordination processes enabled through information technologies ranging from email and the Internet to EDI and Web services. A familiar example of such coordination is the Vendor Managed Inventory (VMI) [Waller et al, 1999] approach used by many retail firms.

These trends can also be examined in terms of economic theories such as Transaction Cost Economics that argue the merits of market mechanisms for business transactions [Williamson, 1981], but recognize the inherent risks and costs of using markets rather than intra-firm hierarchies [Malone et al, 1987]. Although improved information technologies have enhanced the ability of firms to access markets, an interesting phenomenon that has been observed over the past few years is that most large firms (and also many smaller firms) have shied away from using pure market mechanisms such as online marketplaces on the Web for their mainstream supply chain transactions. At the same time, the move away from vertically integrated in-sourcing has also not reversed. What instead has happened is that firms are increasingly setting up flexible relationships with other firms, in networks that afford each participant both cost effectiveness and agility.

In this paper, we use a graph-theoretic approach to modeling business processes, which addresses the above concerns and challenges. In other words, we show how business process analysts and managers within each firm can represent their processes in a way that not only facilitates formal analysis of these processes, but that also facilitates the creation of external views of these processes that can be shared with business partners. Our approach is based on a graph-theoretical approach to the specification of business processes and workflows, using a construct called a *metagraph* [Basu and Blanning, 1994].

Proceedings of the CAiSE'05 Forum - O. Belo, J. Eder, J. Falcão e Cunha, O. Pastor (Eds.)

Metagraphs and Business Process Modeling

A metagraph is a graph-theoretic construct in which each edge is used to denote directed relationships between two sets of elements, the invertex and the outvertex of the edge. These relationships can be represented visually, as shown in Figure 1. Each set of elements in a vertex is identified by surrounding them by a closed boundary such as an oval. Each arrow denotes a relationship, from the invertex of the edge to its outvertex. Metagraphs are an extension of traditional graphs and directed graphs, as well as of hypergraphs [Berge, 1989]. From a visualization perspective, they are similar to directed hypergraphs and higraphs [Harel, 1988].

In addition to the visual representation, there is also a formal matrix representation of a metagraph, in terms of an adjacency matrix ***A*** [Basu and Blanning, 1994]. Furthermore, using appropriate algebraic operators defined on this matrix representation, a variety of transformation, connectivity-based properties and procedures have been defined on metagraphs, and these have also been applied to a variety of structural analyses of metagraphs. In particular, connectivity features of metagraphs are very useful. For instance, two kinds of paths can be defined on metagraphs. The first type is a simple path, which represents a sequence of edges linking two individual elements. This is similar to connectivity as defined for traditional graphs such as simple and directed graphs. The second type is special to metagraphs, and is called a metapath. A metapath defines connectivity between two *sets* of elements, and is a powerful construct that can be exploited for a variety of different analyses. The formal properties of metagraphs, and various algebraic operators on them, have been developed elsewhere, and the interested reader is referred to [Basu and Blanning, 1994; 1997, 2000] for details.

In the metagraph representation of business processes, each process is represented as a collection of tasks, and each task is represented as an edge linking sets of inputs and outputs [Basu and Blanning, 2000]. The inputs and outputs may be organized as documents such as forms and reports. In effect, each edge provides a black-box representation of a task, since it does not reveal the task's internal structure or procedural specification, only what inputs are needed to drive it and what outputs are generated upon successful completion of the task. Each task can also have additional attributes associated with it, such as the resources (people, machines, etc.) needed to execute the task, the duration of the task, the cost of the task, and its reliability. The representation has a formal algebra associated with it, which enables analysis of process structure. This analysis can also be extended to the synthesis of processes from several component sub-processes, and the decomposition of complex processes [Basu and Blanning, 2003], [Mukherji et al, 2004].

An example of a metagraph-based representation of a process is shown in Figure 1, which depicts a simplified version of the process of loan evaluation in a bank. The vertices in the metagraph consist of information elements needed in the process. To illustrate the representation, consider the edge e_3, which represents an applicant risk assessment task. This task is performed by a credit analyst (c), and generates a value of CR, the credit risk rating of the applicant, based on the credit history of the applicant. This task is estimated to take one week (perhaps because the credit history may be quite extensive, and will take time to analyze). This example shows many features of the metagraph representation of processes, such as the assignment of resources to tasks, the scope of each resource in terms of the tasks they are involved in, the possibility of requiring multiple resources for a task (as in task e_5, which is performed by the credit analyst and loan officer together), the use of numerical attributes on edges to denote expected durations of tasks, and the sequential dependencies of tasks. While outside the scope of this paper, the metagraph representation supports formal transformations of process representations so that the process can be represented as a metagraph with the tasks as elements, or even the resources as elements. This ability to analyze processes from either an information element, task or resource perspective, is a major strength of the approach [Basu and Blanning, 2000].

Modeling Inter-organizational Processes

To start with, we assume that each of the relevant processes within each firm in the business network are represented as metagraphs accessible to analysts and managers within the firm. This internal specification of each process details its complete structure, and is intended for internal use within the firm owning that process. However, the business partners of that firm may also need to have some understanding of the structure and scope of the process, so that they can align the process with their own related processes. An obvious challenge in this area is the representation of each business process at these different levels of specificity, so that different entities involved with that process can not only be aware of the process, but also factor their understanding of the process into whatever process analysis they need to perform.

Process Views for External Use

The metagraph approach to process representation allows multiple representations. For instance, a ***projection*** operator [Basu, Blanning and Shtub, 1997] can be used on any metagraph, which enables a large metagraph S defined on a set of variables X to be simplified into a corresponding view S_1 defined in terms of a specific subset $X_1 \subset X$. The benefit of this operator is that internal details of *S* that involve elements other than the specified subset X_1 are not visible in the projected view, yet any changes in the original metagraph that impact the relationships between the elements in the projection set X_1 are propagated to the view. In other words, if a process and its views are defined in terms of metagraphs, then any changes to process structure are propagated as relevant to the views, and can be factored into any analysis of the process at the level of the view. We can illustrate the notion of the projection operator, using our earlier example. For instance, say we wanted to project the metagraph in Figure 1 over the elements (PD, AD and LV), to focus on the loan value generation process. The resulting view is the metagraph shown in Figure 2. This is a metagraph consisting of a single edge that represents a process that takes the applicant data and property data as inputs, and produces the loan to value ratio as an output. Note that other tasks such as an appraisal task performed by a realtor as part of this process are shielded from users restricted to this view.

The value of the projection operator is that it provides a simpler view of a process or system. In the context of business process modeling, this hierarchical abstraction serves another useful purpose. It enables selective disclosure of process knowledge, thus facilitating knowledge sharing across firms. However, this requires a refinement of the projection operator, which only identifies edges that correspond to complete metapaths in the base metagraph.

In the projection operator as defined in [Basu, Blanning and Shtub, 1997], each projected edge represents a metapath from the invertex to the outvertex in the base metagraph. In other words, if the projection set does not include all the pure inputs needed for a metapath, then the edge corresponding to that metapath does not appear in the projected view. However, in the multi-organizational context, a firm may want to project an edge without necessarily showing all its invertex elements. To see this, consider the edges e_2 in Figure 1, and assume that in addition to the property data PD, the appraisal task also requires an economic indicator EI. Also, this task is performed by a realtor, and the firm may not want to reveal the fact that it uses the services of a realtor. While PD and AD may be externally procured items from applicant data or real estate reports, EI may be an exclusive resource that the bank purchases and wants to keep private. In such situations, it may be preferable to use an external view as shown in Figure 2, which hides the use of EI. Note here that EI does not appear in the projected edge, even though it is a pure input to the process. Nevertheless, the edge is a reasonable characterization of the risk exposure assessment process, for external purposes.

This variant of the basic projection operator is called an external projection operator, and can be defined as follows:

Definition: Given a metagraph S = $\langle X, E \rangle$ with a subset X_1 of X being *private* elements, then an *external projection* of S over a subset *X'* of X such that $X' \cap X_1 \neq \phi$ is obtained by taking the corresponding projection of S over *X'* and then removing all elements of X_1 from it.

Note that the external projection can be easily derived from the regular projection operator, so no new procedures are needed, beyond the structured procedures for constructing projections described in [Basu, Blanning and Shtub, 1997]. Also, by definition, each externally projected edge is a feasible task in an internal process once the private elements are also made available. However, it is important to recognize that the external projection operator depends upon its associated projection operator. In other words, the external projection should be defined by an *internal* manager of the firm owning the process, who first identifies the complete projection for the relevant elements, and then removes the internal elements. To see why this is important, consider the two following issues:

Assume that an external user (e.g., an analyst from a business partner firm) queries for a view involving a subset of elements X_1. The relevant view would be the external projection of all projections over the smallest superset of X_1. Since this would be hard to predict, it would be a potentially risky functionality to delegate to external users.

Assume that two separate external projections of the same process are visible to an external user, such that there is no metapath in the combined view over those two projections between a given vertex pair A and B. This does not mean that in the complete internal process there is no metapath between A and B. This is formalized in the following statements.

Theorem 1: Given two projection sets X_1 and X_2 for a metagraph $S = \langle X, E \rangle$ and the corresponding external projections S_1 and S_2 of S over any subsets $X'_1 \subset X_1$ and $X'_2 \subset X_2$ of these two sets respectively, any metapath in the union of these two external projections corresponds to a metapath in the external projection of S over $X'_1 \cup X'_2$.

Proof: Let M(B,C) be a metapath from B to C in the union of the two external projections. Then B, C $\subset$ $X'_1 \cup X'_2$. Since every edge in these external projections corresponds to at least one metapath in the base metagraph (with possibly some additional input elements that were hidden), it follows that there is a metapath M'(B,C) in the base metagraph. Since the external projection of S over $X'_1 \cup X'_2$ includes all metapaths over that projection set, and since B, C $\subset$ $X'_1 \cup X'_2$, then there must be a metapath M"(B,C) in the external projection of S over $X'_1 \cup X'_2$, which is the desired result.

QED.

Corollary: The lack of a metapath in the union of two external projections of the same metagraph (over X_1 and X_2 respectively) does not imply that there isn't such a metapath in the external projection over the set $X_1 \cup X_2$.

The external projection provides a very useful way to share process knowledge. We illustrate this using the example process in Figure 1, which reveals the loan evaluation process assuming that all the tasks are performed within a single organization. Now assume that the process is to be disaggregated into component sub-processes managed by two organizations. The first organization is the bank, which has the loan officer and credit analyst resources. The second organization is a realtor's office, which consists of the realtor resource (for space reasons, the loan decision propositions are used to correspond to the approval and rejection decisions). An external view of these interacting processes that could be used to integrate this process with other business partners could consist of the two edges shown in Figure 3.

The strength of this approach is that each organization can represent, analyze and manage its own processes using the metagraph representation. At the same time, the external views of the processes collectively comprise a metagraph too, which can be analyzed using the same formal analytical tools and procedures.

Most business processes are also governed by business rules, which determine the specific conditions under which each task can apply. In the metagraph representation, rules can be incorporated seamlessly in the representation. This is because rules stated in the form "IF <A> and <B> and … THEN <C>" can be represented as edges in a metagraph, with the conditions (antecedent) forming the invertex of each edge and the consequent forming its outvertex. In other words, a collection of rules can be represented as a metagraph, and rule-based inference can be implemented using connectivity properties and procedures on the metagraph. This has been shown in [Basu and Blanning, 1997].

In the context of a business network, business rules show up in two ways. First, there are business rules that apply to a firm's own processes. Such rules can be incorporated into the metagraph representation of each relevant process. Furthermore, such rules would be abstracted out of the external view of the processes as seen through suitable projections applied to the process metagraphs. It is easy to see how each firm in the network can keep its internal rules secure, even while revealing the appropriate information about its processes to its partners. An internal rule would appear in a projected view of a process only if all the antecedents and the consequents of the rule were part of the projection set (which is controlled by the firm that owns the process). At the same time, a business partner may want to impose conditions upon its partner's processes. For instance, a manufacturer may insist that the component produced by a supplier meet a particular quality requirement.

The shared representation of inter-organizational processes can also be embellished with additional business rules that are visible to all partners, and can be used to refine the process. For instance, in our example, consider the addition of a negotiated rule among the partners that if the credit rating of the applicant is below B, then the risk is too high. Such a rule can be superimposed on the shared process by adding it to the appropriate view, and this also propagated to the relevant organizations (the ones that owned processes touched by the new rule). It is important to recognize that any shared rule can be applied to the external (or shared) view of a multi-firm process could be designed for use only in this particular business network, without affecting how each individual firm may conduct its process internally, or with other partners. This is because each firm can construct different views for different networks in which it participates, and the collective processes in these networks could be very different, yet all managed in conjunction with each firm's internal processes, and without violating any privacy constraints for any of the internal processes. This ability to organize networked processes so that it can behave differently in different contexts is a valuable feature of the metagraph approach.

Sharing Other Features of Processes

In this paper, we have focused our attention on two types of knowledge sharing about processes that can be valuable for managing inter-organizational processes, namely process structure and process logic. However, the metagraph representation supports a variety of other types of process knowledge that can be shared for effective process management. For instance, process metagraphs can be transformed into equivalent metagraphs that focus on the interactions between resources, rather than information elements. These resource interaction metagraphs (RIMs) can be analyzed in the same way, since they are based on the same construct [Basu and Blanning, 2000]. In other words, the RIMs of the interdependent processes of the different firms in a business network can be used to identify the resources that need to interact across organizational boundaries, and furthermore, the nature of these cross-boundary interactions. This can be a valuable tool in designing communication and coordination mechanisms across the business network.

Another very useful type of process analysis involves the use of quantitative attributes such as task duration. For instance, in Figure 1, each task edge has a number associated with it, which is the estimated duration of that task in days. Using such attributes, quantitative analysis of features such as critical paths, critical tasks, and process durations for different workflows can be formally done, as shown in [Basu and Blanning, 2001].

Conclusion

In this paper, we have shown how representation of business processes and workflows as metagraphs can be used to share knowledge about process structure and scheduling across organizational boundaries in ways that support not only useful visualization and abstraction of processes but also structural analysis of these processes. In particular, we have showed how the projection operator on metagraphs, and an extension of it called the external projection, can be exploited for inter-organizational process representations at appropriate levels of specificity and disclosure. We have also shown how temporal information about processes can be represented in process metagraphs, which can be used in critical path analysis to improve analysis and sharing of temporal knowledge about such processes, both within individual firms as well as across the participating firms in a business network.

It should be recognized that while the exposition in this paper has been primarily in terms of the visual representation of metagraphs, all the features and analysis that we have discussed can be implemented in computer-based tools that manipulate the algebraic representation of process metagraphs in terms of algebraic operations on the adjacency matrix and derivative structures such as the closure matrix. Detailed description and discussion of such algebraic analysis is available in many of the archival papers cited in the references.

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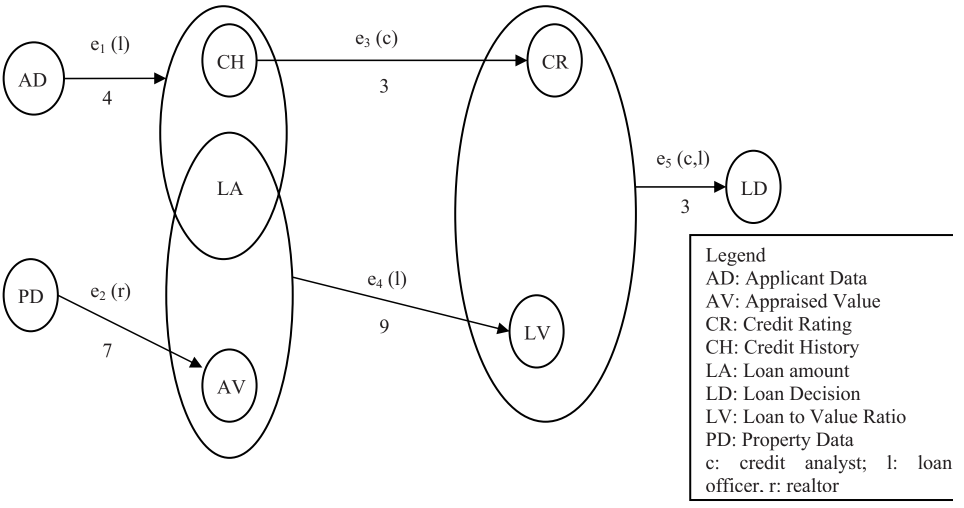

Figure 1: A Loan Evaluation Process Metagraph

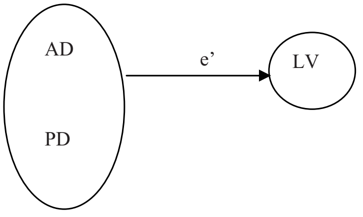

Figure 2: Projection of Figure 2 over {AD, LV, PD}

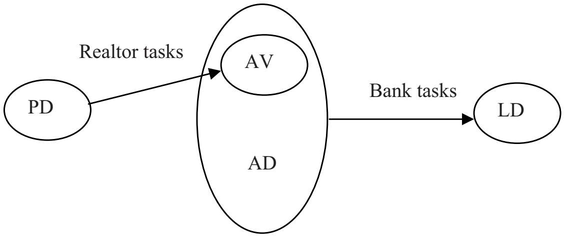

Figure 3: Externally Projected View of Loan Process