Requirements for Workflow Modeling in P2P-Workflows derived from Collaboration Establishment

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Abstract

Web services advocate loosely coupled systems, although current applications are limited to centrally controlled structures. The reason for this limitation is the lack of a method for deciding collaboration consistency, that is deadlock freeness and boundedness, in a decentralized way. In particular, an intuitive approach classifies collaborations incorrectly being inconsistent due to the loss of information introduced by the decentralization. In the paper loss of message ordering and message parameter value constraints caused by the decentralization are identified to be the reasons for incorrect decision results. The proposed approach to overcome this issue is to explicate these constraints, which cannot be represented in common workflow models.

1. Introduction

Service Oriented Architectures (SOA) have the potential to enhance B2B e-commerce over the Internet by supporting loosely coupled business collaborations allowing companies and organizations' business processes to interact with each other. This can give rise to new business paradigms based on dynamic trading relations as companies, particularly small to medium scale, can cheaply and flexibly enter into fruitful contracts, e.g., through subcontracting from big companies by simply publishing their business processes and the services they offer.

The inherent flexibility and dynamicity of the sketched B2B scenarios also applies to enterprise application integration (EAI) ¹. Different departments offer services to other departments of the enterprise, that is, each department is

'market' driven aiming to optimize its own revenues by minimizing the operational costs.

Establishing a multi-lateral collaboration based on existing workflows/processes results in a global workflow which is not necessarily guaranteeing successful business interactions. In particular, the global workflow might contain infinite loops in conjunction with parallel execution (unboundedness) or states where no further actions are possible although no final state has been reached (deadlocks). v.d.Aalst [18] introduced an approach to decide boundedness and deadlock-freeness of a multi-lateral collaboration based on an instantiation of the global workflow constructed from the local ones. Establishing the global workflow to make a decision is impractical because of the containment of mission critical information within the local workflows, which will not be provided by the different parties to a coordinator making the decision.

Thus, the aim is to develop a method to establish multi-lateral collaborations without instantiating the corresponding global workflow by deciding boundedness and deadlock-freeness of the resulting global workflow in a decentralized way. As a consequence, the intended method must explicate **message orderings** and **parameter value constraints**, which are not represented explicitly within a local workflow, but are derivable under consideration of all local workflow models. In particular, this effect is observable in multi-lateral collaborations, where the involved parties and the related bilateral interactions represent a graph structure, that is have cyclic depended interactions, rather than being tree-structured and thus having acyclic bilateral interactions.

In the paper exemplary scenarios are illustrated for a three party procurement use case. Next, the requirements for a workflow modeling approach are summarized being able to locally decide boundedness and deadlock-freeness of the related virtual global workflow. Followed by an in-

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¹ This statement is applicable to real as well as virtual enterprises.

vestigation of existing approaches with regard to their readiness of fulfilling these requirements. Finally, the presentation concludes with an outline of future work.

2. Example

The exemplary scenario used for further discussion is a simple procurement workflow within a virtual enterprise incorporating a buyer, an accounting department, and a logistics department. The accounting department checks orders (*order* message) of buyers and forwards them to the logistics department (*deliver* message) to deliver the requested goods. The logistics department confirms the receipt (*deliver_conf* message), which is forwarded by the accounting department to the buyer (*delivery* message). Further, the buyer may perform parcel tracking (*get_status* and *status* messages) as sometimes offered by logistics companies. The overall scenario is depicted in Figure 1.

Figure 1. Global Procurement Scenario

Figure 1 represents the global relationships, but not the local workflows of the parties involved. While different models have been proposed to model workflows, in the following, the Workflow Net (WF-Net) model [17] is used due to the conformance to [18] addressing properties of inter-organizational workflows constructed from local workflows. Other notations like for example, Petri Nets [12], or state-charts [9] could also have been used.

A Workflow Net (WF-Net) consists of places (circles) representing business tasks and transitions (squares) connecting places representing a message exchange. The transitions are labeled with $s\#r\#msg$ representing sender s and receiver r of the message as well as its message name msg . WF-Nets contain a single final place represented by a circle with a solid line within the graph. A token is depicted as a dot within a circle. A transition is enabled if all input places of a transition contain a token. If a transition is enabled, it might fire, that is removing tokens from incoming places and inserting new tokens to outgoing places of the

transition. The current distribution of tokens over the places describes the actual status of the workflow and is named marking.

Figure 2. Local WF-Net Models

The local workflows of the parties involved are depicted in Figure 2 forming the global workflow described above and guaranteeing a successful execution of it. The process is started by the buyer b sending a $b\#a\#order$ message to the accounting department a , which informs the logistics department l via a $a\#l\#deliver$ message to deliver the ordered goods. The logistics department l confirms this request ($l\#a\#deliver\_conf$ message) to the accounting department a , which forwards the delivery details of the order ($a\#b\#delivery$ message) to the buyer b . Afterwards, the buyer b is allowed to do parcel tracking directly with the logistics department l by sending a $b\#l\#get\_status$ message answered by a $l\#b\#status$ message. Finally, the buyer and logistics department process is terminated by the buyer b sending a $b\#l\#terminate$ message.

The corresponding global workflow can be constructed as described in [18] by relating two transitions labeled equally and owned by different parties via an asynchronous channel. Each channel finally results in an additional place connected by an incoming arc with the "sending" transition of a message and an outgoing arc to the "receiving" transition. A token located in a newly introduced place can be interpreted as a message contained in the channel waiting for being received by the corresponding party. Finally, to fulfill the WF-Net constraints of a single token as an initial marking and a single final place, new initial and final places are introduced connected to the previous ones by new transitions t_{start} and t_{final} distributing tokens to the local start places and collecting tokens from local final places respectively.

Within the above example, transitions of different parties labeled with the same message $s\#r\#msg$ are related by an asynchronous channel. The resulting global workflow is depicted in Figure 3, where the original local workflows are emphasized by the grey boxes with the buyer local workflow being on top followed by the accounting local workflow, and finally the logistics local workflow. Note, that one parcel tracking option of the logistics department has been neglected because no corresponding sender transition exists at the buyer local workflow, thus it is never used. It can be shown that the global workflow depicted in Figure 3 is bounded and deadlock-free, further called sound.

Figure 3. Global WF-Net Model

3. Collaboration Establishment

Soundness of an interorganizational workflow as introduced in [18] is defined as soundness of the global workflow and the local workflows respectively. While this definition requires an evaluation of the global workflow, an intuitive approach of a decentralized solution might be to rely on the soundness of a constructed view based on the local workflow combined with the party's view on the "virtual" workflow, that is the global workflow not specified explicitly. In particular, the local workflows will be extended by bilateral interactions they are involved in.

This approach extends the local workflow by the relevant parts of the trading parties' local workflows, which can be derived by neglecting those parts of the trading parties' workflows not being part of this particular bilateral interaction. In particular, those transitions are omitted, which are neither sent nor received by the corresponding trading partner. A transition is omitted by relabeling with a silent message, that is the WF-Net equivalent to ϵ -transitions in finite state automata. Thus, a silent message represents an internal state change not resulting in a message exchange between the trading partners. In [1] such a definition on WF-Nets is provided known as projection inheritance. Apply-

ing this projection definition to the trading partners interaction results in the party's view on the trading partners local workflows. Combining these views and the party's local workflow results in a workflow model used by the party to decide soundness of the global workflow in a decentralized way.

Unfortunately, this intuitive approach does not work out due to the information loss introduced by the projection. In the following, two scenarios are described illustrating two categories of information loss during projection, which need to be considered for deciding soundness of cyclic multi-lateral collaborations in a decentralized fashion.

3.1. Message Ordering

Applying this approach to the above example results in a deadlock at the logistics department's constructed workflow, although the exemplary global workflow is sound. Figure 4 depicts the logistics local workflow (grey box) combined with the minimized projections of the accounting department (below the grey box) and the buyer local workflow (above the grey box).

Figure 4. Logistics department constructed workflow

The WF-Net can result in the following execution sequence: $b\#l\#get\_status$ $l\#b\#status$. This sequence results in a marking where no other transition is enabled and the final place is not marked, thus is deadlocked. The detected deadlock in the constructed workflow indicates the virtual global workflow not to be sound, although it is sound.

An investigation of the reasons for the detected deadlock results in the observation that it is a consequence of the projection of the buyer local workflow. In particular, the inherent constraint that the $b\#l\#get\_status$ message will never be sent initially, but is dependent on messages sent by the accounting department got lost. In the logistics constructed

The lesson learned from this example is that the information loss about inherent message ordering constraints in the extended logistics department workflow results in options, which actually cannot occur due to constraints imposed by another party but locally not visible.

3.2. Parameter Constraints

Another type of information loss is related to parameter values within messages, which are constrained by conditions assigned to transitions. The following example modifies the introductory example described in Section 2 by considering the volume of an order and related constraints. In particular, it modifies the previous example by (i) adding a maximum volume of the order to the buyers local workflow, which is implicitly affecting the related *b#l#get_status* messages supported within the buyer workflow, and (ii) constraining the logistics workflow to a maximum order volume, which is implicitly affecting the related *b#l#get_status* messages supported within the logistics workflow. The resulting local workflows are depicted in Figure 5.

Figure 5. Parameter Constraint Conflict

The local workflows result in a sound global workflow not depicted due to the structural equivalence to the previous one presented in Figure 3. Applying the above mentioned approach to these local workflows again results in a deadlock indicating the global workflow to be non-sound.

Figure 6 depicts the logistics local workflow (grey box) combined with the minimized projections of the accounting department (below the grey box) and the buyer local workflow (above the grey box).

All message sequences containing a $a\#l\#deliver(a)$ with $a > 100USD$ result in a deadlock like, e.g. $a\#l\#deliver(120$

Figure 6. Logistics department constructed workflow

USD) `b#l#get_status(120 USD)`. The deadlock is due to the limitation of the logistics local workflow to order volumes below 100 USD. Again, the deadlock in the constructed workflow indicates that the virtual global workflow may not to be sound, although this is not the case.

Similarly to the previous case, the inherent parameter value constraint of the buyer local workflow, which has been omitted by the projection, causes this deadlock on the constructed logistics workflow. The observation here is that again neglecting these constraints results in irrelevant options not applicable to the global workflow, but causing a deadlock in the constructed workflow.

4. Approach

The approach used in the previous section guarantees that only sound global workflows will be accepted, although it is too restrictive by discarding some sound global workflows. As stated above, neglecting parameter value as well as message ordering constraints are the reasons for these wrong results.

Based on this observation, a valid approach for decentralized decision making on sound multi-lateral collaborations should extend the above sketched approach by making these constraints explicit and enable their local use. In particular, the transitivity property of these constraints should be exploited.

Applying the idea of explicating the constraints in the different local workflows requires an extension of the workflow model. In the following, the general principle is discussed rather than introducing a specific workflow. Further, the effects of these additional constraints on the observed deadlocks is discussed.

The parameter value constraints can be explicated without extending the workflow model. The buyer workflow de-

picted in Figure 5 has to be modified by adding the volume constraint as an additional condition to the *b#l#get_status* transition. This modification can be done, because within the buyer's local workflow the volume of the *b#a#order* message equals to the one of the *b#l#get_status* message. Due to this equivalence, the assigned volume constraint applies to both messages, that is transitivity of constraints. Having done this, there are no more message sequences causing a deadlock in the original constructed logistics workflow depicted in Figure 6. This is because the inherent constraint has been made explicit by using the transitivity property of the less-than relation.

Explicating the message order constraint is more difficult and can not be captured by the WF-Net model. In particular, message order constraints require an exchange of these orderings by the involved trading parties. This allows them to reason on the constraints and thus discover potential deadlocks. An explicit representation of message orders is provided by message sequence charts [18]. Applied to the introductory example depicted in Figure 2 the buyer has an explicit order of *a#b#delivery* message being executed before *b#l#get_status* message. Further, the accounting department provides the order of *l#a#deliver_conf* exchanged before *a#b#delivery* message. Based on the transitivity axiom these orders result in *l#a#deliver_conf* message sent before *b#l#get_status* message. Using this derived constraint prevents the deadlock observed in the constructed logistics workflow depicted in Figure 4.

This approach may require additional communication between the trading parties to determine appropriate transitivity chains in case of cyclic dependencies. This applies to both message order as well as parameter value constraints. The advantage of this approach is that nobody needs to instantiate the global workflow, because in case of doubt it suffices to collect constraints within cyclic dependencies to make a local decision resulting in a decentralized multi-lateral collaboration establishment. In particular, it can be shown that this collaboration establishment can be applied to generic workflows guaranteeing exact decisions.

5. Related Work

Various approaches are discussed starting with an analysis of classical workflow management theory, logic based approaches, and finally coordination theory. All these approaches have in common that they do not provide sufficient reasoning capabilities supporting for example the derivation of additional dependency constraints by exploiting transitivity.

Workflow Management Theory

Models for representing workflows known from workflow theory are finite state automata [11], Petri Nets [12], or statecharts [9]. They allow to represent control flows, but

in many cases introduce a notion of data flow. In particular, all these approaches are based on structural representations, thus, do not provide sufficient reasoning capability. The same holds true for technology specific language proposals based on these approaches like for example BPEL related to web services or the ebXML process specification language BPSS. Although these technologies provide language proposals aiming to solve the addressed issue, but not having right now means to realize it.

Alternatively, the workflow community has addressed the issue of direct coordination between workflow engines [10] rather than implementing coordination based on bilateral interactions as presented in the examples of this paper. Corresponding approaches require a centralized coordination checking the consistent execution of the distributed workflow engines, thus do not support a decentralized decision and execution of multi-lateral collaborations.

logic based Approaches

Dynamic deontic logic [14] is another model representing illocutionary acts. In this approach a transition named action represents a change from one propositional world to another. In addition, deontic operations express permission, prohibition and obligation of actions, that is corresponding transitions. The drawback of the approach is that reasoning based on actions is quite limited and does not provide the full potential as required by the decentralized decision making.

Another logic based approach is Courteous Logic Programs [8] being a non-monotonic logic, that is allowing change of predicate truth assignments. The limitation of this approach again is the limited reasoning possibilities.

Coordination Theory

Within [19] coordination is identified as a critical principle in the study of workflow within organizations. [13] defined "coordination as managing dependencies between activities" and examined all sorts of scientific domains like social, psychological, economical and computer science to identify relevant *activities* and their *dependencies*. Most of the approaches are based on a general indirect, anonymous, undirected and asynchronous communication model, where data can be inserted, read and withdrawn from a shared multi-set.

Coordination theory has also been applied to workflow coordination [15] being data-driven rather than control-driven. An example of such an approach are place transition nets modeling state changes by events. The WorkSpace [16] approach is based on the notion of steps representing a transformation of one or several data elements. Another similar approach is [5]. The limitation of these approaches to decentralized decision making for multi-lateral collaborations is the missing reasoning framework.

6. Conclusion and Future Work

Nowadays, collaboration establishment is done in a top-down manner based on negotiated contracts split into local workflows and implemented manually afterwards. Opposed to this top-down approach web services provide the concept of loose coupling supporting a bottom-up approach, where a multi-lateral collaboration based on already existing local workflows is established without an a-priori knowledge of a global workflow. Within this paper, an exemplary scenario has been used to discuss problems occurring in a decentralized collaboration establishment. In particular, the issue of the implicit/inherent constraints on message orders and parameter values between bilateral interactions has been discussed and several requirements have been derived.

The next steps are to specify a workflow modeling approach being able to explicate the message order and parameter value constraints and enable a decentralized consistency decision of multi-lateral collaborations. This model will be based on the business offer language (BOL) [3, 2] developed earlier and will be extended by a formal semantics providing reasoning capabilities. Furthermore, a workflow engine supporting the modeling approach will be realized based on the formal semantics and evaluated by the multi-lateral collaboration establishment described in this paper.

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