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An Intelligent Procurement Marketplace for Web Services Composition

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Abstract

This paper presents an intelligent procurement marketplace for finding the best mix of web services to dynamically compose the business process desired by a web service requester. We develop a combinatorial auction approach that leads to an integer programming formulation for the web services composition problem. The model takes into account the Quality of Service (QoS) and Service Level Agreements (SLA) for differentiating among multiple service providers who are capable of fulfilling a functionality. An important feature of the model is interface aware composition.

1 Introduction

Mohabey and co-authors have recently presented a combinatorial auction approach to QoS-aware dynamic web services composition [4]. Their approach considers not only stand-alone web services but also composite web services to be a part of a business process, as compared to other approaches that consider only stand-alone services for composition of business process. Such an approach allows the WSPs to provide composite web services at a price and quality that can be different from that of constituent stand-alone services. Moreover, their approach allows representation of scenarios where different WSPs have different number of stages/steps for achieving the same task and they can expose the services at different points. The combinatorial auction leads to an IP formulation for the web services composition problem.

The current work builds upon and extends the above work in the following ways:

- The current approaches do not consider the problem of interface matching. Gao et al [3] present an approach for interface aware composition, however, they represent the problem as a weighted multistage graph, which does not take into account global constraints and preferences set by the user (eg. budget constraints). We present a novel way of interface aware composition by means of adding simple constraints to the IP formulation of web service composition problem.
- The current approaches [6, 1, 3] consider only QoS and cost for differentiating among various WSPs, however, the SLA guarantees given by various WSPs are also a crucial factor in selecting the web services. When multiple service providers are capable of fulfilling a functionality, our model differentiates on the basis of not only QoS but also the SLA guarantees provided by various WSPs.

The rest of the paper is organized as follows. Secion 2 describes the modeling of three important features, namely interface matching, service level agreements, and presence of exogenous service providers. We provide the mathematical formulation of the constraints arising due to these features. In Section 3, we briefly describe some numerical experiments to show the effect of modeling these features. The notation for this paper is described in Table 1.

2 Features of the Intelligent Procurement Marketplace

2.1 Interface Matching

The services offered by different WSPs may not be interoperable, if they have incompatible input output interfaces. Service interface is used to transfer control and data messages between web services. When performing the same task, different service implementations may make different data structures and classes, which result in heterogeneities among different interfaces [3]. For example in Figure 1, there are three WSPs capable of providing functionality for the tasks A, B, C, however the interfaces are different. The edges represent compatible interfaces. Thus B_2 can process output of A_1 but not A_3. We represent different interfaces by l_is.

Thus a typical bid structure would be as follows:
$< index, (S_1{=}\{t_1\}, q_1, q_2, \ldots, q_n, c(S_1), P(S_1), \mathcal{L}^i(S_1), \mathcal{L}^o(S_1)), (S_2{=}\{t_2\}, q_1, q_2, \ldots, q_n, c(S_2), P(S_2), \mathcal{L}^i(S_2),$

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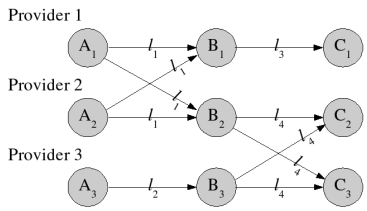

Figure 1. Multistage graph showing interface matching constraints

$\mathcal{L}^o(S_2)), \ldots, (S_n{=}\{t_n\}, q_1, q_2, \ldots, q_n, c(S_n), P(S_n),$
$\mathcal{L}^i(S_n), \mathcal{L}^o(S_n)), (S_{12}{=}\{t_1, t_2\}, q_1, q_2, \ldots, q_n, c(S_{12}),$
$P(S_{12}), \mathcal{L}^i(S_{12}), \mathcal{L}^o(S_{12}))), \ldots >$
where,
$index$ = index of the WSP
t_i = i^{th} task in the statechart
q_i = i^{th} quality attribute of web service
$c(S)$ = price per hit for given subset *S* of tasks
$P(S)$ = penalty for subset *S* of tasks in case of violation of SLA.
$\mathcal{L}^i(S)$ = input interface for a given subset *S* of tasks
$\mathcal{L}^o(S)$ = output interface for a given subset *S* of tasks

Note that $\mathcal{L}^i(S)$ will be zero for all S if start task is an element of S. Similarly, $\mathcal{L}^o(S)$ will be zero for all S if end task is an element of S. For example in Figure 1, if there are two quality attributes then the bid of WSP 1 will look as follows:
$< x, (\{A\}, q_1, q_2, c(A), P(A), 0, l_1), (\{B\}, q_1, q_2, c(B),$
$P(B), l_1, l_3), (\{C\}, q_1, q_2, c(C), P(C), l_3, 0),$
$(\{A, B\}, q_1, q_2, c(AB), P(AB), 0, l_3),$
$(\{B, C\}, q_1, q_2, c(BC), P(BC), l_1, 0) >$

2.2 Service Level Agreements

A service level is used to define the expected performance behavior of a deployed web service, where the performance metrics are, for example, average response time, supported throughput, service availability, etc [2]. Different WSPs may offer the same web service with different QoS and SLAs.

In our model, we capture different service levels from the same WSP by representing them as different combinatorial bids. Note that, violation of any pre-agreed service levels results in a penalty assessment on the part of the service provider. We have modeled the penalty aspect by including $P_i(S)$, the penalty of WSP *i* for subset *S* in case of violation of SLA, in the bid description.

Table 1. Notation

$N = \{1, 2, \ldots, n\}$	Set of WSPs
$i \in N$	Index for web service Providers
$A = \{t_1, t_2, \ldots, t_m\}$	Set of tasks in the statechart
m	Number of tasks in the statechart
$k \in A$	Index of tasks
$S \subseteq A$	Any subset of *A*
$t(S)$	Number of tasks in subset S of web services
$L = \{1, 2, \ldots\}$	Set of all service interfaces
$l \in L$	Index of service interfaces
$\mathcal{I}_i^l(S)$	Integer variable which takes value 1 if *l* is the output interface of WSP *i* for subset *S*, -1 if *l* is the input interface of WSP *i* for subset *S* and 0 otherwise
$y_i(S)$	Boolean variable which takes value 1 if WSP *i* is allocated the subset *S* and 0 otherwise
$F = \{f_1, f_2, \ldots, f_p\}$	Set of all QoS Parameters
p	Number of QoS parameters
w_j	Weight assigned to j^{th} QoS criterion such that $w_j \in [0, 1]$ and $\sum_{j=1}^{p} w_j = 1$
$q_{ij}(S)$	Value of j^{th} QoS criterion in the bid of i^{th} WSP for subset S of tasks
$Q_{ij}(S)$	Value of j^{th} QoS criterion in the bid of i^{th} WSP for subset S of tasks after scaling
$c_i(S)$	Per unit price demanded by WSP *i* for subset *S*
$P_i(S)$	Per unit penalty of WSP *i* for subset *S* in case of violation of SLA
B	Maximum budget available with the WSR
q_{rat}	The probability that a request is correctly responded, in compliance with the quality parameters indicated in the web service description
p_{rat}	$= 1 - q_{rat}$
$T_i(S)$	Time taken by WSP *i* to execute subset *S* of web services, $T_i(S) \in \mathbb{R}_+$
$a_i(S)$	Success rate of composite web service *S* of WSP *i*, $a_i(S) \in [0, 1]$
$g_i(S)$	Availability of composite web service *S* of WSP *i*, $g_i(S) \in [0, 1]$
$r_i(S)$	Reputation of composite web service *S* for i^{th} WSP
D	Total demand from each state/task in statechart

2.3 Exogenous Service Providers

If the providers are external entities then a plausible goal will be to minimize cost subject to quality constraints. We will call this *Exogenous Problem*. The problem of selecting an optimal execution plan for a given execution path for exogenous problem can be mapped into an ILP as follows:
minimize

$$\sum_{S \subseteq A} \sum_{i \in N} y_i(S) c_i(S) \tag{1}$$

subject to
Allocation Constraints:

$$\sum_{S \ni k} \sum_{i \in N} y_i(S) = 1, \quad \forall k \in A \tag{2}$$

$$y_i(S) \in \{0, 1\}, \quad \forall S \subseteq A, \forall i \in N \tag{3}$$

Constraints on Execution Duration and Reputation:

$$\sum_{i \in N} \sum_{S \subseteq A} y_i(S) T_i(S) \leq T \tag{4}$$

Constraint (4) ensures that the execution duration of the composite service does not exceed *T*. Assuming that variable $r_i(S)$ represents the reputation of the subset of web service *S* for i^{th} WSP, we impose the following constraint to capture the overall reputation of the execution plan:

$$q_{rep} \leq \sum_{i \in N} \sum_{S \subseteq A} y_i(S) r_i(S) \tag{5}$$

Constraints on Success Rate and Availability: We define the successful execution rate q_{rat} of a service as the probability that a request is correctly responded, in compliance with the quality parameters indicated in the web service description. p_{rat} of a service is the probability that a request is not responded correctly. Thus, $p_{rat} = 1 - q_{rat}$.

$$ln(q_{rat}) \leq \sum_{S \subseteq A} \Big(\sum_{i \in N} y_i(S) ln(a_i(S)) \Big) \tag{6}$$

Similarly, for availability,

$$ln(q_{av}) \leq \sum_{S \subseteq A} \Big(\sum_{i \in N} y_i(S) ln(g_i(S)) \Big) \tag{7}$$

Interface Matching Constraints: Following additional constraints have to be added to the IP formulations discussed in previous sections to guarantee that the input interface of each service is matched to a compatible output interface. Thus, these constraints ensure feasibility of execution plan for the execution path.

$$\sum_{S \subseteq A} \sum_{i \in N} y_i(S) \mathcal{I}_i^l(S) = 0, \quad \forall l \in L \tag{8}$$

SLA Constraints: Violation of any pre-agreed service levels results in a penalty assessment on the part of the WSP. In this model we assume that, in case of critical failure, a WSR penalizes the defaulting WSP, a standard amount, as agreed in SLA. A WSR associates some value with the successful execution of the composite web service say v_{succ}. Similarly, failure in execution of the composite web service may result in loss. Let $v_{failure}$ represent the value that the WSR associates with the failure in execution of the composite web service, in compliance with the SLA, by any of the constituent services. $v_{failure} < v_{succ}$. A WSR's goal is to maximize the utility obtained. Thus we can write[1]

$$\begin{aligned} maximize \quad & utility \\ = \quad & (value - cost) \\ = \quad & \Big[(1 - p_{rat}) v_{succ} + (p_{rat}) v_{failure} + \end{aligned}$$

$$\sum_{S \subseteq A} \sum_{i \in N} y_i(S) \Big\{ (1 - a_i(S)) P_i(S) - (a_i(S)) c_i(S) \Big\} \Big]$$

$v_{succ}(1 - p_{rat}) + v_{failure}(p_{rat})$ being constant, we can rewrite as
minimize

$$\sum_{S \subseteq A} \sum_{i \in N} y_i(S) \Big\{ (a_i(S)) c_i(S) - (1 - a_i(S)) P_i(S) \Big\} \tag{9}$$

subject to, constraints 2-4, 5, 6, and 7. In the above formulation, we have assumed that when a end to end composite service is invoked, all its constituent web services are invoked. But, if one of the web services fails completely then it may not make sense to invoke the subsequent web services. However, if the failure is minor (eg. slight violation of some SLA parameter) then invoking the subsequent services may be of some positive value to the WSR. In the above formulation we consider all failures to be of latter category.

3 Experiments

We evaluated the solutions given by combinatorial auction and non-combinatorial version in case of exogenous scenario, in different settings. Further, we investigated how the presence of penalty changes the selection of optimal outcome in case of exogenous problem. Due to space constraints, we are unable to provide the details of the experiments. We only report our experiments on interface matching. An elaborate description of experiments can be found in [5].

Consider the multistage graph in Figure 1. There are three service providers $\mathcal{P}_1$, $\mathcal{P}_2$, and $\mathcal{P}_3$. Let the composite

[1] We assume quasi-linear environment where agent's utility = value - cost

web service desired by WSR be ABC and the WSR requests for a composite service of minimum cost subject to the constraint that execution duration of end-to-end composite service is ≤ 50. WSPs submit bids as shown in Table 2. The $\surd$ in the last two columns of Table 2 show the winning bids, for the cases when interface matching constraints are not considered for composition of end-to-end web service, and when interface matching constraints are considered. As it is clear from Table 2, the composite web service selected, $A_3B_3C_1$, when interface matching constraints are not considered, has less cost and execution duration as compared to the composite web service selected, $A_3B_3C_2$, when interface matching constraints are considered. However, C_1 is not interoperable with composite web service A_3B_3. Thus selecting $A_3B_3C_1$, though optimal, is not a feasible execution plan. Adding constaint (8) to the optimization problem gives the optimal execution plan among all the feasible execution plans.

Table 2. Bids submitted by WSPs for exogenous problem and the winning bids with and without interface matching

No	WSP	Comp svc	Exec dur	Cost/ unit	Intf		W/o intf	W/ intf
					I/p	O/p	mat	mat
1	$\mathcal{P}_1$	A	10	15	0	l_1		
2	$\mathcal{P}_1$	B	22	11	l_1	l_3		
3	$\mathcal{P}_1$	C	13	17	l_3	0	$\surd$	
4	$\mathcal{P}_1$	AB	30	25	0	l_3		
5	$\mathcal{P}_1$	BC	34	27	l_1	0		
6	$\mathcal{P}_1$	ABC	42	43	0	0		
7	$\mathcal{P}_2$	A	11	14	0	l_1		
8	$\mathcal{P}_2$	B	20	12	l_1	l_4		
9	$\mathcal{P}_2$	C	14	18	l_4	0		$\surd$
10	$\mathcal{P}_2$	AB	30	24.5	0	l_4		
11	$\mathcal{P}_2$	BC	33	30	l_1	0		
12	$\mathcal{P}_2$	ABC	44	41	0	0		
13	$\mathcal{P}_3$	A	12	13	0	l_2		
14	$\mathcal{P}_3$	B	24	10	l_2	l_4		
15	$\mathcal{P}_3$	C	12	19	l_4	0		
16	$\mathcal{P}_3$	AB	34	22	0	l_4	$\surd$	$\surd$
17	$\mathcal{P}_3$	BC	34	29	l_2	0		
18	$\mathcal{P}_3$	ABC	45	40	0	0		

4 Future Work

The current work limits discussion to a linear execution path. Introducing forks and joins will model a more generalized scenario. A rational WSP may not find it in its best response to reveal true information about the web services provided by it. We intend to extend the model to take into account the rationality of the WSPs.

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