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Web Service Composition - BPEL vs cCSP Process Algebra

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***Abstract*—Web services technology provides a platform on which we can develop distributed services. The interoperability among these services is achieved by various standard protocols. In recent years, several researches suggested that process algebras provide a satisfactory assistance to the whole process of web services development. Business transactions, on the other hand, involve the coordination and interaction between multiple partners. With the emergence of web services, business transactions are conducted using these services. The coordination among the business processes is crucial, so is the handling of faults that can arise at any stage of a transaction. BPEL models the behavior of business process interaction by providing a XML based grammar to describe the control logic required to coordinate the web services participating in a process flow. However BPEL lacks a proper formal description where the composition of business processes cannot be formally verified. Process algebra, on the other hand, facilitates a formal foundation for rigorous verification of the composition. This paper presents a comparison of web service composition between BPEL and process algebra, cCSP.**

***Keywords*-BPEL, Web Services, Orchestration, cCSP, Process Algebra**

I. Introduction

Web services technology provides a platform on which we can develop distributed services. The interoperability among these services is achieved by the standard protocols (WSDL [1], UDDI [2], SOAP [3]) that provide the ways to describe services, to look for particular services and to access services. With the emergence of web services, business transactions are conducted using these services [4]. Web services provided by various organizations can be interconnected to implement business collaborations, leading to composite web services. Business collaborations require interactions driven by explicit process models. Web services are distributed, independent processes which communicate with each other through the exchange of messages. The coordination between business processes is particularly crucial as it includes the logic that makes a set of different software components become a whole system. Hence it is not surprising that these coordination models and languages have been the subject of thorough formal study, with the goal of precisely describing their semantics, proving their properties and deriving the development of correct and effective implementations.

Process calculi are models or languages for concurrent and distributed interactive systems. It has been advocated in [5], [6] that process algebras provide a complete and satisfactory assistance to the whole process of web services development. Being simple, abstract, and formally defined, process algebras make it easier to formally specify the message exchange between web services and to reason about the specified systems. Transactions and calculi have met in recent years both for formalizing protocols as well as adding transaction features to process calculi [7]–[10].

Several research issues, both theoretical and practical, are raised by web services. Some of the issues are to specify web services by a formally defined expressive language, to compose them, and to ensure their correctness; formal methods provide an adequate support to address these issues [11]. Recently, many XML-based process modeling languages (also known as choreography and orchestration [12] languages) such as WSCI [13], BPML [14], BPEL4WS [15], WSFL [16], XLANG [17] have emerged that capture the logic of composite web services. These languages also provide primitives for the definition of business transactions.

Several proposals have been made in recent years to give a formal definition to compensable processes by using process calculi. These proposals can be roughly divided into two categories. In one category, suitable process algebras are designed from scratch in the spirit of orchestration languages, e.g., BPEL4WS (Business Process Execution Language for Web Services, BPEL in short). Some of them can be found in [18]–[20]. In another category, process calculi like the π-calculus [21], [22] and the join-calculus [23] are extended to describe the interaction patterns of the services where, each service declares the ways to be engaged in a larger process. Some of them are available in [9], [10], [24], [25].

Inspired by the growing interest in transaction processing using web services, this paper presents our on-going experiment of comparing the composition of web services by BPEL and process algebra cCSP [20]. cCSP is an extension of CSP, especially defined to model business transactions. The formal semantics of the algebra has already been defined [20], [26].We model the transaction of a Car Broker web service using both BPEL and cCSP examining the expressiveness of both languages.

In the remainder of the paper, Section II gives an overview of the cCSP process algebra and its constructs. Section III first briefly describes our case study web service and then model the web service in both BPEL and cCSP. For brevity

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only an abstract version of the Car Broker web service is modeled in this paper. Finally, we conclude our paper and outline our future plans.

II. COMPENSATING CSP (CCSP)

The introduction of the cCSP language was inspired by the combination of two ideas: transaction processing features, and process algebra. Like standard CSP, processes in cCSP are modeled in terms of the atomic events they can engage in. The language provides operators that support sequencing, choice, parallel composition of processes. In order to support failed transaction, compensation operators are introduced. The processes are categorized into standard, and compensable processes. A standard process does not have any compensation, but compensation is part of a compensable process that is used to compensate a failed transaction. We use notations, such as, $P, Q, ..$ to identify standard processes, and $PP, QQ, ..$ to identify compensable processes. A subset of the original cCSP is considered in this paper, which includes most of the operators. The cCSP syntax, considered in this paper, is summarized in Fig. 1.

Standard Processes:		**Compensable Processes:**	
$P, Q ::= A$	(atomic event)	$PP, QQ ::= P \div Q$	(compensation pair)
$\mid P \,;\, Q$	(sequential composition)	$\mid PP \,;\, QQ$	
$\mid P \,\Box\, Q$	(choice)	$\mid PP \,\Box\, QQ$	
$\mid P \parallel Q$	(parallel composition)	$\mid PP \parallel QQ$	
$\mid SKIP$	(normal termination)	$\mid SKIPP$	
$\mid THROW$	(throw an interrupt)	$\mid THROWW$	
$\mid YIELD$	(yield to an interrupt)	$\mid YIELDD$	
$\mid P \,\triangleright\, Q$	(interrupt handler)		
$\mid [PP]$	(transaction block)		

Figure 1. cCSP syntax

The basic unit of the standard processes is an atomic event (A). The other operators are the sequential ($P \,;\, Q$), and the parallel composition ($P \parallel Q$), the choice operator ($P \,\Box\, Q$), the interrupt handler ($P \triangleright Q$), the empty process *SKIP*, raising an interrupt *THROW*, and yielding an interrupt *YIELD*. A process that is ready to terminate is also willing to yield to an interrupt. In a parallel composition, throwing an interrupt by one process synchronizes with yielding in another process. Yield points are inserted in a process through *YIELD*. For example, ($P \,;\, YIELD \,;\, Q$), is willing to yield to an interrupt in between the execution of P, and Q. The basic way of constructing a compensable process is through a compensation pair ($P \div Q$), which is constructed from two standard processes, where P is called the forward behaviour that executes during normal execution, and Q is called the associated compensation that is designed to compensate the effect of P when needed. The sequential composition of compensable processes is defined in such a way that the compensations of the completed tasks will be accumulated in reverse to the order of their original composition, whereas compensations from the compensable parallel processes will be placed in parallel. In this paper, we define only the asynchronous composition of processes, where processes interleave with each other during normal execution, and synchronize during termination. By enclosing a compensable process PP inside a transaction block $[PP]$, we get a complete transaction and the transaction block itself is a standard process. Successful completion of PP represents successful completion of the block. But, when the forward behaviour of PP throws an interrupt, the compensations are executed inside the block, and the interrupt is not observable from outside of the block. $SKIPP, THROWW$, and $YIELDD$ are the compensable counterpart of the corresponding standard processes and they are defined as follows:

$$SKIPP = SKIP \div SKIP, \qquad YIELDD = YIELD \div SKIP$$
$$THROWW = THROW \div SKIP$$

A cCSP process is described in terms of its interactions with its environment or other processes. The interactions are described by using atomic actions via channels as in standard CSP. We add some constructs to the language as syntactic sugar. A communication is an event described by a pair $c.v$ where c is the name of the channel on which communication takes place and v is the value of the message. A construct is defined to allow an input of an item x from a set M to a channel in and the value x determines the subsequent behaviour. Output is the complement of the input.

$$\begin{aligned} in?x : M \,;Q(x) &\;\widehat{=}\; \Box_{x \in M}\, in.x \,;Q(x) \\ out!x &= out.x \end{aligned}$$

When drawing diagrams of processes, the channels are drawn using arrows in the appropriate direction to define them as input or output and labeled with channel name. Let P and Q are two processes and c an output channel of P and an input channel of Q. When P and Q composed in parallel ($P \parallel Q$), a communication $c.v$ can occur only when both processes engage simultaneously, i.e., when P outputs v on the channel, simultaneously Q receives the value. The choice is a binary operator. While modeling a transaction we use the indexed version of the operator, which is defined as: $\Box_{x \in S} P_x$, e.g.,

$$\Box_{x \in \{S_1, S_2 \ldots S_n\}} P_x \quad = \quad P_{S_1} \,\Box\, P_{S_2} \ldots \Box\, P_{S_n}$$

The parallel operator is associative. For processes P, Q and R

$$P \parallel (Q \parallel R) \quad = \quad (P \parallel Q) \parallel R$$

In the composition $P \parallel_X Q$, the processes synchronize over events of the set X. We also use I/O parameters for compensation pair:

$$(A?x \div B.x) \,;P(x) \quad = \quad \Box_{x \in S} (A.x \div B.x) \,;P(x)$$

III. Car Broker Web Services

A car broker web service negotiates car purchases for its buyers and arranges loans for these. The car broker uses two separate web services: a Supplier to find a suitable quote for the requested car model and a Lender to arrange loans. Each web service can operate separately and can be used in other web services. In this case study, our focus is on how the processes communicate with each other and how the compensations are handled when there is an interrupt. For brevity, several details are abstracted from the description. The original car broker example can be found in [27], [28].

A. Broker Web Service

We model a car broker web service **Broker**. It provides online support to customers to negotiate car purchases and arranges loans for these. A buyer provides a need for a car model. The broker first uses its business partner **Supplier** to find the best possible quote for the requested model and then uses another business partner **LoanStar** to arrange a loan for the buyer for the selected quote. The buyer is also notified about the quote and the necessary arrangements for the loan. Both **LoanStar** and the **Buyer** can cause an interrupt to be invoked. A loan can be refused due to a failure in the loan assessment and a customer can reject the loan and quoted offer. In both cases, there is a need to run the compensation, where the car might have already been ordered, or the loan has already been offered. We first model this web service using BPEL and then in cCSP. The behaviour of the **Broker** we service in relation to BPEL modeling is illustrated in Fig 2.

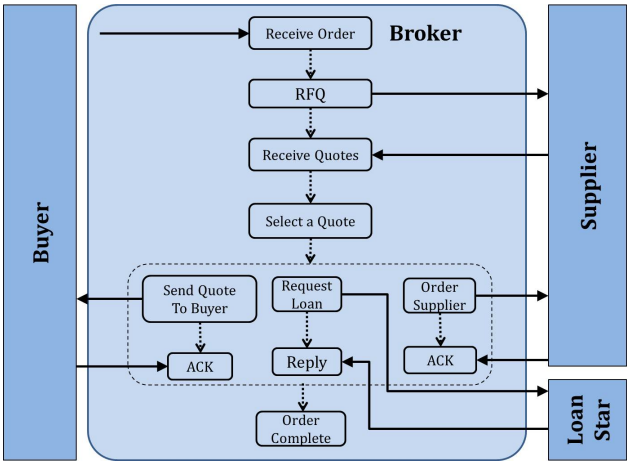

Figure 2. Architectural view of Car Broker web Service

```
<process name="CarBroker".../>
 <scope>
 <compensationHandler>
  <sequence>
  <invoke partnerLink="BrokerPL"
      operation ="cencelOrder"...../>
  </sequence>
  </compensationHandler>
 <sequence>
 <receive partnerLink="order_Broker",
    Variable="orderReq...../>
  <scope>
  <compensationHandler>
......
  </compensationHandler>
 <sequence>
 <invoke partnerLink="RFQ_Suppiler",
   outputVariable="SuppilerQuote",
   inputVariable="orderReq".../>
 <reply partnerLink="Quote_Broker",
  variable="SuppilerQuote".../>
</sequence>
 </scope>
 <flow>
<scope>
<compensationHandler>
<sequence>
 <invoke partnerLink="BrokerPL"
    operation ="cencelLoan"...../>
  </sequence>
  </compensationHandler>
 <sequence>
<invoke partnerLink="ReqLoan_loanstar",
outputVariable="Reply",
 inputVariable="SupplierQuote"..../>
<reply partnerLink="Reply_broker",
  variable="Reply...../>
</sequence>
</scope>
......
</process>
```

BPEL construct `sequence` is defined to arrange the services in sequential order, `flow` is used to model the tasks in parallel. Each operation is defined within a scope (`scope`) which is used for the scope of that particular service and the range of compensation handler when an error has occurred and compensation is triggered. Due to brevity, a limited part of the BPEL is presented here. The cCSP representation of the Broker web service is defined in Fig. 3

$$\mathbf{Broker} \mathrel{\widehat{=}} (Order?m : M \div CancelOrder.m)\ ;\mathbf{ProcessOrder(m)}$$

$$\mathbf{ProcessOrder(m)} \mathrel{\widehat{=}} RFQ.m\ ;\ Quote?q : \mathbb{F}\ Q\ ;\ \Box_{c \in q} \bullet \Big((\mathbf{Sendorder(c)} \parallel \mathbf{Loan(a)}) \parallel \mathbf{SendQuote(c)}\Big)$$

$$\mathbf{SendOrder(c)} \mathrel{\widehat{=}} (Order.c \div SKIP)$$

$$\mathbf{Loan(a)} \mathrel{\widehat{=}} (ReqLoan.a : Amt \div CancelLoan.a)\ ; (Reply?Accept\ ; SKIPP \ \Box\ Reply?Reject\ ; THROWW)$$

$$\mathbf{SendQuote(c)} \mathrel{\widehat{=}} Quote.c\ ; (Ack?Accept\ ; SKIPP \ \Box\ Ack?Reject\ ; THROWW)$$

Figure 3. cCSP model of Broker service

The first step of the transaction is a compensation pair, where the primary action is to receive an order from the buyer and the compensation is to cancel the order. M is a finite set of car models ranged over by m.

The Broker requests the Supplier for available quotes (**RFQ**) and then selects a quote from the received quotes (Quote). The Broker arranges a loan for the quoted car by requesting a loan from **LoanStar**. The loan amount (*Amt*) of loan to be requested is decided from the selected quote and passed to the process Loan. It requests loan from **LoanStar** which is either accepted or rejected. If the loan cannot be provided then an interrupt is thrown to cancel the actions that have already taken place. A compensation is added to **ReqLoan** (**CancelLoan**) so that in the case of failure in a later stage the compensation can be invoked to cancel the event. the quote is also sent to the buyer (**SendQuote**). An interrupt can be raised either by the Buyer by rejecting the quote or by the **LoanStar** by rejecting the requested loan. In either case, the Supplier will terminate yielding an interrupt thrown by the Broker and compensations from both Broker and Supplier will run in parallel.

The behaviour of the car broker web service is defined by combining the behaviour of Broker, Buyer, Supplier, and LoanStar, where the processes synchronize over the sets A, B and C.

$$\textbf{System} \;\widehat{=}\; \textbf{Buyer} \parallel_A [\textbf{Broker} \parallel_{\textbf{B}} \textbf{Supplier}] \parallel_C \textbf{LoanStar}$$

$A = \{ Order, Quote, Ack \}$,
$B = \{ RFQ, Quote, Order, Cancel \}$
$C = \{ ReqLoan, Reply \}$

The example illustrates the synchronization of processes within a transaction block, [**Broker** $\parallel_{\textbf{B}}$ **Supplier**] and between transaction blocks (**Buyer** and **LoanStar** are transaction blocks). It also outlines how the compensations are handled in each case.

B. Lender Web Service

A loan service is a common example of a business process (please refer to [27] for a full description). We assume a lender web service **LoanStar**, that offers loans to online customers. A customer submits a request for an amount to be loaned along with other required information. **LoanStar** first checks the loan amount and if the amount is £10,000 or more, then **LoanStar** asks its business partner **FirstRate** to thoroughly assess the loan. After a detailed assessment of the loan, **FirstRate** can either approve the loan or reject the loan. A full assessment is costly, so if the loan amount is less than £10,000, the loan is evaluated more simply. **LoanStar** asks its business partner **Assessor** to evaluate the risk for the loan. If the associated risk is low then loan is approved, otherwise **LoanStar** asks **FirstRate** to perform a full assessment.

We give a simple specification of the lender and do not consider any attached compensation for it. The processes are defined as standard processes. At the top level, the transaction is defined as a sequence of two processes: receiving an order and processing the order.

$$\textbf{LoanStar} \;\widehat{=}\; \mathit{LoanOrder?a} : \mathit{Amt} \;;\textbf{Process}(a)$$

The Process first checks the loan amount to determine the type of evaluation that needs to be performed. The process **ChkAmt** checks the loan amount control is passed to either Below or Over depending on the loan amount.

$$\textbf{Process}(\mathbf{a}) \;\widehat{=}\; \mathit{ChkAmt.a} \;;\; (\mathit{Below.a} \;;\textbf{Assessor}(\mathbf{a}) \;\square\; \mathit{Over.a} \;;\textbf{FirstRate}(\mathbf{a}))$$

The process Assessor starts for a loan amount lower than 10,000. It first checks the risk associated with the loan. If the risk is low the loan is approved. If the risk is high control is passed to the **FirstRate** for a full assessment. After performing a full assessment and depending on the outcome, **FirstRate** either accepts or rejects the requested loan.

$$\textbf{Assessor}(\mathbf{a}) \;\widehat{=}\; \mathit{ChkRisk.a} \;;\; (\mathit{Low.a} \;;\mathit{Reply.Accept} \;\square\; \mathit{High.a} \;;\textbf{FirstRate}(\mathbf{a}))$$

$$\textbf{FirstRate}(\mathbf{a}) \;\widehat{=}\; \mathit{Assess.a} \;;\; (\mathit{Ok} \;;\mathit{Reply.Accept} \;\square\; \mathit{NotOk} \;;\mathit{Reply.Reject})$$

In the example, we abstract the details of the behaviour of Assessor and **FirstRate**. Both of them can be modeled as a separate web service or as a part of the lender web services. A part of the corresponding BPEL model is as follows:

```
<process name="LoanStar"...>
<scope>
<compensationHandler>
<sequence>
<invoke partnerLink="LoanStarPL"
  operation ="cencelRequest"...../>
</sequence>
</compensationHandler>
<sequence>
<receive partnerLink="Loan_Req",
  Variable="Amt...../>
<invoke partnerLink="Chk_AmtPL",
 outputVariable="ProceedLoan",
 inputVariable="Amt..../>
<reply partnerLink="Amt_Check",
  variable="ProceedLoan...../>
<invoke partnerLink="BrokerPL",
inputVariable="ConfrimLoan..../>
...
</sequence>
</scope>
</process>
```

C. Supplier Web Service

Car supplier web service provides buyers a good deal on car orders. Supplier is a supplier that takes orders for a car from buyers (or from brokers as in Sect. III-A). The supplier sends a request for quotes (RFQ) to a dealer to get available quotes for the requested car model. The dealer collects quotes from all of its associated partners and passes the accumulates quotes to the supplier. An offer (or a list of offers) is selected by the supplier and sent to the buyer. The offer is also sent to the dealer as a definite order for the selected model as it is expected that the buyer will accept the offer. The buyer can either accept or reject the quote.

If the order is rejected by the buyer, a compensation is invoked to cancel the order that is sent to the dealer. Here, we give a simple representation of the order receipt and dealer activities and focus on the behaviour of the car supplier in more detail (Fig. 4).

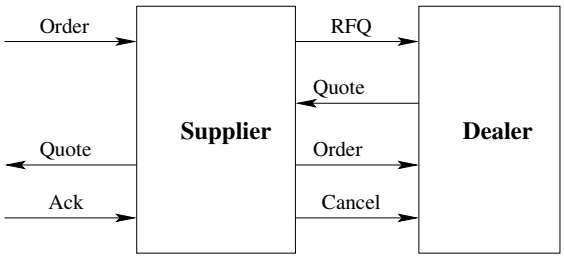

Figure 4. A car supplier web service

$$\begin{array}{lll} \textbf{Supplier} & \widehat{=} & \big[\ (Order?m : M \div CancelOrder.m)\ ; \\ & & \textbf{ProcessOrder}(\mathbf{m})\ \big] \\ \text{where,} & & M = \text{Car Models} \end{array}$$

The transaction steps for the **Supplier** are same as that of a Broker described earlier, except that lender service is not attached here.

$$\begin{array}{lll} \textbf{ProcessOrder}(\mathbf{m}) & \widehat{=} & RFQ.m\ ; RecQuote?q : \mathbb{P}\,Q\ ; \\ & & \Box_{c \in q} \bullet \Big((Order.c \div Cancel.c) \\ & & \parallel \textbf{SendQuote}(\mathbf{c}) \Big) \\ \text{where,} & & Q = \text{Available Quotes} \end{array}$$

After receiving a quote from the supplier, the buyer acknowledges the receipt of a quote by either accepting or rejecting it. In the case of rejection, an interrupt is thrown to compensate the activities that have already taken place. It has been discussed earlier that as **SendOrder** and **SendQuote** interleave with each other, the interrupt from the buyer can be thrown before sending the order to the dealer. The compensations are stored dynamically during the execution of processes, which is in this case empty and compensation mechanism can take care of it. The **SendQuote** process sends a quote, then receives an acknowledgement as either Accept or Reject.

$$\begin{array}{lll} \textbf{SendQuote}(\mathbf{c}) & \widehat{=} & Quote.c\ ;\ (Ack?Accept\ ; SKIPP \\ & & \Box\ Ack?Reject\ ; THROWW) \end{array}$$

The behaviour of the supplier system is defined by composing the behaviour of Supplier, Dealer and Buyer.

$$\begin{array}{rcl} \textbf{System} & \widehat{=} & \Big(\textbf{Buyer} \parallel_A \textbf{Supplier} \Big) \parallel_B \textbf{Dealer} \\ A & = & \{Order, Quote, Ack\} \\ B & = & \{RFQ, Quote, Order, Cancel\} \end{array}$$

The BPEL process model is defined as follows,

```
<process name="Supplier".../>
 <scope>
 <compensationHandler>
  <sequence>
  <invoke partnerLink="SuplierPL"
     operation ="cencelOrder"../>
  </sequence>
 </compensationHandler>
<sequence>
 <receive partnerLink="order_Supplier",
           Variable="orderReq"...../>
 <invoke partnerLink="RFQ_Dealer",
  outputVariable="DealerQuote",
  inputVariable="orderReq"..../>
  <reply partnerLink="Quote_Supplier",
  variable="DealerQuote".../>
 <invoke partnerLink="BrokerPL",
  outputVariable="Ack",
  inputVariable="DealerQuote"..../>
 <reply partnerLink="Reply_Supplier ",
  variable="Ack".../>
 <invoke partnerLink="Order_Dealer",
  outputVariable="confrim",
  inputVariable="DealerrQuote"..../>
  <reply partnerLink="Confrim_Dealer",
  variable="confrim"...../>
 </sequence>
</scope>
</process>
```

IV. Conclusions

We have shown how cCSP process algebra constructs can be used to model business transactions. Importantly, we have shown how compensations are orchestrated to model the business processes. The compensations are accumulated during the execution of the processes. The compensations are defined in such a way that when an interrupt occurs at any stage of the transaction, the appropriate compensations (which might be empty when interruption occurs before occurring an event with attached compensation) are executed for the actions that already did take place. Having been able to model the web services both by using BPEL and a process algebra confirms suitability of a proper formal verification of the web service composition. As this composition is crucial to business organizations, our comparative case study made a significant leap towards the development of a verified web services. Our future plan includes the encoding the process algebraic model into a suitable model checker such as FDR [29] to check various properties of the whole web service compositions.

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