Augmenting Web Services Composition with Transactional Requirements

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Abstract

Current Web services composition approaches do not take into account transactional requirements defined by designers. The transactional challenges raised by the composition of Web services are twofold: relaxed atomicity and dynamicity. In this paper, we propose a new process to automate the design of transactional composite Web services. Our solution enables the composition of Web services not only according to functional requirements but also to transactional ones defined using the Acceptable Termination States model. The resulting composite Web service is compliant with the consistency requirements expressed by designers and its execution can easily be coordinated using the coordination rules provided as an outcome of our approach.

1. Introduction

Web services composition has been gaining momentum over the last years as it leverages the capabilities of simple operations to offer complex services. These complex services such as airline booking systems result from the aggregation of Web services offered by different organizations. As for all cross-organizational collaborative systems, the execution of composite services requires transactional properties (*TP*) so that the overall consistency of data modified during the process is ensured. Yet, existing Web services composition systems appear to be limited when it comes to integrate at the composition phase the consistency requirements defined by designers. Composite Web services indeed require different transactional approaches than the one developed for usual database systems [6, 7]. The transactional challenges raised by the composition of Web services are twofold. First, like classical workflow systems, composite services raise less stringent requirements for atomicity in that intermediate results produced by some components may be kept without rollback despite the failure to complete the overall execution of a composite service. Second, composite services are dynamic in that their components can be automatically selected at run-time based on specific requests. To cope with these challenges, the existing approaches only offer means to validate transactional requirements (*TR*) once a composite Web service has been created [4] but no solution to integrate these requirements as part of the composite service building process.

In this paper, we propose a systematic procedure to automate the design of transactional composite Web services. Given an abstract representation of a process wherein instances of services are not yet assigned to component tasks, our solution enables the selection of Web services not only according to functional requirements but also to transactional ones. In our approach, *TR* are defined by designers using the Acceptable Termination States model (*ATS*). The resulting composite Web service is compliant with the defined consistency requirements and its execution can be easily coordinated as our algorithm also provides coordination rules that can be plugged into a transactional coordination protocol. The remainder of the paper is organized as follows. Section 2 introduces the methodology of our approach. In section 3, we present our transactional model. In section 4 we provide details on the termination states of a composite Web service then in section 5 we describe how *TR* are formed based on the properties of the termination states. The transaction-aware composition process through which transactional composite Web services are designed is detailed in section 6. Finally, section 7 discusses related work and section 8 presents the conclusion.

2. Preliminary definitions and methodology

Consistency is a crucial aspect of composite services execution. In order to meet consistency requirements at early stages of the service composition process, we need to consider *TR* a concrete parameter determining the choice of the component Web services. In this section we present a high level definition of the consistency requirements and a methodology taking into account these requirements during the composition of Web services.

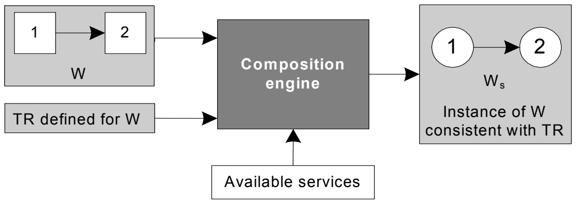


Figure 1. Principles

2.1. Consistent composite Web services

A composite Web service W_s consists of a set of n Web services $W_s = (s_a)_{a \in [1,n]}$ whose execution is managed according to a workflow W which defines the execution order of a set of n tasks $W = (t_a)_{a \in [1,n]}$ performed by these services (for the sake of simplicity, we consider that one service executes only one task). The assignment of services to tasks is performed by means of composition engines based on functional requirements. Yet, the execution of a composite service may have to meet *TR* aiming at the overall assurance of consistency. Our goal is to design a service assignment process that takes into account the *TR* associated with W in order to obtain a consistent instance W_s of W as depicted in Figure 1. We consider that each Web service component might fulfill a different set of *TP*. For instance a service can have the capability to compensate the effects of a given operation or to re-execute the operation after failure whereas some other service does not have any of these capabilities. It is thus necessary to select the appropriate service to execute a task whose execution may be compensated if required. The assignment procedure based on *TR* follows the same strategy as the one based on functional requirements. It is a match-making procedure between the TP offered by services and the *TR* associated to each task.

Once assigned, the services $(s_a)_{a \in [1,n]}$ are coordinated with respect to the *TR* during the process execution. The coordination protocol is indeed based on rules deduced from the *TR*. These rules specify the final states of execution or termination states each service has to reach so that the overall process reaches a consistent termination state. Two phase-commit the famous coordination protocol uses for instance the simple rule: all tasks performed by different services have to be compensated if one of them fails. The challenges of the transactional approach are therefore twofold.

- Specify a Web service assignment procedure that creates consistent instance of W according to defined TR
- Specify the coordination protocol managing the execution of consistent composite services

2.2. Methodology

In our approach, the services part of W_s are selected according to their *TP* by means of a match-making procedure. We therefore need first to specify the semantic associated to the *TP* defined for services. The match-making procedure is indeed based on this semantic. This semantic is also to

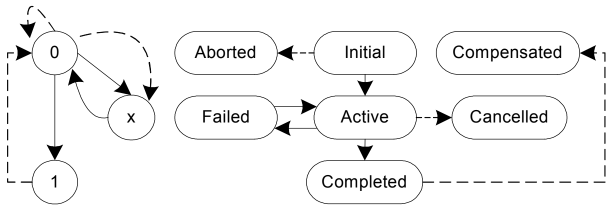


Figure 2. State model

be used in order to define a tool allowing workflow designers to specify their *TR* for a given workflow. Using these *TR*, we are able to assign services to workflow tasks based on rules which are detailed later on. Once the composite service is defined, we can define a protocol in order to coordinate these services according to the *TR* specified at the workflow designing phase.

3. Transactional model

In this section, we define the semantic specifying the *TP* offered by services before specifying the consistency evaluation tool associated to this semantic. Our semantic model is based on the "transactional Web service description" defined in [4].

3.1. Transactional Properties of Services

In [4] a model specifying semantically the *TP* of Web services is presented. This model is based on the classification of computational tasks made in [13, 15] which considers three different types of *TP*. An operation and by extension a Web service executing this task can be:

- Compensatable: the results produced by the task can be rolled back
- Retriable: the task is sure to complete successfully after a finite number of tries
- Pivot: the task is neither compensatable nor retriable

These *TP* allows to define four types of services: Retriable (r), Compensatable (c), Retriable and Compensatable (rc) and Pivot (p).

To properly detail the model, we can map the *TP* with the state of data modified by the services during the execution of computational tasks. This mapping is depicted in Figure 2. Basically, data can be in three different states: initial (0), unknown (x), completed (1). In the state (0), either the task execution has not yet started $initial$, the execution has been stopped, $aborted$ before starting, or the execution has been properly completed and the modifications have been rolled back, $compensated$. In state (1) the task execution has been properly $completed$. In state (x) either the task execution is not yet finished $active$, the execution has been stopped, $canceled$ before completion, or the execution has $failed$. Particularly, the states $aborted$, $compensated$, $completed$, $canceled$, and $failed$ are the possible final states of execution of these tasks. Figure 3 details the transition diagram for the four types of transactional services. We must distinguish within this model the inherent termination states: $failed$ and $completed$ which result from the normal course of a task execution and the one resulting from a coordination message received during a coordination protocol instance: $compensated$, $aborted$ and $canceled$ which force a task execution to either stop or rollback. The *TP* of the services are only differentiated by the states $failed$, and $compensated$ which indeed respectively specify the retriability and compesatability aspects.

Definition 3-1. We have for a given service s:

- $failed$ is not a termination state of $s \Leftrightarrow s$ is retriable
- $compensated$ is a termination state of $s \Leftrightarrow s$ is compensatable

From the state transition diagram, we can also derive some simple rules. The states $failed$, $completed$ and $canceled$ can only be reached if the service is in the state $active$. The state $compensated$ can only be reached if the service is in the state $completed$. The state $aborted$ can only be reached if the service is in the state $initial$.

3.2. Termination states

The crucial point of the transactional model specifying the *TP* of services is the analysis of their possible termination states. The ultimate goal is indeed to be able to define consistent termination states for a workflow i.e. determining for each service executing a workflow task which termination states it is allowed to reach.

Definition 3-2. We define the operator termination state $ts(x)$ which specifies the possible termination states of the element x. This element x can be:

- a service s and $ts(s) \in \{aborted, canceled, failed, completed, compensated\}$
- a workflow task t and $ts(t) \in \{aborted, canceled, failed, completed, compensated\}$
- a workflow composed of n tasks $W = (t_a)_{a\in[1,n]}$ and $ts(W) = (ts(t_1), ts(t_2), ..., ts(t_n))$
- a composite service W_s of W composed of n services $W_s = (s_a)_{a\in[1,n]}$ and $ts(W_s) = (ts(s_1), ts(s_2), ..., ts(s_n))$

The operator $TS(x)$ represents the finite set of all possible termination states of the element x, $TS(x) = (ts_k(x))_{k\in[1,j]}$. We have especially, $TS(W_s) \subseteq TS(W)$ since the set $TS(W_s)$ represents the actual termination states that can be reached by W_s according to the *TP* of the services assigned to W. We also define for x workflow or composite service and $a \in [1, n]$:

- $ts(x, t_a)$: the value of $ts(t_a)$ in $ts(x)$
- $tscomp(x)$: the termination state of x such that $\forall\ a \in [1, n]\ ts(x, t_a) = completed.$

For the remaining of the paper, $W = (t_a)_{a\in[1,n]}$ represents a workflow of n tasks and $W_s = (s_a)_{a\in[1,n]}$ a composite service of W.

3.3. Transactional consistency tool

We use the Acceptable Termination States (ATS) [14] model as the consistency evaluation tool for our workflow. ATS defines the termination states a workflow is allowed to reach so that its execution is judged consistent.

Definition 3-3. $ATS(W)$ is the subset of $TS(W)$ whose elements are considered consistent by workflow designers. A consistent termination state of W is called an acceptable termination state $ats_k(W)$ and we note $ATS(W) = (ats_k(W))_{k\in[1,i]}$ the set of Acceptable Termination States of W i.e. the *TR* of W.

$ATS(W)$ and $TS(W)$ can be represented by a table which defines for each termination state the tuple of termination states reached by the workflow task as depicted in Figure 4. As mentioned in the definition, the specification of the set $ATS(W)$ is done at the workflow designing phase. $ATS(W)$ is mainly used as a decision table for a coordination protocol so that W_s can reach an acceptable termination state knowing the termination state of at least one task. The role of a coordination protocol indeed consists in sending messages to services in order to reach a consistent termination state given the current state of the workflow execution. The coordination decision, i.e. the termination state that has to be reached, made given a state of the workflow execution has to be unique, this is the main characteristic of a coordination protocol. In order to cope with this requirement, $ATS(W)$ which is used as input for the coordination decision-making process has therefore to verify some properties that we detail later on.

4. Analysis of $TS(W)$

Since $ATS(W) \subseteq TS(W)$, $ATS(W)$ inherits the characteristics of $TS(W)$ and we logically need to analyze first $TS(W)$. In this section, we first precise some basic properties of $TS(W)$ derived from inherent execution rules of a workflow W before examining $TS(W)$ from a coordination perspective.

4.1. Inherent properties of $TS(W)$

We state here some basic properties relevant to the elements of $TS(W)$ and derived from the transactional model presented above. $TS(W)$ is the set of all possible termination states of W based on the termination states model we chose for services. Yet, within a composite service execution, it is not possible to reach all the combinations represented by a n-tuple $(ts(t_1), ts(t_2), ..., ts(t_n))$ assuming $\forall\ a \in$ [1,n] $ts(t_a) \in \{aborted, canceled, failed, completed, compensated\}$. The first restriction is introduced by the sequential aspect of a workflow:

(P_1) A task becomes $activated \Leftrightarrow$ all the tasks executed beforehand according to the execution plan of W have reached the state $completed$

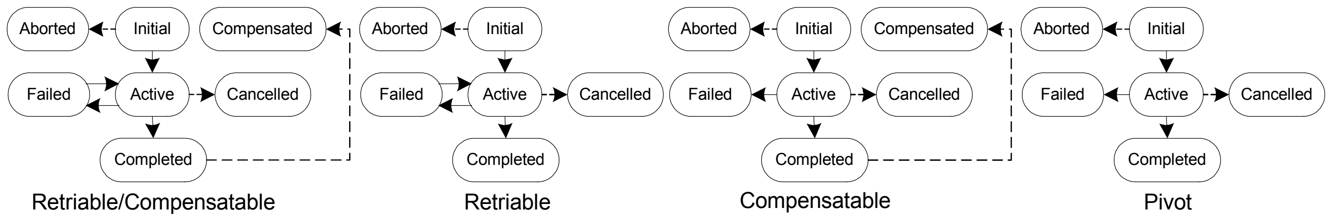


Figure 3. Service state diagram according to their Transactional Properties

(P_1) simply means that to start the execution of a workflow task, it is required to have properly completed all the workflow tasks required to be executed beforehand.

Second, we consider in our model that only one single task can fail at a time and that the states *aborted*, *compensated* and *canceled* can only be reached by a task in a given $ts_k(W)$ if one of the services executing a task of W has failed. This means that the coordination protocol is allowed to force the abortion, the compensation or the cancellation only in case of failure of a service. We get (P_2):

(P_2) if $\exists\ a, k \in [1, n] \times [1, j]$ such that $ts_k(W, t_a) \in \{compensated,\ aborted,\ canceled\} \Rightarrow \exists\ !\ l \in [1, n]$ such that $ts_k(W, t_l) = failed$.

4.2. Classification within $TS(W)$

As we explained above the unicity of the coordination decision during the execution of a coordination protocol is a major requirement. We try here to identify the elements of $TS(W)$ that correspond to different coordination decisions given the same state of a workflow execution. The goal is to use this classification to determine $ATS(W)$. Using the properties P_1 and P_2, a simple analysis of the state transition model reveals that there are two situations whereby a protocol coordination has different possibilities of coordination given the state of a workflow task. Let $a, b \in [1, n]$ and assume that the task t_b has failed:

- the task t_a is in the state $completed$ and either it remains in this state or it is $compensated$
- the task t_a is in the state $active$ and either it is $canceled$ or the coordinator lets it reach the state $completed$

From these two statements, we define the *incompatibility from a coordination perspective* and the *flexibility*.

Definition 4-1. Let $k, l \in [1, j]$. $ts_k(W)$ and $ts_l(W)$ are said incompatible from a coordination perspective $\Leftrightarrow \exists\ a,b \in [1, n]$ such that $ts_k(W, t_a) = completed$, $ts_k(W, t_b) = ts_l(W, t_b) = failed$ and $ts_l(W, t_a) = compensated$. Otherwise, $ts_l(W)$ and $ts_k(W)$ are said compatible from a coordination perspective.

The value in $\{compensated, completed\}$ reached by a task t_a in a termination state $ts_k(W)$ whereby $ts_k(W, t_b) = failed$ is called recovery strategy of t_a against t_b in $ts_k(W)$. By extension, we can consider the recovery strategy of a set of tasks against a given task.

If two termination states are compatible, they correspond to the same recovery strategy against a given task. In fact, we have two cases for the compatibility of two termination states $ts_k(W)$ and $ts_l(W)$. Given two tasks t_a and t_b such that $ts_k(W, t_b) = ts_l(W, t_b) = failed$:

- $ts_k(W, t_a) = ts_l(W, t_a)$
- $ts_k(W, t_a) \in \{compensated, completed\}$ and $ts_l(W, t_a) \in \{aborted, canceled\}$

The second case is only possible to reach if t_a is executed in parallel with t_b. Intuitively, the failure of the service assigned to t_b occurs at different instants in $ts_k(W)$ and $ts_l(W)$.

Definition 4-2. Let $a, b \in [1, n]$. A task t_a is flexible against $t_b \Leftrightarrow \exists\ k \in [1, j]$ such that $ts_k(W, t_b) = failed$ and $ts_k(W, t_a) = canceled$. Such a termination state is said to be flexible to t_a against t_b. The set of termination states of W flexible to t_a against t_b is denoted $FTS(t_a, t_b)$.

From these definitions, we now study the termination states of W according to the compatibility and flexibility criterias in order to identify the termination states that follow a common strategy of coordination.

Definition 4-3. Let $a \in [1, n]$. A termination state of W $ts_k(W)$ is called generator of $t_a \Leftrightarrow ts_k(W, t_a) = failed$ and $\forall\ b \in [1, n]$ such that t_b is executed before or in parallel of t_a, $ts_k(W, t_b) \in \{completed, compensated\}$. The set of termination states of W compatible with $ts_k(W)$ generator of t_a is denoted $CTS(ts_k(W), t_a)$.

The set $CTS(ts_k(W), t_a)$ specifies all the termination states of W that follow the same recovery strategy as $ts_k(W)$ against t_a.

Definition 4-4. Let $ts_k(W) \in TS(W)$ be a generator of t_a. Coordinating an instance W_s of W in case of the failure of t_a consists in choosing the recovery strategy of each task of W against t_a and the $z_a < n$ tasks $(t_{a_i})_{i \in [1, z_a]}$ flexible to t_a whose execution is not $canceled$ when t_a fails. We call coordination strategy of W_s against t_a the set $CS(W_s, ts_k(W), (t_{a_i})_{i \in [1, z_a]}, t_a) = CTS(ts_k(W), t_a) - \bigcup_{i=1}^{z_a} FTS(t_{a_i}, t_a)$. If the service s_a assigned to t_a is retriable then $CS(W_s, ts_k(W), (t_{a_i})_{i \in [1, z_a]}, t_a) = \emptyset$

W_s is said to be coordinated according to $CS(W_s, ts_k(W), (t_{a_i})_{i \in [1, z_a]}, t_a)$ if in case of the failure of t_a, W_s reaches a termination state in

$CS(W_s, ts_k(W), (t_{a_i})_{i\in[1,z_a]}, t_a)$. Of course, it assumes that the *TP* of W_s are sufficient to reach $ts_k(W)$.

From these definitions, we can deduce a set of properties:

Theorem 4-5. *W_s can only be coordinated according to a unique coordination strategy at a time.*

Proof: Let $a \in [1,n]$. Two termination states $ts_k(W)$ and $ts_l(W)$ generator of t_a are incompatible.

Theorem 4-6. *Let $a, k \in [1,n] \times [1,j]$ such that $ts_k(W, t_a) = failed$ but not generator of t_a. If $ts_k(W)$ $\in TS(W_s) \Rightarrow \exists\, l \in [1,j]$ such that $ts_l(W) \in TS(W_s)$ is a generator of t_a compatible with $ts_k(W)$.*

Proof: We define $ts_l(W)$ by: $ts_l(W, t_a) = failed$, $\forall\ i \in [1,n] - \{a\}$ $ts_l(W, t_i) = ts_k(W, t_i)$ if $ts_k(W, t_i)$ $\in \{completed, compensated, aborted\}$, $ts_l(W, t_i) = completed$ otherwise.

Given a task t_a the idea is to classify the elements of $TS(W)$ using the sets of termination states compatible with the generators of t_a. Using this approach, we can identify the different recovery strategies and the coordination strategies associated with the failure of t_a as we decide which tasks can be $canceled$.

5. Forming $ATS(W)$

Defining $ATS(W)$ is deciding at design time the termination states of W that are consistent. $ATS(W)$ is to be inputted to a coordination protocol in order to provide it with a set of rules which leads to a unique coordination decision in any cases. According to the definitions and properties we introduce above, we can now explicit some rules on $ATS(W)$ so that the unicity requirement of coordination decisions is respected.

Definition 5-1. Let $a, k \in [1,n] \times [1,j]$ such that $ts_k(W, t_a) = failed$ and $ts_k(W) \in ATS(W)$. $ATS(W)$ is valid $\Leftrightarrow \exists\ !\ \ l \in [1,j]$ such that $ts_l(W)$ generator of t_a compatible with $ts_k(W)$ and $CTS(ts_l(W), t_a) - \bigcup_{i=1}^{z_a} FTS(t_{a_i}, t_a) \subset ATS(W)$ for a set of tasks $(t_{a_i})_{i\in[1,z_a]}$ flexible to t_a.

The unicity of the termination state generator of a given task comes from the incompatibility definition and the unicity of the coordination strategy. A valid $ATS(W)$ therefore contains for all $ts_k(W)$ in which a task fails a unique coordination strategy associated to this failure and the termination states contained in this coordination strategy are compatible with $ts_k(W)$. In Figure 4, an example of possible ATS is presented for the simple workflow W_1. It just consists in selecting the termination states of the table $TS(W_1)$ that we consider consistent and respect the validity rule for the created $ATS(W_1)$.

6. Deriving composite services from ATS

In this section, we introduce a new type of service assignment procedure: the transaction-aware service assignment procedure which aims at assigning n services to the n tasks t_a in order to create an instance of W *acceptable* with respect to a valid $ATS(W)$. The goal of this procedure is to integrate within the instantiation process of workflows a systematic method ensuring the transactional consistency of the obtained composite service. We first define a validity criteria for the instance W_s of W with respect to $ATS(W)$, the service assignment algorithm is then detailed. Finally, we specify the coordination strategy associated to the instance created from our assignment scheme.

6.1. Acceptability of W_s with respect to $ATS(W)$

Definition 6-1. W_s is an acceptable instance of W with respect to $ATS(W) \Leftrightarrow TS(W_s) \subseteq ATS(W)$.

Now we express the condition $TS(W_s) \subseteq ATS(W)$ in terms of coordination strategies. The termination state generator of t_a present in $ATS(W)$ is noted $ts_{k_a}(W)$. The set of tasks whose execution is not $canceled$ when t_a fails is noted $(t_{a_i})_{i\in[1,z_a]}$.

Theorem 6-2. $TS(W_s) \subseteq ATS(W) \Leftrightarrow \forall\ a \in [1,n]$ $CS(W_s, ts_{k_a}(W), (t_{a_i})_{i\in[1,z_a]}, t_a) \subset ATS(W)$.

Proof: straightforward derivation from 4-6 and 5-1 .

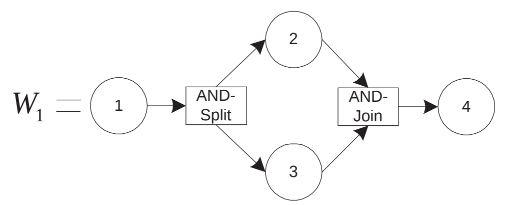
An instance W_s of W is therefore an acceptable one $\Leftrightarrow$ it is coordinated according to a set of n coordination strategies contained in $ATS(W)$. It should be noted that if $failed$ $\notin ATS(W, t_a)$ where $ATS(W, t_a)$ represents the acceptable termination states of the task t_a in $ATS(W)$ then $CS(W_s, ts_{k_a}(W), (t_{a_i})_{i\in[1,z_a]}, t_a) = \emptyset$. From 4-6 and 6-1, we can derive the existence condition of an acceptable instance of W with respect to a valid $ATS(W)$.

Theorem 6-3. *Let $a, k \in [1,n] \times [1,j]$ such that $ts_k(W, t_a) = failed$ and $ts_k(W) \in ATS(W)$. $\exists\ W_s$ acceptable instance of W with respect to $ATS(W)$ such that $ts_k(W) \in TS(W_s) \Leftrightarrow \exists\ !\ \ l \in [1,j]$ such that $ts_l(W) \in TS(W_s)$ is a generator of t_a compatible with $ts_k(W)$ in $ATS(W)$.*

This theorem only states that an $ATS(W)$ allowing the failure of a given task can be used to coordinate a composite service also allowing the failure of the same task $\Leftrightarrow$ $ATS(W)$ contains a complete coordination strategy associated to this task, i.e. it is valid.

6.2. Transaction-aware assignment procedure

In this section, we present the procedure that is used to assign services to tasks based on *TR*. This algorithm uses $ATS(W)$ as a set of requirements during the service assignment procedure and thus identifies from a pool of available services those whose *TP* match the *TR* associated to workflow tasks defined in $ATS(W)$ in terms of acceptable termination states. The assignment procedure is an iterative process, services are assigned to tasks one after the other. The assignment procedure therefore creates at each step i a partial instance of W noted W_s^i. We can define as well the set $TS(W_s^i)$ which represents the termination states of



$TS(W_1)$	Task 1	Task 2	Task 3	Task 4
ts_1	completed	completed	completed	completed
ts_2	completed	completed	completed	failed
ts_3	completed	completed	compensated	failed
ts_4	completed	compensated	compensated	failed
ts_5	completed	compensated	completed	failed
ts_6	compensated	compensated	compensated	failed
ts_7	compensated	compensated	completed	failed
ts_8	compensated	completed	completed	failed
ts_9	compensated	completed	compensated	failed
ts_{10}	completed	completed	failed	aborted
ts_{11}	completed	compensated	failed	aborted
ts_{12}	completed	canceled	failed	aborted
ts_{13}	compensated	completed	failed	aborted
ts_{14}	compensated	compensated	failed	aborted
ts_{15}	compensated	canceled	failed	aborted
ts_{16}	completed	failed	completed	aborted
ts_{17}	completed	failed	compensated	aborted
ts_{18}	completed	failed	canceled	aborted
ts_{19}	compensated	failed	completed	aborted
ts_{20}	compensated	failed	compensated	aborted
ts_{21}	compensated	failed	canceled	aborted
ts_{22}	failed	aborted	aborted	aborted

Available Services		Retriable	Compensatable
Task 1	s_{11}	yes	no
	s_{12}	no	yes
Task 2	s_{21}	no	no
Task 3	s_{31}	yes	yes
	s_{32}	no	yes
Task 4	s_{41}	yes	no

$ATS_1(W_1)$		Task 1	Task 2	Task 3	Task 4
ats_1	ts_1	completed	completed	completed	completed
ats_2	ts_6	compensated	compensated	compensated	failed
ats_3	ts_{14}	compensated	compensated	failed	aborted
ats_4	ts_{15}	compensated	canceled	failed	aborted
ats_5	ts_{20}	compensated	failed	compensated	aborted
ats_6	ts_{21}	compensated	failed	canceled	aborted

$ATS_2(W_1)$		Task 1	Task 2	Task 3	Task 4
ats_1	ts_1	completed	completed	completed	completed
ats_2	ts_4	completed	compensated	compensated	failed
ats_3	ts_{17}	completed	failed	compensated	aborted

Figure 4. Example of Transactional Composite Service

W that the *TP* of the i services already assigned allow to reach. Intuitively the acceptable termination states refer to the degree of flexibility offered when choosing the services with respect to the different coordination strategies verified in $ATS(W)$. This degree of flexibility is influenced by two parameters:

- The list of acceptable termination states for each workflow task. This list can be determined using $ATS(W)$. This is a direct requirement which specifies the termination states allowed for each task and therefore introduces requirements on the service's *TP* to be assigned to a given task: this service can only reach the states defined in $ATS(W)$ for the considered task.
- The assignment process is iterative and therefore, as we assign new services to tasks, $TS(W_s^i)$ changes and the *TP* required to the assignment of further services too. For instance, we are sure to no longer reach the termination states $CTS(ts_k(W), t_a)$ allowing the failure of the task t_a in $ATS(W)$ when we assign a service (*r*) to t_a. In this specific case, we no longer care about the states reached by other tasks in $CTS(ts_k(W), t_a)$ and therefore there is no *TR* introduced for the tasks to which services have not already been assigned.

We therefore need to define first the *TR* for the assignment of a service after i steps in the assignment procedure.

6.2.1. Extraction of *TR*. From the two requirements above, we define for a task t_a :

- $ATS(W, t_a)$: Set of acceptable termination states of t_a which is derived from $ATS(W)$
- $DIS(t_a, W_s^i)$: This is the set of *TR* that the service assigned to t_a must meet based on the previous assignments. This set is determined based on the following reasoning:

  (DIS_1): the service must be compensatable $\Leftrightarrow$ $compensated \in DIS(t_a, W_s^i)$

  (DIS_2): the service must be retriable $\Leftrightarrow failed \notin DIS(t_a, W_s^i)$

Using these two sets, we are able to compute $Min_{TP}(s_a, t_a, W_s^i) = ATS(W, t_a) \bigcap DIS(t_a, W_s^i)$ which defines the *TP* a service s_a has at least to comply with in order to be assigned to the task t_a at the $i + 1$ assignment step. We simply check the retriability and compensatability properties for the set $Min_{TP}(s_a, t_a, W_s^i)$:

- $failed \notin Min_{TP}(s_a, t_a, W_s^i) \Leftrightarrow s_a$ has to verify the retriability property
- $compensated \in Min_{TP}(s_a, t_a, W_s^i) \Leftrightarrow s_a$ has to verify the compensatability property

The set $ATS(W, t_a)$ is easily derived from $ATS(W)$. We need now to compute $DIS(t_a, W_s^i)$. We assume that we are at the $i+1$ step of an assignment procedure, i.e. the current partial instance of W is W_s^i. Computing $DIS(t_a, W_s^i)$ means determining if (DIS_1) and (DIS_2) are true. From these two statements we can derive three properties:

1. (DIS_1) implies that state $compensated$ can definitely be reached by t_a
2. (DIS_2) implies that t_a can not fail
3. (DIS_2) implies that t_a can not be $canceled$

The two first properties can be directly derived from (DIS_1) and (DIS_2). The third one is derived from the fact that if a task can not be $canceled$ when a task fails, then it has to finish its execution and reach at least the state $completed$. In this case, if a service can not be $canceled$ then it can not fail, which is the third property. To verify whether 1., 2. and 3. are true, we introduce the theorems 6-4, 6-5 and 6-6.

Theorem 6-4. *Let* $a \in [1, n]$. *The state compensated can definitely be reached by* $t_a \Leftrightarrow \exists\ b \in [1, n] - \{a\}$

verifying (6-4b): s_b not retriable is assigned to t_b and $\exists$ $ts_k(W) \in ATS(W)$ generator of t_b such that $ts_k(W, t_a) = compensated$.

Proof: $\Leftarrow$: Since the service s_b is not retriable, it can fail and $ts_k(W) \in ATS(W)$ generator of t_b such that $ts_k(W, t_a) = compensated$ is in $TS(W_s)$.

$\Rightarrow$: Derived from (P_2) and 4-6.

The two following theorems are proved similarly:

Theorem 6-5. *Let $a \in [1, n]$. t_a can not fail $\Leftrightarrow \exists\ b \in [1, n] - \{a\}$ verifying (6-5b): (s_b not compensatable is assigned to t_b and $\exists\ ts_k(W) \in ATS(W)$ generator of t_a such that $ts_k(W, t_b) = compensated$) or ($t_b$ is flexible to t_a and s_b not retriable is assigned to t_b and $\forall\ ts_k(W) \in ATS(W)$ such that $ts_k(W, t_a) = failed$, $ts_k(W, t_b) \neq canceled$).*

Theorem 6-6. *Let $a, b \in [1, n]$ such that t_a is flexible to t_b. t_a is not canceled when t_b fails $\Leftrightarrow$ (6-6b): s_b not retriable is assigned to t_b and $\forall\ ts_k(W) \in ATS(W)$ such that $ts_k(W, t_b) = failed$, $ts_k(W, t_a) \neq canceled$.*

According to the theorems 6-4, 6-5 and 6-6, in order to compute $DIS(t_a, W_s^i)$, we have to compare t_a with each of the i tasks $t_b \in W - \{t_a\}$ to which a service s_b has been already assigned. This is an iterative procedure and at the initialisation phase, since no task has been yet compared to t_a, s_a can be *(p)*: $DIS(t_a, W_s^i) = \{failed\}$.

1. if t_b verifies *(6-4b)* $\Rightarrow compensated \in DIS(t_a, W_s^i)$
2. if t_b verifies *(6-5b)* $\Rightarrow failed \notin DIS(t_a, W_s^i)$
3. if t_b is flexible to t_a and verifies *(6-6b)* $\Rightarrow failed \notin DIS(t_a, W_s^i)$

The verification stops if $failed \notin DIS(t_a, W_s^i)$ and $compensated \in DIS(t_a, W_s^i)$. With $Min_{TP}(s_a, t_a, W_s^i)$, we are able to select the appropriate service to be assigned to a given task according to *TR*.

6.2.2. Service assignment process. Services are assigned to each workflow task based on an iterative process. Depending on the *TR* and the *TP* of the services available for each task, different scenarios can occur:

(i) services *(rc)* are available for the task. It is not necessary to compute *TR* as such services match all *TR*.

(ii) only services *(p)* are available for the task. We need to compute the *TR* associated to the task and either pivot is sufficient or there is no solution.

(iii) services *(r)* and *(c)* but no *(rc)* are available for the task. We need to compute the *TR* associated to the task and we have three cases. First, (retriability and compensatability) is required in which case there is no solution. Second, retriability (resp. compensatability) is required and we assign a service *(r)* (resp. *(c)*) to the task. Third, there is no requirement.

The idea is therefore to assign first services to the tasks verifying *(i)* and *(ii)* since there is no flexibility in the choice of the service. Tasks verifying *(iii)* are finally analyzed. Based on the *TR* raised by the remaining tasks, we first assign services to tasks with a non-empty *TR*. We then handle the assignment for tasks with an empty *TR*. Note that the *TR* of all the tasks to which services are not yet assigned are also affected (updated) as a result of the current service assignment. If no task has *TR* then we assign the services *(r)* to assure the completion of the remaining tasks' execution.

Theorem 6-7. *The service assignment procedure creates an instance of W that is acceptable with respect to a valid $ATS(W)$.*

Proof: Let W_s be an instance of W resulting from the service assignment procedure and a service s_a assigned to a task t_a in W_s. The definition 6-1 has to be verified and we therefore consider (A) and (B) (with the notations of 6-2):

(A) $\forall\ a \in [1, n],\ failed \in ATS(W, t_a) \Rightarrow CS(W_s, ts_{k_a}(W), (t_{a_i})_{i\in[1,z_a]}, t_a) \subset ATS(W)$

(B) $\forall\ a \in [1, n],\ failed \notin ATS(W, t_a) \Rightarrow CS(W_s, ts_{k_a}(W), (t_{a_i})_{i\in[1,z_a]}, t_a) \subset ATS(W)$

(A): We suppose that $failed \in ATS(W, t_a)$ then we have two possibilities: s_a is retriable and $CS(W_s, ts_{k_a}(W), (t_{a_i})_{i\in[1,z_a]}, t_a) = \emptyset \subset ATS(W)$. s_a can fail and with 1, 2 and 3 we get $ts_{k_a}(W) \in TS(W_s)$ and therefore $CS(W_s, ts_{k_a}(W), (t_{a_i})_{k\in[1,z_a]}, t_a) \subset ATS(W)$ since $ATS(W)$ is valid.

(B): We suppose that $failed \notin ATS(W, t_a)$ then $failed \notin Min_{TP}(s_a, t_a, W_s^i)$ and s_a is retriable. Therefore, $CS(W_s, ts_{k_a}(W), (t_{a_i})_{i\in[1,z_a]}, t_a) = \emptyset \subset ATS(W)$. $CS(W_s, ts_{k_a}(W), (t_{a_i})_{i\in[1,z_a]}, t_a) \subset ATS(W)$ and W_s is an acceptable instance of W with respect to $ATS(W)$.

6.3. Coordination of W_s

Now, using (A) and (B) defined in the proof of 6-7 and keeping the same notations, we are able to specify the coordination strategy of W_s against each workflow task. We get indeed the following theorem.

Theorem 6-8. *Let W_s be an acceptable instance of W with respect to $ATS(W)$. We note $(t_{a_i})_{i\in[1,n_r]}$ the set of tasks to which no retriable services have been assigned. $TS(W_s)=\{tscomp(W_s)\} \bigcup \bigcup_{i=1}^{n_r}(CTS(ts_{k_{a_i}}(W), t_{a_i}) - \bigcup_{j=1}^{z_{a_i}} FTS(t_{a_{i_j}}, t_{a_i}))$.*

Having computed $TS(W_s)$, we can deduce the coordination rules associated to the execution of W_s.

6.4. Example

We consider the workflow W_1 of Figure 4. Designers have defined $ATS_2(W_1)$ as the *TR* and the set of available services for each task of W_1 is specified in the Figure. The goal is to assign services to workflow tasks so that the instance of W_1 is valid with respect to $ATS_2(W_1)$ and we apply the presented assignment procedure. We first start to assign the services *(rc)* for which it is not necessary to compute any *TR*. s_{31} which is the only available service *(rc)* is therefore assigned to task 3. We then try to assign the services *(p)*, and we verify whether s_{21} can be assigned to task 2. We compute

$Min_{TP}(s_a, t_2, W^1_{1s}) = ATS_2(W_1, t_2) \bigcap DIS(t_2, W^1_{1s})$. $ATS_2(W_1, t_2) = \{completed, compensated, failed\}$ and $DIS(t_2, W^1_{1s}) = \{failed\}$ as s_{31} the only service already assigned is *(rc)* and the theorems 6-4, 6-5 and 6-6 are not verified. Thus $Min_{TP}(s_a, t_2, W^1_{1s}) = \{failed\}$ and s_{21} can be assigned to task 2 as it matches the *TR*. Now we compute the *TR* of task 1 and we get $Min_{TP}(s_a, t_1, W^2_{1s}) = \emptyset$, a service can therefore be assigned to task 1 if it is retriable, which is the case of s_{11}. Finally, we compute the *TR* of task 4 and we get $Min_{TP}(s_a, t_4, W^3_{1s}) = \emptyset$ as theorem 6-5 is verified with the service s_{21}. The service s_{41} can thus be assigned to task 4 as it matches the *TR* of the task.

7. Related work

Transactional consistency of workflows and database systems has been an active research topic over the last 15 years yet it is still an open issue in the area of Web services [5, 8, 12] and especially composite Web services. Composite Web services indeed introduce new requirements for transactional systems such as dynamicity, semantic description and relaxed atomicity. Existing transactional models for advanced applications [6] are lacking of flexibility to integrate these requirements [3] as for instance they are not designed to support the execution of dynamically generated collaboration of services. In comparison, our solution allows the specification of *TR* supporting relaxed atomicity for an abstract workflow specification and the selection of semantically described services respecting the defined *TR*.

Our work is based on [4] which presents the first approach specifying relaxed atomicity requirements for Composite Web services based on the *ATS* tool and a transactional semantic. Despite a solid contribution, this work appears to be limited if we consider the possible integration into automatic Web services composition systems. It indeed only details transactional rules to validate a given composite service with respect to defined *TR*. In this approach, *TR* do not play any role in the component services selection process which may result in several attempts for designers to determine a valid composition of services. On the contrary, our solution provides a systematic procedure enabling the automatic design of transactional composite Web services. Besides, our contribution also defines the mathematical foundations to specify valid *ATS* for workflows using the defined concept of coordination strategy.

Finally, our solution can be used to augment recent standardization efforts lead in the area of transactional coordination of Web services [1, 11]. Our approach indeed provides adaptive coordination specifications based on the *TP* of the component services instantiating a given workflow. Existing Web services coordination specifications [9, 10] are indeed not flexible enough as they do not neither allow workflow designers to specify their *TR* nor take into account the *TP* offered by Web services.

8. Conclusion

We presented a systematic procedure to automate the design of transactional composite Web services. Our solution enables the selection of component Web services not only according to functional requirements but also to transactional ones. Transactional requirements are defined by designers and serve as an input to define both reliable composite Web services and coordination protocols used to ensure the consistency of their execution. On the one hand this service assignment approach can be used to augment existing Web services composition systems [2] as it can be fully integrated in existing functional match-making procedures. On the other hand, our approach defines adaptive coordination rules that can be deployed on Web services coordination specifications [11] in order to increase their flexibility.

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