Checkpointing Orchestrated Web Services

A.Vani Vathsala
Department of Computer Science
CVR Engg College University of Hyderabad
atlurivv@yahoo.com

Hrushikesha Mohanty
Department of Computer and Information Sciences
University of Hyderabad
mohanty.hcu@gmail.com

Abstract-Web Services are built on service-oriented architecture which is based on the notion of building applications by discovering and orchestrating services available on the web. Complex business processes can be realized by discovering and orchestrating already available services on the web. In order to make these orchestrated web services resilient to faults; we proposed a simple and elegant checkpointing policy called “Call based Global Checkpointing of Orchestrated web services” which specifies that when a web service calls another web service the calling web service has to save its state. But performance of the web services implementing this policy reduces due to checkpointing overhead. In an effort to improvise this policy, we propose in this paper, a checkpointing policy which uses Predicted Execution Time and Mean Time Between Failures of the called web services to make checkpointing decisions. This policy aims at reducing the required number of Call based Checkpoints but at the same time maintains the resilience of web services to faults.

Keywords: Checkpoints, Web Services, Mean Time Between Failures, Orchestration, Predicted Execution Time.

I. INTRODUCTION
A service in execution may take service of another service and this may result in nested call of services. This is known as Orchestration of services. In case of such service execution pattern, if a service fails to complete (for any possible reason) then all the services dependent on the failed service are to be re-executed causing a voluminous rework.

Traditionally such a situation is handled (for avoiding re-work) by checkpointing. In our earlier work, [5], we have proposed “Call Based Checkpointing Policy” that saves status of caller services so that in case of failure of callee service, the computation at the former can be resumed at this saved point. However this method is time consuming due to the overhead of maintaining caller status at every service call.

In this work, we propose a method that does not necessitate checkpointing at every call thus reducing instances of checkpointing. The rationale on decision making is based on two factors i.e, Execution Time Prediction and Mean Time Between Failures. A caller service predicts the execution time of the callee $S_i$, say PET($S_i$). This is a possible estimate from the execution history of callee services. Let the Mean Time Between Failures of the callee be MTBF($S_i$). If PET($S_i$) $<$ MTBF($S_i$) then the caller most probably can avail the service from the callee. Hence checkpointing the caller at the service call is not required. This paper details on this concept and advocates its utility for orchestrated services in making them resilient to possible errors.

If $S_1$ is a composite web service, a call to $S_1$ might result in a nested call; whether to take a checkpoint or not while calling each of the services involved in the nested call, has to be decided. This decision at each step has to be taken without needing many computations (Execution Time predictions of the services involved in the nested call). Hence we have proposed to use the already available computations, i.e, PET of $S_i$ and composition operators used to compose involved web services, to take the decisions. We have proved the fact that PET of the composite service $S_1$ and knowledge of composition operators alone are sufficient to take these decisions.

In section II we present our analysis of work done in this area. In section III we present our basic Call based Checkpointing policy and in section IV we give a detailed description of our Execution Prediction based checkpointing policy. In subsection ‘A’ of this section we give briefly the method for calculating MTBF for web services. In subsection ‘B’ we describe the method of using Euclidean distances to predict Execution time of web services. In subsection ‘C’ we describe how to minimize the number of checkpoints to be taken. We also discuss the role of composition opera-tors and PET of a composite service in making Call based Checkpointing decisions with necessary proofs. Towards the end of this section we have demonstrated the generation of Global checkpoints of an orchestrated web service using the new Execution Prediction Based Checkpointing policy. We conclude by giving a sketch of our future work.

II. RELATED WORK
Few papers [6,7,8] have been published discussing the need and techniques for checkpointing web services. But all these works require the user to specify the exact checkpointing locations. In contrast we proposed a simple and elegant checkpointing policy[5] for orchestrated web services which specifies that whenever a web service calls another web service, the state of calling web service must be saved. But checkpointing web services at all pre specified locations (at all service calls) may lead to overzealous checkpointing that results in degradation of the performance altogether. Hence to improve the performance of composed web services with call based checkpoints, we propose Execution Prediction based
**Checkpoints.**

The research works presented in [2,3,4] propose methods for predicting runtime of web services. These works advocate the use of predicted execution time for selection of web services to construct composite web service workflows. To the best of our knowledge there is no work which concentrates on using Predicted Execution Time and MTBF for checkpointing of web services.

Zoltan Balogh et al presented a knowledge based approach[2] for predicting runtime of stateful web services. To predict the execution time of a web service instance, it maintains a knowledge base of possible different past cases for different combinations of input parameters. Given a web service instance, Euclidean distances are used to find out most similar past cases. The runtime for the given web service instance is predicted to be the average output value of the most similar past cases. Estimation of web services runtime is done keeping in view construction of composite web service workflows.

Zhengdong Gao uses Back Propagation Neural Networks to predict the runtime of a given web service [4]. He uses Availability, Network Bandwidth, Response Time, Reliability of the given web service as inputs to the Neural Network which produces predicted execution duration as output. The core of his work is the design and implementation of BP Neural Network which is used to predict performance of services.

In order to predict timing failures, Laranjeiro [3] proposes to use a graph based approach. He analyzes the service code and builds a graph to represent its logical structure. He then gathers time-related performance metrics during runtime. This data is used to predict if a given execution will or will not conclude in due time.

The research presented in [1] intends to provide the concept of MTTF (Mean Time To Failure) of composite web service. It describes the calculation method of MTTF of composite web services based on the workflow composition pattern. The authors use the concept of MTTF of web services to find out reliability of a given composite web service.

**III. CALL BASED CHECKPOINTING POLICY**

Calling a web service includes several steps and incurs considerable cost and time at run time. When the calls are nested and if there is any kind of failure the entire sequence of calls has to be re-invoked causing considerable delay in response which results in degradation of quality of the service provided. Our Call-based checkpointing policy aims at avoiding expensive re-invocations of web services and hence we propose that Checkpoints must be taken when web services interact with each other. According to our policy: "Save the state of the service requestor after sending the request. Similarly save the state of the service provider after sending the response".

A state of a web service in execution is characterized by the state of its local memory and a history of its activity. If such a state of the web service is saved on a stable storage, then the saved state is called as a local checkpoint for the web service. A local checkpoint that is taken most recently is called as the latest local checkpoint for the web service.

An orchestrated web service \( S_0 \), is a composition of one or more constituent web services. It has pieces of code that it executes on itself and also calls other web services based on some conditions. If the orchestrated web service is not having any active calls (time \( t_2 \) in Fig 1), and is executing its own piece of code, then its latest local checkpoint gives the latest global checkpoint of the composed application.

When \( S_0 \), calls another web service, there may be nested chain of service calls because of which more than one web service can be active (not completed their execution) at a given point of time. (at time \( t_1 \) in Fig 1) web services \( S_0, S_1 \), and \( S_4 \) are active. Hence the state of the orchestrated web service is collectively represented by the states of all active web services when a service call is in place. Thus, Call-based Global checkpoint for an orchestrated web service which has a service call in process, is defined as the set of the latest local checkpoints of each of the web services that are active during the call.

**Motivating example**

A customer requests a web service for his loan processing. This loan processing web service receives the request from the customer which consists of information like his name and requested credit amount. This loan processing web service, \( S_0 \), invokes two more web services: Loan approver web service(\( S_1 \)) and accessor web service(\( S_2 \)). If the amount requested is less than 10,000 \( S_0 \) calls the loan accessor web service \( S_2 \). This web service, based on some customer records, decides and reports back whether there is high risk in approving loan to the customer. If \( S_2 \) reports low risk, \( S_0 \) itself approves the loan. If the amount requested is greater than 10,000 or if \( S_2 \) reports high risk, the loan approver web service \( S_1 \), is invoked by \( S_0 \) to enquire about the customer and report whether to approve the loan to the customer or not. If the amount requested is greater than 1,00,000 \( S_1 \) outsources the job to another web service \( S_3 \). \( S_1 \) calls another loan approver web service \( S_4 \) to take second opinion and sends back the reply to \( S_0 \). Finally loan processing web service \( S_0 \) sends back its reply to the customer. Fig 1 depicts an execution instance of this loan processing web service.
let c_0 represent the local checkpoints generated by s_0. let c_1 represent local checkpoints generated by the service s_1, c_2 represent local checkpoints generated by the service s_2 and so on. s_0 might make several web service calls, while in execution. let c_{0 i} represent the checkpoint generated by s_0 for ith service call that it has placed. let s_0 invoke s_1 in its ith service call. then c_{1 ij} represents the jth local checkpoint taken by s_1 when it is serving ith call of s_0.

To provide the service, if s_1 makes use of services provided by other web services we have three superscripts in checkpoint numbering. in general, checkpoint c_{m ij} indicates: s_0 invokes s_1 as part of its ith service call, s_1 invokes s_m as part of its jth service call, and this is the kth local checkpoint taken by web service s_m. By applying the call-based checkpointing policy to the execution instance depicted in Fig 1, we can see that number of local checkpoints generated as part of call-based global checkpoint is ‘9’ as shown in Table I.

Thus we see from Table I that when the service reply is received back by s_0, the Call-based Global checkpoint reduces to the latest local checkpoint of s_0. Upon failure the application has to be rolled back to latest global checkpoint and all the messages received after the latest global checkpoint have to be replayed from the message logs. Execution of the composed application can thus continue from latest global checkpoint without re-invocation of already finished constituent web services.

IV. EXECUTION PREDICTION BASED CHECKPOINTING OF WEB SERVICES

In order to improve the performance of composed web services with call based checkpoints, we propose

## Table 1: Local Checkpoints generated as part of Call-based Global Checkpoints (CBGC)

<table>
<thead>
<tr>
<th>Status of execution</th>
<th>CBGC</th>
</tr>
</thead>
<tbody>
<tr>
<td>invoke s_2</td>
<td>{c_{21}} /* first CBGC */</td>
</tr>
<tr>
<td>End s_2</td>
<td>{c_{21}, c_{21}, c_{21}} /<em>End of first CBGC</em>/</td>
</tr>
<tr>
<td>invoke s_1</td>
<td>{c_{21}} /* second CBGC */</td>
</tr>
<tr>
<td>invoke s_3</td>
<td>{c_{21}, c_{21}}</td>
</tr>
<tr>
<td>End s_3</td>
<td>{c_{21}, c_{21}, c_{21}, c_{21}}</td>
</tr>
<tr>
<td>End s_4</td>
<td>{c_{21}, c_{21}}</td>
</tr>
<tr>
<td>End s_5</td>
<td>{c_{21}, c_{21}} /<em>End of second CBGC</em>/</td>
</tr>
<tr>
<td>End s_6</td>
<td>{c_{21}} /* third CBGC */</td>
</tr>
<tr>
<td>Total No of Local checkpoints generated = 9</td>
<td></td>
</tr>
</tbody>
</table>

Execution Prediction based Checkpointing scheme. For each service call, this scheme decides, considering the PET and MTBF of the called web service, whether a checkpoint has to be taken on making a call to the service. Hence to implement this scheme, a caller should know the MTBF and PET of the callee.

MTBF of a service is an average measure of the time duration for which the service can run without failure. MTBF of a service has to be made public by the service itself by placing the MTBF in its WSDL (Web Services Description Language). This MTBF can then be used by the service requestors to implement the checkpointing policy. When s_0 calls another web service s_1, PET of s_1 is calculated by s_0 using Euclidean distances method as explained in subsection 'B' below.

Checkpointing Rule:

If PET (s_1) < MTBF (s_1), then s_1 will execute within its MTBF and eventually send back the reply to s_0. In such a case s_0 need not take a checkpoint while calling s_1 with anticipation that s_1 might fail.

Else if PET (s_1) ≥ MTBF (s_1) then s_1 might fail before sending a reply back to s_0 and hence s_0 must take a checkpoint before calling s_1.

A. Calculation of MTBF

Let \( \lambda \) represent the Failure rate of a web service S and let \( \tau \) represent the MTBF. Then \( \tau = 1/\lambda \).

MTBF of a web service can be obtained by taking inverse of its Failure rate. Failure rate of a web service can be obtained by measuring its number of failures per unit time. (Ex: Failure rate = 5 failures in one hour. MTBF = 1/Failure rate = one hour/5 = 12 minutes).

MTBF of composite services: If a web service is a
composition of other web services, then their MTBFs will affect the MTBF of the composite service. Let \( i \) represent the MTBF of a constituent web service \( S_i \) where 1 ≤ \( i \) ≤ \( n \) and \( n \) is the maximum number of web services involved in the composition. A web service may be composed of a set of web services using the three primitive operations sequence, parallel and choice as depicted in Table 2. Fig 2 shows different cases of MTBF calculation. Other composition operations can be derived from these three primitive operations.

For example, Input parameter 'Risk' in the example has fixed non-numeric values 'Irrelevant', 'Low', 'High'. They can be mapped to corresponding numeric values 1,2,3. Similarly input parameters that have range values, like 'LoanAmount' in our example, where the range in which they fall is more important than the actual value, we have to map each range to a numerical value.

Calculation of Euclidean distances for this example reveals that there is one case similar to current execution instance. Take the average of execution times of similar cases to predict the execution time of the current execution instance, which is 7 time units.

**C. Minimizing the number of Checkpoints**

Goal of Execution prediction based Checkpointing policy is to minimize the number of local checkpoints that are generated as part of the Call-based Global checkpoint.

When a web service \( S_0 \) calls another web service \( S_1 \) and if \( PET(S_1) < MTBF(S_1) \) then it indicates that the called web service completes its execution within its MTBF. Hence the calling web service will get its reply and there is no need to take a checkpoint in the calling web service. If the called service is a composite service and results in nested calls, **decision has to be taken whether the checkpoints have been taken throughout the path of the nested call or not.**

For example, if a composite service \( S_1 \) calls two constituent services \( S_2 \) and \( S_3 \), then it must be decided whether \( S_1 \) must take checkpoints while calling \( S_2 \) and \( S_3 \). According to the policy, when \( S_1 \) calls \( S_2 \), \( S_1 \) must calculate \( PET(S_2) \) and obtain \( MTBF(S_2) \) from WSDL file of \( S_2 \). If \( PET(S_2) < MTBF(S_2) \) then there is no need to take checkpoint \( S_2 \) while calling \( S_2 \). But in order to take this decision, \( S_1 \) must calculate the \( PET(S_2) \). Similar is the case of calling \( S_3 \). These calculations can be avoided if the decision can be taken by using \( PET(S_1) \) and \( MTBF(S_1) \) alone. We have that \( PET(S_1) < MTBF(S_1) \). If it can be proved that \( PET(S_2) < PET(S_1) \) and \( MTBF(S_1) < MTBF(S_2) \) then it can be deduced that:
\[
PET(S_2) < PET(S_1) < MTBF(S_1) < MTBF(S_2)...
\]
Hence \( PET(S_2) < MTBF(S_2) \). Whether \( PET(S_2) \) is less than \( MTBF(S_2) \) or not can thus be found without calculating \( PET(S_2) \).

**PROOF:** \( PET \) of a composite service = It’s Local Computation time + Time taken to place Service calls + \( PET \) of constituent services.

\[
PET(S_1) = Local \ Computation \ time + (S_1) + Time \ taken \ to \ call \ S_2 \ and \ S_1 + PET(S_2) + PET(S_i).
\]

**Hence** \( PET(S_1) > PET(S_2) \) and \( PET(S_i) > PET(S_1) \). **OR** \( PET(S_2) < PET(S_1) \) and \( PET(S_i) < PET(S_1) \). Hence first half of equation (1) is proved. We have to consider MTBF calculations to prove second half. MTBF for a composite service is calculated taking into account MTBF of its constituent services also, as shown

---

**TABLE II: MTBF CALCULATION**

<table>
<thead>
<tr>
<th>Composition Operation</th>
<th>MTBF Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sequence: ( S = S_1 \ &amp; \ S_2 )</td>
<td>( x = x_1 + x_2 )</td>
</tr>
<tr>
<td>Parallel: ( S = S_1 \ &amp; \ S_2 )</td>
<td>( x = x_1 + x_2 )</td>
</tr>
<tr>
<td>Choice: ( S = (S_1 + S_2) )</td>
<td>( x = x_1 * p_1 + x_2 * p_2 )</td>
</tr>
</tbody>
</table>

**TABLE III: EXECUTION INSTANCES OF LOAN PROCESSING EXAMPLE**

<table>
<thead>
<tr>
<th>Input Parameters</th>
<th>Parameter used for Prediction</th>
<th>Parameter used for Prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loan Amount</td>
<td>Risk</td>
<td>Execution time</td>
</tr>
<tr>
<td>9000</td>
<td>Low</td>
<td>2 tu</td>
</tr>
<tr>
<td>8000</td>
<td>High</td>
<td>6 tu</td>
</tr>
<tr>
<td>25,000</td>
<td>IR</td>
<td>4 tu</td>
</tr>
<tr>
<td>12,500</td>
<td>IR</td>
<td>7 tu</td>
</tr>
<tr>
<td>7000</td>
<td>Low</td>
<td>2 tu</td>
</tr>
<tr>
<td></td>
<td>IR=Irrelevant I=Invoked tu=Time units</td>
<td></td>
</tr>
</tbody>
</table>

While calculating Euclidean distances, input parameters having non-numeric values pose a problem. In such a case, map Non-numeric values to numerical values.
in Table II. Fig 2 explains MTBF calculation.

Hence it cannot be generalized that $1$ is lesser than $2$ and $3$, i.e., it cannot be generalized that MTBF ($S_1$) < MTBF ($S_2$) OR MTBF ($S_1$) < MTBF ($S_3$). Hence If PET ($S_1$) < MTBF ($S_1$) and if the called web service $S_1$ is a composite service resulting in a nested call, then equation (1) holds good if composition operation is either 'sequence' or 'parallel composition' but does not hold good in case of 'choice' operation.

Hence using above observation, Execution time prediction based checkpointing policy can be stated as:

When a web service $S_0$ calls another web service $S_1$ then, $S_0$ must:

i) Obtain the MTBF ($S_1$) being called from its WSDL.
   If $S_1$ is a composite service, then the composite service should calculate its MTBF using the formulae briefed in previous section and make it’s MTBF available in its WSDL.

ii) Use Euclidean distances to find out similar cases and take their average execution time as Predicted Execution Time, PET ($S_1$).

iii) If PET ($S_1$) ≥ MTBF ($S_1$) then $S_0$ has to take a checkpoint while calling $S_1$.

   else if PET ($S_1$) < MTBF ($S_1$) then
   
   a) If $S_1$ is not a composite service then $S_0$ need not take a checkpoint while calling $S_1$.

   b) If $S_1$ is a composite service: policy is explained using the Fig 3 for basic cases of composition and using Fig 4 for combination of composition operations.

For any combination of sequence and parallel composition operations, equation (1) holds good because in any case, $\lambda_s$ is the sum of $\lambda_x$ of constituent services. The same is explained using Fig 4. But in case of choice composition operation, equation (1) does not hold good. Hence any sub composition involving 'choice' operation leaves us with no choice other than taking checkpoints for that sub composition.
Fig 4: Execution prediction based Checkpointing Policy for combination of composition operations

But when Execution prediction based checkpointing policy is used, the number of checkpoints generated as part of Call based Global checkpoint reduces to 3 as shown in Table IV. This is because when S0 calls S1, S1 calls S3 and S4 in sequence resulting in a nested call. Before S0 calls S1, S0 calculates that PET (S1) = 4tu and MTBF (S1) = 5tu. Hence it is found that PET (S1) < MTBF (S1) and S0 need not take a checkpoint before calling S1.

S1 calls S3 and S4 in sequence and since composition operation is ‘sequence’, we can see that equation (1) holds good and there is no need to calculate PET (S3) and PET (S4). Hence it can be deduced that PET (S3) < MTBF (S3) and PET (S4) < MTBF (S4) and S1 need not take checkpoints while calling them. Also S1 and S4 need not take checkpoints after sending reply back to S1 since their predicted execution time is less than their MTBF and they will not fail.

Thus we can see that total number of Local checkpoints generated is greatly reduced by implementing Execution time Prediction based Checkpointing.

### Table IV: Demonstration of Execution Prediction Based Checkpointing

<table>
<thead>
<tr>
<th>Current node visited</th>
<th>PET and MTBF Calculation by the caller</th>
<th>Action Taken</th>
</tr>
</thead>
<tbody>
<tr>
<td>invoke S₂</td>
<td>PET (S₂) = 2tu and MTBF (S₂) = 1tu.</td>
<td>[C₀₂] generated by S₀ → first CBGC */</td>
</tr>
<tr>
<td>End S₂</td>
<td></td>
<td>End of first CBGC */</td>
</tr>
<tr>
<td>invoke S₁</td>
<td>PET (S₁) = 4tu and MTBF (S₁) = 5tu</td>
<td>[C₂₁] not generated by S₁</td>
</tr>
<tr>
<td>invoke S₃</td>
<td>PET (S₃) &lt; MTBF (S₃) can be deduced from PET (S₃) &lt; MTBF (S₃)</td>
<td>C₃₂²¹ not generated by S₃</td>
</tr>
<tr>
<td>End S₃</td>
<td>PET (S₃) &lt; MTBF (S₃) can be deduced from PET (S₃) &lt; MTBF (S₃)</td>
<td>C₃₂²¹ not generated by S₃</td>
</tr>
<tr>
<td>invoke S₄</td>
<td>PET (S₄) &lt; MTBF (S₄) can be deduced from PET (S₄) &lt; MTBF (S₄)</td>
<td>C₄₂²² not generated by S₄</td>
</tr>
<tr>
<td>End S₄</td>
<td>PET (S₄) &lt; MTBF (S₄) can be deduced from PET (S₄) &lt; MTBF (S₄)</td>
<td>C₄₂²² not generated by S₄</td>
</tr>
<tr>
<td>End S₁</td>
<td>PET (S₁) &lt; MTBF (S₁)</td>
<td>[C₁₃] not generated by S₁</td>
</tr>
<tr>
<td>End S₀</td>
<td></td>
<td>third CBGC */</td>
</tr>
</tbody>
</table>

Total No of Local checkpoints generated = 3

V. CONCLUSION AND FUTURE WORK

In this paper we have proposed to use PET and MTBF of web services to decide whether checkpoints have to be taken at service calling locations. We have used Euclidean distances method to find out similar cases for the given web service execution instance and use them to estimate the execution time of the instance. If this estimated execution time of the called web service is less than its MTBF then there is no need to checkpoint its calling web service.

Recovery of applications based on checkpointing policies has been well studied in database and distributed computing fields. Due to lack of space we are not describing the implementation of recovery policy for web services. We intend to cover it in our future work.

When web services are orchestrated each service call results in creation of a new service instance and when the called service sends a reply back that service instance is destroyed. But if web services are choreographed service calls may be directed to already existing service instances. Also, when the called service sends a message to the caller, it might be in the middle
of an operation, expecting some communication from the caller. Our previous checkpointing policy does not suffice to such a scenario. Hence we propose to develop a new checkpointing policy for Choreographed services as part of our ongoing research work.

REFERENCES


