Resource Mining: Applying Process Mining to Resource-Oriented Systems*

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Abstract Service Oriented Architecture is an increasingly popular approach to implement complex distributed systems. It enables implementing complex functionality just by composing simple services into so called business processes. Unfortunately, such composition of services may lead to some incorrect system behavior. In order discover such depreciances and fix them, process mining methods may be used. Unfortunately, the current state of the art focuses only on SOAP-based Web Services leaving RESTful Web Service (resource-oriented) unsupported. In this article the relevance of adapting the Web Service Mining methods to new resource-oriented domain is introduced with initial work on process discovery in such systems.

Keywords: process mining, business process, logging, SOA, REST.

1 Introduction

Currently, often used approach to the implementation of distributed systems is Service Oriented Architecture (SOA). This approach reduce costs of development, maintenance and provides an easy integration of system implemented accordingly to it. It is possible by splitting simple system functionalities into independently developed applications called Web Services (WS). Later on, composition of many WS into business processes is used to provide more complex functionality.

Nowadays, two different approaches to SOA are widely recognized [20]. The first one are SOAP-based WS, which are highly standardized, and use WSDL (Web Services Description Language) to describe their procedural interfaces and rely on SOAP (Simple Object Access Protocol) as their communication protocol. The second approach, introduced in [11] is REST (Representational State Transfer) and RESTful (resource-oriented) WS, which take a declarative approach, are based on resources rather than functions [21].

In both of the approaches however, the same problems with composition may yield incorrect system behavior, i.e. deadlock, livelock. In addition, number of

* This work was supported by the Polish National Science Center under Grant No. DEC-2012/05/N/ST6/03051.

W. Abramowicz and A. Kokkinaki (Eds.): BIS 2014, LNBIP 176, pp. 217–228, 2014.

composed and invoked services during system execution may be tremendous, making it hard to manage. In order to deal with this problem, a research of process mining (PM) [2] may be used. Up to date, a lot of work has been already done concerning: log extraction [15,19], process model discovery [1,13,3], conformance checking and enhancement [5].

Being a prominent and fast developing research area, PM has been also applied to SOA, raising a new problems and challenges [12] that need to be address like: cross-organization PM [8], event data preprocessing [2], process models discovery from SOA services logs [9,10,6], improving WS behavior [4] and gathering logs [16]. As it can be seen process discovery, and generally PM, has been only applied to SOAP-based WS SOA systems. We believe that REST systems could also benefit from applying PM techniques. For that to be possible, one first needs to gather logs from a system, which are always the first step in every PM method. There are papers that deal with gathering and collecting logs from SOA systems in order to apply PM techniques, or Web Service mining techniques. In [16] Authors tackle with the problem collecting event logs in order to extract process traces from application systems and integration portal log files. In [7] and [18] methods to deal with correlation of events with processes and processes instances are presented.

Unfortunately, authors are considering only the interactions between services without taking into account local events. Furthermore, all the articles focus on SOAP-based systems, so the results they present cannot be directly applied to resource-oriented systems (ROS, consisting of RESTful WS), due to different nature of SOAP-WS and REST.

In this article we tackle the problem of adapting the Web Service Mining methods to RESTFul WS domain. In addition, we introduce context logging, a technique of log enrichment in order to make possible to infer process related data in ROS (Sec. 2). Furthermore, process and process instance reconstruction algorithm for ROS, based on approaches for SOAP-based WS is presented (Sec. 2.1). We also propose and discuss a prototype framework implementation (Sec. 3). Finally, utilization of proposed methods with classic PM methods in order to achieve Resource Mining (RESTful Web Service Mining) is shown (Sec. 4).

2 Resource Mining: The Resource-Oriented Approach to Web Service Mining

In order to discover process models in ROS there is a need to adopt the already existing methods of Web Service Mining and/or develop new ones to respect differences in ROS features in contrast to SOAP-WS:

1. A service is only an application component composed of a callable set of resources, which are important from a client's perspective. Therefore, only individual resources need to be considered.
2. A service execution state is stored on a client's side (active), not on a server side (resources). Thus, a process logic is executed in a client by executing a predefined, finite set of CRUD operations on resources.

3. Resources are passive, they only provide data representation and implementation of a client callable operations. This approach introduces stateless communication, and unified interface [11].
4. Business process is a resource. Complex functionality in ROS is achieved by composing system resources invocations into workflows or business processes. Upon client's action, a passive resource may, on behalf of that client, act as client for other resources, we call it a *process resource*.
5. Resources are hierarchically dependent on each other, some of resource representations may be included in other resource representations. Correctly modeled and implemented ROS will use `URI`s to pinpoint such inclusion [21].
6. HTTP protocol is used as communication layer (in SOAP-WS it only serves as one of transport layers to ensure SOAP messages delivery), so the semantics of HTTP messages drives request handling.
7. HTTP guarantees receiving response for every request. We assume only synchronous communication as a basis for further discussion about more complex communication patterns (sequence of synchronous interactions modeling asynchronous communication).
8. In contrary to SOAP, HTTP lacks one-way communication so there is no such type of communication in ROS (standard request-response model).
9. There are no standards like WS-Addressing or WS-Conversation, so there is no support for using and logging process related information like process IDs and process instance IDs, so the correlation patterns from [7] are hard to fulfill and solutions like [18] are not sufficient for ROS.
10. Process resources may be nested, and may be further orchestrated into complex process resources. In such a case, process logic is also nested in internal events of resources. Consequently, there is a need to discover not only traces of communication events and correlate them into process instances but also internal resource events.

The crucial problem in log collecting in ROS is the lack of appropriate logging level available in the current SOA implementations [10]. This problem occurs due to the usage of application servers developed exclusively for request-response model of interaction. In this model, server passively awaits for requests, upon receiving it, it is processed and a response is sent back to the client. Hence, only information about received message and returned response is stored in an event log. What is lacking is process related data: process instance id and process id. In addition, resources may act as clients and such events are usually not stored in log (difference (4)).

Next, there is a need to group events concerning each of the resources belonging to the particular RESTful service (difference (1)). Usually, services store invoked URI address in log so this information may be used, or if application server does not support such feature, a solution is presented in Sec. 3. Next, there is also a problem of handling resources by parallel instances. Current application servers like Apache Tomcat create new instance of resource for each incoming request to the same URI. In consequence, each resource instance, logs information concurrently into a log file, so event log interleaving problem occurs (Fig. 1).

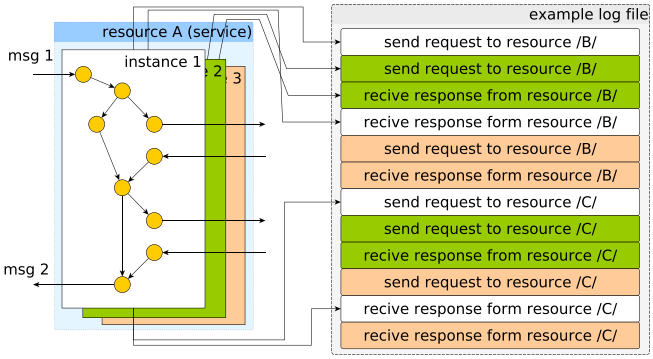


Fig. 1. log interleaving problem

`Instance 1` of `Resource A` is invoked and sends a request to `resource B`, an appropriate log entry in log is stored. Next, `instance 2` is created upon second request to `resource A`. The `instance 2` request to `resource B` is sent, and response for that request is received (line 2 and 3 at Fig. 1). Next, `instance 1` receives response and logs this information (line 4). As the example shows, if there is no information about instances in the log, that create log entry, there is no possibility to tie the receiving of message to sending it. In addition, log also includes information about incoming messages like `msg 1` and returned messages `msg 2`. There is a need to correlate the messages with each other and with outgoing messages, in order to associate them with proper service instances, as well as to keep log ordering relation [3]. This allows to discover local process of each resource (Fig. 2b):

$$a \succ_L b \text{ iff there is trace where event } b \text{ immediately precedes event } a \tag{1}$$

This relation orders all local events of some resource (local process at Fig. 2b). In order to deal with above problems we introduce context logging. The main concept is to add a unique ID (Context ID) of the resource instance to each logged event. As a result each service instance will add additional field to event log during logging called `context`. This context simply correlates incoming messages, with outgoing messages, and some local events. Such a context log allows to specify events that take place within different instances of resources allowing to generate an independent event log files for each resource in the service, and each instance of that resource (local log at Fig. 2b). In addition, if we enforce adding local context as a additional HTTP header (it is possible because of difference (6)) it is also possible to correctly preserve ordering (correlation) relation introduced in [18] (*atomic correlation condition*) or in [7] (*reference-based correlation*) between interacting resources (`res`) based on context information in HTTP header (Eq. 2).

$$
\begin{aligned}
a \succ_{ctx} b \text{ iff there is trace in event log where } & \#_{ctx}(a) = \#_{hctx}(b) \wedge \ \#_{res}(a) = resA \\
& \wedge \#_{res}(b) = resB \wedge resA, resB \in Res \wedge resA \neq resB \wedge \#_{destURI}(a) = resB \\
& \wedge \#_{srcURI}(b) = resA, \text{ where } Res \text{ is a set of all resources in the system,} \\
& \text{and } \#_{ctx}(e) = A \text{ means value of field } ctx \text{ of event } e \text{ is A}
\end{aligned} \tag{2}
$$

These relations describe a situation where `resA` invokes `resB` ($\#_{destURI}(a) = resB \wedge \#_{srcURI}(b) = resA$) and logs this information with $\#_{ctx}(a)$ label as event a and `resB` receives this message and logs this event with context label passed by `resA` ($\#_{hctx}(b) = \#_{ctx}(a)$) and with local context label $\#_{ctx}(b)$. Next step is to reconstruct session and a global process and generate appropriate `processID` and `instanceID`, basing on context information (session reconstruction and global process in Fig. 2b). In order to reconstruct session one needs to apply information about which resource instance invokes other resource instance. Such information allows to retrieve the whole workflow information of interacting resources during business process execution. In order to achieve that, we ask each resource to send its local context in HTTP header to its callees. Then each callee needs to log this header as a receiving event log entry with its own local context. As a result, each of invoked service has information about local context within it was called. Based on the context ordering relation and partial context information, the algorithm for session reconstruction can be applied.

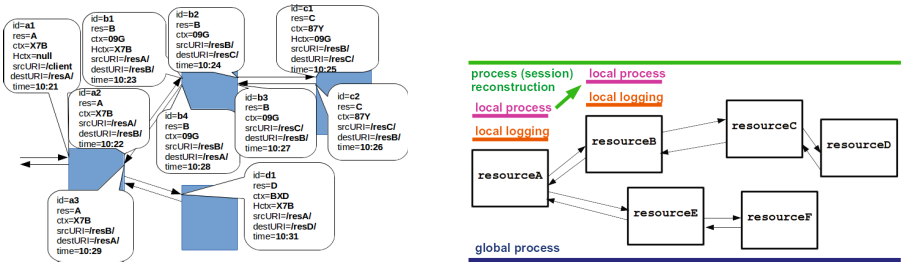
2.1 Simple Process and Instance Reconstruction Algorithm for Resource-Oriented Systems

The main idea behind session reconstruction is to add appropriate `processID` and `instanceID` to events in the log. The main problem is to tie events with a process instance, i.e. process run. In our approach we are using the idea of context logging from Sec. 2. We are assuming that each resource enriches its log entries with context field generated by each of its instances. This allows us to distinguish event log entries created by different resource instances (even if they are in the same log file). Next, if resource plays client role during process execution, it must include context information into its all outgoing messages. This ensure that context information is transfered to nearest neighbors, and allows to tie interacting resource instances with each other. We use HTTP header (`hctx`) to transfer context. The example of log entries generated by resources during interaction is presented in The Fig. 2a.

Therefore, based on the relation in eq. 2, and the obtained context log, we are construct a chain of connected resource instances. First, we generate a set `CTX` that contains information about the dependence among resource instances occurring in the log:

$$CTX = \{(e_1, e_2) \mid e_1 \in L \wedge e_2 \in L \wedge (e_1 \succ_{ctx} e_2)\} \tag{3}$$

We are looking a pair of events in the event log that represent communication between two resource. Such events in resource-oriented (RESTful) log are easy



(a) Log entries example (b) Idea and limitation

Fig. 2. Context logging

to find because they include additional data related to HTTP protocol (header, method etc.). The sender of message will include its local context into `hctx` header of message, so as a result the receiver will log in event e_2 the sender local context (it is included in HTTP header) next to its own local context. Into set CTX we put tuples of events between communication resources, where local context of first event (e_1) is equals to received from communication invoker context in event e_2. Next, we search the log for global process starting events (communication event sent by process principal), according to:

$$F = \{f \mid f \in L \wedge \#_{hctx}(f) = null\} \tag{4}$$

Global process starting event is recognized be empty `hctx` HTTP header value ($\#_{hctx}(f) = null$). This occurs when $\#_{res}(f)$ resource is invoked by a process principal, because process principal is not a part of process so it does not include context information in invoke messages. Each event in F represents the initial event in global process execution so the size of set $|F|$ represents a number of process instances occurring in event log. Next, all so called context chains of events are calculated (based at correlation condition in [18]). The context chain is an ordered set of events that represents context flow during process execution in one global process instance (one chain represents one global process instance).

foreach $f_j \in F$ **do** $CHAIN_j = \{f_j, E_j, CTX_j\}$, where f_j is a starting event in this chain , and E_j is a set of events in this j-th chain and$CTX_j$is a set of context dependency between events in $E_j \cup \{f\}$, where $j = 1...|F|(|F|$ is a number of process instances occurring in log). (5)

In order to do that, we need to find all events sets of context dependent events in each of the context chains (one context chain for each starting event):

$$E_j = \{e \mid (e \in L \wedge \exists_{e' \in L \wedge e' \in E_j}(e \succ_{ctx} e' \vee e' \succ_{ctx} e))\}, \text{ where } (\exists_{e'' \in E_j}\ f_j \succ_{ctx} e'') \tag{6}$$

Set E contains events e, such that all events in this set are context dependent on at least one other event in this set, additionally at least one event from this set is context dependent on starting event f_j. Next, the set of context dependencies (CTX_j) between events of set E_j is calculated as follows:

$$CTX_j = \{(e_1, e_2) \mid e_1 \in E_j \wedge e_2 \in E_j \wedge e_1 \succ_{ctx} e_2\} \tag{7}$$

Set CTX consists of tuples (e_1, e_2) where event e_2 is context dependent on event e_1. In consequence, each context chain shows mutually interacting process instances in some (still unknown) global process. As a result, the process `instanceID` may be generated and added to each of context chains. Further, each event can obtain `instanceID` from context chain it belongs to. Unlike most of approaches, other events (e_l) – not only invocation events, must be added in order to take local processing of resources under consideration (differences (10)). This results in more accurate process models because sending messages may be dependent on some local resource event. This results in the $Instance$ set:

$$Instance_j = \{(f_j, E_j \cup \{e_l \mid e_l \in L \wedge \exists_{e' \in E_j} \#_{ctx}(e_l) = \#_{ctx}(e')\}, CTX_j, SUCCj)\} \text{ , where } \\ f_j \text{ is a starting event in chain } CHAIN_j \text{ and } E_j \text{ is a set of events in chain } \\ CHAIN_j, \text{ and } CTX_j \text{ is a set of context dependency occurring in this, } \\ \text{process instance and } SUCC_j \text{ is a local resource events ordering set} \tag{8}$$

$SUCC_j$ is a set of tuples showing local order relation among events of the same resource instance. It contain all the events belonging to the resources (instances) involved in $j-th$ context chain.

$$SUCC_j = \{(e_1, e_2) \mid e_1 \in L \wedge e_2 \in L \wedge \exists_{e' \in E_j} (\#_{ctx}(e_1) = \#_{ctx}(e_2) = \#_{ctx}(e')) \\ \wedge (\#_{res}(e_1) = \#_{res}(e_2)) \wedge (e_1 \succ_L e_2) \wedge (e_1 \neq e_2)\} \tag{9}$$

The final step is to determine which of the found instances belong to which process. The idea to discover processes, and correlate instances with them is based on differences (1) and (4) that everything is represented in form of resource (even business process). In ROS, business processes are executed by invoking resources call other resources on behalf of the *process principal*. Therefore, the final step is to analyze resource property of each first log entry $(\#_{res}(f_j))$ of each of $Insance_j$ in order to find such process resources. We are analyzing only the first event in each instance, as they are invoked by process principals $(\#_{hctx}(f) = null)$, so they are the starting point of process execution. Next, for each unique resource (called *process resources*) we are generate `processID`, because each instance starting from the same resource is an instance of the same process resource. This allows us to correlate instances with process by calculating sets of processes instances for each of process resources occurring in the log:

$$Process_n = \{i \mid i \in AllInstaces \wedge \exists_{i' \in Process_n} ((\#_{res} first(i) = \#_{res} first(i') \\ \wedge i \neq i') \oplus i{=}i')\}, \text{ where function } first() \text{ returns } f_j \text{ for } CHAIN_j \tag{10}$$

As a result the algorithm returns a set of $Process_n$ sets that include several $Instance_j$. Based on this, there is a need to review all events in event logs of all resources in the system, and add to them instanceID accordingly to ID of $Instance_j$ that this event belongs to. Then add `processID` accordingly to ID of $Process_n$ to which that event $Instance_j$ belongs to. As presented in Fig. 2a there is only one global process $(Process_0 = \{Instance_0\})$ and one instance $(Instance_0 = \{\{a1\}, E_0, CTX_0, SUCC_0\}$, where $E_0 = \{a2, a3, a4, b1, b2, b3, b4, c1, c2, d1, d2\}, CTX_0 = \{(a2, b1), (b2, c1), (a3, d1)\}$, and $SUCC_0 = \{(a1, a2), (a2, a3) \ldots (d1, d2)\})$

3 Non-invasive Context Logging for JSR-311 with AspectJ: A Case Study

Context logging can be used to differentiate among separate resource instances in separate process instances of multiple processes. The idea behind context logging is to inject HTTP headers into messages that pass through the system. This simple technique can be implemented in three ways: service instrumentation, proxy servers introduction, and semi non-invasive way.

We show that non-invasive logging is possible for a wide range of enterprise systems, i.e. Java based RESTFul-WS, implemented according to the JSR-311 standard [14]. Here we use AspectJ [17] (Aspect Oriented Programming paradigm, AOP) and Apache Tomcat application server.

Jersey comprises to JAX-RS, a JSR-311 standardized API of implementing RESTful-WS in Java. Both, the standard, and Jersey are widely used in a number of enterprise application servers and frameworks. We present a proof of concept implementation of our AspectJ context logger for RESTful systems implemented according to JSR-311, and in fact, this is our only technical requirement. Our approach will work for any Java application server and implementation of JAX-RS. We believe that the same approach can be used for any other technology that offers support for AOP, such as .NET, Python or Ruby.

We take advantage of the fact that in JAX-RS (Jersey), every RESTful Web service needs to be defined in a class, annotated with certain decorators, e.g. `@Path`. The listing below shows a simple Web service implemented in Jersey. `@Path("/hello")` says that the Web service will be accessible under `"/hello"` URI resource. The method annotated with `@GET` and `@Path` handles every GET operation issued on `"/hello/world"` resource, `@GET` can be substituted with any other HTTP operation. `@Produces` or `@Consumes` in the case of POST, PUT defines content type the resource returns or accepts.

```
@Path("/hello") // every class has @Path
public class Hello {
   // every method has @OP annotation
   @Produces("text/html") @GET @Path("/world")
   public Resource handler(@Context HttpHeader headers,
        @Context HttpServletRequest request) {}
```

Thanks to the standardized API, AspectJ context logger for incoming messages can be implemented in a simple way. One needs only to define pointcut, which catches every execution of any method placed in any class annotated with `@Path`, `@Produces` and `@GET`. In our implementation an advice is called when the pointcut is reached. First local context is generated, which in our case is the hash-code of a current object instance. Next, if the `HCTX` header is present in the request, it is stored and logged alongside with the local context, remote caller IP, HCTX value, and request URI from the `@Path`. Local context is then appended to every outgoing request from the current service instance in a `HCTX` header.

```
execution(@javax.ws.rs.GET @javax.ws.rs.Produces public * *(..)) &&
          within(@javax.ws.rs.Path *)
```

The situation gets more complicated when we want to catch and log messages sent from a service. In that case, not only we have to alter the outgoing message

with context logging HTTP header `HCTX` but also the HTTP client call may be done in some arbitrary way. In our case, we assume that these external calls are done from the same thread that handles the incoming request, i.e. synchronously. We also assume that JSR-311 client API is used. Therefore, a pointcut can be defined to catch all calls to methods named `request*` within classes annotated with `@Path`. Such an approach allows us to alter the request headers originating from the service, and thus pass the context to external services, according to context logging approach. Assuming that external services are also equipped with our aspect context logger, logs of all messages received and sent in the whole system can be created.

```
call(public * *.request(..)) && within(@javax.ws.rs.Path *)
```

There are some requirements we need to impose on how services are implemented with Jersey. We require that every method handling requests needs to return `Resource` object, and take the following arguments: `@Context HttpHeader` and `@Context HttpServletRequest`. This is needed to extract information, such as remote caller IP, request headers, and to inject our own header. Another difficulty we came across is the way the situation when service we equip with aspects calls some external service. In our approach we assumed that the call is done in the same thread as incoming request handling but this does not need to be the case. If it's not the case, it is still possible to implement a logger, by examining the call stack to determine how the current thread was called. By comparing this with the call list kept in aspects, it is possible to determine which service instance was the original caller.

4 Applying Alpha Algorithm for Resource-Oriented Context Preprocessed Log

After preprocessing the context log by the algorithm in Sec. 2.1, it is now possible to apply classic PM algorithms. As it is shown in Sec. 1, there are a lot of process model discovery approaches available up-to-date, but in our initial work on service mining in ROS, we have used basic alpha algorithm (AA) [3]. The reason for this is to show on simple and representative example that PM is applicable but some additional work is still need to be done. The idea behind AA is to use ordering relation (Eq. 1) that occurs in the log file to discover process model in form of a petri net. Unfortunately, in the real case scenario in ROS, it is unlikely that each resource in the system will log into the same log file with respect to some global clock and with respect to some global ordering relation. Therefore the problem of gathering logs from distributed resources with respect to global ordering arises. In addition, the basic version of AA does not take the resource perspective into account. So the first step is to make logs unique globally (usually events IDs are only unique locally at resource). Without distinction of resources, two events occurring at different resources may leave identical log entries, so as a global identifier is the concatenation of resource URI (is unique by the definition) and its local identifier (unique at the resource).

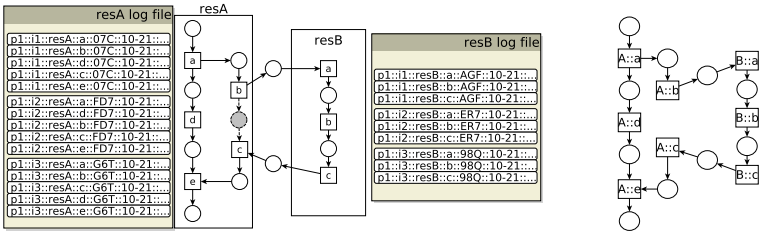


Fig. 3. a(left) – original process model, b(right) – discovered process model

Lets consider example shown in Fig. 3. The resource `resA` is a process resource and invokes resource `resB` during its execution. Next, two events with IDs `a` occur in two different resources `resA` and `resB`. If we omit resource information they are indistinguishable form each other. In order to use basic AA we need to flatten the log, to make sure ID of such events in the system are unique, we are concatenate resource URI and local ID — `A::a` and `B::a`. AA takes one log file with multiple traces (instances) of exactly one process as its input. In order to use it, first we need to gather distributed resource log files and concatenate them into one file for each process found by algorithm from Sec. 2.1. The first problem with concatenation, of independently generated log files, is the order in which concatenation is performed. Different approaches to deal with this problem have different impact on the results. It is because the AA only uses flat order of events in a log file to determine if two events are executed in parallel, in some order, or are independent on each other. In consequence, simple concatenation of resource log files will result in violation of causal dependency of events. In the considered example (Fig. 3a) adding `resB` log file at the and of `resA` file will result in incorrect dependency relation between event `A::e` and `B::a`. This will lead to incorrect conclusion that these events are not independent. In order to deal with this problem there we need to perform another preprocessing phase of the event log in order to identify the communicing resources and appropriately concatenate event logs of subinvoked resources. We consider only synchronous communication so if a resource does not execute multiple parallel threads, all invocation events must be followed by corresponding response events (`A::b` and `A::c`). If there are two parallel threads, then all events in the second thread must be parallel to both the invocation and the response handling event (`A::d`). In order to concatenate log files and respect ordering relation among events in both resources (context dependency between two events in different resource `A::b` and `B::a`), and in addition to respect local ordering of events, we use previously calculated sets of context chains in Eq. 5. For each chain, and for each resource instance occurring in context chain, we look for communication events invoking and handling response (*communication pair* $CP = (start, end, ctx_1, ctx_2)$). Each of such pairs consists of: *start* - starting event (invoking event), *end* - ending event (response handling event), ctx_A - context of invoking resource and ctx_B - context of invoked resource. Thanks to that, during pre-processing phase we put all events in the invoked resource event log file between the starting event

and the ending event. Additionally, not to disturb parallel relation of concurrent events there is a need to generate additional traces, not originally included in log file. Lets consider example in Fig. 3. We search for all *CP*s in the log. The only found *CP* is: `A::b`, `A::c`, `A::07C` and `B::AGF`. Because we are dealing with synchronous communication, we add all events of resource instance `B::AGF` between the events `A::b` and `A::c` of resource instance `A::07C`. The problem occurs with event `A::d`, which is parallel to communication events in `resA`. In order to respect the parallel relation, we need to generate new traces (the minimal set of them) that will render all events in log file of `resB` to be also parallel to event `A::d`. To do that, we need to generate new process traces (instances) with respect to the following condition:

$$\forall_{CP \in Log_A}((e \mid\mid start \wedge e \mid\mid end) \implies (\forall_{f \in Log_B}(f \mid\mid e)), \text{ where } Log_A \text{ is invoking resource log and } Log_B \text{ is invoked resource log, and } a \mid\mid b \Leftrightarrow a \succ_L b \wedge b \succ_L a \text{ , where } L \text{ is some log} \tag{11}$$

As a result, new traces are generated and we can execute the AA for each process occurring in the log. The discovered petri net is shown at Fig. 3b. In comparison to the original model in Fig. 3a, the dotted places and arcs are not present. It is because, there is no longer relation between events `b` and `c` at `resA` after log preprocessing. This is a side effect of adding `resB` log. In conclusion, presented example shows that AA is able to mine processes based on a preprocessed resource-oriented log. Some drawback of this approach is that during mining interaction between resources, some local dependencies are lost. In context of global PM this is not an issue, because from a global point of view the workflow is in fact transfered to invoked resource.

5 Conclusions and Future Work

We have shown how our approach may be used to extend the current methods of PM and Web Service Mining discussed in Sec 1 to make them applicable in ROS. We have discussed how RESTful log, including interaction events of ROS, can be obtained, and further used to discover the process model in such systems.

Presented considerations leads to several conclusions and feature challenges. First, framework to obtain context enriched log concerns only ROS implemented accordingly to JSR-311. In the case of other technologies more work may be required. In future we would like to address this problem. Another direction of research is to develop algorithms dedicated for ROS that do not need to preprocess event log. This may lead to more accurate process models by using all information available in the log, like hierarchy relation along resources and/or message semantics. Finally, current PM methods work only with global process. In our approach to reconstruct process related information we discover multiple process resources but later we execute process discovery algorithm for each of them separately. Our current work concerns developing methods for discovering processes models based on multiple process logs.

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