Configurable Process Mining: Semantic Variability in Event Logs

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Abstract: Configurable process model represents a reference model regrouping multiple business process variants. The configurable process models offer various benefits like reusability and more flexibility when compared to business process models. The challenges encountered while managing this type of models are related to the creation and the configuration. Recently, process mining offers techniques to discover, check conformance of models, and enhance configurable process models using a collection of event logs, that captures traces during the execution of process variants. However, existing works in configurable process discovery lack the incorporation of semantics in the resulting model. Historically, semantic process mining has been applied to event logs to improve process discovery with respect to semantic. Furthermore, from the best of our knowledge, configurable process mining approaches do not fully support semantics. In this paper, we propose a novel method to enrich the collection of event logs with configurable process ontology concepts by introducing semantic annotations that capture variability of elements present in the logs. This is a first step towards discovering a semantically enriched configurable process.

1 INTRODUCTION

Configurable Process models regroup multiple process behaviours into a single model with the possibility to be configured according to the needs of an execution environment. Each one of the resulting business process models, called process variant, captures a specific behaviour of the reference model (Derguech, 2017).

Configurable process models seem to be useful for large organizations that manage similar processes in different conditions like insurance companies, banks, and universities (Benítez, 2017).

Configurable process models offer also multiple advantages such as guaranteeing consistency between business process models, avoiding business process clones (De Medeiros, 2008) and offering a certain degree of flexibility regarding the possible ways to execute the process (Benítez, 2017). They are constructed using two methods: i) manual approach: which preconizes merging multiple process variants from scratch (La Rosa, 2013); (Derguech, 2011); (Assy, 2013), ii) automatic approach: which is based on the application of mining techniques (Buijs, 2013).

Concerning the manual approach, since the variability is identified in a specific domain, designer collects different process variants which will be merged into one model and represented by one of the existing configurable process modeling languages like C-EPC (La Rosa, 2011); C-BPMN (Rosa, 2017); C-YAWL (Gottschalk, 2008) and EVR-BPMN (Sbai, 2015). Contrary to automatic approach (Buijs, 2013), where configurable process models are created directly from real time recorded data of a collection of event logs. There are three main process mining axes:

- Discovery: creation of configurable process models using a collection of event logs,
- Conformance: analysis of configurable process models regarding a collection of event logs,
- Enhancement: improvement of configurable process models using data captured in collection of event logs.

The use of event logs for business process mining, redresses the problem of having limited information about the way of working in organizations (Detro, 2017). However, business process mining based on the real-life logs, have some weaknesses: i) production of large and spaghetti-like models, ii) production of models with low fitness and iii) production of models with low precision or low

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generalization (Augusto, 2018). Hence, to improve the quality degree of process models discovered, it is crucial to start with high-level event logs. For that reason, existing approaches introduced semantic processing, based on ontologies, to enhance the quality of event logs and ensure that the events present in the event log directly correspond to the activities that are recognizable for process stakeholders. Then, the analysis made based on event logs data will be more accurate and correct compared to syntactic analysis.

Similarly, to business process mining, existing approaches in the configurable process mining field use domain ontology to unify event logs data. As the analysis of configurable process models are based on a collection of event logs, the challenge is to consider the variability expressed in the collection of event logs and make sure to capture the same in the resulting configurable process model.

Despite of efforts that has been made to introduce semantic in process discovery, configurable process discovery approaches are limited to the syntactic level. The challenge with the syntactic analysis is the dependence on labels presented in the event logs and this causes a lack of the abstraction level required for real world applications (Okoye, 2020). To overcome this, few papers combine semantic concepts with process mining techniques to provide semantic analysis in a high level of abstraction (Detro, 2017). The incorporation of semantics in the configurable process models can help to exchange process information between the applications in the most efficient manner (Detro, 2017).

Many works in the context of manual approach, propose the integration of semantics for managing configurable process models and their customization (Detro, 2017); (Benítez, 2017); (Buijs, 2013). However, for the automatic approach, in which the configurable process is discovered from event logs, they focus on the discovery of variable fragments and shared fragments to derive the configurable process model without including semantic concepts in the final model. As well, the semantic technologies are used to reduce the complexity of the configurable process model or to give assistance during process configuration without the inclusion of semantics in the configurable process model.

According to our previous work (Khannat, 2020), we proposed a framework to discover semantically enriched configurable process models based on a collection of semantically enriched event logs.

In this paper, we propose an approach to enrich the collection of event logs with variability concepts and domain ontology as part of the event logs pre-processing component. The objective is to prepare the collection of event logs using ontologies as a first step towards discovering a semantically enriched configurable process model.

The remainder of this paper is structured as follows: Section 2 describes the main concepts related to our work. Section 3 provides main ideas of related works regarding semantic enrichment of event logs. Section 4 presents an overview of the proposed approach. Finally, Section 5 concludes this paper and discusses future work.

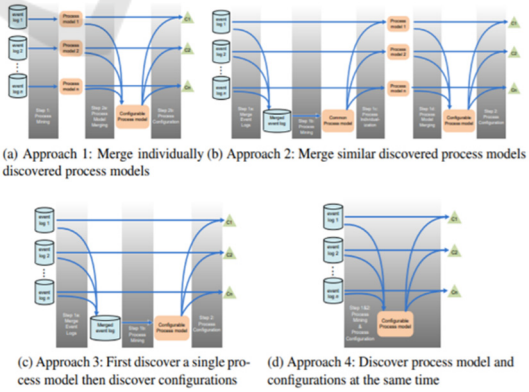
2 BASIC CONCEPTS

In this section, we present two main concepts related to our work that are configurable process model discovery and semantic in the event log.

2.1 Configurable Process Model Discovery

Configurable process model is a process model that describes both the commonalities shared by all process variants and their differences (Derguech, 2017). Common parts are presented in all process variants, while variable parts represent options that can be configured depending on the process execution context. Process Mining techniques are used to automatically discover configurable process models based on collection of event logs.

Figure 1 (Buijs, 2013) illustrates existing approaches for automatic discovery of configurable process models.



(a) Approach 1: Merge individually discovered process models (b) Approach 2: Merge similar process models

(c) Approach 3: First discover a single process model then discover configurations (d) Approach 4: Discover process model and configurations at the same time

Figure 1: Configurable process model discovery approaches.

- Approach 1: Mining of the process variant corresponding to each event log and merging models, then discovering its configurations.

- Approach 2: Merging event logs and discovering common parts then extracting process variants and merging them to obtain the configurable process model.
- Approach 3: Merging event logs and mining configurable process model, then discovering the configurations.
- Approach 4: Discovering the configurable process model and its configurations at the same time.

The approach 4 is proposed to overcome challenges of other approaches, the configurable process model is smaller and simpler compared to other models.

The quality of the configurable process model directly impacts the customization and the extraction of process variants (Detro, 2017), the more comprehensive is the model, the easier will be the customization. Thus, enriching configurable process model with semantics improves the representation of processes and allows automation of configuration task with more flexibility and adaptation to different business contexts (El Faquih, 2020). Semantics consist of the integration of ontologies during the process creation phase or the process analysis phase. Ontology is defined as a set of concepts and existing relationships between them in formalized representation (Detro, 2020). Introduction of ontologies enables sharing knowledge, unifying vocabularies, and adjusting the level of details. Two main ontologies are used in the field of configurable process models: i) domain ontology: regroups concepts that belong to specific domain, and ii) variability ontology: captures the variability of the process variation points. Some existing approaches use these ontologies for two main purposes: i) configuration: derives rules that assist users during the configuration process, and ii) validation: ensures semantic correctness of the process variants.

Existing approaches use Semantic Business Process Mining techniques to perform analysis on process execution traces at the conceptual level, this enables deriving knowledge from event logs. Thus, the stage related to preparation of event logs is crucial in process mining, specifically in semantic configurable process mining.

2.2 Semantics in Event Logs

Event logs resume information about the process execution, such timestamp, case, activity, and resources (Allani, 2016). These real data are considered with great importance in the field of process mining, as they allow discovering, conforming, and enhancing business process models.

There are two formats to represent and store event logs: MXML (Mining eXtensible Markup Language) and XES (eXtensible Event Stream) (Verbeek, 2010). Both formats define an event log as a sequence of events but using different concepts and attributes.

MXML uses the below concepts to describe process execution traces (Günther, 2006):

- WorkflowLog: represents a log file.
- Process: regroups events having been occurred during the execution of a specific process.
- ProcessInstance: represents single execution of the process.
- Data: represents Data attributes that can be associated to each element of the log.
- AuditTrailEntry: describes one event in the log and contains the below child elements:
  - WorkflowModelElement: captures the activity name that triggered the event.
  - EventType: captures the type of the event (e.g. start, complete).
  - Originator: captures the resource name that executed the activity.
  - Timestamp: captures the time at which the event occurred in the system.

XES uses also specific concepts to represent event log data (Verbeek, 2010):

- Log: corresponds to Workflow in MXML.
- Extension: specifies semantics of an attribute, which could be either a standard extension or some user-defined extension.
- Trace: matches to ProcessInstance in MXML.
- Classifier: assigns an identity to each event.
- Attribute: stores data about each element of

Regarding expression of semantics in event logs, the two formats store semantic annotations in different ways:

- Case of MXML event log: New format SA-MXML (Semantically Annotated MXML) has been defined to represent MXML event logs enriched semantically. The SA-MXML format is an extension of the MXML format whereby all elements (except for AuditTrailEntry and Timestamp) have an optional extra attribute called modelReference that links to a list of concepts in ontologies (the concepts are expressed as URIs) (De Medeiros, 2008).
- Case of XES event log: XES uses the extension Semantic to support semantic annotations that refers to ontology concepts. This is inserted as an attribute in all levels (log, trace, event and meta) of type ‘string’ with key

'modelReference' and value that reference to model concepts in an ontology.

Both formats SA-MXML and XES are supported by ProM framework in process mining applications.

3 RELATED WORK

In this section, we present existing works on semantic enrichment of event logs.

The approach presented in (Okoye, 2020) introduces semantic annotations to link the event log to the domain ontology in order to answer some questions with regards to different learning patterns/behaviour and discover unobserved learning behaviours or patterns. They argue that the analysis provided by process mining techniques can be improved using semantics. The authors in (Cairns, 2014) propose a (semi)automatic procedure to link training labels of the educational event log to the right concepts of a training ontology, in order to generate and analyze a less complex process model. The work (Yongsiriwit, 2017) proposes to semantically represent event logs using the extended ontology NCFO (Neighborhood Context Fragment Ontology) in order to compare event logs to an under-design process for assisting business process variants design.

Authors in (Nykänen, 2015) defined two main ontologies to be associated with an event log: i) process ontology: describes activities of the target process model and relationships between them and ii) product ontology: describes the object (resource) used by the process. The main purpose of enriching process mining using events logs with associated ontology structures is to analyze the process models in different abstraction levels, which greatly helps to understand complicated processes. (Jareevongpiboon, 2013) introduces a methodology to combine domain ontology, company-specific ontologies, and databases to obtain multiple levels of abstraction for mining and analysis. They propose to map concepts from ontologies to process execution data for improvement of results in process mining and analysis. The process discovered can be viewed in two ways: i) it can be viewed at the domain concepts level and ii) it can be viewed at a company specific level. The application of this methodology proves that semantics enhance the business object dimension of analysis. The authors of (Detro, 2017) propose an approach to explore event logs data using domain ontology and variation points ontology with the objective of giving suggestions during configurable process model customization. The work (Sellami, 2012) takes interest of the organizational perspective, it presents an approach to semantically annotate event log with organizational ontology, which allows creating a knowledge base related to the relationship between performers in a workflow.

To sum up, Table 1 shows a comparison of the related works, presented in this section, according to the following criteria:

- **Event Log Category:** indicates if the approach uses a single event log or a collection of logs.
- **Event Log Language:** specifies the language used to represent the event logs.
- **Element Annotated:** indicates the element annotated using the ontology (task or resource).
- **Type of Ontologies:** determines the type of ontology used.
- **Ontology Language:** determines the language used to represent the ontologies.
- **Objectives:** identifies the objectives for semantic enrichment of traces.

The comparison of these works shows us that few approaches are interested in semantic enrichment of event logs collection. The works (Detro, 2017) and (Yongsiriwit, 2017) enrich the collection of event logs to extract process variants. The other approaches (Okoye, 2020); (Cairns, 2014); (Nykänen, 2015); (Jareevongpiboon, 2013); (Sellami, 2012) are limited to the enrichment of a single event log. Thus, the existing approaches are not sufficient for the preparation of the collection of event logs with the purpose of mining configurable process models. In addition, most of the works are limited to activity elements in the semantic annotation. Few works (Nykänen, 2015); (Jareevongpiboon, 2013); (Sellami, 2012) that propose semantic annotation for resource element. So, there is a need to integrate all perspectives when semantically enriching event logs.

As well, the existing approaches (Okoye, 2020); (Cairns, 2014); (Sellami, 2012) use domain ontologies, and this presents a lack for the discovery of configurable process models, knowing that this type of models should manage variability.

Moreover, approaches that handle with collection of event logs (Yongsiriwit, 2017); (Detro, 2017) are using semantics for configuration only and the configurable process model extracted is not enriched with semantics.

The existing works use OWL (Web Ontology Language) and WSML (Web Service Modeling Language) to represent ontologies and use event logs expressed in XES (eXtensible Event Stream) or MXML (XML-based user interface markup language).

Table 1: Summary of approaches related to semantic enrichment of event logs.

Work	Event log category	Event log language	Element annotated	Type of ontologies	Ontology language	Objectives
(Okoye, 2020)	Single	--	Task	Domain ontology	OWL	Process discovery and enhancement
(Cairns, 2014)	Single	MXML	Task	Domain ontology	WSML	Process discovery
(Yongsiri wit, 2017)	Collection	XES	Task	Process model ontology	OWL	Assisting business process variants design
(Nykänen, 2015)	Single	--	Task Resource	Process model ontology Domain ontology	OWL	Analysis of process models in different abstraction levels
(Jareevon gpiboon, 2013)	Single	MXML	Task Resource	Domain ontology	WSML	Process discovery and enhancement
(Detro, 2017)	Collection	MXML	Task	Domain ontology Variability ontology	OWL	Automatic suggestions during process configuration
(Sellami, 2012)	Single	XES	Resource	Domain ontology	OWL	Discovery of relationship between performers in a workflow

When analyzing the existing approaches, we deduce that most of them are limited to semantic annotation of activity element with domain ontology and apply their approaches to single event log. These approaches seem to be not suitable for the preparation of event logs collection in the field of configurable process models, as we need to enrich the collection of event logs with domain concepts and variability concepts. For these reasons, we propose an approach to semantically annotate collection of event logs with configurable process model ontology and domain ontology. Then, process mining techniques will be applied on the enriched event logs to discover semantically annotated configurable process models.

4 APPROACH OVERVIEW

In our previous work (Khannat, 2020), we proposed the framework for discovering semantically enriched configurable processes. Fig 2 represents a simplified illustration of the proposed framework.

Event Logs Pre-processing Component. This component is used to merge the collection of event logs and prepare the resulting log by adding semantic annotations that link event logs elements to concepts formalized in two ontologies: domain ontology and configurable process model ontology (CPMO).

Configurable Process Model Discovery. This component takes as input the event log prepared in the first component and applies process mining techniques to discover the configurable process model, that is enriched semantically with the same ontologies as the event log prepared, and the appropriate rules of configuration.

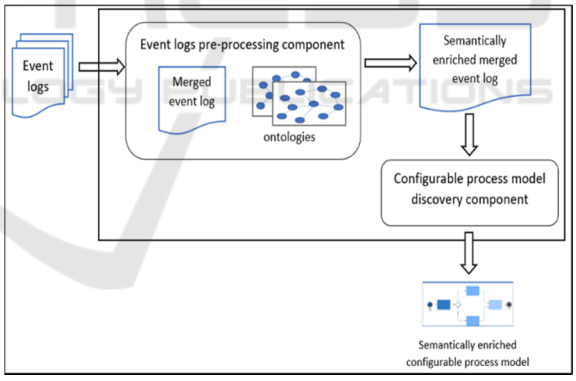


Figure 2: Framework for automatic discovery of semantically enriched configurable process model.

The main idea is to semantically enrich collection of event logs as this will lead to enhance the quality of the discovered model and gives analyst views in multiple abstraction levels, it will also improve the quality of process variants extracted from the configurable process model, knowing that they will be enriched and validated semantically. We propose to enrich event logs using two ontologies, the first one to express variability in event logs and the second one to link event log to domain concepts. This step will allow creation of high-level annotated event logs that

will optimize process mining application and allow semantic validation of process elements before being discovered. In this paper, we focus on the annotation of event logs using the CPMO. We suppose that the collection of event logs is already constructed and contains only instances of similar process variants. The corresponding variables fragments are supposed already identified based on existing methods (Sikal, 2018); (Vaca, 2019). Regarding variability perspectives, we are interested in activities and resources and we consider that the variability of resources depends on the variability of activities.

Figure 3 illustrates the proposed approach for enriching collection of event logs using CPMO.

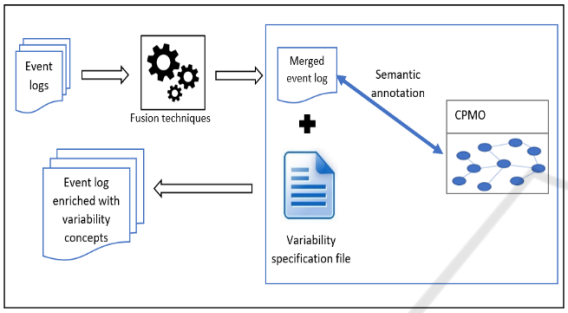


Figure 3: Approach overview of semantic enrichment of event logs.

To achieve our objective of integrating semantic annotations that link activities and resources in event logs to variability concepts formalized in CPMO, we propose to follow the below steps:

Step 1: Merging the event logs into one consolidate event log: The merging technique is similar to the techniques presented in the approach (Suriadi, 2017). We will create one consolidated event log in the same format as the input event logs, this file will contain all instances included in starting logs. Each element of types: process, process instance and activity will have a unique identifier (e.g. (i), (i, j), (i, j, k)) that links the element to its parent element in the new event log.

Step 2: Defining semantic annotations to use: In this step, we define the semantic annotations to be integrated in the event log, resulting from the merge of the collection. These semantic annotations will refer to concepts of CPMO.

Table 2 (El Faquih, 2020) depicts the CPMO variability classes, subclasses, and relationships.

Table 2: CPMO concepts.

CPMO variability classes	**Subclasses**	**Relationships**
Variable	------	CPM **contains** variable
Variation_ point	Alternative Optional Optional_ alternative	CPM **contains** variation point Variation_point **is_a** alternative Variation_point **is_a** optional Variation_point **is_a** optional _alternative Variation_point **has_variant** variant
Variant	Default	CPM **contains** variant Variant **has** default

The main idea is to insert new attributes, in the event log merged, that will contain values of the CPMO classes. Table 3 presents the attributes that will be inserted in the event log, their values, and the concerned elements in the case of MXML event log or XES event log.

We use the notation CPMO#ontology_concept while referring to a concept in the CPMO.

Step 3: Marking variability into the event log: This step is about including the defined attributes into the log based on the variability specification file. To achieve this, we propose the algorithm, illustrated in Figure 4, which takes as input the event log in MXML

Table 3: Attributes used for semantic annotation with CPMO.

Attributes	**Signification**	**Possibles values**	**Targeted element in MXML event log**	**Targeted element in XES event log**
VariabilityType	The type of variability	CPMO#variable	Process / ProcessInstance	Trace
		CPMO#variationPoint	AuditTrailEntry	Event
		CPMO#variant	AuditTrailEntry	Event
VarPtType	The type of variation point	CPMO#alternative CPMO#optional CPMO#optionalAlternative	AuditTrailEntry	Event
VarType	The type of variant	CPMO#default CPMO#variant	AuditTrailEntry	Event

format and the variability specification file and generates as output the semantically annotated event log using CPM ontology. The same algorithm can be adapted to XES event logs format.

Input: MXML Event log + variability specification file
Output: MXML-CPM (enriched event log with CPM concepts)
1 For each element <**AuditTrailEntry**> that is variable do
2 Add new attribute **VariabilityType** with value **CPMO#variationPoint**
3 Add new attribute **VarPtType** and assign it one of the values **CPMO#alternative** **CPMO#optional** or **CPMO#optionalAlternative**
4 Add new field **modelReference** to <**Originator**> with one of the values **CPMO#alternative** **CPMO#optional** or **CPMO#optionalAlternative**
5 For all variants of this element do
6 For each element <**AuditTrailEntry**> do
7 Add new attribute **VariabilityType** with value **CPMO#variant**
8 Add new attribute **VariantType** with **VarType** and assign it one of the values **CPMO#default, CPMO#variant**
9 Add new field **modelReference** to <**Originator**> with one of the values **CPMO#default** or **CPMO#variant**
10 End For
11 End For
12 End For
13 For each element <**ProcessInstance**> do
14 If the element contains variable <**AuditTrailerEntry**> do
15 Add new attribute **VariabilityType** with value **CPMO#variable**
16 End If
17 End For
18 For each element <**Process**> do
19 If the element contains variable <**ProcessInstance** > do
20 Add new attribute **VariabilityType** with value **CPMO#variable**
21 End If
22 End For

Figure 4: Algorithm proposed to enrich MXML event log with CPMO concepts.

```
<Process id="Order">
<Data>
<Attribute name="ID"> (1) </Attribute>
 <Attribute name="VariabilityType" modelReference="file:/:C/CPMO#variable">
CPMO#variable</Attribute>
 </Data>
<ProcessInstance id="Order 1" description="instance with Order 1">
<Data>
<Attribute name="ID"> (1,1) </Attribute>
<Attribute name="VariabilityType" modelReference="file:/:C/CPMO#variable">
CPMO#variable</Attribute>
</Data>
<AuditTrailEntry>
<WorkflowModelElement> Create </WorkflowModelElement>
<EventType> complete </EventType>
<Originator modelReference="file:/:C/CPMO#alternative"> Tester1 </Originator>
<Timestamp> 2019 - 01 - 03T15:30:00.000+01:00 </Timestamp>
<Data>
<Attribute name="ID"> (1,1,1) </Attribute>
<Attribute name="VariabilityType" modelReference="file:/:C/CPMO#variationPoint">
CPMO#variationPoint</Attribute>
<Attribute name="VarPtType" modelReference="file:/:C/CPMO#alternative">
CPMO#alternative</Attribute>
</Data>
</AuditTrailEntry>
<AuditTrailEntry>
<WorkflowModelElement> Submit </WorkflowModelElement>
<EventType> start </EventType>
<Originator modelReference="file:/:C/CPMO#default"> System </Originator>
<Timestamp> 2019 - 01 - 03T15:32:00.000+01:00 </Timestamp>
<Data>
<Attribute name="ID"> (1,1,2) </Attribute>
<Attribute name="VariabilityType" modelReference="file:/:C/CPMO#variant">
CPMO#variant</Attribute>
<Attribute name="VarType" modelReference="file:/:C/CPMO#default">
CPMO#default</Attribute>
</Data>
</AuditTrailEntry>
</ProcessInstance>
</Process>
```

Figure 5: Fragment of SA-MXML file enriched with CPMO.

Through application of the algorithm proposed, we can generate semantically enriched event log that links variable elements to CPMO concepts. Figure 5 represents an extract from the resulting merged and annotated event log in SA-MXML format.

5 CONCLUSIONS AND FUTURE WORK

Configurable process mining still confronting challenges related to variability and complexity of the discovered models. Semantics represent a great key to enhance configurable process model quality, however, the application of semantic techniques still limited to validation or configuration. Thus, our framework aims to integrate semantics in the discovery of configurable process models to manage variability more easily and give a conceptual view of the model. The proposed framework is based on two ontologies: Domain ontology and CPMO. In this paper, we proposed an algorithm to semantically enrich collection of event logs using CPMO. The resulting event log will be enriched with domain ontology and then used as input for configurable process mining techniques to discover semantically enriched configurable process model.

As future work, we aim to complete the first component implementation by annotating the event log with domain ontology and validate this component by presenting a use case application. Moreover, we will focus on the application of process mining techniques on the event log prepared to discover the configurable process model.

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