Extracting Features From Process Variants in Case Management

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Abstract. Case Management supports knowledge workers in performing knowledge-intensive processes in a flexible way. An essential ingredient of Case Management are template processes that are modified for a specific case to suit the context of that case. Modifying templates results in many different yet related process variants. However, modifying a template is time consuming and may lead to errors. This paper defines an approach to extract fragments, called features, from artifact-centric process variants in case management. By composing the extracted features, the input variants and other process variants can be derived. This way, complex artifact-centric process variants can be designed more efficiently and their quality improves, since well-known modifications are applied.

Keywords: Business artifacts; feature extraction; variability management

1 Introduction

Many business processes in modern organizations rely on knowledge workers that have to make informed decisions about specific cases. The available data and knowledge drives the decision making and processes in such knowledge-intensive processes (KiPs) [10]. Case management is a key paradigm in BPM to support KiPs [30]. A key notion in case management is that of a template: a representation of a “baseline” process. The template is modified to suit the needs of the particular case being processed. Common modifications are adding and deleting elements of the template [13]. Such modifications result in a case management process model variant, or a process variant for short.

Modifying a case management template is labor intensive, since the exact changes need to be explicitly specified. Moreover, the changes may have undesirable side effects, for instance a deadlock or a task that is done twice. This paper develops support for reuse of modifications to case management templates. By applying a modification that already was applied before to the template for another variant, the design time for new variants is reduced. Moreover, the quality of new process variants is improved, since well-proven modifications are applied.

More concretely, this paper defines an approach to extract fragments from a case management template and a set of process variants that are based on the
template. Each fragment represents work done for a case that was incorporated in an input process variant by modifying the template. We view these extracted fragments as features. The notion of feature comes from the field of Software Product Line Engineering [3], where they are used to distinguish common and variable parts in software artifacts and this way support reuse of software artifacts. Composing different but related features yields different variants of a software product [4].

As host modeling language, we use Guard-Stage-Milestone (GSM) schemas, a technique to declaratively model life cycles of key business entities, called business artifacts [9]. In previous work, we defined a feature composition operator for GSM schemas [12], which defines how a GSM fragment viewed as feature is applied to a base GSM schema (template). Using feature composition, extracted GSM fragments can be composed into variants in a declarative way. GSM schemas are one of the predecessors of CMMN [8]. Thus, the results in this paper provide a basis for applying feature extraction to CMMN models.

The remainder of this paper is organized as follows. Section 2 introduces GSM schemas, feature composition and the problem of extracting features from GSM variants. Section 3 defines GSM schemas and feature composition. Section 4 defines the approach for templates and variants that all refine the template. Section 6 discussed related work. Finally, Section 7 concludes the paper.

## 2 Overview

We introduce GSM schemas, feature-based composition of GSM fragments, and the problem of extracting features from a set of GSM schema variants.

### GSM schemas

A Guard-Stage-Milestone (GSM) schema defines the life cycle of a business artifact [9]. A business artifact is a key business entity that is changed during a business process, for instance an order or a claim request [26]. Key modeling constructs in GSM schemas are stages and milestones. A stage represents a cluster of business activity performed for the artifact. Stages are organized into a hierarchy. Each atomic stage contains exactly one task, an atomic piece of work. A milestone represents a business objective, usually achieved by completing an attached stage. Stages and milestones change status if certain conditions, called sentries, are met. There are two kinds of sentries. Plus sentries ensure that a stage is opened or a milestone achieved, while minus sentries ensure that a stage is closed or milestone invalidated. Guards are plus sentries of stages.

**Example.** Fig. 2 shows sample GSM schemas. Rounded rectangles denote stages, circles denote milestones, and each diamond denotes the presence of a guard. Other sentries are not visualized. In the base process (Fig. 1), business criteria for a partner contract are assessed: first data about the partner is gathered and prechecked, and next a detailed check is performed to decide whether the criteria should be changed or not. If new information arrives before the business criteria
Fig. 1: Base GSM schema Business Criteria Assessment (BCA\textsuperscript{base})

Table 1: Stages and sentries for BCA\textsuperscript{base} in Fig. 2. ‘;’ separates different sentries

| Stage                      | Plus sentries (guards) | Minus sentries (closing) |
|----------------------------|------------------------|--------------------------|
| Initial Data Gathering     | E:StartAssessment ;    | IDGS                     |
|                            | E:AdditionalInfo       |                           |
| Preliminary Check          | IDGS                   | PCS ; PCU ; E:AdditionalInfo |
| Business Performance       | +Preliminary Check     | BPECS ; BPECU ; -Preliminary Check |
| Evaluation Check           |                        |                           |
| Detailed Check             | PCS                    | DCS ; DCU                |

have been assessed, the data is gathered anew and the business criteria check is restarted, if applicable. Sentries for the base process are listed in Table 1 and 2.

GSM variants and feature composition. A GSM schema can be modified into another GSM schema. This way, from a base GSM schema a set of variant GSM schemas can be derived. To derive a variant, several change operations can be applied to a GSM schema \[13\]. For instance, Fig. 2(a) and Fig. 2(b) show two variants that are modifications of the base GSM schema in Fig. 1. They have been derived by inserting stages and milestones for an additional checks on the credit level and the addressable market. Also sentries need to be modified for these variants: Table 3 shows as an example the modified sentries for PCS and

Table 2: Milestones and sentries for BCA\textsuperscript{base} in Fig. 2

| Milestone     | Full Name                          | Plus sentries                  | Minus sentries |
|---------------|------------------------------------|--------------------------------|----------------|
| IDGS          | Initial Data Gathering Successful  | C:Initial Data Gathering       | E:AdditionalInfo |
| BPECS         | Business Performance Evaluation    | C:Business Performance Evaluation Check ∧ BP_good | E:AdditionalInfo |
| BPECU         | Business Performance Evaluation    | C:Business Performance Evaluation Check ∧ ¬BP_good | E:AdditionalInfo |
| PCS           | Pre-checks Successful              | BPECS                          | false          |
| PCU           | Pre-checks Unsuccessful            | BPECU                          | false          |
| DCS           | Detailed Check Successful          | C:Detailed Check ∧ ...         | false          |
| DCU           | Detailed Check Unsuccessful        | C:Detailed Check ∧ ...         | false          |
PCU. Space limitations prevent a completing listing of the sentries for the other stages and milestones of the variants.

To enable reuse of shared parts between GSM variants, we proposed in earlier work [12] to view GSM fragments as features and to use feature composition, well-known from the field of Software Product Line Engineering [4,6], to compose GSM fragments into GSM schemas.

**Extracting features.** Though the feature composition approach [12] allows to generate different variants from a common base GSM schema (template), it assumes that the composed features already exist. But defining features manually can be time consuming and costly, as it depends on domain knowledge from domain experts.

We define an approach to extract features from a set of variant GSM schemas derived from the same base GSM schema. The approach is efficient, since it can be automated and does not rely on domain knowledge, because that knowledge is already encoded in the different variants. Moreover, extracting features enables the reuse of modifications among different GSM variants, each feature representing one set of related modifications.

In essence, the approach decomposes a base GSM schema and set of GSM schema variants into features. For example, for the base schema $BCA^\text{base}$ and
Table 3: Sentries for milestones PCS and PCU in variants of BCA\textsuperscript{base} in Fig. 2

| Variant | Milestone | Plus sentries (achieving) | Minus sentries (invalidating) |
|---------|-----------|---------------------------|------------------------------|
| BCA\textsuperscript{1} | PCS | BPECS \land CCS | false |
| BCA\textsuperscript{1} | PCU | BPECU ; CCU | false |
| BCA\textsuperscript{2} | PCS | BPECS \land CCS \land AMCS | false |
| BCA\textsuperscript{2} | PCU | BPECU ; CCU ; AMCU | false |

its two variants BCA\textsuperscript{1} and BCA\textsuperscript{2}, two features can be extracted, one related to Credit Checking, one related to Addressable Market Check. Each feature represents the insertion of a stage and two milestones and the modification of sentries. Each input GSM schema variant can be derived by composing one or more of the extracted features with the base schema, using feature composition [12]. However, also other variants can be derived by composing the extracted features. For instance, another variant for BCA\textsuperscript{base} can be composed that contains Addressable Market Check and its connected milestones, but not Credit Check.

3 GSM Schemas

In this section, we define GSM schemas. A GSM schema [9] of a business artifact consists of data attributes and status attributes. Data attributes model the information state of the business artifact. A status attribute is a Boolean variable that denotes the status of a stage or milestone. For a status attribute of a stage, value \textit{true} denotes that the stage is open, value \textit{false} that the stage is closed. For a status attribute of a milestone, value \textit{true} denotes that the milestone is achieved, value \textit{false} that the milestone is invalid.

Event-Condition-Action rules define for which event under which condition a status attribute changes value (action). The event-condition part of a rule is called a \textit{sentry}. The event of a sentry is optional. We distinguish between external and internal events. An external event signifies a change in the environment. It is either a task completion event C:T, where T is a task, as defined below, or a named external event E:n, where n is an event name. An internal event signifies a change in value of a status attribute a: internal event +a denotes that a becomes true, −a that a becomes false. For instance, +Preliminary Check in Table 1 is an internal event that signifies that stage Preliminary Check gets opened. The condition of a sentry is a Boolean expression that can refer to data attributes or status attributes. The action of each rule is that a status attribute becomes true or false, which leads to two types of sentries. A \textit{plus sentry} defines when a stage becomes open or a milestone gets achieved. A \textit{minus sentry} defines when a stage is closed or a milestone gets invalid.

Stages and milestones can be nested inside other stages. A milestone cannot contain any other milestone or stage. We require that the nesting relation induces a forest, i.e., the nesting relation is acyclic and if a stage or milestone is nested
in two other stages $S_1$, $S_2$, then either $S_1$ is nested in $S_2$ or $S_2$ in $S_1$. The most nested stages, which are called \textit{atomic}, launch tasks. To ease the presentation, we assume for this paper that stages launch tasks having the same label, so for instance stage \textit{Detailed Check} launches a task with the same name.

We next formally define GSM schemas \cite{9,13}.

\textbf{Definition 1 (GSM schema)} A GSM schema is a tuple $\Gamma = (A = D \cup S \cup M, \mathcal{E} = \mathcal{E}_{\text{ext}} \cup \mathcal{E}_{\text{comp}}, \preceq, R = R_+ \cup R_-)$, where

- $A$ is a set of attributes, partitioned by the following three subsets:
  - $D$ is a finite set of data attributes;
  - $S$ is a finite set of stage attributes;
  - $M$ is a finite set of milestone attributes;
- $\mathcal{E}_{\text{ext}} = \{E: n | n \text{ is an event name}\}$ is a finite set of named external events;
- $\mathcal{E}_{\text{comp}} = \{C: S | S \in S_{\text{atomic}}\}$ is the set of stage completion events;
- $\preceq \subseteq (S \cup M) \times (S \cup M)$ is a partial order on stages and milestones, where $a_1 \preceq a_2$ means that $a_1$ is child of $a_2$. Relation $\preceq$ induces a forest, i.e., if $a_1 \preceq a_2$ and $a_1 \preceq a_3$ then $a_2 \preceq a_3$ or $a_3 \preceq a_2$. We let $S_{\text{atomic}}$ denote the set of stages that have no children;
- $R_+, R_-$ are functions assigning to each status attribute $S \cup M$ non-empty sets of sentries (see Definition 2). For $a \in S \cup M$, $R_+(a)$ is the set of plus sentries that define the conditions when to open stage $a \in S$ or achieve milestone $a \in M$, while $R_-(a)$ is the set of minus sentries that define the conditions when to close stage $a \in S$ or invalidate milestone $a \in M$.

Relation $\preceq$ is visualized using nesting. For instance, Business Performance Evaluation Check $\preceq$ Preliminary Check and BPEC $\preceq$ Preliminary Check in Fig. 2?.

Each sentry $\varphi$ in set $R_+(a)$, where $a \in S \cup M$, maps into an Event-Condition-Action rule "\textit{\varphi then } +a\textit{"}, where sentry $\varphi$ is the Event-Condition part and action $+a$ denotes for $a \in S$ that stage $a$ gets opened and for $a \in M$ that milestone $a$ gets achieved. Each sentry $\varphi$ in set $R_-(a)$ maps into a rule "\textit{\varphi then } −a\textit{"}, where action $−a$ denotes for $a \in S$ that stage $a$ gets closed and for $a \in M$ that milestone $a$ gets invalid. Each sentry in set $R_+(a)$ or $R_-(a)$ is sufficient for triggering a status change in the stage or milestone $a$.

For the definition of sentries, we assume a condition language $\mathcal{C}$ that includes predicates over integers and Boolean connectives. The condition formulas may refer to stage, milestone and data attributes from the universe of attributes $\mathcal{U}$. Keyword \textit{orig} denotes the original condition formula defined in another GSM schema for the same status attribute \cite{12}.

\textbf{Definition 2 (Sentry)} A sentry has the form $\tau \land \gamma$, where $\tau$ is the event-part and $\gamma$ the condition-part. The event-part $\tau$ is either empty (trivially true), a named external event $E$, a task completion event $C.T$, where $T$ is a task, or is an internal event $+a$ or $−a$, where $a$ is a stage or milestone attribute. The condition $\gamma$ is a Boolean formula in CNF in the condition language $\mathcal{C}$ that refers to $\mathcal{A} \cup \{\text{orig}\}$, so data attributes in $D$ and status attributes in $S \cup M$ and the keyword \textit{orig} can be used in $\gamma$. The condition-part can be omitted if it is equivalent to true.
The condition part of a sentry is a boolean formula in conjunctive normal form (CNF) in order to ease the presentation. However, this is not a severe restriction: if the condition part of a formula in $C$ is not in CNF, it can be rewritten using Boolean laws into an equivalent set (disjunction) of sentries. For instance, formula $E:n \land (a > 10 \lor b < 5)$ is equivalent to set of sentries $\{E:x \land a > 10, E:x \land b < 5\}$.

In earlier work we proposed a declarative composition operator $\cdot$ for GSM schemas [12]. Given a GSM schema fragment $\Gamma^1$ and a GSM schema $\Gamma^2$, the GSM schema $\Gamma^1 \cdot \Gamma^2$ results by merging the GSM schemas by taking the union of the different components of a GSM schema tuple, except for sentries (rules). For shared stages and milestones the definition of sentries in $\Gamma^1$ override those in $\Gamma^2$.

If the sentries of a shared stage or milestone should be merged rather than overridden, keyword $\text{orig}$ can be used in the sentries of $\Gamma^1$, which in the evaluation of $\cdot$ is replaced with the sentries of the shared stage or milestone in $\Gamma^2$. For instance, if $\Gamma^1$ and $\Gamma^2$ share milestone $m$, the sentry of $m$ in $\Gamma^1$ is $x > 10$ and in $\Gamma^2$ is $\text{orig} \land x < 100$, then the sentry of $m$ in $\Gamma^1 \cdot \Gamma^2$ is $x > 10 \land x < 100$.

GSM schema fragments contain $\text{orig}$ in their sentries, while base schemas and variants do not contain sentries with $\text{orig}$, i.e., they can be executed.

4 Extracting Features

We next define a method that extracts a set of features from a template (base) GSM schema and a set of GSM schema variants that refine the template. Each extracted feature is specified as a GSM schema fragment.

4.1 Requirements

First, we list requirements on the set of features that the method extracts:

R1 The feature set must be minimal: there is no feature in the set that itself is a combination of other features in the set.

R2 The feature set must be complete: each variant can be derived by composing one or more features with the template.

Requirement R1 states that features are not overlapping, so orthogonal. For instance, variant $BCA^2$ can be derived by applying two features, one of which is defined for generating variant $BCA^1$. Introducing a third feature that derives $BCA^2$ directly from $BCA^{base}$ is therefore redundant. Requirement R2 ensures that each variant that is input can in fact be derived by a combination of features.

4.2 Method

The input, output and different steps of the method are shown in Fig. 3. We next explain and define the different steps in detail.
Step 1 creates a variant graph that shows the refinement relations between the different GSM schema variants. Nodes are $\Gamma^{\text{base}}$ and the variant GSM schemas. An edge $(\Gamma, \Gamma')$ in this variant graph denotes that $\Gamma'$ refines (extends) $\Gamma$, written $\Gamma \subseteq \Gamma'$. Fig. 4 shows the variant graph for the GSM schema variants in Fig. 2, which all refine $\text{BCA}^{\text{base}}$. Moreover, $\text{BCA}^2$ refines $\text{BCA}^1$.

The refines relation, $\subseteq$, is defined as follows.

**Definition 3 (Refinement)** Let $\Gamma^1, \Gamma^2$ be two GSM schemas. Then $\Gamma^2$ refines $\Gamma^1$, written $\Gamma^1 \subseteq \Gamma^2$, if

- $D^1 \subseteq D^2$;
- $S^1 \subseteq S^2$;
- $M^1 \subseteq M^2$;
- $E_{\text{ext}}^1 \subseteq E_{\text{ext}}^2$;
- $E_{\text{cmp}}^1 \subseteq E_{\text{cmp}}^2$;
- for each $a \in A^1$, if $\varphi \in R^1_+(a)$ then there is a $\varphi' \in R^2_+(a)$ s.t. $\varphi$ implies $\varphi'$;
- for each $a \in A^1$, if $\varphi \in R^1_-(a)$ then there is a $\varphi' \in R^2_-(a)$ s.t. $\varphi$ implies $\varphi'$.

In the definition, most lines are straightforward given the definition of GSM schemas, except the one about the rules. If $\Gamma^1 \subseteq \Gamma^2$ then for each plus (minus) rule $\varphi$ of status attribute $a$ in $\Gamma^1$, the same plus (minus) rule or plus (minus) rule $\varphi \wedge \psi$ for $a$ is in $\Gamma^2$. If the rule is of the form $\varphi \wedge \psi$ in $\Gamma^2$, then a feature can be constructed that extends $\varphi$ with conjunct $\psi$, by defining a sentry $\text{orig} \wedge \psi$. A rule in $\Gamma^2$ of the form $\varphi \lor \psi$ is not allowed (cf. Def. 2); instead, a set of rules $\{\varphi, \psi\}$ can be specified.
Step 2 removes each transitive edge from the variant graph, i.e., each edge \((\Gamma, \Gamma')\) for which there is an alternative path from \(\Gamma\) to \(\Gamma'\). Step 2 is needed to ensure that the feature set is minimal. A refinement relation that is implied by one or more other refinement relations can be safely deleted, since its effect can be obtained from the other refinement relations. For the variant graph in Fig. 4, edge \((BCA^{\text{base}}, BCA^1)\) is transitive and removed in step 2.

Step 3 creates for each edge \((\Gamma, \Gamma')\) in the variant graph a feature. Since \(\Gamma \subseteq \Gamma'\), constructing a feature seems straightforward: simply delete \(\Gamma\) from \(\Gamma'\). However, to ensure that composing the feature with \(\Gamma\) yields \(\Gamma'\), the feature must include some attributes from \(\Gamma\).

For instance, consider \(BCA^{\text{base}}\) and \(BCA^1\) in Fig. 1. Deleting \(BCA^{\text{base}}\) from \(BCA^1\) gives the GSM schema fragment in Fig. 5(a). But applying this as feature to \(BCA^{\text{base}}\) results in a GSM schema variant in which the result of stage Credit Check, represented by milestones CCS and CCU, is not linked to the sentries of the stages and milestones of \(BCA^{\text{base}}\). Fig. 5(b) shows the correct feature: the fragment includes milestones PCS and PCU; the sentry of PCS is \(\text{orig} \land CCS\) while the sentries for PCU are CCU and \(\text{orig}\). These sentries connect CCS and CCU to \(BCA^{\text{base}}\).

Given a core feature extracted by subtracting \(\Gamma\) from \(\Gamma'\), the next definition characterizes which status attributes from \(\Gamma\) should be added to the core feature, in order to derive \(\Gamma'\). We call these the border attributes, since they are the attributes from \(\Gamma\) that link with the core feature.

**Definition 4 (Border attributes)** Let \(\Gamma^1, \Gamma^2\) be two GSM schemas such that \(\Gamma^1 \subseteq \Gamma^2\) (e.g., \(\Gamma^1\) is the template, \(\Gamma^2\) the variant). Then \(\text{borderAtts}(\Gamma^1, \Gamma^2)\) is the set of status attributes of \(\Gamma^1\) that indirectly reference attributes in the part of \(\Gamma^2\) that is not in \(\Gamma^1\):

\[
\text{borderAtts}(\Gamma^1, \Gamma^2) = \{a \in A^1 \mid \exists \varphi \in R^1(a) : \text{atoms}(\varphi) \cap (A^2 \setminus A^1) \neq \emptyset\} \\
\quad \cup \{a \in A^1 \mid \exists \beta \in A^2 \setminus A^1 : a \leq^1 b \lor b \leq^1 a\}.
\]

The definition shows that border attributes need to be included for two reasons. First, if there is a sentry for a stage or milestone, such that the sentry references attributes of \(\Gamma^2\) that are not in \(\Gamma^1\). For instance, the sentry of PCS of \(BCA^1\) is \(\text{BPECS} \land CCS\) and CCS is in \(BCA^1\) but not in \(BCA^{\text{base}}\). Therefore, PCS is a border attribute for \(BCA^{\text{base}}\) and \(BCA^1\), to ensure that the extracted feature modifies the sentry of PCS.
Second, if a stage or a milestone that is in $\Gamma^2$ but not in $\Gamma^1$, is in a direct hierarchical relation with a status attribute that is in $\Gamma^1$, then that status attribute needs to be a border attribute, to ensure that the hierarchy relation is preserved in the feature. For instance, stage Credit Check is in $\text{BCA}^1$ but not in $\text{BCA}^\text{base}$. Compound stage Preliminary Check is a border attribute, to ensure that hierarchy relation Credit Check $\preceq$ Preliminary Check of $\text{BCA}^1$ is included in the extracted feature.

We now define how a feature is extracted.

**Definition 5 (Feature extraction)** Let $\Gamma^1, \Gamma^2$ be two GSM schemas such that $\Gamma^1 \subseteq \Gamma^2$ (e.g., $\Gamma^1$ is the template, $\Gamma^2$ the variant). Then $\Gamma^2 \setminus \Gamma^1$ is the GSM schema $\Gamma = (A = D \cup S \cup M, E = E_{\text{ext}} \cup E_{\text{cmp}}, \preceq, R = R_+ \cup R_-)$ where

- $D = D^2 \setminus D^1$;
- $S = (S^2 \setminus S^1) \cup (S^1 \cap \text{borderAtts}(\Gamma^1, \Gamma^2))$;
- $M = (M^2 \setminus M^1) \cup (M^1 \cap \text{borderAtts}(\Gamma^1, \Gamma^2))$;
- $E_{\text{ext}} = E_{\text{ext}}^2 \setminus E_{\text{ext}}^1$;
- $E_{\text{cmp}} = E_{\text{cmp}}^2 \setminus E_{\text{cmp}}^1$;
- $\preceq = \preceq^2 \setminus \preceq^1$;
- for each $a \in A$,
  - $R_+(a) = \{ \{ \varphi[\psi/\text{orig}] \mid \varphi \in R_+^2(a), \psi \in R_+^1(a) \}$, if $a \in \text{borderAtts}(\Gamma^1, \Gamma^2)$
  - $R_-(a) = \{ \{ \varphi[\psi/\text{orig}] \mid \varphi \in R_-^2(a), \psi \in R_-^1(a) \}$, otherwise
  - $R_+(a) = \{ \{ \varphi[\psi/\text{orig}] \mid \varphi \in R_-^2(a), \psi \in R_-^1(a) \}$, if $a \in \text{borderAtts}(\Gamma^1, \Gamma^2)$
  - $R_-(a) = \{ \{ \varphi[\psi/\text{orig}] \mid \varphi \in R_-^2(a), \psi \in R_-^1(a) \}$, otherwise

Most lines of the definition are straightforward. Above we already explained why border attributes need to be included. For the definition of rules, note that for a status attribute $a$ in $\Gamma^2$ but not in $\Gamma^1$, the rules of $a$ in $\Gamma^2$ are incorporated in the feature. However, for a status attribute $a$ that is a border attribute, both $\Gamma^1$ and $\Gamma^2$ have defined rules. In that case, for pairs of rules that are similar, i.e., the rules are equal or the rule in $\Gamma^2$ extends the rule in $\Gamma^1$, the feature should contain the rule of $\Gamma^2$ but with keyword orig replacing the rule of $\Gamma^1$. For instance, in $\text{BCA}^\text{base}$ milestone PCS has sentry $\text{BPECS}$ while in $\text{BCA}^1$ the sentry for PCS is $\text{BPECS} \land \text{CCS}$. In $\text{BCA}^1 \setminus \text{BCA}^\text{base}$, the sentry for PCS is orig $\land$ CCS.

We state the correctness of the approach with a few lemmas. The first lemma states that feature extraction results in a GSM schema fragment.

**Lemma 1.** Let $\Gamma^1, \Gamma^2$ be two GSM schemas such that $\Gamma^1 \subseteq \Gamma^2$. Then $\Gamma = \Gamma^2 \setminus \Gamma^1$ is a GSM schema.

The next lemma ensures that applying a feature that was generated for a template and a variant to the template yields the variant.

**Lemma 2.** Let $\Gamma^1, \Gamma^2$ be two GSM schemas such that $\Gamma^1 \subseteq \Gamma^2$. Then $\Gamma^2 = (\Gamma^2 \setminus \Gamma^1) \cdot \Gamma^1$.

The next lemma follows easily from the method defined in Fig. 3.

**Lemma 3.** Let $\Gamma^{\text{base}}$ be a base GSM schema and $\{\Gamma^1, \ldots, \Gamma^n\}$ be the set of variant GSM schemas such for each $\Gamma^i$, $\Gamma^{\text{base}} \subseteq \Gamma^i$. The set of features generated by the method in Figure 3 is minimal and complete.
Table 4: Descriptive statistics of extracted features for Due Diligence Process and its variants

|                     | Base schema | Feature 1 | Feature 2 | Feature 3 | Feature 4 |
|---------------------|-------------|-----------|-----------|-----------|-----------|
| # Non-border stages | 9           | 1         | 2         | 1         | 1         |
| # Non-border milestones | 15       | 1         | 2         | 1         | 1         |
| # Non-border sentries | 60        | 5         | 10        | 4         | 5         |
| # Border stages     | 1           | 1         |           | 1         |           |
| # Border milestones | 1           | 1         |           | 0         | 0         |
| # Border sentries   | 5           | 5         | 3         | 3         |           |

5 Evaluation

To evaluate the feasibility of the approach, we applied the method to a real-world process of an international high tech company with offices in different regions of the world. In the process the expired due diligence qualification of a business partner of the company is renewed. The company has defined a standard due diligence process, but offices in certain regions can use their own process variant.

The standard process and three variants had been modeled before in separate GSM schemas [32]. The method could not be applied directly to these GSM schemas, since in one variant a fragment of the standard process was replaced with another fragment. Therefore, the standard process could not act as base process. We therefore manually created a base process, specified as GSM schema, such that both the standard process and the variant refine the base process. Thus, the standard process becomes another (fourth) variant. The GSM schemas for all these processes are available in the appendix.

Applying the feature extraction method to the base process and the four variants gave the following results. In the variant graph created in step 1, each variant refines the base schema, but not any other variant. Consequently, in step 2 no transitive edges were removed. In step 3, four features were created, one for each variant. The GSM schema fragments of the four extracted features are available too in the appendix.

Table 4 gives descriptive statistics of the base schema and the four features. All extracted features use border attributes to link properly to the base schema. For each border attribute there is at least one sentry that uses the \texttt{orig} construct. Composing each feature with the base schema gives the original variant. However, since three from the four features are complementary, additional variants can be derived [12].

This preliminary evaluation shows that the method can be used to extract features from a base schema and a set of GSM schema variants. However, it also shows that some preprocessing can be needed to ensure that all variants refine the base schema. In future work, we plan to extend the method to variants that do not refine the base schema but are overlapping.
6 Related Work

For artifact-centric process models, there is no directly related work on extraction of model fragments. The general problem of designing artifact-centric process models, either by defining a methodology for specifying business artifacts [7] or by defining an automated synthesis of artifact-centric process models [11,15,21,27] has been addressed, but without considering fragments that are composed.

Alternatives to artifact-centric process models are object-aware [18] and object-centric [28] process models and case management models [1,24,29] (though artifact-centric process models can be used for case management too [13,22]). A few of these alternatives support management of process variants [2] and, related, the use of model fragments [24,25]; we next discuss these in more detail.

Andrews et al. [2] present concepts for managing variants in object-aware processes. Each object-aware process model is defined by a logged sequence of modeling actions. A process variant is derived from another process variant by copying the log of modeling actions of that other process variant into a new log and then adding new modeling actions to the log. The focus of that paper is on efficiently managing updates for related variants, while this paper focuses on extracting composable fragments from variants.

Meyer et al. [24] define an approach for production case management in which procedural, activity-centric process fragments are composed at run-time by linking them, i.e., a case is executed in a distributed fashion by executing linked process fragments. The fragments are linked via shared data objects. Mukkamala et al. [25] define a commutative composition operator on instances of DCR graphs, a declarative, activity-centric process modeling notation. Each DCR graph instance can be viewed as a process fragment being executed. Both approaches focus on composition of existing process fragments, whereas the approach in this paper focuses on extracting fragments from variants such that the fragments can be composed.

For activity-centric process models, approaches exist to extract shared fragments in process model repositories [11,31], to discover configurable process fragments from activity-centric process models [5], or to discover variants from events log [17,19]. All these approaches consider graph-like process models, which differ considerably from declarative, rule-based process models like GSM schemas.

In software engineering, feature extraction has been studied for software artifacts, e.g., [20,23]. However, those features need to be manually identified, whereas in our method features are derived automatically. Studying how domain knowledge from experts can improve the quality of the generated features is an interesting direction for further work.

In sum, the main contribution of this paper is an approach to extract composable fragments from declarative, artifact-centric process variants.
7 Conclusion

This paper has defined a novel approach to extract model fragments, viewed as features, from declarative, artifact-centric process model variants. Using feature composition [12] the declarative fragments can be composed in a declarative way into the original variants, but also other variants can be composed. The approach can be used to decompose variants of case management templates into reusable fragments, that encode well-known modifications. This way, complex case management variants can be efficiently composed in a declarative way.

There are several directions for future work. An open challenge is to reconcile features, which are additive, with modifications of variants, which are non-additive, since they may be the result of deletions [13]. Next, we plan to realize a tool implementation of the approach geared towards CMMN [8]. In addition, we plan to apply this tool to several case study examples to further evaluate the approach.

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Appendix

This appendix describes features extracted from the variant GSM schemas presented in chapter 5 of Yi [32]. The GSM schemas of Yi have been converted into the notation used in this paper. Each GSM schema models three interacting artifacts. To suit the single artifact framework used in the main text, we have converted the multi-artifact schemas of Yi into single-artifact schemas. Another change is that Yi models a base process that contains a GSM fragment that in one variant is replaced with another GSM fragment. To be able apply the feature extraction method, we have modeled a new base process that contains neither of these fragments. The new base process is refined by the old base process and all the variants.

Base schema

The (new) base schema concerns the process of due diligence qualification of business partners for an international high-tech company that has international offices in different countries in Europe, Asia and America. The process starts when a due diligence qualification of a business partner has expired. To renew the qualification, first information needs to be collected about the partner such that the company has a sufficient level of information (milestone Confirmed). Next, based on the collected information, the due diligence qualification is checked. In some cases, mitigation actions need to be taken for the RequestForQuotes that the business partner can receive from the company. Finally, the due diligence qualification is signed off, resulting in either an approved or rejected status. An approved due diligence leads to an activated partner status, a rejected due diligence leads to an inactivated partner status.

Figure 6 shows the GSM schema DDP<sub>basc</sub> and Table 5 and 6 the sentries of the stages and milestones, respectively.
Fig. 6: Base GSM schema Due Diligence Process (DDP<sub>base</sub>)

Table 5: Stages and sentries for DDP<sub>base</sub>. ";" separates different sentries

| Stage                | Plus sentries (guards)                      | Minus sentries (closing)                  |
|----------------------|---------------------------------------------|-------------------------------------------|
| Drafting             | E:RegularDDQRenewal                        | +Drafted                                  |
| CompanyConfirming    | +Drafted                                    | +Confirmed; +Drafting                     |
| Refinement           | CompanyConfirming                           | +RefinementVersionAchieved                |
| DeskSearchScreening  | +MitigationActionNeeded; +Validated         | -CompanyConfirming; +Confirmed; +Drafting |
| ProcessMitigation    | +RespondMitigationAction; +MitigationAction| +Responded; -DeskSearchScreening          |
| Action               | +ProcessMitigationAction                   | +MitigationActionResponded; -ProcessMitigationAction |
| FillinRFQ            | MitigationActionNeeded ∧ ProcessMitigationAction | +RFQassessed; +RespondMitigationAction; -ProcessMitigationAction |
| SigningOff           | Responded; +Validated                      | +Approved; +Rejected; +ProcessMitigation  |
| Authorizing          | +Approved; +Rejected                       | +Activated; -Inactivated                  |
Table 6: Milestones and sentries for $\text{DDP}_{baxc}$. "\" separates different sentries

| Milestone | Plus sentries (achieving) | Minus sentries (invalidating) |
|-----------|---------------------------|-------------------------------|
| Drafted   | C:Drafting                | +Drafting                     |
| RefinementVersion-Achieved | C:PhilipsRefinement ∧ CompanyConfirming | +Refinement                  |
| Confirmed | +RefinementVersionAchieved | +CompanyConfirming            |
| MitigationAction-Needed | mitigation _ needed | +Validated; +DeskSearch-Screening |
| Validated | ¬ mitigation _ needed | +MitigationActionNeeded; +DeskSearchScreening |
| MitigationAction-Responded | C:RespondMitigationAction ∧ +FillinRFQ | |
| RFQassessed | C:FillinRFQ ∧ ProcessMitigationAction | +FillinRFQ |
| Responded | +RFQassessed               | +ProcessMitigationAction |
| Approved  | signed _ off               | +Rejected; +Signing off       |
| Rejected  | ¬ signed _ off             | +Approved; +Signing off       |
| Activated | partner_ status _ activated | +Inactivated; +Authorizing   |
| Inactivated | ¬ partner_ status _ activated | +Activated; +Authorizing     |
Variant 1

Variant $\text{DDP}_1$ specifies that a first verification check is performed before stage $\text{Refinement}$; see Table 7 for the new stages and milestones, plus the stages and milestones from the base schema whose sentries have been modified in this variant.

Table 7: New and modified sentries for variant $\text{DDP}_1$. $S=$Stage; $M=$Milestone

| Type | Name         | Plus sentries                             | Minus sentries                      |
|------|--------------|-------------------------------------------|-------------------------------------|
| S    | FirstVerification | +CompanyConfirming                        | +Verified; -CompanyConfirming       |
| M    | Verified     | $\text{C.FirstVerification} \land \text{CompanyConfirming}$ | +FirstVerification                   |
| S    | Refinement   | CompanyConfirming $\land$ Verified        | +RefinementVersionAchieved          |
|      |              |                                           | -CompanyConfirming ; +FirstVerification |

Feature $\text{F}^{\text{DDP}}_1 = \text{DDP}_1 \setminus \text{DDP}_{\text{base}}$ ; see Table 8

Table 8: Sentries for feature $\text{F}^{\text{DDP}}_1$. $S=$Stage; $M=$Milestone

| Type | Name         | Plus sentries                             | Minus sentries                      |
|------|--------------|-------------------------------------------|-------------------------------------|
| S    | CompanyConfirming | orig                                      | orig                                 |
| S    | FirstVerification | +CompanyConfirming                        | +Verified; -CompanyConfirming       |
| M    | Verified     | $\text{C.FirstVerification} \land \text{CompanyConfirming}$ | +FirstVerification                   |
| S    | Refinement   | Verified $\land$ orig                     | orig; +FirstVerification             |
Variant 2

Variant DDP₂ specifies that a PreCheck and ExpertReview are performed before stage Refinement; see Table 9 for the new stages and milestones, plus the stages and milestones from the base schema whose sentries have been modified in this variant.

| Type | Name | Plus sentries | Minus sentries |
|------|------|---------------|----------------|
| S    | PreCheck | +CompanyConfirming | +Checked; -CompanyConfirming |
| S    | ExpertReview | Checked ∧ CompanyConfirming | +Reviewed; -CompanyConfirming |
| M    | Checked | C:PreCheck ∧ CompanyConfirming | -PreCheck |
| M    | Reviewed | C:ExpertReview ∧ CompanyConfirming | +ExpertReview |
| S    | Refinement | CompanyConfirming ∧ Reviewed ∧ +RefinementVersionAchieved | -CompanyConfirming; +PreCheck |

Feature $F_{DDP}^2 = DDP₂ \backslash DDP_{base}$; see Table 10.

| Type | Name | Plus sentries | Minus sentries |
|------|------|---------------|----------------|
| S    | CompanyConfirming | orig | orig |
| S    | PreCheck | +CompanyConfirming | +Checked; -CompanyConfirming |
| S    | ExpertReview | Checked ∧ CompanyConfirming | +Reviewed; -CompanyConfirming |
| M    | Checked | C:PreCheck ∧ CompanyConfirming | -PreCheck |
| M    | Reviewed | C:ExpertReview ∧ CompanyConfirming | +ExpertReview |
| S    | Refinement | Reviewed ∧ orig | orig; +PreCheck |
Variant 3

Variant DDP$_3$ specifies that for a new partner the completion of the profile triggers the due diligence qualification process; see Table 11 for the new stages and milestones, plus the stages and milestones from the base schema whose sentries have been modified in this variant.

Table 11: New and modified sentries for variant DDP$_3$. S=Stage; M=Milestone

| Type | Name                  | Plus sentries          | Minus sentries  |
|------|-----------------------|------------------------|-----------------|
| S    | InitiatePartner       | E:NewPartnerRequest    | +ProfileCreated |
| M    | ProfileCreated        | C:InitiatePartner      | +InitiatePartner|
| S    | Drafting              | E:RegularDDQRenewal; ProfileCreated | +Drafted |

Feature $F^{DDP}_3 = DDP_3 \setminus DDP_{base}$; see Table 12.

Table 12: Sentries for partial feature $F^{DDP}_3$. S=Stage; M=Milestone

| Type | Name                  | Plus sentries          | Minus sentries  |
|------|-----------------------|------------------------|-----------------|
| S    | InitiatePartner       | E:NewPartnerRequest    | +ProfileCreated |
| M    | ProfileCreated        | C:InitiatePartner      | +InitiatePartner|
| S    | Drafting              | orig; ProfileCreated   | orig            |
Variant 4

Variant DDP₄ specifies that the due diligence process can be completed in a fast way; see Table 13 for the new stages and milestones, plus the stages and milestones from the base schema whose sentries have been modified in this variant.

Table 13: New and modified sentries for variant DDP₄. S=Stage; M=Milestone

| Type | Name                     | Plus sentries | Minus sentries                  |
|------|--------------------------|---------------|----------------------------------|
| S    | ConfirmNoScreening       |               | +NoScreeningConfirmed            |
| M    | NoScreeningConfirmed     |               | ¬no_screen_authorization;        |
|      |                          |               | +ConfirmNoScreening              |
| S    | SigningOff               | Responded;    | -Approved; +Rejected;            |
|      |                          | +Validated;   | +ProcessMitigation               |
|      |                          | NoScreeningConfirmed |                          |

Feature F₄DDP specifies that the due diligence process can be completed in a fast way; see Table 14.

Table 14: Sentries for partial feature F₄DDP. S=Stage; M=Milestone

| Type | Name                     | Plus sentries | Minus sentries                  |
|------|--------------------------|---------------|----------------------------------|
| S    | ConfirmNoScreening       |               | +NoScreeningConfirmed            |
| M    | NoScreeningConfirmed     |               | ¬no_screen_authorization;        |
|      |                          |               | +ConfirmNoScreening              |
| S    | SigningOff               | orig;         | NoScreeningConfirmed             |
|      |                          |               | orig                             |