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VE4OCPM: An Object-Centric Process Mining Variant Explorer Visualisation Approach

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Abstract

This work presents the Variant Explorer, a dual-mode visualisation for Object-Centric Process Mining that reveals control-flow variability and object interactions across process variants, combining object details and subway-map views for intuitive analysis of complex processes. Understanding process variants is essential to detect deviations, exceptions, and improvement opportunities. However, traditional process mining tools assume one case per process instance, which do not work well when events involve multiple objects, such as orders, products, and packages.

Existing Object-Centric approaches, like OCπ and Object-Centric Process Analysis (OCPA), introduced models and libraries to support multi-object analysis, but many face technical and usability limitations. To address this gap, this proposal provides two complementary visualisations that show object participation and variant differences side-by-side. Evaluation with real logistics data and user interpretation tests shows that users are able to identify repetitions, skipped activities, deviations, and object interactions clearly. This work offers a practical and interpretable solution for variant analysis in Object-Centric Process Mining (OCPM) and supports better understanding for analysts and business stakeholders.

Keywords: Object-Centric Process Mining; Event Data Models; Object-Centric Variant Discovery; Process Visualization; Graph-Based Analysis; Anomaly Detection.

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1. Introduction

Understanding process variants is central in process mining [1]. In traditional process mining, a variant is a unique sequence of activities for a given case [2]. In contrast, in Object-Centric Process Mining, events can involve multiple objects. For example, an order, its items, and a package may all appear in the same event. This means that the single well-defined case identifier does not exist, making it difficult to define and analyse distinct execution variants [3, 4]. Understanding these variants is crucial because it helps stakeholders see how processes deviate in practice, revealing exceptional paths, compliance issues, and opportunities for optimization [1, 2].

Traditional tools work well for case-centric scenarios, but Object-Centric models, involving multiple related objects like orders, products, and packages, generate new challenges [1, 3, 5]. Single-case abstractions are insufficient, requiring tools that reveal sequences of activities and how objects interact, which are currently lacking [5, 6, 7].

Earlier solutions, like OCπ, in [7], built on OCPA, used graph-based techniques for Object-Centric variant analysis. However, OCPA is no longer maintained [8] and depends on outdated Process Mining for Python (PM4Py) versions, limiting integration of new features like advanced DFGs [3]. These gaps motivated the creation of a custom way to explore the *Variants Explorer*.

The Variant Explorer aims to provide effective support for process variant analysis in a Object-Centric Process Mining context. By identifying differences in activity sequences and object participation, the Variant Explorer provides a deeper and more realistic view of complex processes than conventional case-based approaches.

This research also considers the importance of visualisation for understanding process variation. Studies in visual analytics and business process visualisation show that effective visual design can improve decision-making [9]. For this reason, two visualisation models are proposed. The first is a detailed and descriptive representation that shows how objects are involved across different variants. The second model, inspired by the "subway map" metaphor, offers a compact and visually simplified view that makes it easier to recognize patterns and compare process structures through colour and spatial organization. Together, these visual approaches aim to balance detail and clarity, giving users a flexible and intuitive way to explore process variants.

In summary, this work contributes to the field of Object-Centric Process Mining in two main ways. First, it provides a technically viable and visually expressive method for exploring process variants enriched with object context, overcoming the limitations of current tools. Second, it introduces a dual visualisation paradigm that combines transparency and simplicity, supporting accessibility and better decision-making. Ultimately, the Variant Explorer addresses a concrete gap in the field and establishes a foundation for more comprehensive and interpretable variant analysis. It demonstrates how integrating object-aware perspectives can significantly enhance both the expressiveness and the usability of process mining techniques. The remainder of this paper is organized as follows: Section 2 presents related work, Section 3 describes the proposed methodology, while Section 4 outlines the design specifications and presents the implementation and demonstration of the artifacts. Section 5 evaluates the proposed artifact through practical case analysis and user interpretation tests. Finally, Section 6 discusses the conclusions and highlights directions for future research.

2. Related Work

The OCπ and OCPA library [7, 10], enable analysis of variants using graph-based and Petri net representations, introducing mechanisms to discover and visualize relationships among multiple interrelated objects. However, their limited scalability and maintenance issues restrict current applicability. Other studies also expand this concept. Adams et al. formalized process executions as directed graphs and introduced object-centred variants through graph isomorphism, while tools like OCπ support the discovery and filtering of frequent variants in object logs, generating multi-entity Petri nets [7, 5]. The OCPA Python library implements algorithms to discover and visualize complex Object-Centric variants [11], and Ghahfarokhi et al. proposed Process Cubes for comparing variants across dimensions [10]. Berti and van der Aalst presented integrated frameworks for variant discovery and visualisation based on Object-Centric Petri nets [12]. These contributions together create a foundation for understanding and visualizing Object-Centric process variants as Directed Acyclic Graphs (DAGs) of activities. Our proposed visualisation builds on this foundation, offering an interactive graphical representation aligned with the Object-Centric variant structure. Unlike traditional sequential visualisations, our method shows object interactions and variant structures together, supporting

multi-perspective exploration and clearer interpretation of OCED behaviour. Some works tried to define and show Object-Centred process variants [7, 6, 11, 10, 12, 3, 1, 9]. Even though these studies made theoretical frameworks, libraries, and ideas for visualisation, most tools have problems with scaling, keeping them up to date, or showing visuals clearly [10, 12]. Different from them, the Variant Explorer goes further by bringing multi-object information and comparative visualisation together in one system.

Table 1. Application of the Design Science Research Methodology (DSRM) (Peffers et al., 2007) to the project [13, 14].

DSRM Step	Execution in this Project
Problem Identification and Motivation	The identified problem was a tools gap and unsupported updates, observed in process mining tools and OCPA deprecation, which affects Object-Centric Process Mining variants explorer artifacts.
Definition of Objectives for a Solution	The main objectives were defined as design and build a new solution to look at process sequence variants with objects information at the same time. These aim to ensure that the proposed solution effectively scalable and usual for process variant analysis.
Design and Development	The developed artifacts were built using a 2 layers architecture, designed and implemented using PM4Py for business and process logic.
Demonstration	The artifact was demonstrated through real data, applying it to logistic processes. This allowed verification of its practical applicability.
Evaluation	The artifact was tested with real datasets. Users answered questions about activity sequences, repetitions, and object participation. Results showed users correctly identified deviations, skipped activities, and object interactions.
Communication	Findings were shared through publications, conference presentations, and project reports. Internal workshops with stakeholders were also held to explain the results.

3. Methodology

This research follows the Design Science Research Methodology (DSRM) to develop and evaluate the Variant Explorer component of the Object-Centric Process Mining platform. The methodology is structured into six phases, each of which is detailed below with a focus on the Variant Explorer artifact in Table 1 [14].

4. Variants Explorer

The Variant Explorer provides visual modes to analyse process variants in Object-Centric Process Mining. The visual specification defines the architecture, interaction logic, and graphical elements that allow users to explore both detailed object participation and high-level behavioural patterns across variants.

4.1. Artifacts design

The proposed Subway Map visualisation gives a high-level comparative view of process flows and deviations between variants. Each variant is shown as a column, with activities connected by coloured lines from left to right. Each activity has its own colour, and objects (Orders, Products, Packages) are displayed as coloured nodes: brown for Orders, green for Products, and pink for Packages. This visualisation shows convergences, divergences, and repetitions of activities, allowing users to quickly detect anomalies, repeated steps, or missing activities. The layout is dynamic, avoiding overlaps and keeping the view clear, useful for comparative analysis and for understanding global patterns. This visualisation can allow another one visualisation due to type objects omission passing to have just a single object visualisation, applied to traditional process mining.

In the Object Focused approach, each variant is represented similarly to Subway Map approach, with objects associated with each activity displayed beside them. The same colour scheme is maintained for consistency and easier interpretation. This model focuses on transparency and traceability, useful for precise verification such as auditing or compliance checking, where it is important to see clearly which objects participate in each activity.

Users can switch between detailed and abstract views depending on the analysis needed. Both visualisation serve different purposes as emphasizes clarity, consistency, scalability, and analysis. Specifically, the Subway Map, show

deviations between variants more activity order oriented. The Object-Focused visualisation highlights variations in object participation across variants. By representing the presence of each object within activities, this view enables users to quickly identify differences in object involvement between variants. By another side, over Subway Map Visualisation it is simpler to observe the activities behaviour over the selected variants.

Table 2 summarizes the visual elements used in the prototype shown in Figure 1 b) and their respective meanings. In this example, variants are identified as V1 to V5 as a column that allows multiple activities, object types and repetitions; and V5 has been expanded in order to show its object-centric detail, indicating the involvement of each

Table 2. Visual elements and their meanings in process variant representation.

Visual Element	Representation	Colour / Style	Meaning
Variant	Vertical column (List View)	—	Represents a process group composed of exactly equal process instances
Activity	Node or label along the variant flow	Unique colour per activity	Represents a specific process step
Object type	Circular marker attached to an activity	Brown (Order), Green (Product), Pink (Package)	Object participating in the activity over a variant
Repetition	Bifurcation of a line with same colour	Curved or branched line	Indicates repeated execution of an activity in the same variant
Missing Activity	Continuous line skipping a node	—	Activity was skipped in that variant
Object-Activity Association	Side-by-side in list view	Consistent colour mapping	Indicates relationship between object and activity

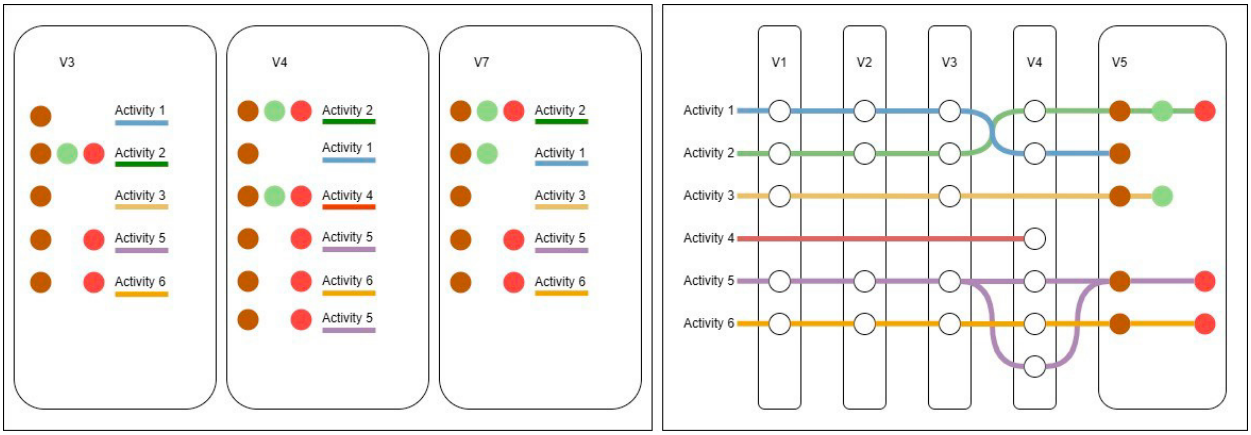

Fig. 1. a) Object focused visualisation b) Subway map visualization.

one of 3 different objects. In particular, Activity 2 can be seen as involving all objects while Activity 1 only involves one (brown or ”orders”). Horizontal lines that represent an activity connect the same activity on different variants, to express conformance or not over the selected variants. For example, between V3 and V4 happens an order change, related to Activity 1 and 2. This visualisation mode helps to show the difference in the variants. Another case where the subway metaphor is usual is between V3 and V4 because it is possible to look at the same activity execution over the same variant. It is visible in V3 and V4 in Activity 5. Here is possible to look at one execution in V3 and two executions of this activity in V4. Another interesting case study for processes analyst is the case that happens in V1, V2 and V3 in the activity 4 execution. Here is shown non-executed activities in variants. So, it is possible to conclude that exists four types/groups of processes that does not executes Activity 5. The Object Focused visualisation in Figure 1 a) used too some features in Table 2, exactly with the same way. For example, variants representation, objects type participation and activities. In the object focused visualisation the remainder elements have some changes. This approach is not so clean for end users. Lines that represent activities over different variants does not exists. In this visualisation, variation is identified by underlined activities colour. In the Figure 1 a) is possible to analyse exactly the same case shown in Figure 1 b) where Activities 3 and 4 changes the execution order. Particularly the meaning is the same, but this visualisation facilitates to identify simpler the object’s interaction with activities. Now is possible to

identify that multiple objects are involved firstly than in another variants. In this visualisation, repetitions are identified too, but are more difficult to identify. This object focused visualisation has an advantage that the Subway Map visualisation does not have. Due to not being needed to get spaces to pass the lines, the object's design pattern is compressed, which helps to look faster on object perspective variation. For example, in Variants 3 and 7, it is easy to identify similarity. But due to objects composition in activities 1 and 2, it is simple to identify the order change over objects participation.

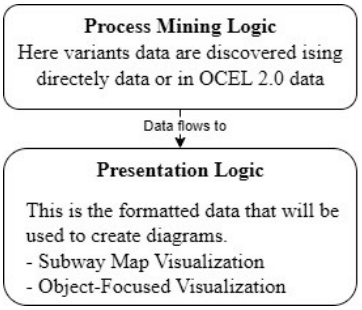

Fig. 2. Variants explorer architecture.

```
{ "variants":[
   {"cases":["1"],"count":1,"packages":[124370056],
    "products":["MOD00/17665200461123"],
    "trace":["Payment by Customer","Order Creation","Available for Warehouse",
                "Processing by Warehouse","Order Pickup by Carrier",
                "Temperature Variation Alert (+)","Temperature Variation Alert (-)",
                "Temperature Variation Alert (+)","Final Delivery Delayed - Carrier" ]}
]}
```

Listing 1: Variants data structure with object information.

4.2. Artifacts implementation

The practical samples followed a specific architecture. It was defined as a two-layers architecture (Figure 2). These two layers are responsible for Process Mining variants discovering and presentation logic respectively. With this architecture it's possible to scale in the future. Whether it is needed to use another Process Mining machine, it can be replaced without affect presentation logic. This architecture is valid for both approaches because it can ensure scalability.

In both visualisation modes the Process Mining Logic layer is the same. Here was used PM4Py library to get conventional Process Mining variants information. This library has a filter that returns the sequence variants in some passed log. With this information is possible to add objects information and object participation on activities over a process. Like this, is achieved a structure that presents process sequence variants with his related objects and related activities.

In the List 1 is represented one variant related to order ''1", one package and one product. This variant cluster is executed by one process instance locked at count attribute and his path is composed by activities, presents in trace attribute. This outcome is the basis to the presentation logic.

4.2.1. Object focused visualisation (presentation logic)

To build the object-focused approach, the input comes from the result of Process Mining logic. From this point, the interpretation of data produced by Process Mining begins. For visualisation, every activity in the sequence is evaluated

according to these object lists, and classification rules are applied to identify events related to product, package, or, if not belonging to these categories, events at order level. This process and business rules define the case study and add a semantic layer to the process sequence. Now, every activity carries explicit information about which object types participate in it, transforming the abstract control-flow sequence into an object-aware event sequence, making the process multidimensional. After semantic enrichment of activities, the system constructs a sequential visual layout for each selected variant.

The visualisation maps each activity to a node, along a sequential axis. The node layout encodes both the position of the activity in the process and the type of object interaction. If an activity is associated only with an order, it is shown with a single circle; if it involves both order and product, it uses a double circle; and if it involves order, product, and package, a triple circle is used. Each one with his colour. This graphic encoding helps to immediately recognize the level of object involvement across process variants.

Semantic colour mapping also helps interpretation. Each activity label has a colour corresponding to its operational meaning, giving visual cues to distinguish categories of operations, like logistics, validation, delivery, or exception handling. Contextual continuity is preserved by arranging the visual nodes in a continuous line to keep relational events derivation. Using identical symbols and consistent spacing allows multiple variants to be visually compared side by side without losing comparative coherence.

After building the graphical structure of each variant, the system renders an interactive visualisation panel called the Variant Explorer.

4.2.2. Subway map visualisation (presentation logic)

The Subway Map approach follows a similar method to the Object-focused approach, mainly in obtaining and handling variant data. Configurations such as Visual Node Generation, Object-level Encoding, and Contextual Continuity are applied in the same way. However, Semantic Colour Mapping is different because it requires drawing lines and building a new data structure to create the Subway Map visualisation. This visualisation component is composed of reusable and modular elements, primarily the ‘’Station” and ‘’Connection” entities. Each cell in the grid represents the execution or absence of an activity within a specific process variant and can be rendered either as a station, representing the activity, or as a connection, representing the transition. This modular design enables a compact and visually intuitive representation of activity execution, repetition, omission, and reordering within process variants.

The ‘’Station” component represents activities or states along alternative paths in a process variant. It is highly configurable and supports multiple visualisation modes, including central circles that indicate objects and activity execution, horizontal lines that show variation or stability across variants, coloured backgrounds, and vertical borders and curves that depict deviations or bifurcations in process paths. Each cell configuration allows visual differentiation when an activity is executed by all objects, only a subset of objects, or is completely omitted in a given variant. This flexibility allows the user to identify behavioural differences at the object level directly through visual cues.

Complementing the ‘’Station” component, the ‘’Connection” component draws links between activities. It supports horizontal, vertical, and diagonal connections, including crossings and deviations shown through smooth curves. Each connection can be individually coloured to reflect different activity types in motion across variants. This visual mechanism is essential to observe the simultaneous and interdependent flow of multiple process variants, revealing both structural similarities and divergences.

The Variant Grid component acts as a container integrating multiple instances of ‘’Station” and ‘’Connection” components. It enables the construction of an interactive matrix that maps activities as rows and process variants as columns. Internally, the component processes a matrix of activity execution per variant and per object, using structured information about object types, associated activities, and their traversal paths. This design allows visualisation of selective execution of activities by object type, cycles, skips, or parallelisms among variants, and overlapping or missing activities depending on the represented object. Colour-coded trajectories show multi-entity involvement within a single process instance. Furthermore, this artifact supports dynamic updates, reacting to incoming structured data and integrating seamlessly with Process Mining outputs and OCEL logs. Its data-driven parametrization makes the system adaptable to new scenarios, datasets, or business contexts.

4.3. Demonstration

This section demonstrates the practical application of the Subway Map visualisation in real-world cases. Here, the visualisation is applied to logistics scenarios. As shown in Figure 3 a), the visualisation effectively highlights deviations in activity sequences across process variants and enables a straightforward way to identify activity repetitions. For instance, repetitions of Activity 3 are clearly distinguishable: variants V1, V2, and V3 include a single occurrence, while V4 and V5 contain two and three repetitions, respectively. These patterns are made evident through bifurcations, visually encoded as multiple markers or branches of the same colour along the sequence path, each representing a repeated execution. In such cases, the absence of a marker indicates that the corresponding activity was skipped in that variant. One real-world example involves a deviation in the expected ordering of activities: a payment is recorded after the order creation, reversing the normal execution flow. This anomaly is immediately visible in the visualisation

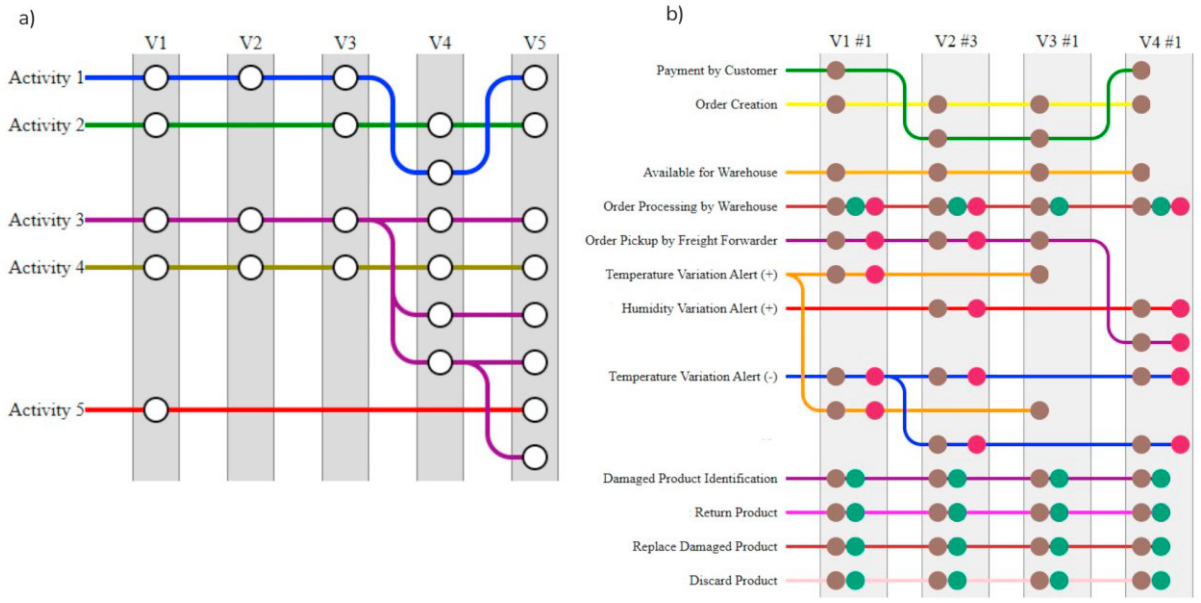

Fig. 3. a) Sample implementation b) Real data sample implementation

by comparing the second variant to the others, as illustrated in Figure 3 b). The visualisation also reveals repeated executions of specific events such as temperature alerts. These appear as distinct branches of the same colour and make it easy to count how many times the alert was triggered in a given variant. In this dataset, the method proved effective in visually distinguishing between well-behaved and anomalous variants, providing immediate insight into process performance. Additionally, the visualisation clearly indicates omitted activities. For example, in variant V1 (identifier 10), a temperature alert in the delivery stage is not triggered. This is represented by the line skipping over the corresponding circle, signalling that the activity was not performed in that execution path. The consistent object-colour mapping enables users to track object interactions across variants and better understand their role in execution variability. In summary, these case studies illustrate the capability of the Subway Map visualisation to highlight process structure, detect activity anomalies, and provide a clear representation of object behaviour in complex Object-Centric process scenarios.

5. Evaluation

Following Design Science Research Methodology (DSRM), the Subway Map Variant Explorer was evaluated for its usefulness, quality, and how well it works. Because this research is exploratory and the tool is interactive, two aspects are covered in the evaluation: practical tests with real cases and checking if users can understand it.

In the practical test, real business cases from logistics and order management are analysed with the visualisations to see known process variants. The Subway visualisation shows patterns like repeated activities, skipped steps, and different execution paths. The position and crossing of coloured lines and object markers help to see problems, for example, payments after order creation. Repeated activities, like temperature alerts or packaging, are clear in branching structures, so analysts can compare similarities and differences between variants. The results (Table 3) show the visual model gives clear and easy understanding of object-centred process behaviour.

In the user interpretation test, business stakeholders from the logistics domain were asked to interpret the simplified Subway Map View and answer predefined questions about activity order, variant divergence, and object participation. The goal was to evaluate whether non expert users could correctly understand the visualisation and draw meaningful conclusions, further supporting the artifact's interpretability and practical relevance.

Table 3. Usability test questions and corresponding answers, based on Figure 1b).

Question	User Answered
Q1: "What does Activity 3 in Variant 2 represent?"	A1: "This activity does not occur in Variant 2."
Q2: "What does a bifurcation in a line represent?"	A2: "It indicates the repetition of an activity, likely representing an AND logic."
Q3: "What does the crossing of lines between variants indicate?"	A3: "A change in the sequence of activity occurrences."

The responses indicated a strong level of understanding, given the explained context level. Users correctly interpreted bifurcations as activity repetitions and identified missing activities or differences in execution order. These insights support the artifact's usability and alignment with user expectations. Evaluation Summary while a comprehensive usability study with formal metrics (e.g., time-on-task, accuracy) is planned as future work, the current evaluation phase demonstrates that the Variant Explorer is both functional and useful in its current form. The visual metaphors employed effectively support analysis of object-enriched process variants, and the dual visualisation modes address distinct analytical needs. The combination of demonstration and interpretability testing provides a preliminary but methodologically grounded validation of the artifact, in line with DSR standards.

6. Conclusion and Future Work

This work presents the Variant Explorer (VE4OCPM), developed following the Design Science Research Methodology (DSRM) to address challenges in Object-Centric Process Mining. The identified problem is that existing tools can not show clearly how many objects participate together in process variants and it is difficult for users to understand differences between executions. The motivation was to provide analysts and stakeholders with a better understanding of deviations in process behaviour, repetitions, omissions, and interaction of objects [3, 5].

According to this problem, the objectives were specified to build artifacts capable of showing sequence of activities for multiple variants and also showing participation of different object types. The design includes two complementary visualisations, the Object-focused shows which exact objects are involved with each activity, it is useful for auditing compliance and for detailed inspection and the Subway map inspired visualisation showing multiple variants side by side highlighting deviations and repetitions activities useful for comparison and pattern recognition.

In practice, these artifacts were implemented with two layers. The process mining logic layer discovers variants using PM4Py and adds object participation information and the presentation layer builds visualisations. The

Objectfocused mode presents activities as nodes with colour and size indicating object type and number. The Subway map mode presents activities as stations and connections with colours showing type and repetition, that allow clear visualisation of object interactions activity order deviations repetitions and missing steps.

The results show both visualisations provide strong support for users. The Object-focused visualisation advantage is precise detail and traceability showing exactly which objects participate in each step and the Subway map visualisation advantage its intuitive overview and comparison of many variants enabling fast detection of differences, similarities and patterns. Practical tests with logistics and order management cases show users can identify activity order deviations repeated or skipped activities and understand object interaction, that confirms the artifacts usefulness and contribution to real world analysis.

For future work the plan is to improve the drawing algorithm to make layouts more readable and scalable, define more expressive Object-Centric cases allowing clusters of related objects, use graph-based methods for variant detection and perform larger user evaluation with metrics like time accuracy and ease of understanding to validate usability further.

In summary by following DSRM the Variant Explorer identify and motivate the problem specify clear objectives design and develop a tool with two complementary visualisations demonstrate practical usefulness with real cases and evaluate interpretability and usefulness for users. This work show how Object-focused and Subway map visualisations together contribute to better understanding and analysis of Object-Centric process variants and provide foundation for future research, practical application and delivery.

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