On the Analysis of Structural Process Variety (Extended Abstract)

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Abstract

Structural process variety is a fundamental characteristic of processes and an important indicator of their complexity, flexibility, and dynamic drifts. It manifests across a wide range of domains, from highly standardized organizational workflows to human behavioral processes. Despite its relevance, existing approaches to measuring process variety lack a rigorous theoretical foundation for capturing structural variety in a meaningful and consistent manner. Drawing on established diversity measurement theories from economics and ecology, the thesis addresses this limitation by conceptualizing structural process variety as a function of pairwise distances between process traces. Building on the derived theory, a measurement framework is proposed that preserves desirable mathematical properties through hierarchical clustering and enables valid and interpretable quantification of structural process variety. To further improve the structural comparison between traces within an event log, the thesis introduces a novel measurement approach for trace similarity. By representing traces as graph structures and extracting common process patterns, the proposed approach captures structural characteristics that are often overlooked by conventional similarity measures, thereby enabling more accurate trace comparisons. The validity of the proposed concepts and measures is demonstrated through two empirical studies. The first study shows how structural process variety can support business process standardization by providing a quantitative basis for evaluating trade-offs between flexibility and efficiency. The second study extends the application of structural process variety and graph-based trace similarity to human behavior analysis, demonstrating their ability to uncover meaningful cognitive patterns in eye-tracking data. Overall, the thesis establishes structural process variety as an analytical construct and provides a foundation for future research on process analytics.

Keywords

Process Variety, Process Flexibility, Process Complexity, Business Process Management

1. Introduction

Structural process variety describes the structural similarities and differences between alternative execution paths within a process. While process variety has generally been considered an important indicator for a number of process analysis tasks, such as performance analysis [1, 2], complexity analysis [3], drift analysis [4], and process discovery [5, 3], there does not exist a common theoretical foundation for the measurement of process variety. Thus, making it difficult to interpret and to assess the validity of the applied measures. Furthermore, existing variety measures commonly measure variety based on distributions of structural properties within an event log rather than through explicit pairwise trace comparisons [1, 3, 5]. Thus, mixing up different perspectives of variety [6, 7], which additionally makes it difficult to interpret and to assess the validity of the applied measures.

To overcome these limitations, this thesis proposes a measurement framework for structural process variety grounded in theory on diversity measurement from ecology and economics [6, 7]. The measurement framework is based on the pairwise comparisons of process execution paths that define a process, commonly referred to as traces. The structure of a trace is characterized by the ordering and repetition of its activities. For example, the trace $\langle A, B, C \rangle$ represents a purely sequential execution, whereas the trace $\langle A, B, B, C \rangle$ contains a repeated occurrence of activity B, indicating the presence of a loop. Structural process variety thereby refers to the overall structural similarities and differences between traces contained in an event log, i.e., a multiset of traces. For example, the event log $L_1 = \{\langle A, B, C \rangle, \langle A, B, B, C \rangle\}$

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exhibits a higher structural process variety than the event log $L_2 = \{\langle A, B, C\rangle, \langle A, B, C\rangle\}$ due to the structural difference between the traces in L_1.

The measurement of the structural process variety thereby substantially relies on the measurement of the structural similarity and differences between traces, i.e., trace similarity measures [8, 9]. However, existing similarity measures from the literature again fail to capture structural differences and similarities between traces, especially with regard to common process patterns such as loops, skips, and choices [9]. To address this challenge, the thesis introduces a new trace similarity measurement approach, considering three different levels of abstraction within traces, i.e., activities, directly-follows relations, and process patterns.

Finally, structural process variety remains a comparatively underexplored concept within process analysis. In contrast to well-established constructs such as process similarity [8, 9] and process complexity [3], its theoretical foundations, measurement principles, and practical implications have received limited attention. Consequently, both methodological development and empirical validation are required to establish structural process variety as a robust and useful concept within business process management (BPM) and process mining. To this end, the thesis presents two empirical studies that examine structural process variety in the contexts of business process standardization [10] and user behavior analysis [11].

Overall, the thesis seeks to establish both the theoretical foundations and the empirical validity of structural process variety as a novel concept in process analysis.

2. Background

Variety can be understood similarly to diversity, namely as the composition of distinct entities within a set or system. Diversity has been studied extensively across disciplines such as ecology, economics, physics, and computer science [12]. Existing diversity measures are commonly characterized by three complementary dimensions: the number of variants (i.e., types of entities), their relative frequencies (i.e., the distribution of variants), and the disparity between them (i.e., the extent to which variants differ from one another) [6, 7, 12].

Although the terms diversity and variety are often used interchangeably, they are typically applied at different levels of analysis. In ecology and economics, diversity commonly describes the composition of a larger system, such as an ecosystem or a market [12]. In process analysis, by contrast, variety refers to the composition of trace variants that characterize a particular process type, such as an administrative process or a purchase-to-pay process [1, 5, 3]. Despite this difference in scope, both concepts capture the heterogeneity of entities within a set. Consequently, the axiomatic foundations developed for diversity measurement are also well suited for defining structural measures of process variety.

To account for the disparity between variants, a diversity measure needs to consider the similarities and differences between the variants, commonly achieved through the application of a distance measure [6, 7, 12]. Such a measure satisfies several desirable axiomatic properties. First, diversity increases monotonically with the number of distinct variants when all variants are equally distributed. Second, adding a duplicate of an already existing variant does not increase diversity, since no new characteristic is introduced into the system. Diversity only increases when a genuinely distinct variant is added. Third, the contribution of a variant to the overall diversity is determined by its relationship to the remaining variants. Accordingly, removing a variant reduces the diversity by exactly the distance represented by the link through which that variant contributes to the diversity of the set.

However, one important limitation of deriving diversity from distances is that such a measure only guarantees uniqueness when the underlying distance function is an ultrametric [6, 7]. Ultrametric distances impose a hierarchical structure on the set of variants and can be represented by a taxonomic tree. While such hierarchies naturally arise in some application domains, they cannot be assumed in general.

3. Research Approach and Contributions

The thesis makes the following four key contributions to research in BPM and process mining.

3.1. A Measurement Framework for Structural Process Variety

To address a gap in existing process analysis research, the thesis introduces structural process variety as a novel concept grounded in the theoretical foundations of diversity measurement [6, 7]. Building upon established diversity theory, the thesis presents a corresponding measurement framework that quantifies the structural heterogeneity of process behavior within an event log [10]. The proposed framework comprises three stages: (i) the computation of pairwise distances between all traces, (ii) the application of hierarchical clustering to derive an ultrametric distance structure, and (iii) the iterative aggregation of inter-cluster distances to calculate the overall structural variety of the event log. Under a deterministic clustering procedure, the framework guarantees the uniqueness of the resulting variety measure. Beyond quantifying overall variety, our approach provides a principled mechanism for ranking trace variants according to their marginal contribution to the event log's structural variety, a capability that is largely absent from existing measures.

Extensive empirical evaluations across event logs exhibiting diverse structural characteristics demonstrate that the proposed framework captures structural process variety more effectively than existing approaches. These findings highlight both the theoretical rigor and the practical value of the framework, establishing it as a robust foundation for advanced process analysis and variety assessment.

3.2. Graph-based Trace Similarity Measures

The second key contribution addresses a fundamental prerequisite for variety measurement: the comparison of individual traces [9]. The thesis identifies ten formal properties that should be satisfied by structural trace similarity measures. These properties provide a systematic basis for evaluating existing approaches and reveal substantial shortcomings in the current literature.

An important insight is that existing similarity measures often fail to adequately represent structural process patterns. As a consequence, activity-agnostic structural similarities and differences between traces may remain undetected. To address this shortcoming, the thesis proposes a graph-based method that systematically extracts high-level behavioral patterns from process traces. The method transforms traces into graph structures using adjacency-list representations and exploits graph-theoretic algorithms to identify recurring process patterns, indicating loops, skips, and choices. In addition, it determines the size of each detected pattern by measuring the number of activities in the corresponding subsequences. The resulting pattern-aware representation supports a more expressive structural comparison of traces and enables deeper insights into process behavior.

Extensive evaluations using synthetic and real-life event logs demonstrate that the proposed approach consistently outperforms established trace similarity measures in capturing structural similarities and differences between traces. Consequently, the introduced similarity measures not only improve trace comparison but also strengthen the validity of structural process variety measures built upon them.

3.3. Study on Structural Process Variety in Business Process Standardization

To demonstrate the practical relevance of the proposed concept, this thesis presents an empirical investigation of the role of structural process variety in business process standardization [10]. Organizations must continuously balance the competing objectives of flexibility and standardization [13, 10]: while standardization can improve efficiency and reduce operational complexity, excessive standardization may diminish a process's ability to adapt to changing requirements. In the thesis, it is argued that structural process variety provides a novel quantitative lens through which this trade-off can be systematically analyzed and managed.

Drawing on multiple real-world event logs, the study demonstrates that the proposed measurement framework not only quantifies overall process variety but also identifies and ranks trace variants according to their marginal contribution to that variety. This capability enables a detailed assessment of the behavioral patterns that drive process flexibility and allows organizations to evaluate the potential impact of eliminating, consolidating, or standardizing specific variants.

The empirical results further reveal a consistent relationship between reductions in structural process variety and increasing alignment costs associated with diminished flexibility. These findings highlight the explanatory power of the proposed measure and demonstrate its value as a decision-support mechanism for process redesign and standardization initiatives. By linking structural characteristics of process behavior to managerial trade-offs, the study establishes structural process variety as a theoretically grounded and practically applicable instrument for supporting evidence-based process improvement decisions.

3.4. Study on Structural Process Variety in User Behavior Analysis

The second empirical study broadens the scope of structural process variety beyond the domain of business process management and demonstrates its applicability to the analysis of human behavior. Specifically, the study introduces a novel integration of process-analytic techniques with multimodal eye-tracking data, treating visual scanpaths as process traces composed of sequences of fixation points generated during process model comprehension tasks. This perspective enables the systematic investigation of cognitive behavior through the structural analysis of observed viewing patterns.

Beyond providing new insights into process model comprehension, including the influence of task complexity and the effects of model modularization on human cognition [14, 11], the study demonstrates the analytical value of structural process variety and graph-based trace similarity measures in eye-tracking research. The results show that these measures capture meaningful differences in visual behavior and enable the identification of distinct cognitive strategies, particularly patterns associated with information search and information inference. By revealing structural differences in scanpath behavior, the proposed approach offers a richer characterization of cognitive processes than traditional sequence-based analysis.

Furthermore, a subsequent concept drift analysis demonstrates that the proposed graph-based similarity measures outperform conventional approaches in detecting transitions between behavioral patterns over time. This finding underscores the advantages of structurally informed representations for modeling and analyzing dynamic cognitive behavior. The study therefore establishes structural process variety as a versatile analytical concept that extends beyond process management and provides a foundation for novel applications in adaptive user support, and behavioral analytics.

4. Conclusion and Outlook

This thesis establishes structural process variety as a theoretically grounded and practically relevant concept for process analysis. By integrating insights from diversity theory and graph theory, it develops a comprehensive framework for measuring both structural process variety and structural trace similarity.

The contributions of the thesis can be summarized as follows: first, it establishes structural process variety as a new concept for quantifying the structural diversity of process behavior and proposes a corresponding theoretically grounded measurement framework. Second, it introduces novel graph-based trace similarity measures, enabling a more effective structural comparison between traces, than previous similarity measures. Third, through empirical studies in both business process management and eye-tracking-based user behavior analysis, it demonstrates the practical value and generalizability of the proposed concepts, highlighting their potential for process standardization and behavioral analytics.

Beyond the immediate application domains investigated in this thesis, the results point to several promising avenues for future research. In particular, the concept of structural process variety could support the design and evaluation of software customization strategies by providing quantitative insights into the trade-off between standardized functionality and user-specific adaptations. Such an approach could help organizations identify levels of customization that maximize user requirements while limiting unnecessary complexity and maintenance effort. A second promising direction concerns the governance of agentic AI systems. As autonomous agents increasingly participate in complex organizational workflows, managing the balance between autonomy, flexibility, and regulatory compliance becomes a critical challenge. Structural process variety may provide a means to systematically assess the diversity of agent behaviors, identify undesirable deviations from intended processes, and support the design of governance mechanisms that preserve innovation and adaptability while maintaining sufficient control. Furthermore, the proposed framework could contribute to the resilience analysis of information systems. By quantifying the variety of alternative process execution paths, structural process variety may offer new perspectives on an organization's ability to respond to disruptions, failures, or changing environmental conditions.

More broadly, structural process variety offers a promising foundation for studying and managing the fundamental tensions between flexibility and standardization, as well as between autonomy and control in increasingly dynamic socio-technical systems.

Declaration on Generative AI

During the preparation of this extended abstract, the author used Copilot for grammar and spell checking. After using this tool, the author reviewed and edited the content as needed and takes full responsibility for the publication's content.

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