Combining Object Type Level and Workflow Level Object-Centric Process Models

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Abstract

Modern business processes are increasingly complex, involving multiple interacting entities of different types. Object-centric process mining addresses this complexity by analyzing the interdependencies between multiple process objects instead of restricting the analysis to a single case identifier. However, early object-centric process models generalize their case-centric counterparts and focus mainly on the ordering of activities. They are unable to represent two types of object-centric specific process characteristics: (1) type-level relations that describe how objects of different types relate to each other (such as temporal relations and cardinality constraints), and (2) object-centric specific workflow characteristics such as concrete object cardinalities, optional object type involvement, object synchronization, and object distribution. This project investigates how these object type level and workflow level characteristics can be discovered from event data and used for conformance checking, and how both dimensions can be integrated into a unified view of an object-centric process. We have proposed the temporal object type model (TOTeM) for the type level and object-centric causal nets for the workflow level, including a dedicated conformance-checking algorithm. The remaining work focuses on conformance checking on the type level and on integrating both dimensions, supported by a unified tool.

Keywords

Object-centric Process Mining, Process Modeling, Conformance Checking, Object type relations

1. Research Problem and Motivation

Modern business processes are getting more and more complex, involving multiple entities and having various inter-dependencies. At the same time they are getting more digital and are supported by information systems. This allows analyzing the event data that is stored in the information system to investigate the process in a data driven way. This data driven way of analyzing processes is called process mining which can be used in the context of business process management to generate insights into the process and improve the process based on the insights [1].

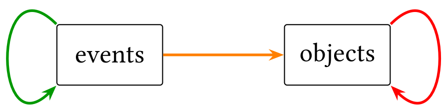

Figure 1: The relational dimensions of object-centric processes: event-event (green) is explored well, event-object (orange) partially, object-object (red) barely.

To address the increasing complexity of business processes, object-centric process mining gained traction in recent years. In object-centric processes one can analyze the interdependencies between multiple process entities. Each event can be connected to multiple objects of different object types. For example, in a hospital one can analyze how the processes for the nurses, doctors, patients, and machines are connected and co-dependent on each other. In traditional case-centric process mining, one had to restrict the analysis to one single case in isolation, so for example investigating the patient journey in isolation. It has been shown that by focusing on case-centric processes, valuable information is lost, which can lead to issues like convergence, divergence, and deficiency [2].

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Traditional process mining looks at events and mainly investigates how events relate to each other, represented in the ordering of activities in process models [1]. Object-centric process mining has events *and* objects [2]. This adds two new relational dimensions that can be investigated: the event-object dimension and the object-object dimension. As illustrated in Figure 1, the three relational dimensions of an object-centric process differ strongly in how well they are explored. The event-event dimension (how events follow each other) is explored well since a large body of research from the case centric world can be reused here. The event-object dimension is partially explored, but several object-centric specific characteristics are still missing. The object-object dimension is barely explored from a process mining perspective.

The **event-object dimension** is represented in early object-centric process models by allowing multiple object types per activity and by annotating whether a variable number of objects or exactly one object is involved in an event [3]. This shows that there exists initial work in that dimension, but it has more to offer than what is investigated so far and requires further research. Characteristics like object synchronization, concrete object cardinalities, and object distribution are object-centric specific characteristics that exist only if multiple objects are involved in a process. For example, synchronization can mean that the same doctor who did the preparation talk with the patient is also performing the operation on that patient. Concrete object cardinalities mean that one can specify the range of how many objects of a certain type are allowed in an activity, for example to model that between 2 and 5 doctors need to sign a patient release document. Object distribution describes how objects that participated together in an event are split up over the succeeding activities. These characteristics should be integrated into object-centric process models. We showed these limitations of object-centric Petri nets [3] and proposed object-centric causal nets [4] to address some of them in earlier work. In addition, conformance-checking approaches that use these models should be developed, so that deviations in the modeled characteristics can be detected. We recently proposed such an algorithm for object-centric causal nets [5].

The **object-object dimension** is nearly not analyzed at all from a process mining perspective. Object-centric behavioral constraints touched on it [6], and relational diagrams like entity-relationship models are related as well. But the relations that are relevant from a process characteristics perspective remain an open research question. Examples are the temporal relation between object types and the question on how many objects of a type are related to objects of a given type. A well-known process characteristic that must be modeled via such relations is the lean management pull principle [7]. It says that goods (objects of certain types, e.g. cars) must be produced only after there is demand (another object type, e.g. an order). In [8], we showed that this simple process characteristic cannot reliably be derived from the ordering of activities alone, and thereby object-centric Petri nets, for example, cannot reliably model this characteristic. Also, we showed that log-wide cardinality relations, i.e. the information on how many objects of another type an object of a certain type shares an event with, cannot be determined reliably from workflow-based models. A simple example for this is that although a patient and a doctor both may only ever share an event with one of the other type, the doctor interacts with multiple patients but the patient only with one doctor. Distinguishing these characteristics and modeling them precisely is essential for representing object-centric behavior and also for checking the conformance of real-world processes with regard to these characteristics.

These two underexplored dimensions motivate the research questions of the dissertation project. We want to investigate how the object-centric specific characteristics of both dimensions can be modeled so that they can be discovered from event data and used in conformance checking, and how the two dimensions can be combined into one integrated view of an object-centric process. We refer to the object-object relation characteristics as the *object type level* dimension, since they aggregate behavior over the whole log and describe the process on the level of object types. Since the number of object types tends to be significantly lower than the number of activities, this dimension gives a more high level overview of the process. We refer to the event-event and event-object characteristics as the *workflow level* dimension, since they describe the fine-grained workflow behavior showing the details about the activities and the involvement of objects in these activities.

RQ-1: How can object type level relations be integrated into the object-centric process mining pipeline to represent type-level characteristics relevant in object-centric processes?

RQ-2: How can we integrate object-centric specific workflow level event-to-object characteristics (like synchronization, concrete cardinalities, and object distribution) into object-centric process models for discovery and conformance checking?

RQ-3: How can we combine object type level and workflow level models and represent the interplay of both dimensions in object-centric processes?

In the following, we present related work in Section 2. The research approach and methodology is presented in Section 3. Section 4 shows the current status and the roadmap.

2. Related Work

Business process management aims to improve business processes by analyzing and redesigning them [9]. Process mining is a set of techniques to analyze and improve processes based on event data [1], with the three main tasks of process discovery, conformance checking, and process enhancement. To better represent real-world processes that involve multiple objects of different types, object-centric process mining was introduced, which avoids representation problems of traditional process mining like convergence, divergence, and deficiency [2]. As a consequence, research interest grew over the recent years, resulting in both knowledge graph-based [10] and table-based [11] formats for object-centric event data [12], as well as studies on the limitations of object-centric data models [13] and their normalization [14]. The object-centric process management research manifesto [15] summarizes current challenges in the field, including the issues described in the introduction.

The increased complexity of object-centric workflows has been addressed by multiple object-centric process model notations, each coming with its own representational bias. The most commonly used model is the object-centric Petri net [3], which can be discovered from object-centric event logs. Other notations include object-centric process trees [16], object-centric declarative models [17], and Petri nets with identifiers [18]. These models describe the process behavior by modeling precedence constraints between activities. We proposed object-centric causal nets [4] which model additional object-centric specific workflow characteristics like object cardinalities, optional object types, and concrete object distributions. Some approaches recently started to integrate further object-centric characteristics: object-centric Petri nets with exact synchronization model whether objects are split or kept together [19], but a holistic representation of the workflow dimension remains an open challenge.

A second line of work integrates the relations between object types. Object-centric behavioral constraints combine data and declarative process modeling [6]. Multi-model approaches like PHILharmonicFlows [20] and the MERODE approach [21] combine state models for the lifecycle of object types with class diagrams that model the cardinality relations between types. However, these models distribute the information over multiple models, the temporal relations between types are only modeled indirectly via state-change dependencies, and they cannot be discovered from event data but must be modeled by a domain expert. As we showed in [8], no model focused on the process-relevant type-level relations alone, which is why we propose TOTeM. The ideas behind TOTeM are also related to temporal database concepts [22]. We discuss TOTeM in more detail in Section 4.

Conformance checking relates the modeled behavior to the real behavior stored in event logs [23]. The main approaches are token-based replay [24], alignments [25], and constraint based approaches [26, 17]. They have been adapted to object-centric processes, where conformance checking can detect deviations that case-centric approaches cannot detect [27, 28, 29]. However, existing object-centric conformance-checking approaches are based on object-centric Petri net variants and therefore focus on the workflow dimension, inheriting the representational bias of these models. As we showed in [4, 8], this means that object-centric specific characteristics on both the workflow and the type level cannot be checked. Recently we proposed a conformance checking approach for object-centric causal nets [5]. Conformance checking that takes the type-level relations into account is still missing, which is one of the open issues presented in the roadmap.

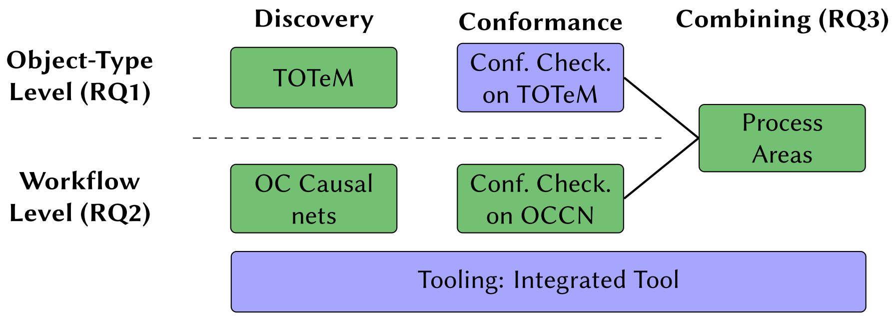

Figure 2: Overview of the contributions per research question. Green boxes are completed; blue boxes are open work that forms the roadmap.

3. Research Approach and Methodology

This project plan follows a methodology, in which we iteratively design new artifacts (process models, discovery algorithms, and conformance-checking algorithms) and evaluate them on object-centric event data. The research is structured along the three research questions and proceeds in the following steps.

Identifying capability gaps. We first investigate the literature of existing object-centric process models and analyze which object-centric specific process characteristics they can and cannot represent. This analysis led us to distinguish the object type level relations from the workflow level characteristics and motivates the design of two dedicated models.

Designing new process models. For each dimension, we design a new object-centric process model that closes the identified gap. The model is defined formally with a syntax and an execution semantics. For the type level (RQ1), we generalize ideas from class diagrams and temporal logic; for the workflow level (RQ2), we generalize traditional causal nets [30] to the object-centric setting. We deliberately design both models to be discoverable from event data.

Discovery and conformance checking. For each model, we develop a discovery algorithm that computes the model from an object-centric event log. We then develop conformance-checking algorithms that, given a model and a log, detect process executions that deviate from the modeled behavior. These algorithms have to detect deviations in the newly representable object-centric characteristics, which existing approaches systematically overlook.

Integration. Finally, we investigate how the type-level and the workflow dimension can be combined (RQ3). We study how information from one dimension can be used to structure, filter, or enrich the analysis of the other dimension, and how both can be presented in a single, coherent view of the process.

Implementation and evaluation. Every proposed artifact is implemented and made publicly available, so that the contributions are reproducible and applicable in practice. We evaluate each artifact both qualitatively and quantitatively, by applying it to publicly available real-world object-centric event logs and measuring properties such as runtime and the behavior captured compared to existing models.

4. Progress, Open Issues, and Roadmap

Figure 2 gives an overview of the progress and the remaining work, structured along the two dimensions (rows) and the process mining tasks discovery and conformance checking (columns). Green boxes are completed contributions, blue boxes are open work.

Progress. We started by identifying the model capability gaps presented in Section 2, distinguishing the object type level relations from the object-centric workflow level characteristics. For both dimensions, we have already proposed dedicated, discoverable process models.

For the type level (RQ1), we proposed the temporal object type model (TOTeM) [8]. TOTeM is a graph with object types as nodes and arcs between connected types. It describes three process-relevant type-level relations: the *temporal relation* between the lifespans of two types, the *log cardinality* that describes how many objects of one type are connected to how many objects of another type over the whole log, and the *event cardinality* that describes how many objects of a type are involved in shared events. We provided a definition, a discovery algorithm, and a publicly available implementation, and evaluated TOTeM on real-world logs.

For the workflow level (RQ2), we proposed object-centric causal nets [4]. They generalize traditional causal nets [30] to the object-centric setting and use input and output marker groups to model object-centric specific characteristics that object-centric Petri nets cannot represent: concrete object cardinalities, optional object type involvement, object synchronization, and the distribution of objects over succeeding activities. We defined their syntax and execution semantics, proposed a discovery algorithm, and provided a publicly available implementation. Building on this model, we recently proposed a dedicated conformance-checking algorithm [5] that detects deviations in exactly these characteristics that object-centric Petri net based approaches systematically overlook.

We also made first progress on the integration of both dimensions (RQ3). In our work on process-area extraction by multilevel resource detection [31], we use the temporal relations of TOTeM to detect a resource hierarchy among the object types and to structure the workflow analysis into process areas, so that higher-level processes are not cluttered by unrelated lower-level activities. This shows that information from the type level can be used to improve the analysis of the workflow level. In addition, we developed a streaming-based discovery framework [32] that supports the discovery of object-centric Petri nets and TOTeM from object-centric event streams, addressing the scalability challenges that arise from the larger data volume of object-centric event data.

Open Issues. Several issues remain open. First, conformance checking on the object type level relations is still missing; it is open how deviations from temporal relations and cardinality constraints can be detected, diagnosed, and quantified. Second, the integration of both dimensions is so far limited to using the object type level to structure the workflow analysis. A tighter integration, in which both dimensions enrich and constrain each other, and tool support that combines the individual approaches into one coherent analysis, are still missing. Third, a unified, overall evaluation of the combined approach on real-world object-centric event logs is still open. A threat is the availability of suitable real-world object-centric event logs that exhibit the modeled characteristics, which we partially mitigate by extracting logs from new domains such as game data [33].

Roadmap. For the remainder of the project, we plan the following steps. (1) We will develop a conformance-checking approach for the type-level relations to complete RQ1 and combine it with the workflow conformance checking. (2) We will investigate further integration approaches for the two dimensions (RQ3), studying how one dimension can filter or enrich the other and how both can be presented in one integrated view. (3) We will create a unified tool that supports both dimensions. (4) Finally, we will perform a unified overall evaluation of the combined approach on publicly available real-world object-centric event logs.

5. Conclusion

This research project addresses the limitation that early object-centric process models focus on the ordering of activities and simple object involvements and cannot represent the object type level relations and advanced workflow level characteristics of object-centric processes. We proposed the temporal object type model (TOTeM) for the type level and object-centric causal nets together with a dedicated conformance-checking algorithm for the workflow level, and made first steps toward integrating both dimensions. This work thereby contributes to the BPM goal of understanding and improving complex object-centric processes.

Declaration on Generative AI

During the preparation of this work, the author used Claude Opus 4.8 and Grammarly for grammar and spelling checking. After using these tools, the author reviewed and edited the content as needed and takes full responsibility for the publication's content.

References

[1] W. M. P. van der Aalst, Process Mining - Data Science in Action, Second Edition, Springer, 2016. doi:10.1007/978-3-662-49851-4.

[2] W. M. P. van der Aalst, Object-centric process mining: Dealing with divergence and convergence in event data, in: SEFM, Springer, 2019, pp. 3–25. doi:10.1007/978-3-030-30446-1_1.

[3] W. M. P. van der Aalst, A. Berti, Discovering object-centric Petri nets, Fundam. Informaticae 175 (2020) 1–40. doi:10.3233/FI-2020-1946.

[4] L. Liss, C. Mensing, W. M. P. van der Aalst, Object-centric causal nets, in: CAiSE, volume 15702 of *LNCS*, Springer, 2025, pp. 94–110. doi:10.1007/978-3-031-94571-7_6.

[5] L. Liss, W. M. P. van der Aalst, Object-centric conformance checking on object-centric causal nets, in: L. Fuentes, P. Plebani, C. Combi, H. A. Reijers (Eds.), Advanced Information Systems Engineering - 38th International Conference, CAiSE 2026, Verona, Italy, June 8-12, 2026, Proceedings, Part II, volume 16559 of *Lecture Notes in Computer Science*, Springer, 2026, pp. 331–347. URL: https://doi.org/10.1007/978-3-032-28117-3_19. doi:10.1007/978-3-032-28117-3_19.

[6] W. M. P. van der Aalst, A. Artale, M. Montali, S. Tritini, Object-centric behavioral constraints: Integrating data and declarative process modelling, in: International Workshop on Description Logics, volume 1879 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2017.

[7] W. J. Hopp, M. L. Spearman, To pull or not to pull: What is the question?, Manuf. Serv. Oper. Manag. 6 (2004) 133–148.

[8] L. Liss, J. N. Adams, W. M. P. van der Aalst, Totem: Temporal object type model for object-centric process mining, in: BPM Forum, volume 526 of *LNBIP*, Springer, 2024, pp. 107–123. doi:10.1007/978-3-031-70418-5_7.

[9] M. Dumas, M. L. Rosa, J. Mendling, H. A. Reijers, Fundamentals of Business Process Management, Second Edition, Springer, 2018. doi:10.1007/978-3-662-56509-4.

[10] A. Swevels, D. Fahland, M. Montali, Implementing object-centric event data models in event knowledge graphs, in: ICPM Workshops, Springer, 2023, pp. 431–443. doi:10.1007/978-3-031-56107-8_33.

[11] A. Berti, et. al, OCEL (object-centric event log) 2.0 specification, CoRR abs/2403.01975 (2024). doi:10.48550/ARXIV.2403.01975. arXiv:2403.01975.

[12] D. Fahland, M. Montali, J. Lebherz, W. M. P. van der Aalst, M. van Asseldonk, P. Blank, L. Bosmans, M. Brenscheidt, C. D. Ciccio, A. Delgado, D. Calegari, J. Peeperkorn, E. Verbeek, L. Vugs, M. T. Wynn, Towards a simple and extensible standard for object-centric event data (OCED) - core model, design space, and lessons learned, CoRR abs/2410.14495 (2024). doi:10.48550/ARXIV.2410.14495. arXiv:2410.14495.

[13] H. Hooshyar, M. Fumagalli, M. Montali, G. Guizzardi, Time and relations into focus: Ontological foundations of object-centric event data, in: L. Fuentes, P. Plebani, C. Combi, H. A. Reijers (Eds.), Advanced Information Systems Engineering - 38th International Conference, CAiSE 2026, Verona, Italy, June 8-12, 2026, Proceedings, Part II, volume 16559 of *Lecture Notes in Computer Science*, Springer, 2026, pp. 348–365. URL: https://doi.org/10.1007/978-3-032-28117-3_20. doi:10.1007/978-3-032-28117-3_20.

[14] A. Kumar, P. Soffer, A. Tsoury, Normalizing object-centric process logs by applying database principles, Inf. Syst. 115 (2023) 102196. URL: https://doi.org/10.1016/j.is.2023.102196. doi:10.1016/J.IS.2023.102196.

[15] A. S. et al., Object-centric process management: A research manifesto, Information Systems 141 (2026) 102728. URL: https://www.sciencedirect.com/science/article/pii/S0306437926000426. doi:https://doi.org/10.1016/j.is.2026.102728.

[16] J. N. van Detten, P. Schumacher, S. J. J. Leemans, Discovering compact, live and identifier-sound object-centric process models, in: 6th International Conference on Process Mining, ICPM 2024, Kgs. Lyngby, Denmark, October 14-18, 2024, IEEE, 2024, pp. 113–120. URL: https://doi.org/10.1109/ICPM63005.2024.10680659. doi:10.1109/ICPM63005.2024.10680659.

[17] A. K. F. Christfort, A. Rivkin, D. Fahland, T. T. Hildebrandt, T. Slaats, Discovery of object-centric

declarative models, in: ICPM, IEEE, 2024, pp. 121–128. doi:10.1109/ICPM63005.2024.10680680.

[18] J. M. E. M. van der Werf, A. Rivkin, A. Polyvyanyy, M. Montali, Data and process resonance - identifier soundness for models of information systems, in: L. Bernardinello, L. Petrucci (Eds.), Application and Theory of Petri Nets and Concurrency - 43rd International Conference, PETRI NETS 2022, Bergen, Norway, June 19-24, 2022, Proceedings, volume 13288 of *Lecture Notes in Computer Science*, Springer, 2022, pp. 369–392. URL: https://doi.org/10.1007/978-3-031-06653-5_19. doi:10.1007/978-3-031-06653-5_19.

[19] A. Gianola, M. Montali, S. Winkler, Object-centric processes with structured data and exact synchronization - formal modelling and conformance checking, in: CAiSE, volume 15702 of *LNCS*, 2025, pp. 185–202. doi:10.1007/978-3-031-94571-7_11.

[20] V. Künzle, M. Reichert, Philharmonicflows: towards a framework for object-aware process management, J. Softw. Maintenance Res. Pract. 23 (2011) 205–244. URL: https://doi.org/10.1002/smr.524. doi:10.1002/SMR.524.

[21] M. Snoeck, C. Verbruggen, J. D. Smedt, J. D. Weerdt, Supporting data-aware processes with MERODE, Softw. Syst. Model. 22 (2023) 1779–1802. URL: https://doi.org/10.1007/s10270-023-01095-4. doi:10.1007/S10270-023-01095-4.

[22] A. U. Tansel, Temporal databases, in: B. W. Wah (Ed.), Wiley Encyclopedia of Computer Science and Engineering, John Wiley & Sons, Inc., 2008. URL: https://doi.org/10.1002/9780470050118.ecse432. doi:10.1002/9780470050118.ECSE432.

[23] J. Carmona, B. F. van Dongen, A. Solti, M. Weidlich, Conformance Checking - Relating Processes and Models, Springer, 2018. URL: https://doi.org/10.1007/978-3-319-99414-7. doi:10.1007/978-3-319-99414-7.

[24] W. M. P. van der Aalst, A. Adriansyah, B. F. van Dongen, Replaying history on process models for conformance checking and performance analysis, WIREs Data Mining Knowl. Discov. 2 (2012) 182–192. doi:10.1002/WIDM.1045.

[25] A. Adriansyah, N. Sidorova, B. van Dongen, Cost-Based Fitness in Conformance Checking, in: 2011 Eleventh International Conference on Application of Concurrency to System Design, 2011, pp. 57–66. URL: https://ieeexplore.ieee.org/document/5988918/metrics. doi:10.1109/ACSD.2011.19, iSSN: 1550-4808.

[26] G. Li, R. M. de Carvalho, W. M. P. van der Aalst, Automatic discovery of object-centric behavioral constraint models, in: W. Abramowicz (Ed.), Business Information Systems - 20th International Conference, BIS 2017, Poznan, Poland, June 28-30, 2017, Proceedings, volume 288 of *Lecture Notes in Business Information Processing*, Springer, 2017, pp. 43–58. URL: https://doi.org/10.1007/978-3-319-59336-4_4. doi:10.1007/978-3-319-59336-4_4.

[27] L. Liss, J. N. Adams, W. M. P. van der Aalst, Object-centric alignments, in: ER, volume 14320 of *LNCS*, Springer, 2023, pp. 201–219. doi:10.1007/978-3-031-47262-6_11.

[28] J. N. Adams, W. M. P. van der Aalst, Precision and fitness in object-centric process mining, in: ICPM, IEEE, 2021, pp. 128–135. doi:10.1109/ICPM53251.2021.9576886.

[29] A. Gianola, M. Montali, S. Winkler, Object-centric conformance alignments with synchronization, in: CAiSE, Springer, 2024, pp. 3–19. doi:10.1007/978-3-031-61057-8_1.

[30] W. M. P. van der Aalst, A. Adriansyah, B. F. van Dongen, Causal nets: A modeling language tailored towards process discovery, in: CONCUR, Springer, 2011, pp. 28–42. doi:10.1007/978-3-642-23217-6_3.

[31] L. Liss, W. M. P. van der Aalst, Process area extraction by multilevel resource detection for object-centric process mining, in: BPM, volume 16044, Springer, 2025, pp. 197–214. URL: https://doi.org/10.1007/978-3-032-02867-9_13. doi:10.1007/978-3-032-02867-9_13.

[32] L. Liss, N. Löseke, W. M. P. van der Aalst, Object-centric streaming-based process discovery, 2025. Under review.

[33] L. Liss, N. Elbert, C. M. Flath, W. M. P. van der Aalst, Framework for extracting real-world object-centric event logs from game data, in: ICPM Workshops, volume 533 of *LNBIP*, Springer, 2024, pp. 363–375. doi:10.1007/978-3-031-82225-4_27.