ProAmbitIon, reloaded: A two-year retrospection

Marco Franceschetti[1,*,†], Ronny Seiger[1,†], Luciano García-Bañuelos[2] and Barbara Weber[1]

[1]Institute of Computer Science, University of St.Gallen, Switzerland
[2]Department of Computer Science, Tecnológico de Monterrey, Mexico

Abstract

The rapid digital transformation of business processes holds significant promise for enhancing process automation, analysis, and optimization. However, digital traces of real-world processes–particularly those involving human activities–are frequently incomplete, thereby constraining the capabilities for automated process analysis. With the *ProAmbitIon* project, we address this challenge by leveraging the Internet of Things (IoT) to bridge the gap between real-world process executions and their digital representations. First, by augmenting the process environment with sensors, we enable a fine-grained monitoring and contextualization of process activities. Next, by generating and enriching digital traces from and with IoT data, we enable online conformance checking without depending on traditional information systems. With the development of new approaches for IoT-driven process conformance checking, we also address the issue of ambiguities originating from process-related artifacts. The project is validated through real-world scenarios from healthcare and manufacturing. We report on the results and insights from the first two years of the project, and outline current work and next steps.

Keywords

Process Mining, Conformance Checking, Explainability, Internet of Things, Ambiguity in BPM

1. Introduction

Business processes instructing humans, software, and other resources of any kind how to interact and execute specific activities to yield a specific business outcome are becoming increasingly digitized and interwoven with the physical world [1, 2]. *Conformance checking* as a sub-discipline of process mining empowers analysts with methods and tools to automatically detect deviations of process executions–based on process event data [3]–from their normative formal description [3]. Traditionally, conformance checking assumes the availability of an event log describing execution traces, which are usually recorded by a Business Process Management System (BPMS) or some kind of process-aware information system (PAIS). However, for real-world process executions that are not (fully) orchestrated by such systems (e.g., in healthcare), event logs are unavailable, only partially available, or available at an abstract and coarse-grained level, which challenges process conformance checking [1, 4]. This, in turn, complicates planning, prediction, optimization, and adaptation in case of non-conformance. The challenge is exacerbated by the focus of most conformance checking techniques on the post-mortem event log analysis [3], which limits their applicability for timely analyses of executions in the real world. Moreover, process descriptions instructing humans are rarely available as formalized models, but rather as informal specifications presented through guidelines, checklists, or policies in natural language [5]. As such, these process descriptions are inherently ambiguous, i.e., they allow for multiple valid interpretations from a reader's perspective [6]. Along with ambiguities in event logs [6], these ambiguities pose a further challenge to conformance checking.

The *ProAmbitIon*[1] research project proposes to use the Internet of Things (IoT) to enable improved

RPEatCAiSE25: Research Projects Exhibition at the International Conference on Advanced Information Systems Engineering, June 16-20, 2025, Vienna, Austria

[*]Corresponding author.
[†]These authors contributed equally.
marco.franceschetti@unisg.ch (M. Franceschetti); ronny.seiger@unisg.ch (R. Seiger); luciano.garcia@tec.mx (L. García-Bañuelos); barbara.weber@unisg.ch (B. Weber)
0000-0001-7030-282X (M. Franceschetti); 0000-0003-1675-2592 (R. Seiger); 0000-0001-9076-903X (L. García-Bañuelos); 0000-0002-6004-4860 (B. Weber)

[1]https://data.snf.ch/grants/grant/208497

monitoring and conformance checking of real-world processes that may exhibit ambiguity. Leveraging sensors as new data sources installed in the process environment enables the sensing of process executions in the physical world. Thereby, we can generate corresponding digital representations (traces) that can be used for conformance checking in settings where traditionally event logs are unavailable or unsuitable for analysis.

The **goals** of the *ProAmbitIon* project (cf. [7]) are to:

- *G1*: Investigate how to enable domain experts to enrich process descriptions with IoT-related execution aspects and use these for the monitoring of process elements.
- *G2*: Investigate how conformance checking can be used in the presence of ambiguities to check the correctness of process executions and provide interpretable feedback to users.

In order to reach these goals, the project aims to answer the following four research questions:

- *RQ1*: How can domain experts be enabled to enrich informal process descriptions with IoT-related execution criteria for event abstraction and correlation?
- *RQ2*: How can stream analysis techniques be used to derive process event logs and event streams from possibly ambiguous IoT data?
- *RQ3*: How can conformance checking be used in both offline and online settings on IoT-based process event logs and streams that possibly contain ambiguities?
- *RQ4*: How can end-users be provided with understandable feedback about conformance regarding process execution and with means for resolving remaining ambiguities?

ProAmbitIon is a basic research project funded by the Swiss National Science Foundation (SNSF) within the *SPIRIT* framework. The project's principal investigators are **Barbara Weber** (University of St.Gallen) and **Luciano García-Bañuelos** (Tecnologico de Monterrey). The project has a duration of three years, from 01.11.2022 until 31.10.2025.

2. Project objectives and tangible outputs

The main objective of *ProAmbitIon* is the development of an IoT-based process monitoring and conformance checking framework. The framework will allow to: (i) annotate informal process descriptions with monitoring points that associate activities with IoT data; (ii) monitor and check conformance of process executions from IoT data in the presence of ambiguity at runtime; (iii) provide end-users with interpretable feedback on process conformance. Following design science research principles, the project is set to produce the following revised set of artifacts:

- A framework for IoT-driven process event log and event stream generation.
- A catalog of IoT event patterns that relate process activities with low-level IoT data to facilitate event abstraction [8].
- A domain-specific language (DSL) to annotate process descriptions with IoT pattern-based monitoring points and to translate them into executable activity detection services.
- A software architecture for the abstraction of IoT event streams into process events [8].
- Alignment techniques for online conformance checking considering the presence of ambiguities in process events derived from IoT data and in process specifications.
- Mechanisms for providing interpretable feedback about process conformance to visualize and resolve ambiguities.

3. Relevance of the project

ProAmbitIon addresses several open challenges at the intersection of BPM and IoT [1], especially considering IoT data as basis to derive process-related information [4]. The project aims to advance the state of the art of information systems engineering as follows.

IoT devices, especially their sensors, serve as new data sources that enable a fine-grained and augmented monitoring of both, automated *and* manual process activity executions, which reduces the dependencies on fully-fledged PAISs or BPMSs. Furthermore, the developed methods for monitoring and analysis have the potential of complementing existing BPMSs and PAISs by enriching process event logs with IoT data [9], thereby providing further contextualization to event logs. By closing the gap between real-world executions and their digital representations, the project helps to bridge event-based and process-based systems as stated in the BP-meet-IoT manifesto [1] and it facilitates the development of *digital twins* of business processes using IoT data [10]. Being one of the first projects to focus on applying IoT technologies in the context of BPM, ProAmbitIon also aims to produce extensive datasets for the two application domains manufacturing and healthcare–correlating data from IoT sensors with process event data–and make these datasets openly available to the information systems research community.

In defining monitoring points [11] to abstract IoT events into process events for activity monitoring, the project will contribute a catalog of IoT event patterns, which will facilitate further research in information system analysis by means of pattern support. Furthermore, it will facilitate the systematic development of novel event-based systems. With the DSL we aim to empower domain experts to contribute their valuable expertise in information systems and IoT engineering–focusing on the human-in-the-loop instead of aiming for full automation.

In developing online conformance checking procedures capable of considering ambiguities, ProAmbitIon will advance the state of the art of conformance checking with respect to concepts and procedures. By targeting the healthcare domain, which is characterized by high human involvement and which typically uses informal process descriptions, the project will explore novel approaches to presenting conformance results and feedback to the end-users at runtime.

4. Current project status and intermediate results

4.1. Scenario definitions and IoT setups

With *ProAmbitIon*, we explore new approaches for IoT-driven conformance checking. For validation we consider the application domains of manufacturing and healthcare as the diversity of processes from these domains (e.g., in terms of repetitiveness and variability, structuredness, or degree of automation) allows us to demonstrate the generalizability of our solutions. In prior work [7], we presented suitable scenarios for the two application domains as a first milestone.

The *manufacturing scenario* involves an order-to-product process executed with a small-scale smart factory in our lab [12]. Given the sequential nature and low variability of the process, we employ a BPMN-based approach for its representation [12]. In similar production environments, data quality and frequency vary significantly. Legacy machines, limited sensors, and independently controlled devices–along with manual operations and human-machine collaborations–complicate the creation of a consistent event log, particularly without a central process orchestrator or monitoring component [4]. This makes conformance checking, despite the process structuredness, a very challenging task [13].

The *healthcare scenario* involves a blood donation process following the World Health Organization guidelines, with a particular focus on adhering to hand hygiene guidelines [7]. Although the guidelines dictate a strictly sequential process, real-world healthcare settings are frequently subject to unpredictable disruptions (e.g., a donor fainting). These may force healthcare workers to deviate from the prescribed sequence, interleave the execution of process instances, or repeat activities. This complexity presents significant challenges for IoT-driven monitoring and conformance checking, particularly in associating sensed data with the correct event and process instance [4]. To evaluate our contributions, we completed a lab setup to monitor simulations of the blood donation process using a combination of IoT sensors (e.g., proximity, motion, ambient light, and weight). Within this setup, we had to carefully balance the privacy-invasiveness of sensors to employ for monitoring of activities and the accuracy with which we are able to detect these activities and distinguish them from similar ones. Moreover, we acknowledge that the installation and operation of additional IoT devices to monitor the activity executions requires a comprehensive analysis of their impact on *sustainability* along different dimensions [14]. The final process and lab setup were validated by domain experts from the Division of Infectious Diseases & Hospital Epidemiology of the Cantonal Hospital of St. Gallen.

4.2. Activity Detection

We address *RQ2* on deriving process event logs and event streams with multiple research contributions, advancing the state of the art in IoT-based activity detection following an extensive discussion of associated challenges [4]. In [11], we present a conceptual metamodel for process monitoring and conformance checking based on activities detected from IoT data. The metamodel links the BPM and IoT worlds and discusses properties that process events derived from IoT data must meet to support online monitoring and conformance checking. In [15], we propose a novel process to non-invasively augment legacy IoT systems to facilitate IoT-based monitoring with simple domain-specific sensor processing services for event abstraction.

An extended interactive method leveraging domain expert knowledge for activity identification is presented in [16]. It allows for the manual identification and annotation of *activity signatures*, i.e., patterns over a multivariate timeseries representing a prototypical activity execution in the IoT data. Building on this method, in [17] we propose a framework to automatically generate activity detection services from activity signatures and a service-based software architecture for execution. At their core, the activity detection services leverage a complex event process (CEP) system to detect the occurrence of relevant change patterns in the IoT data to identify the activities (i.e., their start, end, and intermediate patterns). These change patterns relate to the combination and processing of low-level events emitted from the IoT sensors that are deployed in the individual IoT setups. To alleviate the manual task of annotating IoT data, in [18] we propose a semi-automated approach to detect activity signatures in sensor data, providing suggestions to the annotator. As the approach assumes highly repetitive activities with very little variability to identify repeated subsequences of symbols, it is particularly suitable for the manufacturing scenario.

To demonstrate the framework's applicability, we implemented a prototype based on a CEP platform enabling the online detection of activities from data streams in the manufacturing scenario. An exemplary pattern in the IoT sensor data of the Oven production station in the factory involves one of its motors changing its speed from 0 to 512 and a switch changing its state from 1 to 0 to indicate that an execution of the *Burn* activity has started.

In addition, we captured IoT data from multiple executions of the blood donation process in our lab during a data collection workshop with medical students. We used these data for simulation and an extended framework evaluation in [19], demonstrating the feasibility of the online activity detection method. An exemplary pattern in the IoT sensor data here involves a scale registering a significant brief increase of weight and a distance sensor noticing a person at close distance to derive the start of an execution of the *Sanitize Hands* activity performed by a healthcare worker. Extensive datasets with IoT timeseries data and process events for the manufacturing and healthcare scenarios are publicly available in [20].

Motivated by the need to assess the effectiveness of our activity detection methods, in [21] we present a tool for comparing an event log derived from IoT data with an event log representing the ground truth (generated, e.g., via a BPMS or manual tracking). The tool is publicly available and has an extensible set of metrics for log comparison. It is suitable for the general, often encountered use case to compare two process event logs with events stored in XES format with each other. This makes it applicable and highly interesting for BPM and process mining related evaluations, beyond IoT-based activity detection.

4.3. Ambiguity characterization

We aim to address potential ambiguities originating from informal process descriptions and the lack of process-awareness in IoT data. Therefore, to answer *RQ2–RQ4*, we set to deepen our understanding of ambiguity in business processes. With the study presented in [6], we investigate different sources of ambiguity in process artifacts–informal specifications, process models, and event logs–resulting in a taxonomy of ambiguity. Furthermore, we discuss the potential cascading effects of ambiguity in different process artifacts across the BPM lifecycle, increasing awareness about ambiguity. In an empirical follow-up study [22], we demonstrate the adverse cognitive effects of ambiguity in process models on the model readers. These results highlighted the need to address ambiguity across different artifacts representing processes, as it can hinder process analytics at different levels and end-user comprehension. Building on these results, in [23] we propose a framework toward enabling IoT-driven ambiguity-aware conformance checking by leveraging the explicit representation of ambiguity. The framework takes as input IoT data from sensors installed in the process environment and abstracts these data into (partial) traces of process events explicitly representing ambiguity by encoding these traces as Event Knowledge Graphs [24].

4.4. Conformance checking

Addressing *RQ3* on conformance checking of IoT-based event logs, in [25] we introduce an efficient conformance checking approach that leverages the notion of *optimal alignments*, i.e., the commonalities with the minimum number of differences between two traces. The approach uses a text indexing technique known as *FM-index* to efficiently compute all k-bounded optimal alignments, i.e., alignments with up to k differences. This work marks a significant advancement in the state of the art of conformance checking, since existing approaches return only few approximations of the optimal alignments. Furthermore, the use of a k bound allows the proposed algorithm to be particularly efficient compared to existing algorithms. This paves the way to alignment-based techniques for online conformance checking.

4.5. Current work and insights

As part of ongoing work, we have completed the development of the DSL empowering domain experts to annotate process specifications. The DSL supports the specification of generic sensor-related monitoring points to track the execution of activities and generate high-level process events for process mining [11], thereby fully addressing *RQ1*. From these monitoring points, we generate activity detection services based on CEP, similar to [17], and execute these services according to the proposed software architecture to detect activity executions at runtime [17].

One of the significant insights we got from working with the IoT data is that the quality of activity executions is highly influenced by variations in the underlying IoT data [4]. These variations result in slightly different sensor values and change patterns for executions of the same type of activity. While we are able to anticipate and encode these variations with additional patterns, optional patterns, and variability in patterns using the DSL (e.g., via discretizations and value ranges), the approach in [17] that only relies on one prototypical execution of an activity instance is only able to handle variations in execution times, but not in the sensor data itself. We are currently pursuing two different additional approaches to make the activity detection methods more robust. The first relies on case-based reasoning to classify and learn activity executions from previously observed occurrences (*cases*) stored in a case base, and to then find matching cases based on similarity for unclassified, unknown IoT data [26]. Second, we are developing an extension of the automata-based method in [18] with *error tolerance* by allowing matching activity patterns within an error margin as additional acceptable states of the activity detection automatons, thus providing a more sophisticated answer to *RQ2*.

We are investigating different approaches to check the conformance of ambiguous traces generated from IoT event abstraction, thereby fully addressing *RQ3*. 1) The integration of event abstraction with deep learning-based image processing methods: by activating cameras–in scenarios where they are allowed (e.g., in controlled medical training settings)–on-demand, in case of detected ambiguities, we capture and integrate rich activity contextualizations to aid ambiguity resolution. 2) The integration of a formal representations of (partial) traces as Event Knowledge Graphs [24] with disambiguation methods based on graph grammar constructs defined from domain knowledge. Toward answering *RQ4* on providing interpretable feedback about the online conformance of traces to the end-users, we plan to develop user-friendly interactive applications using different modalities in the last phase of the project. The interface design will be based on a user-centered design process informed by the medical students' feedback collected during data collection workshops.

5. Conclusion

The adoption of IoT technologies enables the application of BPM concepts, methods, and techniques to cyber-physical domains such as smart manufacturing and healthcare where real-world processes exist but cannot (fully) benefit from BPM technologies. The *ProAmbitIon* project enables the IoT-driven online monitoring and conformance checking of such processes, while considering ambiguities in the respective process descriptions and event logs.

The achievements from the first two project years advance the state of the art of information systems engineering along several dimensions. The characterization and study of ambiguity in BPM shed light on a–so far–understudied topic and promote the development of novel ambiguity-aware information systems. Despite being challenged by variations in IoT data, the developed activity detection methods bridge the gap between physical-world process executions and their digital representations, paving the way for the convergence of event-based and process-based systems and digital twin development. The method for efficiently computing all k-bounded optimal alignments enables and stimulates further research on online conformance checking methods. Furthermore, by posing compelling challenges for monitoring and conformance checking, the manufacturing and healthcare processes promote further research community engagement with problems arising from the IoT-BPM integration. Here we provide support for further research endeavors through the published datasets, prototypes, and evaluation tool.

The ongoing and planned research activities for the third project year aim to further advance the state of the art of information systems engineering by providing a) a new language to encode domain expertise and IoT data patterns, b) disambiguation methods, c) ambiguity-aware online conformance checking, and d) end-user support in presenting conformance checking results. Overall, we are well on track towards a successful completion of the research project.

Acknowledgments

This work has received funding from the Swiss National Science Foundation under Grant No. IZSTZ0_208497 (*ProAmbitIon* project).

Declaration on Generative AI

During the preparation of this work, the authors used ChatGPT in order to: Grammar and spelling check, Paraphrase and reword. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the publication's content.

References

[1] C. Janiesch, A. Koschmider, M. Mecella, B. Weber, A. Burattin, C. Di Ciccio, G. Fortino, A. Gal, U. Kannengiesser, F. Leotta, et al., The internet of things meets business process management: a manifesto, IEEE Systems, Man, and Cybernetics Magazine 6 (2020) 34–44.

[2] B. Weber, A. Abbad-Andaloussi, M. Franceschetti, R. Seiger, H. Völzer, F. Zerbato, Leveraging digital trace data to investigate and support human-centered work processes, in: Int. Conf. Evaluation of Novel Approaches to Software Engineering, Springer, 2023, pp. 1–23.
[3] W. Van Der Aalst, A. Adriansyah, A. K. A. De Medeiros, F. Arcieri, T. Baier, , et al., Process mining manifesto, in: BPM 2011 International Workshops, Springer, 2012, pp. 169–194.
[4] J. Mangler, R. Seiger, J.-V. Benzin, J. Grüger, Y. Kirikkayis, F. Gallik, L. Malburg, M. Ehrendorfer, Y. Bertrand, M. Franceschetti, et al., From internet of things data to business processes: Challenges and a framework, arXiv preprint arXiv:2405.08528 (2024).
[5] J. Becker, K. Bergener, O. Mueller, F. Mueller-Wienbergen, Documentation of flexible business processes-a healthcare case study, AMCIS 2009 Proceedings (2009).
[6] M. Franceschetti, R. Seiger, H. A. López, A. Burattin, L. García-Bañuelos, B. Weber, A characterisation of ambiguity in bpm, in: International Conference on Conceptual Modeling, Springer, 2023, pp. 277–295.
[7] M. Franceschetti, R. Seiger, M. J. G. González, E. Garcia-Ceja, L. A. R. Flores, L. García-Bañuelos, B. Weber, Proambition: Online process conformance checking with ambiguities driven by the internet of things., in: CAiSE Research Projects Exhibition, 2023, pp. 52–59.
[8] S. J. van Zelst, F. Mannhardt, M. de Leoni, A. Koschmider, Event abstraction in process mining: literature review and taxonomy, Granular Computing 6 (2021) 719–736.
[9] J. Mangler, J. Grüger, L. Malburg, M. Ehrendorfer, Y. Bertrand, J.-V. Benzin, S. Rinderle-Ma, E. Serral Asensio, R. Bergmann, Datastream xes extension: Embedding iot sensor data into extensible event stream logs, Future Internet 15 (2023).
[10] F. Fornari, I. Compagnucci, M. C. De Donato, Y. Bertrand, H. H. Beyel, E. Carrión, M. Franceschetti, W. Groher, J. Grüger, E. Kilic, et al., Digital twins of business processes: A research manifesto, Internet of Things (2024) 101477.
[11] M. Franceschetti, R. Seiger, B. Weber, An event-centric metamodel for iot-driven process monitoring and conformance checking, in: International Conference on Business Process Management, Springer, 2023, pp. 131–143.
[12] R. Seiger, L. Malburg, B. Weber, R. Bergmann, Integrating process management and event processing in smart factories: A systems architecture and use cases, Journal of Manufacturing Systems 63 (2022) 575–592.
[13] I. Beerepoot, C. Di Ciccio, H. A. Reijers, S. Rinderle-Ma, W. Bandara, et al., The biggest business process management problems to solve before we die, Computers in Industry 146 (2023) 103837.
[14] M. Albert, A. Mestre, R. Seiger, V. Torres, P. Valderas, Sustainability in and through iot-enhanced business processes, in: Proc. of the Best Dissertation Award, Doctoral Consortium, and Demonstration & Resources Forum at BPM 2024, volume 3758 of *CEUR Workshop Proc.*, 2024, pp. 151–156.
[15] R. Seiger, M. Franceschetti, A. Abbad-Andaloussi, A process to non-invasively augment legacy iot systems using business processes and microservices, in: Proceedings of the 14th International Conference on the Internet of Things, 2024, pp. 1–9.
[16] R. Seiger, M. Franceschetti, B. Weber, An interactive method for detection of process activity executions from iot data, Future Internet 15 (2023).
[17] R. Seiger, M. Franceschetti, B. Weber, Data-driven generation of services for iot-based online activity detection, in: Service-Oriented Computing, Springer, 2023, pp. 186–194.
[18] L. García-Bañuelos, M. J. G. González, R. Seiger, M. Franceschetti, A. G. S. Trujillo, A semi-automated approach to detecting process-level activities from sensor data, Procedia Computer Science 257 (2025) 856–863.
[19] R. Seiger, A. F. Kurz, M. Franceschetti, Online detection of process activity executions from iot sensors using generated event processing services, Available at SSRN 5165943 (2025). doi:10.2139/ssrn.5165943.
[20] A. F. Kurz, R. Seiger, M. Franceschetti, Prototype of an iot-based activity detection service generator with evaluation datasets, 2025. doi:10.5281/zenodo.14860395.
[21] A. F. Kurz, R. Seiger, M. Franceschetti, B. Weber, Activity and sequence detection evaluation metrics: A comprehensive tool for event log comparison, in: Proceedings of the Best Dissertation

Award, Doctoral Consortium, and Demonstration and Resources Forum at BPM 2024, 2024.
[22] M. Franceschetti, A. Abbad-Andaloussi, C. Schreiber, H. A. López, B. Weber, Exploring the cognitive effects of ambiguity in process models, in: International Conference on Business Process Management, Springer, 2024, pp. 493–510.
[23] M. Franceschetti, D. M. Buchegger, R. Seiger, B. Weber, Toward iot-based process analytics: Extending event knowledge graphs with ambiguity, in: International Conference on Business Process Modeling, Development and Support (to appear), Springer, 2025.
[24] D. Fahland, Process mining over multiple behavioral dimensions with event knowledge graphs, in: Process Mining Handbook, Springer, 2022, pp. 274–319.
[25] A. Rivera-Partida, A. Armas-Cervantes, L. García-Bañuelos, L. Rodríguez-Flores, All optimal k-bounded alignments using the fm-index, in: International Conference on Cooperative Information Systems, Springer, 2024, pp. 75–92.
[26] R. Seiger, A. Schultheis, R. Bergmann, Case-based activity detection from segmented internet of things data, in: Case-Based Reasoning Research and Development - 33rd International Conference, ICCBR 2025, Biarritz, France, June 30 - July 3rd, 2025, Proceedings., Lecture Notes in Computer Science (LNCS), Springer, 2025. Accepted for Publication.