Executable Digital Process Twins

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An Executable Digital Process Twin (xDPT) is a digital twin specifically designed for process-driven systems. It enriches the monitoring and analysis functionalities of a digital process twin with the possibility of actively driving the execution of the entire system. An xDPT receives real-time event logs from the running organization and allows direct monitoring by marking the status of the system in the running process. Moreover, it can exploit existing process mining techniques to check the conformance of the executed behavior, to provide an enriched view over multiple system perspectives, and to store historical data to predict process evolution. Finally, the process driving the system behavior can be refined and deployed into the organization. The main objective of an xDPT is to enable the monitoring and analysis of a system but also to execute it. In this regard, the process should serve both for performing monitoring and analysis stages and for enacting and controlling the whole system execution.

digital process twin process-driven system BPMN

1. Digital Process Twin

The concept of the DT is evolving to include system information models that describe the properties and relationships of all data and information required to achieve a task, as well as the elements and connections of organizational systems, to understand the factors affecting a decision and to predict decision outcomes [1]. In the literature, this concept is referred to as a DPT [2]. Notably, DPTs are considered part of a wider concept, known as the digital twins of an organization [1]. DPTs still generate many concerns among organizations trying to figure out the benefits they bring to the whole system and how to overcome challenges such as implementing real-time changes and developing the DPT to reflect these changes [3]. To overcome these concerns, Becker et al. [4] prescribed a set of criteria to provide clarification and suggestions regarding emerging DPTs. Specifically, a DPT should involve:

- Multiple and interdependent processes;
- Agents capable of making choices, learning from experience, and achieving goals;
- Models showing different aspects of the organization;
- Simulation and prediction capabilities to understand how the organization might behave when it faces different situations.

Indeed, a DPT can be seen as a digital replica of the business processes of an organization. Therefore, it enables runtime monitoring, analysis, simulation, and improvements, providing an extension to the current state of the art in process modeling and mining [5]. Moreover, DPTs are more effective when applied to organizational contexts described by an enterprise architecture modeling language, such as BPMN [6]. Riss et al. [7] evaluate the characteristics and benefits of using a DPT in these contexts. By exploiting a continuous data flow, the DPT shows the real-time performance of its actual counterpart and associates the process with the current behavior of the entities. Additionally, the collection of data on past behavior enables simulations and predictions of future process behavior under changed conditions. Notably, when the DPT is applied to a process-driven system, researchers refer to it as DPT.

2. Executable Digital Twin

Traditional DTs serve as simulation and predictive tools to enable engineers and developers to optimize performance, conduct simulations, and predict failures without risking damage to the actual physical object. However, DTs remain separate entities, only influencing their real-world counterparts through insights and adjustments [8]. To bring the DT closer to the physical side, Hartmann and Van der Auweraer [9] introduced the concept of an Executable Digital Twin (xDT) for the application of DTs in industrial contexts. Indeed, an xDT aims to bridge the gap between a DT and the corresponding execution on the physical side. It can be seen as a specific DT whose models can be executed by dedicated execution engines both in simulation environments and in physical devices.

The core goal of exploiting xDT is to support the whole lifecycle of a system, from its design to the analysis steps. Therefore, an xDT is a high-fidelity simulation model that expands its applications beyond the design and validation phases to also manage in-operation and service phases [10]. Currently, xDTs are proposed for industrial scenarios as self-contained, executable, digital representations of a specific behavior of a physical device [11], with the aim of testing configurations that can be complex to recreate in real life, validating the system dynamics, and predicting future behaviors [12]. Indeed, the main goal of an xDT is to deploy the digital twin itself into the physical world, enabling the knowledge contained in the digital representation to create value for the physical counterpart directly.

3. Executable Digital Process Twin

Currently, with the rising adoption of business processes for specifying and driving the behavior of distributed systems [13][14], it becomes increasingly evident that the application of DPTs is essential to enhance the whole system. Indeed, the ability to monitor, analyze, and understand the complex behavior of process-driven systems makes DPTs the key to gaining insight into processes and improving their decision-making skills. Therefore, a DPT of a process-driven system should combine a virtual representation of each participant with the representation of the process itself. This combined representation shows the interdependencies between the participants and the process [15].

Nevertheless, a DPT capable of virtually representing an organizational system and its operational processes is still a theoretical concept and is far away from reality [16]. Therefore, there is a need to understand how it is possible to exploit DPTs, and in particular DPTs, not only for performing monitoring and analysis steps but also for executing the whole system. In this regard, the process should serve both as a DPT, for performing monitoring and analysis steps, and as an xDT, for enacting and controlling the whole system's execution. Researchers refer to the application of an xDT in a process-driven organizational context as an executable digital process twin (xDPT).

Notably, since the reference organization is built upon a process model, the proposed xDPT is known in advance. Therefore, it does not need to rely on techniques for process discovery from streams of logs, which currently are not mature enough to allow the discovery of processes representing collaborative distributed systems [16][17]. The authors of **Figure 1** present an overview of an xDPT representing a process-driven organization. Notably, the workflow of this organization is described in BPMN. Specifically, the xDPT receives real-time event logs from the running organization and allows direct monitoring by marking the status of the system in the running process. Moreover, it can exploit existing process mining techniques to check the conformance of the executed behavior [18], to provide an enriched view over multiple system perspectives [19], and to store historical data to predict process evolution [20]. Finally, the process driving the system behavior can be refined and deployed into the organization [21]. Summing up, **Table 1** compares DPT, xDT, and xDPT to show the characteristics and potentiality of applying an xDPT. In particular, the comparison is made with respect to their distinctive features of (i) representing the system behavior (representation), (ii) knowing in advance the model defining the system behavior (prior knowledge), (iii) simulating and predicting future states of the system (prediction), (iv) improving the system at run-time (improvements), and (v) deploying the behavioral model in the physical system (deployment). Notably, features supported by a DT are represented by a check mark, while unsupported features are indicated by a cross symbol.

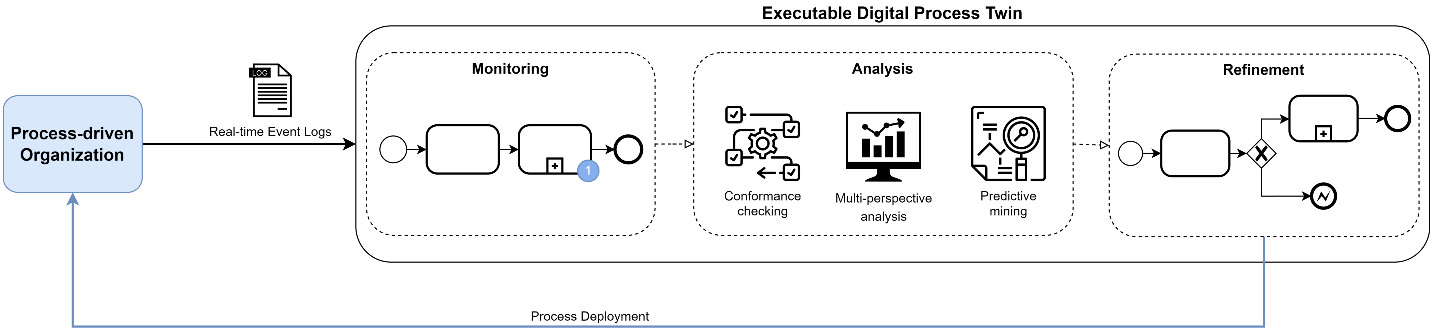

Figure 1. Overview of the functionalities of an executable digital process twin.

Table 1. Comparison of the three types of DTs.

	DPT	xDT	xDPT
Representation	✓	✗	✓
Prior knowledge	✗	✓	✓

	DPT	xDT	xDPT
Prediction	✓	✓	✓
Improvements	✗	✗	✓
Deployment	✗	✓	✓

References

1. Parmar, R.; Leiponen, A.; Thomas, L.D. Building an organizational digital twin. Bus. Horiz. 2020, 63, 725–736.
2. Caesar, B.; Hänel, A.; Wenkler, E.; Corinth, C.; Ihlenfeldt, S.; Fay, A. Information Model of a Digital Process Twin for Machining Processes. In Proceedings of the Emerging Technologies and Factory Automation, Vienna, Austria, 8–11 September 2020; pp. 1765–1772.
3. Caporuscio, M.; Edrisi, F.; Hallberg, M.; Johannesson, A.; Kopf, C.; Perez-Palacin, D. Architectural concerns for digital twin of the organization. In Proceedings of the Software Architecture, L'Aquila, Italy, 14–18 September 2020; pp. 265–280.
4. Becker, M.C.; Pentland, B.T. Digital twin of an organization: Are you serious? In Proceedings of the Business Process Management Workshops, Rome, Italy, 6–10 September 2021; pp. 243–254.
5. Park, G.; Comuzzi, M.; van der Aalst, W. Analyzing Process-Aware Information System Updates Using Digital Twins of Organizations. In Proceedings of the Research Challenges in Information Science, Barcelona, Spain, 17–20 May 2022; pp. 159–176.
6. OMG. Business Process Model and Notation (BPMN), version 2.0; OMG: Milford, MA, USA, 2011.
7. Riss, U.V.; Maus, H.; Javaid, S.; Jilek, C. Digital twins of an organization for enterprise modeling. In Proceedings of the Practice of Enterprise Modeling, Riga, Latvia, 25–27 November 2020; pp. 25–40.
8. Lo, C.; Chen, C.; Zhong, R.Y. A review of digital twin in product design and development. Adv. Eng. Inform. 2021, 48, 101297.
9. Hartmann, D.; der Auweraer, H.V. Digital Twins. arXiv 2020, arXiv:abs/2001.09747.
10. Scurria, L.; Risaliti, E.; Buss, D.; Kubo, P.; Tamarozzi, T.; Cornelis, B. Executable digital twin-prevent the early failure of a truck anchorage using smart virtual sensors. Int. J. Adv. Curr. Pract. Mobil. 2022, 4, 1309–1317.
11. Hartmann, D.; der Auweraer, H.V. The Executable Digital Twin: Merging the digital and the physics worlds. arXiv 2022, arXiv:abs/2210.17402.

12. Allamaa, J.P.; Patrinos, P.; der Auweraer, H.V.; Son, T.D. Sim2real for Autonomous Vehicle Control Using Executable Digital Twin. IFAC-PapersOnLine 2022, 55, 385–391.

13. Valderas, P.; Torres, V.; Serral, E. Modelling and executing IoT-enhanced business processes through BPMN and microservices. J. Syst. Softw. 2022, 184, 111139.

14. Bourr, K.; Corradini, F.; Pettinari, S.; Re, B.; Rossi, L.; Tiezzi, F. Disciplined use of BPMN for mission modeling of Multi-Robot Systems. In Proceedings of the Forum at Practice of Enterprise Modeling, Riga, Latvia, 24–26 November 2021; Volume 3045, pp. 1–10.

15. Valderas, P. Supporting the Implementation of Digital Twins for IoT-Enhanced BPs. In Proceedings of the International Conference on Research Challenges in Information Science, Corfu, Greece, 23–26 May 2023; pp. 222–238.

16. van der Aalst, W. Concurrency and objects matter! Disentangling the fabric of real operational processes to create digital twins. In Proceedings of the Theoretical Aspects of Computing, Tbilisi, Georgia, 27–29 September 2022; pp. 3–17.

17. Corradini, F.; Re, B.; Rossi, L.; Tiezzi, F. A Technique for Collaboration Discovery. In Proceedings of the Business Process Modeling, Development and Support, Leuven, Belgium 6–7 June 2022; Volume 450, pp. 63–78.

18. Carmona, J.; van Dongen, B.; Weidlich, M. Conformance checking: Foundations, milestones and challenges. In Process Mining Handbook; Springer: Berlin/Heidelberg, Germany, 2022; Volume 448, pp. 155–190.

19. Fahland, D. Process mining over multiple behavioral dimensions with event knowledge graphs. In Process Mining Handbook; Springer: Berlin/Heidelberg, Germany, 2022; Volume 448, pp. 274–319.

20. Di Francescomarino, C.; Ghidini, C. Predictive process monitoring. In Process Mining Handbook; Springer: Berlin/Heidelberg, Germany, 2022; Volume 448, pp. 320–346.

21. Flavio Corradini; Sara Pettinari; Barbara Re; Lorenzo Rossi; Francesco Tiezzi; A BPMN-driven framework for Multi-Robot System development. *Robotics and Autonomous Systems* **2023**, *160*, 104322.