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Enhancing Digital Shadows with Workflows

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Abstract: The vast amount of data in modern manufacturing demands acquisition of contextualized data to enable fast decision making where domain expertise must be provided at run-time. Within this paper, we investigate the research question how to handle human-machine-interactions for engineering of digital shadows and still ensure the traceability of computation and simulation results. Current research for digital shadows concentrates on modeling key elements such as data sharing or metadata, but does not incorporate human-machine-interaction or the traceability of data aggregation. In this paper, we present a conceptual model which covers the base concepts for digital shadows integrating human-machine-interaction by utilizing workflows. We extend the conceptual digital shadow model defined within the "Internet of Production" excellence cluster and showcase our approach on an example. This contribution presents an applicable modeling approach for designing digital shadows which provide contextual information of the underlying human integrated process.

Keywords: Digital Shadow; Digital Twin; BPMN; Production; Human Computer Interaction

1 Introduction

Modern manufacturing processes produce huge amounts of data which demand for a contextualized data acquisition for fast decision making. Digital Shadows (DS) [Be21] promise to provide a data entity which can be used to reason about reality [vdA21] in a timely manner. In the following, "*A Digital Shadow is a set of contextual data traces and their aggregation and abstraction collected for a specific purpose with respect to an original system*" [Be21]. When aggregating data in digital shadows, we often assume a fully automatic process, executed either by an additional software component, e.g., a digital twin, or by some software service. Semi-automated processes arise when a DS operator might need to first set some parameters or must transfer intermediate results between software or hardware systems for which yet no digital communication exist.
Current research on digital shadows does not consider human-machine-interaction by domain experts which might be needed to execute all computations, and lacks the traceable modeling of the complex aggregation process. Within this paper, we investigate how to handle human-machine-interactions within the engineering of digital shadows and still ensure the traceability of computation and simulation results.
In an interdisciplinary work within the Cluster of Excellence "Internet of Production" (IoP)[2], Becker et al. [Be21] developed a conceptual model for digital shadows. In this paper,

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we aim to provide an extended version of this conceptual model which is able to model complex aggregation processes and allows human-machine-interaction using workflows.

2 Related Work

According to Bibow et al. [Bi20] "*a Digital Shadow is a set of contextual data traces and their aggregation and abstraction collected concerning a system for a specific purpose with respect to the original system*". Existing approaches include only some of these concepts, such as data analysis and data access [LKC19] or a data and knowledge holding [La21]. Van der Aalst et al. [vdA21] propose process mining to create digital shadows as an entity used to reason about the system. Nonetheless, their modeling lacks human interaction and the complex processes of lifting data to a useful aggregation.
Becker et al. [Be21] present a conceptual model for the engineering of digital shadows fulfilling the definition given above. Their model includes concepts such as assets describing the machine and its parts, data within data traces originating from a source, a purpose the DS must be tailored to, and models that the DS uses to fulfill its purpose. This approach provides the conceptual foundation for designing digital shadows. In contrast to this paper, the overall process is underspecified and remains domain knowledge which can not be modeled in the DS. Moreover, human interaction is limited to providing initial data.

To cover human interaction, the Business Process Management Notation (BPMN) [OM13] is commonly appreciated by business users [CT12] for its intuitive graphical notation which comprises the difficult details of business processes. Elements are, e.g., *data*, *flow objects* or *connection objects* to connect *activities* and *events* in a control logic. The BPMN provides further concepts which cope with the complexity of business process, e.g., hierarchical structuring or causal branching.

3 Implementing Workflows for Digital Shadow Creation

We make use of workflows to enable a digital shadow designer to capture the details of complex aggregation processes, having the data flow traceable, and integrating the human. Workflow modeling languages like the BPMN are designed to integrate human interaction into a semi-automated process. The conceptual model described in [Be21] already captures the conceptual basics for modeling DSs. However, it was clear that it has to be extended when we were exploring further use cases.

Fig. 1 shows the conceptual model using the UML class diagram [Ru16] notation with the workflow extensions. Please note that Fig. 1 shows only the related elements relevant for this extension. The digital shadow stands for an *Asset* and is tailored to a *Purpose*, e.g., a DS of a cyber-physical production system with the purpose of finding optimized parameters to

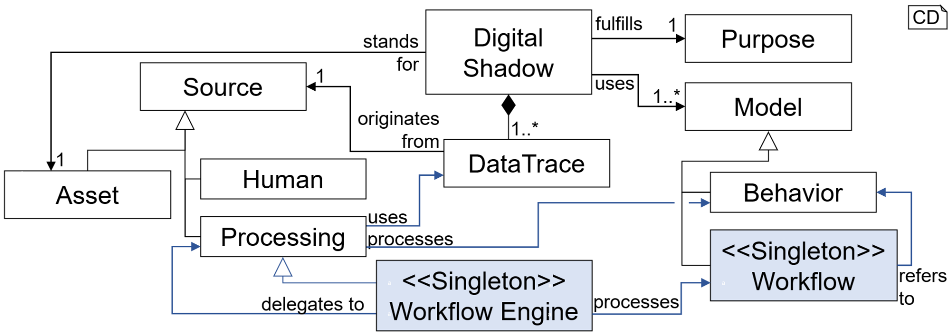

Fig. 1: Adapted conceptual model of digital shadows with workflows. The blue colored elements mark the added classes and associations.

minimize scrap. *Data Traces* build the core of the digital shadow and hold all data provided to and from the DS. Each data trace has its origin in a *Source* which could be the asset itself or, e.g., a *Human* via manual input or a *Processing* component that, for instance, converts data coming from the machine. *Models* are used to describe the asset or to express system or digital shadow behavior. Here, we have added a *Workflow* model which is processed by a *Workflow Engine*. The *Processing* component is super class to the workflow engine and has a connection to the *Behavior* models as well as to the data traces in use. The data traces can be input, intermediate result, or end result of the workflow execution; behavior models are utilized to specify the computation of the resulting data trace. This way, we have a clear traceability of how and with which input new data traces are computed. Our variant of the digital shadow conceptual model uses one main workflow model which controls the process of aggregating and abstracting. This way, there is no misconception on how data traces are produced and on how the digital shadow acts. Since the workflow model only presents a control structure, the actual computations are modeled in behavior models. Therefore, the workflow model needs to refer to those in the occurring tasks. The workflow engine can then delegate the execution of this behavior model to the responsible processing component.

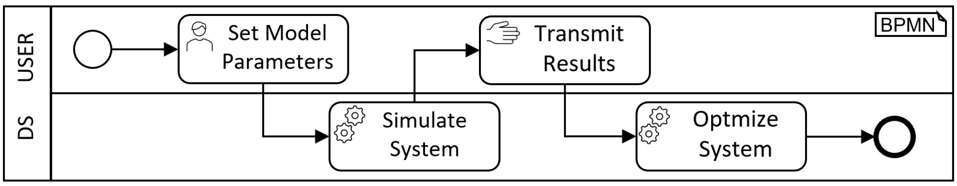

Fig. 2: A human integrated workflow to aggregate data modeled as BPMN.

We demonstrate our concept on a small example. Given a system, the DS first runs an analytic simulation on the initial data set and its result is then used to optimize the asset's parameters regarding some purpose. Before processing the initial data coming from the asset, a domain expert wants to set configuration parameters of both behavior models. The simulation is executed in one software component and the optimization is executed in another. In the current state, there exists no connection which results in a gap in communication. Therefore, a DS operator needs to interact with the system and manually transmit the simulation results to the optimization execution as input. This process is modeled in BPMN as shown in Fig. 2 with one lane for the DS operator and one for automatic tasks, as well as the four tasks of setting the parameters, simulate the system's behavior, manual transmitting between the software components and computing the optimized new machine parameters. For simplicity, we omitted modeling data transmissions in the BPMN model. Fig. 3 outlines how a digital

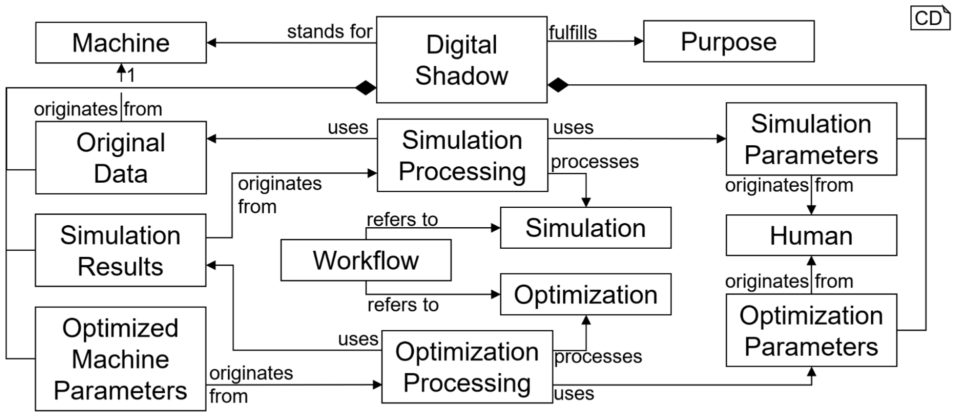

Fig. 3: Exemplary modeling of a digital shadow incorporating a workflow with human interaction.

shadow design benefits from our modeling technique. The DS is composed of the five data traces: *Original Data* as initial input which originates from the machine and is used by the *Simulation Processing*, the *Simulation Results* as intermediate result which now originates from the simulation processing and also acts as input for the *Optimization Processing*, the final result *Optimized Machine Parameters* which only originates from the optimization processing, and finally the two user entered *Simulation/Optimization Parameters*. Both of the processing components process the behavior models referenced by our *Workflow* model. Other elements are left out for the purpose of readability, such as the connection from the DS to the models in use or the workflow engine. In the BPMN model, these data traces would act as in- and output for the different tasks. Data stored in our digital shadow can now exactly be traced back to its origin and to the calculation specifications used for its computation. The human-machine-interaction is modeled in the BPMN model and all set parameters can be stored as well.

4 Discussion/Conclusion

In this paper, we proposed a methodology to incorporate complex and human interactive processes to the modeling of a digital shadow. We extended the conceptual model by a workflow model which captures the individual steps needed for computing the data the digital shadow shall provide. Integrating the human interaction modeled as part of the digital shadow aggregation process changes the way of perceiving the digital shadow as a fully autonomous software component. This lets a digital shadow designer model systems for which the digital automation is not yet as advanced. Workflows can model complex processes with many single activities which might split into parallel processes or loop back to previous tasks. Control logic such as conditional gates allows for actual logic affecting the aggregation process inside.

In the long run, such workflow models could be used to further increase automation or to train new users. If we analyze the manual tasks in workflow models we could further automate, e.g., data transferring between different systems as relevant input and output parameters are already defined in the workflow models. The workflow models can be used within training material and assistive systems [MRV20] which guides the human worker through the processes. Clearly, this approach has to be validated by further use cases.

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