Cognitive Digital Twins: Challenges and Opportunities for Semantic Technologies (Keynote)

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According to the IIC[1], a digital twin is a digital representation of an asset (e.g. sensor, machine, process, product, etc.) that captures attributes and behaviors of that asset suitable for communication, storage, interpretation or processing within a certain context. From a technical perspective, the digital twin includes the data (e.g. master data, time-series data, etc.), models (e.g. 3D models, physics-based models, data-driven models, etc.) and services (e.g. visualization). Since the digital twin usually comprises many different types of data and models and offers proprietary services, having all these heterogeneous entities together introduces interoperability problems.

Additionally, there are many application scenarios where a digital twin is not used in isolation but rather it collaborates with other digital twins to achieve a given objective together. For example, a digital twin of a machine includes digital twins of all its components or a product digital twin interacts with a production digital twin to collect the real-time production data. This results in digital twins for system of system, which usually rely on proprietary solutions. The interoperability between the digital twins throughout their lifecycle may arise and is a challenge for the industry, especially because the digital twins evolve over time.

Semantic technologies are well-known to be suitable for resolving the interoperability problem of heterogeneous and distributed systems. Whereas there are many ontology-based approaches to deal with the interoperability at the data and service level, the interoperability among different models is still an open research topic. In this talk, we will present the ideas and benefits of exploiting semantic technologies not only for mastering the interoperability problems, but rather for providing new level of services to achieve greater potential for industrial applications.

Having a comprehensive understanding of an asset requires to combine its models. To exploit the full potential of different digital twin models we introduce the concept of a hybrid twin. The hybrid twin revolutionizes the digital twin concept by integrating individual models into a holistic digital twin representation

[1] https://www.iiconsortium.org/pdf/IIC_Digital_Twins_Industrial_Apps_White_Paper_2020-02-18.pdf

of an asset to represent and/or infer complex relationships between individual models that cannot simply be detected by a single model. There are several possibilities to combine individual models: (i) sequentially, by providing input for a next model in a pipeline (e.g. a simulation model could be used to generate enough training data for machine learning models); (ii) parallelly, by allowing competition among the models (e.g. majority vote approach could be used for consolidating the results of different models); (iii) exploratory, by fine-tuning the input parameters (e.g. machine learning methods could be used to identify highly-relevant, but non-obvious parameters to enhance the first principle models); etc.

We propose going a step further by introducing industrial knowledge graphs to intertwine individual digital twin models as well as to enable intelligent interlinking of digital twins. By semantically enriching the digital twin models, the model interoperability and higher-level inference can be achieved. For example, questions like what?, when?, how?, in what context?, what-if?etc. can be answered based on reasoning in knowledge graphs.

However, there are many situations where the physical asset cannot be properly understood by its models e.g. due to over-simplification of complex situations[2]. Especially for resolving previously unseen, undesired situations, human involvement is mandatory. A cognitive twin represents the next step in the evolution of the digital twin concept to effectively deal with unforeseen situations by exploiting expert knowledge. It combines human tacit knowledge with the power of digital twin models in order to utilize synergies and enable better reactions in situations where, when tackling the problem alone, neither human nor digital twin models can perform well without interactions.

Formalizing and making available human knowledge is a challenge. Advanced methods for knowledge extraction from software systems (e.g. bug reports), existing documents (e.g. related to quality control), by analyzing on the fly what an expert says or even by observing experts during their intervention are needed. Semantic technologies could be used for enhancing these methods by proving a controlled vocabulary, by guiding the extraction and annotation tasks and by providing mapping into the digital twin structure to have effect on digital twins behavior. The resulting cognitive digital twin will be an intelligent entity, which does not only recognize a problem, but rather has deep understanding of a given situation, supporting the decision whether, how and when to react.

[2] Zillner, S., et all (2018). Data-Driven AI for European Economic Competitiveness and Societal Progress: BDVA,11/2018.