Semantics for I4.0 Smart Manufacturing (Draft)

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Abstract: The properties of things, respectively properties of energy transportation shall be described in terms of formal operational syntax and semantics. The explanation of semantics shall be achieved on two levels. The the first (informal) level explains semantics as a narrative of how things are processed in an SM plant, whereas the second (formal) level defines semantics by graph manipulations which represent sequences of events being morphic to the narrative of processing of things. At same time a graph is also computational in terms of appropriate tools from the shelve. Thus graph computations and told narratives are ‚similar', respectively ‚comparable' to each other, since they are restricted by a morphism i.e. the formal relationship of artifacts of graphs to the artifacts of narration.

Keywords: I4.0, Security & Safety, Industrial Automation and Control Systems, Digital Twin, Production Ontologies, Smart Manufacturing, Asset Administration Shell, OPC-UA, AutomationML, OT/IT Security, Syntactic and Semantic Interoperability.

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1. Meaning of Smart Manufacturing

1.1. What is the Meaning of Smart Manufacturing?

[computerweekly.com] on its page defines ‚Smart Manufacturing (SM)‚ as ‚the approach of control of distributed production machines for the purposes of automatization and optimization‘ of interconnected production processes, whereas automatization is based on safe and secure interconnection systems and optimization is based on production data analyses.

Similar [wikipedia.org] defines ‚Smart Manufacturing‚ as a ‚category of manufacturing using computer-integrated manufacturing. SM is characterized by ‚high degree of adaptability, rapid design changes, optimized supply chains, efficient production etc.‘. Making manufacturing smart may include new technologies like ‚big data processing capabilities, industrial connectivity of devices and services, robotics, Internet of Things, Machine Learning, Human-to-Machine, Machine-to-Machine Communication etc.‘ and last not least Syntactic and Semantic Interoperability. etc.

The Reference Architecture Model of I4.0 (RAMI4.0) [https://www.dke.de/de/arbeitsfelder/industry/rami40] represents a ‚three-dimensional roadmap‘ that guides through the I4.0 landscape comprising the three dimensions of the IT layers of considering assets, of the life cycle of assets, i.e. the product type and instance management, of the hierarchy of a distributed production plant beginning with the basic product up to the connected world of enterprises.

1.2. What is the Meaning of an Asset?

The asset is the central element of RAMI4.0 since each asset has a certain function and specific properties which are to be described on every IT layer, in every phase of the life cycle and on each level of the plant hierarchy.

An IoT ‚*thing*’ respectively an ‚*asset*‘ according to RAMI4.0, could be built by a plant that processes things by using *Smart Manufacturing* (SM) Technologies. Another example could be a plant that generates electrical energy (to be the asset) for a remote production plant and manages the energy transportation by automatized control processes.

The properties of things, respectively of energy transportation shall be described in terms of formal operational syntax and semantics. The declaration of semantics shall be achieved on two levels. The the first (informal) level explains semantics as a narrative of processing things in a SM plant, whereas the second (formal) level defines semantics by performing graph manipulations that represent sequences of events being morphic to the narrative of processing things. As anticipated a graph is also computational in terms of appropriate simulation tools from the shelve. Thus computational graphs and narratives are‚similar‘, or ‚comparable‘ to each other, since they are restricted by a morphism i.e. the formal relationship between artifacts of graphs to the artifacts of narration.

2. Informal Semantics of Smart Manufacturing

2.1. SM Complexity

Industrial Standards such as the multiple part IEC62443 standard on Security of Industrial Automation and Control Systems (IACS) that is currently elaborated by a couple of standardization committees such as ISA99, ISO JTC1/SC27/WG4, IEC TC65/WG23 etc. become more and more complex in the sense of yielding a common understanding, e.g. with respect to a unique implementation, thus interpretation of a production system that shall be conform to a set of complex standards with complex dependencies.

2.2. SM Informal Semantics Collection

With respect to the issue of semantics the so-called ‚System Committee on Smart Manufacturing (for short: SyC SM)‘ has started a task force called ‚ISO/IEC Joint Smart Manufacturing Standards Map (for short: TF SM2)‘ to solve the issue of a common understanding of a set of standards by a methodology based on classification of technical concepts. The classification activity is supported by a platform of tools comprising visualization and a central repository of classified data.

The process of SM Standards Classification comprises three steps:

1. to collect formats and characteristics of standardized products or of processes of production (Notice: In future this step needs to be supported by a SM2 Vocabulary that is to-day not available);

2. to actualize parameters of SM standards by assigning specific values to the characteristics of standards identified in the SM2 catalogue;

3. to perform tool-supported graphic analysis in 2D or 3D graphic representations to standards contained in the SM2 catalogue.

The method of graphic analysis means the mapping of product or production characteristics to two, three or more dimensional axis representing a standardized Reference Model, i.e. the Life-Cycle Phases of Product Types or Production Systems Model.

2.3. SM Characteristics Language

E.g. if you would like to inspect the SM2 catalogue in order to retrieve some features from the PLC (i.e. Production Life Cycle of IEC 61131-4) language then you may get the following ‚answers‘ depending of the used classification schemes:

<product class := control> & <production system phase := design | implementation> & <product usage := functional layer>;

where ‚product class‘, ‚production system phases‘, ‚product usage‘ are dimensional components of a more-dimensional asset characteristic and ‚control‘, ‚design‘, ‚implementation‘, ‚functional layer‘ are characteristic values that are assigned to the dimensional components.

The ‚language‘ used above describe data of SM characteristics that are represented by <tuples> [cp. Section 12 in Zohar Manna and Richard Waldinger ‚The Logic Basics for Computer Programming, Addison Wesley Publisher 1985] that may contain none, one or more elements, i.e. asset characteristics. Each element of a tuple is an atom (not compared to lists where an element could be another list). Thus an asset characteristic is a tuple-atom specified by a pair of:

(ID_{char} := VAL_{char}), with the separator ‚:=‘ .

2.4. SM Asset Interoperability

The standardization documentation series of JTC1/SC41 of the IIoT project ‘ISO 21823’, i.e. IoT Framework, Transport Interoperability, Semantic and Syntactic Interoperability, distinguishes explicitly between syntactic and semantic ‘Interoperation among Industrial Things’ - whereas 21823 part 4 describes syntactic and 21823 part 3 describes semantic “Interoperability between IoT Models”.

Thus syntactic interoperability means syntactic data exchange among multiple information modelings of IoT data - semantic interoperability means data exchange among multiple IoT device ontologies.

In the IEC white paper(2019) ‚Semantic Interoperability‘ it is defined that ‘semantics and semantic interoperability’ comprises ‘linked (data) structures onto which data is mapped and then it is propagated across these structures to produce new data; the latter operation is called inferencing’.

The mapping to semantic structures (i.e. artifacts), however is a kind of “assignment”, namely specific assertions about the asset some kind of metadata, are assigned to characteristic data types. In standardization the metadata assignment to data types often is denoted annotations or labelling. However the latter is more or less bound to ‘AI Data’ and the former to ‘Big Data’.

(Notice: In the SemNorm project of the German DKE the preference is given to the concept of assignment because it is an arbitrary activity and can change during life cycle of the asset considered and thus of the metadata assigned.)

The Standardization Committee SC42/WG3 on AI in the documents of ISO SC42/WG3 24029-2 and SC42/WG3 TR24029-1 does not directly address semantics even not in the realm of Validation and Verification of Robustness of *Neural Networks (NN)*. However Formal Method Techniques should help ‘to determine strong (robustness) properties that are proven true on a whole domain of inputs to a NN and not just isolated ones’ of ISO SC42/WG3 24029-2. The essence is on proving properties with formal methods

> (Notice: Proving properties are also applied by the DKE SemNorm Project by which the properties to be proven are directly represented by semantical artifacts and indirectly by terms of language artifacts (e.g. such as *CSlang* of ETSI in GS ISI006).

based on many-sorted Algebras and because of this kind of mathematics it is designed to be computational. The textual language term artifacts share the identical semantics of the given formal methods approach. Thus a term may have the same semantical meaning as a piece of behavior of a Digital Twin (Model) in the semantic domain.

In the TR24029 of SC42/WG3 it is stated that the NN Architecture is ‘hard to explain … and have non-linear behavior’. As a result formal methods are needed which are grouped into:

1. statistical methods
2. empirical methods
3. (other) formal methods.

The third group contains e.g. a method to calculate the uncertainty of the learned Data Model of a NN which is the case when an NN has ‘an insufficient interpolation performance and thus insufficient robustness’ of TR24029 of SC42/WG3. Another example method would be the measurement of adversarial input around a given point which is achieved by the ‘notion of distance’ of SC42/WG3 and an optimization algorithm that look for a maximum of distance among good inputs of a set of inputs.

3. Formal Semantics of Smart Manufacturing

In figure 1 the diagram shows the isomorphy between digitalization and modeling providing with same semantics of the anticipated Digital Twin. Digitalization is the process of translating the cyber-physical assets into the semantic representation of an anticipated digital twin. Modeling is the process of translating syntactically described assets into semantic representations. From SM standards a ‚guided derivation‘ lead to acceptable implementation of cyber-physical assets. Similar by applying rules of formalization a syntactic representation will be derived.

Thus Isomorphy ensures that both mappings, i.e. the technical and the formal translation, result in the identical digital twin.

The formal translation comprises the nodes of:

A. (English-written) Standards of SM Ontology

B. Regular Terms of SM Signatures (Syntax)

C. Computational Model of the Digital Twin (Semantics)

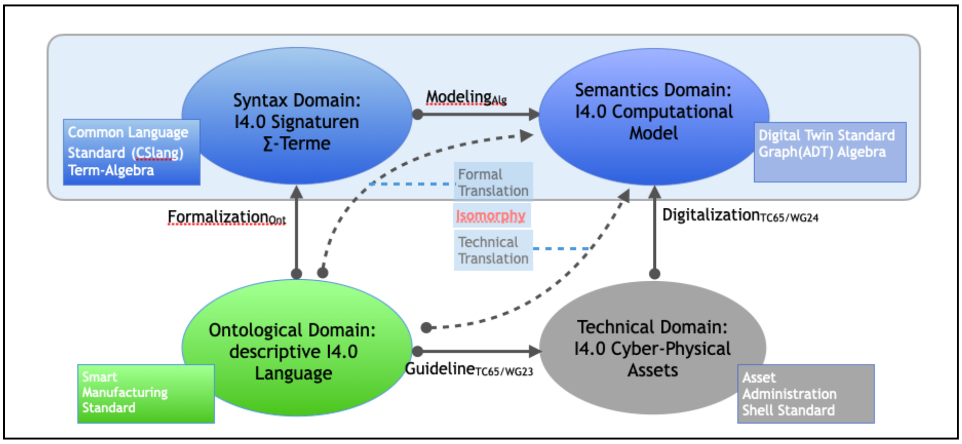
The technical translation comprises the nodes of:

A. (English-writtten) Standards of SM Ontology

B. Programmed Terms of SM Behavior (Programming)

C. Computational Modle of the Digital Twin (Semantics)

Notice isomorphy means that both paths the formal translation and the technical translation have in common the starting points (A) and the end points (C). However the intermediate nodes (B) are different. Thus standard descriptions and semantics of Digital Twins are fixed whereas the signatures and programs can freely be chosen such that



isomorphy is not violated.

figure 1: I4.0 Methodology: Isomorphy between Digitalization and Modeling

The isomorphy property is useful for validation or verification purposes of the free derivation of the digital twin from a set of standards by comparing the results of both paths i.e. the one of using guidelines and digitalization and the other one of using formalization and modeling. The degrees of freedom which are proven are the programming and the definition of signatures.

4. Semantics of Interoperability

The formal semantics based on graph theory shall demonstrate the interoperability between two big systems of a smart grid power management system (according to IEC TC57) and a smart manufacturing fabric (according to IEC TC65).

5. Conclusion

It has been shown that formal semantics using graph theory makes sense in the SM domain because it provides mathematical and operational correctness. Operational correctness can be proven by applying graph manipulation tools, by which forward and backward simulation can be evaluated. Whereas predictive maintenance

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