Ontology Based Semantic Interconnection of Distributed Numerical Simulations for Virtual Production

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Abstract

The focus of this work is to promote the semantic interconnection of distributed numerical simulations for virtual production systems. The product planning phase usually requires a huge range of various numerical simulations that are used by different departments of a company. To effect increasing productivity on the one hand and reducing complexity of simulation chains on the other hand it is essential to be able to interconnect the differing syntax and semantics of the distributed numerical simulations. The interconnection is realized by an ontology based data integration tool that is used within a simulation platform.

1. Introduction

A manufacturing company in a high-wage country has to position themselves in two stress fields. The first stress field is between the mass production with a very limited product range (scale) and the manufacturing of products with a very large variety in small quantities (scope). The second stress field involves the dichotomy between planning and value orientation. The vertices of this stress fields shaping the so-called polylemma of production technology (Figure 1) [1]. To create a lasting competitive advantage over low-wage countries, it is necessary for the research to develop methods to reduce or to dissolve the polylemma. It is not enough, to examine and optimize just a singular vertex to satisfy the desire of customers for a tailored product to the cost of a mass product, because every change on one of the four vertices affects the corresponding vertex.
The Cluster of Excellence "Integrative Production Technology for High-Wage Countries" at RWTH Aachen University is engaged in the reduction of the mentioned polylemma. In the integrative clusters domain (ICD) "Virtual Production Systems" the issue of the second stress field is discussed. The development of a simulation platform for the interconnection of simulations that are used in the product or production planning process is one objective of the ICD. The simulation platform realizes to build up whole simulation chains according to a specific manufacturing process. The use of automatically interconnected simulations reduces the stress field orientation of the planning orientation towards value orientation, whilst ruling out that there will be a reduction in the quality of planning. The challenge lies in the combination of monolithic simulations to represent an entire production processes sensible for virtual production [2].

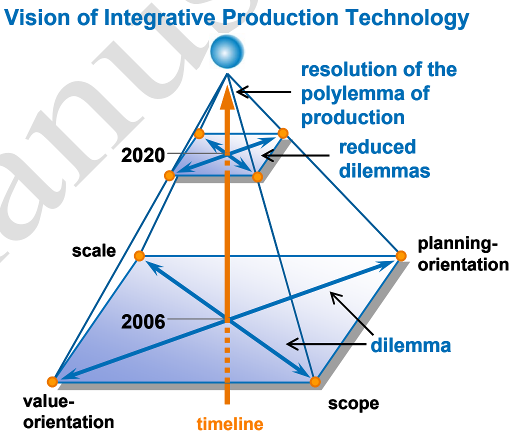

Figure 1. Polylemma of production

This paper shows the components of software that enables the simulation platform to interconnect simulations syntactically and semantic. Here process simulations, such as welding or forming of the assemblies and microstructure simulations to look at the fabric of the assembly, are considered. Focus is on the components necessarily needed for the syntactic and semantic interconnection. Then on the basis of an use case the application of the platform is described. The paper closes with a summary of the idea of the simulation platform.

2. Use Case

The interconnection of simulations used in a manufacturing process of a gear wheel is considered for the validation of the simulation platform. The gear wheel is manufactured in several working steps (Figure 2). Two levels of detail are examined in the manufacturing process of a gear wheel. The first level of detail is linked to macro-structure processes like forming, heat treatment

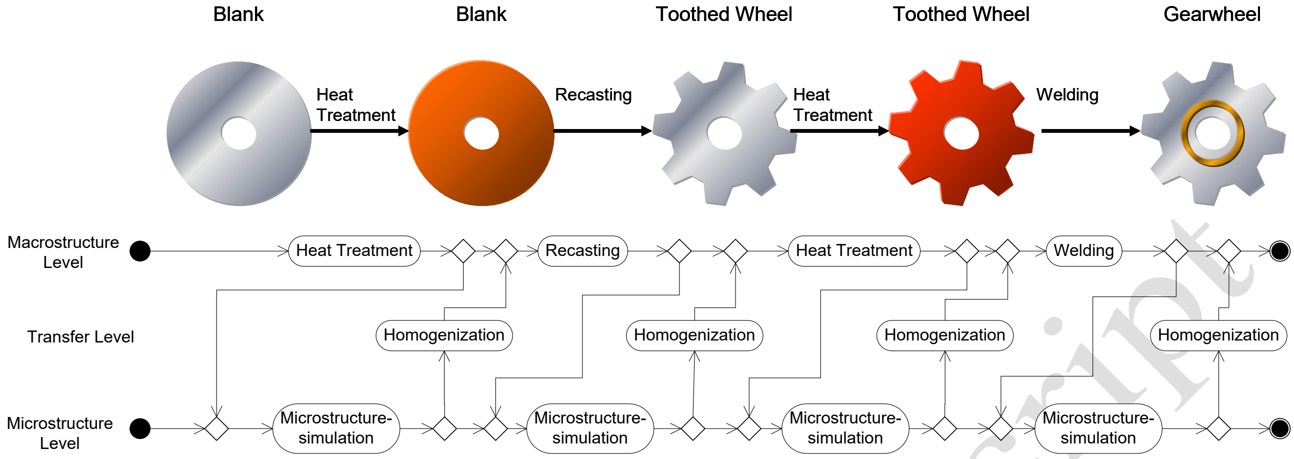

Figure 2. Simulation chain "gear wheel"

and welding. The second level of detail is linked to the examination of the micro-structure. The micro-structure data is homogenized on a transfer level for the use on the macro-structure level.

Each simulation that is used in the manufacturing process must be integrated in the simulation platform. That means all used parameters of the five simulations must be represented by meaning and value. The meaning is stored in the simulation platform, the values are provided by the simulations. By this meaning includes: unit, range and context.

In the use case the blank will get a heat treatment as a preparation for the recast process, in order to use the best material data a microstructure analyses will be made after every macrostructure process step. With the results of the heat treatment we will find out the micro-structure data for a few representatives points of the blank. In order to use this information for the whole macrostructure a homogenization tool is used to step up the micro-structure data to the macro level. The results of the heat treatment and the micro-structure simulation are used as input for the following recast process. This procedure is repeated for the next heat treatment and the welding process [3].

The simulation platform gathers all parameters that are needed for a complete and automated run through the whole simulation chain. The platforms user has to select the manufacturing process that should be simulated via the simulations that are integrated in the platform. The user has to provide all data that is not generated by the simulations before the simulation chain is started. The simulation platform will organize and administrate the order of the simulations to match the manufacturing process. Furthermore it will provide for each simulation the input data.

Via the components of the simulation platform the syntactic and semantic simulation interconnection is realized. On the base of this interconnection many manufacturing processes can be represented by the simulation platform via using the simulations in different orders. All parameters and their values that are generated by the simulations are available for every downstream simulation in the chain. Thus, in any further process step which will be simulated the entire process history is accounted, this leads ultimately to a better data set for all simulations.

In the following section the software architecture of the simulation platform with its main components for the semantic interconnection is displayed.

3. Simulation Platform

The system architecture for the simulation platform consists of the platform itself and the simulations that are linked to it. Figure 3 shows the system architecture of the platform. The platform consists of the components Web Interface, Visualization, Data Integrator and Middleware. The Web Interface is part of the human machine interface which also includes the visualization. It serves the operation of the platform by the user. The user can choose the process steps that should be simulated and the order of the process steps. Data that is not generated by the simulations or producible by the Data Integrator component out of the simulations results must be entered via the Web Interface through the user. The visualization presents the simulation results, either individually or comparatively. For example, the results of the simulations can be displayed as single results or as interlinked results. For the interlinked representation all or a collection of results can be used. Through this representation the user is able to take a parallel look at the effects of a change in the macro and microstructure at every time step of the manufacturing process. The Middleware is used for data exchange between the platform components and the platform and the simulations. The components and the simulations are distributed through a network. The Data Integrator is required to realize the syntactic and semantic interconnection between the simulations and to ensure that the chosen manufacturing process can be displayed by the simulation platform correctly. The described components of the simulation platform should work as services in a service oriented architecture [4].

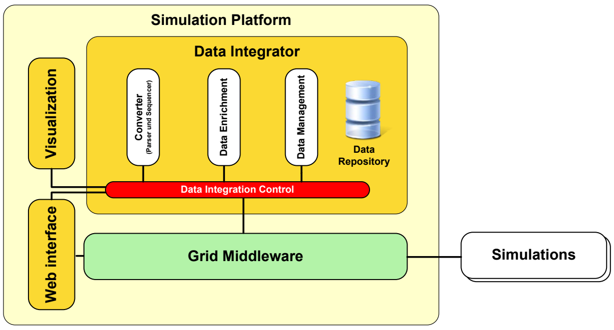

Figure 3. Simulation Platform

In the following sections the components of the Data Integrator that are used for the syntactic and semantic coupling are exposed. The Data Integrator uses as components a Data Management, a Data Enrichment, a Converter, a Data Repository and a Data Integration Control. The Data Repository is used for the storage of the simulation in- and output data and process related information. As an interface for the communication between the Data Integrator and the other components of the platform the Data Integrator uses a Data Integration Control component. The whole in- and out coming data of the Data Integrator is administrated by this component. The Data Integration Control coordinates the data transfer between the Data Integrators internal components and the order and time of execution of these components. Because of the minor scientific interest in the functionality of the Data Repository and the Data Integration Control the following sections does not go into detail on these components.

Converter

Figure 4 shows the software architecture of the Data Integrator subsystem Converter. The Data Integration Control executes the component Converter Core. The Main objectives of the Converter are to convert simulation data in a common format and to convert simulation data out of the common format.
Most simulations are developed as monolithic software with specific in- and output data format and structures. In order to compute the data of another simulation, the data must be converted from its origin form to match the requirements of the actual simulation. Because the simulations are used in different manufacturing processes in different on the process depending orders and because it is not useful for the syntactic interconnection of the various simulations to use for each connection a converter, this would rise the number of converters with each other to be integrated simulation exponential $(n^2\text{-}n)$. Instead of the adoption of many converters, two configurable converters are used. A parser converts the simulation data, which is provided in specific formats into a common format. A sequencer converts from the common format to the simulation specific formats. The Visualization Toolkit (VTK) [5] is used as common format for the Data Integrator. By using the common data format all simulation data is provided by the Data Integrator in a format and can be processed by the later mentioned Data Enrichment without further conversions.
To achieve these tasks the Converter needs following components: A Converter Core as an Interface to the Data Integration Control and to control the subsystem. A Configuration File Reader to read and interpret a file that contains the information which conversions should be performed. A Data Input Reader to read and interpret the files that are generated by the simulations. A VTK Reader to read and interpret VTK files. A Data Output Writer to provide the files that are needed by the simulations. A VTK Writer to provide the achieved data to the simulation platform. The Conversion Routines comprehend all needed routines to get from one format into another.

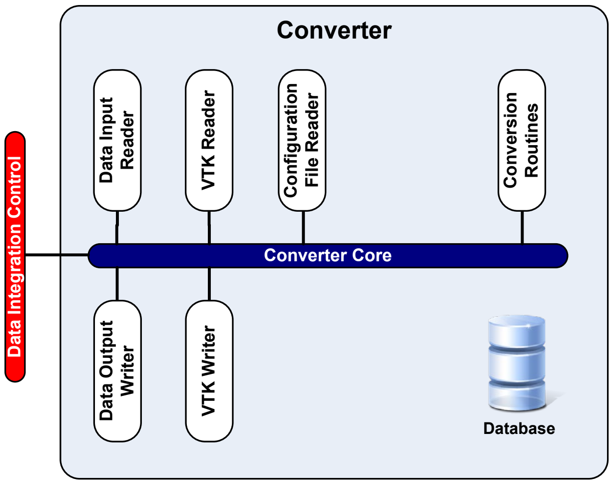

Figure 4. Converter

The Converter Core decides based on the data provided by the Data Integration Control if a simulation file or VTK data must be computed. Depending on this decision the needed configuration file is processed. For every file format one configuration file is needed. After processing the configuration file the Data Input Reader

or VTK Reader gathers data that will be converted by the Conversion Routines, all Routines that are needed are stored in this component, if you need new conversions, because you integrate a new simulation to the platform, you have to extend this component.
The before mentioned generation of data or integration of former simulation results to a simulation input file, will happen in VTK format. In the following section the Data Enrichment is described. The Data Enrichment realizes the semantic interconnection.

Enrichment

The Data Enrichment (Figure 5) subsystem of the Data Integrator consists on following components: A Query Processor, a Reasoner, a Knowledge Base Parser, a Knowledge Base, a Compiler and a Planer.
To interconnect the simulations with different semantics a common interface is needed, the Data Enrichment will provide this. All information concerning the parameters used by into the platform integrated simulations is stored with the additional information value, value range, dependencies and context in the Knowledge Base. Via the Data Integration Control the Query processor has to compute the query if a certain parameter is generated by a simulation, part of a manual input or can be generated and provided through the Data Enrichment. For example one simulation generates a value for the parameter amperage (I), another simulation generates a value for the parameter voltage (U), but the next simulation needs a value for the parameter resistance (R) then the Data enrichment will transform amperage and voltage following the algorithm U/I=R to the resistance [6].

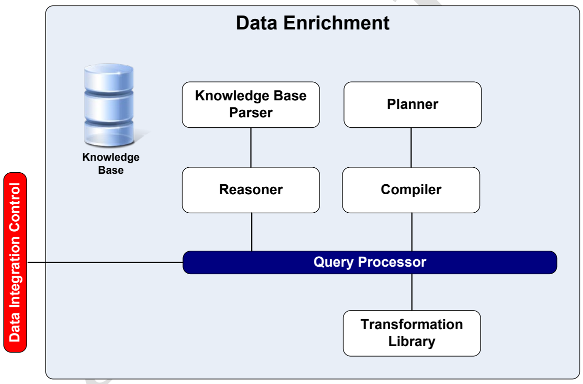

Figure 5. Data Enrichment

The stored parameters are represented by an ontology [7]. The Knowledge Base Parser provides information out of the Knowledge Base to the Reasoner. To compute a certain query the Query Processor has to gather all information concerning the query via the Reasoner out of the Knowledge Base by using the representation structure of the ontology. After all needed information is available the Planner is used to identify the needed transformations like the examples algorithm. The Compiler uses the identified transformations out of the Transformation Library to perform the transformation. Then the Query Processor can provide the generated data to the Data Integration Control.
A different case can be the identification of equal data that is represented by the simulations in different ways. A material is represented in one simulation by its chemical composition and in another simulation by its name (e.g. 20MnCr5 = Saarstahl), without knowledge concerning the meaning no direct conversion is possible, by using an ontology which represents this additional information an transformation can be chosen to provide this parameter to the next simulation.
Cooperation of the above mentioned components of the subsystem Data Enrichment enables the Data Integrator to connect simulations not only on the level of syntax but on level of semantics. The ontology, of which the importance of individual parameters is derived, makes semantic mappings possible. Parameters respectively their values assigned to their importance and meanings will be linked for comparison. The comparison performed by the Data Enrichment will run through following steps. First it will be checked whether the meanings directly match. If this is the case, the parameter values will be directly circulated to the Converter. The second step in comparison is used when the first does not generate a result. If the Data Enrichment does not find a direct matching it must be checked if the required data can be generated via the use of the Transformation Library out of existing data. If so, the parameter values will be generated. Should this not be possible the missing data must be made available via the web interface by the user. The data that is provided by the user via the Web Interface is also stored in the Knowledge Base [8].
The next section describes the subsystem Data Management.

Data Management

The component architecture of the subsystem Data Management is shown in Figure 6. The Data Management consists of a Database, a Data Management Control, a Storage Manager, an Indexer and a Data Extractor.
Via the Data Integration Control the core component of the Data Management the Data Management Control is executed. The task of the Data Management is to provide data and additional information concerning the data. To be able to solve this task the Data Management has to index the data and to store the indices related to the data and information. If certain data and information has to be

provided for the Data Enrichment the Data Management uses the Data Extractor component to identify the needed data and information and extract these from the Database via the indices.

The next section will give a brief summary of the promoted Data Integrator as an ontology based semantic interconnection of distributed numerical simulations for virtual production.

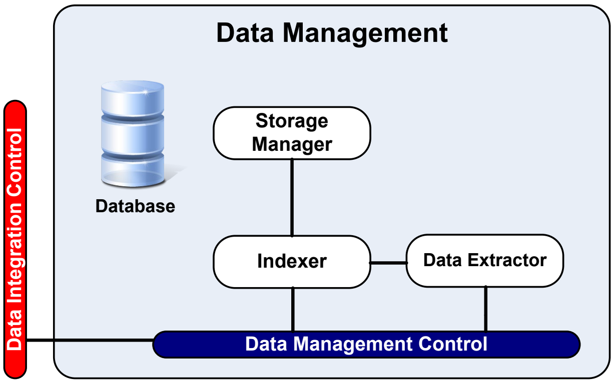

Figure 6. Data Management

4. Summary

The need for semantic interconnection of distributed numerical simulations derives from the need of reducing the planning effort of production processes and therefore the requirement of flexible simulation chains. Investigating in this research means increasing the insight and understanding of the scientific and the technical processes, the product quality or the market advantages as well as reducing production costs. This paper has introduced a concept of semantic interconnection of distributed numerical simulations. It also presents how it can be realized by using a Data Integrator. The approach shown of semantic interconnection by using an ontology that is representing the simulations parameter, -value, -value range and –meaning has the advantage that all in- and output data of the whole simulated process chain are correlated and stored, this will affect the loss of semantic information. It can be reduced to a minimum, because every data is linked to a certain process step of the simulation chain. This circumstance allows identifying the completeness of the requested data. If it is not complete the system is able to localize the missing data and where the missing data can be generated.

To increase the understanding of how the semantic interconnection of distributed numerical simulations can be successfully implemented as basis for the realization of virtual production systems is the main research goal. The development of tools and techniques to support the interoperability of simulations along the process chain supports the achievement of the main goal.

The simulation platform is the first step in implementing a virtual production system that contains the product planning, the process planning, the process itself, the process chain and the factory design planning [9]. The simulation platform enables the user to observe manufacturing process from the scale of microstructure of the used material up to the scale of linked manufacturing process steps.

Acknowledgements

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