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SIMULATION AND INTEROPERABILITY IN THE PLANNING PHASE OF PRODUCTION PROCESSES

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ABSTRACT

Interoperability is a progressive issue in the development of holistic production process simulations that are based on stand-alone simulation interconnections. In order to tackle the problem of missing interoperability, the standardization of simulation and model interfaces and transfer protocols can be taken into account. This procedure is endorsed by many organistaions like DIN ISO, IEEE, ASME or SISO and one of the most effective proceedings if a new simulation is developed and if the source code of the used simulations is available as well as changeable. However, as most simulations for a holistic production simulation already exist and as those simulations are usually isolated, high precisely solutions, which have no common interfaces for interconnection, a different approach is needed. The contribution at hand focuses on a framework that provides adaptive interfaces to establish interoperability of stand-alone simulations.

1. INTRODUCTION

By reason of low costs, production in low-wage countries has become popular in the last few years. To slow down the trend of outsourcing production to low-wage countries, new production concepts for high-wage countries have to be created. Therefore today's production industry in high-wage countries is confronted with two dichotomies: value orientation vs. planning orientation as well as economies of scale vs. economies of scope.

Developing new concepts means to overcome the polylemma of production, shown in Figure 1, which summarizes the two dilemmas mentioned above. Future-proof production systems have to accomplish the apparent incompatibility of the two dichotomies. To improve the competitiveness of production in high-wage countries compared to production in low-cost countries, it is not sufficient to achieve a better position within one of the dichotomies; it is necessary to resolve the polylemma of production [1]. The research questions pursued within the Cluster of Excellence "Integrative Production Technology for High-Wage Countries" aims at dissolving this polylemma.

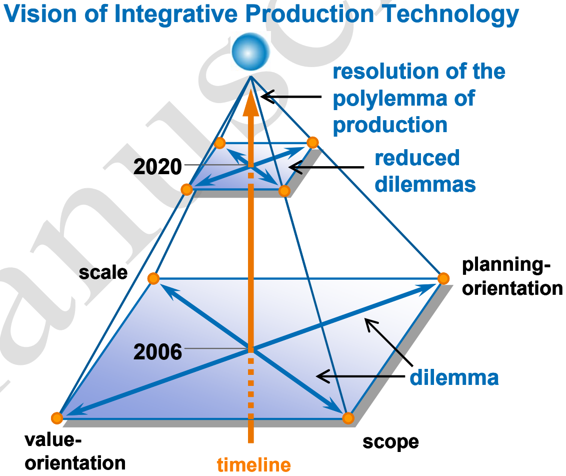

Figure 1: Polylemma of production

This research cluster unites more than twenty institutes and companies collaborating for this purpose. Professional competencies of the research partners are domain specific for certain aspects in production processes.

These companies and research institutions have implemented simulation applications, which diverge from each other with regard to the simulated production technique and the examined problem domain. One group simulates specific production techniques with exactness close to the real object. The other group that comprise a holistic production process do not achieve prediction accuracy comparable to the one of specialized applications. However, both types are state-of-the-art and commonly applied in university research. Furthermore most of the applied algorithms are not yet implemented in commercial tools. Hence, the simulation of a holistic production process is often not realizable due to insufficient prediction accuracy or the missing support of the regarded production techniques.

The combination of existing simulations covering and addressing specific aspects in process chains suggests creating a new and augmented comprehension of process chains as a whole. Using adequately simulated input parameters, which reflect the production history, to feed the next simulation in the chain, will most probably produce better results for that specific simulation than using standard assumptions or pre-computed values to parameterize the model. While the overhead for modelling and planning will be increased by simulating entirely interlinked processes, the expected results will be more accurate. Hence criterion for judging this highly planning oriented approach is the better value of the benefits in terms of insight, understanding, efficient technical processes, lower production costs or higher product quality without ignoring the costs of creating simulated process chains [2].

In solving the problem, it is necessary to interconnect different specialized simulation tools and to exchange the resulting data. However, the interconnection is often not achievable because of missing interoperability. To establish this interoperability of stand-alone simulations four levels of heterogeneity must be overcome. The first level comprises the technical heterogeneity. On this level, a communication infrastructure for data exchange has to be established. This problem is already solved by using middleware applications. On the second level, the syntactic heterogeneity is handled, which means that a common data format must be introduced with regard to information exchange. The third level addresses the semantic heterogeneity. The meaning of data and information has to be distributed, as an unambiguous definition of the information content is needed. The fourth level consists in the pragmatic heterogeneity. On this level, the differences between the used methods and procedures have to be compensated [3].

2. RELATED WORK

In the field of simulations, the process development time using manually linked simulations incurs an overhead of 60%, caused solely by the manual operation of the individual simulation components and conversion tools of a simulation chain [4].

At the same time, integration problems belong to the most frequented topics with reference to finding answers to questions which are raised across application boundaries [5][6]. The complexity of such integration problems arises by reason of the many topics that have to be regarded to provide a solution. Besides application interconnection on the technical level, the data has to be propagated and consolidated. Furthermore, user interfaces are required to model the underlying process and a unified visualization of the data for the purpose of analysis. The necessary visualization depends on the requirements of the user and therefore has to consider the user's background. In addition, the integration of data requires the understanding and thus the comprehension of domain experts. Because of those reasons, integration solutions are often specialized and highly adapted to the specific field of application. One example for such a solution is the Cyber-Infrastructure for Integrated Computational Material Engineering (ICME) [7] concerning the interconnection of MATLAB applications. Other examples are solutions that require making adjustments on the source level of the application, like CHEOPS [8] or the FlowVR toolkit [9]. Yet others require the implementation of standards like SimVis [10]. Realizing a flexible solution, the technical, the data and the analysis level have to be taken into account.

The interconnection on the technical level has been researched intensively. Several solutions have been presented during the last years [11][12][13]. In particular the use of middleware technologies has been established to provide a solution to such kind of problems. Middleware solutions used in the field of simulation interconnecting often require linking of hardware resources, in addition to the associating of the simulations. This issue is addressed in the field of grid computing. Popular grid middleware agents include Globus (www.globus.org) [14], g-lite (glite.cern.ch), UNICORE (www.unicore.eu) [15] and Condor (www.cs.wisc.edu/condor) [16].

Concerning the data and information level, a conversion of the data syntax is not sufficient. Instead, the structure and the semantics of data have to be considered in the conversion process [17][18][19]. For such processes, the usage of schema- and ontology-based integration methods [20][21][22] has been established as a solution. Thereby, research mainly focuses on data schemas based on the relational or XML data model. In this respect, knowledge bases containing background knowledge about the application domain are often used to facilitate the semantic integration of data[17][23]. There are various research projects in this field which have produced different solutions for schema- and ontology-based integration, like COMA++ [24][25] and FOAM [26][26]. Both systems feature algorithms analyzing the structure of the schema and do not regard the stored dataset. Hence, these systems are unable to identify different dataset semantics within one schema.

3. INTEROPERABILITY

The core objective is to achieve interoperability of the simulation tools without negating the autonomy of the individual applications. In this respect, autonomy means the degree to which the various applications can be developed and operated independently of one another [27]. The development of standards and an application's need for implementation of such standards, in particular, constitute intervention in the autonomy of the individual applications. Often such intervention is not possible for technical, legal or competition-related reasons. Simulation tools developed within the field of production technology are characterised by different data formats, terminologies or definitions and the use of various models. The integration system developed creates a basis for overcoming the heterogeneity between the simulation tools, as mentioned in the introduction.

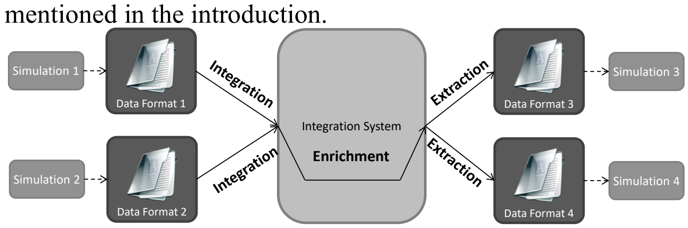

Figure 2: Semantic interoperability between simulations

Figure 2 depict that Integration, preparation and extraction are key functionalities for interoperability realization. Through integration, data provided by a simulation tool in one data format is transferred to the central data store of the integration system then, using extraction, this data is converted into the data formats of other simulation tools while the semantics of the data are retained. To this end, there is a data preparation step prior to the actual extraction in which the data provided is transformed using semantic transformations to make it suitable for extraction into a specific data format. Hence, some material processing simulation tools require, for instance, specification of the outer surfaces of a component's geometry. This information, however, cannot be contained in the data captured. Within data preparation, these surfaces are automatically identified and enhanced in the data. Extraction takes this data into account and can therefore deliver a valid geometry description.

The basis for the integration system is the AdIIuS framework (Adaptive Information Integration using Services) developed in the Department for Information Management in Engineering at RWTH Aachen University, Germany [28]. The AdlluS provides a basic framework for integration systems in which applications with complex data models and formats are integrated along a process allocated during run time. It was built in this Cluster of Excellence in order to facilitate the development and networking of other integration systems in the field of production technology. The framework is based on process-driven information and application integration. This means that each request is handled by means of a process of pre-defined work steps. In this respect, application integration involves tracking the provision of data for the simulation tool used in the next simulation process, while information integration entails integrating the data provided into the central data store of the information system.

The integration system must first integrate the result data into the collected simulation process data and then provide the data for the next simulation in the simulation process. In so doing, it is essential to overcome the heterogeneity of the data formats and models of the simulation tools by applying transformations.

The integration stage of the process involves transferring the data from the data model of the data source into the central data model of the integration system, the "canonical data model" [29]. Given the volume of data and the complexity of the data structures, the canonical model used in the integration system is a relational database model. Besides the relational model, the AIIuS framework also supports other canonical data models. Hence the data can be deposited in the XML data model, for example. The integration process is based on the ETL process whereby first the data source is opened to allow the data to be extracted, then the data is transformed so that it can be loaded into the canonical data model. Data transformation to achieve the necessary syntactic and structural adaptation does not, in this case, produce any changes in the semantics of the data. Semantic transformation is not executed until the data preparation stage. In order to distinguish between the different types of transformation, the transformations designed to overcome syntactic and structural heterogeneity will hereinafter be referred to as data transformations, while the transformations executed in the data preparation stage to overcome semantic heterogeneity will be referred to as semantic transformations.

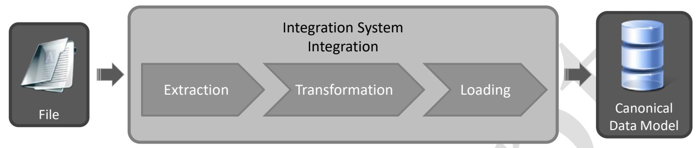

Figure 3: Integration process

Once the data has been integrated into the canonical data model, it can be prepared for extraction. Within the AIIuS framework, this is achieved through a combination of methods from semantic information integration and artificial intelligence planning. Data preparation results in transformed data with semantics that meet the requirements of the data format to be extracted. Data preparation also comprises enhancement with new information, e.g. the temperature profile in selected points.

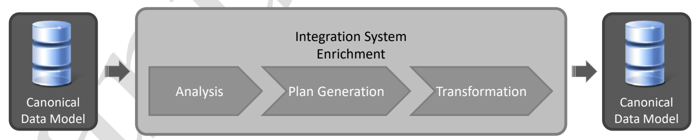

Figure 4: Preparation process

Data preparation uses the structure and methods of schema integration. In this respect, the focus is on overcoming semantic heterogeneity. Generic schema integration processes, such as DELTA (Data Element Tool-based Analysis) [30], DIKE (Database Intensional Knowledge Extractor) [31][32], which operate on the basis of the identifiers and the structure of the schema, may well provide an initial approach, but they are not sufficient for identifying the required semantic transformations of the data accumulated in the integration system. Likewise, instance-based processes like iMap [33], Automatch [34] and Clio [35], which are designed to identify correspondences using the datasets included, are also inadequate. This is because the actual transformation process depends not on the schema, but on a specific dataset and is only applicable for that dataset. In a first step, the preparation process analyses the data concerned according to the kind of attributes and identifies the requirements placed on the attributes by the target schema. In a second step, a plan is generated which contains the transformation process for preparing the data. The actual semantic transformation of the data takes place in the third step. Below is a description of the extraction process which ensures that after it has been prepared, the data is transferred into the required data format and model.

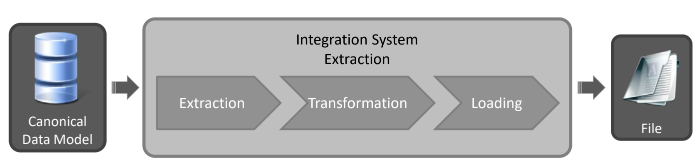

Figure 5: Extraction process

During extraction, first the data is extracted from the data store. Its structure and syntax is then adapted via data transformations to match the required data format and model. Finally, the data is loaded into the specific physical file. Implementation of the processes requires certain functionalities, which are provided by corresponding services. The integration, preparation and extraction services are used to overcome the heterogeneity of the stand-alone simulations.

4. USE CASE

The interconnection of simulations used in a production process of a gearwheel is considered for the validation of the simulation interoperability. The gearwheel is manufactured in several working steps (Figure 6). Two levels of detail are examined in the manufacturing process of the gearwheel. The first level of detail is linked to macro-structure processes like forming, heat treatment 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.

For each used simulation along the production process interoperability must be granted. That means all used data of the five simulations must be represented by structure, meaning, value etc.

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 macro-structure 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 macro-structure 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 [36].

The framework gathers all parameters that are needed for a complete and automated run through the whole simulation chain. The framework will organize and administrate the order of the simulations to match the production process. Furthermore it will provide for each simulation the input data.

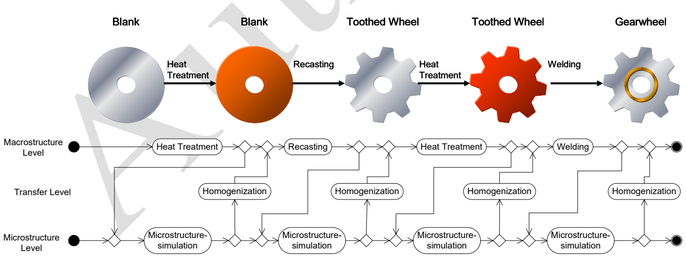

Figure 6: Simulated gearwheel production process

Via the components of the framework the syntactic and semantic simulation interconnection is realized. On the base of this interoperability 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. Figure 7 shows the simulation results of the gearwheel production process.

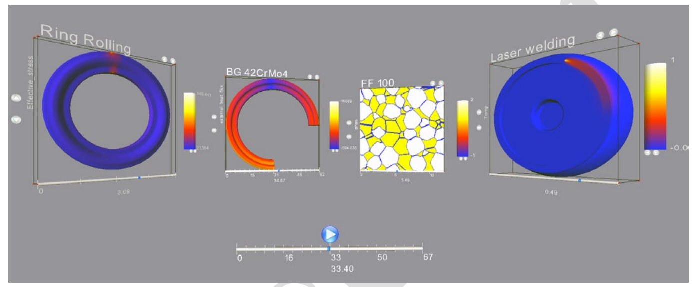

Figure 7: Simulation results - gearwheel production process

5. CONCLUSION AND OUTLOOK

The Framework reads the input and output files of the previously mentioned simulations. Additional it understands and generates new files according to the schemes presented in figures 3 to 5. Therefore, all parameters that cannot be generated by the process must be known in addition to the input file of the first simulation.

Integrating these inputs and results of a simulation process into a data model is the first step towards gaining insights from these databases and being able to extract hidden, valid and useful information. This information encompasses, for example, the quality of the results of a simulation process and, in more specific use cases, also the reasons why inconsistencies emerge. To identify such aspects, at present the analysts use the analysis methods integrated in the simulation tools. Implementation of the framework, however, opens up the possibility of unified consideration of all the data since it encompasses the study and analysis of the data generated along the entire simulation process. Various exploration processes can be called upon for this purpose. What needs investigating in this respect is the extent to which the information extracted through exploration processes can be evaluated. Furthermore, how this data can be visualised and how information, such as data correlations, can be adequately depicted should also be investigated. To this end, there are various feedback-supported techniques that experts can use via visualisation feedback interfaces to evaluate and optimise the analysis results.

The afore-mentioned data exploration and analysis may be further undertaken as follows: First, the data along the simulation process is integrated into a central data model and schema. Then, the data is analysed at analysis level by the user by means of visualisation. In so doing, the user is supported by interactive data exploration and analysis processes which can be directly controlled within the visualisation environment. Since it is possible to send feedback to the analysis component, the user has direct control over data exploration and can intervene in the analyses.

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