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A SEMANTIC REPRESENTATION FOR PROCESS-ORIENTED KNOWLEDGE MANAGEMENT BASED ON FUNCTION BLOCK DOMAIN MODELS SUPPORTING DISTRIBUTED AND COLLABORATIVE PRODUCTION PLANNING

B. Gernhardt, FernUniversität in Hagen; F. Miltner, FernUniversität in Hagen; T. Vogel, FernUniversität in Hagen;
H. Brocks, InConTec GmbH in Burghaslach; M. Hemmje, FernUniversität in Hagen;
L. Wang, Royal Institute of Technology Stockholm

Abstract

Semantic knowledge representation, management, sharing, access, and re-use approaches can support ***Collaborative Adaptive Production Process Planning (CAPP)*** in a flexible and efficient as well as an effective way. Therefore, semantic-technology based representations of such CAPP knowledge integrated into a machine readable process formalization is a key enabling factor for sharing such knowledge in cloud-based semantic-enabled knowledge repositories supporting CAPP scenarios as required in the CAPP-4-SMES project [1]. Beyond that, ***Small and Medium Enterprises (SMEs)*** as represented in CAPP-4-SMES request for a standardized CAPP-oriented product-knowledge- and production-feature- representation that can be achieved by applying so-called ***Function-Block (FB)*** based knowledge representation models. Semantic Web- and at the same time Cloud-based technologies, tool suites, and application solutions which are based on process-oriented semantic knowledge representation methodologies such as ***Process-oriented Knowledge-based Innovation Management (***German: Wissens-basiertes Prozesess-orientiertes Innovationsmanagement***, WPIM)*** [2] can satisfy these needs. In this way WPIM can be applied to support the semantic integration, management, access and re-use in a machine readable and integrated representation of distributed CAPP knowledge that is shared within a cloud-based centralized semantic-enabled knowledge repository. Furthermore semantic knowledge representation and querying add value to knowledge-based and computer-aided re-use of such knowledge within CAPP activities. Finally, it will pave the way towards further automating planning, simulation and optimization support in a semantic web for CAPP.

Introduction, Motivation, and Problem Statement

In [1] the general concept of developing a knowledge-based and process oriented CAPP support by using the WPIM method as a basis was proposed. The WPIM approach offers the possibility of modeling and representing innovation processes in a machine-readable semantic format and furthermore enables annotating the semantic process representation in a semantic way with further knowledge resources. This whole representation structure can then later be accessed by means of semantic queries. However, so far WPIM has only been applied in domains like design and development, including ***Product Life Cycle Management (PLM)*** support but has not yet been practically applied in the domain of CAPP. In parallel to the development of WPIM Wang et al. have introduced a method for representing web-based ***Distributed Process Planning (DPP)*** activities in [3], [4], and [5]. In the following we will use slightly adapted excerpts from [3] to introduce the necessary concepts and rationale of the DPP method. The DPP method includes the concepts of ***Meta Function Blocks (MFBs), Execution Function Blocks (EFBs) and Operation Function Blocks (OFBs)***. However, while Helgoson et al. state in [6] that "Today, machining-feature based approaches combined with artificial-intelligence (AI) based methods are the popular choices for process planners", their introduced approach, which is already based on a DPP modeling-method, does not yet support machine-readability and semantic interoperability of such models as it could be achieved by utilizing semantic representations as available in nowadays semantic web technologies and as, e.g., supported by WPIM.

This means, while the proposed DPP approach is very useful and valid in terms of representing the product and machining features within MFBs, EFBs and OFBs, it does not yet support semantic-web based cross-organizational and cross-domain knowledge sharing to make such knowledge more widely available, e.g., to be shared in collaborations of SMEs within CAPP activities. As this DPP knowledge is so far not available in a machine-readable semantic representation at all, the interoperability of such a representation with technologies of the semantic web and therefore with other applications and tools, like, e.g., from the area of ***Artificial Intelligence (AI)*** and ***Machine Learning (ML)***, cannot easily be achieved.

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Furthermore, this knowledge cannot easily be automatically shared, managed, accessed, exchanged, and re-used within collaborations that take advantage of cloud-based semantic repositories of CAPP-knowledge and therefore can also in general not easily be accessed on-line quasi in real-time during computer-supported CAPP activities within state of the art ICT infrastructures across knowledge domain and organizational boarders.

At the same time, if it would exist, such a semantic and process-oriented CAPP-knowledge representation utilizing semantic web technologies, could be very well supported by other semantic-web enabled technologies and corresponding methods, like, e.g., WPIM and in this way interoperability and therefore integration of cloud-based semantic CAPP knowledge repositories with other, e.g., AI and CAPP-support technologies by means of integrating them based on the semantic web software development paradigm could be achieved.

In consequence, this insight requires the application of semantic technologies and corresponding methods, like, e.g., WPIM to the process-oriented semantic representation of CAPP knowledge where product and machining features are formalized within MFBs, EFBs and OFBs, as domain-specific representations, i.e., as domain models of the DPP knowledge domain that could support the CAPP knowledge domain.

The remainder of this paper is based on this insight and is applying and implementing the necessary DPP and semantic web integration approach within a mediator architecture that is typical for semantic web repositories solving semantic integration challenges and integrating several local knowledge sources into a global, potentially cloud-based, semantic repository. This can then be considered a semantic and cloud-based CAPP-knowledge repository which has been implemented in a very (technologically) open and distributed way. From the point of view of WPIM, the domain models for MFBs, EFBs and OFBs can be covered by a semantic integration in this repository with the existing WPIM domain concepts of WPIM Master Processes, WPIM Process Instances and WPIM Tasks and Activities and therefore allow for the integration of WPIM- and DPP-based knowledge modeling as well as for the semantic representation of DPP knowledge to become available as a knowledge-based support to CAPP activities.

In the remainder of this paper we will describe this integration more in detail. Therefore, this paper covers the following aspects: the State of the Art of FB-based production planning models, in detail the proposed DPP method including the necessary planning processes producing and handling MFBs, EFBs and OFBs, the State of the Art w.r.t. Process Ontologies, in detail w.r.t. the WPIM-Ontology, a comparison of the DPP modeling approach of Wang et al. [3] with the expressiveness of the WPIM-Ontology, prototypical extension of the WPIM-Ontology to cover, i.e., semantically wrap and integrate the DPP planning processes and there resources including MFB, EFB and OFB concepts of the DPP-model. We will further outlined our mediation approach to a DPP-based distributed knowledge representation. This will result in an extension of the WPIM tool suite and application solution by means of a mediator architecture to support the integration of distributed local knowledge sources into a centralized and potentially cloud-based global CAPP repository. In this way, such a repository that can then support in the future cross-domain and cross-organizational CAPP processes, tasks, and activities in terms of knowledge sharing and online process-driven semantic access support.

State of the Art and Analysis

The following paragraphs will briefly summarize and analyze the State of the Art of FB based DPP modeling. The section is based on a slightly adapted excerpt from [3] and WPIM-based semantic process-modeling. It also introduces the necessary concepts of information integration and mediation as well as of mediator architectures as a background for the integration and mediation approach to be applied for the integration of DPP and WPIM. The integration itself will then be described in the following section.

A. Function Blocks

FBs are initially defined in the IEC 61499 standard [7], which explains the usage, development, and implementation of FBs in distributed industrial process measurement and control systems, in a component-oriented approach [8]. IEC 61499 was developed jointly from the existing concepts of FB diagram in the ***Programmable Logic Controllers (PLC)*** language standard IEC 61131-3 [9] and standardization work concerning Fieldbus [9]. It was developed after the need for a common model for the application of software modules called FBs had been raised. FB diagrams were initially introduced (in IEC 61131-3) to solve problems with textual programming, ladder diagrams, and the reuse of common tasks. In the new standard of IEC 61499, an FB is an event-triggered component containing algorithms and an ***Execution Control Chart (ECC)*** with inputs and outputs of data and events. Algorithms are executed when triggered by input events, reading data from the input data and producing new output data. The algorithm execution and scheduling is controlled by the ECC functioning like a finite state machine and at the end of algorithm execution an output event is created. As basic building blocks, many FBs can be combined in a distributed network to create complex control applications with their data/event interfaces interconnected to control the flow of data and events. One FB's output event could then be the input event of another FB. A common way of describing or viewing an in summary, FB can be considered as a model of software or process representation, treating the encapsulated behavior in a form that is similar to an electronic circuit. A literature review related to the FB related research targeting the areas of machining and assembly is available in [4] [3] as well as an introduction into ***Distributed Process Planning (DPP)*** as an important stepping stone towards supporting CAPP with DPP methodology.

B. Distributed Process Planning and Meta Function Blocks

Furthermore, as outlined in more detail in [3], the required functionality for implementing a web-based DPP system is consisting of three core components of the DPP, namely the planning processes of ***Supervisory Planning (SP), Operation Planning (OP)*** plus a new ***Execution control Planning process (EP)*** which are explicitly modeled in a conceptual ***ICAM Definition for Function Modeling (IDEF0,*** where '***ICAM***' is an acronym for ***Integrated Computer Aided Manufacturing***) process formalization model together with their inter-relationship and dataflow. ***Meta Function Blocks*** (MFBs) are used in this research to encapsulate machining sequences (of setups and machining features), and are the output of supervisory planning. As its name suggested, an MFB only contains generic information about process planning of a product. It is a high-level process template, with suggested cutting tool types and tool path patterns, for subsequent manufacturing tasks.

C. Execution and Operation Function Blocks

Within the DPP methodology, ***Execution Function Blocks (EFBs)*** are the FBs that are ready to be downloaded to a specific machine. Basically, an EFB can be created by instantiating a series of MFBs associated with a task. Each manufacturing task corresponds to its own set of EFBs, so that the monitoring functions can be conducted for each task unit. Furthermore, the DPP methodology offers the concept of an ***Operation Function Block (OFB).*** The structure of an OFB is the same as that of an EFB. However, an OFB specifies and completes EFB with more detailed, machine-specific data about machining processes and operation sequences. Moreover, operation planning module can override and update the actual values of variables in the EFB, so as to make it locally optimized and adaptable to various events happened during machining operations. Wang et al. use the two different terms of EFB and OFB in [3] to distinguish a given FB, because they are two separate entities with different level of detail in contents, fulfilling different level of execution, residing in different systems, and moreover, they may be deployed in physically distributed ***Computerized Numerical Control (CNC)*** controllers. In other words, a FB holds a set of pre-defined algorithms that can be triggered by an arriving event to the FB. A decision can thus be made by executing the algorithm.

D. WPIM

The concept of WPIM was developed to support capturing and usage of knowledge around innovation processes [2] [1] [10]. It assumes that innovation has both a knowledge and process perspective which needs to be used in a combined manner. Therefore activities of a process can be annotated with resources, such as experts and documents [10].

The web-based WPIM application and corresponding tool suite [www.inKNOWvation.de] allows the integration and mediation of semantic representations of process structures and specific knowledge resources. To support CAPP the so far used domain of innovation-processes needs to be extended to be able to represent collaborative production planning processes that are built on the basis of distributed production planning processes which actually are more detailed representations and therefore domain models for one of the phases of so-called innovation value chains. Therefore, activities in the generic collaborative production planning process need to be expressed in terms of distributed planning processes that are annotated with resources, such as experts and formal representations of their tacit knowledge as well as documents capturing and bearing externalized knowledge. Future collaborative production planning processes will in this way be enabled to benefit from reusing and instancing these annotated generic planning processes as well as from underlying semantically annotated representations of planning activities and planning knowledge resources. The semantic schema of the WPIM application and corresponding tool-suite is based on the ***Resource Description Framework (RDF)*** [11] and enables semantic-based searching by using the ***SPARQL Protocol And RDF Query Language (SPARQL)***. These enabling technologies provide a well-defined formal semantic description of knowledge. Using these explicit and machine readable semantic representations of knowledge in distributed cross-organizational environments as known from the requirements of collaborations in the SME domain can improve collaboration between heterogeneous partners and add value to an advanced and even more integrated CAPP.

The WPIM application and corresponding tool suite is using four layers for knowledge representation. It offers the opportunity to get on a top layer a brief overview of the innovation, i.e., in the case of the CAPP planning process and if needed to navigate to deeper more detailed process descriptions, accompanying knowledge resources, documents as well as annotated attributes and features. The underlying ontology in the WPIM application and corresponding tool suite offers a machine-readable structure for con-

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cepts that can also be read and understood by human experts. Ontologies offer the opportunity to order concepts hierarchically as in, e.g., a taxonomy but furthermore add non-hierarchical relationships between such concepts. For example coming from a functional point of view for some applications the two concepts mechanical cutting and laser cutting can be understood as replaceable concepts. The ***Web Ontology Language (OWL)*** [12] [13] allows to model concepts in classes and e.g. this replaceable relationship between these two classes of cutting technology. A production planner using semantic search/reasoning for cutting methods will find both options of cutting and also will get the hint that these two concepts can potentially substitute each other. In this way, representing such knowledge in a machine-readable semantic way can pave the way towards applying AI methods as can, e.g., be build by means of automated semantic reasoning over semantic knowledge representations. Additionally with the concepts of a ***Master Processes*** (German: Masterprozess, ***MP***, see Figure 1), ***Process Instances*** (German: Prozessinstanz, ***PI***, see Figure 1) as well as **Activities** and ***Tasks*** the separation of modeling and capturing generic and instance specific (in the domain of CAPP, this means, e.g., knowledge related to a certain machine vendor) knowledge is supported. In this way process artifact representation toolbox of WPIM allows re-using process steps and their associated knowledge in a seamless way

WPIM in the domain of Process Planning

WPIM was originally developed to support innovation processes by providing existing innovation process knowledge in an explicitly represented form to innovation process experts as well to computer agents, i.e., computing machines and their software programs. In the field of innovation processes the usage and potential of semantically represented processes as enabled by WPIM has already been elaborated. Furthermore, WPIM has already been applied to represent PLM data in the field of technical products. In both domains next to executing processes also planning processes has been modeled and used for representation. Semantics as offered by WPIM have the advantage of being easily exchangeable and machine readable. This helps, e.g., to plan cross-organizational and distributed innovation processes.

The following Figure 1 describes the interaction of a MP with its PIs. If such processes need to be represented in WPIM, the user in a first step selects classes in the WPIM ontology repository to register an instance of a process resource. This means the user, e.g., selects the process classification systems to be used as the global set of ontologies into which the knowledge resource structure and contents are to be mapped. In a second step the user selects attributes for each selected resource class for populating virtual objects in these classes with content resources. This means the user has to also, e.g., map the attributes of the resources to specific ontologies, thus indicating that an attribute's contents (their range) are mapped to an ontology, such as mapping a resource attribute onto an expert ontology. Finally, the user selects the populating methods or populates the resource instances and their specific content manually. This means the user maps the attributes of contents to classes in the ontology manually or semi-automatically using word-matching or other provided techniques, e.g., map "hole" from a product property ontology concept to the "drilled hole" concept in the machining feature ontology.

However, before such mappings can be established the sources' local data schemas must first be registered. For example, in our implementation we used the two activity-based schemas displayed in Figure 1 for representing the MP and PI resources.

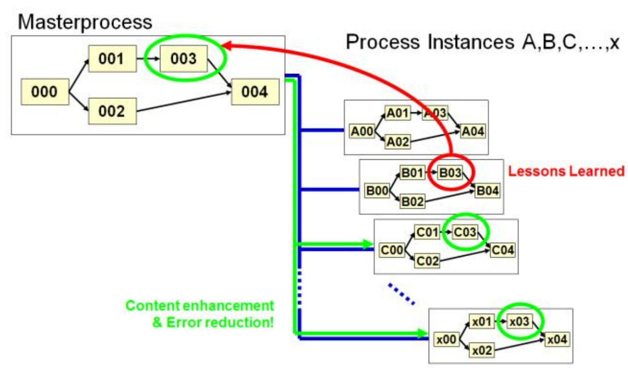

Figure 1. Master Process and Process Instances [2]

The next two sections describe in detail what an activity-based MP is and how activity-based executions of this MP, i.e., PIs are defined.

A. Master Processes

A MP is a generic high-level description of a process. In WPIM, from a data set point of view, a MP describes a data structure and attributes of a higher level template for a process. The representation approach goes beyond the sole representation of the process structural schema but describes process structures and their attributes by using semantic representations. As WPIM offers such semantic descriptions of MPs the semantic MP schema exists as a generic and formal description of a process, independent of generated data instances during a certain execution of the process. As an example, a MP defines next to a well defined structure of contained activities, resources which will be involved during execution the process. For example this can be experts, documents or, in the case of a CAPP adaptation, could be production machines and their production activities.

B. Process, Activity and Task Instances

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When executing a process, data is gathered. WPIM describes this, from the data set point of view, as a PI. The Activity structure that exists in WPIM and is displayed in Figure 2 is used to store all outgoing and incoming data as well as Activity states. Beyond that, WPIM also allows to describe and represent PIs including their Activities in a semantic, machine-readable format. Furthermore, WPIM PIs are ordered in a chronological way. That means, if a first instance is, e.g., executed, Lessons Learned during that execution can be stored within the higher level MP and this gathered information can be provided for the following process execution within the next PI (see Figure 1).

An activity needs well defined inputs to generate a required output. Activities within WPIM contain one to many tasks. An instance of an Activity defines a cluster of tasks, e.g. an Activity can bundle tasks that are assigned to a single resource. Such an assignment can contain planning tasks that need to be executed by an expert (e.g. a planner) or tasks can also be assigned to a resource like a machine in order to represent the execution of a machine operation.

In a WPIM context a Task structure is an action that cannot be further split into sub-actions. WPIM offers a semantic data representation to archive status and values when performing a Task. Such a Task can for example represent an operation that can be executed by a machine and create a specified result. By having such a semantic representation containing incoming and outgoing status, progress attributes, and result specification, WPIM allows to delegate a Task instance to various executing entities. An example in the context of planning tasks is, to finalize a plan by signing the plan and setting it into action. A Signature to release a plan is a very unique task and it is obvious, that such a signing task cannot be split – either the plan is released via signature or it is not signed and therefore not released.

As displayed in Figure 2, an Activity consists of at least one up to many Tasks. These Tasks represent the transformation of an input of the Activity into an output.

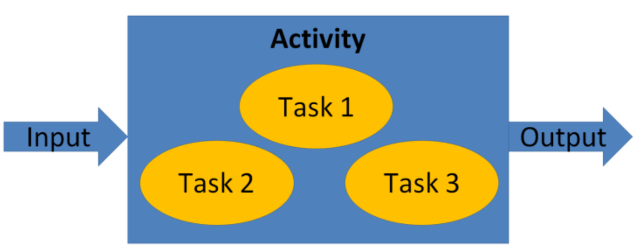

Figure 2. Visualization of an Activity as a set of Tasks

Semantic Integration and Information Mediation within Knowledge-based Information System Architectures

Mediators are a standard approach in the construction of information system architectures. They have originally been introduced by Wiederhold in [14] as early as in 1991 when the web was still in its infancies and the semantic web did not even exist. However, since then, the use and application of these architectures in building web-based information systems supporting, data, information, and knowledge integration has grown into a de-facto standard and is widely used in all types of scientific and industrial infrastructures supporting data, information, content, and knowledge sharing, management, and access for re-use. In the following we will introduce the different levels of interoperability that can be addressed by mediator architectures in terms of integration. Furthermore, we will introduce markup languages as a means of defining global schemata and semantics for the purpose of semantic information integration and exchange. Finally we will introduce mediator architectures of different types at increasing levels of detail supporting increasing levels of integration.

A. Levels of Interoperability and Integration

As outlined, e.g., in [15] data, information and knowledge integration can be understood at varying levels of interoperability and heterogeneity. In the following we will describe this a bit more in detail based on a slightly adapted excerpt from [15]. When trying to share distributed, heterogeneous data, a number of technical challenges must be overcome. Consider, for example, two systems having data sets that should be made interoperable. One can employ standards and technologies to overcome the various kinds of heterogeneities and to facilitate interoperability at different levels. At the systems level, one may find different operating systems (Linux, MS Windows, MacOS, etc.), different data transport protocols (FTP or HTTP, which are built on top of a stack of internet protocols called TCP/IP etc.), or higher-level protocols for discovery and interoperation of web services. Differences in system platforms and operating systems are usually overcome by standardizing protocols for data transport and remote service execution. For the latter, for example, one can employ web service descriptions (WSDL, 2001), which specify the input and output parameters of a web service. System level interoperability can also be achieved at the grid or cloud service level. Grid and cloud services extend the basic web-service infrastructure and include additional features such as user authentication for secure data access. Apart from the generic issues of data access, transport, and remote execution, there are also a number of application specific system level issues, e.g., the choice and architecture of the mapping technology for the integration and mediation of information and knowledge resources (server-side, client-side, mixed). At the syntactic level, one has to consider heterogeneities such as different data file formats depending on the type of content or knowledge

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resource and corresponding representation format of the information and knowledge representation. The ***Extensible Markup Language (XML)*** [16] provides a simple and very flexible syntax for structuring many kinds of data, metadata, content and knowledge resources to enable their exchange. Defining such a new structure in XML syntax can be done in different ways. For example, one can provide an XML ***Document Type Definition*** (DTD) or an ***XML Schema Definition (XSD, XML Schema)*** [17] [16] to specify the allowed nesting structure and (in XML Schema) the data types of XML elements.

In this way, XML not only yields a data, information, content and knowledge resource exchange syntax but also prescribes a schema for the exchanged resource. However, additional explicit representations of semantics such as domain specific integrity constraints have to be encoded by other means. The ***Resource Description Framework (RDF)*** [11] can be seen as an XML dialect for encoding labeled, directed graphs and in particular ontologies as an example of a standardized semantic vocabulary. For querying databases, query languages such as the ***Standardized Query Language (SQL)*** [18] for relational databases) or ***XQuery*** (for XML databases) [19] are used, each of which come with their own syntax for query expressions. Differences at the syntactic level, i.e., heterogeneity of the underlying data models of sources are usually resolved either by adhering to a standard or by using format converters that can translate from one format to another. At the schema level, heterogeneities can exist because the same (or at least similar) data can be represented using vastly different schema structures (even when the same file format or syntax is used). For example, two datasets may be organized in different ways across two relational databases, i.e., the table and column structure may be very different although the content (at the conceptual level) of the databases may be very similar. Similarly, for XML databases, different DTDs or XML Schemas can be used to describe the same data. To overcome schema level heterogeneities, we can again apply two approaches, schema standardization or schema transformation. For the latter, i.e., schema transformation, database query languages in general and XQuery in particular provide powerful means to express complex queries and transformations. Thus (XML) query languages play an important role in database mediators. Finally, at the semantic level, we consider issues such as differences in terminology, different classification schemes, and differences in the definition of and constraints for the various concepts that are relevant to the data sets being integrated. Therefore, the main approach for reconciling semantic heterogeneities is the use of agreed-upon ontologies, which in their simplest form provide a controlled vocabulary with more or less formal descriptions of the pertinent concepts. In more sophisticated forms ontologies include formalizations (often through logic formulas) of properties of concepts and “inter-dependencies” of concepts. A prominent emerging standard for ontologies is OWL, which comes in three increasingly expressive variants: ***OWL Lite, OWL DL, and OWL Full*** [20]. OWL is also an interesting example of how several interoperability levels and standards may be intertwined: for example, OWL DL builds upon the RDF model and syntax which in turn is usually denoted in XML syntax.

B. Mediator Architectures

Database mediator systems can be used to provide uniform access to distributed heterogeneous data sets, and thereby overcome a number of the interoperability challenges mentioned above. Figure 3 depicts a typical mediator architecture in which a number of local data sources are “wrapped” as XML sources and subsequently combined into an integrated global view. Thus a client application or end user is provided with the illusion of querying a single, integrated (or global) database with one integrated schema.

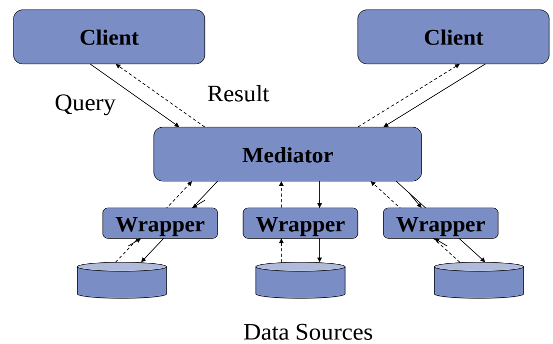

Figure 3. Mediator architecture integrating data sources

Mediators are software components that serve to simplify, reduce, combine and explain data. They are mainly used for providing a common access level onto different distributed data sources. The source wrappers not only provide a uniform syntax, but also reconcile system aspects, e.g., by means of a unified data access and query protocol [15]. In a conventional relational or XML-based mediator system, interoperability is facilitated at the structural level. That is, differences in schema can be reconciled by corresponding schema transformation as part of the view definitions for the global view. However, terminological differences or other semantic differences are not adequately handled at the purely structural, e.g., XML level. To this end, source schema and contents can be registered to an ontology, which encodes additional “knowledge” about the registered concepts. In the next section we will explain more in detail how by means of “ontology-enabling” the system in this way, one can evaluate high-level queries over concepts that are not directly in the source databases, yet indirectly linked via an ontology. The task of the mediator is, to transform queries to the global schema into queries to the sources, to collect the results and to integrate and link them. The global scheme is based on a suitable data model, for which for example XML or RDF can be used as representation. The wrappers are software components that represent the contents of a data

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source for the unification in another data model or schema. For example, XML wrappers are used to enable access to relational databases. The coupling between source and mediator via wrappers allows the mediator uniform access to the sources, by creating a mapping between the data model of the mediator and the data model of the local source. Also incoming requests of the mediator can be translated into requests into the local source system.

C. Ontologies in Information Integration and Mediation

In information integration systems based on a mediator architecture as displayed in Figure 4 ontologies can be used to provide information at the level of conceptual models and terminologies, thereby facilitating conceptual-level queries against sources, and resolving some of the semantic-level heterogeneities between them. In our original WPIM system the process classification ontology and the innovation ontology are used as a global view for registering process resources and processing queries. When a resource is registered to an ontology, a mapping from the data set to the selected ontology is generated. However, before such mapping can occur, the sources' local data schemas have to be registered first. After these steps, wrappers are created for the registered resources. Each wrapper uses the mappings between the data source and ontology to translate queries from the global ontology to the local schema, and also to translate content from the local schema to the global ontology. As explained above, the system can automatically use the subclass relation to expand concept queries when required. Note that although all system-registered ontologies can be considered as conceptual-level query mechanisms, the system can suggest suitable ontologies based on, first, the user's choice of resources and, second, the sources' schema information. Database mediator systems can be used to provide uniform access to distributed heterogeneous data sets [15]. Figure 4 depicts a typical mediator architecture, in which a number of local data sources are wrapped as XML sources and subsequently combined into an integrated view. Thus a client application or end user is provides with the illusion of querying a single, integrated database [15].

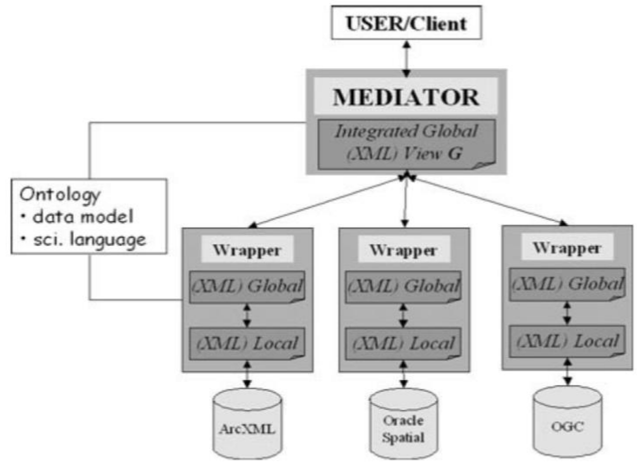

Figure 4. Extended Mediator Architecture [15]

CAPP Knowledge Integration and Mediation

Beyond integrating data from distributed data sources, our proposed CAPP knowledge integration and mediation approach also describes how to combine heterogeneous data, information, content and knowledge sources by a mediation approach. For that approach DPP process knowledge supporting CAPP activities need to be integrated by means of utilizing the WPIM semantic as well as need to be supported by mediation function which allows integrated access through a global schema to the distributed CAPP knowledge resources in a DPP process. Over the course of the research on WPIM its field of application has been extended beyond just innovation management [21] [22] and potentially can be applied as well in DPP and CAPP which can be considered one of the phases of an innovation value chain. Furthermore the web-based approach of the WPIM-Application-Tool suite supports working collaboratively in dispersed teams. In the domain of CAPP that means planning activities and consecutive manufacturing processes which are handled by a network of many SMEs could benefit from such a common platform and therefore such use cases need further consideration.

A. Collaborative Planning Processes

CAPP processes aim to combine and integrate distributed information and knowledge resources, e.g. about machine and tool descriptions, machine features and process constraints in order to create an executable plan for a certain task. Such CAPP activities can happen within the boundary of one organization or even across organizational boundaries. The CAPP-4-SMEs project [1] explicitly has defined the goal to research in the field of CAPP e.g. for the use case ***where Original Equipment Manufacturers (OEMs)*** work with global partners and suppliers, which are mainly SMEs,

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more collaboratively to achieve entire manufacturing value chain optimization [5]. This paragraph describes the concept of Collaborative Process Planning in CAPP-4-SME and the challenge of turning **the supervisory plan** into an **operational plan** in an optimized manner. The planning process approach to be used in CAPP-4-SMEs is a form of DPP. Most process plans generated using existing CAPP systems are tied to specific resources (machines, fixtures, cutters, etc.) and therefore are inflexible and not responsive to unexpected changes. So every time a resource becomes unavailable the plan needs to be reworks massively which might mean doing similar planning tasks repetitively [23, p. 5]. The goal of DPP is to improve flexibility and adaptability and ultimately allow real-time manufacturing intelligence. Therefore a process plan consists of two parts: While *generic data* (machining method, machining sequence and machining strategy) is used to describe one or many alternative plans (which then is called Non-Linear Process Planning [3, p. 54]) *machine-specific data* (tool, data, cutting conditions and tool paths) serves to choose from the actual resources available to produce the parts. This leads to a two-layer hierarchy, where the two different tasks can be accomplished at two different levels: shop-level SP and controller-level OP [23, p. 5ff]

As enabling technologies to represent the derived planning information the concepts of ***Machining Features (MFs)*** and FBs are used. MFs typically represent shapes which can be achieved by the available machining resources. As already described above, FBs are a concept provide control based on data flow and finite-state machine concept [23, p. 8ff]. While the Decision Making for SP is non-trivial as there is not one single correct plan how to produce a part as machining features applied in different sequences can be used to achieve the same result making non-linear process planning necessary, this task is covered in the steps machining sequence processing within the supervisory planning [23, p. 11ff]. In the following and as a first step of semantic knowledge representation for the CAPP domain, this paper does focus on the semantic representation of SP and OP processes. These processes include cutter selection, operation sequencing, cutting parameter assignment and tool path generation. They vary on the basis of chosen machining strategy and machining dynamics that affect tool life and surface finish quality. Improper decisions at this level may result in tool breakage, chatter vibration and even scrap. The knowledge about choosing the right resources is either covered in vendor-specific handbooks or was gained through long-lasting experience of engineering experts working for a specific company. That knowledge is either not extractable and therefore not representable in a standardized form (at least when looking at its informal encoding in handbooks) or even must be considered as implicit or tacit knowledge when looking at the expert's experience. While the ultimate goal of DPP is to do operation planning in an automated fashion adapting to available scheduling and availability monitoring information, the current reality is, that in many cases this planning step is still time and labor intensive and the required planning process themselves are not yet computer supported in terms of representing them in a machine readable semantic way. In the following we will explain the semantic representation, integration as well as mediation that can be achieved for representing CAPP activities based on DPP knowledge in an integrated way that is accessible on a global level although the DPP knowledge resources are coming from distributed sources of the collaborating agents/processes. Figure 5 outlines our integration approach that will further be elaborated in the following.

Planning Process Type	WPIM Representation-Model	Output
CAPP - Process	Process	CAPP - Process
Supervisory Planning Process (SPP)	Activity	Meta Function Block (MFB)
Execution Control Planning Process (ECPP)	Activity	Execution Function Block (EFB)
Operation Planning Process (OPP)	Activity	Operation Function Block (OFB)
Planning Tasks	Task	Result / Resource

Figure 5. CAPP Ontology based on WPIM Models and DPP Process Types and Resources/Results

When combining function blocks with WPIM we see strong advantages in both approaches. FBs are very planning oriented and focused on production domain. WPIM offers well described data structures for processes, activities, and tasks. In the following we will now apply such WPIM process and resource representation structures which are semantic-based and therefore give the possibility to represent data in an exchangeable, human-understandable and machine-readable format. For example the created representation structure allows navigation from process level to activity and task level and vice versa. In this way, the semantic representation structure will add value to distributing and at the same time sharing knowledge about production planning processes, e.g., when exchanging single activities between processes and during allocation of tasks, i.e., resources/results to a machine level. In the understanding of WPIM the DPP planning process and resource knowledge is represented by planning activities consuming and producing planning knowledge resources. These can e.g. be FBs over all levels of CAPP activities from ***SP Process (SPP)*** activities through ***Execution Control Planning Process (ECPP)*** activities to ***OP Process (OPP)*** activities (see Figure 5). Therefore, a production of resulting planning results/resources from MFBs through EFBs to OFBs. This process and resource knowledge can be brought into one integrated and well defined semantic schema with certain instances. In this way the semantic representation of the different types of planning activities producing and consuming function block resources by means of WPIM's semantic process representation schemas allows to represent a top down planning process representation schema as well as a top-down mediation of differ-

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ent types of knowledge-resource and planning-result representations from higher levels of planning abstraction to lower levels of operational planning representation. In this way WPIM provides an integrated and well-structured schema to be filled during execution with instances of semantic data on each level of planning abstraction and corresponding process and resource/result distribution.

As displayed in Figure 6, a SPP can be represented by a WPIM Activity representation instance that transforms an input MFB on the basis of some additional planning resources produced by its tasks into an output MFB. Therefore the EFB uses at least one EFB of an earlier iteration of a SPP activity

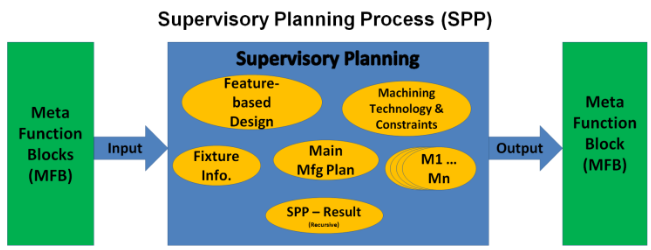

Figure 6. Supervisory Planning Process Activity

This means, that the MFBs produced by the SPP activity as displayed in Figure 6 are not only consumed by future iterations of such an SPP activity but also get consumed by the underlying ECPP activity.

Also an ECPP can be represented by an instance of a WPIM activity as shown in Figure 7. This process transforms the incoming MFB provided by the SPP activity, the additional resource information (also MFBs) and the delivered OFB from the underlying OPP activity outgoing in an EFB. Therefore an EFB uses at least one earlier iteration of a SPP activity and an OFB of the subsequent OPP activity. An ECPP activity (Figure 7) itself produces EFBs which get assigned to machines and consumed by them. In addition, the EFBs are used as inputs for the OCPP activities which are for producing and output of corresponding OFBs.

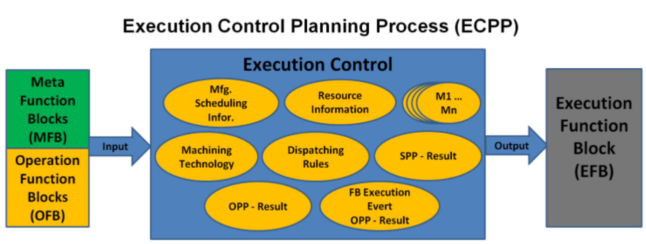

Figure 7. Execution Control Planning Process Activity

Analogously to the first two, an OPP can also be represented by an instance of WPIM activity representation. The OPP activity (Figure 8) transforms the already explained EFB that created apriori from the ECPP activity as well as several other information like status and events (all MFBs) in an outbound OFB. Furthermore, in the DPP methodology OFBs have a direct link to the real execution of the process. That means, that OFBs are executed by a directly assigned resource, e.g., a machine that at the same time produces a certain result in this way that can be re-used as a resources in the remainder of the planning process.

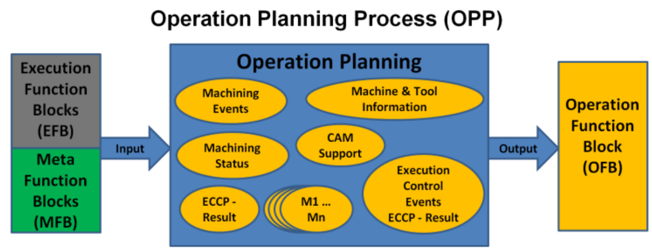

Figure 8. Operation Planning Process Activity

To achieve a representation of this this kind of subprocess structure on the basis of WPIM, the Process Planning levels ECPP and OPP have to be represented as additional underlying WPIM activities of the same MP. Therefore, the resulting outputs EFBs and OFBs of these processes have be represented as planning results and therefore as knowledge resources that are handed over between these three planning activity levels of the same overall DPP MP. In summary this means that the whole DPP methodology as applied in CAPP application domains can be represented by WPIM as a three level integrated WPIM Activity representation that belongs to one overall DPP MP where the WPIM Activities represent SPPs, ECPPs. and OPPs and their results/resources which are tasks for the activities itself.

However, besides an integration on the level of the knowledge representation the WPIM system also needs to be extended to support access to distributed resources of such potentially distributed planning processes from a system distribution point of view. Therefore we conclude our approach in the following with a corresponding design of a three level mediator architecture that can handle the above described process and resource representations.

Extending WPIM to integrate DPP knowledge and mediate its access during CAPP

Figure 9 displays a first level mediator architecture that integrates MFBs and other relevant and potentially distributed resources for the SPP activity from the different levels of the overall CAPP process that is implemented by means of the DPP method. The resulting mediator is called the SPP Mediator.

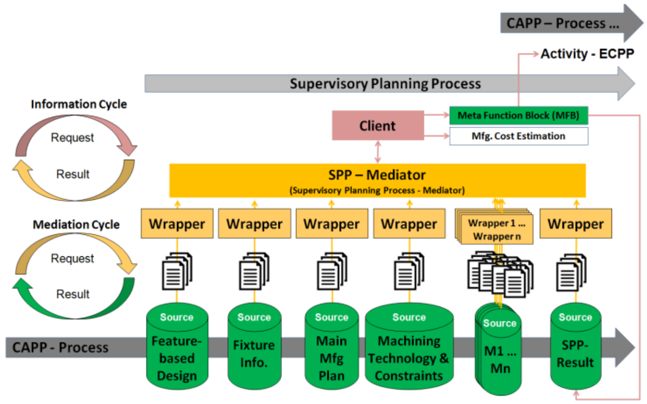

Figure 9. First level Mediator Architecture using for SPP

Therefore, a down-stream DPP mediation can be implemented by means of two analogously derived additional mediators on the second and the third DPP level.

On the second level of the mediator architecture follows then the deduced and so-called ECPP mediator which supports the above-mentioned ECPP activity. Figure 10 shows this second level of the mediator architecture. They assimilated at least an earlier iteration of the SPP-mediator as MFB, and a OFB of the subsequent OPP mediator (level 3) and various other relevant and potentially distributed resources.

Coming from the machining-data point of view, the corresponding up-stream Mediation Process starts from machines with a defined need of steering information which can be harmonized by using wrappers and offering a mediated interface to clients.

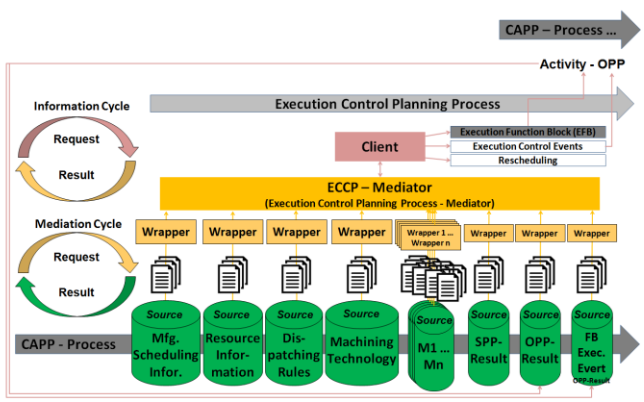

Figure 10. Second level Mediator Architecture using for ECPP

The third and final level of the mediator architecture of the CAPP process forms the again derived OPP mediator. Figure 11 represents this level graphically and displays how the so-called OPP mediator completes the mediation process. This integrates relevant and potentially distributed machine resources as MFBs and by the second level generated EFBs (ECPP-mediator) for the OPP activity. This three-tier architecture can support an Information Process by, providing data from distributed data repositories, combining various data formats, in a single semantic enabled format as well as a mediation process requesting, accessing and collecting/gathering/combining data from different distributed resources.

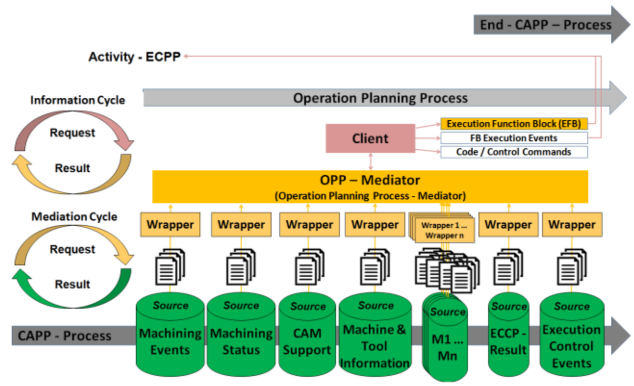

Figure 11. Third level Mediator Architecture using for OPP

The appendix contains a detailed illustration of the entire CAPP process of the mediator architecture (Figure 12).

In summary this means that DPP, i.e., deriving the Operational Plan from the Supervisory Plan through the Execution Control Plan is therefore a three-level WPIM Process where the three levels can be modeled as interlinked WPIM Activities.

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Conclusion

This paper has presented the relevant State of the Art and derived a method to support semantic knowledge management of DPP knowledge in the CAPP application domain based on semantic process representations producing and consuming function blocks and other relevant planning resources for distributed production planning. In this way the challenges of planning resource distribution, sharing and mediation that are inherent to CAPP are addressed in a first initial step of modeling this domain. Besides this, requirements towards representing this know2ledge on the one hand in a machine readable way and on the other hand designing an implementation architecture that can deploy such a CAPP support into a cloud-based, i.e. highly distributed or even fully virtualized system distribution are proposed.

In this way, our approach will allow e.g. SMEs to participate in a cloud based CAPP activity that is implemented on the basis of the DPP method which is represented by the WPIM methodology in a machine readable way and where the distribution architecture within the cloud and beyond is achieved on basis of applying a three level mediator architecture. By extending the WPIM system with such a three level resource mediation architecture, users will be enabled to create process instances of the provided DPP master processes representing all three levels of the DPP planning process activities and all their resources and results from the highest level of product features down to the lowest level of machining features. By doing so the individual SMEs can reflect which resources they have available and can annotate the DPP knowledge representation they have received an in this way documenting their potential competitive advantage. With this approach we see the potential to address several issues existing today. First on a general level currently tools to capture DPP knowledge needed for process planning are still rather complex to maintain and therefore not every SME has the capacity to run and maintain such a system. By delivering this functionality through a cloud-based repository approach building on semantic –web enabled knowledge representations and integration as well as mediation support, the usage of such tools can be provided at an affordable usage fee. Secondly by the ability to provide knowledge not specific to a certain company or vendor of machines via, e.g., a subscription model that is enabled through such an approach, SMEs which do not have the manpower to build up that knowledge within their own research and engineering organization can source this generic CAPP knowledge out and start directly on enhancing their specific DPP knowledge increasing their competitive advantage in their respective production support niche. On a more specific level this approach fosters two aspects: From a knowledge management point of view the existence of explicit knowledge being available through handbooks etc. is made visible in a consistent and machine readable manner and the fact that tacit knowledge exists within the minds of long-standing employees is externalized by annotating these persons to specific process steps as expert. Referencing the SECI model [21, p. 20] this can be used for knowledge conversion through socialization (based on the annotation in the WPIM process colleagues start asking questions to the experts about that matter and the tacit knowledge gets spread). From a collaboration aspect this approach can support teams within a company and beyond the borders of an organization to collaboratively improve planning results as can trigger knowledge conversion through socialization across the boundary of different sites of a company, which unlikely would happen if the fact that tacit knowledge exists (even though not the knowledge itself) would not be externalized. While supporting such a scenario within one company can be beneficial it would also be beneficial when several companies do work together in a manufacturing network.

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Appendix

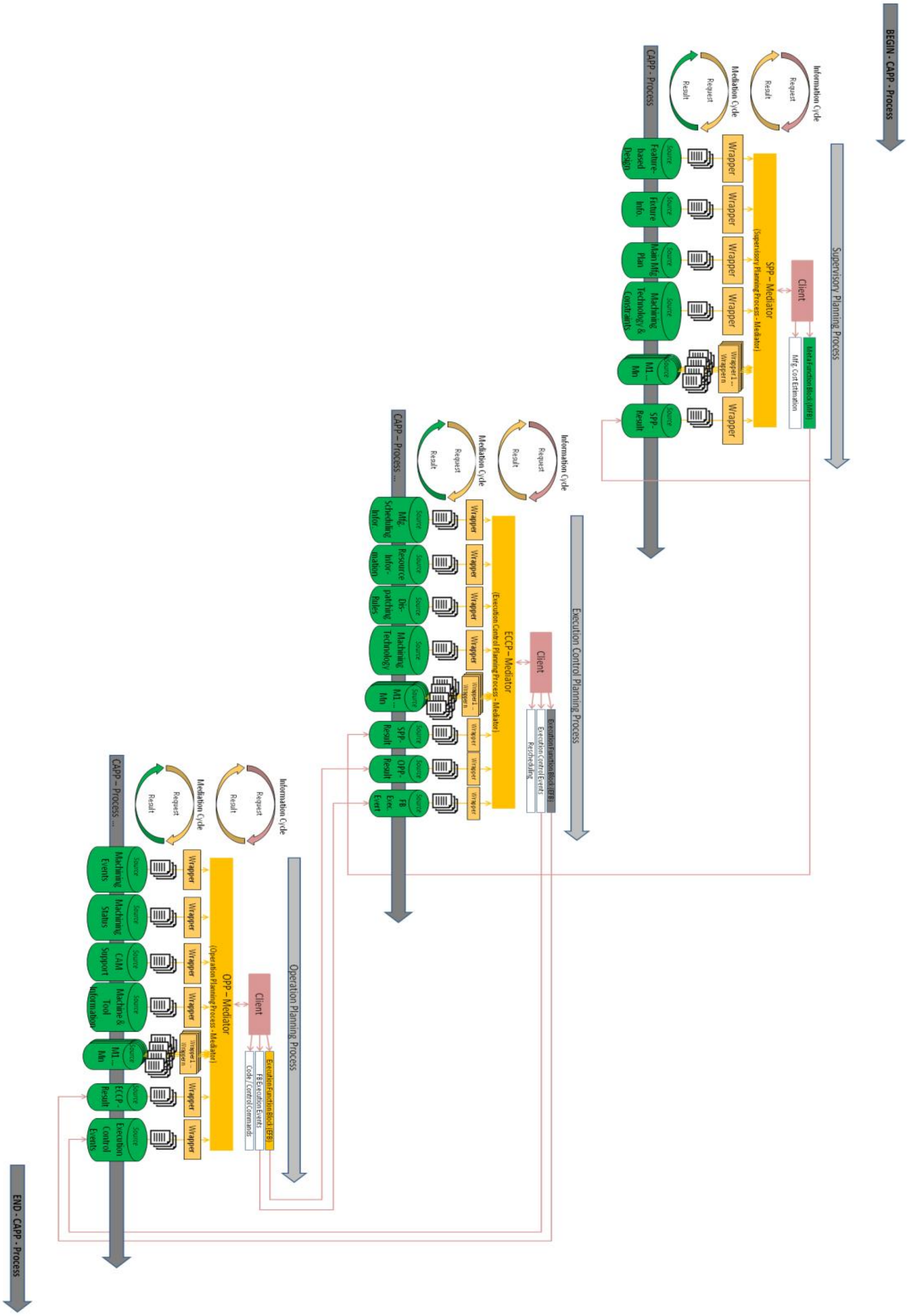

Figure 12. Entire CAPP process mediator architecture

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Biographies

B. GERNHARDT received the M.Sc. degree in Computer Science from the University of Applied Sciences Dresden, Germany, in 2013. Currently, he is being a Ph.D. candidate at the chair of M. Hemmje at the University of Hagen, Germany. Beside he is working as a IT-Project-Manager and Consultant for a Software Company in Germany.

F. MILTNER received the M.Sc. degree in Computer Science from the Cooperative State University Ravensburg, Germany. Currently, he is being a Ph.D. candidate at the chair of M. Hemmje at the University of Hagen, Germany. Beside he is working as a Engineer for Collaboration Systems for a Pharmaceutical Company in Germany.

T. VOGEL received the Ph.D. degree in Computer Science from the University of Hagen, Germany in 2012. He is a Postdoctoral Researcher and supports also M. Hemmje. Beside he is working as Managing Director for a Technology Company in Germany.

H. BROCKS received the Diploma in Computer Science from the University of Trier, Germany in 2000. Currently, he is being a Research Associate at the chair of M. Hemmje at the University of Hagen, Germany.

M. HEMMJE received the Ph.D. degree in Computer Science from the University of Darmstadt, Germany in 1999. He is an associate Professor in Computer Science at University of Hagen. His teaching and research areas include information retrieval, multimedia databases, virtual environments, information visualization, human-computer interaction and multimedia. He is holder of the Chair of Multimedia and Internet Applications, at the University of Hagen.

L. WANG received the Ph.D. degree in Mechanical Engineering from the University of Kobe, Japan in 1993. He is a Professor in Production Engineering at Royal Institute of Technology Stockholm. His teaching and research areas include distributed process planning, web-based real-time monitoring and control, human-robot collaboration, cloud manufacturing and sustainable and adaptive production systems. He is holder of the Chair Sustainable Production Systems, at the Royal Institute of Technology Stockholm, Stockholm, Schweden.