A Review of Data Representation of Product and Process Models

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1 Product Modeling Methods

As a type of semantic data model, a product data model is a set of data in a consistent data structure that ideally represents product information efficiently, effectively, and concisely [8, 20]. In the current information era, a product data model should satisfy the technical and quality requirements of the whole product lifecycle. Engineers and manufacturers need a product data model that has a common, unified, and global definitions of the product information resources and also can be interpreted by various computer programs. In recent decades, a variety of product modeling methods and incidental software has been created, developed, improved, and used effectively. The main methodologies can be categorized into four classes: solid product modeling, feature-based product modeling, knowledge-based product modeling, and integrated product modeling methodologies [42].

1.1 Solid Product Modeling

Solid product modeling was created as a technology to precisely embody 3D product geometry information. The most common solid product modeling methods are boundary representation (B-Rep) and constructive solid geometry (CSG) [42]. The B-Rep modeling method uses a model to bound the edge and vertices of the solid object in order to clearly store and speedily display geometric information, including the faces, edges, and vertices in the representation. In contrast, the CSG modeling method is based on primitive solids (e.g., cubes, cylinders, and spheres). Boolean operators are used to define a set of operations to put together a complex

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product solid model by adding or subtracting volumes. The common operations are *union*, *subtraction*, *supplementary set*, and *intersection*. The CSG modeling method can define objects with a relatively concise and simple data structure.

Solid modeling methods are now very mature, and are widely utilized in various product development phases. However, because solid modeling concentrates on geometric details, it lacks the functionality to present other information indispensable to the entire product development lifecycle. To solve this problem, the feature concept was created and has since been utilized in many computer-aided product modeling processes.

1.2 Feature-Based Product Modeling

1.2.1 Definition of Feature Concept

A feature "represents engineering meaning or significance of the geometry of a part or assembly" [32]. Features can be understood as information sets that refer to aspects of form or other attributes of a part. A feature can be thought of as a representation of an engineering pattern that contains the associations of the relevant geometry data with other kinds of data, such as manufacturing data, in order to provide sufficiently rich and versatile information and to speed up product engineering processes. It therefore represents a great improvement over B-Rep and CSG techniques [5, 17].

1.2.2 Definition of Feature Model

A feature model is a data structure that is comprised of a variety of types of features. These features are all recognizable entities that have specific representations. The choice of features depends on what function the feature model is intended to support. Additional features can be added into the feature model according to new requirements. For example, manufacturing companies can choose a specific range of machining features that include the geometry to be produced and the related nongeometric technical information. Such a manufacturing feature model is not only related to the manufacturing requirement for customizability but also makes feature technology more influential in related industrial applications [32].

1.3 Knowledge-Based Product Modeling

Knowledge-based product modeling uses Artificial intelligence technologies to model product development expertise and rules and to automate the many logical reasoning and optimization processes of engineering design and manufacturing.

Systems developed using this approach can also store a large amount of information and knowledge about previous designs, which can help avoid unnecessary time spent on planning and redesign. This approach can be used to simplify the modeling tasks and enhance modeling quality. Although capturing, representing, and using knowledge is both costly and risky, knowledge engineering plays an important role in business globalization and product development.

1.4 Integration-Based Product Modeling

The integrated product modeling methodology can be considered a functional combination of several modeling methods by associating data and processes of engineering in a systematic approach. All kinds of product data, including feature information, geometric data, and product knowledge, can be modeled and stored in a comprehensive and thoroughly integrated product model. This is an active research domain; the modeling methodology is not well established and still needs to be explored systematically.

1.5 Data Requirement in Product Lifecycle Management

Product lifecycle management (PLM) is the business activity of managing production effectively, from the initialization of a product to its withdrawal from the market. Full PLM involves various applications and several complex processes. It has to support cyclic engineering process modeling in order to represent, exchange, reuse, and store knowledge, and track decision-making processes in all application domains. To achieve these goals, PLM needs information technology (IT) to support its connections and a central data repository for gathering all the information during data exchange at all stages of manufacturing and production. IT services have to connect PLM to the product design and analysis processes. PLM also needs to have a relationship with the supply chain process, which includes processes such as enterprise resource planning (ERP), customer relationship management (CRM), supply and planning management (SPM)), and component supplier management (CSM) [28]. Information and communications technology (ICT) can support PLM to cover product process such as holding, retrieving, manipulating, sending, or receiving knowledge. In a new PLM paradigm, PLM is defined as an integrated business model that employs ICT technologies and implements an integrated cooperative and collaborative management system for product-related information throughout the entire product lifecycle, from a product's conceptualization until its dismissal. In this paradigm, ICT solutions are expected to bring many advantages for PLM, including customer satisfaction requirements, reduced time-to-market for new products, and decreased environmental issues in product manufacturing [13].

2 Data Repository

Every computer system must have a data repository for the collection and organization of data [20]. The advantage of storing information in a data repository is that it creates a supporting module in a demanding information system with a high level of data organization and reusability. Usually, the database involves several tables where each row stores the same sort of information. The tables can reference each other by building in data relationships. Each table holds the information about a particular entity, which is a virtual data representation of an existing artifact that is important to the application system and on which the database wants to keep information. To achieve the advantage of efficient data access and storage, a data repository needs data schema to efficiently manage information that can support reusability.

A modern networked data repository is a logical and physical facility that can be a collection of databases with objectives and tasks combined into one vast unified database. It can also be defined and developed as a unified and global business solution from customer services to manufacturing and shipping, which are essentially managed by accurate information interaction processes interfacing many database entities. A data repository needs to provide a strong and comprehensive relationship among all the data to help with decision-making and decision-support systems (DSS). Having one data repository that reflects all the information and knowledge in a system is useful for updating data quickly and efficiently [25].

A data repository can also bring competitive advantages for businesses. When several companies or organizations want to improve their business collaboration relations, they can use the semantic repository approach to integrate with each other via their databases. A semantics-oriented engineering data repository can support the complex and dynamic engineering and business information flows among associated and networked databases in the modern economy. For instance, the ICT project aiming to decrease the distance between government and business is using the semantic data repository approach. Figure 1 shows a few key components of a semantic data repository [24].

A data repository consists of data records and interrelated tables [45]; therefore, a data repository first needs to collect data. Although modern informatics tools enable active data collection, such as Web-based data crawling from numerous sources, the majority of engineering systems use passive data collection, such as designing a specific application programming interface (API) function to extract information from existing data sheets or files. The data gathered through active or passive data collection is initially stored in a local storage system, but needs to be integrated into a networked data repository to support accessibility expectations. At the end of the collection process, the data is accumulated and ready for use. In addition, the type of data source determines the structure and the module of data storage. Because a data repository has to keep data current and consistent, it will be designed to trace data change impact and schedule data updating procedures

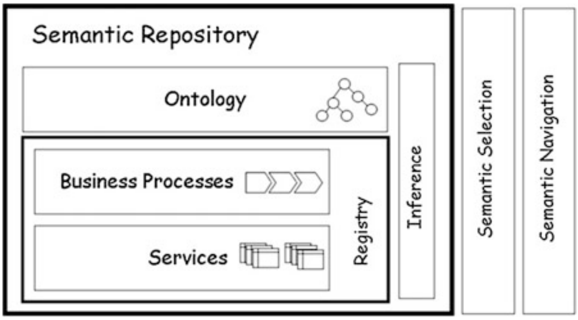

Fig. 1 Layers of a semantic repository of services [24]

constantly and dynamically with a generic "road-map". Scheduling frequent data access and updates requires the prioritizing of data operations [45].

Operating on a larger scale than can be managed by a database, data warehouses are a kind of optimal data repository system that include historical and static data. "Data warehouses are built in the interests of business decision support and contain historical data, summarized and consolidated from detailed individual records" [31]. A data warehouse can also be defined as an abundant database that combines distributed operational data in one place, linking a collection of subject-oriented data with the original sources. The objective of warehouse design is to provide a database that can support different kinds of applications such as decision making, online analytical processing (OLAP), data mining, and (DSS) [6].

2.1 Engineering Database Technology Status

Implementing an engineering data repository system requires designing data integration schemes and interfacing information sources that can be in a variety of forms, such as artifacts, functions, failure signals, physical objects, performance indicators, sensory input, and media related records. The scheme designer has to select the best type of category to store and extract data. For instance, in a product database [3], *function type* is useful for describing product features or finding an existing product. After the type of category has been selected and the schema designed, the database tables must then be designed. A design repository can store two types of data: artifacts and taxonomies. An artifact contains the field name and data type, and a serial-based ID as in a typical database. A serial ID makes a unique number for each artifact stored in the database, and data can be extracted according to this ID. Taxonomies, by contrast, make data interpretable by associating more information together such as a product's color, parameter, functions, material, and/or sensors. In addition, a design repository can support inheritance relationships to organize the inherited Attributes. Figure 2 shows a representation diagram of data repository tables. Usually, a repository model needs to be implemented into a structured query language (SQL) compatible database or a set of networked databases [3].

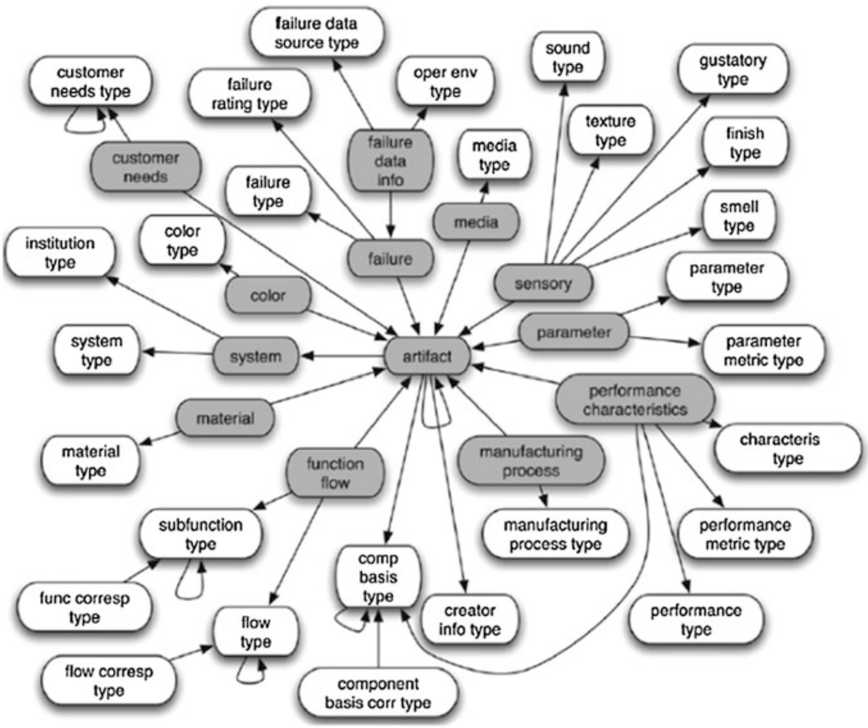

Fig. 2 Graphical view of repository database tables [3]

2.2 Data Repositories in Integrated Systems

Collaborative engineering is a systematic business approach that facilitates the exchange of useful sources and information-sharing for multi-disciplinary groups in real time [23]. A data repository supporting collaborative engineering must be designed to support dynamic data interactions, which requires integration and collaboration tools [18]. Information integration for a product model can have different layers of data granularity, i.e., functional applications, dynamic and persistent information entities, structural representations, and physical storage records, as suggested by Tang [35]. The application layer (AL) is the top layer, which contains various feature-based functional applications. The information layer consists of a feature-oriented meta-product model, unified feature components, application feature components, and STEP EXPRESS-based [14] specifications. The representation layer keeps the relation between EXPRESS-defined and database schema. The physical records layer forms the basis of a data repository, which includes feature properties and geometrical entities. The data repository can exchange and share information with various levels of granularity. For instance, the data repository can call on interactive system class methods

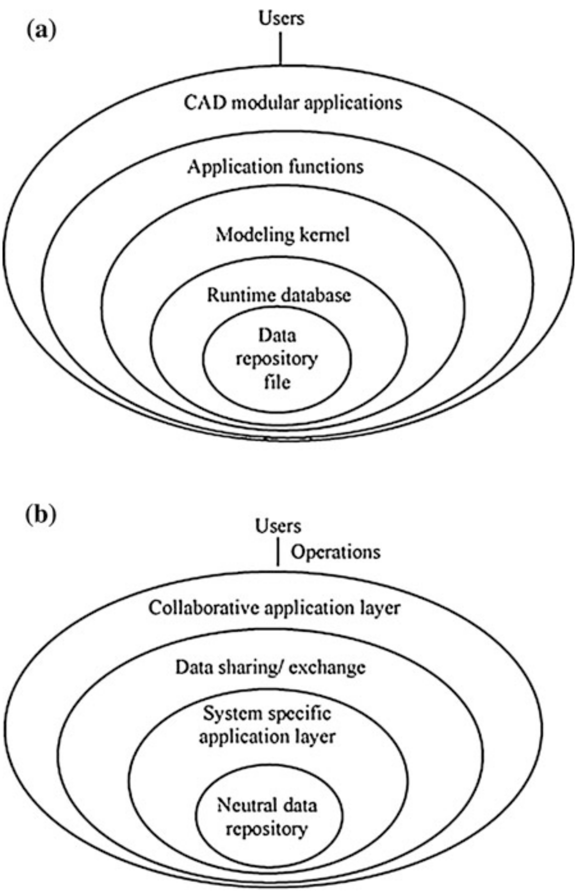

Fig. 3 Comparison of traditional and proposed CAx structure [18] **a** Traditional CAD structure. **b** Proposed CAx structure

(functions) to synchronize data transactions between computer-aided design (CAD) systems and their databases. The goal of the integrated engineering data repository is to support concurrent engineering activities, such as design phases and CAx analyzes, and to reduce the cost and time involved in data management. In general, this kind of repository can use an Internet browser as a front end, and can interface with application servers. Figure 3 compares the traditional CAD structure and proposed CAx structure [18].

Efficient information sharing and data interchange can create competitive advantages for companies and organizations. One of the most notable companies that focuses on collaboration in the supply chain is Dell. Dell has a unique supply chain management system, which has created outstanding sales for Dell. It uses the direct sales system to build exactly the product that the client wants. The computer industry grows significantly every year, but rapid technology changes are to the disadvantage of this industry. Dell must therefore keep little inventory and introduce new products to the market quickly. Dell fosters a close relationship with its suppliers and uses five key strategies to create a unique supply chain: rapid time to accommodate low-volume orders, customized products built to order, elimination of the retailer, superior services, and support, and low inventory and low capital investment [10].

3 Informatics Modeling in Chemical Process Engineering

In a typical chemical process engineering (CPE) development project, such as designing a refinery facility, thousands of process flow diagrams (PFDs), piping and instrument diagrams (P&IDs), electrical circuit diagrams, and mechanical engineering drawings are generated during the design, engineering, and construction phases of the project. There is a host of information embedded in these diagrams and engineering documents which also serves in the downstream phases, such as equipment procurement, construction engineering, operation, and maintenance, as either input or reference. Currently, most engineering documents are generated with domain-specific software applications, such as SmartPlant and Aspen. In such projects, it is necessary that the effective flow of engineering semantics, not just the data, be achieved via an integrated computer system throughout each CPE project.

3.1 Embedded Semantics and Issues in CPE Documents

A CPE project involves a series of development phases across various departments and disciplines. Domain-specific software applications are used to complete the activities in each phase but also to generate heterogeneous data sources [40]. The typical engineering documents generated in a chemical engineering project are summarized in Table 1, from a very general block diagram to a detailed flow diagram. Some of these documents have semantic information beyond one specific domain, i.e., chemical engineering alone. For example, a P&ID specifies many relevant semantic constraints for mechanical engineering and electrical engineering as well. Data files, such as spreadsheets or a 3D process model, provide even more detailed specifications to downstream engineering activities. A variety of types of flow sheet can be found in the work of Ludwig [15].

To generate more and more detailed engineering designs, engineering activities involved in the chemical process project often use information from those data files resulting from earlier engineering phases. Associations between activities involved and files generated are shown in Fig. 4, with three critical activities (conceptual design, process engineering, and mechanical engineering and design) as an illustration.

One major problem faced by engineers is the conflict among intense associations and the heterogeneity of data sources. As illustrated in Table 1, the data files

Table 1 Semantics embedded in a typical data sources in chemical process engineering

Engineering documents	Software tools	Semantics
Input/output flow diagram (IOFD)	Any flow chart packages, e.g., MS Visio	Raw materials Reaction stoichiometry Products
Block flow diagram (BFD)	Any flow chart packages, e.g., MS Visio	Everything above, plus: Materials balances Major process units Process unit performance specification
Process flow diagram (PFD)	Any flow chart packages, e.g., MS Visio CAPE packages, e.g., Aspen	Everything above, plus: Energy balances
	CAD packages	Process conditions (T & P) Major process equipment specification
Process & instrument diagram (P&ID)	Any flow chart packages, e.g., MS Visio	Key piping and instrument details Process control schema
	SmartPlant P&ID CAD packages	Symbol representation of all equipment and components involved
Mechanical flow diagram (MFD)	Any flow chart packages, e.g., MS Visio CAD packages	Pipe specification All valves (sizes and types) Operation condition specification
Spreadsheets	Any spreadsheet packages, e.g., MS EXCEL	Engineering calculations Materials balances Process conditions Detailed equipment specification
3D process model	SmartPlant 3D	Piping routing and specification Process conditions Process equipment and component topological and geometrical features

generated by CPE projects come in a variety of formats, including unstructured data, semi-structured data, and structured data; this situation leads to structural heterogeneity [15, 22, 36]. For example, the requirement analysis document used at the start of a chemical process project is an unstructured data source, while the specification in the spreadsheets is a kind of semi-structured data source, and the data stored in the databases of, for example, SmartPlant 3D belongs to a structured data source.

To make the engineering processes even more complicated, differences also exist in the interpretation of the semantics of the data, which leads to another level of heterogeneity, called semantic heterogeneity [11]. For example, process engineering requires PFDs, and the information embedded in them is used as the input for process simulations; the simulation results will in turn influence the conceptual

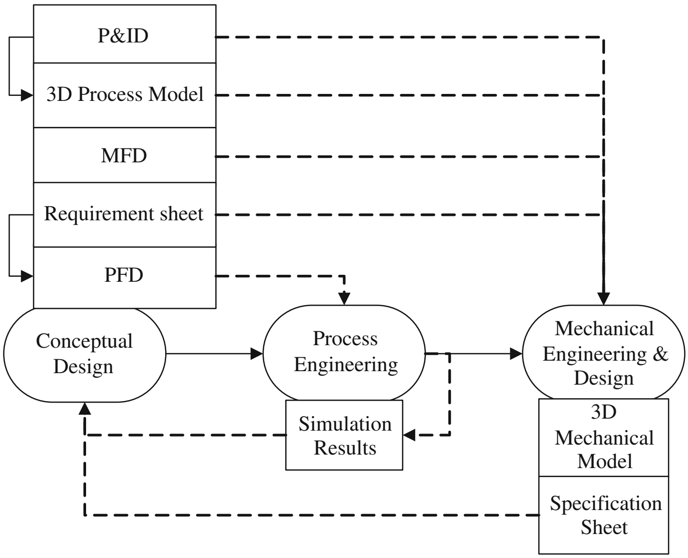

Fig. 4 Associations between activities involved and files generated

design activity. To implement the downstream mechanical engineering design (ME&D) with the accurate interpretation of the constraints embedded in data, i.e., using the semantic information, consistency-checking with the data sources in the conceptual design phase has to be achieved.

Meanwhile, the output of the ME&D, i.e., the 3D models as well as the specification sheets, need to be interpreted face-to-face by engineers in order to provide information feedback for conceptual design.

As discussed in chapter “Introduction to Engineering Informatics”, some neutral data formats have been developed to deal with geometry heterogeneity, such as the STEP standard, but they can do nothing with semantic heterogeneity. Existing feature technology has improved interoperability between heterogeneous applications but still has limited capability to handle semantic heterogeneity. This is due to the fact that, currently, feature semantics has not been well-defined or maintained [2]. The lack of semantic interoperability may lead to severe information loss and, further, economic loss due to potential operation breakdown and maintenance.

To achieve interoperability on the semantic level, a specification of the interpretation of terminology used in different computer-aided systems has to be formalized [40]. However, there is little, if any, representation of semantics embedded in the data files generated with the existing software packages. Fortunately, the increasing research trend in semantic modeling, which covers semantic conceptual schema with embedded semantic information, provides reason for optimism in overcoming the semantic interoperability problem.

3.2 The Current State of Informatics Modeling Research in CPE

The emerging informatics methodologies for the integration of CPE activities, including mechanical engineering activities, lead in two different directions.

On the one hand, semantic modeling (which comes from the domain of software engineering, as does the development of database design theory) is now applied in many other disciplines, including CPE and mechanical engineering. In the chemical engineering domain, ontology has been applied to facilitate semantic technology [21, 40]. A large research project, IMPROVE, is being conducted in Germany, with a goal of developing a collaborative environment for CPE based on ontology [12, 21, 40]. A flexible and extensible data structure is also proposed to apply to heterogeneous and distributed data. With the knowledge representation capability embedded, it provides a basis for knowledge engineering to incorporate knowledge to guide the activities. Semantic modeling offers a common ground to enable interoperability for both disciplinary domains. However, there is currently no formal definition of semantic modeling. Semantic modeling is understood in the engineering domain to be the information-modeling activities that develop a high-level representation of semantic schema, which provides specifications for the interpretation of data and relations that are then used to capture comprehensive information from different entities [29, 39]. The essence of semantic modeling is to represent relationships between data elements in an explicit way, which helps maintain the consistency of semantic information. Ontology, defined as "an explicit specification of a conceptualization, typically involving classes, their relations and axioms for clarifying the intended semantics," is perfectly suitable for use in implementing semantic modeling in CPE [38].

On the other hand, feature technology, which is believed to be versatile enough to support the encapsulation of tedious mechanical engineering parameters, Attributes, and constraints, is also flexible enough to be associated with semantic modeling entities in an abstracted and declarative form. Feature is still the main technology in the mechanical engineering domain, but is equipped with more capability to represent semantics, such as design intent. Hence, a hybrid semantic modeling that bridges ontology modeling and feature modeling is believed to be a practical way to realize interoperability between multidisciplinary systems. In the authors' recent the research [16], with reference to the feature models proposed by Bidarra and Bronsvoort et al. [2, 4], a declarative feature modeling method called semantic feature modeling was proposed. In the proposed framework, chronological order dependence is removed and the semantics of all the features are well-defined and maintained through the product lifecycle by means of a detection and consistency-checking mechanism. Although some modeling freedom may be sacrificed, this is acceptable considering the improvement to semantic representation capability.

3.3 Semantic Modeling Methods in CPE

There are two approaches to semantic modeling in CPE: integration and mapping.

3.3.1 Semantic Integration Model

The architecture of the proposed semantic integration model is shown in Fig. 5. It consists of three layers: a data layer (DL), a semantic schema layer (SSL), and an AL. The SSL works as a mediator to generate a semantic view for a particular user/engineer from the original distributed, heterogeneous data embedded in various formats. The model proposed here forms the core of the integration framework, which will be discussed in detail in "Features and Interoperability of Computer-Aided Engineering Systems".

Data Layer (*DL*). The data sources, such as those listed in Table 1, lie in the DL in various formats.

Semantic Schema Layer (*SSL*). The central unified semantic mediator lying in this layer includes three basic modules: (1) information extraction, which extracts necessary information from the data sources according to local ontology; (2) semantic mapping, which maps the information extracted into consensual and formal specifications according to the semantic schema; (3) view generation and management, which generates the views with only the necessary semantic information. The knowledge library, holding the domain-specific knowledge, exists to

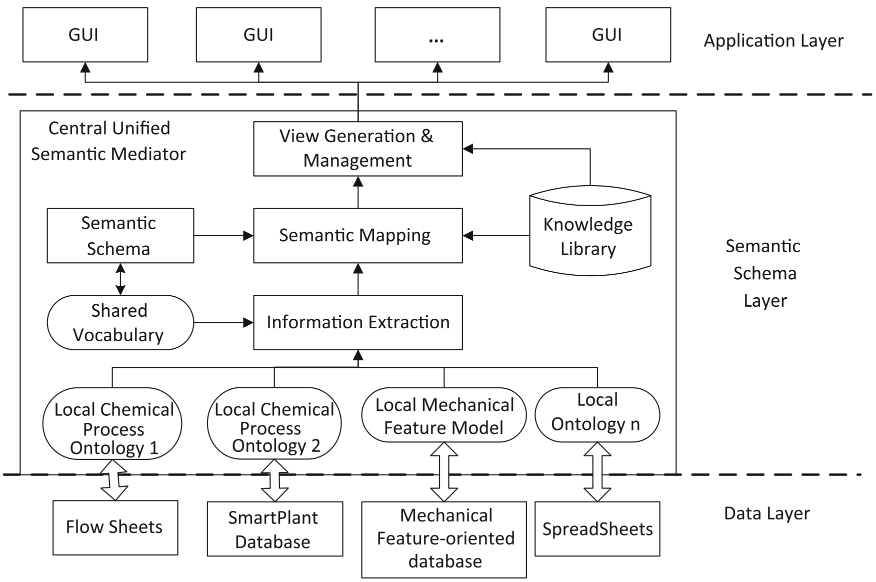

Fig. 5 Architecture of semantic integration model

facilitate the mapping process as well as view generation and management. A hybrid approach for content explication is applied here, as it is scalable and supports heterogeneous views with reasonable implementation cost, as compared to single- and multiple-ontology approaches [34].

Application Layer (*AL*). Graphical user interfaces (GUIs) for different potential users, based on the views generated in the SSL, are provided in this layer.

3.3.2 Semantic Mapping

The information retrieved from distributed data sources can be first mapped based on the semantic schema defined, and then mapped to any other engineering disciplinary view as required by referencing. The partial semantic schema of pressure vessels is given as an example in Fig. 6. To generate a requirement for a vessel, the material as well as its temperature and flow rate will be grouped together to form the input. Pressure, capacity, and temperature retrieved from P&ID will be grouped into the operating conditions. Design pressure, material, and thickness retrieved from the specification sheet supplied by the vendor will be grouped into vessel specifications.

However, to collaborate with different systems, there are still two potential causes of semantic inconsistency: different meanings attached to the same terminology, and the same meaning represented by different terminologies [34]. For example, as shown in Fig. 6, vessel specification has two pressures specified, design pressure and operating pressure, but only one pressure is required in the operating conditions. During ontology mapping, it should be therefore explicitly

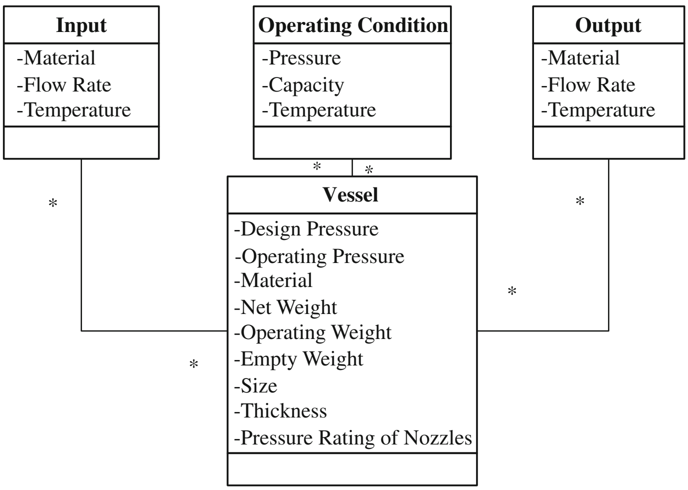

Fig. 6 A semantic schema of vessels

reflected in the shared vocabulary that the *pressure* in the *operating conditions* should be interpreted as the *operating pressure* in the *vessel* vocabulary. In the same example, the *material* in the *input* and the one in *vessel* specification sets do not mean the same thing: one is the material of input and the latter means the material of the vessel. Within the shared vocabulary, these two instances of the term *material* have to be interpreted into different meanings automatically.

Therefore, in semantic modeling, a well-structured semantic schema, along with the shared vocabulary that serves the function of "dictionary" to accurately interpret the meaning of the information, keeps the semantics consistent among the instances of different entity types, and provides the schema to map the data elements accordingly.

4 New Development in Product and Process Modeling with Engineering Informatics

Storing and extracting geometric and nongeometric feature information for engineering design in an integrated and dynamic data repository is an important step in managing and improving product and process engineering lifecycles. Currently, the state of industrial practices is still based on holding engineering design models in file storage [1] and then managing data through various data controllers. This situation constrains the integration of applications, and implementing concurrent design development processes also demands more complicated data controllers. Further, the situation leads to redundancy in storing consistent product and process information. An unfortunate fact is that a lack of integration among CAD and CAM systems leads to a deficiency in the computer numerical control (CNC) programming process, which seriously limits the implementation of digital manufacturing technology. Many industries find that they need to convert various CAD file formats into one another for different engineering applications. Clearly, as many people have realized, an interoperable engineering platform will help industries to effectively share their digital assets among various computer systems and to achieve full return on their investment in digital intellectual properties. If the projected vision can be achieved, the centralized data repository can be managed at different levels of abstraction based on the root-level geometric or nongeometric data.

To leverage the widely-accepted feature technology with database technology, a unified feature-based fine-grain product repository has been suggested with the aim of interoperability among engineering applications [37]. For instance, Ma et al. [18] provided a fine-grain and feature-based product data repository design. They suggested using a complete SQL database to accommodate the complex neutral features and extracted feature information via database API functions. However, this database has limitations, as the table of databases must be created manually, and the database cannot perform validation of feature changes.

Global research in the area of integrated feature-based systems can be divided into two approaches: developing the architecture of an integrated feature-based system, and implementing feature-mapping functions between systems. The majority of the current research focuses on the latter approach and explores the concept of reusing CAD models and converting design results from one feature model to another. Much of the previous research also focused on the integration of CAD and CAE processes, but was limited to operating geometric entities or storing layer-base information in a database. The most common problem is that CAD designs have much more complex structures than CAE geometric meshes. Consequently, full-scale implementation of CAD and CAE integration has yet to be attempted.

5 Engineering Change Management in Design: The Propagation Method

Engineering change management (ECM) is an essential aspect of concurrent engineering, and comprises all related activities during the design and manufacturing stages. To reduce product development time, many companies adopt the concurrent engineering approach by stressing a parallel and collaborative engineering procedure. ECM is typically time-consuming, as it frequently involves disparate information systems issued frequently during the product lifecycle. Due to its complexity, building a system that enables seamless design change propagation is likely to be a very demanding task. This section introduces a preliminary propagation-based methodology for design change management in collaborative design and manufacturing.

5.1 The Design Change Process Framework

Design changes (DCs) are known as engineering changes (ECs), which is an important phase in the computer-integrated manufacturing system [19]. Reducing the time for ECs can greatly shorten the product lifecycle and improve the productivity of an enterprise. Figure 7 shows a framework for the process of DC.

Due to the application of modular technology, companies can choose a particular supplier who is focused on a series of components, and build a collaborative unit in order to maximize the benefit margin and shorten the product lifecycle. In this collaborative product development process?, speeding up EC requires that EC information should be represented precisely and clearly in a standard format and be shared among participating companies. However, part suppliers do not always use the same CAD system and are often unwilling to share their CAD data with other cooperating companies, in order to honor policies of protecting corporate intellectual property. These circumstances make it difficult for collaborating

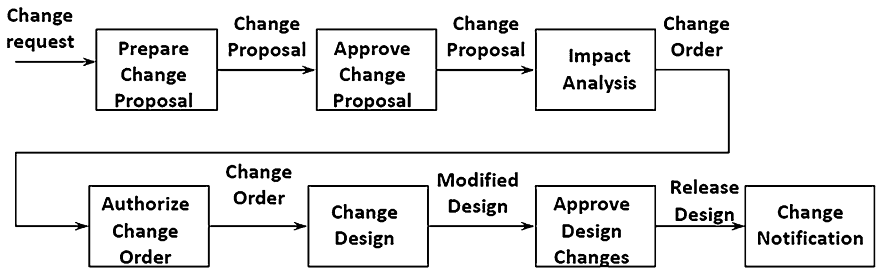

Fig. 7 Framework for the process of design change

companies to conduct efficient EC, since a part supplier who is responsible for one part of a product needs other CAD part model data designed by other companies for the ECs in the typical CAD product assembly modeling process. While much research still needs to be done to address this issue, there are a few methods that have been both published and practiced in the industry domain in recent years.

5.2 *Recent Research and Implementation of ECM*

ECM (especially design change management) occupies an irreplaceable position throughout the product lifecycle. Much effort has been put toward using a propagation-based approach. With the development of product data management (PDM) systems, conceptual design change management based on product structure has been studied by Peng and Trappey [26] and Do and Choi [7, 8]. Upon improvement in the parametric modeling capabilities of commercial CAD systems, a parameter-based approach was suggested for ECM [41]. Recently, common platform specifications and implementation guidelines have been developed by standardization research organizations, such as ProSTEP, toward the development of an ECM system [27, 30]. Two methods in particular, an engineering change propagation (ECP) system based on the STEP neutral data format and a neutral reference model based on parameter referencing, are discussed below for representation and propagation of ECs in collaborative product development.

5.2.1 Engineering Change Propagation with STEP Data Structures

You and Yeh [44] proposed an ECP system based on STEP. This system for modeling ECs in models of engineering data, geometry, and features using the STEP standard provides a flexible, virtually integrated framework to enable EC. Figure 8 shows the basic conceptual structure of the approach.

Figure 8 illustrates the overall structure of the ECP system. The ECP, CAD, and PDM system databases are organized as a three-tier architecture of individual

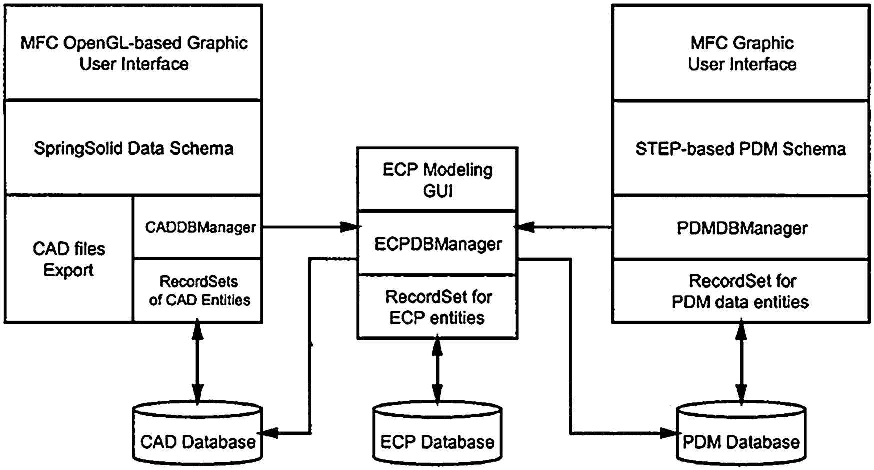

Fig. 8 The ECP system architecture [44]

databases, which stores the original data. The open database connectivity (ODBC) protocol and the record sets class of Microsoft foundation classes (MFCs) are applied to the database operation modules of these systems. Two additional modules, *CADDBManager* and *PDMDBManager*, are used to handle the EC transactions when a change is issued. When a DC is issued in the CAD system, the *CADDBManager* searches and triggers the *ECPDBManager*, which manages the database of the ECP system. *ECPDBManager* obtains the ECP network of the affected data section and gains all the changed items in the CAD and PDM systems. The ECP system then propagates the change from CAD to PDM. The CAD feature editing functions and PDM system commands are applied via implemented COM technology to assist interoperation. Functions defined by these systems are made available to the public and compiled as COM automation documents. The client can request, through a public interface, access to the functions defined in the server. The automation server inherits *IUnkown* and *IDispatch* interfaces in the MFC class and provides clients with public methods to call automation objects. The operation of the ECP network in the study [44] relies on the COM-based change propagation mechanism in the ECP system. The ECP triggering module, CAD feature editing, and the PDM system are all COM object servers that can call and be called by other COM automation objects.

A DC may be propagated through the related features, if they are affected. Collaborative product design can be classified into two categories: collaborative component design and collaborative assembly design [33, 43]. Changes in the design of a part often involve the shape modification of other parts in the assembly model, especially in places where there is a tight connection between parts. When the feature of a part is changed, the tight connection feature with this part should thus also be changed. The process shown in Fig. 9 facilitates the propagation of changing information throughout the whole model.

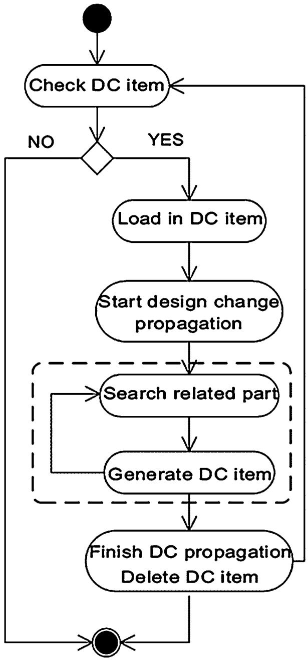

Fig. 9 The propagation process [43]

Searching the propagated parts and establishing the items impacted by the DC is the critical algorithm of the propagation process. Therefore, the related parts must satisfy the following conditions:

1. A relational part must have the characteristics of features.
2. It has to be one of the mating couples with the parts feature that has the DC data.
3. The mating condition has to be a tight connection.

After the above conditions are satisfied, when a related feature is changed, the corresponding features should also change shape in order to keep the same mating conditions of the assembly relationship. In order to accelerate the process, before propagation is begun, it is better to initialize the information in the assembly model for higher efficiency and shorter search time.

5.2.2 Engineering Change Propagation with a Feature Reference Model

Hwang and Mun [9] proposed a neutral reference model for the representation and propagation of EC information in collaborative product development. This neutral reference model consists of a neutral skeleton model and an external reference model, which is implemented on the parametric referencing functions supported by most available CAD systems. If the referenced geometric entity is changed, the consequent parameter value changes are automatically propagated to the referencing geometry entities, which trigger an automatic change of the referencing model. Employing this mechanism, an external referencing model was used by Hwang and Mun [9] with the aim of managing the relations between the original skeleton and the NSM CAD files. Do and Choi [7] also proposed a comprehensive procedure for ECP in order to maintain consistency between various product data views. Their procedure used the history of product structure changes based on an integrated product data model. The effectiveness of these methods is, however, still to be proved.

Clearly, much research has yet to be done to set up an integrated product information database with a common standard for ECM that is accessible and useful for supporting the entire product lifecycle.

6 Summary

This chapter provided a review of the state of the art in product and process informatics modeling and implementation. It is clear that currently there are numerous computer solutions that are addressing engineering application support requirements piece by piece. However, there are many gaps among these piecemeal solutions in communicating associated information effectively. Such integration and data sharing difficulties have been the main hurdles in realizing the potential economic benefits of engineering informatics. A systematic study of interoperability among computer systems is in high demand, which happens also to justify the purpose of this book, i.e., exploring a theoretical framework for interdisciplinary and multifaceted informatics engineering. To do so, the authors believe extended feature technology will play a pivotal role in future technology development.

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