ELSEVIER

Computer-Aided Design 33 (2001) 521–529

COMPUTER-AIDED DESIGN

www.elsevier.com/locate/cad

Mapping product structures between CAD and PDM systems using UML

Youchon Oh[a,*], Soon-hung Han[a], Hyowon Suh[b]

[a]Department of Mechanical Engineering, ME3080, Korea Advanced Institute of Science and Technology, 373-1, Kusong-Dong, Yusong-Ku, Taejon 305-701, South Korea

[b]Department of Industrial Engineering, Korea Advanced Institute of Science and Technology, 373-1, Kusong-Dong, Yusong-Ku, Taejon 305-701, South Korea

Received 3 January 2000; revised 30 April 2000; accepted 4 July 2000

Abstract

The product data exchange between heterogeneous CAD and PDM systems is a crucial issue for the integration of product development systems. STEP offers an efficient mechanism of product data exchange between heterogeneous systems. This paper introduces a UML-based mapping methodology for the product data models. The suggested mapping method has been applied to exchange the product structure data between a CAD system and a PDM system. Based on the STEP methods, we developed an interface module. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Product data exchange; STEP; Mappings

1. Introduction

Manufacturing industry today faces challenges. In order to meet the competition in the market, the information technology has become one of the significant factors [5]. Early introduction of information technology applied computers to tasks previously carried out manually. For example, computer systems such as CAD (computer aided design), CAE (computer aided engineering), and CAM (computer aided manufacturing) have been successfully introduced and increased the productivity. However, the models of these computer systems are heterogeneous because they have been developed independently. The product data exchange between these automation systems becomes a crucial issue for the integration of product development systems. Recently the PDM (product data management) system is being used to integrate these systems into a common environment throughout the product lifecycle. The PDM system also has the problem of exchanging product data with legacy systems, especially with the CAD system that generates the product data. The interface between CAD and PDM systems is considered as an enabling technology for CE (concurrent engineering), CALS (commerce at light speed), and CIM (computer integrated manufacturing).

To integrate a CAD system with a PDM system, we need to develop a data translator. The mapping between the internal models of each system must be defined first. There are four different solutions for the data exchange problem; the manual re-input of data, direct translation, neutral format translation, and shared product database [5]. Each approach has its own pros and cons. Direct translation is the simple and accurate solution, but the number of translators increases exponentially with the number of systems involved. The last two solutions are reasonable, flexible, and adaptable. The product data exchange in this paper is based on STEP (standard for the exchange of product model data). Demartini et al. [4] presented a migration path to the STEP technology. Loffredo [14] studied an efficient database implementation of EXPRESS models. Zhang et al. [27] introduced a systematic approach to implement the interoperation between STEP APs (application protocols). Shin et al. [21] enhanced a ship design model using the STEP methodology and a non-manifold modeler. Hardwick et al. [8] studied sharing manufacturing information in a virtual enterprise. Bliznakov et al. [3] integrated a CAD system with engineering application programs in a distributed heterogeneous environment and proposed the information integration infrastructure based on an object-oriented multidatabase. PDMI2 (product data modelling on the basis of international standards) [19] project have developed a translator using the STEP PDM Schema.

Many different mapping methods such as EXPRESS-M [2], EXPRESS-V [7], EXPRESS-C, EXPRESS-X [1],

---

[*] Corresponding author. Tel.: +82-42-869-3080; fax: +82-42-869-3210.
E-mail addresses: youchon@icad.kaist.ac.kr (Y. Oh), shhan@kaist.ac.kr (S. Han), hwsuh@kaist.ac.kr (H. Suh).

PII: S0010-4485(01)00051-3

XP-rules, and view mapping language have been proposed [26]. Liebich et al. [13] compared different approaches in this field. Hardwick et al. [9] proposed data protocols for a virtual enterprise using EXPRESS-X. The mapping methods can be classified into two types based on whether the models are homogeneous or heterogeneous. EXPRESS-X is a mapping language for the data described only in EXPRESS. Oh et al. [17] proposed a UML (unified modeling language) based mapping for the heterogeneous models. No one mapping method can be used in every situation, so the more flexible and general mapping methodology is needed, especially for the heterogeneous systems.

This paper discusses how CAD and PDM systems can be integrated using STEP standards in the product development environment. It is organized as follows: (1) STEP standards and their data structures are explained, (2) A mapping methodology based on UML is suggested for the mapping between heterogeneous systems, (3) The suggested mapping methodology is applied to the data exchange between a CAD system and a PDM system. Various types of integration between CAD and PDM systems are presented and (4) The STEP based interface of CAD and PDM systems is experimented with and implemented in an industrial field.

2. STEP

2.1. Exchange of the product data using STEP

STEP is an international standard for the representation and exchange of product model data. The objective is to provide a mechanism that is capable of describing product data throughout the lifecycle of a product, independent from any commercial system. It is organized into six main categories: description methods, implementation methods, conformance testing methodology, integrated information resources, abstract test suites, and application protocols (AP). The APs use the integrated information resources (IR) to define information models for various application domains. In this paper, the AP203 (the configuration controlled 3-D designs of mechanical parts and assemblies) [12] and the STEP PDM Schema [23] have been used.

STEP offers the data exchange mechanism of both neutral format and shared database. The STEP neutral file format is the most basic and simple implementation method. Fig. 1 shows the product data exchange among heterogeneous CAD/CAM/PDM systems and Web applications using STEP standards. It requires two kinds of translations. The translation from the internal data format of an application to the STEP standard is the pre-processing, and the reverse translation is the post-processing [18].

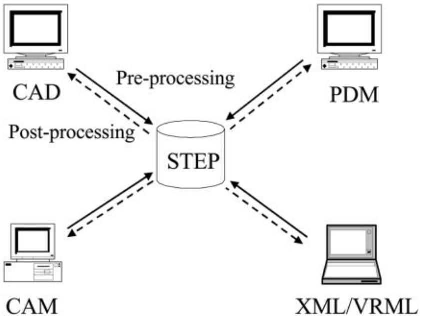


Fig. 1. Product data exchange using STEP.

2.2. The STEP PDM Schema

The STEP PDM Schema [23] is generated and maintained by ProSTEP of Germany and PDES, Inc. of USA. It is interoperable with STEP AP203, AP212, AP214, and AP232 because it is a common subset of these APs (Fig. 2). It is organized into 15 UoFs (unit of functionality) such as Part Identification, Part Classification, Part Structure and Relationships, Document Identification, Authorization, Work Management Data. The Usage Guide of the STEP PDM Schema [25] has also been published, which helps for consistent interpretation of the STEP PDM Schema.

2.3. Product structure data of STEP

AP203 has the *Part Identification* UoF and the *Bill of Materials* UoF to represent the product structure. The mapping table of AP203 shows how ARM (application reference model) UoF and application objects map to AIM (application interpreted model) entities. For example, the *product* entity in the AIM represents a part and maps to the *Part* object in the ARM. The *next_assembly_usage_occurrence* AIM entity represents the relationship of two parts, where the *relating_product_definition* attribute is a reference to the parent part and the *related_product_definition* attribute is a reference to the child part. The EXPESS-G representation of these entities is shown in the left side of Fig. 7. The STEP PDM Schema is interoperable with AP203. It also has the *Part Identification* UoF for the definition of a product and the *Part Structure and Relationships* UoF for the definition of assemblies and product configuration.

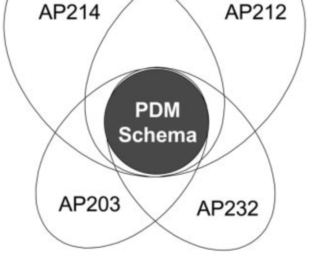


Fig. 2. The position of STEP PDM Schema.

3. UML-based mapping

3.1. Mapping methodology for the product modeling

Different mapping methods have been proposed to implement the system integration within the product modeling area. A formal mapping notation is required for the definition of mappings on the conceptual level. This notation provides a method to describe the correspondences between models. After the mapping is defined, it is then possible to convert data on the implementation level. Fig. 3 shows the architecture of a general mapping problem [13].

There are two types of mapping problems. One is the transformation performed on two schemas specified by the same EXPRESS modeling language. EXPRESS-M, EXPRESS-V, and EXPRESS-X are the solutions for this problem. The other is the transformation performed on two schemas specified by different languages. We consider this as the mapping problem between heterogeneous systems.

The requirements for an EXPRESS mapping language such as human and computer interpretability, similarity to EXPRESS, formal specification, ARM to AIM mapping, and Mapping between APs are specified by ISO [11]. In addition, there are more requirements for a general mapping language to map a legacy system to a STEP model. It should define the mapping between the heterogeneous models and support a graphical notation.

3.2. UML mapping diagram

The UML is a visual modeling language for specifying, visualizing, and constructing software systems. It unifies the object-oriented methods of Booch, Rumbaugh, and Jacobson [6]. It can be easily applied to the development of a data translator, because it is made for the development of software systems. However, there is no mapping notation in UML. This paper suggests UML mapping diagrams as a UML extension for data exchanges. The usage of UML diagrams for the STEP standards is also being discussed in ISO/TC184/SC4.

The proposed UML mapping diagram looks like a class diagram. Fig. 4 shows the UML mapping diagram. It is drawn as a rectangle with three compartments separated by horizontal lines. The name compartment at the top holds the mapping name. The attribute compartment in the middle holds a list of one to one mappings and one to many mappings. The operation compartment at the bottom holds a list of operational mappings. To implement operational mappings, we need specialized algorithms. UML mapping diagrams are used for the development of a translator with UML class diagrams.

Fig. 5 shows the architecture of the UML-based mapping methodology, which is applied to the mapping between STEP and a PDM system. According to Fig. 3, schema mapping is on the conceptual level and data translation is on the implementation level. The separation of conceptual models from implementation forms allows two different levels of implementations: data exchange using files, and data access based on a shared database. Because the data model and the implementation method are separated, the mapping methodology used for the file format implementation can be applied to the database implementation, too.

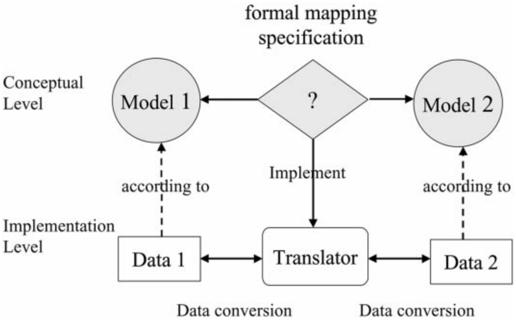


Fig. 3. A general mapping problem.

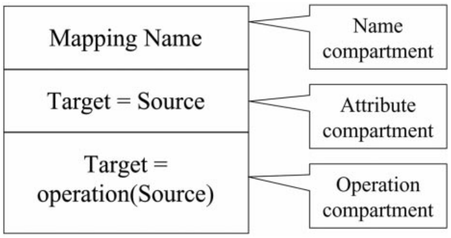


Fig. 4. UML mapping diagram.

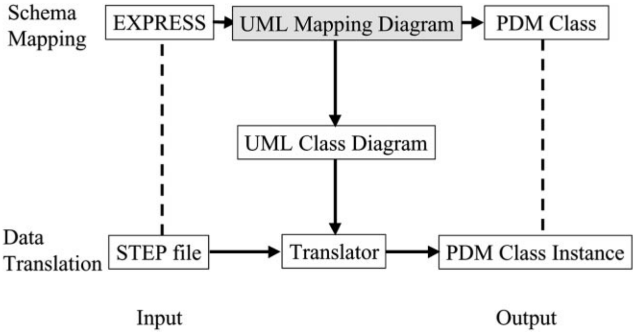


Fig. 5. UML-based mapping methodology.

4. Exchange of product structure data between CAD and PDM

4.1. Integration of CAD and PDM systems

PDM is a tool that helps engineers manage both the engineering data and the product development process throughout the product lifecycle. The main functions of a PDM system are the data vault management, the process management, the product structure management, the classification, and the program management [20]. As PDM systems are

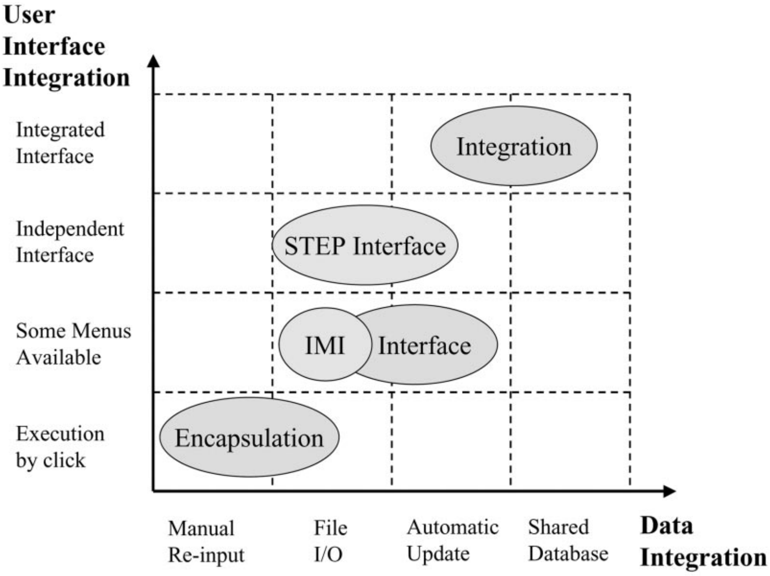


Fig. 6. Integration plane of CAD and PDM systems.

widely used to reduce the product development time, they need to exchange product data with CAD systems.

It is necessary to integrate CAD and PDM systems, because the CAD system generates the product data and the PDM system manages the product data. The CAD system generates not only geometry data but also product structure data. The management of product structure data is the main function of a PDM system. Without the integration of CAD and PDM systems, engineers would have to re-input the product structure data into the PDM system and update the data whenever it changes.

There are several types of integration between CAD and PDM systems according to the level of integration. The factors that decide the types of integration are as follows.

1. Data integration
    - Manually re-input the data
    - Data exchange using file
    - Stand-alone databases but the data is updated automatically.
    - Shared database
2. User interface integration
    - PDM system recognizes CAD files and can launch the CAD system.
    - Some PDM functions are available via the CAD menu.
    - A new interface independent from CAD and PDM systems.
    - Fully integrated interface.

The level of integration depends on the data and the user interface. Fig. 6 shows the integration plane of CAD and PDM systems, where the x-axis is the level of data integration and the y-axis is the level of user interface integration. In addition, the openness of the integration system is decided by whether it adopts the standards. Usually a PDM system supports a specific CAD system. If the integration is based on standards, it is possible to integrate with all the systems support those standards.

CIMdata defines three types of integration between a PDM system and an application, which are integration, interface, and encapsulation [15]. *Integration* provides full, automatic exchange of product data and all the PDM functions are available within the application (or vice-versa). *Interface* means that the PDM and the application can exchange files without user intervention, and PDM functions are available as the application's menus (or vice-versa). *Encapsulation* is that PDM recognizes application's files and can launch the application. These three types of integration are also placed on the integration plane of CAD and PDM systems. In Fig. 6, the STEP interface is an interface based on STEP standards. The IMI (IDEAS Metaphase Interface) [10]is a commercial interface between IDEAS™ CAD system and Metaphase™ PDM system. If the systems are more tightly integrated, they are easier to use but it costs more. Which level of integration is appropriate should be decided considering the cost, the organization, and user requirements.

4.2. Exchanging product data based on STEP

This section describes how a CAD system and a PDM system can exchange the product structure data based on the STEP standards. Many CAD vendors have implemented the STEP interfaces that exchange AP203 data, but only a few PDM vendors support STEP interfaces according to STEP-net [24] and PDMnet [23] which are the STEP interoperability test bed. To transfer the product structure data created in a CAD system into a PDM system, the following

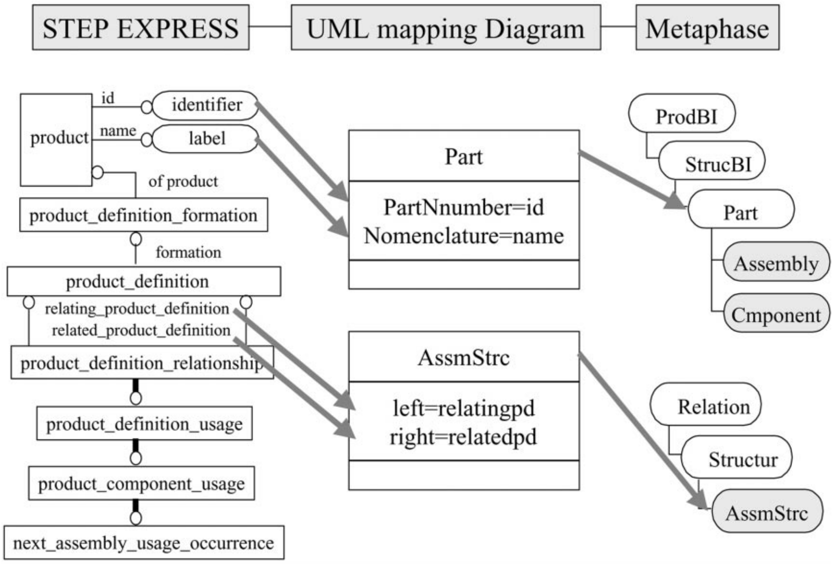


Fig. 7. STEP and PDM mapping.

steps are needed. First, the assembly model from a CAD system is converted into a STEP physical file by the pre-processor. This STEP file is then converted into the product structure data of a PDM system by the post-processor. We need the schema mapping between STEP entities and PDM classes on the conceptual level, and the data translator on the implementation level.

4.3. Mapping product structure data using UML mapping diagram

To exchange the product data between a CAD system and a PDM system, the schema mapping on the conceptual level must be considered. In this paper, SDRC Metaphase [16] system is used as a PDM system. Its PSM (product structure manager) module manages the product structure and the BOM (bill of materials). Metaphase is composed of classes. *Assembly* and *Cmponent* are the part identification class, and *AssmStrc* is the relation class of product structure [16]. Fig. 7 shows the mapping between STEP entities and PDM classes of Metaphase based on UML mapping diagrams. The *identifier* and *label* attributes of the STEP's *product* entity map respectively to the *Part Number* and *Nomenclature* attributes of the Metaphase's *Assembly* or *Cmponent* class. The *relating_product_definition* attribute of the STEP's *next_assembly_usage_occurrence* entity maps to the *left* attribute of the Metaphase's *AssmStrc* class for the representation of a parent part. The *related_product_definition* attribute of the STEP's *next_assembly_usage_occurrence* entity maps to the *right* attribute of the Metaphase's *AssmStrc* class for the representation of a child part.

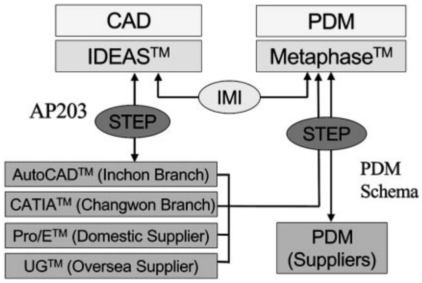
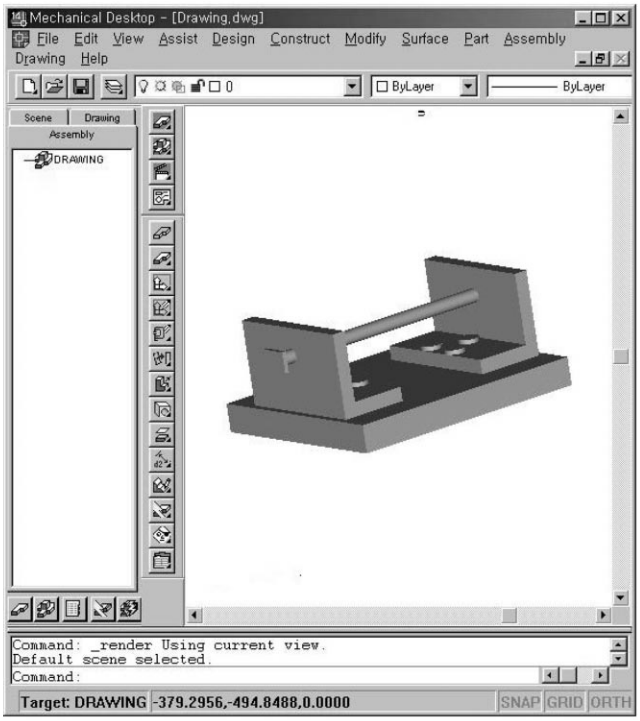


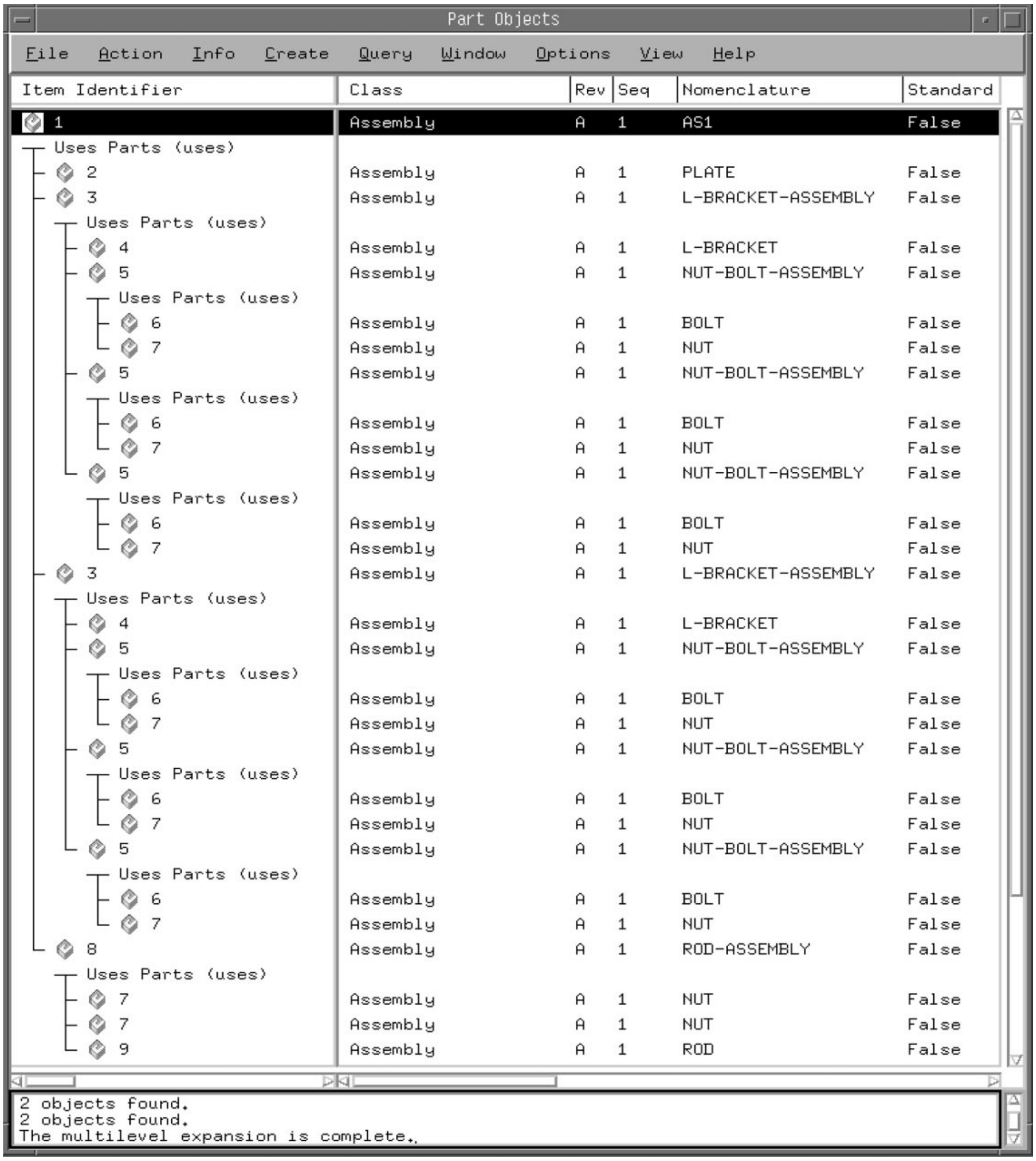
Fig. 8. The problems of DHI and STEP-based solution.



```
Command: _render Using current view.
Default scene selected.
Command:
```

Target: DRAWING -379.2956,-494.8488,0.0000 SNAP GRID ORTH

Fig. 9. The assembly model for the test.



```
Item Identifier              Class            Rev Seq  Nomenclature           Standard
1                            Assembly         A   1    AS1                    False
 Uses Parts (uses)
  2                          Assembly         A   1    PLATE                  False
  3                          Assembly         A   1    L-BRACKET-ASSEMBLY     False
   Uses Parts (uses)
    4                        Assembly         A   1    L-BRACKET              False
    5                        Assembly         A   1    NUT-BOLT-ASSEMBLY      False
     Uses Parts (uses)
      6                      Assembly         A   1    BOLT                   False
      7                      Assembly         A   1    NUT                    False
    5                        Assembly         A   1    NUT-BOLT-ASSEMBLY      False
     Uses Parts (uses)
      6                      Assembly         A   1    BOLT                   False
      7                      Assembly         A   1    NUT                    False
    5                        Assembly         A   1    NUT-BOLT-ASSEMBLY      False
     Uses Parts (uses)
      6                      Assembly         A   1    BOLT                   False
      7                      Assembly         A   1    NUT                    False
  3                          Assembly         A   1    L-BRACKET-ASSEMBLY     False
   Uses Parts (uses)
    4                        Assembly         A   1    L-BRACKET              False
    5                        Assembly         A   1    NUT-BOLT-ASSEMBLY      False
     Uses Parts (uses)
      6                      Assembly         A   1    BOLT                   False
      7                      Assembly         A   1    NUT                    False
    5                        Assembly         A   1    NUT-BOLT-ASSEMBLY      False
     Uses Parts (uses)
      6                      Assembly         A   1    BOLT                   False
      7                      Assembly         A   1    NUT                    False
    5                        Assembly         A   1    NUT-BOLT-ASSEMBLY      False
     Uses Parts (uses)
      6                      Assembly         A   1    BOLT                   False
      7                      Assembly         A   1    NUT                    False
  8                          Assembly         A   1    ROD-ASSEMBLY           False
   Uses Parts (uses)
    7                        Assembly         A   1    NUT                    False
    7                        Assembly         A   1    NUT                    False
    9                        Assembly         A   1    ROD                    False

2 objects found.
2 objects found.
The multilevel expansion is complete.
```

Fig. 10. Data translated into the PDM system.

5. An implemetation

5.1. The problem

Daewoo Heavy Industries (DHI) of Korea recently customized Metaphase PDM system for the implementation of a concurrent engineering environment. Problems were identified as it was launched into the production line. One of the problems is the manual re-input of product data into the PDM system because the CAD system cannot transfer the data. In addition, the data in the PDM system must be updated manually whenever the CAD model changes. To solve this problem, DHI has a plan to introduce the IMI (IDEAS Metaphase Interface) module. It is a commercial tool to transfer the IDEAS^{TM}'s TDM (Team Data Manager) data to Metaphase^{TM}.

DHI prefers the direct translation such as IMI. It is a simple solution for the specific case, but has two unsolved problems. One is the interface between Metaphase^{TM} and other CAD systems such as AutoCAD^{TM}, Catia^{TM}, Pro/E^{TM}, and UG^{TM}. The other is the exchange of product data between Metaphase^{TM} and other PDM systems. The second problem occurs when a company has two different PDM systems or parts suppliers use different PDM systems. Fig. 8 shows three problems of DHI. One is the data exchange between the different CAD systems. Another is the data exchange between CAD and PDM systems. The other is the data exchange between the different PDM

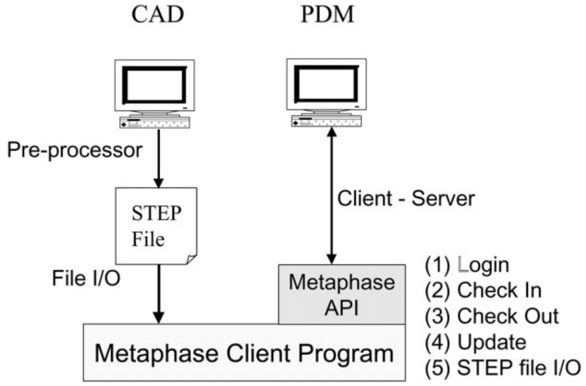


Fig. 11. The architecture of CAD and PDM interface.

systems. Fig. 8 also shows the STEP based solutions. The data exchange between different CAD systems can be solved using STEP AP203, and the data exchange between different PDM systems can be solved using the STEP PDM Schema. The data exchange between CAD and PDM systems can be solved using the STEP based interface, which will be presented in the following sections.

5.2. An experimental exchange of product structure data

According to the mapping between STEP and PDM models, we have developed a data translator which converts a STEP model into the Metaphase PSM instances. The translator has been developed as a Metaphase client program based on the Metaphase API (Application Programmer's Interface) [16]. The STEP assembly model of Fig. 9 generated by AutoCAD™ is used for the test. This model is borrowed from the CAD data exchange test of STEPnet [24]. The translator reads the STEP file and constructs the product structure according to the local PDM classes. Fig. 10 shows the result of data translation. It shows the product structure of Metaphase.

5.3. The STEP based interface

According to the integration plane of Fig. 6, the STEP based interface between CAD and PDM systems uses the *independent* user interface and exchanges data using *files*. Fig. 11 shows the architecture of the STEP based interface. CAD models are translated into STEP physical files using the STEP pre-processor provided by the CAD vendor. Then the STEP data is converted into the PDM data using the Metaphase client program we developed. The main functions of this interface are login, check in/out, update, and STEP file input/output. These functions have been implemented using ST-Developer [22] and Metaphase API [16].

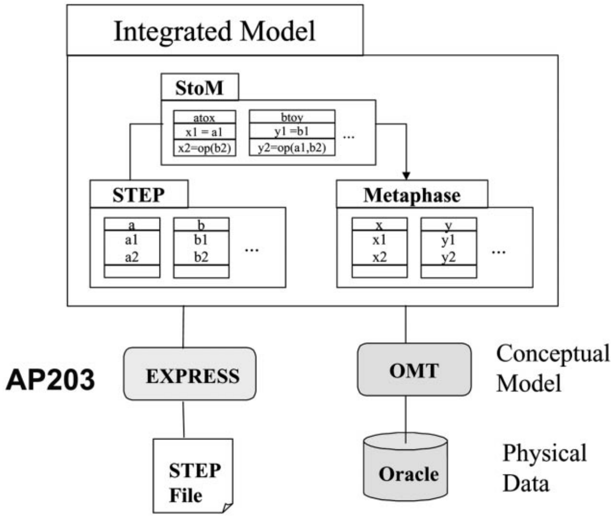


Fig. 12. The integrated model of STEP based interface.

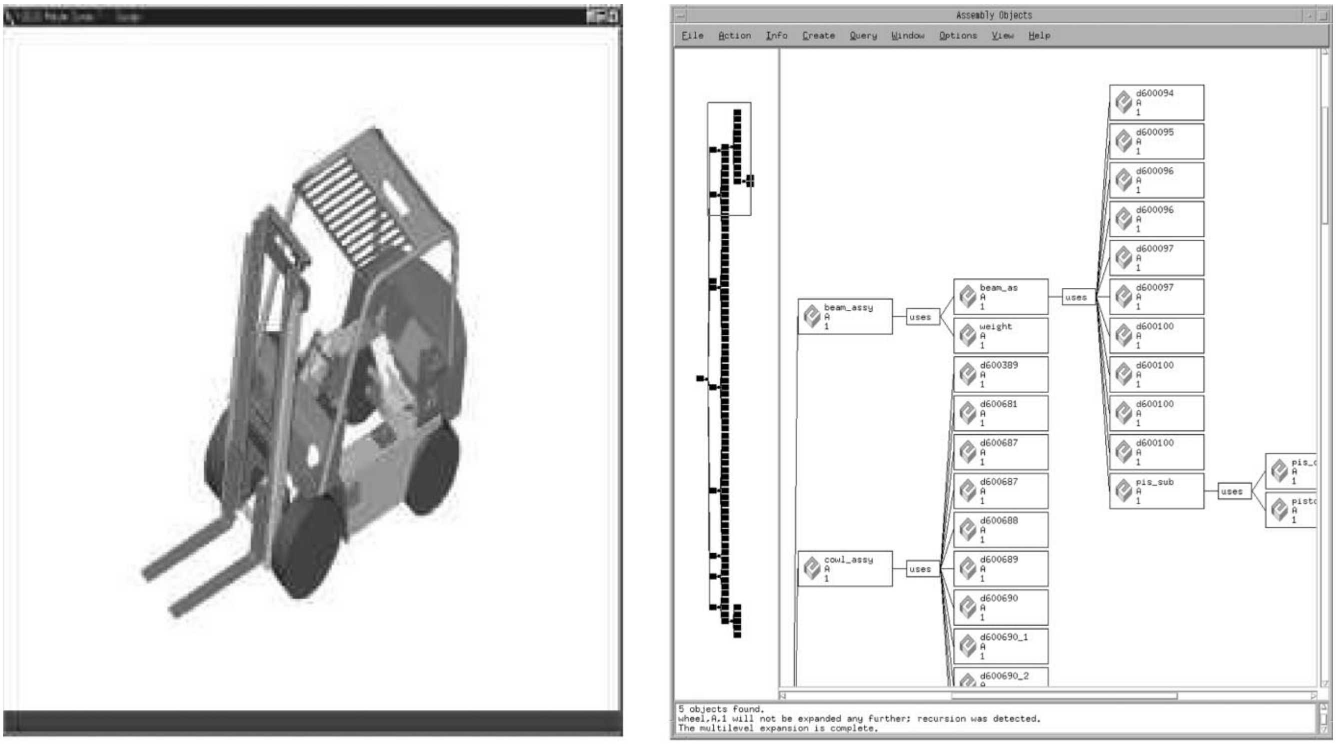
Fig. 12 shows the integrated model of the STEP based interface. It consists of a STEP AP203 model, a Metaphase model, and a mapping model between STEP and Metaphase. The mapping model is described in UML mapping diagram. The conceptual models are modeled in EXPRESS and OMT (Object Modeling Technique). The physical data is stored in STEP physical files or the Oracle™ database. Fig. 13 shows the result of the STEP interface applied to the model of DHI's forklift truck. The left of Fig. 13 is a forklift model from IDEAS, and the right of the figure is its product structure of Metaphase.

6. Conclusion

In this paper, we explained how the product structure data of STEP can be exchanged between CAD and PDM systems.

We suggested a UML-based mapping methodology for the mapping between heterogeneous product models. The UML-based mapping methodology has strong points in that it is suitable for any object-oriented modeling language. Also it is easy to use and easy to read because it is a graphical notation. The weak point is that it is not yet computer interpretable, so it needs human interpretation. The computer interpretable syntax must be defined in the future. The choice of mapping language is dependent on the project. EXPRESS-X is suitable for the mapping between EXPRESS models such as the ARM to AIM mapping and the mapping between different APs. On the other hand, the UML-based mapping methodology of this paper is suitable for the mapping between any legacy system and a STEP model.

For the data exchange between CAD and PDM systems, the suggested UML based mapping methodology has been applied to real data. The various types of integration besides the STEP based interface have been investigated through the integration plane. Integrating a CAD system with a PDM system would be a step forward from the geometry-centered CAD systems. Finally, the STEP based interface has been implemented and applied to the product development



```
5 objects found.
wheel.A.1 will not be expanded any further; recursion was detected.
The multilevel expansion is complete.
```

IDEAS V6.0

Metaphase

Fig. 13. Application to a forklift truck.

environment of DHI. The STEP based interface is an open solution for the system integration, so it can be applied to the various CAD and PDM systems.

References

[1] Bailey I, Hardwick M, Laud A, Spooner D. Overview of the EXPRESS-X Language, Proceedings of the Sixth EXPRESS Users Group Conference, Toronto, Canada, 5–6 October 1996.

[2] Bailey ID, Mead M. EXPRESS-M: A schema mapping language, Proceedings of the Third Annual EXPRESS User Group Conference, Berlin, Germany, 2–3 October 1993.

[3] Bliznakov P, Shah J, Urban S. Integration infrastructure to support concurrence and collaboration in engineering design, Proceedings of ASME Design Engineering Technical Conferences, Irvine, California, 18–22 August 1996.

[4] Demartini C, Rivoira S, Valenzano A. Product data exchange using STEP, Proceedings of the Tenth International IFIP WG 5.2/5.3 Conference, Trento, Italy, 9–12 September 1998.

[5] Fowler J. STEP for Data Management, Exchange and Sharing, Technology Appraisals, 1995 (ISBN 1-871802-36-9).

[6] Fowler M. UML distilled. USA, Addison-Wesley, 1997 (ISBN 0-201-32563-2).

[7] Hardwick M, Spooner D, Kilty M, Jiang Z. Mapping EXPRESS AIM's to ARM's using database views: a comparison of three approaches, Proceedings of the Forth Annual EXPRESS User Group Conference, Greenville, South Carolina, 13–14 October 1994.

[8] Hardwick M, Spooner D, Rando T, Morris K. Sharing manufacturing information in virtual enterprises. Communications of the ACM 1996;39(2):46–54.

[9] Hardwick M, Spooner D, Rando T, Morris KC. Data protocols for the industrial virtual enterprise. IEEE Internet Computing 1997;1(1):20–29.

[10] IDEAS Metaphase Interface, Metaphase Technology, Inc, 1999.

[11] ISO TC/184/SC4/WG11 N013, Requirements specification for EXPRESS mapping language, 1997.

[12] ISO TC184/SC4 AP203, Configuration controlled design, 1994.

[13] Liebich T, Amor R, Verhoef M. A comparison of mapping methods available within the product modelling arena, Proceedings of the Fifth EXPRESS User Group Meeting, Grenoble, France, 21–22 October 1995.

[14] Loffredo D. Efficient database implementation of EXPRESS information models, Ph.D Thesis, Rensselear Polytechnic Institute, 1998.

[15] MacKrell J, Al-Timimi K. Integrating PDM with CAD systems, The Tutorials Proceedings of PDM Conference, Los Angeles, California, 23–25 April 1997.

[16] Metaphase manual, Metaphase Technology, Inc, 1997.

[17] Oh Y, Han SH, Lee SK, Shin SH, UML-based mapping of the product structure data between CAD and PDM systems, Proceedings of ASME Design Engineering Technical Conferences, Las Vegas, California, 12–15 September 1999.

[18] Owen J, STEP: an introduction, 2nd ed., Information geometers, 1997 (ISBN 1-874728-11-9).

[19] PDMI2 (Product Data Modelling on the basis of international standards), ProSTEP, http://www.prostep.darmstadt.gmd.de, 1999.

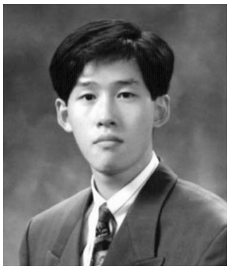
[20] Product Data Management: The definition, CIMdata, http:\\www.cimdata.com, 1997.

[21] Shin Y, Han S-H. Data enhancement for sharing of ship design models. Computer-Aided Design 1988;30(12):931–41.

[22] ST-Developer User Guide, STEPTools, Inc., 1995.

[23] STEP PDM Schema, PDMnet, http://www.pdmnet.org, 1998.

[24] STEPnet, http://www.stepnet.org, 1999.
[25] Usage guide for the STEP PDM Schema, PDM Implementor Forum, http://www.pdm-if.org, 1999.
[26] Verhoef M, Liebich T, Amor RA. Multi-paradigm mapping method survey, http://dutcu15.tudelft.nl/~marcel/mapping.html, 1995.
[27] Zhang Y, Zhang C, Wang HP. Interoperation of STEP application protocols for product data management. Concurrent Engineering: Research and Application 1998;6(2):161–9.



Youchon Oh is a PhD student of the Department of Mechanical Engineering at KAIST (Korea Advanced Institute of Science and Technology). He received a BS degree in Mechanical Engineering at Yonsei University, and an MS degree in Automation and Design Engineering at KAIST. His current research interests include the STEP, PDM, and CALS.

Soon-hung Han is an associate professor in the Department of Mechanical Engineering at KAIST. He received BS and MS degrees from the Seoul National University and a PhD from the University of Michigan. He has work experience at Korea Research Institute of Ships and Ocean Engineering. His current research interests include STEP, geometric modeling kernel, and intelligent CAD.

Hyowon Suh is an assistant professor in the Department of Industrial Engineering at KAIST. He received the BS degree in mechanical Engineering from Yonsei University, the MS degree in mechanical engineering from KAIST, and the PhD degree in industrial engineering from West Virginia University, USA. His current research interests include concurrent engineering, product data management, and STEP.