An Enhanced Data Model for CAD/CAM Database Systems

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ABSTRACT

The record-based conventional data models have been criticized as not powerful enough to model a complex data domain of CAD/CAM. This paper proposes a Semantic Network *plus* Model (SN^+M) as a data model for an integrated CAD/CAM database system. The SN^+M basically is a model coupling semantic network capability developed in artificial intelligence and relational table capability developed in database in order to naturally accommodate the features of a complex data domain.

In this paper, we first discuss some of the special features of a CAD/CAM data domain which make it very desirable to have a higher level data model. The SN^+M data model concept is then briefly discussed. We then discuss on how the proposed model can be used adequately and naturally to model some of the important and representative information of CAD/CAM data domain. Finally, a conclusion is made to summarize the major advantages of the proposed use of SN^+M as compared the use of conventional data models.

1. Introduction

One of the key issues in CAD/CAM database systems is a common database shared by CAD and CAM [1] [2] [3]. That is, a CAD/CAM database system should include every piece of information from the design stage to the control and support of the manufacturing processes.

The following features can be found in a CAD/CAM application:

[1] The application domain consists of both a formatted data type, such as the tables for material properties and machinability data reference, and an unformatted data type, such as machining and assembly operations.

[2] Some of the CAD/CAM data are individual events rather than records. For example, every machining process is an event which includes not only the process itself but also other related information to support the process.

[3] The application domain has many strongly related entities leading to a complex network structure.

[4] Part of CAD/CAM data is treated as individuals, not as a set of entities. For instance, each part may be machined in a different process and each pair of parts may be assembled by a different operation sequence with different related information to support it.

[5] The CAD/CAM application needs representation of semantics such as part hierarchies and geometry, in a system in addition to the storage of data.

Therefore, the data model used in a CAD/CAM database system should be capable of modeling data which are often in both formatted (record-type) and unformatted forms, and in both static and dynamic status [4] [5] [6]. Many CAD, CAM and CAD/CAM systems have been developed [7] [8] [9] [10] [11] [12] based on the conventional database models : hierarchical, network and relational models, and their extensions. The features that record-based models provide are so rigidly structural in their organization that their modeling powers are not capable enough to model a more complex data domain such as CAD/CAM [4] [13] [14].

In the following sections, we will propose Semantic Network *plus* Model (SN^+M) as a data model for an integrated CAD/CAM database system. Notice that we do not intend to design a complete CAD/CAM database system nor to specifically deal with the interface between CAD and CAM. Instead, our purpose is to model some of the important and representative information of CAD/CAM by SN^+M to show how SN^+M can *adequately* and *naturally* model such a *complex* data domain.

In a CAD/CAM data domain, information can be classified into three categories: library information containing the technical know-how of the firm, information created at the design stage describing the goal of a product design and information created for manufacturing is actually used to manufacture products. These three kinds of data are strongly related and form a complete set of information for design and manufacturing activities.

2. The Semantic Network *plus* Model (SN^+M)

The SN^+M [15] is a data model which couples network and table capabilities to naturally accommodate the features of a complex data domain such as CAD/CAM. SN^+M is the same as a semantic network model developed in artificial intelligence , with the exception that the table methodology developed in the relational model is augmented to accommodate the sets of tabulated information.

The $SN^{+}M$ therefore consists of two parts: the semantic network part (briefly, the network part) and the table part. The basic structure for $SN^{+}M$ is shown in Figure 1. In the network part, information is represented as a set of nodes connected to each other by a set of labeled arcs which represent relations among nodes. A directed arc with label L between nodes X and Y means the relation $L(X, Y)$ is true. The table part is set of relational tables to act as a collector of the members of the relation defined by a atble. Each row of such a table conveys an understood association for all elements in the row. The two parts are connected by links showing the semantics of data in tables. The idea of $SN^{+}M$ will be more clear as we go to the following sections.

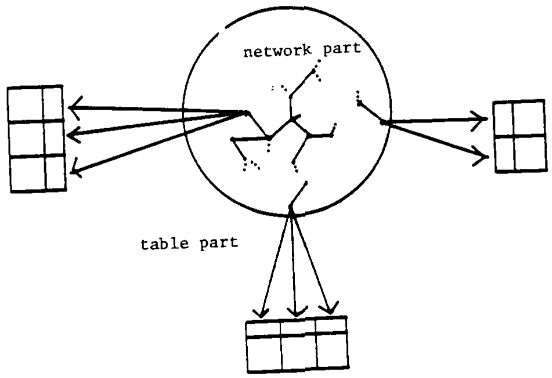


FIGURE 1: STRUCTURE OF $SN^{+}M$

3. On Modeling Library Information by $SN^{+}M$

In manufacturing domain, library data concern the work material (material code. Brinell hardness. elongation, cutting stiffness, etc.), the machine tools (description, list of operations, maximum and minimum tool diameter, maximum speed and feed, etc.), the tools (description, tool material, cutting speed, depth of cut, etc.), speed and feed data handbooks. For example, Figure 2 represents different robot features. Such information typically resides in handbooks or catalogs. It also needs to be stored in a CAD/CAM database system since it is needed for designing and manufacturing [16].

ASSEMBLY TOOLS:

id	acc	rep	#-ax	ty-ax	load-cap
ROBOT-1	0.05	0.05	6	rrr'rrr	30
ROBOT-2	0.01	0.01	5	rss'rr	8

FIGURE 2: A SET OF LIBRARY INFORMATION

One special feature of library information is that it is all in the regularly structured form of tables which is best modeled by table method such that this information will be stored in the database in the same forms in which it resides in handbooks or catalogs [13].

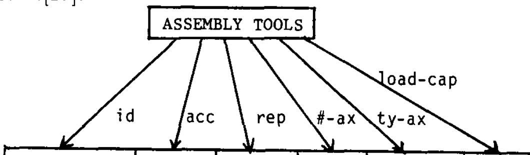
Because $SN^{+}M$ has the table part to model tabulated data, no complex conversion algorithm is needed to represent library information in a database. One thing more required is a network attached to each table to show the semantics of the data in the table. The corresponding relations between an original table and its associated $SN^{+}M$-modeled table can be summarized as in the following table:

original table	enhanced table in $SN^{+}M$
table with degree n	table with degree n
table name	a class node with table name
column domain	an edge with domain as relation relating the column and the class node
unit in a column	domain in the column
data in one row	data in one row

The first four corresponding relationships serve to set up a network attached to the table to show the semantics of the data in the table. The last corresponding relationship is used to represent the originally tabulated library data in the database by a one-to-one correspondence. The algorithm for modeling library information into an $SN^{+}M$-based database is:

ALGORITHM : modeling library data into a CAD/CAM database by $SN^{+}M$
INPUT : library data W = {T, C, R, D, U, I}
where T = the table name
C = the number of columns in the table
R = the number of rows in the table
D = {set of C column domains in the table}
U = {set of data units in columns}
I = {set of R rows of data in the table}
OUTPUT : the library data W in database
METHOD :
(1) : add database node t with content of table name T
(2) : create a table T' with C columns and R rows
(3) : for every u ∈ U, put u as domain of one column in T'
(4) : for every d ∈ D, find a u ∈ U, where u is the unit of the column domain d in table T, add to the database a link with attribute d to relate the node t to the column containing u in T'
(5) : for every i ∈ I, insert i as one row of T'

So the library information is modeled into an $SN^{+}M$-based database in Figure 3. The only difference between the tables in the database and their original forms is that each of the former is enhanced by a network attached to the table by means of which the semantics of the data in the tables is fully and explicitly shown. For any column in a table, there is an arc pointing to that column from the network showing the attribute for that column. The one-to-one correspondence between the data in the database and the original data makes it faster to incorporate data in the database and easier for database designers to set up and users to use a database system[17].



alpha-num	inch	inch	ins	alpha	lb
ROBOT-1	0.05	0.05	6	rrr'rrr	30
ROBOT-2	0.01	0.01	5	rss'rr	8

FIGURE 3: A LIBRARY INFORMATION MODELED BY SN^+M

4. Modeling Geometrical Information

Geometric information is one of the central ingredients in the design stage to describe the product in a CAD/CAM database. One of the most advanced methods for geometrical solid modeling is Constructive Solid Geometry (CSG) [9] [18]. The legitimate set operations in CSG are restricted to regularized set union (∪), intersection (∩), and difference (-) [19]. Figure 5 shows the complete CSG tree for the mechanical object shown in Figure 4, which is a specially designed touch sensor (TS) used in robotic operation experiments. All the operations in Figure 5 are binary operations. The left link of an operation in Figure 5 represents the operator's "first term" indicating the semantic of "subject" of the operation. The right link of an operation represents the operation's "second term" which is either "object," serving as a focus of a combinational operation, or "argument," indicating the movement scale in a motional operation. The distinction between first term and second term is of particular importance for the difference (-) operation.

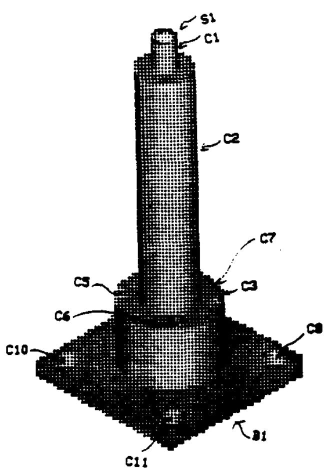


FIGURE 4: TOUCH SENSOR

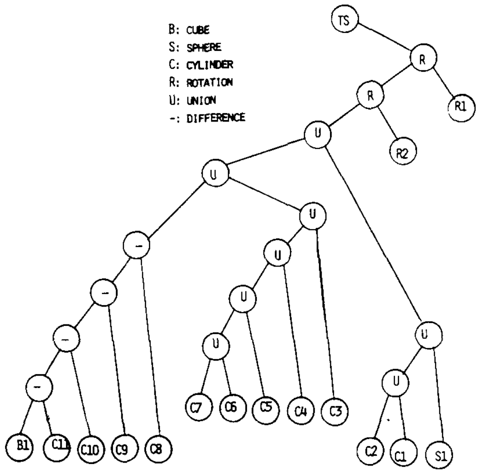


FIGURE 5: CSG REPRESENTATION FOR TOUCH SENSOR

A CSG tree is really a network. Instead of using complicated conversion algorithms which are required in using record-based data models, SN^+M directly puts, not translates, this information into the database system by one-to-one correspondence. The modeling of CSG tree information in a database by SN^+M can be performed by the following algorithm:

ALGORITHM : modeling CSG-based geometrical description in a CAD/CAM database by SN^+M
INPUT : CSG-based geometrical description W = {N, E}
where N = {set of nodes}
E = {set of edges}
OUTPUT : information W in database
METHOD :
(1) : for every node n ∈ N, add the node n to database.
(2) : for every edge e of the form (n1, e, n2) in E, where n1 ∈ N and is an operation node and n2 ∈ N,
(i) if e is the left link of the operation n1, add the edge e with attribute "subject" to the database to relate n1 to n2.
(ii) if e is the right link of the operation n1,
(a) if n1 is a motional operation, add edge e with attribute "argument" to the database to relate n1 to n2.
(b) if n1 is a combinational operation, add edge e with attribute "object" to the database to relate n1 to n2.

The CSG-based solid modeling database for the touch sensor is therefore as shown in Figure 6. As seen by comparing Figure 5 and Figure 6, the latter mirrors the original structure and enhances its representation such that the information in the database becomes easier to use. The semantics of Figure 6 clearly show which is

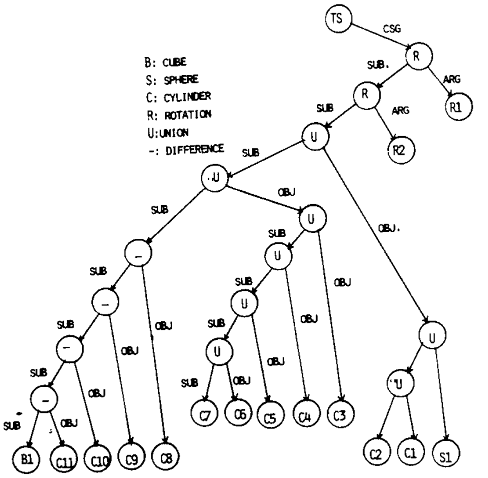


FIGURE 6: CSG-BASED DATABASE MODELED BY SN$^+$M FOR TOUCH SENSOR

the subject, object, or argument of an operation in the tree. The above algorithm performing modeling by the *one–to–one* correspondence preserves the advantage of maintaining a simple and direct relationship between the original data and its corresponding representation in the database.

5. Modeling Manufacturing Information by SN$^+$M

The manufacturing domain consists of machining and assembly phases. They both consist of a sequence of events (not records), in which each event involves a collection of related information. This information should be clearly represented in a database system and related to the other necessary information so that the database system can be used to command the manufacturing mechanisms.

Since the machining and assembly information share the same logic, we will demonstrate how SN^+M is used to model assembly information. The methodology and results described below for assembly information can also be applied to machining information.

5.1. Assembly Statements

The assembly mechanisms assemble the parts based on assembly statements and other related information stored in the database, such as geometrical features, material and assembly tool properties.

The follwoing four statements are part of assembly operation statements describing how the touch sensor is assembled:

1) Insert SHAFT into HOUSING-BODY-MAIN-HOLE
by-tool ROBOT-1 such that
SHAFT-HEAD goes-through
HOUSING-BODY-TOP-HOLE.

2) Insert ROD-TAIL into BASE-BOSS-MAIN-HOLE
by-tool ROBOT-1 such that
HOUSING-BOSS adjacent-to BASE-BODY
and
BASE-BODY-SCREW-HOLE-1 aligned
HOUSING-BOSS-SCREW-HOLE-1.

3) Screw BASE-BODY-SCREW-HOLE-1
with HOUSING-BOSS-SCREW-HOLE-1
by-part HEXAGON-HEAD-CAP-SCREW
by-tool ROBOT-2.

4) Screw BASE-BODY-SCREW-HOLE-4
with HOUSING-BOSS-SCREW-HOLE-4
by-part HEXAGON-HEAD-CAP-SCREW
by-tool ROBOT-2.

More details might be required for the above assembly statements to make information complete in a practical system.

Each of these statements describes an event to be performed. The assembly performance will proceed from statement 1 to statement 2 sequentially. After statement 2 is done, the two screwing operations can be performed concurrently.

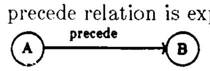
The information for an assembly event can be classified into assembly operations indicating what kind of action needs to be taken, conditions which must be met during and after execution of an assembly operation, and supporting attributes necessary to support an assembly operation such as assembly tools and any time factor connected with the assembly event.

5.2. Modeling Assembly Information by SN$^+$M

The supporting attributes are always specified in the form of operation:attribute:value. One example is "OP-1 tool-is ROBOT-1", where OP-1 is an operation, tool-is is an attribute and ROBOT-1 is a value. To model such information by SN^+M, the value is expressed by a node containing that value and the attribute is expressed as a link with that attribute as relation to relate the operation and the value. Thus, in the above example, tool-is corresponds to a relation linking a node containing the OP-1 operation and a node containing ROBOT-1 value.

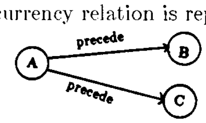
A crucial aspect of modeling assembly information is modeling the precedence relations existing among assembly operations. In SN^+M, such precedence relations will be expressed by the Petri-net-like [21] labeled relations. The "precede" relation is used in SN^+M to mean one event must precede another event.

Let A , B , C be assembly tasks. Then, in SN^+M, the precede relation is expressed by



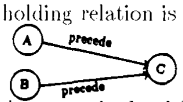
which means operation B cannot start until operation A has finished.

The concurrency relation is represented by



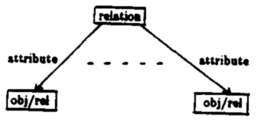
which means operation B and operation C can start concurrently after operation A is done. Operations B and C are independent of each other.

The holding relation is represented by

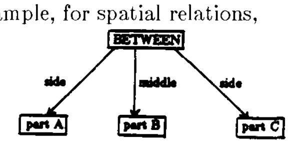


This is always paired with a concurrency relation. It means that operation C cannot start until both operation A and operation B have finished.

In the assembly domain, conditions are combinations of spatial relations occurring in CAD/CAM, such as colinear, coplanar, aligned or centered, with the logical AND and OR relations. The word "such-that" is used to express conditions in the above assembly statements for the touch sensor. To model a condition, an n-ary relation in SN^+M will be represented as a node indicating the relation, several nodes representing the affected objects (for nonlogical relations) or relations (for logical relations), and links expressing the attribute relations between the node and the associated objects or relations:

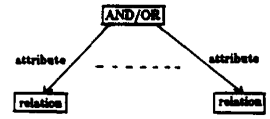


For example, for spatial relations,



From the relation BETWEEN and the semantics of attributes of the relation (side, middle), it is understood that PART B is located between PART A and PART C.

Logical relations AND and OR can be represented by



The AND relation is true only if all the elements are true; the OR relation is true if any of the elements are true. The AND and OR relations can be nested.

The four assembly statements required to specify assembly of the touch sensor are modeled by SN^+M as shown in Figure 7.

The AKO relation is used to link a tool or object (parts and their associated primitive objects) with the associated property table in Figure 7. Also every node representing an object has a link with attribute "csg-inf" pointing to the corresponding SN^+M-modeled CSG-tree showing its geometrical information.

As seen in Figure 7, all the information related to an operation is grouped together to form a *complete set*, every object is related to its geometrical properties in a CSG-tree and to its material properties, and every tool is related to its property features. Thus, all the information from the beginning design stage to the end of controlling the manufacturing mechanisms is related to form a complete description of how the product is to be manufactured.

6. Conclusions

The nature of a CAD/CAM database is fundamentally different from databases in business type applications, which results in quite different needs with regard to modeling requirements. The usefulness of a CAD/CAM database system would be severely restricted if we used conventional data models or their extensions because of their relatively limited modeling ability.

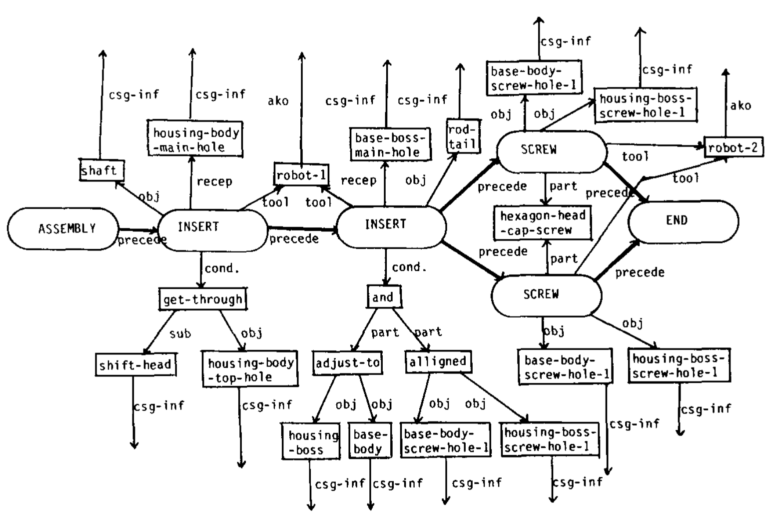


FIGURE 7: ASSEMBLY INFORMATION MODELED BY SN^+M

From the above sections describing modeling of different types of data in a CAD/CAM data domain, the advantages of using the SN^+M as compared with the use of conventional data models or their extensions can be summarized as follows:

[1] SN^+M is capable of modeling various kinds of data types, procedures and events in a CAD/CAM database system, which is the most important requirement for setting up such a database system. Because of this modeling capability, all kinds of information required in a CAD/CAM domain can be represented in the database under a *unified* data model.

[2] An SN^+M-modeled database is a management-oriented, rather than file-oriented, database system, which reduces operation cost greatly for overlapped data in the system. There is a significant information overlap between CAD and CAM. The data redundancy caused by information overlap is costly in a file-oriented CAD/CAM database because of the effort of entering and reentering data into the system and keeping the accuracy and consistency of the data [3].

[3] An SN^+M-modeled database explicitly shows the manufacturing flow along with its related information, rather than treating manufacturing information simply as a list of instructions (statement by statement) in computer memory, which is a requirement for a CAD/CAM database to directly control manufacturing mechanisms.

[4] An SN^+M-modeled database strongly relates all the information required for a specified product, rather than widely distributing this information throughout the system, which makes the information easier and faster to retrieve and update.

[5] SN^+M mirrors the domain's original data structure, which is the form most familiar to human beings, rather than using a complicated conversion method or algorithm to force translation of the primitives of a CAD/CAM data domain into artificially specified constructs. This mirroring will make a database system much easier to be used and maintained.

The above advantages principally come from the network and table modeling capabilities the SN^+M adapts from the semantic network and the relational model, respectively, to accommodate naturally and adequately the diverse data types in a complex data domain and tackle the problems caused by using record-based data models.

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