Process capability modelling: a review report of feature representation methodologies

Process Capability Modelling: A

Review Report of

Feature Representation Methodologies

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PREFACE

Approximately 150 technical papers on the features methodology have been carefully studied and some selected
papers have been commented upon. The abstracts of the comments are documented and attached to this report. The
methodologies reviewed are mainly divided into two approaches, ie. feature recognition and design by features.
Papers which deal with some specific topics such as feature taxonomies, dimensions and tolerances, feature
concepts, etc. are also included in the document.

CONTENTS

SECTION ONE: Feature Recognition Methodologies

Feature extraction: Henderson's algorithm

S. H. Chuang & M. R. Henderson, "Three-dimensional shape pattern recognition and vertex classification and vertex-edge graphs", Computer Aided Design, Vol 22 No.6, July/August 1990

This paper presents a vertex type classification scheme for features recognized from 3D Brep models using a graph-based feature recognition approach. The shape of a 3D object can be characterized by a vertex-edge (V-E) graph labeled with classified vertices. This is because for different engineering applications, such as finite element analysis and metal cutting, the topological and geometric properties surrounding a vertex have different significances.

The vertex-edge graph can be extracted directly from the complete graph representations of the topological entities (faces, edges and vertices) of an object in the Brep model. The V-E graph is then added with the vertex type information. The V-E graph with classified vertex types will be used as the feature model for different applications.

M. R. Henderson, S. H. Chuang, P. Ganu & P. Gavankar, "Graph-based feature extraction", Arizona State University, 1990.

P. Gavankar, M. R. Henderson, "Graph- based extraction of protrusions and depressions from boundary representations", Computer-aided Design, Vol 22, No.7, September 1990.

These two papers describe how the theory of graphs can be implemented to meet the requirements of feature extraction, the first step toward recognition of features. Features are defined as geometric and topological patterns of interest in a part model which represent high level entities useful in part analysis.

A solid model can be represented as a graph-based model with data pointers linking together an object's faces, edges and vertices. Two types of graphs are commonly used in the representation of solid models: edge-vertex and edge-face graphs. In this paper, the face-edge graph is extracted from the complete graph model of a Brep model. The main advantage of a graph-based approach to feature recognition is that only topological information of a boundary model is required for some types of ex- tractions.

Subgraphs are decomposed from the graph of the part through the identification of the "cut nodes" by which the subgraphs are connected to each other. Those subgraphs are feature graph models. The algorithm is implemented in the logic programming language, Prolog, i.e. the pattern matching rules are written in Prolog routines.

There are some limitations. One of them is that the method does not apply to blind holes and pockets (this is really severe).

Feature recognition: the XCUT system

S. L. Brooks, K. E. Hummel & M. L. Wolf, "XCUT: a rule-based expert system for the automated process planning of machined parts", Allied Corporation, Bendix Kansas City Division, Missouri, 1987.

This paper introduces an automatic process planning system, XCUT, developed by Allied Corporation (Bendix Kansas City Division, Missouri) using rule-based expert system techniques. XCUT is made up of four major components: the user interface, the ROMULUS solid modeller, a relational data base and the expert planning system. Features are identified through use of a user interface. A mouse is used to manually indicate what surfaces of the part belong to the feature. When the complete geometric information is extracted from the Brep model, it has been passed to the planning system.

The planning system contains a knowledge base, a working memory and an inference engine, HERB (Hierarchical Expert Ru1e Bases). The knowledge base contains process planning data which is stored in relational tables in the data base, a Lisp programming interface is used to retrieve the data base through relational queries. The working memory of HERB captures the dynamic planning information created during planning and is used by HERB to activate the appropriate rules each cycle. The type of information stored includes features (symbolic part description), constraints, cut nodes, cutting tools and machinability data. HERB is the central control of XCUT's expert planning system through control rules. Feature representations are discussed in another paper [HUMMEL86].

K. E. Hummel & S. L. Brooks, "Symbolic representation of manufacturing features for an automated process planning system", Knowledge-based expert systems for manufacturing (ASME), Vol 24, Dec. 1986.

This paper describes a symbolic feature representation scheme which is used in the XCUT process planning system. Features are defined as regions of the part that have some degree of manufacturing significance, or, features form recurring geometric and technological patterns for which the process engineer has acquired years of manufacturing experience.

An object-oriented programming language, MIT Flavors, is used to implement feature representations. One of the common notions of object-oriented programming languages is the uniform use of message passing between conceptual objects, as this makes geometric reasoning straightforward. A structural description is used to define features as a composite object consisting of various attributes and sub-objects. Each feature object in XCUT represents a volume of material to be removed from the ini-tial stock to form a specific region on the final part geometry. A feature decomposition tree is applied.

Flavors is also used for the representation of the feature taxonomy in XCUT. One of the major advantages of using a taxonomy is the notion of inheritance (Properties of the same class can be shared without repetition). The taxonomy in brief is: Feature (root); Implicit, Explicit (2nd level); Depression, Protrusion, Composite (3rd level for Explicit);

All geometric and topological information for a feature is extracted from the solid modeller, ROMULUS (see also [BROOKS87]). Tolerances of size and location are input manually.

K. E. Hummel, "Coupling ruled-based and object-oriented programming for the classification of machined features", Computers in Engineering, Vol 1, 1989.

This paper emphasizes the use of object-oriented programming for the automatic classification of features. Procedural representation of knowledge is used to replace the declarative representation methodology used in the earlier XCUT system. For in- stance, a through cylindrical hole feature was represented as an object consisting of the attributes location, diameter and length. In the declarative description, these attributes are represented and evaluated explicitly. For the procedural approach, those at- tributes are computed through rules and pointers which refer to the related data in the CAD model or other database. A pattern matching algorithm is also used to identify feature classes.

Since the features were classified automatically, the user of XCUT need not under- stand the meaning of the names in the feature taxonomy hierarchy. Feature classification will thus not be a burden on the designer.

Feature recognition: The STOPP system

B. K. Choi, M. M. Barash & D. C. Anderson, "Automatic recognition of machined surfaces from a 3D solid model", Computer-aided Design, Vol 16, No.2, 1984.

This paper describes the feature recognition algorithm in the STOPP system. Features are called machined surfaces. A machined surface is defined as a portion of the workpiece generated by a certain mode of metal cutting. The system uses a pattern-matching feature recognition algorithm, When a feature is recognized from the

3D Brep model, it is eliminated from the Brep data and stored in another feature data structure as a 2-1/2D representation.

In syntactic pattern recognition, a picture is represented by some semantic primitives, which are written in a picture language. A set of grammars consisting of some re- write rules define a particular pattern. A parser is then used to apply the grammar to the picture. If the syntax of the picture matches the grammar, then the picture can be classified as belonging to the particular pattern class.

B. K. Choi & M. M. Barash, "STOPP: an approach to CADCAM integration", Computer-aided Design, Vol17, No.4, 1985.

The STOPP system employs a sequential decision making procedure. Its planning logic is based on the capabilities of manufacturing facilities (tools). A cutting tool is modelled as a surface generator, since a surface shape is generated from the tool profile when it is swept through its path. The surface generated by a single unit machining operation is defined as an Elementary Machined Surface (EMS). The unit machining operation is called a Simple Processing Cycle (SPC). A manufacturing feature is called a Machined Surface. Thus, a workpiece consists of a collection of machined surfaces; a machined surface consists of a sequence of EMS's; and the process plan is a collection of SPC's.

This method links the cutting tools to the feature types and geometry directly. There- fore, tool selection is straightforward and the sequence of operations for each feature is also easy to determine. 2D representation of the profile of a feature is sufficient for this purpose, since 3D shapes can be generated from the 2D profiles by operations such as revolution, sweeping, projection,etc.

Feature recognition: the PART system

F. J. A. M. van Houten, A. H. Erve, H. J. J. Kals, "PART, a feature based computer aided process planning system", University of Twente, SPIN-project PART, Feb. 1989.

PART (Planning of Activities, Resources and Technology) is the prototype of a generative computer aided process and operation planning system which is currently under development at the Laboratory of Production Engineering of the University of Twente.

A Brep modeller, GPM is used together with a CAD interface which translates the GPM format into STEP/PDES (and vice visa) is under development. The product model is mapped to a memory resident network database (RIOT) for reasons of performance. The common relational database of the whole PART system is used for permanent storage. This implies that a product model has to be transferred from the relational database into the network database format before it can be used.

A manufacturing feature is considered as a volume which should be removed by a series of machining operations. Each feature, whether it is a simple one or a very complex one, is said to be a "compound feature". The compound feature provides a way to describe a feature as a combination of so called "atomic features" (elementary shapes which can be described using a pre-defined fixed set of parameters). The CAM-I John Deere scheme of feature taxonomy is used for the PART system. Atomic features are linked to the product geometry by storing the names of the faces, which constitute an atomic feature, in the relational database. Therefore, all faces of an atomic feature can be retrieved, and all atomic features which include a specific face can be retrieved.

Tolerances on atomic features are dealt with through the faces that construct the feature. This allows for both tolerances between faces of a single feature and for tolerances between faces of different features. However, the tolerances cannot be defined before the feature recognition.

A syntactic pattern recognition approach is used for manufacturing feature extraction. There are two extraction modules, ie. an atomic feature pattern recognition and a parameter value extraction.

Feature recognition: the LUMP system

P. J. Herbert, C. J. Hinde, A. D. Bray, V. A. Launders, D. Round, D. Temple, "Feature recognition within a truth maintained process planning system", Int J. Computer Integrated Manufacturing, Vol 3, No.2, 1990. [HINDE90]

C. J. Hinde, A. D. Bray, P. J. Herbert, V. A. Launders, D. Round, "An integrated approach to process planning", International CIS Journal, 1990.

The above papers introduce a truth maintained blackboard system - LUMP (Loughborough University Manufacturing Planning). The concept behind blackboard systems is that of a collection of experts collaborating round a blackboard in order to solve a problem of common interest

A feature is defined as a group of geometric entities with some meaning for the particular activity to be performed with them. The feature recognition system extracts manufacturing features from a CSG string. The principle of this feature extraction is based on the idea of rewriting one representation into a target representation according to a set of rules. These rules will recognize parts of the description (using tem- plates) and replace them with an equivalent description in terms of the new format, such as process planning features. Both the feature recognition system and the process planning system are written in CProlog.

The main problem with the extraction of features from CSG models is that CSG descriptions are not unique and so it is possible to have a number of different CSG strings all of which describe the same object. A partial solution is to pre-condition the CSG string and thereby remove some of the ambiguities present in the set-theoretic solid model.

Feature recognition: Davies's EXCAPP system

K. F. Zhang, A. J. Wright, B. J. Davies, "Geometric model input for EXCAPP", MATADOR UMIST, Manchester, 1988.

K. F. Zhang, A. J. Wright, B. J. Davies, "A feature-recognition knowledge base for process planning of rotational mechanical components", Int J. Advanced Manuf. Technology, 1989.

A. T. Joseph, M. Kalta, B. J. Davies. "Automatic generation of NC programs for turned components from CAD product models", Proc of the 28th MATADOR, UMIST, 18-19 April 1990.

M. W. Park, G. C. Vosniakos, B. J. Davies. "Automatic feature extraction in wire-frame models of 2-1/2-D prismatic parts", Proc of the 28th MATADOR, UMIST, 18-19 April 1990.

> The above papers introduce the generative process planning system - EXCAPP (Ex- pert Computer-Aided Process Planning) for rotational parts developed at UMIST, Manchester. Two major tools - POPLOG and GKS are used in EXCAPP. POPLOG is an AI development environment combining three AI languages - POP11, Prolog and Lisp; GKS (Graphics Kernel System) is an international standard for computer- graphics applications.

> In EXCAPP, a feature recognition knowledge base, rather than an algorithmic approach is used for identifying features. It is based on syntactic feature-recognition methods. Pre-defined features are represented as rules in Prolog form. A control mechanism has been developed for applying the rules.

> The system now has been integrated with a CAD system and called CADEXCAPP. Two and half dimensional components can be extracted from any CAD system in the form of wireframes through IGES. A sister system of EXCAPP - ICAPP (Iterative Computer Aided Process Planning) is now under development for prismatic components.

Feature recognition: Jared and Kyprianou's approach

G. E. M. Jared, " Feature recognition & expert systems for operation planning in NC machining", Proc. Int. Conf. AI Europa, 1986.

G. E. M. Jared, "Reasoning and using geometric features", Geometric Reasoning (J Woodwark ed), Clarendon Press, Oxford, 1989.

> These papers introduce Kyprianou's work in feature recognition. The overall objective is to partition a Brep model into facesets, each corresponding to a feature in a specific domain.

> Kyprianou extended "shape grammars" to "feature grammars". The basic elements in a feature grammar are the basic entities of the face-edge-vertex graph of a Brep modeller. The feature grammar is used to construct a recognizer that uses a "bottom up" approach. Firstly, all edges of the solid to be partitioned are classified as convex, concave or smooth and then the recognizer applies the rules of the feature grammar to put sequences of elements together to form higher lever entities. Recognition is complete when the whole object has been "parsed".

> The above method can be classified as syntactic pattern recognition.

Feature recognition: Joshi's AAG approach

Sanjay Joshi, N. N. Vissa, T-C Chang, "Expert process planning system with a solid model interface", in Knowledge based system in manufacturing (Andrew Kusiak ed.), 1987.

S. Joshi, T. C. Chang, "Graph-based heuristics for recognition of machined features from a 30 solid model", Computer-aided Design, Vol 20, No. 2, March 1988.

> The above papers introduce graph-based heuristics for feature recognition from 30 solid models (Brep) and the expert system based process planning system which makes use of the approach.

> The Concept of an Attributed Adjacency Graph (AAG) built on the underlying Brep is proposed, using a data-driven or forward chaining procedure. This solves the problem of backward chaining and exhaustive search strategy implicit with the expert sys- tem rule-based recognition approach. (The expert system-based approach normally checks the presence of each feature one by one using its rules).

> A Brep model of an object can be defined as B = (V, E, F), where V is a set of vertices, E is a set of edges and F is a set of faces. The AAG graph can be defined as G = (N, A, T) where N is the set of nodes, A is the set of arcs and Tis the set of at- tributes to arcs in A, such that: for every face fin F, there exists a unique node n in N; for every edge e in E, there exists a unique arc a in A, which connect the nodes ni and nj (corresponding face fi and fj) and share the common edge e; every arc a in A is assigned an attribute t, where t=O when the faces sharing the edge form a concave angle and t=l when the faces sharing the edge form a convex angle. The AAG is represented in the form of a matrix.

> A heuristic method is used to identify components of the graph (subgraphs of the complete AAG) that could form a feature. It is based on the following observation: a face that is adjacent to all its neighbouring faces with a convex angle does not form part of a feature.

> The definitions of the features are stored in frames, and the frames form a hierarchy.

Feature recognition: Li and Perng's approach

Rong-Kwei Li, Ming-Hwang Yu, "A framework for prismatic part-data generation--unit- machine loop concept", INT. J. Computer Integrated Manufacturing, Vol3, No. 2, 1990.

Der-Baau Perng, Zen Chen, Rong-Kwei Li, "Automatic 3D machining feature extraction from 3D CSG solid input", Computer-aided Design, Vol 22, No. 5, June 1990.

> The above papers introduce a "unit-machine loop" to replace the conventional feature representation and a Destructive Solid Geometry (DSG) concept for feature recognition in the domain of prismatic components.

> A unit-machine loop is defined as a unique removing volume which can be machined by one cutting tool in one operation (such as roughing or finishing). The advantages of using the unit-machine loop to replace the traditional features are:

(1) it can be used to represent any removing volume no matter how complex;

(2) the unit-machine loop is constructed by considering the influence of the process information and

(3) because of (2) the process-planning reasoning logic development is simplified.

A system has been developed to extract unit-machine loops from a 3D solid model or 2D CAD representation. Syntactic pattern matching approach is used in the two modules. The 3D solid model is of CSG (Constructive Solid Modelling) representation. A CSG model is first converted into a DSG (Destructive Solid Modelling) model. A DSG tree is a special case of a CSG tree with difference operation only. A primitive in the DSG representation can be viewed as a machining feature or a unit- machine loop. A pattern matching algorithm is then used to identify the primitives (features) in the DSG model.

Feature recognition: Lee's FEXCAPP system

Kyo II Lee, Jin Whan Lee, "Pattern recognition and process planning prismatic workpieces by knowledge based approach", Annals of the CIRP, Vol 38, No.1, 1989.

This paper describes a system FEXCAPP which uses a graph-based feature recognition approach. A Brep modeller, ROMULUS, is used as the input A Directed Edge Data Structure (DEDS) is proposed to represent the topology of faces and edges of a solid model. The directions of edges are defined so that the inner area of a face can be determined.

The AAG (Attributed Adjacency Graph) proposed by Joshi and Chang, which is limited to polyhedral features, is extended to the features formed by combination of planar and cylindrical faces.

Feature recognition: Mortensen's rule-based approach

K. S. Mortensen, B. K. Belnap, "A rule-based approach employing feature recognition for engineering graphics characterisation", Computer-aided Engineering Journal, Dec. 1989.

The above paper describes a prototype system which uses production rules to facilitate pattern matching for part features and discernment between features. 2D CAD data is used as the input and three steps are included in interpreting the data, ie.

1) template matching

2) basic shape rectification and

3) relation determination

A template is a Prolog predicate which consists of relationships satisfying a particular pattern to be matched. Each template usually corresponds to a feature, but could, for efficiency reasons, represent a composition of several features.

Feature recognition: Lee and Fu's algorithm

Y. C. Lee, K. S. Fu, "Machine understanding of CSG: extraction and unification of manufacturing features", IEEE CG&A, Jan. 1987.

This paper introduces an algorithm for the extraction of features from CSG models. The main problem with the CSG models for feature extraction is the un-uniqueness of their binary trees. To solve this problem, arbitrary CSG trees need to be reconstructed to form unique and computer understandable trees, then the nodes (primitives) of the re-constructed trees can be recognized.

Lee and Fu do not agree with the approach of relating all difference operations to removal processes (see [PERNG90] for DSG approach), since some removal processes may be implied without using any difference operations. Instead, the principal axes of the primitives in a CSG tree are used for feature extraction.

An arbitrarily constructed CSG tree is first traversed to generate all principal axes. Before these axes are used to locate a certain kind of feature, they are first partitioned into several clusters based on spatial relationships. Within each cluster, axes involved in a specific feature can be located according to the conditions defined by the feature. The second phase of the proposed approach is to unify feature representations by re- building the CSG tree. It consists of two steps: (1) Tree re-construction in which all participating nodes of the feature are relocated and grouped together to form a subtree and (2) tree transformation in which the subtree resulting from step 1 is replaced by an equivalent subtree. ·

Feature recognition: Nnaji's system

B. O. Nnaji, Hsu-Chang Liu, "Feature reasoning for automatic robotic assembly and machining in polyhedral representation", Iut. J. Prod. Res., Vol 28, No.3, March 1990.

The above paper introduces a system which extracts features from a Brep model derived from a CSG representation. The CAD system used is the ROBMOD solid modeller which is based on a CSG structure and with Brep information. The application domain is automatic robotic assembly and machining.

The reasons for using the CSG representation in the work are:

1) CSG is concise;

2) it guarantees automatically that objects are valid;

3) one can derive Brep from the CSG and have them present within the same domain and such BREP is guaranteed to be valid.

The system extracts the CSG-based information from a CAD system, the CSG tree and the Brep information which are used to present the object are then reconstructed into Prolog format (a different CSG tree which is represented in a hybrid format, with the composite nodes being represented in a LISP-like format). The Prolog database is used to determine concave edges, convex edges, concave faces and convex faces to find features. Convex borders of concave features are then found. These imply the possible assembly directions, the relationships that aid in linking features and the in- formation to interpret the features.

Feature recognition: Wang's Turbo-CAPP system

Hsu-Pin Wang, Richard A. Wysk, "Intelligent reasoning for process planning", Computers in Industry 8, 1987

H-P Wang, "A knowledge based computer aided process planning system", Knowledge based expert systems in engineering:

planning and design, 1987.

Hsu-Pin Wang, Richard A. Wysk, "AIMSI: a prelude to a new generation of integrated CAD CAM systems", Int J. Prod. Res., Vol 26, No. 1, 1988.

The above papers introduce a Knowledge based process planning system, Turbo- CAPP, which is a combination of a production rule-based and a frame-based system. It extracts features from 2-1/20 wireframe CAD systems.

SECTION TWO: Design by Features Methodologies

Design by Features: IMPPACT

Krause, F. L., Kramer, S. & Reiger, E. "PDGL- A language for efficient feature based product gestaltung". Submitted for publication in the CIRP Annals, Vol. 40. No. 1, 1991.

Bohms, H. M. "Feature Based Modelling of Products and Production Processes in IMPPACT". IMPPACT Workshop, Saarbrucken, December 1990.

Schultchen, E. "Application of Features for Sheet Metal Manufacture". Proc. of the Workshop "Integrated Modelling of Products and Processes Using Advanced Computer Technologies", Berlin, February 1991.

IMPPACT is a large European research project within the Esprit program and is concerned with Product Modelling for CIM. There are two strands to the work, the first being illustrated by sheet metal parts and the second on ship's propeller blades. The propeller work uses a normal set of "solid" features such as milled holes, turned profiles etc., supplemented by special application features related to the sculptured surfaces of ships' propellers. The feature set used in the sheet metalwork includes developed features from the bending of flat plate.

The propeller example is implemented using a proprietary CAD package (Ailsys) which is accessed via an interface based upon a Part Design Graph Language (PDGL). PDGL uses the syntax of EXPRESS and takes a textual description of a feature and maps it into the internal representation of the feature modeller. The feature modeller and geometric modeller each maintain their own databases with communication via a "bidirectional interface". A Product/Process model interface enables the feature information to be entered in the system-wide data model as a feature library. Features are not pre-defined, but can be constructed when required to meet the needs of particular industries and/or companies.

The sheet metal work is based on the Imaginer hybrid modeller which has been pro- vided with a set of two-dimensional and "bent" features as part of its geometric specification of primitives capability. This interacts with the Locam process planner and NC code generating software.

Design by Features: CAPE-LUT

Hart, N. M., Case, K. & Bennaton, J. A. "A CAD Engineering Language to Aid Manufacture", Proc. Int. Conf. on Computer-Aided Production Engineering, Edinburgh, April, 1986

Hart, N. M. "A CAD Engineering Language to Aid Manufacture", Ph.D Thesis, Loughborough University of Technology, 1986.

A familiar engineering language is provided as an interface to a Constructive Solid Geometry modeller (BOXER) so that the manufacturing task can be expressed as the removal of features from stock material or part-finished component. The geometric model and outline process plan (sequence of operations) are constructed simultaneously. The language used is English-like, for example "tum the outside diameter of the bar down to 60mm ", but is not a natural language application. Instead a language of limited variability (in syntax and semantics) can be generated using GILT (Graph Input Language Translator), and this language can thus be tailored to the needs of particular industries or companies. The domain of application is limited to simple turned parts.

Case, K., Acar, B. S. & Hart, N. M. "Computer Aided Production Engineering Linking CAD, Process Planning and Tool Design". Proc. of ACME Grantees Conference, Cambridge, 1987

Case, K., Acar, B. S. "Learning Studies in the Use of Computer Aided Design Systems for Discrete-parts Manufacture". Behaviour and Information Technology, Vol. 8, No. 5, pp353-368

Case, K., Acar, B. S. "The Manufacturing Features Approach to Design and Its Impact on the Learning and Use of Computer Aided Design Systems". in "Contemporary Ergonomics", ed Megaw, E.D., Taylor & Francis, pp132-136, 1989.

Acar, B. S. and Case, K. "Attitudes to Integrated Design and Process Planning", Proc. of 21st Int. Seminar on Manufacturing Systems, Stockholm, June 1989, Vol. 1, ppl.115-1.128

These papers describe CAPE-LUT (Computer Aided Production Engineering - Loughborough University of Technology) a development of the work of Case and Hart (above). The "familiar engineering language" is replaced by interactive graphical specification of features in the prismatic component part domain. Once again the geometric design is constructed simultaneously with an outline process plan (which defines operation sequences and gross parameters such as direction and depth of cut). CAPE-LUT was a prototype system used to carry out formal experiments with the use of features. These experiments were designed to determine (a) the ease with which a geometric modelling system might be learned if provided with a feature- based rather than geometric user interface, (b) the relative merits (speed, accuracy, etc.) of feature-based modellers, a solid modeller with a geometric interface and two- dimensional modellers, and (c) industrial attitudes to the concept of simultaneous generation of detail design and outline process plan.

Ongoing work is investigating the editing of a "designed and planned" part so that the impact on manufacture of a geometric change can be determined or alternatively the impact of manufacturing changes on the geometric integrity of the model can be determined.

Design by features: Chung's geometric reasoning system

J. C. H. Chung, R. L. Cook, D. Patal & M. K. Simmons, "Feature-based geometry construction for geometric reasoning", Computers in Engineering, Vol 1, 1988.

This paper demonstrates the geometric reasoning module in a prototype design system based on features. The design system is proposed to be used in the domain of the investment casting process.

The overall system consists of a solid modeller, a reasoning system, a communication interface between the solid modeller and the reasoner, and a user interface system. The solid modeller is I-DEAS (Integrated-Design Engineering Analysis System) with programmability. The reasoning system uses a knowledge-based system KEE (Knowledge Engineering Environment). Geometric data such as dimensions, locations and orientation is represented and/or supplied by the solid modeller. Higher level data and

knowledge such as features and rules are represented and/or supplied by the reasoning system. Data communications and action requests are facilitated through the communication interface.

A standard (or application-independent) primitive feature set is provided upon which application-dependent features can be defined. Each type of primitive feature is represented by an object class in an object-oriented programming methodology (see also XCUT system). Feature operations are limited to additions and full-surface attachments.

The reasoning system supports frame-based object-oriented programming and rule- based reasoning. Each object in KEE is represented as a single frame, called an unit Each unit is composed of slots. Each slot can contain data or a procedure which describes the characteristics of the particular object and the relational data. Objects of an application domain are represented in a hierarchical class-subclass-member structure.

I-DEAS is used for generating geometry and providing geometric data (when required by the query commands) to the reasoning system. It also proves a programmability language which can be used for writing modules to perform specific geometric operations. In the prototype system, the user interacts with KEE through the user interface whilst I-DEAS runs in the background. KEE parses the user's commands and sends requests to I-DEAS for geometry manipulation and geometric data query. I-DEAS then sends back the information required by the reasoning system and KEE builds the frame and slot (feature data model) for the object.

Comments: feature manipulation is limited. Creation, modification, deletion of features may be supported by the solid modeller. Common feature operations such as subtraction need to be supplied.

Design by features: Luby's CASPER system and Libardi's system for plastic extrusion

S. C. Luby, J. R. Dixon & M. K. Simmons "Designing with features: creating and using a feature data base for evaluation of manufacturability of casting", Computers in engineering, July 1986.

Eugene C. JR Libardi, John R. Dixon & Melvin K. Simmons, "Designing with features: design and analysis of extrusions as an example", ASME-Spring Natl. Design Engineering Conf. and Show, Chicago, March 1986.

Luby's system is a sister system of Chung's. It is used in the domain of aluminum casting processes. Two types of features are supplied by the design system, which are macro-features and co-features. Macro-features are classes of geometric forms such as boxes, U-channels, L-brackets and slabs. Co-features are attachments or design details which may be added to macro-features, such as holes, bosses and ribs.

Casper has been implemented in a frame based object oriented programming style and the features are represented in symbolic forms. A user interface has been developed to supply the user with the design facilities such as add, create, modify and delete. A wireframe based displaying system is used for in-progress design display.

Libardi's system is also a sister system of Chung's. It is used in the domain of plastic extrusion. Two dimensional micro-features are used, e.g. walls, intersections, fillets.

Design by features: Dixon's intelligent CAD system

J. R. Dixon, J. J. Cunningham & M. K. Simmons, "Research in design with features", IFIP WG 5.2 First international workshop on intelligent CAD (Cambridge MA), October 1987.

J. J. Cunningham & J. R. Dixon, "Designing with features: the origin of features", Computer in Engineering, Vol 1, 1988.

J. R. Dixon, "Design with features: building manufacturing knowledge into more intelligent CAD systems", ASME Manuf. Inter 88 Atlanta GA, Apri11988.

The above papers describe the architecture of a design by features system. A feature is defined as any geometric form or entity uniquely defined by its boundaries, or any uniquely defined geometric attribute of a part, that is meaningful to any life-cycle activity.

The system consists of two parts. The first part consists of a user interface, a design with features library, an operations library and a monitor, which allows the user to create primary representations of features. The features used by the designers are available in the design with features library (it does not intend to contain all the features). The operation library contains add, modify, and delete options. The monitor ensures that the operations requested and performed by the user are allowable and understandable to the system. A primary representation of an object is produced by the first part of the system.

The second part of the system is used for converting the primary representations of the objects into the secondary representations needed by respective activities such as design and manufacturing activities. This conversion may involve some feature ex- traction to obtain more abstract features. A Knowledge-based system is used in this part to assist in the design tasks. The value of the design by features systems will be determined by the degree of sophistication and the helpfulness of these knowledge- based systems. Visual display equipment is also included in this part and further re- design suggestions can be given.

Design by features: Chang's QTC system

G. P. Turner, D. C. Anderson, "An object-oriented approach to interactive, feature-based design for quick turnaround manufacturing", School of Engineering, Purdue University, May 1988.

Tien-Chien Chang, "Expert process planning for manufacturing", Addison-Wesley Publishing Company, 1990.

The QTC (Quick Turnaround Cell) system developed at Purdue University contains design, process planning and cell control and vision inspection. It is designed for one-of-a-kind prismatic parts, therefore it is a generative process planning system. A feature based design interface is used in the design part.

A 3D solid modeller, TWIN, is linked to the design system to provide drawings of the design. The feature based design system is independent of the solid modeller TWIN, therefore, it allows future expansion of the system to include more powerful solid modellers. After a design is completed, the design data, in the form of feature files, is sent to the process planning system. The planning system needs to reason about the exact manufacturing features, their relationships and feasible tool approach directions. This information (of features) is stored in a feature database for the consequent use of planning. The geometric reasoning is called feature refinement. For the feature refinement and NC cutter path generation, a solid modeller which could be different from the one used in the design system, is needed (again) to evaluate the model.

A design by features interface to the design system allows the user to define features. Each feature is loosely related to

machining operations, They are not stringent manufacturing features, and this frees the designer from the burden of considering manufacturing sequences. The flexibility of the feature operation is limited to one difference operator only. To assist the designer in interacting with the 3D geometry of the features and in the model construction, geometric entities, called handles (such as points and lines). Line handles are used to attach dimensions, tolerances and surface finish information. Point handles are used for locations and reference datum. The final representation of the part is a data structure consisting of a list of features. This data is written to an ASCII file for storage. The part file is used to re-create the part data for use by the process planning, the cell control and vision inspection. The TWIN solid modeller is used to generate a Brep model for display and verification of the design.

There are three major tasks in the feature refinement (geometric reasoning): feature classification, features relation identification and feasible approach and feed direction determination. The feature refinement module uses both the feature data file from the design system and the Brep model re-created in the planning system to produce a complete manufacturing feature model for a part. The problem with the use of two models is how to relate the faces in the feature model defined in the design system to the faces in the re-created Brep model and vice versa. The approach is to add a pointer to the TWIN data structure. Faces in the Brep model are tagged with feature information such as face type and feature type (identifications) so that they can be easily recognized.

Comments: the solid modeller is used twice in the system, this is the major drawback. The output (feature data structure) from the design system is in the form of files, this may need to be replaced by the use of relational database or other database such as hierarchical database. The use of two models for the feature refinement may not be necessary either, when considering a design by features system.

Design by features: Ando's intelligent CAD system

Koichi Ando & Hiroyuki Yoshikawa, "Generation of manufacturing information in intelligent CAD", Annals of the CIRP, Vol 38, No. 1, 1989.

This paper identifies the requirements for an intelligent CAD system in the design process and integration with the subsequent manufacturing planning process. In the design process, intelligent CAD systems should be able to assist the designer in finding suitable components to meet the design specifications and functional requirements (decision making); However, in the integration with process planning, sufficient manufacturing information including the designer's intention should be sup- plied and accessed automatically without human intervention.

Geometric and Functional data of elements (features) are represented in the form of frames (tables). A network of frames is used for representing a component consisting of a number of elements. Additional data or decisions can be made by rule-based routines. Geometric reasoning can be performed by these routines.

Design by features: the FIRST-CUT and NEXT-CUT systems

M. R. Cutkosky, J. M. Tenenbaum, D. Muller, "Features in process-based design", Computers in Engineering, Vol 1, 1988.

M. R. Cutkosky, J. M. Tenenbaum, "A methodology and computational framework for concurrent product and process design", Mechanism and Machine Theory, 1989.

Subbarao Kambhampati, M. R. Cutkosky, "An approach towards incremental and interative planning for concurrent product and process design", ASME Winter Annual Meeting on Computer based Approaches to Concurrent Engineering, 1990.

D. R. Brown, M. R. Cutkosky, J. M. Tenenbaum, "NEXT-CUT: a second generation frame- work for concurrent engineering", Computer aided cooperative product development (D Sriram ed), to appear in Springer-Verlag, 1991.

The above papers describe a concurrent product and process design system. The designer works in the manufacturing environment (mode), adding features to the design or manipulating the process plan itself. By concept its design part is feature- based. It tries to improve the current feature-based design system by using visual programming tools which enables the designer to define their own macro and primitive features and by using geometric, functional and process features to solve the feature mapping problem.

Design by features: Husbands's KBS process planning system

P. Husbands, F. Mill, S. Warrington, "A knowledge based process planning system", in Knowledge based expert systems in engineering: planning and design, 1987.

P. Husbands, F. Mill, S. Warrington, "Part representation in process planning for complex components", in Geometric reasoning (J Woodwark ed), Clarendon Press, Oxford, 1989.

The above papers describe a proposed feature-based system, which uses a design by features front end to drive a solid modeller, BOXER and a Knowledge Based System (KBS). The feature representation system uses a binary relational database to represent the component, blank and machines.

The binary relations have the form

<entity> <relation> <entity> It can also extended to

<entity> <relation> <entity> <with attribute>

such as "face A is parallel to face B with tolerance 0.03". The use of binary relations has advantages over other database methods such as Hierarchical and network databases in that a consistent framework can be used throughout the total planning system. Since much of the manufacturing knowledge is represented using rules which have a series of binary relations.

The main drawback of the binary relations approach is that there are too many relations for describing a part. For instance, multi-attribute retrieval might prove inefficient.

Design by features: Mantyla's prototype system

Manti Mantyla, Jussi Opas, Jukka Puhakka, "A prototype system for generative process planning of prismatic parts", IFIP, 1987.

This paper introduces a design by features system which uses "design feature" in the front end and then converts these into

"manufacturing features" for process planning.

The definitions of basic features are based on a classification of machine tool types. Hence, each basic feature can (in principle) be manufactured with a single tool or with tools of the same type. In contrast, compound features must be processed with tools of several types. A pocket with fillets on the bottom is a compound feature, for instance, because its production will require several kinds of milling tools.

A LISP frame is used in the system for feature representation. A part is represented by means of a "part frame" whose slots include some general attributes of the part and a list of named features. Each feature is presented by a "feature frame" that includes the attributes related to this particular instance. The type field of the feature frame contains a reference to a "feature type frame". A feature type frame contains a reference to its "class frame". The class frame contains attributes shared by its subclasses and a reference to its superclass.

In the process planning part, frames are also convenient since it is easy to store procedural information and make the implementation of the class hierarchy straightforward.

Design by features: Requicha's proposed architecture

A. A. G. Requicha, J. H. Vandenbrande, "Form feature for mechanical design and manufacturing", Computers in Engineering, Vol. 1, 1989.

Aristides A. G. Requicha, "Solid modelling and its applications: progress in tolerancing, inspection, and feature recognition", 16th NSF design & manufacturing systems grantees conf., 1990.

The above papers introduce an architecture of design by features that is based on functional (design) features and CSG representations. It uses more traditional solid modelling input techniques, which provide an escape mechanism when designers cannot, or prefer not to use features.

The input is parsed into a feature-based representation, which is converted into CSG representations by an expander. A feature recognizer is used to extract manufacturing features from the CSG and the Brep model which is evaluated from the CSG model.

Volumetric Features, which are generic solids with specified tolerances, are distinguished from Surface Features, which are groups of faces in a part, and are associated with volumetric features. Volumetric features are solids which can be removed in single machining operations in a single setup, and thus, machinable features are subtractive. A surface feature is a subset of the boundary of a volumetric feature such that it satisfies certain validation rules.

Design by features: Shah's FBMS system

Jami J. Shah, Mary T. Rogers, "Functional requirements and conceptual design of the feature-based modelling system", Computer-Aided Engineering Journal, Feb. 1988.

J. Shah, A. Bhatnagar, D. Hsiao, "Feature mapping and application shell", Computer Aided Engineering, 1988.

J. J. Shah, Mary T. Rogers, "Feature based modelling shell: design and implementation", Computers in Engineering Journal, Jan. 1990.

Jami Shah, Mary T. Rogers, "Geometric modeling for automated manufacturing", Dept Mech. Eng., Arizona State University, 1989.

The above papers introduce a Feature Based Modelling System (FBMS), which consists of an advanced feature based modelling shell (integrated with a solid modeller) - FMDS, and a feature mapping shell - FMPS.

Three types of features are defined in the system, they are:

Form Features: these are groups of geometric entities that define attributes of a part's nominal size and shape. The grouping of geometric entities to define form features depends on the task for which they are to be used, eg. design features, manufacturing features, etc.

Precision Features: these are acceptable deviations from the nominal geometry. Included in this set are dimensional tolerances and surface finish. Material Features: these specify material types, grades, properties, heat treatment, surface treatment, etc.

The feature modelling shell (FMDS) provides all necessary facilities for creating a product database except the actual definition of features. It consists of three modellers, a form feature modeller, a precision feature modeller and a material feature modeller. Form features are used as the fundamental representations and the other models are defined separately and networked to the form feature models. Each modeller operates in two modes:

Set-up mode - allows the definition of generic features by specifying feature properties in a frame-based system. This includes specifications of user defined parameters, inherited parameters, expressions, solid representations and sets of rules.

Modelling mode - allows generic features to be instanced and attached to the model as well as related to the other features. The modelling mode is controlled by the user interface, which determines the modeller to be activated.

An object oriented programming approach to representing feature descriptions leads to property lists stored in a database. The solid representation of form features is stored as a Feature Producing Volume (CSG subtree) and Boolean operators. Feature operations such as modifying, deleting and manipulating are available since the CSG syntax is applied.

The wireframe co-modeller has been incorporated to provide quick response to the user when interacting with the model.

The feature mapping shell is provided for the purpose of extracting and reformulating product data as needed by the application. The information to be extracted is classified into three types:

Type 1: the parameters which are explicitly available in the feature database;

Type 2: the information which can be calculated from those that are explicit in the feature data of one feature. It is implicit but model-invariant.

Type 3: this kind of information depends on a relation between two or more features, ie. it must be calculated from type 1 or type 2 of several features. Such parameters are model-dependent.

Design by features: Pratt and Wilson's report for CAM-I

M. J. Pratt, P. R. Wilson, "requirements for support of form features in a solid modelling system", CAM-I, R-85-ASPP-01, 1985.

This report is concerned with the representation and manipulation of features in a geometric solid model. A feature is defined as a region of interest on a surface of a part. A feature can be considered as a design feature (functional feature) by the designers; a manufacturing feature by the process planners and a volume removal feature by the NC part programmers.

The feature study is based upon the conceptual solid modeller defined by the CAM-I Experimental Boundary File (XBF) and Applications Interface Specification (AIS). The former is an IGES-based format for the transmission of solid modelling data which specifies the entities and data structures assumed to exist in the modeler; the latter is a design for an active or procedural interface to a solid modeller which will enable a FORTRAN application program to access the creation, modification and interrogation functions of any modeller in a standard way. The XBF and AIS include the entities and functionality associated with both of Brep and CSG systems.

The feature representations are divided into two types, i.e.,

1) EXPLICIT, where all the geometric details of a feature are fully defined, and

2) IMPLICIT, where sufficient information is supplied to define the feature but the full geometric details have to be calculated when required.

A further classification of features may be made, into SIMPLE and COMPOUND types. A compound feature is a combination of more elementary features which may themselves be compound in some cases.

The simple explicit features can be classified into four main classes, as follows:

a) Through holes;

b) Protrusions;

c) Depressions and d) Areas.

Many types of explicit features can be further classified in terms of their cross-sectional shapes as Rotational and Prismatic.

There are three ways to handle the feature database, ie.

1) The application program copies data from the solid model via the AIS into application specific data structures.

2) The application program refers to the model data (by name of surface etc) from an application specific data structure.

3) The. geometric modeller is augmented to hold the data needed by the application program.

It is suggested that the application program should manage its own data unless the data has been formally specified by the modeller as being part of the modeller's data. A feature processor has been advocated to manipulate feature data and communicate with the geometric modeller, the feature model database is suggested to exchange information with the geometric model database. AIS is extended to allow the user to interact with both the geometric modeller and the feature processor.

An explicit feature in the Brep model may be defined as a set of faces (facet) of the part which will contain a name, a taxonomy code and pointers to the entities representing the faces involved. Whilst, in the CSG context, a feature is defined as the interaction of two or more volumes involved in the part definition, whose addition to or removal from the part creates a feature.

Design by features: Faux's CAM-I report

I. D. Faux, "Reconciliation of design and manufacturing requirements for product description data using functional primitive part features", CAM-I report, R-86-ANC/GM/PP-01.1, 1986.

This report summarizes the design by features methodologies with an emphasis on the dimensions and tolerances models associated with feature models.

The definitions of features are that all features belong to some generic feature class in the sense that they obey the rules of the class, so that application software operations can always and only be applied to features whose classes lie in the domain of the operation concerned.

At the highest level, features are defined as implicit "specific features" of a particular generic class. (There may be a number of specific features on a component which be- long to the same generic feature class). A "generic feature" is held in implicit form as a specific feature with default parameter values and the set of generic features form the feature library. To create a specific feature, the user can select a feature (generic) from the library and overwrite the default parameters.

A feature is a set of faces of a component, structured into one or more primitives and subfeatures, and whose faces, primitives and subfeatures obey the rules of its declared generic feature class. A primitive is a set of one or more faces which are treated as a single indivisible unit for the purposes of defining and tolerancing its shape (size and form) and location (position and orientation). Four standard primitives are defined, ie., plane primitives (defined by surface normals and the distances from the model origin), cylindrical primitives (defined by axes and radii), plane pair primitives (two parallel planes) and swept profile primitives.

A generic feature class is characterised by a number of structuring rules, selection rules, combination rules and sizing rules. A generic feature can be created by a generic modeller. The purpose of a generic modeller is to provide a means to enable companies to design their own generic features in a user-friendly way.

SECTION THREE: Feature Definitions and Taxonomy Schemes

Feature taxonomy: Gindy's form feature classification

N. N. Z. Gindy, "A Hierarchical Structure for Form Features", Int J. Prod. Res., Vol 27, No.12, 1989.

This paper presents a model which treats form features as volumes enveloped by entry/exit and depth boundaries. The geometric characteristics of a feature are determined by the degree of accessibility to its volume, its boundary type, its exit boundary status and its form variation with respect to its depth axis.

The feature classification is based on the External Access Directions (EADs) from which the feature volume can be machined by cutting tools. A feature is "through" if there is a pair of opposing external access directions (EADs).

Form features are first divided into three Categories, ie. Protrusions, Depressions and Surfaces. Feature geometry is described by deciding on its external access directions (0,1,2,3,4,5,6), its boundary type (open, closed) and its exit boundary status (through, not through). The results of grouping features according to these characteristics is a list of orm features Classes or primary features, such as Boss, Pocket, Hole, Slot, Notch, and Real and Imaginary Surfaces. A feature Subclass is decided by attaching a perimeter geometry to the feature class. It is at this stage that the feature becomes a fully recognisable entity such as a Square pocket, Round hole, Rectangular slot, etc.

Feature definition: Gandhi's approach

A. Gandhi, A. Myklebust, "A natural language approach to feature based modelling", Mobil Research and Development Corporation, Princeton, New Jersey, 1989.

This paper presents a parametric approach to the definition of features. The taxonomy of features is based on the topology of feature primitives, ie. features having the same topology are grouped together so that they could be defined using the same number of parameters. The geometry of the features is represented by B-rep models, but the surfaces of the B-rep model are non-uniform B-spline surfaces, this extends the complexity of the shapes that can be modelled, since B-spline surfaces are usually used for free-form surface modelling.

Feature definition: Karinthi's algebra approach

R. R. Karinthi, D. S. Nau, "Geometric reasoning as a guide to process planning", Computers in Engineering, Vol l, 1989.

This paper introduces the research in developing an algebra for feature definitions and for feature operations (Boolean). Some of the properties of the algebra of features are found. The algebra could solve the problems of the Boolean operations of features with the current CAD model based representations of features and the symbolic representations of features.

Feature concept: Shah's summary paper

Jami J. Shah, "Philosophical development of form feature concept", Dept. of Mech. & Aerospace Eng., Arizona State Univ. Tempe, AZ 85287, 1989.

This paper discusses the concept and properties of form features. It is a good reference for people who are going to define and use features.

Feature taxonomy: John Deere scheme

W. R. Butterfield, M. K. Green, D. C. Scott, W. J. Stoker, "Part features for process planning", CAM-I C-85-PPP-03, 1985.

This is a CAM-I report prepared by Butterfield et al.. Features are classified into three categories: Sheet features, non-rotational (prismatic) features and rotational features.

Sheet features were classified as fiat or formed. Flat patterns were further classified as depressions and edges; depressions were further classified as internal and external, symmetric and non-symmetric. Formed features were classified as localized and non-localized.

Non-rotational features were classified as depressions, protrusions and surfaces. Depressions can be internal, external, through and non-through, etc. Rotational features were classified as concentric and non-concentric.

The scheme also classified material features and heat treatments. It tried to be the basis for the applications in the process planning domain.

SECTION FOUR: Dimensions and Tolerances

Dimensions and Tolerances: Roy's hybrid CSG/Brep approach

Utpal Roy, C. R. Liu, "Feature-based representational scheme of a solid modeler for providing dimensioning and tolerancing information", Robotics and Computer-Integrated Manufacturing, Vol 4, No. 3/4, 1988.

This paper presents feature representation scheme for a solid modeller to provide dimensions and tolerance information.

CSG models contain higher level entities (primitives) which have advantages of representing features, but lower-level entities such as lines, points and surfaces which are essential for dimensions and tolerances, are not explicitly represented. On the other hand, Brep models contain lower-level entities, but higher-level entities need to be extracted from the database, which is hard work.

The proposed approach uses the hybrid CSG/Brep representation which exploits the advantages of the two models. A hierarchical structure of features (as primitives of the CSG-tree) provides a multi-level representation of the object component relations (CSG) and maintains the boundary representation (as the Face Adjacent Graph) at each level of detail. Note that the CSG-tree used is different from the conventional one in that the proposed CSG-tree is made of both primitives and features and set operations are performed at each level of the hierarchical description of the object, whereas the conventional CSG-tree uses primitives only and the Boolean evaluation is carried out only once. The Face Adjacency Graph (FAG) is also better than the conventional edge-based graph in the way the boundary data file is kept.

Upon completion of the object building process, along with the CSG-tree, the model also retains a structured graph, known as the Structured Face Adjacency Graph (SFAG). A SFAG is a hierarchy of FAG graphs, in which the root is the FAG of the general shape of the object and any other node is the adjacency structure describing its lower design features.

The system data structure is procedural and frame-like. Each feature (used as a node of the object-tree) is an instance of the prototype feature. The object-tree consists of two parts: (1) a feature tree, keeping the object-feature relationship in a binary-tree, and (2) a Spatial Relationship Graph (SRG), which keeps the relationships of location and orientation of a feature with respect to other features in each level of the tree.

Since the SFAG is an explicit representation of basic entities, it is possible to attach all kinds of tolerances in this representation. The tolerances include five types ie. size, form, orientation, runout and location. Tolerance specification involves the specification of a Datum Reference Frame (DRF) and the relationships among five kinds of tolerance shape elements: vertex, edge, surface, axis and median plane.

Dimensions and tolerances: Ranyak's approach

P. S. Ranyak, R. Fridshal, "Features for tolerancing a solid model", Computers in Engineering, 1988.

This paper describes a Dimension and Tolerance (D&T) model designed to unambiguously represent the variational model of a part, in association with the nominal solid model.

There are three model layers defined in the D&T model concept: the solid geometry layer, the feature layer and the tolerance layer. With regard to the interfaces between the layers, the project focused on the interface between the D&T model and the solid model. The Applications Interface Specification (AIS) developed by CAM-I is used for the job. In the D&T model (both feature and tolerance layers) there are three types of entities: features, tolerances and Datum Reference Frames (DRF).

SECTION FIVE: Product Modelling Systems

Product modelling: Kimura's X-MAPP system

Fumihiko Kimura, S. Kawabe, T. Sata, "A study on product modelling for integration of CAD/CAM", Integration of CAD/CAM (D. Kochan ed.), Elsevier Science Publishers B. V. (North-Holland), 1984.

M. Inui, H. Shuzuki, F. Kimura, "Generation and verification of process plans using dedicated models of products in computers", Knowledge-based expert systems for manufacturing (ASME) (S. C. Y. Lu & R. Komanduri edit), V 24, Dec. 1986.

The above papers describe a product modeller in the X-MAPP (eXperimental Model based Assistant for Process Planning) system. X-MAPP consists of two major modules: plan generator and model manager. The plan generator is a rule-based ex- pert system for process plan generation and the model manager is a module to manage product models in process planning.

In X-MAPP, product models include workpieces, jigs, fixtures and components. In general, product models should contain design and manufacturing information and knowledge such as geometrical shape, form features, dimensions and tolerances, assemblies, kinematic relations, materials, standard parts, machine tools and so on.

A solid modelling technique is used for representing geometry of products. The relationships between the geometric elements such as faces, edges and vertices are represented using a relational type database. To overcome some inflexibilities of the relational database (such as limited descriptive power) a model description framework has been developed, which comprised of first order predicate logic and an object-oriented approach.

The product model is implemented as COMET/DB (COnceptual Modelling Experimental Tools/DataBase) in a LISP environment, utilising a Prolog like system for handling relationships, and an object-oriented language, Flavors for dealing with the attributes.

Product modelling: Iwata's CIMS system

Kazuaki Iwata, Eiji Arai, "Development of integrated modelling system for CAD/CAM of machine product", Proc. of PROLAMAT'82, 1982.

Kazuaki Iwata, Nobuhiro Sugimura, "Development of product model for design and manufacturing of machine products", Kobe University, Nada, Kobe, 657 Japan, 1987.

K. Iwata, N. Sugimura "An integrated CAD/CAPP system with "know-how" on machining accuracies of parts", J. of Engineering for industry (Transactions of ASME), V 109, May 1987.

The above papers describe a generative process planning system CIMS (Computer aided Integrated Manufacturing System) for machine parts. The product models in the system contain two types of information: Geometrical data such as geometry, dimensions and structures of products; and technical data such materials, surface finishes and tolerances of products.

Products are represented in hierarchical structures, ie. a product is an assembly of sub-assemblies of parts, an sub-assembly is an assembly of parts (or sub-assemblies). The hierarchical structures are represented by relational database techniques, ie. each node such as product, sub-assembly, part etc. in the hierarchy is represented by a relational table (or record). Boundary representations are used for the geometry (faces, edges and vertices) and topological relations of parts. The material and surface finish data is added to the records for the parts. Since the tolerance data is more complicated, it is stored in separate records which is referred to the relevant geometric elements.

Product modelling: the CADROT system

D. Domazet & M. Manic, "CADROT: a product modeller and CAD module for integrated CAD/CAPP/CAM systems for rotational parts", Proc of the 28th MATADOR, UMIST, 18-19, April 1990.

This paper describes a feature based product modelling system (CADROT) for rotational parts. Features are defined as regions of parts having some functional or manufacturing significances. The product model describes parts using two levels of entities: lower level entities such as faces, edges and vertices and higher level of entities such as features. The product model provides a single part database and data structure for all the tasks involved in integrated design, planning and manufacturing.

The design procedure is: design a component with basic rotational elements (features) using the icon menu (a user interface developed), then specify and edit the dimensions and locations of the features. After defining the geometry of the features, the attributes of the features are defined, such as dimensional and locational tolerances, surface finishes etc. Features can also be moved by editing their locations.

The CADROT product modeller has an array form and can be easily integrated in generative CAPP systems, as it is written in FORTRAN and uses ISO specified GKS graphics subroutine library. Feature operations such as union, difference, common and transformation (except translation) are not applicable.

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