Cellular Genetic Algorithm Feature-based Modelling in Product Data Exchange

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Abstract: Currently, most of CAD/CAM systems are feature-based. Features are important to maintain geometric and non-geometric relations across product models. Often, during data translation some useful geometric and non-geometric information such as features and their associated semantics are stripped off. In this paper, we introduce a new method of feature-based modeling in product data exchange using cellular genetic algorithm (cGA). The cGA feature-based modelling is restructuring the B-rep of a product model based on cellular representation, to enable dynamic transmition of the cellular features into a B-rep at the manufacturing domain.

Keywords: Feature-based modelling, cellular genetic algorithm, CAD/CAM systems.

1 Background

Today, collaborative design is carried out not only amongst multidisciplinary product development teams within a company, but also across the boundaries of companies and time zones, with increased numbers of customers and suppliers involved in the process. During product development, information exists at every stage and stored in various forms. Those are produced by various computer-aided design and manufacturing (CAD/CAM) technologies which govern independent authoring tools and defined in proprietary formats [AR12]. This circumstance creates incompatibility whereas information sharing amongst multiple applications becoming bottleneck.

There are two methods for information sharing amongst heterogeneous CAD/CAM systems. One is direct translation and the other one is indirect translation, i.e., through a neutral intermediate format. In comparison to direct translation, the neutral format method is suitable for product data exchange amongst a large number of applications. In order to enable such interoperability, a commonly acceptable, comprehensive and well-defined information model is crucial [MTAC 09]. However, during data translation, some useful geometric and non-geometric information such as features and their associated semantics are usually stripped off. This paper introduces a new approach of feature-based design modelling using cellular genetic algorithm in product data exchange.

2 Feature-based Design

Currently, most of CAD/CAM systems are feature-based. Features are found very useful to encapsulate engineering intent in computer systems. Feature concept is defined for simple and commonly used design and machining geometry elements [Sh91]. In the field of engineering informatics, a feature is defined as a class of semantically endowed objects that accompanies product development from customer requests through to product release. A type of feature is a class of characteristic and semantic patterns of a set of interrelated domain-application entities involved for understanding, communication, reasoning and technical implementation amongst CAD/CAM systems [YM12].

In the field of product design and manufacturing, those existing feature definitions can be divided into two categories according to their granularity at different application levels, i.e. function features (FFs) and machining features (MFs). In the area of product design, a function feature is described as a spatial unit (element) representing a region of interest within a product which includes values and relationships, i.e., structure and constraints [JL07], [IKC08]. Whilst, in the area of manufacturing a machining feature is defined as the specification of a geometric region of a part, which includes shape, position, dimensions, tolerance, and surface finishing of that volumetric region [GZG04], [CG96], [CBZ08]. This definition is formed from the perspective of manufacturing convenience to minimize the total number of machining set-ups [CG96].

Features are domain-dependent. Features associate some generic solid shapes with engineering semantics to facilitate design and manufacturing processes. Function features contribute to the design construct basis of a part in terms of additive or subtractive volumes, and their semantics reflect the design intent and function. Machining features are normally derived from a manufacturing stock in terms of subtractive volumes, and they are conveniently associated with manufacturability analysis and process planning activities, such as fixture planning, machines and cutting tools selection, and machining operations planning [SM95].

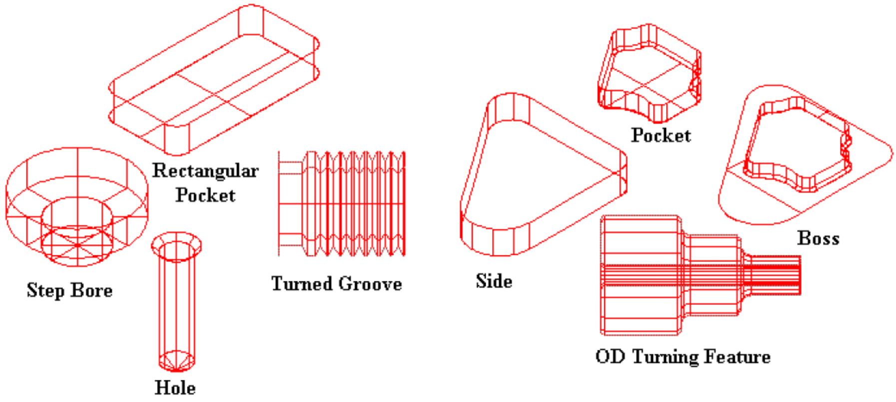


Figure 1: Common features of CAD/CAM applications [Image courtesy: FeatureCAM, 2008]

3 Product Data Exchange

Product design and manufacturing are semantically rich domains. Problems in these domains (e.g., reasoning, analysis, process planning, etc.) are difficult to solve as a large amount of data and information are available and complex decision-making processes are involved. In order to support feature-based applications to cross domains between design and manufacturing, there must be considerable similarity between the CAD/CAM systems. The systems must support the same level of information, same entities, and same semantics; only the representation and implementation can be different.

3.1 Feature Mapping

Feature models are domain dependent, i.e., when a part is designed by features, the resulting model is usually not in a form convenient for other applications, such as engineering analysis, process planning, and manufacturing. The two families of function features and machining features are genuinely different. To transform product information from a design-oriented feature model to a manufacturing-oriented model, it is necessary to transform the model from one viewpoint to another. This process is termed feature mapping. In this paper, the discussion of feature mapping is restricted to one-to-one mapping between spaces of the same dimensionality. Features such as holes, pockets, slots, and ribs might be similarly defined in two systems, even though the names given might be different.

There are several general-purpose methods for feature mapping. Here we use the cell-based mapping technique for mapping by cellular decomposition of solid geometry. The general idea behind cellular schemes for mapping is that in conjugate mapping, volumes are combined into different groups to yield features for different applications. Cellular decomposition, where the cells are solids or voids, might come directly from the original model or be obtained by various partitioning algorithms.

In this study, mapping from function features to machining features is performed by manufacturing feature search on the basis of a convex cellular decomposition [SSS94]. Each volumetric feature class is associated with a collection of topological entities (i.e., a set of characteristic faces) on its boundary, called definitional entities set. Definitional entities have a status attribute that is either positive or negative. Positive definitional entities are part of the model's boundary, whereas negative ones do not belong to that boundary. For instance, a 'slot' must have a positive floor and a negative roof in the model. A set of semantic constraints are imposed on each definitional entities set.

Feature models are represented in a cellular scheme which is a combination of CSG (constructive solid geometry) and B-rep (boundary representation). Feature interaction is detected based on feature definitional entities. Each feature is represented by either a positive cell or a negative one. Whenever two features interact, the respective cells are further decomposed. Parts of the resulting cells belonging to both features represent the interaction extent, while the remaining cells belong to either feature and carry some morphology of the original features.

Figure 2 describes the decomposed cells of a CAD model according to the cellular topology along with the feature modelling process. In comparison to the traditional boundary model, in cellular topology based non-manifold boundary representations, operations on volumes do not discard any input geometry. Part geometries are represented using cellular topologies [MCG09].

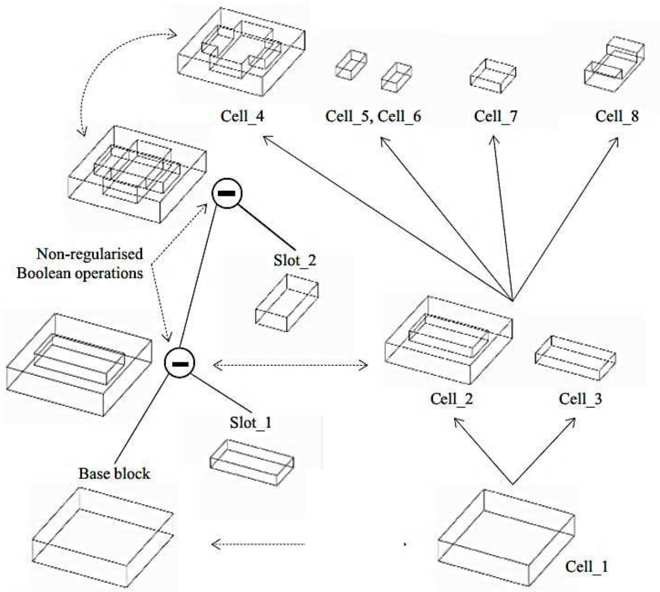


Figure 2: Feature model based on the cellular topology [MCG09]

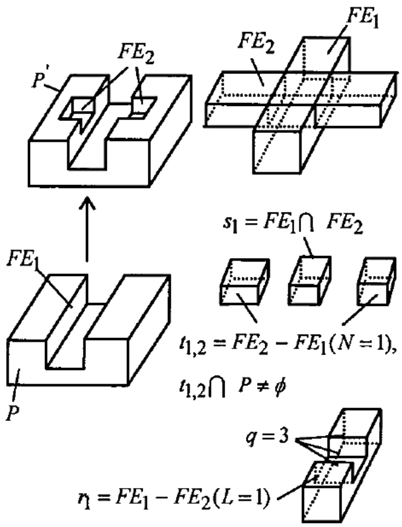
3.2 Cellular Genetic Algorithm Features Model

Features can be defined in various levels of abstractions and specifications, and different data exchange standards (e.g., IGES, DXF, PDES, or STEP) can be used to define different "schemas" for the features. To generate proper interpretations between function features and machining features, we propose an evolutionary method, called cellular genetic algorithm, to enable bi-directional communications and information conversions between various CAD/CAM application domains.

A cellular genetic algorithm (cGA) is a class of evolutionary algorithm (EA) with a decentralized population in which the tentative solutions evolve in overlapped neighborhoods, much in the same sense as cellular automata [AD08]. The essential idea of cellular model is to provide the EA population with a specific structure defined based on a connected feature-based graph, in which each node is to represent a single 'gene' (i.e., a feature) interacting with its nearest neighbors through the cGA operators (recombination, crossover, swap, mutation, insertion, and deletion).

The cGA encodes the decision variables of a search problem in finite length variable chains of an alphabet of a given cardinality. The resulting strings [0,1], which are candidate solutions to the search problem, are called chromosomes. A chromosome represents a mechanical component of the product. It is composed of genes, representing features which construct the component. The different values of these genes are named 'aleles', storing information related to the feature attributes (i.e., dimensions, definitional entities, and orientation). An alele occupies a locus (pl.: loci), containing different values of feature vertex position. A gene is only allowed to recombine with close genes at the same chromosome. This leads us to a kind of locality known as isolation by distance.

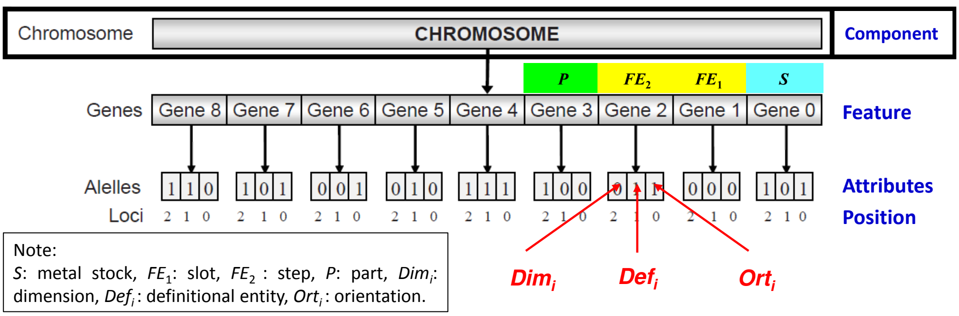
For illustration, Figure 3 depicts a general cGA model. This model analyses the interacting relationship between each function feature in a design feature-based graph with the machining features in an incrementally evolved intermediate manufacturing feature-based graph . In this model, the function feature being traversed is denoted as DF, machining feature being traversed is MF, and the manufacturing stock is S. The Boolean operation of S in volume is additive and the other features are subtractive.



FE_1 is adjacent:
$FE_2 \cap FE_1 \neq 0$,
$FE_2 \not\subset FE_1$,
$FE_1 \not\subset FE_2$,
r_1 and each S_i satisfies $p > 1$.

FE_2 is disconnected:
$FE_2 \cap FE_1 \neq 0$,
$FE_2 \not\subset FE_1$,
$FE_1 \not\subset FE_2$,
$N > 1$,
for each t_i: $t_i \cap P \neq 0$.

(a) The interacting relationship between features [LON06]



(b) Features coding

Figure 3: Cellular Genetic Algorithm features model

Conclusion

Features are important to maintain geometric and non-geometric relations across product models. The generic feature model provides flexibility and finer-level of granularity for an integrated feature-based modelling framework between CAD/CAM applications. Representing feature-level information uniformly is compulsory so that engineering meaning is completely shared amongst various application domains.

In this paper, we introduce a new method of feature-based modeling in product data exchange using cellular genetic algorithm (cGA). The cGA feature-based modelling is restructuring the B-rep of a product model based on cellular representation, and dynamically transmitting and embedding the cellular features into a B-rep at the manufacturing domain. The cGA algorithm applies six operators, i.e., recombination, crossover, swap, mutation, insertion, and deletion. Therefore, features and constraints can be maintained and propagated systematically during the data exchange.

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