

# User-reconfigurable CAD Feature Recognition in 1- and 2-topologies with Reduction of Search Space via Geometry Filters

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## Abstract

*In the context of Computer-Aided Design and Manufacturing, the problem of feature recognition plays a key role in the integration of systems. Until now, compromises have been reached by only using FACE-based geometric information of prismatic CAD models to prune the search domain. This manuscript presents a feature recognition method which more aggressively prunes the search space with reconfigurable geometric tests. This reconfigurable approach allows to enforce arbitrary confluent tests which are topologic and geometric, with enlarged domain. The test sequence is itself a graph (i.e. not a linear or total-order sequence). Unlike the existing methods which are FACE-based, the present one permits combinations of topologies whose dimensions are 2, 1 or 0. This system has been implemented in an industrial environment. The industrial incarnation allows industry-based customization and is faster when compared to topology-based feature recognition. Future work is required in improving robustness of search conditions and improving the graphic input interface.*

## CCS Concepts

•Applied computing → Computer-aided design; Computer-aided manufacturing;

## 1. Introduction

Modern CAPP systems take a CAD-based part model as input, which provides topology and geometry information, and perform automatic feature recognition to extract information about features present in the model, to later define a process plan in order to manufacture such features. Due to the wide variety of CAD systems available, CAPP systems should be able to perform the feature recognition process using a standardized version of the part model.

An important part of research in CAD-CAPP systems is focused on the development and implementation of new and more efficient feature recognition algorithms. Feature recognition algorithms focus on successfully identifying a region of a part with some interesting geometric or topological properties, called form features. Given that feature recognition is a problem whose computational burden is intractable (NP-hard), geometric information from the CAD-based part model is used to prune the search space.

This manuscript presents a reconfigurable feature recognition method which prunes the search space with geometric tests, and shows an industry-based implementation along with the recognition process results.

## 2. Literature Review

Several different approaches have been presented for the problem of recognizing CAD features [BNM08]. The syntactic pattern method ([JK98], [IABJ02], [IBJ05]), which proposes the use of a description language using semantic primitives to describe the input solid. Logic rules systems ([Bab96], [BM97], [BA00]) propose a set of rules that uniquely define a given feature using a base FACE as starting point.

Graph-based approach ([Cha90], [OH02], [GH95], [VW95]) proposes the creation of an AAG (attributed adjacency graph) that contains the adjacency information of all faces of a given solid and match subgraphs of the AAG to a database of different patterns. Volume decomposition approaches ([WS02], [Kim92]) proposes to determine a polyhedron convex hull circumscribed around a part and define the difference in volume between the convex hull and the part as an alternating sum of volumes to be partitioned later. Graph-based algorithms have been resurfacing with the use of artificial intelligence. Hybrid graph-rules systems [SAP10] have been appearing lately, such systems focus on dealing with interacting features.

The idea of reconfigurable methods is treated in [RMF96], where a geometric reasoning server is presented as an effort to develop

robust, flexible and extensible applications that integrate the geometric utilities in a CAD/CAM/CAPP environment.

A STEP-based platform-independent methodology which solves the problem of recognizing interacting features (a major shortcoming of graph-based methodologies) have been presented in [NR10]. Other STEP-based approach which can recognize non-planar features is presented in [VK17], considering basic non-planar surfaces (cylindrical, conical, spherical, toroidal) and advanced non-planar surfaces (B-spline and swept surfaces).

## 2.1. Conclusions of Literature Review

In general, methods found in literature present two major shortcomings: (i) the reduced domain of application, given that recognition is only possible on boolean combinations of prismatic shapes or parts that can be machined on a three-axis machining centre; (ii) the reliance on FACE-based search, therefore excluding valuable information present in topologies whose dimension is other than 2. Responding to such shortcomings, this manuscript presents a feature recognition method which prunes the search space with geometric tests. This method is reconfigurable as it allows to enforce arbitrary confluent tests which are topologic and geometric. Unlike the existing methods, the present one permits combinations of topologies whose dimensions are 2, 1 or 0.

## 3. Methodology

The implemented method consists of two definite separated stages: *parsing stage* and *domain depuration stage*. In the first stage, the geometrical and topological information of the solid is parsed from a STEP file, and in the second stage, the obtained data is put through a series of tests, as shown in Figure 1.

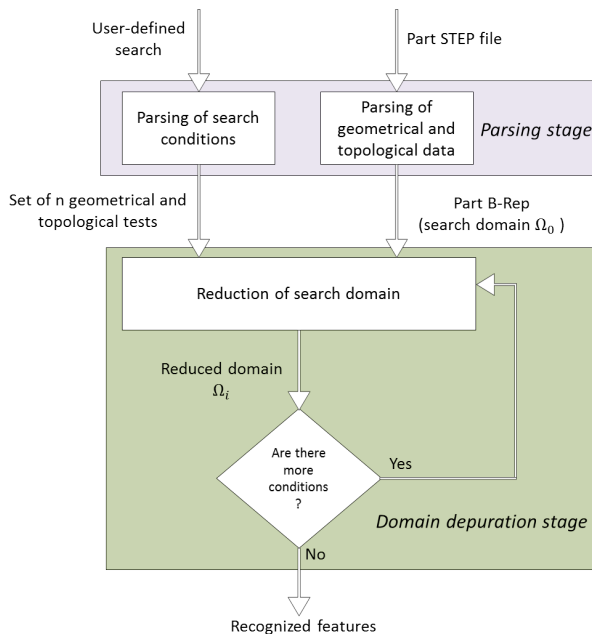


Figure 1: Flowchart of recognition process

The first step of the process, the *parsing stage*, is divided in two parallel processes: (i) parsing of the search conditions and (ii) parsing of the geometry-topology data. The parsing of the search conditions is the process of translating a search graph to a set of geometrical tests. The output of this process is a finite sequence of functions to execute, one after the other, on a data set. Such data set is obtained through the geometry-topology data parsing process, in which we use the libraries of *OpenCascade* [RC12] platform. The *OpenCascade* STEP Processor maps geometrical and topological entities present in the STEP format to the correspondent geometrical and topological entities in the *OpenCascade*-based data structure.

The second step of the process, the *domain depuration stage*, is the process of executing the finite sequence of functions obtained in process (i) of the previous step to the topology-geometry search domain obtained in process (ii) of the previous step. In each iteration, the search domain will be reduced by eliminating the topological entities that do not comply with the desired condition. Once all conditions in the sequence are executed, the resulting search domain correspond to the topologies that constitute the desired features.

### 3.1. Search Graphs

A search graph is a finite set of nodes in which each node corresponds to some search condition. All search graphs are directed graphs, that is, search conditions are executed in a sequence. The user will build the necessary search graph in accordance to the necessary geometry filters to purge the search space until it contains only the desired features once all filters have been applied.

It's important to highlight that search graphs should be precise enough to correctly capture the geometrical and topological characteristics of the desired feature. The precision of the output will be a function of how detailed the search graph is.

### 3.2. Topology-Geometry Data Structure

The data structure implemented is based on the *OpenCascade* [RC12] [Inc95] platform and resembles a B-Rep data structure. Figure 2 shows the implemented data structure.

The hierarchical organization of the data structure allows for easy exploration of the topology-space of the workpiece and easy access to the geometrical properties of any topology. All geometry and topology classes are derived from the base *TopoDS* class in the *OpenCascade* library.

### 3.3. Topological Relations

Topological relations are functions whose objective is to determine whether two topologies comply with a topological characteristic or not. These functions query the search domain for topological information by using the relationships between topologies encoded in the data structure (Figure 2).

The use of topological relations along with geometrical tests allows to explore the geometrical characteristics not only of the main target topology, but of other topologies contained or somehow related to the main target topology.

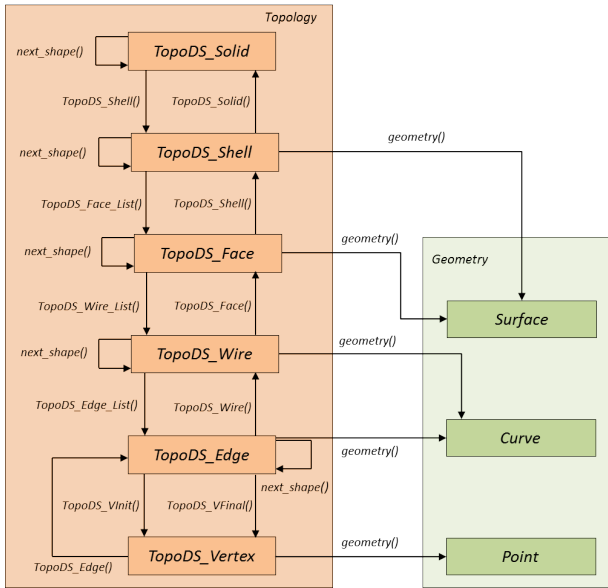


Figure 2: Geometry-topology data structure

### 3.4. Geometrical Tests

A geometrical test is a function whose input is a base topology and whose output is a boolean value ( $\phi : Topology \rightarrow Boolean$ ). These are used as elimination criteria in the reduction of the search space in each iteration.

Several geometrical tests have been implemented in the industrial incarnation of the method to identify desired features. Some of such tests implemented include FACE cylindricity test, FACE planarity test, EDGE circularity test, EDGE parallelism test, among others. Reconfigurability of the method lies in the fact that the user can define more geometrical tests according to the needs of any given feature, therefore, any given feature can be represented as a sequence of geometrical tests and topological relations.

### 3.5. Performance

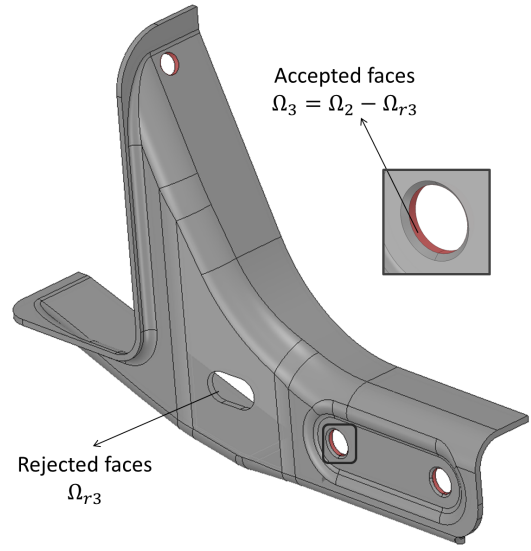
Performance of the algorithm is determined by two aspects: (i) the size of the initial search domain and (ii) the number (and type) of nodes of the search graph. The relationship between performance and the size of initial is clear, a larger domain means a larger number of operations to be performed which implies a longer runtime, but the relationship between performance and number and type of nodes in the search graph is more complicated.

Regarding the number of nodes, when a new filter is added to the search graph, new operations are introduced in the execution sequence but, at the same time, the search domain is further reduced for the next iteration. Hence, adding a new node might improve performance if the number of reduced operations is larger than the number of operations added by the insertion of the new node.

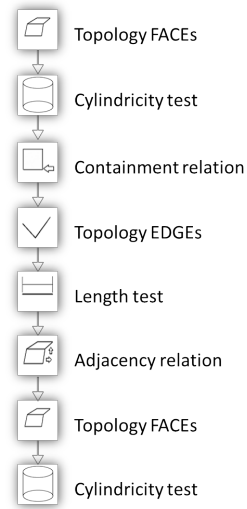
### 3.6. Graphic User Interface

The proposed method has been implemented in an industrial environment, using icon graphs for the rule configuration and allowing the user to further expand the library of available tests. The industrial incarnation of the method is applied in the recognition of features present mostly in metal-sheet parts used in the automotive industry.

### 4. Results



(a) Reduced domain  $\Omega_3 \subset \Omega_0$



(b) Search graph G

Figure 3: Example of hole feature recognition in test data set

To test the industrial incarnation implemented, an application example in two different data sets is presented in Figure 3. The goal is to recognize hole features present in a solid part, an exercise of

importance in various industrial applications, specially in the automotive industry. For that, a holed metal sheet with curved geometries, typically used in the design of automobile chassis, is defined as the initial search domain  $\Omega_0$ .

A new search domain  $\Omega_1$  is the product of pruning the correspondent initial search space  $\Omega_0$  with the condition represented in the first two nodes of the search graph. Therefore, the reduced domain  $\Omega_1$  should only contain all cylindrical FACES present in the workpiece.

In the next step, the next three nodes are used to prune domain  $\Omega_1$  by applying the conditions shown in such nodes; in this case, the specified length is the sheet's thickness  $t$ . Resulting reduced domain  $\Omega_2$ , should then only contain cylindrical FACES that contain an EDGE of length  $t$ .

Up to this step, the domain  $\Omega_2$  contains the desired hole features and other *noise* topologies, therefore, an additional condition is necessary to prune the domain  $\Omega_2$  from those *noise* topologies. The last three nodes of the search graph apply an additional condition to the domain by only keeping elements (FACES) of  $\Omega_2$  that are adjacent to a cylindrical FACE (contained in  $\Omega_1$ ). Hence, a reduced domain  $\Omega_3$  is created only containing FACES of hole features, recognizing successfully the desired features. Notice that the additional condition applied, successfully prunes the *noise* topologies because of the topological construction of hole features in these particular cases, where hole features are composed of two opposed cylindrical faces, but is not a general rule for hole features in all cases.

As a general rule, desired feature's topological and geometrical characteristics must be known a priori to ensure a correct result in the recognition process.

## 5. Conclusions and Future Work

This manuscript presents an implementation of a user-reconfigurable feature recognition method for the correct identification of CAD 3D manufacturing features. Our method prunes the search domain by extracting useful geometric information from topologies whose dimensions are 2, 1 or 0. An actual implementation of our algorithm in an industry provider of metal parts for transportation sector, shows that the capacity of tuning the feature seeker for a particular context enables a very efficient albeit specific feature recognition process.

The presented work implies an improvement with respect to previous attempts of geometry-pruned feature recognition, which are limited to dimension 2 topologies mounted only on prismatic geometries.

Future work is required in improving (a) robustness of search conditions, (b) Graphic User Interface, and (c) graph parsing. These enhancements should precede the application of our initiative to the identification of interacting features, which is not considered at the present time.

## References

[BA00] BOUZAKIS H., ANDREADIS G.: A feature-based algorithm for computer aided process planning for prismatic parts. *Int. J. Prod. Eng. Comput* 3, 3 (2000), 17–22. 1

- [Bab96] BABIC B.: Development of an intelligent cad-capp interface. In *Proceedings of the International Conference on Intelligent Technologies in Human-Related Sciences* (1996), pp. 351–357. 1
- [BM97] BABIĆ B., MILJKOVIĆ Z.: Feature recognition as the basis for integration of cad and capp systems. *Intelligent Manufacturing Processes and Systems* (1997), 596–601. 1
- [BNM08] BABIC B., NESIC N., MILJKOVIC Z.: A review of automated feature recognition with rule-based pattern recognition. *Computers in Industry* 59, 4 (2008), 321–337. 1
- [Cha90] CHANG T.-C.: *Expert process planning for manufacturing*. Addison-Wesley Longman, 1990. 1
- [GH95] GAVANKAR P. S., HENDERSON M. R.: Graph-based extraction of two-connected morphological features from boundary representations. *Journal of Intelligent Manufacturing* 6, 6 (1995), 401–413. 1
- [IABJ02] ISMAIL N., ABU BAKAR N., JURI A.: Feature recognition patterns for form features using boundary representation models. *The International Journal of Advanced Manufacturing Technology* 20, 8 (2002), 553–556. 1
- [IBJ05] ISMAIL N., BAKAR N. A., JURI A.: Recognition of cylindrical and conical features using edge boundary classification. *International Journal of Machine Tools and Manufacture* 45, 6 (2005), 649–655. 1
- [Inc95] INC. S. T.: ACIS geometric modeler, 1995. 2
- [JK98] JAIN P., KUMAR S.: Automatic feature extraction in prizcapp. *International Journal of Computer Integrated Manufacturing* 11, 6 (1998), 500–512. 1
- [Kim92] KIM Y. S.: Recognition of form features using convex decomposition. *Computer-Aided Design* 24, 9 (1992), 461–476. 1
- [NR10] NAGARAJAN S., REDDY N. V.: Step-based automatic system for recognizing design and manufacturing features. *International Journal of Production Research* 48, 1 (2010), 117–144. URL: <https://doi.org/10.1080/00207540701855419>, arXiv:<https://doi.org/10.1080/00207540701855419>, doi:10.1080/00207540701855419. 2
- [OH02] OWODUNNI O., HINDUJA S.: Evaluation of existing and new feature recognition algorithms: Part 1: Theory and implementation. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture* 216, 6 (2002), 839–851. 1
- [RC12] RUSSELL J., COHN R.: *Open Cascade Technology*. Book on Demand, 2012. URL: <https://books.google.com.co/books?id=thWNMQEACAAJ>. 2
- [RMF96] RUIZ O. E., MARIN R. A., FERREIRA P. M.: A geometric reasoning server with applications to geometric constraint satisfaction and configurable feature extraction. In *Modelling and Graphics in Science and Technology*. Springer, 1996, pp. 62–76. 1
- [SAP10] SUNIL V., AGARWAL R., PANDE S.: An approach to recognize interacting features from b-rep cad models of prismatic machined parts using a hybrid (graph and rule based) technique. *Computers in Industry* 61, 7 (2010), 686–701. 1
- [VK17] VENU B., KOMMA V. R.: Step-based feature recognition from solid models having non-planar surfaces. *International Journal of Computer Integrated Manufacturing* 30, 10 (2017), 1011–1028. URL: <https://doi.org/10.1080/0951192X.2016.1268719>, arXiv:<https://doi.org/10.1080/0951192X.2016.1268719>, doi:10.1080/0951192X.2016.1268719. 2
- [VW95] VENUVINOD P. K., WONG S.: A graph-based expert system approach to geometric feature recognition. *Journal of Intelligent Manufacturing* 6, 3 (1995), 155–162. 1
- [WS02] WOO Y., SAKURAI H.: Recognition of maximal features by volume decomposition. *Computer-Aided Design* 34, 3 (2002), 195–207. 1