Title:
**From CAD Assemblies toward Knowledge-based Assemblies using an Intrinsic Knowledge-based Assembly Model**

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Introduction:
CAD assembly models reduce to sets of B-Rep models, often solids, without explicit geometric relationships between them. When exported through STEP files, these files contain the assembly tree that structures the assembly and dependencies between solids that express the occurrence of each component through the assembly.

The purpose of contribution is the proposition and implementation of an assembly model that is intrinsic, i.e., the CAD assembly tree is defined by a designer and can express some of it functional aspects only. This intrinsic model is used as basis to generate symbolic information as part of an ontology where the geometric properties associated with the intrinsic assembly model stand as elementary facts that populate the knowledge base connected to the CAD model. From this set of elementary facts, the inference engine part of our software architecture is equipped with inference rules. Triggering these rules enables the generation of new, higher level facts related to the assembly structure that relates to the functional structure of the assembly. These facts enrich the knowledge base so that it can be queried in accordance with the ontology set up.

Main Idea:
CAD assembly models contain limited information about a product structure. In a first place, CAD assembly modules express an assembly structure through a tree structure. This is restrictive in the sense that an intrinsic description of an assembly where functions can be described and tightly connected with the 3D geometry of the assembly requires a description of the interfaces between its components as well as the relationships between these interfaces. The corresponding information relates to the kinematic schema that synthesizes a mechanism. As such, the structure of the corresponding schema is a graph, i.e., a mechanism exhibits a linkage graph that contains one loop, at least. Consequently, the CAD assembly tree structure cannot describe such a graph structure. Therefore, it is not intrinsic to the assembly model described.
Similarly, the CAD assembly tree structure is used to decompose the assembly into sub-assemblies or sub-systems that may convey some functional meaning. This decomposition, however, is not unique and not all functional meanings can be described with the tree structure. Once again, the tree structure is not adequate to describe explicitly an assembly decomposition. Here, we propose to focus on criteria that relate to:

- the relative position of components to characterize groups of components that can be instantiated several times at different locations,
- identical components that share similar interfaces with the same component.

The results of these criteria are not bound to a tree structure, thus enabling an intrinsic description of an assembly structure.

In a second place, CAD assembly models as described through STEP files contain components names and description under textual form. Such information, however, is not reliable [3] and error prone since it is strictly related to user input and the semantic and functional information contain there can be very poor, ranging from company-dependent names and codes assigned to components to functional designation of components.
Here, we propose to set up an intrinsic geometric descriptor of components so that the concept of occurrence can be robustly implements, enabling efficient queries through the assembly ontology.

*Software Architecture*
The software architecture set up incorporates a CAD modeler, SALOME, developed by OpenCascade, a knowledge base, JENA, describing the ontology as RDF triplets, developed by Apache, and a reasoner to process inferences described as RDF triplets, CoGUI, developed by GraphiK Inria team (see Figure 1). To cover the assembly processing required, a specific module has been developed in SALOME.

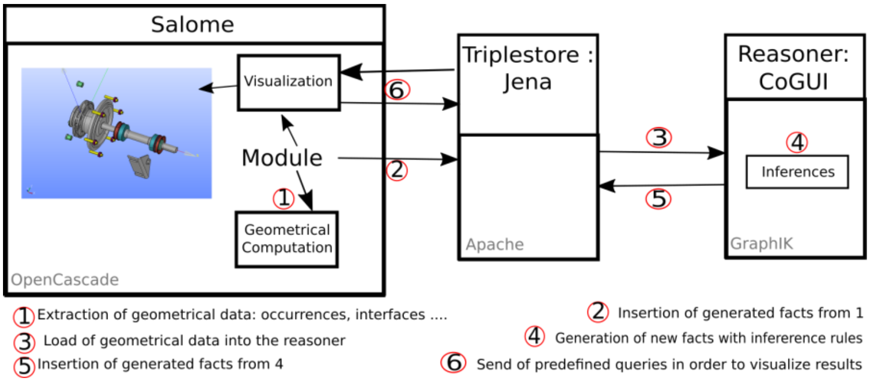


Fig. 1: Software architecture incorporating a CAD modeler, SALOME, a knowledge base, JENA, and a reasoned, CoGUI and interactions between these components.

Based on this architecture, a STEP file describing the assembly input is processed as follows:

- Geometry processing of each assembly component and of the assembly itself takes place in the assembly analysis module developed. The geometric information thus generated is stored in SALOME. A symbolic information can be attached to it to instantiate concepts of the ontology as RDF triplets,
- Each symbolic information derived from a geometry processing algorithm generates a corresponding fact that is inserted in the knowledge base, JENA, as RDF triplets to populate the ontology,
- Symbolic information is loaded into the reasoner, CoGUI, and processed using inference rules expressed as RDF triplets forming queries. The facts derived from these inferences are stored into the knowledge base,
- The visualization of the results is achieved in SALOME, taking advantage of the connections set up between the geometric entities describing the assembly and the entities resulting from the geometry processing algorithms. Using these connections, the symbolic information produced by the queries can be expressed with the proper geometric entities.

This architecture is derived from previous work of Ulliana et al. [7].

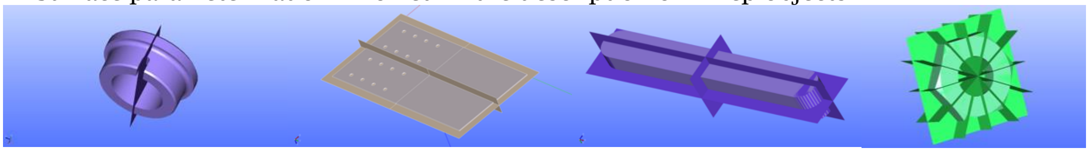
*Geometry and symbolic information processing*
Prior work on functionally enriched assemblies [2] has demonstrated the efficiency of structuring assemblies for simulation preparation purposes. The inferences of functions for screws and nuts were obtained through the repetitive application of inference rules to each component, resulting in a lengthy process. Geometry processing operators are important to take into account repetitive configurations in

assemblies so that similar configurations between components can be identified and used to infer component function more efficiently using the similarity measure.

Here, the purpose of the paper is to focus on the high level description of the geometry processing operators and the symbolic information processing to produce a synthetic overview of interactions between 3D geometric entities and symbolic ones enabling the knowledge-based description of assemblies.

A key point of geometry processing algorithm is the extraction of geometric information that is intrinsic to components or sets of components. This means, this information is independent of the:

- Modelling process of each assembly component,
- Topological constraints of CAD geometric modelers,
- Surface parameterization involved in the description of B-Rep objects.



(a) one symmetry plane (b) two symmetry planes (c) three symmetry planes (d) discrete axi-symmetry

Fig. 2: Global symmetry properties of components organized into categories. Examples with four independent categories.

The geometry processing algorithms perform the following major treatments:

- The generation of the maximal boundary decomposition of each component to obtain a B-Rep boundary that is intrinsic in the sense stated above. This concept of maximal decomposition is based on work from Boussuge et al. [1] and it is placed on top of the B-Rep description of each component,
- The symmetry analysis of each assembly component. The output of this analysis is a set of global symmetry properties characterized by symmetry planes (see Figure 2). It is obtained through the algorithm developed by Li et al. [6] and this analysis is also based on the maximal boundary decomposition obtained previously. Consequently, the symmetry planes and/or axes obtained are intrinsic to the component shape. Further, the symmetry planes obtained can be organized in accordance with categories of symmetries and a set of ten categories appears to cover shapes of solids. Figure 2 illustrates four among the ten categories of symmetries defined,
- The generation of a geometric shape descriptor for each component. This descriptor is based on the maximal boundary decomposition, on the global symmetry properties and the inertia properties of a component. All this information is intrinsic to a component as well as the descriptor itself. The descriptor is defined with the center of gravity of the object and a reference frame defined from principal axes of inertia of the object. Then, the global symmetry properties are used to reduce the maximal boundary decomposition to its minimal subset. The reference frame set up, the symmetry category and the minimal graph of the component boundary form its shape descriptor,

(a) (b)

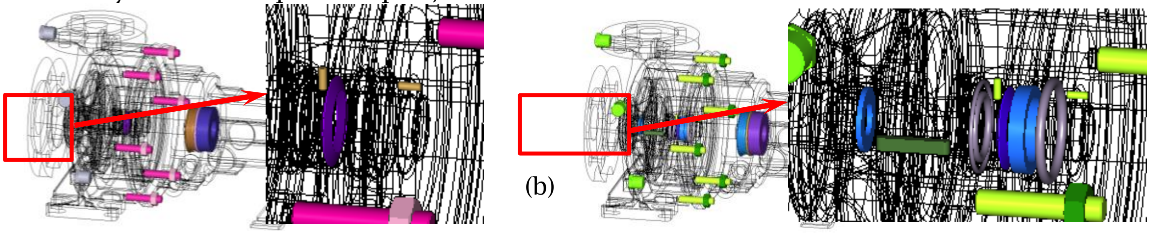


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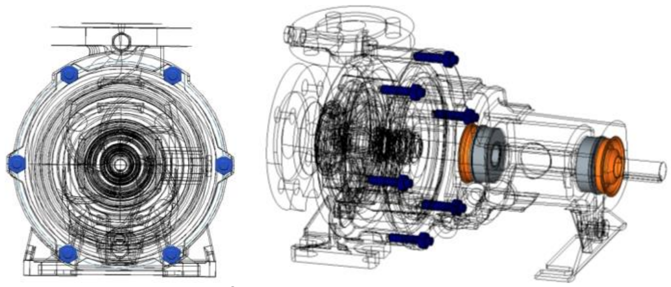
Fig. 3: (a) Extraction of categories of identical components. Each color identifies a different category. (b) Extraction of families of components. Each color identifies a different family.



(a) (b)

Fig. 5: a) Extraction of repetitive patterns of single components in an assembly. An example of rotational pattern. b) Extraction of repetitive patterns of sets of components in an assembly. Each color identifies a different set of components.

- The extraction of identical components. This is based on the comparison of their shape descriptors (see Figure 3a) and produces occurrences of components. Though these occurrences may appear in the STEP file and assembly tree describing the assembly, this is not robust and intrinsic. Here, the comparison of the shape descriptors produce the occurrences intrinsically,
- The extraction of families of components. This is a weaker form of the previous geometric descriptor where the graph comparison is not based on identical faces and dimensional parameters of surfaces. Indeed, the dimensional constraints are dropped and local symmetry properties, or geometric properties, are added to characterize the desired set of shapes (see Figure 3b).
- The symmetry properties and repetition properties of components in an assembly. This information is extracted as a generalization of the symmetry analysis [4] and linear and circular patterns are also detected based on the intrinsic reference frame assigned to each component. This is an extension of Lupinetti et al. [5, 6] with intrinsic information to an assembly (see Figure 5a),
- The extraction of repeated sets of components whose relative positions are identical. This a generalization of the concept of sub-assembly and these sets are called 'modules' (Figure 5b),
- The extraction of the graph of geometric interfaces between components similarly to Boussuge et al. [2], i.e., interfaces of type contact, interference and clearance.

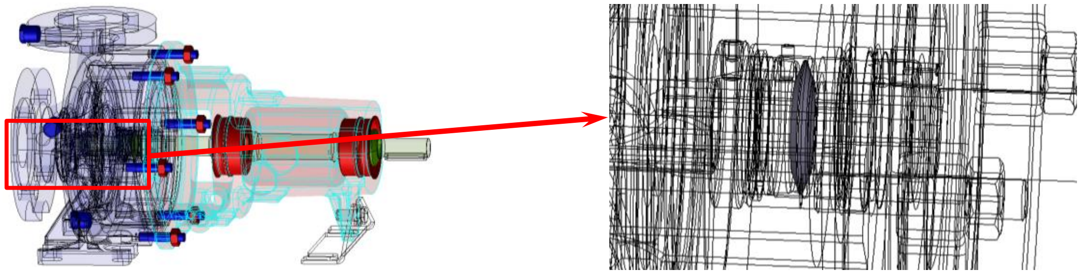
All these geometric informations produce geometric properties that can be described as symbolic information and concepts of the assembly ontology. Consequently, all these geometric information have their symbolic counterpart generated in the knowledge base to provide a symbolic representation of an assembly that can be queried with the reasoner.

From this knowledge base, inference rules can be added to produce new facts and derive higher level structural information about an assembly (see Figure 6). Currently, the inferences implemented enable the extraction of groups and piled up components. A group is a set of components, occurrence of each other, that share a same type of interface with a single component. It is typically the case for nuts and studs assembling a housing or bearings mounted on a shaft (see Figure 6a). These groups convey functional information and characterize the repetitions of this functional information. A set of piled up components is a set of identical components sharing a geometric interface of same type (see Figure 6b). This is the case for Belleville washers (see Figure 6b) in the centrifugal pump of Figure 6a. Similarly, piled up components express functional information. In the present case, it is related to the elastic behavior of the Belleville washers.

Figure 7 summarizes the dependencies between the geometry processing of the assembly and highlights the flow of symbolic information feeding the knowledge base as well as symbolic information derived from the knowledge base.

Conclusion:

The proposed approach structures CAD assembly models based on intrinsic information. The content of the assembly structure is available as 3D entities in the CAD modeler SALOME and it is tightly connected to the knowledge base JENA where it can be queried through the assembly ontology. The initial assembly is now transformed into a first level of knowledge-based assembly.



(a) groups of components (b) piled-up components

Fig. 6: Examples of higher-level structures derived from inference rules.

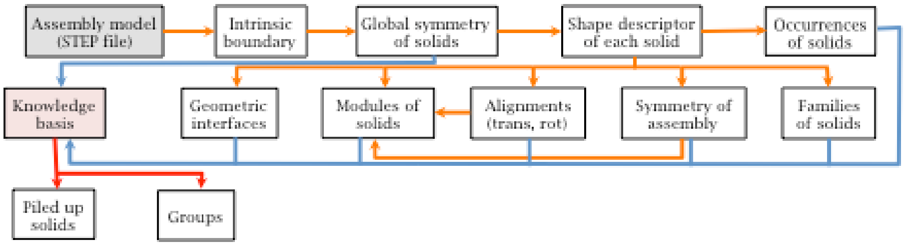



Fig. 7: Process flow generating an intrinsic knowledge-based assembly. Orange arrows indicate geometry processing dependencies, blue ones express the extraction of symbolic information from geometry, red ones characterize dependencies of symbolic information.

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