Title:
Analysis and Evaluation of Partitioning Methods for Multi-User CAD

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Introduction:

Partitioning methods have been previously implemented in various CAD programs, but have not yet been used in a multi-user (MU) CAD systems [8]. Multi-User CAD allows multiple individuals, designers, or engineers, to model, edit, and update a 3D geometry simultaneously on the same file without complicated check-in/check- out procedures [4]. Recent research activities to understand the impacts of Multi-User CAD on collaborative engineering design and modeling have demonstrated the time reduction and other benefits, however, a lack of trust can still persist when sharing models across organizations who need to access the same 3D model. Partitioning the model is one way to concurrently share the model with others while still protecting aspects of the design that are sensitive or are considered proprietary in some way. In order to determine the best partitioning method within a MU CAD system, this research explores, simulates, and evaluates three different partitioning methods within the MU program, NXConnect [9].

Background:

A review of the literature to determine what partitioning methods are potentially feasible in a multi-user CAD environment to protect intellectual property suggested six key requirements or metrics to evaluate the various techniques. These requirements include:

- Well developed algorithm (i.e. a robust and prevalent method)
- Method has been previously been implemented (i.e. used on current CAD software)
- Degree of obfuscated visual information (i.e. degree to which model data was inaccessible)
- Variability of obfuscation (i.e. degree to which moderator could choose the information obscured)
- Versatility (i.e. a method that could be applied to both a single feature and entire part showed more versatility than one that could only be applied to a single part)
- Effect on data transfer and computational speeds

The identified partitioning methods range from simple dated methods, like watermarking, to methods already implemented in many CAD software packages, such as shell [2] and envelope [5]. Other methods still in development, such as multi-resolution surfaces [6] and encryption [1] were also identified.

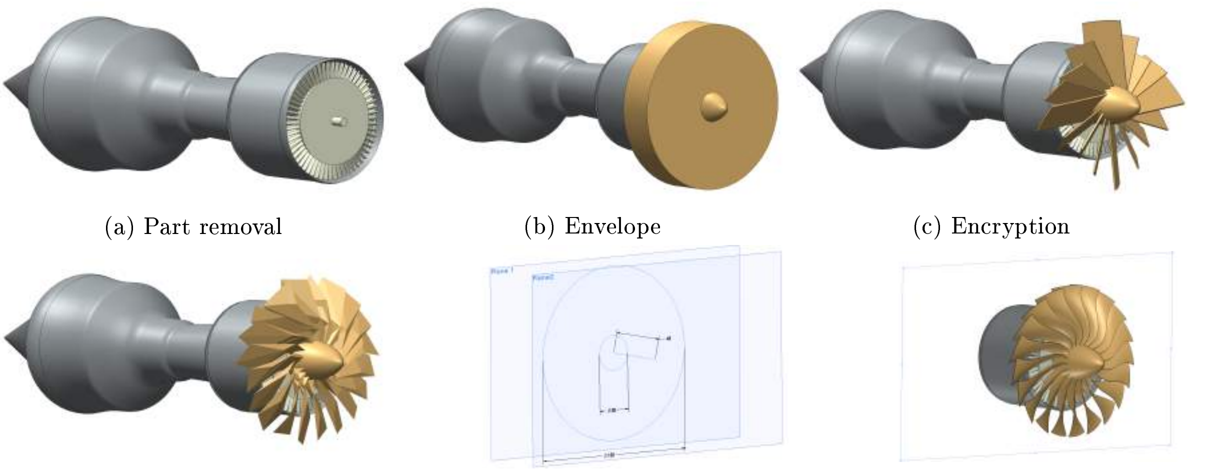
Since many of the partitioning methods were related in some way, high-level categories were established to better define and analyze the key features within and across the options. The two main categories were “methods that removed” and “methods that altered or obscured” presented briefly in the following tables and in Figure 1.

Table 1: Removal partition methods

Name	**Description**
Skeleton	Parts are removed from the view of those without the right security level. Only lines and shapes are left behind that provided the needed dimensions for interfacing geometry or constraints for partial-access designers to use.
Part Removal	Removes an entire part from an assembly
Planar Decomposition	Uses planes or surfaces to define regions that are visible to users

Table 2: Altering/Obscuring partition methods

Name	**Description**
Envelope	Obscures parts by surrounding them with a three-dimensional solid.
Encryption	Alters parts and features by using an encryption key to change dimensions, which thus affects the appearance of a model.
Multi-Resolution Surfaces	Obscures features by adjusting the coarseness of the mesh that makes up the model. Higher coarseness results in a greater degree of obfuscation.



(a) Part removal (b) Envelope (c) Encryption

(d) Multi-resolution surfaces (e) Skeleton (f) Planar decomposition

Fig. 1: Examples of the partitioning methods described in Tables 1 and 2.

One of the methods, planar decomposition, could fit within either of the above categories [8] but is presented in 1. This method uses planes or surfaces to define regions that are visible to other users. For example, administrators or original part owners of a particular model are able to remove whole sections using a plane or alter a model by using surfaces.

Finally, two more methods described in the literature did not pertain to either category. The first, watermarking, is an outmoded method of intellectual property protection and is more common on printed documents than on three-dimensional models [7]. The second, called differing level of detail, was less of a definite partitioning method and more focused on how to administer any partitioning methods in a role-based manner [3].

After evaluating the partitioning methods against the key requirements described above, four partitioning methods stood out: 1) encryption, 2) envelope, 3) multi-resolution, and 4) planar decomposition. All four indicated high levels of variability in application and were already well documented and tested.

Methodology:

With the top four methods remaining after the down-selection process, an experiment was designed to explore their capabilities and appropriateness for implementation in a multi-user CAD environment. It was hypothesized that planar decomposition (PD) would fare best in the testing with multi-resolution (MR) a close second. The envelope (EN) method was also included because of its current implementation in existing CAD software for single Users. By testing EN, it could be evaluated and compared to the other partitioning methods to identify if it is sufficient to meet partitioning criteria in multi-user CAD. Early exploratory tests results in dropping Encryption fro the experimental set, since functionally the results was identical to that represented by the MR method. Thus, in general, conclusions with MR can be generally applied to Encryption as well.

Experiments were run with these three partitioning methods (i.e. MR, PD, and EN) on four different assemblies (Shock Absorber, Boiler Feed Valve, Turbofan, and V6 Engine). The assembly models were selected from various industries on which multi-user CAD could be applied with partitioning methods and differing levels of complexity.

In every assembly, two parts were removed which were then modeled by one of two people in the Multi-User environment (i.e. one of the two parts) in each of the tests. The removed parts met two main criteria: first, the part was simple enough that testers could complete the task within 10 to 12 minutes; and second, the part relied on dimensions from another part of the assembly (e.g., such as coincident to a face, interfacing shaft-hole relationships, or equal hole sizes). These criteria allowed normalization of the data across the four models.Each assembly was then modified to simulate the three partitioning methods (i.e. MR, PD, and EN) in the multi-user setting. Layers were used, allowing the locking or hiding of specific components for individual users within NXC, section views, and a 3D program called Blender for the MR parts.

For example, in one model (a V6 engine), planes were added and used to create section views which simulated the PD environment as seen in Figure 2. To simulate MR, STL files were manipulated in Blender to reduce the resolution and give the part an MR appearance (see Figure 3). The MR files were imported as STLs into the assembly and placed on individual layers. The Envelope partitioning method was simulated by using extrudes to block out features and left only the general outline of the part (see Figure 3). These extrusions were put on a separate layer and locked so that during tests, users would be unable to click on or obtain information (such as dimensions) about the obscured extrusion. Similar processes were used in each of the other assemblies.

Fig. 2: Two different V6 engine planar views.

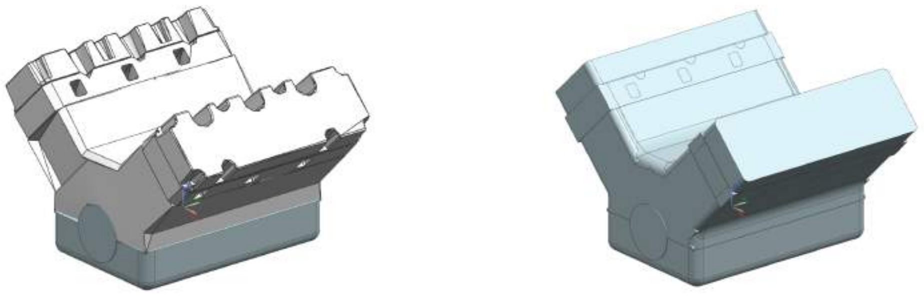


Fig. 3: Example partitioning methods of V6 engine. Multi-resolution (left). Envelope (right).

Description of Experiments:

At the beginning of each test, proctors explained to the users how partitioning worked, that they were going to try out three different methods each with a different model within a multi-user CAD environment, and that they would have 12-15 minutes to model a part within the assembly. The image of the missing part they were to model was provided on a slip of paper. The location and constraining geometry were also shown to each user. The participants were asked to answer the pre-survey questions prior to beginning each model design in order to get the participants to think about the partitioned assembly and the amount of information they could pull from it.

Survey Results of Partitioning:

In the pre-survey given before each round of modeling, users were asked if they thought they had the required information to model their respective part. When asked this question, 65.7% of users responded "No" prior to modeling with a part partitioned based on MR. This was slightly unexpected because planar decomposition, which only showed a small portion of the part, was the method users most often stated they had sufficient information. The results of this survey question indicate that seeing a whole assembly is of far less value compared to being able to access and use the reference geometry. This question in was repeated in the post-survey where the majority of users once again indicated MR was the most difficult to use (see Fig. 4). This question was graded on a scale of one to five (with a five indicating all necessary features could be seen). Only 12.1% found this to be true for MR, which is very low compared to the number of people who gave a five for the other two methods—39.3% for PD and 37.5% for EN. This supports the conclusion that users valued being able to see and reference features they needed in order to model effectively.

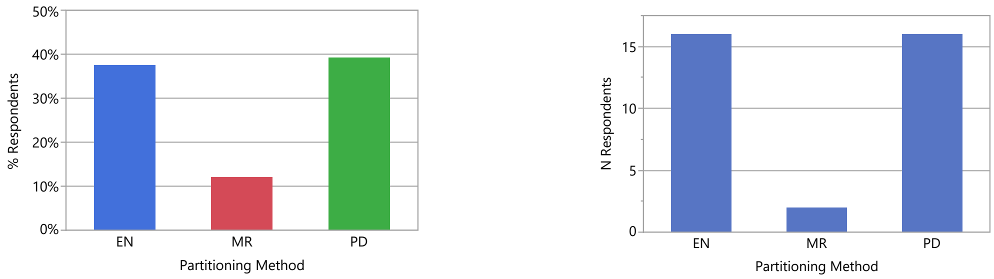


Fig. 4: Post survey responses. Percentage of user participants who chose complete model information was extractable (left). Number of participants who preferred each method (right).

Conclusions:

According to the experimental results, Planar Decomposition is the best method to implement in a MUCAD system. It prevented users from accessing information not needed to complete their own part or section and decreased the amount of distractions so that it was easier to model their part without anything blocking their view. While MR was disliked for various reasons (i.e. made it really hard to model around), it would be useful to implement as part of PD if a user needed to see the whole assembly to gain perspective and a sense for what their part would look like within the whole assembly. MR would also need to be used on parts that had no geometrical references to the part to be modeled as no information should be able to be gathered from it.

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