Title:
A CAD Assembly Simplification Approach with Ray Casting

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Introduction:
CAD assembly models used to design systems in the automotive, aerospace, and other industries often contain thousands of parts. An assembly file of this size slows file load times, makes model manipulation difficult, and reduces computational performance, making common tasks such as checking for part interferences unnecessarily difficult and time-intensive. In the case of supplier provided sub-assemblies, internal bodies in the assembly are beyond the scope of such tasks and could be neglected entirely. A simplified assembly model which preserves the geometry of outer surfaces in high fidelity and does not contain internal bodies would serve as a means by which such tasks could be performed efficiently while maintaining analytical accuracy. An example of where this reduced complexity is beneficial can be seen in Fig. 1. In this example, a designer working to develop a nacelle around the turbofan is unconcerned with the detailed interior bodies that are shown through the translucent body, and these bodies only serve to slow file load time, model manipulation speed, and the computation time of the CAD engine. Thus, it is advantageous to remove them from the assembly model. Previous solutions to this problem found in the literature can identify exterior bodies using tessellations [4] [3]. While these tessellations certainly reduce time spent loading, manipulating, and processing the model, they are not of sufficient accuracy to effect meaningful analysis. We present a new CAD assembly simplification method which features ray casting as the enabler to identify internal bodies of the assembly. After identification, external bodies are copied into a new CAD part and properly positioned via the CAD system API (application programming interface). The method is a relatively straightforward and effective process while preserving external geometry exactly rather than through geometrical approximations. The percent reduction in number of parts is heavily dependent on the part being simplified, but test cases have shown reductions of up to 71% in the number of bodies present in the final assembly.

Previous Work
Research related to simplifying CAD assembly models has been approached in generally two different ways: mesh model simplification and B-rep or feature based solid model simplification [2].

Fig. 1: Image of a turbofan engine with translucent casing showing internal bodies that are irrelevant when designing interfaces/checking clearances, etc. with the exterior casing of the assembly.

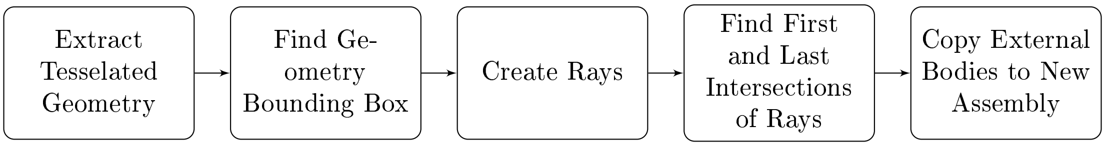


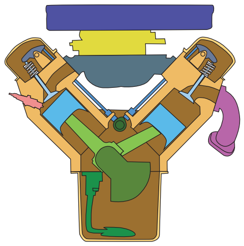
Fig. 2: Process flowchart

The former category seeks to create a mesh from a set of 3D data and afterwards simplify it. A well known example of mesh reconstruction was presented by [4], and was followed by many variants, improving the algorithm in different ways such as that discussed in [1] and [3] who focused on sharp feature preservation. Methods in the second category generally are characterized by an algorithm to detect invisible or internal features or bodies. For example, Kanai et al. [2] pre-rendered models from multiple view directions and read the rendering results from the frame buffer to determine invisible features. Yu et al. [5] used a similar method, but accessed the CAD system frame buffer thereby avoiding format conversion. Our algorithm, which falls into this category of feature/body detection, attempts to perform assembly simplification by identifying all exterior parts using ray casting and removing any non-exterior part while leaving the details on the exterior of the assembly unaffected.

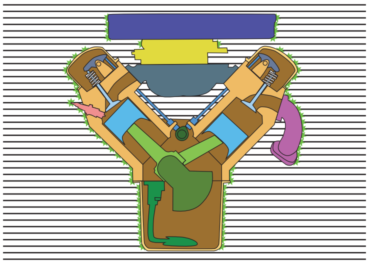
Methodology

As introduced above, the objective of this research was to create an algorithm that would remove all of the interior parts of a CAD assembly while preserving the exterior surface features of the assembly such that interfaces, alignment, and other geometric relationships can be evaluated in the context of a larger assembly. To achieve this, a ray casting algorithm was developed, implemented, and evaluated. The algorithm extracts the geometry from the CAD system, determines which bodies of the assembly are pertinent to the outermost surface of the assembly, and creates a new assembly that contains only the relevant bodies with the correct position and orientation. An flowchart overview of this process is shown in Fig. 2 and the steps are shown graphically for a 2 dimensional example in Fig. 3

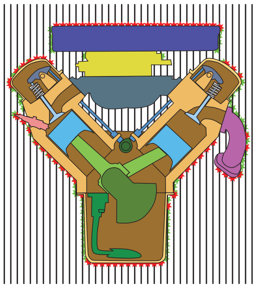
Results and Discussion To evaluate the process in a controlled manner we created a series of test case assemblies that consisted of a series of identical rhombic dodecahedrons tessellated in three dimensions to form cubelike assemblies of NxNxN rhobic dodecahedron. We chose to use tessellated rhombic do-



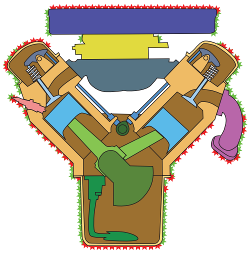
(a) Step 1: The assembly to be simplified is loaded into the process software from the pertinent CAD package.



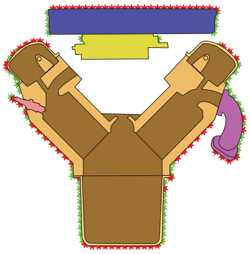
(b) Step 2: Rays are cast in the horizontal direction and the first and last intersections of the rays are recorded.



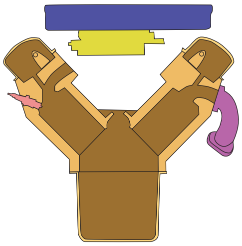
(c) Step 3: Rays are cast in the vertical direction and the first and last intersections of the rays are recorded.



(d) Step 4: The ray intersection points are examined to determine the bodies that correspond to the exterior of the assembly.



(e) Step 5: The bodies not comprising the exterior of the assembly are removed



(f) Step 6: A new assembly file is created which is comprised solely of bodies that pertain to the exterior of the assembly.

Fig. 3: Two-dimensional example of the process steps that lead to the simplification of a complex assembly.

decahedron for these tests because it easily tessellates via translation without rotation to form a large geometric assembly, but it does not result in the larger assembly consisting of planar faces of identical size for each body as would be present in an assembly of cubes. For each of the created assemblies the total number of bodies, the number of exterior bodies, and the number of internal bodies was known. Using this information we were able to perform the simplification of each assembly and determine the computation time required with respect to these different parameters. The results of these trials are shown in Tab. 1.

Assembly size	Num. Bodies	Bodies Remaining	Percent Reduction	Time (min)	.STL Time (min)	Ray Tracing Time (min)
3x3x3	27	26	4%	0.17	0.13	0.05
6x6x6	216	152	30%	1.08	0.83	0.23
12x12x12	1728	728	58%	8.40	7.10	1.28
24x24x24	13824	3176	77%	87.42	77.02	10.40

Table 1: Results of controlled rhombic dodecahedron tessellation trials.

The run time of the process as a whole is dependent on the number of rays that need to be traced and the number of triangles in the tessellation of each body as well as the number of bodies in the assembly. The limiting factor in both methods is the time required to obtain the tessellated data from the CAD software. Our implementation saves each body as a .STL file which with large numbers of bodies (>10,000) can take upwards of one hour to accomplish. As such we expect that the time required to simplify an assembly should scale linearly with the number of bodies in the assembly.

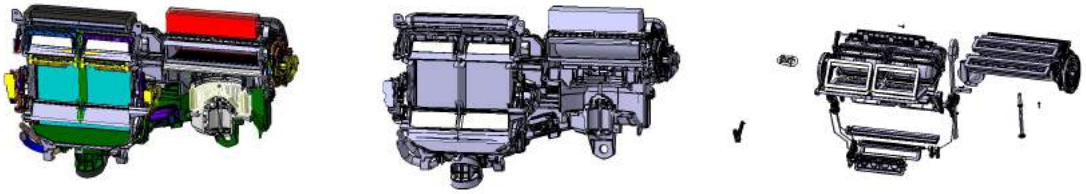
Use Cases

The process we have described relies on the simplification of an assembly through the removal of interior bodies that do not contribute to the exterior surface of the assembly. As a result, the efficacy of the algorithm is highly dependent on the nature of the assembly to be simplified. Tab. 2 presents the results of the algorithm after execution on several example assemblies.

Test Case	Total Number of Bodies	Bodies Remaining	Percent Reduction	Time (min)
1	16	5	68.75%	10.02
2	18	2	88.89%	0.1
3	20	7	65.00%	0.12
4	24	14	41.67%	0.17
5	25	16	36.00%	0.15
6	36	25	30.56%	1.12
7	44	27	38.64%	0.4
8	60	34	43.33%	0.4
9	74	20	72.97%	0.37
10	80	59	26.25%	1.25
11	110	77	30.00%	0.77
12	248	27	89.11%	3.72
13	353	97	72.52%	9.43
14	508	286	43.70%	2.55

Table 2: The results of the algorithm with both ray casting methods. Method 1 used 27 rays per body and Method 2 used 15mm spacing between rays.

As can be seen in the table the percent reduction of the assembly is largely dependent on the nature of the assembly being simplified. Assembly 13 is a particularly interesting use case that we will explore further. It is a complicated automotive HVAC Unit presented in Fig. 4. There are 353 bodies in this assembly (a relatively large number of bodies in our test set) and the ray casting algorithm simplifies the assembly by over 50%. The percent reduction seen using our method is 72.5%. However there are some bodies that are mistakenly categorized as interior bodies due to the constant ray spacing used. An alternative method that implements a more intelligent ray spacing which corrects this issue is presented in the full paper. The run time for this test assembly was one of the longest of the 14 assemblies, despite another assembly (i.e. Assembly 8) with more bodies. This is likely due to the complicated geometry that existed in Assembly 3 that caused the process of extracting the tessellation of the geometry to take longer than other use cases. Assembly 1 which took longer to run was the turbine shown in Fig.1. The long run time associated with this relatively simple assembly is due to large size of the assembly and the fact that the ray casting algorithm used in this set consisted of evenly spaced rays resulting in far more rays that other assemblies in the test set. Using the more intelligent spacing algorithm discussed in the full paper reduced the total time to 0.62 minutes.



(a) Original HVAC cutaway view (352 bodies)

(b) Simplified HVAC cutaway view (160 bodies)

(c) Bodies that were identified as interior bodies to the HVAC unit(192 bodies)

Fig. 4: Section views of the original and simplified HVAC unit and the parts that were identified as interior parts

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