

LayTracks3D: Mesh Generator for General Assembly Models using Medial Axis Transform

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Abstract. This research note presents an extension of all-quad meshing algorithm called LayTracks to generate high quality hex and hex-dominant meshes of 3D assembly models. LayTracks3D uses the mapping between the *Medial Axis* (MA) and the boundary of the 3D domain to decompose complex 3D domain into simpler domains called *Tracks*. Tracks in 3D are tunnels with no branches and are symmetric, non-intersecting, orthogonal to the boundary, and shortest path from MA to the boundary. These properties of the tracks result in near cube shape elements at the boundary, structured mesh along boundary normal with any irregular nodes restricted at MA, sharp boundary feature preservation, and potential all-hex mesh. The algorithm has been tested on few industrial CAD models and work is underway to achieve all-hex meshes on general assembly models.

1 Introduction

Many computational simulations such as non-linear solid mechanics require all-hex meshes. Currently, there is no ideal automatic hex meshing algorithm to mesh general solids or assemblies with commonly desired features listed below. Goal of LayTracks3D is to generate high quality hex meshes of general solids and assembly models with boundary sensitivity, orientation insensitivity, and boundary feature preservation. The mesh generator should have the ability to generate variety of meshes by controlling sizing and anisotropy, generate geometry adaptive meshes, provide fast remeshing during FEM iterations, and should be scalable.

This paper is an extension of all-quad meshing algorithm proposed by the author called LayTracks [1]. LayTracks works analogous to the formation of railway tracks by laying rails on the ground to form set of non-intersecting connected tracks on surfaces (see Figure 1). Rail is a bi-partite graph (one blue rail highlighted in red) with each edge of the graph connecting center of maximal ball to tangent point. Therefore, rails cut through the interface orthogonally. The region between paths of adjacent rails is called track. Quad mesh is

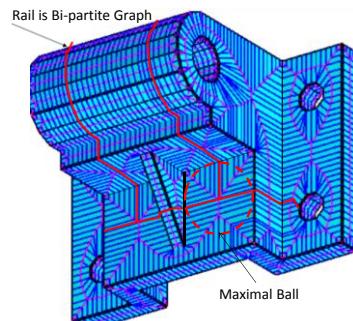


Figure 1 Tracks on surfaces

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obtained by placing sleepers inside each track starting from the boundary towards MA. Two tri elements can be merged at MA and at concave vertex to achieve all-quad mesh. The final mesh obtained is boundary sensitive even at MA branches connected to convex vertices with near square elements at the boundary.

2 Literature Review

Various meshing algorithms have been proposed in the literature and here only a quick review of the MA-based 3D meshing algorithms has been presented. Price and Armstrong [2] described a subdivision yielding one subregion for each medial vertex, medial edge and medial face. The subregions are subsequently meshed by mid-point subdivision. Pete Smpl [3] presented a semi-structured meshing algorithm that generates mixed meshes with hex percentage ranging from 10.6% to 47%. It does not consider assembly models and therefore does not address respecting boundary imprints and obtaining conformal meshes. Makem et al. [4] used MA for detecting thin and thick regions while generating hybrid mesh.

3 Overview of LayTracks3D

LayTracks3D works analogous to 2D LayTracks [1] in decomposing general solid/assembly into tunnel like tracks in 3D. Step 1 (see Figure 2) is to generate 3D medial surface and split 3-manifold medial surfaces at most common 3-valent convex vertex for better hex quality (discussed below). Then data structures to hold 2-way map from MA to B-Rep and B-Rep to MA is established.

One of the original contributions of LayTracks3D is to use MA to resolve all boundary imprints while performing geometry decomposition (see Step 2 & Figure 7). The map is used to project and resolve all the boundary imprints on MA. Also, MA contains non-manifold junction curves which represent critical singularities of 3D shape. First, both imprints & junction curves are meshed. Then, rails are propagated from mesh nodes to define critical partition surfaces that define simpler meshable regions called corridors (see Figure 2 & Figure 7).

LayTracks3D reduces the 3D meshing problem into 2D unstructured meshing problem using MA. Meshing all the surfaces of MA inside each corridor will cover the entire 3D solid or assembly. LayTracks3D is not an inside out method. Therefore, one can mesh the boundary surfaces of corridors instead of MA. It is quite typical to have a 3-manifold medial surface at commonly seen 3-valent convex vertex. It is recommended to have a layer of tri elements along the 3-manifold MA edge in order to obtain a single hex element by combining six tets (see Step 5).

Step 4 involves subdividing the corridor into tracks, which look like tunnels with quad/tri cross section. First, rails are propagated at every quad node of the mesh on MA. Second, tracks are automatically formed using the unstructured quad

mesh topology on MA. Unlike rail, tracks do not branch. Tracks either form a closed tunnel or tunnel with only one entry and only one exit.

Last step is to mesh the tracks from the boundary towards MA in an advancing front manner (without any interference checks) to achieve boundary sensitive mesh. First, even number of nodes are populated on rails (as rails of a track are symmetric inside each solid). Note that node intervals on each rail should be such that each track should be covered by even number of quads in order to obtain all-hex in each track. At the MA two wedges can be combined into a hex (e.g. at convex edge) or six tets can be combined into a hex (e.g. at convex vertex). Degenerate hex elements will arise at MA if all-hex cannot be achieved inside each track.

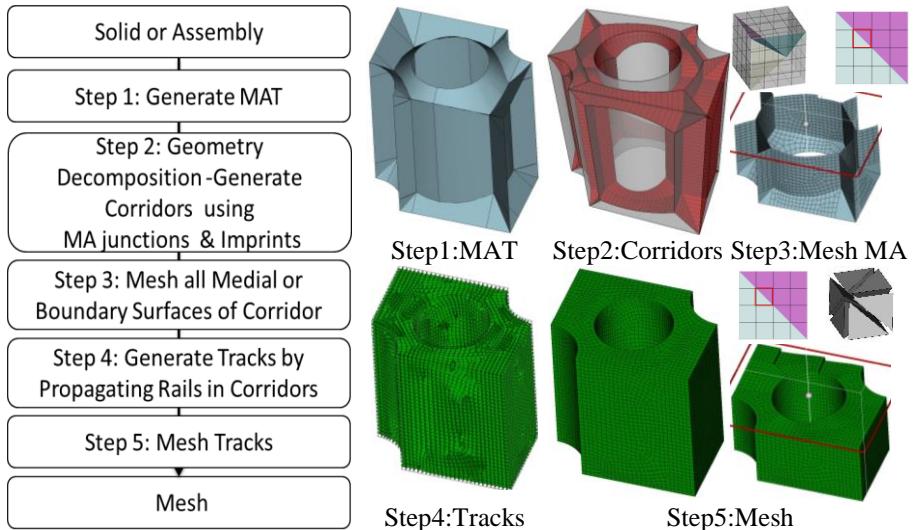


Figure 2 Overview of LayTracks3D

4 Characteristics of LayTracks3D

Handle General Solids: LayTracks3D can decompose any general solid into simpler tracks using mathematically well-defined MA skeletal representation.

Boundary Sensitive: Rails/tracks cut through the boundary/interface orthogonally at tangent points giving boundary sensitive structured mesh along surface normal.

Orientation Insensitive: MAT is independent of input model orientation and hence mesh is orientation insensitive.

Dimension Reduction: MAT reduces hex meshing to quad meshing on medial or boundary surface of corridors.

Feature Preservation: All the sharp boundary features are preserved in the corridors, tracks, and hex mesh.

Sizing and Anisotropy Control: The size/anisotropy specified on the boundary surfaces can be mapped to medial surfaces, which controls the size/anisotropy of hex element in two directions. Node spacing along rails controls the

size/anisotropy in the third principal direction of a hex element. Note that tracks find the shortest path and hence limit the scope of specified size to local region.

Respect Imprints: The 2-way map projects and resolves all the boundary imprints on the medial. Corridors then cut interface of assembly orthogonally and gives automatic conformal mesh respecting imprints.

Geometry Adaptive: Radius function of MAT and its gradients can be used to control element size, anisotropy, and orientation. Rails can be used as control points to generate non-linear tracks.

Fast Remeshing: Fast remeshing is possible as recomputing MAT or corridors is not required as they depend only on geometry but not mesh size. Global and local remeshing can be obtained by remeshing medial surfaces of corridor.

Mesh Morphing: Old meshes can be morphed easily to new deformed geometry if MA topology does not change.

Parallel Friendly: Decomposition-based methods are generally parallel friendly. Meshing rails and tracks can be easily parallelized.

Potential All-Hex: Quad cross section of tracks becomes a point or line cross section when the mapping between boundary and MA is 1-N (e.g. concave vertex and edge) and N-1 (e.g. finite contact in cylinder). Figure 3 shows N-1 map of cylinder transformed to 1-N at concave vertex of cylinder. 1-N map can be further transformed to 1-1 as shown in Figure 4 at a concave vertex. Research is underway to obtain quad cross section in every track to achieve all-hex mesh.

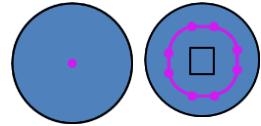


Figure 3 N-1 to 1-N

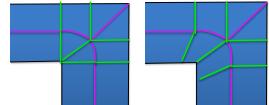
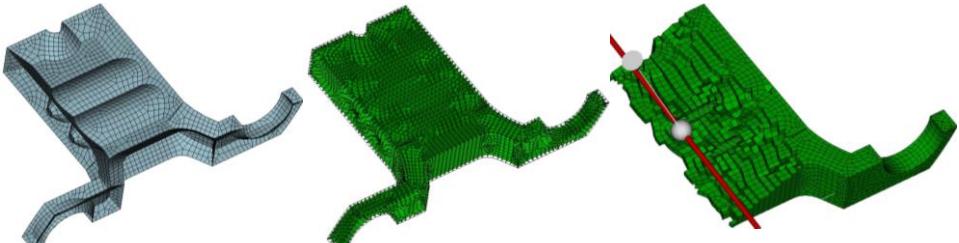


Figure 4 1-N to 1-1

5 Results

Preliminary results obtained by LayTracks3D have been shown in Figure 5 to Figure 7. In these results MA is meshed using all-quad mesh with no tri elements along 3-manifold MA edge at convex vertices. Hence, quality of the hex elements at the convex vertices is poor than Figure 2. Figure 5 shows general solid with two through holes and Figure 6 shows solid with thin walls. Figure 7 shows an assembly model and corridors on the critical part containing imprints. Rest of the parts do not contain imprints and can be meshed using traditional sweeping method. Future work involves validating the generated meshes in non-linear solid mechanics analysis and achieving all-hex meshes in the region where map is not 1-1.

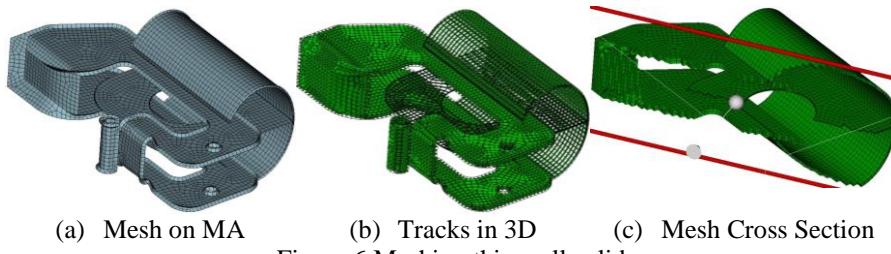


(a) Mesh on MA

(b) Tracks in 3D

(c) Mesh Cross Section

Figure 5 Meshing solid with two through holes

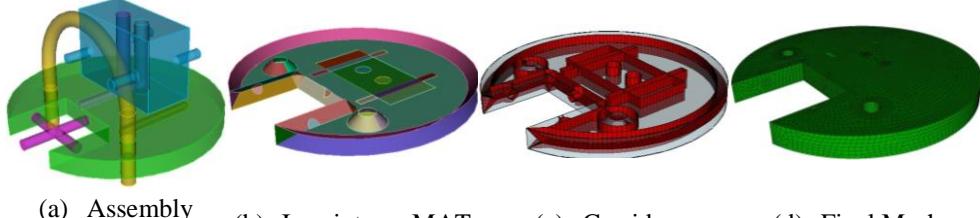


(a) Mesh on MA

(b) Tracks in 3D

(c) Mesh Cross Section

Figure 6 Meshing thin wall solid



(a) Assembly Model

(b) Imprints on MAT

(c) Corridor

(d) Final Mesh

Figure 7 Meshing assembly model with imprinted interface

6 Conclusion

This research note presents an extension of LayTracks to generate hex and hex-dominant meshes of general assembly models using medial axis transform. The algorithm first decomposes any general assembly model into corridors using boundary imprints and MA junction curves. Next corridors are further subdivided based on mesh size into tracks that look like tunnels. Tracks are then meshed to generate high quality boundary sensitive hex or hex-dominant meshes. Work is underway to validate the meshes in non-linear solid mechanics analysis and to achieve all-hex meshes.

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