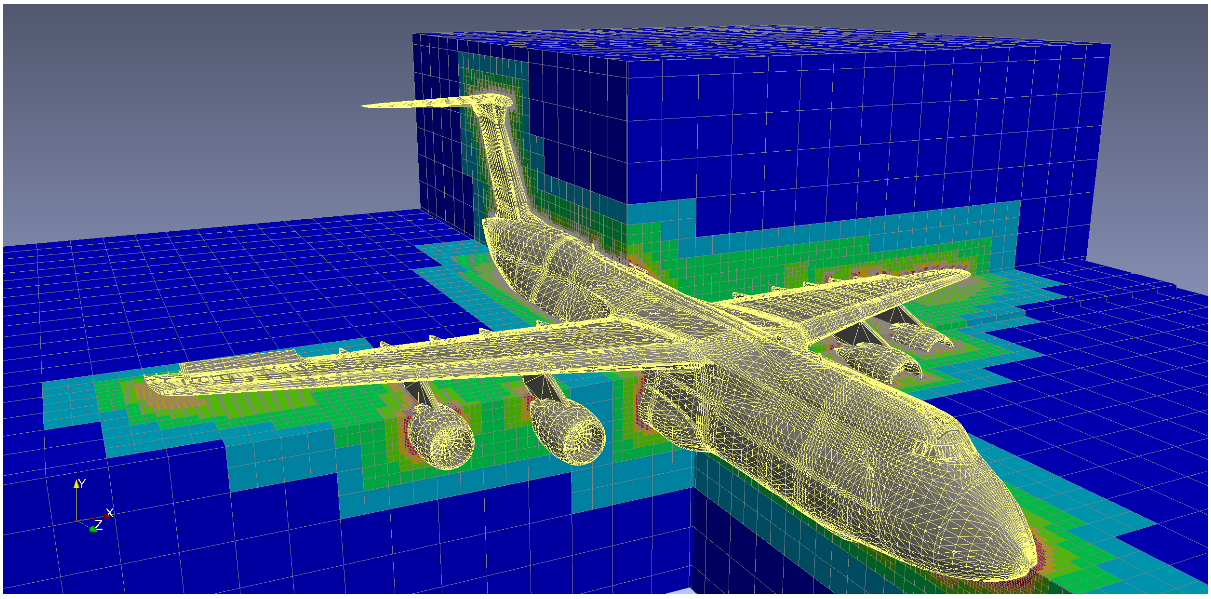
Fast spatial localization with an octree structure

The libOL library



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Cover picture : octree structure of a Lockheed C-5 Galaxy made by Thomas Døhlen.

1 Introduction

The libOL's purpose is to facilitate the spatial localization of mesh entities by allowing basic geometrical queries like searching the closest triangle from a point or building the list of tetrahedra intersected by a bounding rectangle.

The octree build is fast and straightforward and handles many different kinds of mesh entities such as vertices, edges, triangles, quadrilaterals and tetrahedra. The queries can be controlled by specifying the kind of element to look for, the maximum search distance and filtered through a user-defined function.

Two of its main key points are its very small memory footprint, on the order of 10 GB per billion elements, and fast execution time, thanks to the library being thread-safe, make it possible to make queries concurrently.

2 Usage

The input data needed by the library is a mesh in its most basic form : a table of nodes coordinates and some optional elements' connectivity. The libOL generates an octree from this mesh so that its octants, the basic cubic octree's element, contains no more than 20 mesh entities in order to speedup calculation. Consequently, the time and memory needed to build the octree are dependent of the mesh size but also of its geometrical shape. Indeed, as an octree structure is isotropic, very thin or sharp geometries will need more octants to capture those fine features, thus increasing the machine resources needed.

A libOL octree structure can contain only one mesh, so there may be only one table for each kind of data (you cannot have two triangle tables, one for boundary elements and the other one for internal triangles between each pair of tetrahedra). However, you may allocate several octree structures, each defined by its own unique tag, so that each could store a triangle table that may relate to the same mesh.

Let's say that we have a mesh made of $NmbVer$ vertices stored in the table $VerCrd$ and $NmbTri[]$ triangles stored in the table $TriTab[]$ and we wish to look for the closest triangle from the point of coordinates $\{0.5, 2.3, -6.0\}$ as well as the list of triangles included in the rectangular area centered in $\{2, 2, 10\}$ and diameter 2. Here is the simplified source code :

```
int64_t OctIdx;
int IntersectedTriangles[10];
int NmbVer, NmbTri, (*TriTab)[3];
double (*CrdTab)[3], VerCrd[3]={0.5, 2.3, -6.0};
double BoxMin[3]={1,1,9}, BoxMax[3]={3,3,11}, MinDis;
...
(your mesh allocation and reading)
...
OctIdx = LolNewOctree(
```

```
         NmbVer, VerTab[1], VerTab[2],
              0,      NULL,      NULL,
         NmbTri, TriTab[1], TriTab[1],
              0,      NULL,      NULL,
              0,      NULL,      NULL,
              0,      NULL,      NULL,
              0,      NULL,      NULL,
              0,      NULL,      NULL,
              1, 1);

printf("Octree number %d has been build\n", OctIdx);

TriIdx = LolGetNearest(OctIdx, TypTri, VerCrd, &MinDis, 0, NULL, NULL, 0);
printf("the closest triangle from 0.5, 2.3, -6.0 is: %d\n", TriIdx);

NmbBoxTri = LolGetBoundingBox(OctIdx, TypTri, 10, TriTab, BoxMin, BoxMax, 0);
for(i=0;i<NmbTri;i++)
    printf("triangle number: %d\n", TriTab[i]);

LolFreeOctree(OctIdx);
```

3 List of commands

3.1 LolFreeOctree

Simply free an octree structure with all related data and return the total memory used by thie instance. The function does not terminate the library and further octrees can be allocated.

Syntax

```
mem = LolFreeOctree(OctIdx);
```

3.2 LolGetBoundingBox

Intersect the whole mesh with a rectangular box and return the list of entities included in this area. The intersection test is restricted to a single kind of entity and can be performed concurrently as long as the calling processes provide a unique index. The list of entities is stored in a user-provided table whose size must be given and will limit the number of returned included elements.

Syntax

```
NmbTri = LolGetBoundingBox(
         OctIdx, typ, MaxTri, TriTab,
         BoxMin[3], BoxMax[3], ThrIdx);
```

Parameters

Parameter	type	description
OctIdx	int64_t	octree index as returned by LolNewOctree()
typ	int	kind of mesh entity to look for : LolTypVer, LolTypEdg, LolTypTri, LolTypQad or LolTypTet
MaxTri	int	size of the user-provided elements table
TriTab	int *	pointer to a user-provided table that will be filled with the intersected elements
BoxMin	double [3]	coordinates of the upper bounding box corner
BoxMin	double [3]	coordinates of the lower bounding box corner
ThrIdx	int	thread or calling process number or 0 in serial case

Return	type	description
index	int	return the number of entities included in the box

Example

Allocate a return table with 10 entries and ask for the libOL to find the first 10 triangles intersected by the box $\{0,0,0\} - \{1,1,1\}$ and print their indices.

```
int TriTab[10];
double box[2][3]={{0,0,0}, {1,1,1}};
NmbTri = LolGetBoundingBox(OctIdx, TypTri, 10, TriTab, box[0], box[1], 0);
for(i=0;i<NmbTri;i++)
    printf("triangle numéro : %d\n", TriTab[i]);
```

3.3 LolGetNearest

Search for the closest mesh entity from a given point. The kind of entity to search for can be restricted to a specified type or filtered through a user function (see the comment section in LolIntersectSurface for more information) or to a maximum distance from the source point. This procedure can safely be called in parallel as long as the concurrent caller's ID are unique.

Syntax

```
index = LolGetNearest(
        OctIdx, typ, crd, PtrMinDis, MaxDis,
        UsrPrc, UsrDat, ThrIdx);
```

Parameters

Parameter	type	description
OctIdx	int64_t	octree index as returned by LolNewOctree()
typ	int	kind of entity to look for : LolTypVer, LolTypEdg, LolTypTri, LolTypQad or LolTypTet
crd	double [3]	coordinates of the source point
PtrMinDis	double *	pointer to a set of coordinates that will be filled with the closest projection
MaxDis	double	allows restricting the search to a maximum distance, set it to 0 for unbounded search
UsrPrc	int ()(void *, int)	pointer on a user filtering function, this function must take a single integer and a pointer and must return a boolean value, 0 to discard the entity and1 to include it in the test.
UsrDat	void *	pointer to the user's mesh data that will be forwarded to the filtering function
ThrIdx	int	thread or calling process number or 0 in serial case

Return	type	description
index	int	return the closest entity's index or 0 in case of failure

Comments

The processing time need by a search grows with the square of the distance between the source point and the closest entity. Consequently, if the source point if very far way from the whole mesh, the searching will be much slower.

Example

Build an octree from a mesh made of two triangles and four vertices and search for the closest triangle from the location (0,0,0).

```
double crd[5][3] = { {2,-3,5.2}, {3.4,6,8.2}, {5,1,3}, {3,4,1}, {0,0,0} };
double MinDis;
int tri[2][3] = { {1,2,3}, {2,3,4} };
OctIdx = LolNewOctree(4, crd[0], crd[1], 2, tri[0], tri[1], 0);
TriIdx = LolGetNearest(OctIdx, TypTri, crd[4], &MinDis, 0, NULL, NULL, 0);
printf("le triangle le plus proche de l'origine est %d\n", TriIdx);
```

3.4 LolIntersectSurface

This procedure enables some kind of ray-tracing intersection tests. A ray is made of a source vertex and a directional vector and the procedure returns the first mesh entity intersected by this ray. You may restrict the test to a single kind of mesh entity or check against every kind of entity.

Syntax

```
index = LolIntersectSurface(
        OctIdx, crd, tng, PtrMinDis, MaxDis,
        UsrPrc, UsrDat, ThrIdx);
```

Parameters

Parameter	type	description
OctIdx	int64_t	octree index as returned by LolNewOctree()
crd	double [3]	coordinates of the ray source vertex
tng	double [3]	directional unit vector
PtrMinDis	double *	pointer to a set of coordinates that will be filled with the closest intersection
MaxDis	double	give a size to restrict the search distance or 0 for unbounded search
UsrPrc	int ()(void *, int)	pointer on a user filtering function, this function must take a single integer and a pointer and must return a boolean value, 0 to discard the entity and1 to include it in the test.
UsrDat	void *	pointer to the user's mesh data that will be forwarded to the filtering function
ThrIdx	int	thread or calling process number or 0 in serial case

Return	type	description
index	int	return the index of the first intersected entity or 0 if none were found

Comments

The filtering function is a very powerful tool as it allows to focus the searching or intersection a specific subset of entities according to your needs. The functions' prototype is fixed by the library, it must take an integer, that will be set with the entity index being processed, and a pointer to the user's own data. With both information, it is possible to access all useful information like, material reference, patch number, or normal vector, and decide to discard or keep each entity.

3.5 LolNewOctree

Builds an octree from a mesh made of vertices (mandatory) and optionally some elements of various kinds like and dimensions : edges, triangles, quadrilaterals and tetrahedra are handled. The octree returned may be furthered queried to compute distances, projections, intersections and subsets. All queries can be processes concurrently as long as the maximum calling processes is specified at the octree creation. The structure is static and after calling LolNewOctree(), no further elements can be added, removed or modified. Furthermore, as the libOL tries to minimize its memory footprint, it only stores pointers on users' data and does not allocate a private copy, consequently, the user must not free the mesh structures used for the octree building as long as it is still in use by the libOL. Several octree structures may be created within the same library instance and queries shall be performed on a single octree referenced by a unique tag.

Syntax

```
Return = LolNewOctree(
         NmbVer, pVer1, pVer2,
         NmbEdg, pEdg1, pEdg2,
         NmbTri, pTri1, pTri2,
         NmbQad, pQad1, pQad2),
         NmbTet, pTet1, pTet2,
         NmbPyr, pPyr1, pPyr2,
         NmbPri, pPri1, pPri2,
         NmbHex, pHex1, pHex2,
         BasIdx, MaxThr);
```

Parameters

Parameter	type	description
NmbVer	int	number of vertices to insert in the octree
pVer1	double *	pointer to the first vertex's coordinates
pVer1	double *	pointer to the second vertex's coordinates
NmbEdg	int	number of edges to insert in the octree
pEdg1	int *	pointer to the first
pEdg2	int *	pointer to the second
NmbTri	int	number of triangles to insert in the octree
pTri1	int *	pointer to the first triangle's nodes indices
pTri2	int *	pointer to the second triangle's nodes indices
NmbQad	int	number of quadrilaterals to insert in the octree
pQad1	int *	pointer to the first quadrilateral's nodes indices
pQad2	int *	pointer to the second quadrilateral's nodes indices

NmbTet	int	number of tetrahedra to insert in the octree
pTet1	int *	pointer to the first tetrahedron's nodes indices
pTet2	int *	pointer to the seconde tetrahedron's nodes indices
NmbPyr	int	number of pyramids to insert in the octree
pPyr1	int *	pointer to the first pyramid's nodes indices
pPyr2	int *	pointer to the second pyramid's nodes indices
NmbPri	int	number of prisms to insert in the octree
pPri1	int *	pointer to the first prism's nodes indices
pPri2	int *	pointer to the second prism's nodes indices
NmbHex	int	number of hexahedra to insert in the octree
pHex1	int *	pointer to the first hexahedron's nodes indices
pHex2	int *	pointer to the second hexahedron's nodes indices
BasIdx	int	starting index of the user's tables : 0 or 1
MaxThr	int	maximum number of threads or process that can perform requests concurrently : must be 1 or more

Return	type	description
index	int	return a unique octree index that shall be provided to any further libOL procedure or 0 in case of failure

Comments

Setting the number of threads have some consequence on the memory footprint, on the order of 10% additional memory per thread. If you pass on the optional argument `-DWITH_FAST_MODE` to the compiler, the octree structure memory footprint will be 2.5 times higher but all queries will perform 35% faster.

Example

```
double crd[4][3] = { {2,-3,5.2}, {3.4,6,8.2}, {5,1,3}, {3,4,1} };
int tri[2][3] = { {1,2,3}, {2,3,4} };
OctIdx = LolNewOctree(
        4, crd[0], crd[1],
        0, NULL, NULL,
        2, tri[0], tri[1]);
        0, NULL, NULL,
        0, NULL, NULL,
        0, NULL, NULL,
        0, NULL, NULL,
        0, NULL, NULL,
        0, 1);
```

3.6 LolProjectVertex

Geometrical and topological projection of a point on an arbitrary mesh entity. The procedure computes the projection's coordinates, the distance between the point and this projection, as well as its topological location. Regardless the kind of mesh entity that the point is projected on, the projection may lie very close to a specific topological location in this entity. For instance, when projecting a point on a triangle, the image may be close to ont of its vertices, or one of its edges or simply lies within the triangle interior. An image is considered close to an entity if it's closer than the mesh's bounding box size multiplied by the single precision floating point smallest value (i.e. 10E-7).

Syntax

```
status = LolProjectVertex(OctIdx, VerCrd, SrfTyp, SrfIdx, PrjCrd, ThrIdx);
```

Parameters

Parameter	type	description
OctIdx	int64_t	octree index as returned by LolNewOctree()
VerCrd	double [3]	coordinates of the vertex to project
SrfTyp	int	kind of mesh entity to project on : LolTypVer, LolTypEdg, LolTypTri, LolTypQad or LolTypTet
SrfIdx	int	index of the mesh entity
PrjCrd	double [3]	pointer to coordinates that will receive the projection
ThrIdx	int	thread or calling process number or 0 in serial case

Return	type	description
status	int	0 : error, 1 : projection falls on a vertex, 2 : on an edge, 3 : within a triangle or quad