MSTK: Mesh Toolkit, v 1.7

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1 Introduction

1.1 What is MSTK?

MSTK or Mesh Toolkit is a mesh framework that allows users to represent, manipulate and query unstructured 3D arbitrary topology meshes in a general manner without the need to code their own data structures.

1.2 What MSTK is not?

MSTK is not a mesh generator - it can be used to write more easily than starting from scratch. Also, MSTK cannot answer computational questions related to the mesh (for example, is this point in the given mesh element?).

1.3 Salient Features of MSTK

MSTK is a flexible framework in that it allows a variety of underlying representations for the mesh while maintaining a common interface. It will allow users to choose from different mesh representations either at initialization (implemented) or during the program execution (not implemented) so that the optimal data structures are used for the particular algorithm. The interaction of users and applications with MSTK is through a functional interface that acts as though the mesh always contains vertices, edges, faces and regions and maintains connectivity between all these entities.

MSTK allows for the simultaneous existence of an arbitrary number of meshes. However, any entity in MSTK can belong to only one mesh at a time.

MSTK will eventually support distributed meshes for parallel computing. However, this is still not in place.

To support numerical analysis and other applications, MSTK allows applications to attach application or field data to entities. This data may be integers, reals (doubles), integer vectors, real (double) vectors, integer tensors, real (double tensors) and pointers.

The basis for development of MSTK is laid out in the following paper:

1.4 Why should I use MSTK?

MSTK offers a flexible infrastructure for representing and manipulating meshes so that mesh-based application developers do not have to deal with the complexities of managing their own data structures. The functional interface of MSTK is designed to provide easy access to mesh data and allow for easy-to-read but efficient code to be written for mesh based applications. Accessing the mesh data through the functional interface allows the high level application to be unchanged even if the lower level data structures in MSTK change. MSTK supports a wide array of element types and several representations, all of which can take a new developer years to write and make robust. New users of MSTK can typically start writing their own codes to query and manipulate meshes within a few days of familiarizing themselves with MSTK. Finally, use of MSTK allows easy integration with other codes using MSTK as their mesh data framework.

2 MSTK Concepts

2.1 Unstructured mesh representation

Meshes are made up of topological entities of different dimensions. In a “traditional” 3D finite element mesh, nodes are topological entities called vertices and are topologically 0-dimensional entities, while elements are topological entities called regions and are topologically 3-dimensional entities. In general, meshes can be described using vertices (0-dimensional entities), edges (1-dimensional entities), faces (2-dimensional entities) and regions (3-dimensional entities). MSTK has multiple ways of representing meshes as shown in the below. For example, representation F1 has entities of all dimensions up to the dimension of the mesh while representation R1 has entities of the lowest and highest dimension only. Currently, the application has to choose a particular representation type when a mesh is created although it may choose different representations for different meshes in the same program. In the future, the code will be allowed to switch between different representations depending on the needs of the particular algorithm being executed at that time.

NOTE: CURRENTLY THE F1 REPRESENTATION IS THE MOST ROBUST IMPLEMENTATION SINCE IT IS MOST COMMONLY USED. THIS REPRESENTATION HAS GENERALLY BEEN STABLE FOR SEVERAL YEARS. THE REDUCED REPRESENTATIONS HAVE NOT BEEN AS HEAVILY DEBugged AND IT MAY HAVE SOME BUGS. IF YOU CHOOSE TO USE SOME OF THE OTHER REPRESENTATIONS PLEASE REPORT ANY PROB-
LEMS IMMEDIATELY TO rao@lanl.gov.

Even when using reduced representations, MSTK can provide the full set of topological adjacencies as if a full representation were being used. When necessary, entities not represented explicitly in the mesh are created on-the-fly and represented as volatile entities. Even though it is possible to take an algorithm that is written for a full representation and use it as is with a reduced representation, application developers are urged to be aware of the costs of each operation for different representations and use this information to design algorithms optimized for each representation.

2.2 Volatile mesh entities in reduced representations

As discussed above reduced representations, do not explicitly represent all types of mesh entities. For example, R1 representations do not explicitly represent edges and faces while R4 representations do explicitly represent edges only. However, whenever an implicit entity is requested from MSTK, the software creates a temporary entity so that it appears that the entity actually exists in the database. Since these entities are created-on-the-fly they are called volatile mesh entities. For example, if an application asked for the faces of a region in an R1 representation, MSTK will create as many volatile faces as necessary, put them in a list and return them to the calling application. Thus the application can pretend to work with a full representation (although it is not always efficient to do so).

Volatile entities are stored for a period of time in internal data structures in MSTK. Whenever there is a request for a new volatile mesh entity, the code first checks if this entity has already been created. If the volatile already exists in the database, then the entity is returned as is and if it does not, it is created. This ensures that many copies of the same entity are not created in MSTK. However, to ensure that MSTK also does not store every volatile entity forever (thereby, recreating a full representation), there is a mechanism to perform garbage cleaning on volatile entities. Periodically through the execution of the code, volatile entities that have not been used for a long time are deleted from the database freeing up valuable memory (which was the main point of using a reduced representation after all).

To ensure that garbage cleaning does not delete a volatile mesh entity that is being processed or stored by a calling application, MSTK also provides a mechanism for locking entities. One can specify an autolock mechanism for the entire mesh which means that no volatile entity will ever be deleted once it is created. On the other hand, applications may lock specific entities and unlock them when they cease to be useful.
2.3 Mesh entity classification

The concept of mesh entities of various dimensions is actually derived from field of B-rep geometric modeling in which a model is comprised of a hierarchy of topological entities of
Classification is the relationship of each mesh entity to the model entity it represents the whole or a part of.

To clarify further, every mesh is a discrete representation of a geometric model. This geometric model may exist in the analyst’s mind, as schematic on paper or as a full model in a geometric modeling system. Encoding the relationship of the mesh to this geometric model to the extent possible provides enormous algorithmic benefits to the users of meshes.

Recognizing that one may have varying degrees of information about the geometric model in different situations, MSTK allows mesh entities to store different levels of classification information or no classification information.

Every mesh entity can store the dimension of the model entity it is on (GEntDim), the ID of the model entity it is on (GEntID) and a pointer to the model entity it is on (GEntity). The following picture illustrates the classification of various entities in a simple mesh.

Classification information is very useful to have for simplifying algorithms in meshing and analysis applications. For example, using classification information, one can trivially extract all nodes on the boundary and apply a different smoothing algorithm than nodes in the interior of the domain. An FEA code can apply boundary conditions on nodes and faces more easily if it has classification information.
If the application developer has nothing but the material IDs of the mesh elements, MSTK can build the classification information to the best of its ability using topological and geometric information. However, it must be noted that this procedure is not perfect and some classification information cannot be derived unambiguously. So, wherever possible, users are encouraged to generate classification information during mesh generation and supply it to MSTK.

2.4 MSTK Application Programming Interface (API)

Even though MSTK is written in C, MSTK is designed in an object oriented manner. Mesh entities, mesh attributes and entity lists are considered to be objects which have their private data and a set of operators to query and manipulate this data. Even though methods may be devised to circumvent the data hiding in MSTK, this is highly discouraged. If you think that a particular operator is not efficient or you don’t have access to some mesh data, please contact the developer for assistance.

An important feature of MSTK is its ability to provide the full set of mesh operators regardless of the representation used. When using reduced representations, entities not represented explicitly in the mesh are returned as volatile objects. However, it is possible to use most MSTK operators on such objects as well.

Currently, MSTK offers only a C API but C++ and Fortran APIs are planned for the near future.

2.5 Getting meshes in and out of MSTK

There are a few ways of getting mesh data into MSTK. The first is to prepare an MSTK file with the full connectivity of an F1 representation and to read it in using MESH_InitFromFile. This is typically a difficult task for many applications which only have element-node data. In such cases, one can prepare an MSTK file in the R1 file format (in which the node listing is followed by the region-node connectivity) and read it in to any of the other representations, say F1. The other possibility is to write a file in the GMV format and use MESH_ImportFromFile to import the mesh in.

MSTK can write meshes out to different formats including GMV, STL and FLAG X3D. When compiled with the appropriate options and using a partitioner from an external library, MSTK can also write out a parallel X3D file.
\section{MSTK Data Types}

\textit{List\_ptr}: Handle to a List object.

\textit{Mesh\_ptr}: Handle to a Mesh object.

\textit{MVertex\_ptr}: Handle to a Mesh Vertex object (Topological Dimension 0).

\textit{MEdge\_ptr}: Handle to a Mesh Edge object (Topological Dimension 1).

\textit{MFace\_ptr}: Handle to a Mesh Face object (Topological Dimension 2).

\textit{MRegion\_ptr}: Handle to Mesh Region object (Topological Dimension 3).

\textit{MEntity\_ptr}: Handle to a generic Mesh Entity object. Any of the above types of entities can be cast as \textit{MEntity\_ptr}.

\textit{GModel\_ptr}: Handle to a Geometric Model object.

\textit{GEntity\_ptr}: Handle to a Geometric Entity object.

\textit{MAttrib\_ptr}: Handle to a mesh attribute.

\textit{RepType}: Enumerated type describing the type of mesh representation. Can be UNKNOW\_REP, F1, F4, R1, R2, R4. See Appendix 1 for schematics of these representations. \textit{Currently only representation types F1 and F4 are supported.}

\textit{MType}: Enumerated type for mesh entity type. Can be MDELETED, MVERTEX, MEDGE, MFACE, MREGION, MUNKNOWN\_TYPE, MALL\_TYPE.

\textit{MFType}: Enumerated type for mesh face type. Can be FDELETED, FUNKNOWN, TRI, QUAD, POLYGON.

\textit{MRType}: Enumerated type for mesh region type. Can be RDELETED, RUNKNOWN, TET, PYRAMID, PRISM, HEX, POLYHED.

\textit{AttType}: Enumerated type for attribute data. Can be INT, DOUBLE, POINTER, VECTOR or TENSOR.
4 MSTK Functional Interface

4.1 List

Unordered sets or lists of entities in MSTK are returned as type \texttt{List\_ptr}. The following are
the set operations available in MSTK:

\texttt{List\_ptr List\_New(intinisize):} Create a new list with an initial size, \textit{inisize}. If \textit{inisize}
is 0, the initial size is set to be 10.

\texttt{void List\_Delete(List\_ptr l):} Delete a list.

\texttt{List\_ptr List\_Compress(List\_ptr l):} Compress a list (delete all the null entries created
when entities are removed from the list). Doing this while an algorithm is iterating
through the set can currently cause problems!! Calling \texttt{List\_Compress} could change
the pointer for the list due to reallocation.

\texttt{List\_ptr List\_Copy(List\_ptr l):} Return a copy of a list.

\texttt{List\_ptr List\_Add(List\_ptr l, void *entry):} Add an entry to the list. The entry is
strictly appended to the end of the list.

\texttt{List\_ptr List\_ChknAdd(List\_ptr l, void *entry):} Add an entry to a list only if it is
not already in the list.

\texttt{List\_ptr List\_Insert(List\_ptr l, void *nunentry, void *b4entry):} Insert an entry into
the list in the position before \texttt{b4entry}.

\texttt{List\_ptr List\_Inserti(List\_ptr l, void *nunentry, int i):} Insert an entry into the list
at the \texttt{i}’th valid position and push the entries previously at the \texttt{i}’th and later position
back.

\texttt{int List\_Rem(List\_ptr l, void *entry):} Remove an entry from the list. Returns 1 if
successful, 0 otherwise.

\texttt{int List\_Remi(List\_ptr l, int i):} Remove the \texttt{i}’th valid entry in the list. Returns 1 if
successful, 0 otherwise.

\texttt{int List\_RemSorted(List\_ptr l, void *entry, int (*entry2int)(void *)):} Remove an
entry from a list that is sorted according to some correspondence between an entry
and an integer value, e.g., \texttt{MEnt\_ID(entry)} gives the ID of an entity. The mapping between the entry and the integer is given by a call to the routine \texttt{entry2int}. The list could be one from which entities have previously been removed. The routine makes use of the sorted nature of the list to locate entries in $O(\log(n))$ time where $n$ is the size of the list. An example call to this routine is

\begin{verbatim}
find = List\_RemSorted(mregionslist,region,&(MR\_ID));
\end{verbatim}

\begin{verbatim}
int List\_Replace(List\_ptr l, void *entry, void *nuentry): Replace 'entry' with 'nu-entry' in set. Returns 1 if successful, 0 otherwise.
\end{verbatim}

\begin{verbatim}
int List\_Replacei(List\_ptr l, int i, void *nuentry): Replace the i'th valid entry in the list with 'nuentry'. Returns 1 if successful, 0 otherwise.
\end{verbatim}

\begin{verbatim}
int List\_Contains(List\_ptr l, void *entry): Returns 1 if list contains the entry, 0 otherwise.
\end{verbatim}

\begin{verbatim}
int List\_Locate(List\_ptr l, void *entry): Returns the positional index of the entry in the list. Returns -1 if the list does not contain the entry.
\end{verbatim}

\begin{verbatim}
void *List\_Entry(List\_ptr l, int i): Return the i'th valid entry in the list. Returns a NULL pointer if the i'th valid entry could not be found.
\end{verbatim}

\begin{verbatim}
void *List\_Next\_Entry(List\_ptr l, int *i): Return the next valid entry in the list. This routine works like an iterator. To start iterating through the list, set the iteration index i=0 and call the routine to get the first entry in the set. Subsequent calls to the routine will iterate through the entries in the list. The routine will return a NULL to indicate that the end of the set is reached.

The value of the iteration index i will be modified by the routine on each call to indicate where in the list it is. This value should not be modified externally while iterating through the list. Also, no specific meaning should be derived from the iteration index by other applications since the internal implementation and interpretation of the index may change at any time.

Finally, there may be unexpected consequences if entries are removed from the list while an iterator is iterating through it using \texttt{List\_Next\_Entry}.

\begin{verbatim}
int List\_Num\_Entries(List\_ptr l): Return the number of entries in a list.
\end{verbatim}
4.2 Mesh Object

A mesh object is a set of vertices (nodes) possibly connected by other entities such as edges, faces, regions. Depending on the representation chosen and type of mesh, some or all of the entities may be explicitly stored. Full representations contain all types of entities up to the highest dimension of the mesh. For example, a full representation of a tetrahedral mesh contains vertices, edges, faces and regions. However, one type of reduced representation of this mesh may contain only vertices and regions. For a surface mesh, a full representation includes vertices, edges and faces while a reduced representation only has vertices and faces. Also, depending on the type of representation, some adjacencies (information about which entities are connected to which other entities) are stored and others are derived.

Mesh_ptr MESH_New(RepType type): Initialize a new mesh object with the given representation type which can be F1, F2, F3, F4, F5, F6, R1, R2, R3, R4. Of these types F1, F4, R1, R2 and R4 are implemented. If the representation type is not known at the present time (e.g. before reading the mesh from a file), the representation type of UNKNOWN_REP can be specified. Note that this only initializes a mesh object, it does not create or generate a mesh which is the work of high level mesh generation routines.

int MESH_InitFromFile(Mesh_ptr mesh, const char *filename): Initialize or read a mesh from a file in the MSTK format into the given mesh object. Returns 1 if successful, 0 otherwise. It is possible to have a an MSTK file in the R1, R2 and R4 format into a mesh initialized as type F1 or F4. This routine imports any attributes that are into the mesh.

int MESH_InitFromGenDesc(Mesh_ptr mesh, int nv, double (*xyz)[3], int *nfv, int **fvids, int nr, int *nrv, int **rvids, int *nrf, int ***rfvtemplate): Initialize a mesh from a minimal description of the mesh passed into the routine. In the routine, nv is the number of vertices or nodes and xyz is the array of node coordinates. If the mesh is a surface mesh, nf is the number of mesh faces, nfv gives the number of vertices for each face, fvids gives the array indices of the face vertices in ccw manner (starting from 0, not 1). If the mesh is a solid mesh, nr specifies the number of solid elements or regions. If the mesh has only standard element types (tets, pyramids, triangular prisms and hexes), then nrv indicates the number of vertices of each region and rvids gives the array indices of the region vertices. If, on the other hand, the mesh has polyhedral elements, regions have to be described in terms of faces which are in turn described in terms of vertices. Therefore, nrf indicates the number
of faces for each region and \texttt{rfvtemplate} gives the array indices of the vertices for each face of the region.

\textbf{int} MESH\_ImportFromFile(\texttt{Mesh\_ptr mesh}, \texttt{const char *}\texttt{filename}, \texttt{const char *}\texttt{format}): Import a mesh data from an external file format and construct MSTK mesh. Currently the only format supported is the GMV\textsuperscript{1} file format. The routine imports as many attributes as it can from the input file. It also uses special attributes or keywords as data about element and node classification. For GMV files, the routine uses the “material” data to indicate region or face classification depending on the dimensionality of the mesh. If “material” data is not specified, it uses the “itetclr” attribute to assign region or face classification. It also uses the “icr” keyword describing the number of constraints on a node to interpret if the node is classified on a model region, model face, model edge or a model vertex. The “itetclr” and “icr” keywords are usually present in meshes generated by LAGRIT\textsuperscript{2}.

\textbf{int} MESH\_BuildClassfn(\texttt{Mesh\_ptr mesh}): Build classification information for mesh entities if only partial information is present. In other words, if the only data known is the IDs of geometric model entities (“material regions”) of the highest level mesh entities (faces or regions), then this procedure will build information about the type of geometric model entities that the lower dimension entities are on. Faces will be classified as being on a model face (external or interior) or inside model region. Edges will be classified as being on a model edge, model face or in a model region. Vertices will be classified as being on a model vertex, model edge, model face or in a model region. If no classification data is associated with even the highest level entities, the procedure will assume that all the highest level entities are classified on one model entity of that dimension. If partial information is available for lower order entities, this routine will not destroy that information. The procedure also tries to detect mesh edges that should be classified on model edges based on the fact that the dihedral angle between the boundary faces connected to the edge is smaller than some tolerance.

\textbf{int} MESH\_DelInterior(\texttt{Mesh\_ptr mesh}): Delete the interior of a mesh and retain only its boundaries (including interior boundaries). For solid meshes, this results in a surface mesh (i.e., all mesh regions, and mesh faces, edges and vertices classified on model regions are deleted). For surface meshes, this results in curve mesh. For an edge mesh, only the end vertices are retained (unlikely to be used this way). Undefined for a vertex mesh.

\textsuperscript{1}\url{http://www-xdiv.lanl.gov/XCM/gmv/GMVHome.html}
\textsuperscript{2}\url{http://lagrit.lanl.gov}
void MESH_WriteToFile(Mesh_ptr mesh, const char *filename): Save a mesh to a filename. The file is created if it does not exists. It is recommended that the .mstk extension be used for MSTK mesh files. However, there is no such requirement. The routine will write out the mesh and any attributes attached to the mesh except attributes of the type POINTER.

void MESH_ExportToFile(Mesh_ptr mesh, const char *filename, const char *format, int natt, char **attnames): Export a mesh to an external file format. Currently, the only formats supported is the GMV file format (format string: “gmv”) and X3D (format string: “flag”). Only integer and double attributes of the mesh are exported to GMV files and no attributes are exported to X3D files.

void MESH_ExportToGMV(Mesh_ptr mesh, const char *filename, const char *format, int natt, char **attnames): Export a mesh to a GMV file format.

void MESH_ExportToFLAGX3D(Mesh_ptr mesh, const char *filename, const char *format, int natt, char **attnames): Export a mesh to the FLAG X3D format.

void MESH_ExportToFLAGX3D_Par(Mesh_ptr mesh, const char *filename, const char *format, int natt, char **attnames, int *procids): Export a mesh to the FLAG X3D format given a partitioned mesh. The owning processor for each element is given in the array procids.

void MESH_ExportToSTL(Mesh_ptr mesh, const char *filename): Export a mesh to the STL format (SURFACE MESHES ONLY!).

void MESH_Tet2Hex(Mesh_ptr tetmesh, Mesh_ptr *hexmesh): Convert a tet mesh to a hex mesh by splitting the tets - the quality of the resulting hex mesh is usually not very good.

void MESH_Renumber(Mesh_ptr mesh): Renumber the entities of a mesh to avoid gaps in entity IDs. Note that in the current implementation, renumbering mesh entities can make removal of and searching for mesh entities much slower, so this must be avoided as much as possible.

int MESH_PartitionWithMetis(Mesh_ptr mesh, int nparts, int **part): Partition a mesh with the METIS libraries. ’part’ is an array that contains the partition number for each mesh face (surface meshes) or mesh region (volume meshes).
NOTE THAT MSTK HAS TO HAVE BEEN COMPILED USING THE COMMAND ’make PAR=1’ AND THE CALLING APPLICATION MUST LINK WITH THE METIS LIBRARY.

\textbf{GModel\_ptr MESH\_GModel(Mesh\_ptr mesh)}: Return a handle to the underlying geometric model. If there is no geometric model associated with the mesh, NULL pointer is returned.

\textbf{RepType MESH\_RepType(Mesh\_ptr mesh)}: Representation type currently being used by the mesh.

\textbf{char *MESH\_RepType(Mesh\_ptr mesh)}: Representation type currently being used by the mesh returned as a 2-character string.

\textbf{int MESH\_Num\_Vertices(Mesh\_ptr mesh)}: Number of vertices in the mesh.

\textbf{int MESH\_Num\_Edges(Mesh\_ptr mesh)}: Number of edges in the mesh. For reduced representations, this routine returns 0 since it is impractically expensive to count the number of edges when they do not explicitly exist. Applications must find a way to avoid using this routine for reduced representations.

\textbf{int MESH\_Num\_Faces(Mesh\_ptr mesh)}: Number of faces in the mesh. For reduced representations R1 or R2, this routine counts only the faces that are explicitly represented i.e. faces not connected to any mesh region. Therefore, a value of 0 will be returned for the number of faces of a tetrahedral mesh with representation R1 or R2 but the correct number will be reported for a tetrahedral mesh in other representations. Also, the correct number will be reported for the number of faces in a surface mesh in representation R1 or R2. Therefore, this routine must be used carefully.

\textbf{int MESH\_Num\_Regions(Mesh\_ptr mesh)}: Number of regions in the mesh.

\textbf{MVertex\_ptr MESH\_Vertex(Mesh\_ptr mesh, int i)}: Return the i’th vertex in the mesh. Returns NULL if i < 0 or i > number of mesh vertices.
**MEdge_ptr** MESH_Edge(Mesh_ptr mesh, int i): Return the i’th edge in the mesh. Returns NULL if i < 0 or i > number of mesh edges. Returns NULL for reduced representations.

**MFace_ptr** MESH_Face(Mesh_ptr mesh, int i): Return the i’th face in the mesh. Returns NULL if i < 0 or i > number of mesh faces. Only faces explicitly represented in the mesh are returned for reduced representation (See explanation for MESH_Num_Faces).

**MRegion_ptr** MESH_Region(Mesh_ptr mesh, int i): Return the i’th region in the mesh. Returns NULL if i < 0 or i > number of mesh region.

**MVertex_ptr** MESH_Next_Vertex(Mesh_ptr mesh, int *idx): Returns the next vertex while iterating through the vertices of the mesh. See the routine List_Next_Entry above for an explanation of how the iteration works. This routine is in general faster than using the routine MESH_Vertex.

**MEdge_ptr** MESH_Next_Edge(Mesh_ptr mesh, int *idx): Returns the next edge while iterating through the edges of the mesh. See the routine List_Next_Entry above for an explanation of how the iteration works. The routine always returns NULL for reduced representations.

**MFace_ptr** MESH_Next_Face(Mesh_ptr mesh, int *idx): Returns the next face while iterating through the faces of the mesh. See the routine List_Next_Entry above for an explanation of how the iteration works. Only faces explicitly represented in the mesh are returned for reduced representation (See explanation for MESH_Num_Faces).

**MRegion_ptr** MESH_Next_Region(Mesh_ptr mesh, int *idx): Returns the next region while iterating through the regions of the mesh. See the routine List_Next_Entry above for an explanation of how the iteration works.

**MVertex_ptr** MESH_VertexFromID(Mesh_ptr mesh, int id): Return mesh vertex with given ID if it exists; return NULL otherwise.

**MEdge_ptr** MESH_EdgeFromID(Mesh_ptr mesh, int id): Return mesh edge with given ID if it exists; return NULL otherwise. This routine will return NULL for all reduced representations.
MFace_ptr MESH_FaceFromID(Mesh_ptr mesh, int i): Return mesh face with given ID if it exists; return NULL otherwise. If faces are not explicitly represented in the mesh, it will return NULL.

MRegion_ptr MESH_RegionFromID(Mesh_ptr mesh, int id): Return mesh region with given ID if it exists; return NULL otherwise.

int MESH_Num_Attribs(Mesh_ptr mesh): Number of attributes associated with the mesh.

MAttrib_ptr MESH_Attrib(Mesh_ptr mesh, int i): Return the i’th attribute in the mesh. Returns NULL if i < 0 or i > number of mesh attributes.

MAttrib_ptr MESH_Next_Attrib(Mesh_ptr mesh, int *index): Returns the next attribute while iterating through the attributes of the mesh. See the routine List_Next_Entry above for an explanation of how the iteration works.

MAttrib_ptr MESH_AttribByName(Mesh_ptr mesh, const char *name): Return a mesh attribute with given name if it exists in the mesh. Returns NULL if mesh has no such attribute.

void MESH_Set_GModel(Mesh_ptr mesh, GModel_ptr geom): Assign a geometric model handle to the mesh.

void MESH_Add_Vertex(Mesh_ptr mesh, MVertex_ptr v): Add a vertex to the mesh. It is assumed that the vertex and its coordinates set are properly defined. Normally, one need not call this since MV_New will add the vertex to the mesh. Use this only if you know exactly what you are doing.

void MESH_Add_Edge(Mesh_ptr mesh, MEdge_ptr e): Add an edge to the mesh. It is assumed that the edge is and its topology is defined. Normally, one need not call this since ME_New will add the edge to the mesh. Use this only if you know exactly what you are doing.
void MESH_Add_Face(Mesh_ptr mesh, MFace_ptr f): Add a face to the mesh. It is assumed that the face and its topology is properly defined. Normally, one need not call this since MF_New will add the face to the mesh. Use this only if you know exactly what you are doing.

void MESH_Add_Region(Mesh_ptr mesh, MRegion_ptr r): Add a region to the mesh. It is assumed that the region and its topology is properly defined. Normally, one need not call this since MR_New will add the region to the mesh. Use this only if you know exactly what you are doing.

void MESH_Rem_Vertex(Mesh_ptr mesh, MVertex_ptr v): Remove vertex from mesh. Vertex is not deleted and must be deleted afterward separately. Normally, one need not call this since MV_Delete will remove the vertex from the mesh. Use this only if you know exactly what you are doing.

void MESH_Rem_Edge(Mesh_ptr mesh, MEdge_ptr e): Remove edge from mesh. Edge is not deleted and must be deleted afterward separately. Normally, one need not call this since ME_Delete will remove the edge from the mesh. Use this only if you know exactly what you are doing.

void MESH_Rem_Face(Mesh_ptr mesh, MFace_ptr f): Remove face from mesh. Face is not deleted and must be deleted afterward separately. Normally, one need not call this since MF_Delete will remove the face from the mesh. Use this only if you know exactly what you are doing.

void MESH_Rem_Region(Mesh_ptr mesh, MRegion_ptr r): Remove region from mesh. Region is not deleted and must be deleted afterward separately. Normally, one need not call this since MR_Delete will remove the region from the mesh. Use this only if you know exactly what you are doing.

void MESH_Set_AutoLock(Mesh_ptr mesh, int autolock): If autolock is 1, all volatile mesh entities created in reduced representations will be automatically locked and cannot be removed by garbage cleaning procedures (They can still be removed by explicitly calling a delete on them). If it 0, volatile mesh entities can be deleted internally after a period of disuse.

int MESH_AutoLock(Mesh_ptr mesh): Return the autolock status for volatile entities (See MESH_Set_AutoLock for details).
4.3 Mesh Vertex Object

*MV*\_ptr \text{MV\_New(*Mesh\_ptr* mesh)}: Create a new vertex object. No geometric or topological information is embedded in the vertex when it is created. The vertex only knows which mesh it belongs to. The ID of the vertex is set by this function.

*void* \text{MV\_Delete(*MVertex\_ptr* mvertex, *int* keep)}: Delete the vertex. If *keep* is 0, the vertex is removed from the mesh and all topological and geometric information embedded in the vertex is destroyed. If *keep* is 1, the vertex is marked as type \text{MDELVERTEX} and removed from the mesh but the vertex is not destroyed.

**NOTE:** \text{MV\_Delete} AND ITS COUNTERPARTS WILL, IN GENERAL, REMOVE AN ENTITY IN $O(\log(N))$ TIME WHERE $N$ IS THE TOTAL NUMBER OF ENTITIES ADDED TO THE MESH SINCE THE START OF THE PROGRAM. HOWEVER, IF THE MESH ENTITIES HAVE NOT BEEN RENUMBERED (EITHER USING MESH\_RENUMBER OR EXPLICITLY USING MENT\_SET\_ID) OR THE MESH ENTITY LISTS HAVE NOT BEEN COMPRESSED THEN THE REMOVAL TIME IS $O(1)$ WHICH IS CLEARLY MUCH SUPERIOR.

*void* \text{MV\_Restore(*MVertex\_ptr* mvertex)}: Restore a deleted vertex. The vertex type is restored from \text{MDELVERTEX} to \text{MVERTEX} and the vertex is added back to the mesh.

*void* \text{MV\_Set\_Coords(*MVertex\_ptr* mvertex, *double* *xyz)}: Set the coordinates of the vertex.

*void* \text{MV\_Set\_GEntity(*MVertex\_ptr* mvertex, *GEntity\_ptr* gent)}: Set the geometric model entity on which vertex is classified.

*void* \text{MV\_Set\_GEntDim(*MVertex\_ptr* mvertex, *int* gdim)}: Set topological dimension of model entity on which vertex is classified.

*void* \text{MV\_Set\_GEntID(*MVertex\_ptr* mvertex, *int* gid)}: Set ID of model entity on which vertex is classified.

*void* \text{MV\_Add\_AdjVertex(*MVertex\_ptr* mvertex, *MVertex\_ptr* adjvertex)}: Add neighboring vertex, adjvertex, to adjacent vertex list of vertex, mvertex.
void MV_Rem_AdjVertex(MVertex_ptr mvertex, MVertex_ptr adjvertex): Delete neighboring vertex of given vertex.

void MV_Set_ID(MVertex_ptr mvertex, int id): Explicitly set ID of a vertex and overwrite the ID set by the MV.New operator. Does not check for duplication of edge IDs.

Mesh_ptr MV_Mesh(MVertex_ptr mv): Returns the mesh that this vertex belongs to.

int MV_ID(MVertex_ptr mvertex): Returns the ID of the vertex.

int MV_GEntDim(MVertex_ptr mvertex): Returns the dimension of the geometric model entity that the vertex is classified on. Returns -1 if not known.

int MV_GEntID(MVertex_ptr mvertex): Returns the ID of the geometric model entity that the vertex is classified on. Returns 0 if this information is not known.

GEntity_ptr MV_GEntity(MVertex_ptr mvertex): Returns a pointer or handle to the geometric model entity that the vertex is classified on. Returns NULL if this information is not known.

void MV_Coords(MVertex_ptr mvertex, double *xyz): Returns the coordinates of the vertex.

int MV_Num_AdjVertices(MVertex_ptr mvertex): Returns the number of edge connected neighboring vertices of vertex. Not efficient for all representations.

int MV_Num_Edges(MVertex_ptr mvertex): Returns the number of edges connected to the vertex.

int MV_Num_Faces(MVertex_ptr mvertex): Returns the number of faces connected to the vertex.

int MV_Num_Regions(MVertex_ptr mvertex): Returns the number of regions connected to the vertex

List_ptr MV_AdjVertices(MVertex_ptr mvertex): List of adjacent or edge connected neighboring vertices of vertex.
List\_ptr MV\_Edges(MVertex\_ptr mvertex): List of edges connected to the vertex. The list returned by this operator must be deleted by the calling application using \texttt{List\_Delete}.

List\_ptr MV\_Faces(MVertex\_ptr mvertex): List of faces connected to the vertex. The list returned by this operator must be deleted by the calling application using \texttt{List\_Delete}.

List\_ptr MV\_Regions(MVertex\_ptr mvertex): List of regions connected to the vertex. The list returned by this operator must be deleted by the calling application using \texttt{List\_Delete}.
4.4 Mesh Edge Object

*MEdge_ptr ME_New(*Mesh_ptr mesh):* Create a new edge object. No topological information in embedded in the edge when it is created. The edge only knows which mesh it belongs to. The ID of the edge is set by this function.

*void ME_Delete(MEdge_ptr medge, int keep):* Delete the edge. If *keep* is 0, the edge is removed from the mesh and all topological and geometric information embedded in the edge is destroyed. If *keep* is 1, the edge is marked as type *MDELEDGE* and removed from the mesh but the edge is not destroyed. Also, the vertices of this edge no longer point to this edge.

*void ME_Restore(MEdge_ptr medge):* Restore a temporarily deleted edge. The edge type is restored from *MDELEDGE* to *MEDGE* and the edge is added back to the mesh. The vertices of the edge once again point back to the edge.

*void ME_Set_GEntity(MEdge_ptr medge, GEntity_ptr gent):* Set the geometric model entity on which the edge is classified.

*void ME_Set_GEntDim(MEdge_ptr medge, int gdim):* Set the topological dimension of model entity on which edge is classified.

*void ME_Set_GEntID(MEdge_ptr medge, int gid):* Set ID of model entity on which edge is classified.

*void ME_Set_GInfo_Auto(MEdge_ptr medge):* Derive the classification (GEntDim, GEntID) of the mesh edge automatically (if possible) from the classification of its vertices. If it is not possible to unambiguously get this information, the procedure will keep the default information. **THIS MAY GET WRONG OR INCORRECT INFORMATION WHEN THERE IS AMBIGUOUS DATA. FOR EXAMPLE, IF THE VERTICES OF A MESH EDGE ARE CLASSIFIED ON TWO DIFFERENT MODEL VERTICES, IT IS NOT POSSIBLE TO KNOW WHAT ENTITY THE MESH EDGE IS CLASSIFIED USING JUST THE VERTEX INFORMATION.**

*void ME_Set_ID(MEdge_ptr medge, int id):* Explicitly set ID of an edge and overwrite the ID set by the ME_New function. Does not check for duplication of edge IDs.
void ME_Set_Vertex(MEdge_ptr medge, int i, MVertex_ptr vertex): Set the i’th vertex of the edge. i can be 0 or 1.

void ME_Replace_Vertex(MEdge_ptr medge, MVertex_ptr vert, MVertex_ptr nuvert): Replace i’th vertex by new vertex.

Mesh_ptr ME_Mesh(MEdge_ptr medge): Returns the mesh that this edge belongs to.

int ME_ID(MEdge_ptr medge): Returns the ID of the vertex. Returns -1 if not known.

int ME_GEntDim(MEdge_ptr medge): Returns the dimension of the geometric model entity that the vertex is classified on. Returns -1 if not known.

int ME_GEntID(MEdge_ptr medge): Returns the ID of the geometric model entity that the vertex is classified on. Returns 0 if this information is not known.

GEntity_ptr ME_GEntity(MEdge_ptr medge): Returns a pointer or handle to the geometric model entity that the vertex is classified on. Returns NULL if this information is not known.

int ME_Num_Faces(MEdge_ptr medge): Returns the number of faces connected to the edge.

int ME_Num_Regions(MEdge_ptr medge): Returns the number of regions connected to the edge.

MVertex_ptr ME_Vertex(MEdge_ptr medge, int i): Returns the i’th vertex of the edge. i=0 returns the first vertex and i=1 returns the second vertex.

MVertex_ptr ME_OppVertex(MEdge_ptr medge, MVertex_ptr ov): Return the vertex opposite to given vertex in edge.

int ME_UsesEntity(MEdge_ptr medge, MEntity_ptr mentity, int etype): Check if edge uses given lower dimension entity, mentity. The dimension of the entity is specified by the etype variable. For an edge, the only lower dimensional entity is a vertex. If the edge uses the vertex, the function returns 1; otherwise it returns 0. If any other type of entity is specified, the function returns 0.
**List_ptr** ME_Faces(MEdge_ptr medge): Returns the set of faces using this edge. The list returned by this operator must be deleted by the calling application using List_Delete.

**List_ptr** ME_Regions(MEdge_ptr medge): Returns the set of regions using this edge. The list returned by this operator must be deleted by the calling application using List_Delete.

**MEdge_ptr** MVs_CommonEdge(MVertex_ptr v1, MVertex_ptr v2): Return the edge connecting vertices v1 and v2, if it exists. If such an edge does not exist, the function returns 0.

**double** ME.Len(MEdge_ptr e): Return the length of the straight line connecting the two vertices of the edge.

**double** ME.LenSqr(MEdge_ptr e): Return the square of the length of the straight line connecting the two vertices of the edge.

**void** ME_Vec(MEdge_ptr e, double *evec): Return the vector going from the first vertex of the edge to the second vertex of the edge.

**int** MEs_AreSame(MEdge_ptr e1, MEdge_ptr e2): Applicable only to reduced representations. Check if two edges described by only their vertices are the same. In a reduced representation, edges are temporary objects described by their end vertices. If two temporary edges are described by the same vertices, the edges are considered to be the same.

**void** ME_Lock(MEdge_ptr e): Lock a volatile edge so that it cannot be deleted by garbage cleaning procedures (It can still be deleted by ME_Delete).

**void** ME_UnLock(MEdge_ptr e): Unlock a volatile edge so that it may be deleted freely by garbage cleaning procedures.
4.5 Mesh Face Object

*MFace_ptr MF_New(Mesh_ptr mesh):* Create a new face object. No topological information is embedded in the face when it is created. The face only knows which mesh it belongs to. The ID of the face is set by this function.

*void MF_Delete(MFace_ptr mface):* Delete the face. If *keep* is 0, the face is removed from the mesh and all topological and geometric information embedded in the face is destroyed. If *keep* is 1, the face is marked as type *MDELFACE* and removed from the mesh but the face is not destroyed. Also, the vertices/edges of this face no longer point up to this face.

*void MF_Restore(MFace_ptr mface):* Restore a temporarily deleted face. The face type is restored from *MDELFACE* to *MFACE* and the face is added back to the mesh. The vertices/edges of the face once again point back to the face.

*void MF_Set_GEntity(MFace_ptr mface, GEntity_ptr gent):* Set the geometric model entity on which the face is classified.

*void MF_Set_GEntDim(MFace_ptr mface, int gdim):* Set the dimension of the geometric model entity on which the face is classified.

*void MF_Set_GEntID(MFace_ptr mface, int gid):* Set the ID of the geometric model entity on which the face is classified.

*void MF_Set_GInfo_Auto(MFace_ptr mface):* Derive the classification (GEntDim, GEntID) of the mesh face automatically (if possible) from the classification of its vertices or edges. If it is not possible to unambiguously get this information, the procedure will keep the default information. **THIS MAY GET WRONG OR INCORRECT INFORMATION WHEN THERE IS AMBIGUOUS DATA.**

*void MF_Set_ID(MFace_ptr mface, int id):* Explicitly set ID of a face and overwrite the ID set by the *MF_New* operator. Does not check for duplication of face IDs.

*void MF_Set_Edges(MFace_ptr mface, int n, MEdge_ptr *edges, int *dirs):* Set the edges of the face along with their directions. The ordered set of edge pointers and their directions are passed in through arrays along with the number of edges. The edges are assumed to be ordered clockwise around the face. If an edge direction is
along the clockwise direction of the face then the entry in the 'dirs' array must be 1; otherwise it must be 0. This function is relevant only for full representations in MSTK.

\texttt{void MF\_Set\_Vertices(MFace\_ptr mface, int n, MVertex\_ptr *verts):} Set the vertices of the face. The ordered set of vertices (ccw around the face) is passed in through an array along with the number of vertices. This routine will collect/build all lower order topological information (edges, edge directions in the face) as needed by the face.

\texttt{void MF\_Replace\_Edges(MFace\_ptr mface, int nold, MEdge\_ptr *oldedges, int nnu, MEdge\_ptr *nuedges):} Replace a set of edges in the face with another set of edges. The direction in which the new edges are to be used in the face are automatically deduced. This function is relevant only for full representations in MSTK. The old and new edge sets must be comprised of edges connected to each other and the end vertices of the new set must match the end vertices of the new set.

\texttt{void MF\_Replace\_Edges\_i(MFace\_ptr mface, int nold, int i, int nnu, MEdge\_ptr *nuedges):} Replace the \textit{nold} edges in the face starting with the \textit{i}'th edge and going ccw around the face with a new set of edges. The directions in which the new edges are used in the face are automatically deduced. This function is relevant only for full representations in MSTK.

\texttt{void MF\_Replace\_Vertex(MFace\_ptr mface, MVertex\_ptr mvertex, MVertex\_ptr nuvertex):} Replace a vertex in the face with another vertex. This function is relevant only for reduced representations in MSTK.

\texttt{void MF\_Replace\_Vertex\_i(MFace\_ptr mface, int i, MVertex\_ptr nuvertex):} Replace the \textit{i}'th vertex in the face with a new vertex. This function is relevant only for reduced representations in MSTK.

\texttt{void MF\_Insert\_Vertex(MFace\_ptr mface, MVertex\_ptr nuvertex, MVertex\_ptr b4vertex):} Insert a vertex in the face before \texttt{b4vertex} w.r.t. a ccw ordering of the vertex faces.

\texttt{void MF\_Insert\_Vertex\_i(MFace\_ptr mface, MVertex\_ptr nuvertex, int i):} Insert a new vertex before vertex \textit{i} in the face w.r.t. a ccw ordering of vertices.

\texttt{Mesh\_ptr MF\_Mesh(MFace\_ptr mf):} Returns the mesh that this mesh belongs to.
**int MF_ID(MFace_ptr mface):** Returns the ID of the face. Returns 0 if not known.

**int MF_GEntDim(MFace_ptr mface):** Returns the dimensions of the geometric model entity that the vertex is classified on. Returns -1 if not known.

**int MF_GEntID(MFace_ptr mface):** Returns the ID of the geometric model entity that the vertex is classified on. Returns 0 if this information is not known.

**GEntity_ptr MF_GEntity(MFace_ptr mface):** Returns a pointer or handle to the geometric model entity that the vertex is classified on. Returns NULL if this information is not known.

**int MF_Num Vertices(MFace_ptr mface):** Returns the number of vertices of the face.

**int MF_Num Edges(MFace_ptr mface):** Returns the number of edges of the face.

**int MF_Num AdjFaces(MFace_ptr mface):** Returns the number of adjacent faces of a face. This operator is relevant only in planar or surface meshes, i.e., for boundary faces not connected to any regions.

**List_ptr MF_Vertices(MFace_ptr mface, int dir, MVertex_ptr mvert):** Return the ordered set of the vertices of the face. The vertices are ordered in ccw direction while looking down the face 'normal', if 'dir' is 1 and in the cw direction, if 'dir' is 0. If 'mvert' is specified, the vertex set is reordered so that it is the first vertex (This argument will be added soon to the function. For now, omit this argument). The behavior of this function can be illustrated using Figure 3. For the face shown in the figure, a vertex set with ccw ordering or 'dir' = 1 is $V_0, V_1, V_2, V_3$ and a vertex set with cw ordering or 'dir' = 0 is $V_0, V_3, V_2, V_1$. A vertex set with ccw ordering starting with vertex $V_2$ is $V_2, V_3, V_0, V_1$. The list returned by this operator must be deleted by the calling application using **List_Delete**.

**List_ptr MF_Edges(MFace_ptr mface, int dir, MVertex_ptr mvert):** Return the ordered set of edges of the face. The edges are ordered in the ccw while looking down the face 'normal' if dir is 1 and in the cw if dir is 0. If 'mvert' is specified, the edge set is reordered so that the first edge in the set contains this vertex. More precisely, if 'dir' is 1, and the first edge is 'e' used in the face in direction 'd', then **ME.Vertex(e,!d) = mvert.** With reference to Figure 3, the edges of the face in the ccw direction or 'dir' = 1 are $E_0, E_1, E_2, E_3$ and in the opposite dir are $E_3, E_2, E_1, E_0$. If 'mvert' or the starting vertex is specified as $V_2$, the edge set in ccw direction or 'dir' = 1 is $E_2, E_3, E_0, E_1$.
and in the opposite direction is $E_1, E_0, E_3, E_2$. The list returned by this operator must be deleted by the calling application using *List_Delete*.

*List_ptr MF_AdjFaces(MFace_ptr mface)*: List of adacent faces of a face. This operator is relevant only in planar or surface surface meshes, i.e., for boundary faces not connected to any regions. The list returned by this operator must be deleted by the calling application using *List_Delete*.

*int MF_EdgeDir(MFace_ptr mface, MEdge_ptr medge)*: Returns the direction in which the face uses the given edge. If the faces use the edge in the positive direction, the function returns 1; otherwise it returns 0.

*int MF_EdgeDir_i(MFace_ptr mface, int i)*: Returns the direction in which the face uses its i’th edge. If the face uses the edge in the positive direction the function returns 1; otherwise it returns 0;

*List_ptr MF_Regions(MFace_ptr mface)*: Return the set of regions connected to the face. If the face is not used by any regions, the function returns NULL to indicate that the set is empty. If not the set may contain one or two regions. The list returned by this operator must be deleted by the calling application using *List_Delete*. 

Figure 3: Face definition
**MRegion_ptr MF_Region(MFace_ptr mface, int side):** Returns the region on the specified side of the face. The positive side of the face (side = 1) is the side towards which the face normal points. The negative side of the face (side = 0) is the opposite side.

**int MF_UsesEntity(MFace_ptr mface, MEntity_ptr mentity, int type):** Check if the face uses the given lower dimension entity, ‘mentity’. The type of the entity is specified by the ‘etype’ variable. For a face, a lower dimensional entity can be a vertex or an edge. If the face uses the vertex or the edge, the function returns 1; otherwise it returns 0. If any other type of entity is specified, the function returns 0.

**MFace_ptr MVs_CommonFace(int nv, MVertex_ptr *fverts):** Return a face connected to all the given mesh vertices. Returns NULL if no such face exists.

**MFace_ptr MEs_CommonFace(int ne, MEdge_ptr *fedges):** Return a face connected to all the given mesh edges. Returns NULL if no such face exists.

**int MFs_AreSame(MFace_ptr f1, MFace_ptr f2):** *Applicable only to reduced representations.* Check if two faces described by vertices are equivalent. For example, a face described by vertices \{1, 2, 3\} is equivalent to faces described by vertices \{1, 3, 2\} and \{3, 1, 2\}.

**void MF_Coords(MFace_ptr mface, int *n, double (*xyz)[3], int dir):** Returns the coordinates of the face vertices in an array along with the number of vertices.

**void MF_Lock(MFace_ptr f):** Lock a volatile face so that it cannot be deleted by garbage cleaning procedures (It can still be deleted by MF_Delete).

**void MF_UnLock(MFace_ptr f):** Unlock a volatile face so that it may be deleted freely by garbage cleaning procedures.
4.6 Mesh Region Object

\textit{MRegion\_ptr MR\_New(Mesh\_ptr mesh)}: Create a new region object. No topological information is embedded in the region when it is created. The region only knows which mesh it belongs to. The ID of the region is set by this function.

\textit{void MR\_Delete(MRegion\_ptr mregion, int keep)}: Delete the region. Deletes all topological information embedded in the region. If \texttt{keep} is 0, the region is removed from the mesh and all topological and geometric information embedded in the region is destroyed. If \texttt{keep} is 1, the region is marked as type \textit{MDELREGION} and removed from the mesh but the region is not destroyed. Also, the vertices, edges and faces of this region no longer point up to this region.

\textit{void MR\_Restore(MRegion\_ptr mregion)}: Restore a temporarily deleted region. The region type is restored from \textit{MDELREGION} to \textit{MREGION} and the region is added back to the mesh. The vertices, edges and faces of the region once again point back to the region.

\textit{void MR\_Set\_GEntity(MRegion\_ptr mregion, GEntity\_ptr gent)}: Set the geometric model entity on which the region is classified.

\textit{void MR\_Set\_GEntDim(MRegion\_ptr mregion, int gdim)}: Set the dimension of the geometric model entity on which the region is classified.

\textit{void MR\_Set\_GEntID(MRegion\_ptr mregion, int gid)}: Set the ID of the geometric model entity on which the region is classified.

\textit{void MR\_Set\_GInfo\_Auto(MRegion\_ptr mregion)}: Derive the classification (GEntDim, GEntID) of the mesh region automatically (if possible) from the classification of its vertices or faces. If it is not possible to unambiguously get this information, the procedure will keep the default information. \textbf{THIS MAY GET WRONG OR INCORRECT INFORMATION WHEN THERE IS AMBIGUOUS DATA.}

\textit{void MR\_Set\_ID(MRegion\_ptr mregion, int id)}: Explicitly set ID of a region and overwrite the ID set by the \textit{MR\_New} function. Does not check for duplication of region IDs.

\textit{void MR\_Set\_Faces(MRegion\_ptr mregion, int nf, MFace\_ptr* mfaces, int *dirs)}: Set the faces of the region along with their directions. The \textit{unordered} set of faces and
their directions are passed in through arrays along with the number of faces. If the normal of the face points out of the region, the associated direction to be passed in is 1; otherwise it is 0. This function is only relevant for full representations in MSTK.

```c
void MR_Set_Vertices(MRegion_ptr mregion, int nv, MVertex_ptr *mvertices, int nf, int **rfv_template):
```

Set the vertices of the region. This routine will collect/build all lower order topological information (edges, edge directions in the face) as needed by the face. For standard elements, the vertices must be ordered as indicated in Appendix A, while `nf` can be 0 and `rfv_template` can be NULL. For non-standard elements, `nf` is the number of faces of the polyhedron and `rfv_template` gives the vertices used in each face. More precisely, `rfv_template` has `nf` pointers to integer array `i`. The first entry of each `rfv_template[i]` represents the number of vertices in that face and the remaining entries represent the list of vertices of the face listed so that the face defined by them points out of the region.

```c
void MR_Replace_Face(MRegion_ptr mregion, MFace_ptr mface, MFace_ptr mnewface, int dir):
```

Replace a face of the region with another face. The direction in which the new face is used in the region must also be supplied. This function is only relevant for full representations in MSTK.

```c
void MR_Replace_Vertex(MRegion_ptr mregion, MVertex_ptr mvertex, MVertex_ptr mnewvertex):
```

Replace a vertex of a region with another vertex. This function is relevant only for reduced representations in MSTK.

```c
void MR_Replace_Face_i(MRegion_ptr mregion, int i, MFace_ptr mface, int dir):
```

Replace the i’th face in the region with another face. The direction in which the new face is used in the region must also be supplied. This function is only relevant for full representations in MSTK.

```c
void MR_Replace_Vertex_i(MRegion_ptr mregion, int i, MVertex_ptr mvertex):
```

Replace the i’th vertex of the region with another vertex. This function is only relevant for reduced representations in MSTK.

```c
Mesh_ptr MR_Mesh(MRegion_ptr mregion):
```

Returns the mesh that the region belongs to.

```c
int MR_ID(MRegion_ptr mregion):
```

Returns the ID of the region. Returns 0 if not known.
int MR_GEntDim(MRegion_ptr mregion): Returns the dimension of the geometric model entity the region is classified on. Always returns 3 since a mesh region can be classified only on a model region.

int MR_GEntID(MRegion_ptr mregion): Returns the ID of the geometric model entity that the region is classified on. Returns 0 if not known.

GEntity_ptr MR_GEntity(MRegion_ptr mregion): Returns a pointer or handle to the geometric model entity that the vertex is classified on. Returns NULL if this information is not known.

int MR_Num_Vertices(MRegion_ptr mregion): Returns the number of vertices of a region.

int MR_Num_Edges(MRegion_ptr mregion): Returns the number of edges of a region.

int MR_Num_Faces(MRegion_ptr mregion): Returns the number of faces of a region.

int MR_Num_AdjRegions(MRegion_ptr mregion): Returns the number of adjacent regions of a region, i.e., regions sharing a face with this region.

List_ptr MR_Vertices(MRegion_ptr mregion): Returns the set of vertices of a region. For standard elements the vertices are ordered as indicated in Appendix A. For non-standard elements the set is unordered. The list returned by this operator must be deleted by the calling application using List_Delete.

List_ptr MR_Edges(MRegion_ptr mregion): Return the unordered set of edges of a region. The list returned by this operator must be deleted by the calling application using List_Delete.

List_ptr MR_Faces(MRegion_ptr mregion): Returns the set of faces of a region. The list returned by this operator must be deleted by the calling application using List_Delete.

List_ptr MR_AdjRegions(MRegion_ptr mregion): Returns the set of adjacent regions of a region, i.e., regions sharing a face with this region. The set is not ordered.
int MR_FaceDir(MRegion_ptr mregion, MFace_ptr mface): Returns the direction in which the region uses the given face. Returns 1 if the face normal points out of the region and returns 0 if the face normal points into the region.

int MR_FaceDir_i(MRegion_ptr mregion, int i): Returns the direction in which the region uses the i’th face. Returns 1 if the face normal points out of the region and returns 0 if the face normal points into the region.

int MR_UsesEntity(MRegion_ptr mregion, MEntity_ptr ment, int type): Check if the region uses the given lower dimension entity, ’mentity’. The type of the entity is

void MR_Coords(MRegion_ptr mregion, int *n, double (*xyz)[3]): Returns the coordinates of the region vertices in an array along with the number of vertices. For standard elements, the ordering is as given in Appendix A. For non-standard elements, the ordering is arbitrary.
4.7 Generic Entity Object

The following functions operate on generic mesh entities of type \textit{MEntity} \texttt{ptr}. This implies that variables of type \textit{MVertex} \texttt{ptr}, \textit{MEdge} \texttt{ptr}, \textit{MFace} \texttt{ptr}, \textit{MRegion} \texttt{ptr} can all be passed in place of \textit{MEntity} \texttt{ptr} variables in the following functions.

\begin{itemize}
\item \texttt{int MEnt_ID(MEntity} \texttt{ptr mentity):} Returns the ID of a generic entity.
\item \texttt{int MEnt_Dim(MEntity} \texttt{ptr mentity):} Returns the topological dimension or type of generic entity.
\item \texttt{int MEnt_OrigDim(MEntity} \texttt{ptr mentity):} Returns the original topological dimension or type of generic entity before it was temporarily deleted.
\item \texttt{int MEnt_IsVolatile(MEntity} \texttt{ptr mentity):} Is the entity a temporary (volatile) entity in a reduced representation or an explicitly represented persistent entity. For example, this query will return 1 on any edge in a reduced representation.
\item \texttt{Mesh} \texttt{ptr MEnt_Mesh(MEntity} \texttt{ptr mentity):} Returns the mesh that the entity belongs to.
\item \texttt{int MEnt_GEntDim(MEntity} \texttt{ptr mentity):} Returns the dimension of the geometric model entity that the entity is classified on.
\item \texttt{GEntity} \texttt{ptr MEnt_GEntity(MEntity} \texttt{ptr mentity):} Returns a pointer or handle to geometric model entity that the entity is classified on.
\item \texttt{void MEnt_Delete(MEntity} \texttt{ptr mentity, int keep):} Delete a generic mesh entity. If \texttt{keep} is 0, the entity is removed from the mesh and all topological and geometric information embedded in the entity is destroyed. If \texttt{keep} is 1, the region is marked as deleted and removed from the mesh but the entity is not destroyed. Also, lower order entities in the mesh no longer point up to this entity.
\item \texttt{void MEnt_Set_AttVal(MEntity} \texttt{ptr ent, MAttrib} \texttt{ptr attrib, int ival, double lval, void *pval):} Set the value of an attribute for given mesh entity. Depending on the attribute type, different arguments of this function are relevant. If the attribute type is:
\begin{itemize}
\item \texttt{INT} – specify the integer value in \texttt{ival},
\end{itemize}
\end{itemize}
• **DOUBLE** – specify the real value in `rval`,

• **VECTOR** – specify a pointer to an array of doubles in `pval`\(^3\) - the number of doubles should equal the number components specified in the definition of the VECTOR attribute,

• **TENSOR** – specify a pointer to an array of doubles in `pval` - the number of doubles should equal the number of components specified in the definition of the TENSOR attribute,

• **POINTER** – specify the pointer value in `pval`.

```c
void MEnt_Rem_AttVal(MEntity_ptr ent, MAttrib_ptr mattrib);
```

Clear the value of the given attribute from the entity.

```c
int MEnt_Get_AttVal(MEntity_ptr ent, MAttrib_ptr int *ival, double *rval, double **pval);
```

Get the value of an attribute from an entity. Depending on the attribute type, different arguments of this function are relevant. If the attribute type is:

- **INT** – `ival` contains the integer value,
- **DOUBLE** – `rval` contains the real value,
- **VECTOR** – `pval` contains a pointer to an array of doubles,
- **TENSOR** – `pval` contains a pointer to an array of doubles,
- **POINTER** – `pval` contains the pointer value.

```c
void MEnt_Rem_AllAttVals(MEntity_ptr);
```

Remove all attribute values attached to an entity.

\(^3\)Remember to not free the array specified in `pval` without telling the attribute system because MSTK stores the pointer to the array directly and does not make a copy of the array.
4.8 Mesh Attributes

`MAttrib_ptr MAttrib_New(Mesh_ptr mesh, const char *att_name, MAttType att_type, MType entdim, <int ncomponents>):` Define a new mesh attribute. Along with the mesh to which this attribute is assigned (`mesh`) and the name of the attribute (`att_name`), the type of the attribute (`att_type`) must be specified as INT, DOUBLE, VECTOR, TENSOR or POINTER. Also, the dimension of the entity for which the attribute value can be set must be specified as MVERTEX, MEDGE, MFACE, MREGION or MALLTYPE. The last argument `ncomponents` is an optional argument for attributes of type INT, DOUBLE or POINTER but is required for attributes of type VECTOR and TENSOR.

`char *MAttrib_Get_Name(MAttrib_ptr attrib, char *att_name):` Get the name of the given attribute.

`MAttType MAttrib_Get_Type(MAttrib_ptr attrib):` Get the type of the attribute (Can return INT, DOUBLE, PVAL).

`MType MAttrib_Get_EntDim(MAttrib_ptr attrib):` Get the dimension (or type) of entity attribute can be assigned to. Can be MVERTEX, MEDGE, MFACE, MREGION or MALLTYPE.

`void MAttrib_Delete(MAttrib_ptr attrib):` Delete an attribute.
4.9 Entity Marks

Entity marks or markers are a way of tagging entities. Such functionality is useful in algorithms which must keep track of processed entities to avoid duplication of work. An example of such an operation is creating a union of entity sets while extracting upward adjacency information such as the regions connected to an edge. Use of entity marks avoids calling `List_ChknAdd` (search through the list and add item if it is not there) or using attributes to tag entities with 0 or 1. As a result it is much more efficient than either option.

```c
int MSTK_GetMarker(): Returns a unique marker ID which may be used to tag entities.

void MEnt_Mark(MEntity_ptr ent, int mkr): Mark an entity with the given marker 'mkr'.

int MEnt_IsMarked(MEntity_ptr ent, int mkr): Check if an entity is marked with the given marker 'mkr'.

void MEnt_Unmark(MEntity_ptr ent, int mkr): Unmark an entity with respect to the given marker 'mkr'

void List_Mark(List_ptr list, int mkr): Mark a set of entities with given marker.

void List_Unmark(List_ptr list, int mkr): Unmark a set of entities with respect to the given marker.

void MSTK_FreeMarker(int mkr): Release the marker ID given by MSTK_GetMarker() so that it can be reused. Care must be taken to unmark all entities marked with this marker ID before releasing it. If not, subsequent operations with reassigned marker will find a tag on some entities and mistake them for being processed.
```

An example use of entity marks is given below:
/* Code to get the faces of a vertex */
/* NOTE: This code is for illustration of entity marks only. */
/* This functionality is already available through MV_Faces */

vedges = MV_Edges(v); /* Edges of vertex */

mkid = MSTK_GetMarker(); /* Get a new marker */
vfaces = List_New(10); /* Initialize list of faces cncted to v */

idx = 0;
while ((ve = List_Next_Entry(vedges,&idx)) { /* For each edge */

    efaces = ME_Faces(ve); /* Get faces of edge */
    idx1 = 0;
    while ((ef = List_Next_Entry(efaces,&idx1))) {
        if (!MEnt_IsMarked(ef,mkid)) { /* Is the face already in list? */
            List_Add(vfaces,ef); /* No? Add it to the list and */
            MEnt_Mark(ef,mkid); /* mark it as being in the list */
        }
    }
    List_Delete(efaces);
}

List_Delete(vedges);

List_Unmark(vfaces,mkid); /* Unmark all the marked faces */
MSTK_FreeMarker(mkid); /* Very important to free the marker!! */
/* otherwise, we’ll run out of markers */
4.10 Mesh Modification

\begin{verbatim}
int ME_Swap2D(MEdge_ptr e, MEdge_ptr *enew, MFace_ptr fnew[2]): Swap
an edge in a triangular mesh. No checks are performed for topological or geometric
validity.

MVertex_ptr MVs_Merge(MVertex_ptr v1, MVertex_ptr v2): Merge two vertices,
v1 and v2, and return the retained vertex. By default, v1 is retained.

MFace_ptr MFs_Join(MFace_ptr f1, MFace_ptr f2, MEdge_ptr e): Join two faces
along common edge and create new face by eliminating the common edge as shown in
Figure 4. If ‘f1’ has ‘n1’ edges and ‘f2’ has ‘n2’ edges, then the new face has (‘n1’+’n2’-
2) edges.
\end{verbatim}

Figure 4: Joining two faces (a) Two faces $F_1$ and $F_2$ sharing a common edge (b) New
pentagonal face $F_{\text{new}}$ created by eliminating the common edge.
4.11 Utilities

void MSTK_Report(char *module, char *message, ErrType severity): Error handler for MSTK. 'module' is the name of the function in which the error occurs. 'message' is the error message and is recommended to be less than 1024 characters in length. 'severity' is an error code and can be MESSG, WARN, ERROR or FATAL. If the error code is FATAL, the program will quit after printing the error. If the same message is repeated successively, then the message is printed only the first time.

void List_PrintID(List_ptr l): Debugging utility to print the IDs of the entities in a set.

void MV_Print(MVertex_ptr v, int lev): Debugging utility to print information about a mesh vertex, v. The argument lev controls the level of detail of the information printed. lev = 0 prints the minimum information, i.e., vertex pointer, its ID and its coordinates. If lev = 1, the function prints classification information for the vertex (if available), i.e., ID and dimension of the model entity that the vertex is on. If lev > 1, then upward detailed adjacency information is also printed for the vertex, i.e., information is printed about the edges, faces and regions connected to the vertex.

void ME_Print(MEdge_ptr e, int lev): Debugging utility to print information about a mesh edge, e. The argument lev controls the level of detail of the information printed. lev = 0 prints the minimum information, i.e., edge pointer, its ID and the IDs of its two vertices. If lev = 1, the function prints classification information for the edge (if available), i.e., ID and dimension of the model entity that the edge is on. Also, more detailed vertex information printed in this case. If lev > 1, the function prints detailed upward adjacency information for the edge, i.e., information is printed about the faces and regions connected to the edge.

void MF_Print(MFace_ptr f, int lev): Debugging utility to print information about a mesh face, f. The argument lev controls the level of detail of the information printed. lev = 0 prints the minimum information, i.e., the face pointer and its ID. If lev = 1, the function prints classification information for the edge (if available), i.e., ID and dimension of the model entity that the face is on. Also, a signed list of the edges of the face is printed. If lev > 1, the function prints detailed downward and upward adjacency information for the face, i.e., information is printed about the edges and vertices of the face, and about the regions connected to the face.

void MR_Print(MRegion_ptr r, int lev): Debugging utility to print information about a mesh region, r. The argument lev controls the level of detail of the information
printed. \textbf{lev} = 0 prints the minimum information, i.e., region pointer and its ID. If \textbf{lev} = 1, the function prints classification information for the region (if available), i.e., ID of the model entity that the region is on. Also, a signed list of the faces of the region is printed. If \textbf{lev} > 1, the function prints detailed downward adjacency information for the region, i.e., information is printed about the faces, edges and vertices forming the region.
A Conventions for Vertex, Edge Numbering in Standard Region Types

(a) Tetrahedron

(b) Pyramid

(c) Triangular Prism

(d) Hexahedron
B MSTK File Format

B.1 MSTK ASCII File Format

# This is a comment
# The string “MSTK” and File version number (1.0)
MSTK Ver

# char *reptype - Type of representation
# int NV, NE, NF, NR - Number of vertices, edges, face, regions
RepType NV NE NF NR

# VERTEX INFO
# Each record has
# double X,Y,Z Coordinates
# int Mdim - Topological type or dimension of model entity that
# the vertex is on
# int Mid - ID of model entity the vertex is on
# Mdim and Mid can be -1 and 0 resp. if model info. is absent
X_Coord Y_Coord Z_Coord Mdim Mid
X_Coord Y_Coord Z_Coord Mdim Mid
. . .
# Repeated NV times

# EDGE INFO - present only if NE ≠ 0
# Keyword 'edges' followed by edge records # Each edge record has
# int Vid_1, Vid_2 - IDs of first, second vertex of edge
# int Mdim, Mid
edges Vid_1 Vid_2 Mdim Mid
Vid_1 Vid_2 Mdim Mid
. . .
# Repeated NEdges times
# FACE INFO - present only if NF ≠ 0
# Keyword 'faces' # char *FLtype: Keyword for lower order entity describing faces
# Values: Vertex, Edge (case insensitive), e.g. VeRteX or EDGE

faces FLtype

# If face described by vertices, then each face record has
# int NFV - Number of face vertices
# int Vid_1 - ID of first vertex of face
# int Vid_2 - ID of second vertex of face
# ...
# int Vid_NFV - ID of NFV'th vertex of face
# int Mdim, Mid

NFV Vid_1 Vid_2 ... Vid_NFV Mdim Mid
NFV Vid_1 Vid_2 ... Vid_NFV Mdim Mid
...
# Repeated NFaces times

# If face described by edges, then each face record has
# int NFE - Number of face edges
# int ±Eid_1 - signed ID of first edge of face
# int ±Eid_2 - signed ID of second edge of face
# ...
# int ±Eid_NFE - signed ID of NFE'th edge of face
# int Mdim, Mid
#
# if sign of edge is +, face uses edge in direction it was defined
# if sign of edge is -, face uses edge in opposite direction

NFE ±Eid_1 ±Eid_2 ... ±Eid_NFE Mdim Mid
NFE ±Eid_1 ±Eid_2 ... ±Eid_NFE Mdim Mid
...
# Repeated NFaces times

# REGION INFO - present only if NR ≠ 0
# Keyword 'regions' # char *RLtype - keyword for lower order entity describing region

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# Values: Vertex, Face (case insensitive), e.g. VERtex or faCE

regions RLtype

# if region described by vertices, then each region record has
# int NRV - Number of region vertices
# int Vid_1 - ID of first vertex of region
# int Vid_2 - ID of second vertex of region
# . . .
# int Vid_NFE - ID of NRV’th vertex of region
# int Mid, (NOTE: Mdim is not specified, since it has to be 3)

NRV Vid_1 Vid_2 ... Vid_NRV Mid
NRV Vid_1 Vid_2 ... Vid_NRV Mid
...
# Repeat NR times

# if region described by faces, then each region record has
# int NRF - Number of region faces
# int Fid_1 - signed ID of first face of region
# int Fid_2 - signed ID of second face of region
# . . .
# int Fid_NRF - signed ID of NRF’th face of region
# int Mdim, Mid
#
# if sign of face is +, face normal points out of region
# if sign of edge is -, face normal points into region

NRF ±Fid_1 ±Fid_2 ... ±Fid_NRF Mid
NRF ±Fid_1 ±Fid_2 ... ±Fid_NRF Mid
...
# Repeated NR times

# ATTRIBUTES
#
# char *Attrib_name_1 - Name of first attribute
# int Attrib_type_1 - Type of attribute (INT, DOUBLE, VECTOR, TENSOR
# int Attrib_len_1 - 0 (scalars), number of components (vectors), number of components (tensors)

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# char *Attrib_ent_1 - Type of mesh entity attribute is applicable to (VERTEX, EDGE, FACE, REGION, ALLTYPES)

# int Nent - Number entities for which this attribute is specified - Useful if an attribute is to be specified for only a small subset of mesh entities, e.g. boundary conditions

# Entity_dim_1 Entity_ID_1 Attrib_components
# Entity_dim_2 Entity_ID_2 Attrib_components
# Entity_dim_3 Entity_ID_3 Attrib_components

# Entity_dim_n Entity_ID_n Attrib_components

# char *Attrib_name_N - Name of first attribute
# int Attrib_type_N - Type of attribute (INT, DOUBLE, VECTOR, TENSOR)
# int Attrib_len_N - 0 (scalars), number of components (vectors), number of components (tensors)
# char *Attrib_ent_N - Type of mesh entity attribute is applicable to (VERTEX, EDGE, FACE, REGION, ALLTYPES)

# int Nent - Number entities for which this attribute is specified
# Entity_dim_1 Entity_ID_1 Attrib_components
# Entity_dim_2 Entity_ID_2 Attrib_components
# Entity_dim_3 Entity_ID_3 Attrib_components

# Entity_dim_n Entity_ID_n Attrib_components
C Example Mesh and Files

In this section we show a simple square geometric model and an example 2D mesh of that model comprised of triangles, quads (convex and non-convex) and polygons. Assume that the mesh vertices have a velocity associated with them and mesh faces have a symmetric second-order diffusivity tensor associated with them. We then present the MSTK files describing the mesh in the F1 and R1 formats.

Figure 5: Geometric model and a two-dimensional mesh of mixed elements of the model.
MSTK 1.0
F1 18 31 14 0
vertices
0.00 0.00 0.00 0 1
0.33 0.00 0.00 1 1
0.66 0.00 0.00 1 1
1.00 0.00 0.00 0 2
0.00 0.33 0.00 1 4
0.66 0.66 0.00 2 1
0.66 1.00 0.00 1 3
0.16 0.84 0.00 2 1
0.00 0.66 0.00 1 4
0.16 0.33 0.00 2 1
0.50 0.33 0.00 2 1
0.40 0.84 0.00 2 1
1.00 0.66 0.00 1 2
0.00 1.00 0.00 0 4
1.00 1.00 0.00 0 3
0.66 0.50 0.00 2 1
0.33 1.00 0.00 1 3
1.00 0.33 0.00 1 2
edges
2 1 1 1
2 3 1 1
3 4 1 1
4 18 1 2
2 11 2 1
15 7 1 3
14 8 2 1
18 16 2 1
12 16 2 1
10 5 2 1
11 16 2 1
15 13 1 2
14 17 1 3
17 7 1 3
8  9  2  1
18 13  1  2
14  9  1  4
10 11  2  1
10  2  2  1
 9 10  2  1
16  6  2  1
 6 13  2  1
 7  6  2  1
17 12  2  1
 8 17  2  1
 3 11  2  1
11 18  2  1
 1  5  1  4
 5  9  1  4
 7 12  2  1
 8 12  2  1
faces edge
4  3  4  -27  -26  2  1
6 18 11  -9  -31  15  20  2  1
3  25  -13  7  2  1
3  31  -24  -25  2  1
3  2  26  -5  2  1
4  -28  -1  -19  10  2  1
4  16  -22  -21  -8  2  1
4  22  -12  6  23  2  1
3  -30  -14  24  2  1
3  -10  -20  -29  2  1
3  19  5  -18  2  1
4  9  21  -23  30  2  1
3  -15  -7  17  2  1
3  27  8  -11  2  1
attributes
velocity
VECTOR
3
MVERTEX
18
| 0 1 | 0.0 | 0.0 | 0.0 |
| 0 2 | 3.3 | 0.0 | 0.0 |
| 0 3 | 6.6 | 0.0 | 0.0 |
| 0 4 | 10.0 | 0.0 | 0.0 |
| 0 5 | 0.0 | 3.3 | 0.0 |
| 0 6 | 6.6 | 6.6 | 0.0 |
| 0 7 | 6.6 | 10.0 | 0.0 |
| 0 8 | 1.6 | 8.4 | 0.0 |
| 0 9 | 0.0 | 6.6 | 0.0 |
| 0 10 | 1.6 | 3.3 | 0.0 |
| 0 11 | 5.0 | 3.3 | 0.0 |
| 0 12 | 4.0 | 6.6 | 0.0 |
| 0 13 | 10.0 | 6.6 | 0.0 |
| 0 14 | 0.0 | 10.0 | 0.0 |
| 0 15 | 10.0 | 10.0 | 0.0 |
| 0 16 | 6.6 | 5.0 | 0.0 |
| 0 17 | 3.3 | 10.0 | 0.0 |
| 0 18 | 10.0 | 3.3 | 0.0 |

diffusity
TENSOR
3
MFACE
14
| 2 1 | 1.0 | 10.0 | 2.0 |
| 2 2 | 1.0 | 10.0 | 2.0 |
| 2 3 | 1.0 | 10.0 | 2.0 |
| 2 4 | 1.0 | 10.0 | 2.0 |
| 2 5 | 1.0 | 10.0 | 2.0 |
| 2 6 | 1.0 | 10.0 | 2.0 |
| 2 7 | 1.0 | 10.0 | 2.0 |
| 2 8 | 1.0 | 10.0 | 2.0 |
| 2 9 | 1.0 | 10.0 | 2.0 |
| 2 10 | 1.0 | 10.0 | 2.0 |
| 2 11 | 1.0 | 10.0 | 2.0 |
| 2 12 | 1.0 | 10.0 | 2.0 |
| 2 13 | 1.0 | 10.0 | 2.0 |
| 2 14 | 1.0 | 10.0 | 2.0 |
File in R1 format:

MSTK 1.0
R1 18 0 14 0
vertices
0.00 0.00 0.00 0 1
0.33 0.00 0.00 1 1
0.66 0.00 0.00 1 1
1.00 0.00 0.00 0 2
0.00 0.33 0.00 1 4
0.66 0.66 0.00 2 1
0.66 1.00 0.00 1 3
0.16 0.84 0.00 2 1
0.00 0.66 0.00 1 4
0.16 0.33 0.00 2 1
0.50 0.33 0.00 2 1
0.40 0.84 0.00 2 1
1.00 0.66 0.00 1 2
0.00 1.00 0.00 0 4
1.00 1.00 0.00 0 3
0.66 0.50 0.00 2 1
0.33 1.00 0.00 1 3
1.00 0.33 0.00 1 2
faces vertex
4 3 4 18 11 2 1
6 9 10 11 16 12 8 2 1
3 14 8 17 2 1
3 8 12 17 2 1
3 2 3 11 2 1
412 10 5 2 1
4 6 16 18 13 2 1
4 6 13 15 7 2 1
3 7 17 12 2 1
3 5 10 9 2 1
3 2 11 10 2 1
4 12 16 6 7 2 1
3 9 8 14 2 1
3 11 18 16 2 1
attributes
velocity
VECTOR
3
MVERTEX
18
0 1  0.0 0.0 0.0
0 2  3.3 0.0 0.0
0 3  6.6 0.0 0.0
0 4 10.0 0.0 0.0
0 5  0.0 3.3 0.0
0 6  6.6 6.6 0.0
0 7  6.6 10.0 0.0
0 8  1.6 8.4 0.0
0 9  0.0 6.6 0.0
010 1.6 3.3 0.0
011  5.0 3.3 0.0
012  4.0 6.6 0.0
013 10.0 6.6 0.0
014  0.0 10.0 0.0
015 10.0 10.0 0.0
016  6.6 5.0 0.0
017  3.3 10.0 0.0
018 10.0 3.3 0.0

diffusity
TENSOR
3
MFACE
14
2 1  1.0 10.0 2.0
2 2  1.0 10.0 2.0
2 3  1.0 10.0 2.0
2 4  1.0 10.0 2.0
2 5  1.0 10.0 2.0
2 6  1.0 10.0 2.0
2 7  1.0 10.0 2.0
2 8  1.0 10.0 2.0
2 9  1.0 10.0 2.0
D Example program

NOTE: This program is included in the distribution.

```c
#include <stdio.h>
#include <stdlib.h>
#include "MSTK.h"
#include "test.h"

int main(int argc, char *argv[]) {
  int i, idx, idx2, ok, edir, nv, ne;
  double xyz[3];
  char meshname[256];
  Mesh_ptr mesh;
  MVertex_ptr v;
  MEdge_ptr e;
  MFace_ptr f;
  GEntity_ptr gent;
  List_ptr fedges;

  if (argc == 1) {
    fprintf(stderr,"Usage: %s meshfilename (without .mstk extension)\n",argv[0]);
    exit(-1);
  }

  /* Initialize MSTK - Always do this even if it does
   * not seem to matter in this version of MSTK */

  MSTK_Init();
```
/* Load the mesh */

strcpy(meshname, argv[1]);
strcat(meshname, ".mstk");

mesh = MESH_New(UNKNOWN_REP);
ok = MESH_InitFromFile(mesh, meshname);
if (!ok) {
    fprintf(stderr, "Cannot find input file %s\n\n\n", meshname);
    exit(-1);
}

/* Print some info about the mesh */

nv = MESH_Num_Vertices(mesh);
for (i = 0; i < nv; i++) {
    v = MESH_Vertex(mesh, i);

    /* Basic info */
    printf("\n");
    printf("Vertex: 0x%-x ID: %-d ", v, MV_ID(v));

    /* Classification w.r.t. geometric model */

    if (MV_GEntDim(v) == -1)
        fprintf(stderr, "Unknown Classification\n");
    else {
        printf("GEntID: %-d GEntDim: %-d\n", MV_GEntID(v), MV_GEntDim(v));
        if ((gent = MV_GEntity(v)))
            printf("Model entity pointer: 0x%-x\n", gent);
    }

    /* Coordinates */
    MV_Coords(v, xyz);
    printf("Coords: %-16.8lf %-16.8lf %-16.8lf\n", xyz[0], xyz[1], xyz[2]);
}

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idx = 0;
while (f = MESH_Next_Face(mesh,&idx)) {

    /* Basic info */
    printf("\n");
    printf("Face: 0x%-x ID: %-d ",f,MF_ID(f));

    /* Classification w.r.t. geometric model */
    if (MF_GEntDim(f) == -1)
        fprintf(stderr,"Unknown Classification\n");
    else {
        printf("GEntID: %-d GEntDim: %-d\n",MF_GEntID(f),MF_GEntDim(f));
        if ((gent = MF_GEntity(f))
            printf("Model entity pointer: 0x%-x\n",gent);
    }
    printf("\n");

    /* Edges of face */
    fedges = MF_Edges(f,1,0);
    ne = List_Num_Entries(fedges);
    printf("Edges: %-d\n",ne);
    printf("Object ID GEntID GEntDim Vertex IDs\n");
    idx2 = 0; i = 0;
    while (e = List_Next_Entry(fedges,&idx2)) {
        edir = MF_EdgeDir_i(f,i);
        if (edir)
            printf("0x%-8x %-8d %-8d %-1d %-d %-d\n", e,ME_ID(e),ME_GEntID(e),ME_GEntDim(e),
                MV_ID(ME_Vertex(e,0)),MV_ID(ME_Vertex(e,1)));
        else
            printf("0x%-8x %-8d %-8d %-1d %-d %-d\n", e,-ME_ID(e),ME_GEntID(e),ME_GEntDim(e),
                MV_ID(ME_Vertex(e,0)),MV_ID(ME_Vertex(e,1)));
        i++;
    }
    printf("\n");
    List_Delete(fedges);
if ((natt = MESH_Num_Attribs(mesh))) {

fprintf(stderr,"Attributes on the mesh:\n\n");

for (i = 0; i < natt; i++) {

attrib = MESH_Attrib(mesh,i);

attentdim = MAttrib_Get_EntDim(attrib);

/* Won't print out edge, face and region based attributes
   but the code should be quite similar */

if (attentdim != MVERTEX) continue;

fprintf(stderr,"Attribute Number %-d\n",i+1);

MAttrib_Get_Name(attrib,attname);
fprintf(stderr,"Name: %-s\n",attname);

atttype = MAttrib_Get_Type(attrib);
switch(atttype) {
  case INT:
    fprintf(stderr,"Type: Integer\n");
    break;
  case DOUBLE:
    fprintf(stderr,"Type: Double\n");
    break;
  case VECTOR:
    fprintf(stderr,"Type: Vector\n");
    break;
  case TENSOR:
    fprintf(stderr,"Type: Tensor\n");
    break;
  default:
    fprintf(stderr,"Unrecognizable or unprintable attribute type\n");

}
continue;
}

switch(attendim) {
  case MVERTEX:
    fprintf(stderr,"Applicable to vertices only\n");
    break;
  case MEDGE:
  case MFACE:
  case MREGION:
  case MALLTYPE:
    /* Won't print out edge, face and region based attributes 
      but the code should be quite similar */
    continue;
  default:
    fprintf(stderr,"Unrecognized entity type\n");
    continue;
}

ncomp = MAttrib_Get_NumComps(attrib);
fprintf(stderr,"Number of components: %-d\n",ncomp);

switch(attendim) {
  case MVERTEX:
    idx = 0;
    while ((v = MESH_Next_Vertex(mesh,&idx))) {
      if (MEnt_Get_AttVal(v,attrib,&ival,&rval,&pval)) {
        fprintf(stderr,"V %-d: ",MV_ID(v));
        switch (atttype) {
          case INT:
            fprintf(stderr," %-d\n",ival);
            break;
          case DOUBLE:
            fprintf(stderr," %-lf ",rval);
            break;
          case VECTOR: case TENSOR:
            rval_arr = (double *) pval;
            for (k = 0; k < ncomp; k++)
fprintf(stderr," %lf ",rval_arr[k]);
    break;
    default:
        break;
    }
    fprintf(stderr,\"\n\n\");
    }
    }
    break;
    case MEDGE: case MFACE: case MREGION: case MALLTYPE:
    /* Skipped code to print out attributes for all other entity types but it is almost identical */
    break;
    default:
        break;
    }
    /* switch (attentdim) */

    } /* for (i = 0; i < natt) */

} /* if (Mesh_Num_Attribs(mesh)) */

/* Write out a copy of the mesh */
strcpy(meshname,argv[1]);
strcat(meshname,\"-copy.mstk\");
MESH_WriteToFile(mesh,meshname,F1);

/* No need to delete a mesh if program ends right afterwards */

MESH_Delete(mesh);
return 1;
}
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