MSTK: Mesh Toolkit, v 1.1 - DRAFT

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1 Introduction

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. MSTK is a flexible framework in that it allows (or will eventually allow) a wide 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 or during the program execution 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.

MSTK will soon allow 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:

Garimella, R. "Mesh Data Structure Selection for Mesh Generation and FEA Applications," *International Journal of Numerical Methods in Engineering*, v55 n4, pp. 441-478, 2002.

In the following sections, the data types of MSTK will be described followed by a description of the functional interface. The MSTK file format will be described in the last section.

2 MSTK Data Types

Set_ptr: Handle to a Set object

Mesh_ptr: Handle to a Mesh object.

MVertex_ptr: Handle to a Mesh Vertex object (Topological Dimension 0)

MEdge_ptr: Handle to a Mesh Edge object (Topological Dimension 1)

MFace_ptr: Handle to a Mesh Face object (Topological Dimension 2)

MRegion_ptr: Handle to Mesh Region object (Topological Dimension 3)

MEntity_ptr: Handle to a generic Mesh Entity object. Any of the above types of entities can be cast as *MEntity_ptr*

GModel_ptr: Handle to a Geometric Model object

GEntity_ptr: Handle to a Geometric Entity object

RepType: Enumerated type describing the type of mesh representation. Can be UNKNOWN_REP, F1, F4, R1, R2, R4. See Appendix A for schematics of these representations *Currently only representation types F1 and F4 are supported*

MFType: Enumerated type for mesh face type Can be FDELETED, FUNKNOWN, TRI, QUAD, POLYGON

MRType: Enumerated type for mesh region type Can be RDELETED, RUNKNOWN, TET, PYRAMID, PRISM, HEX, POLYHED

3 MSTK Functional Interface

3.1 Sets

Sets of entities in MSTK are returned as sets of type *Set_ptr*. The following are the set operations available in MSTK:

***Set_ptr* Set_New(*int* inisize):** Create a new set with an initial size, *inisize*. If *inisize* is 0, the initial size is set to be 10.

***void* Set_Delete(*Set_ptr* l):** Delete a set.

***Set_ptr* Set_Compress(*Set_ptr* l):** Compress a set. Doing this while an algorithm is iterating through the set can currently cause problems!! Calling **Set_Compress** could change the pointer for the set due to reallocation.

***Set_ptr* Set_Copy(*Set_ptr* l):** Return a copy of a set.

***Set_ptr* Set_Add(*Set_ptr* l, *void* *entry):** Add an entry to the set. The entry is appended to the end of the set.

***Set_ptr* Set_ChknAdd(*Set_ptr* l, *void* *entry):** Add an entry to a set only if it is not already in the set.

***int* Set_Rem(*Set_ptr* l, *void* *entry):** Remove an entry from the set. Returns 1 if successful, 0 otherwise.

***int* Set_Remi(*Set_ptr* l, *int* i):** Remove the i'th valid entry in the set. Returns 1 if successful, 0 otherwise.

***int* Set_Replace(*Set_ptr* l, *void* *entry, *void* *nuentry):** Replace 'entry' with 'nuentry' in set. Returns 1 if successful, 0 otherwise.

***int* Set_Replacei(*Set_ptr* l, *int* i, void *nuentry):** Replace the i'th valid entry in the set with 'nuentry'. Returns 1 if successful, 0 otherwise.

***int* Set_Contains(*Set_ptr* l, void *entry):** Returns 1 if set contains the entry, 0 otherwise.

***int* Set_Locate(*Set_ptr* l, void *entry):** Returns the positional index of the entry in the set. Returns -1 if the set does not contain the entry.

***void* *Set_Entry(*Set_ptr* l, *int* i):** Return the i'th valid entry in the set. Returns a NULL pointer if the i'th valid entry could not be found.

***void* *Set_Next_Entry(*Set_ptr* l, *int* *i):** Return the next valid entry in the set. This routine works like an iterator. To start iterating through the set, 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 set. 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 set it is. This value should not be modified externally while iterating through the set. Also, no specific meaning be derived from from the iteration index by other applications since the internal implementation and interpretation of the index may change at any time.

***int* Set_Num_Entries(*Set_ptr* l):** Return the number of entries in a set

3.2 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. Not all of these types 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 file into the given mesh object. Returns 1 if successful, 0 otherwise.

***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.

***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.

***RepType* MESH_RepType(*Mesh_ptr* mesh):** Representation type currently being used by the mesh.

***int* MESH_Num_Vertices(*Mesh_ptr* mesh):** Number of vertices in the mesh.

***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.

***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.

***int* MESH_Num_Regions(*Mesh_ptr* mesh):** Number of regions in the mesh.

***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 **Set_Next_Entry** above for an explanation of how the iteration works.

***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 Set_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 **Set_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**).

***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.

***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.

***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.

***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.

***void* MESH_Rem_Vertex(*Mesh_ptr* mesh, *MVertex_ptr* v):** Remove vertex from mesh. Vertex is not deleted and must be deleted afterward separately.

***void* MESH_Rem_Edge(*Mesh_ptr* mesh, *MEdge_ptr* e):** Remove edge from mesh. Edge is not deleted and must be deleted afterward separately.

***void* MESH_Rem_Face(*Mesh_ptr* mesh, *MFace_ptr* f):** Remove face from mesh. Face is not deleted and must be deleted afterward separately.

***void* MESH_Rem_Region(*Mesh_ptr* mesh, *MRegion_ptr* r):** Remove region from mesh. Region is not deleted and must be deleted afterward separately.

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

***int* MESH_Change_RepType(*Mesh_ptr* mesh, *int* nurep):** Change the representation type of the mesh. This routine can be used to modify the representation type dynamically to suit different algorithms. However, the cost of making the change and reordering all adjacencies and creating or deleting entities has to be considered while invoking this routine. Also, once a conversion is made from a full representation to a reduced representation, not all information may be retrievable when switching back to a full representation. (particularly classification information, i.e., relationship of mesh entities to the geometric model).

3.3 Mesh Vertex Object

***MVertex_ptr* 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* MV_Delete(*MVertex_ptr* mvertex):** Delete the vertex. Deletes all topological and geometric information embedded in the vertex.

***void* MV_Set_Coords(*MVertex_ptr* mvertex, double *xyz):** Set the coordinates of the vertex.

***void* MV_Set_GEntity(*MVertex_ptr* mvertex, GEntity_ptr gent):** Set the geometric model entity on which vertex is classified.

***void* MV_Set_GEntDim(*MVertex_ptr* mvertex, *int* gdim):** Set topological dimension of model entity on which vertex is classified.

***void* MV_Set_GEntID(*MVertex_ptr* mvertex, *int* gid):** Set ID of model entity on which vertex is classified.

***void* MV_Add_AdjVertex(*MVertex_ptr* mvertex, *MVertex_ptr* adjvertex):** Add neighboring vertex, adjvertex, to ajdacent 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

***Set_ptr* MV_AdjVertices(*MVertex_ptr* mvertex):** Set of adjacent or edge connected neighboring vertices of vertex.

***Set_ptr* MV_Edges(*MVertex_ptr* mvertex):** Set of edges connected to the vertex.

***Set_ptr* MV_Faces(*MVertex_ptr* mvertex):** Set of faces connected to the vertex.

***Set_ptr* MV_Regions(*MVertex_ptr* mvertex):** Set of regions connected to the vertex.

3.4 Mesh Edge Object

***MEdge_ptr* ME_New(*Mesh_ptr* mesh):** Create a new edge object. No topological information is 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):** Delete the edge. Deletes all topological information embedded in 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_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.

***Set_ptr* ME_Faces(*MEdge_ptr* medge):** Returns the set of faces using this edge.

***Set_ptr* ME_Regions(*MEdge_ptr* medge):** Returns the set of regions using this edge.

***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.

3.5 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. Delete all topological information embedded in the face.

***void* MF_Set_GEntity(*MFace_ptr* mface, GEntity_ptr gent):** Set the geometric model entity on which the edge 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_ID(*MFace_ptr* mface, *int* id):** Explicitly set ID of an edge 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.

***void* MF_Set_Vertices(*MFace_ptr* mface, *int* n, *MVertex_ptr* *verts):** Set the vertices of the face. The ordered set of vertices is passed in through an array along with the number of vertices. The vertices are assumed to be ordered clockwise around the face. This function is relevant only for reduced representations in MSTK.

***void* MF_Replace_Edge(*MFace_ptr* mface, *MEdge_ptr* edge, *MEdge_ptr* nuedge, *int* dir):** Replace an edge in the face with another edge. The

direction in which the new edge is used in the face must also be supplied. This function is relevant only for full representations in MSTK.

***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.

***void* MF_Replace_Edge_i(*MFace_ptr* mface, *int* i, *MEdge_ptr* nuedge, *int* dir):** Replace the i'th edge in the face with another edge. The direction in which the new edge is used in the face must also be supplied. This function is relevant only for full representations in MSTK.

***void* MF_Replace_Vertex_i(*MFace_ptr* mface, *int* i, *MVertex_ptr* nuvertex):** Replace the i'th vertex in the face with a new vertex. This function is relevant only for reduced representations in MSTK.

***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.

***Set_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 1. 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.

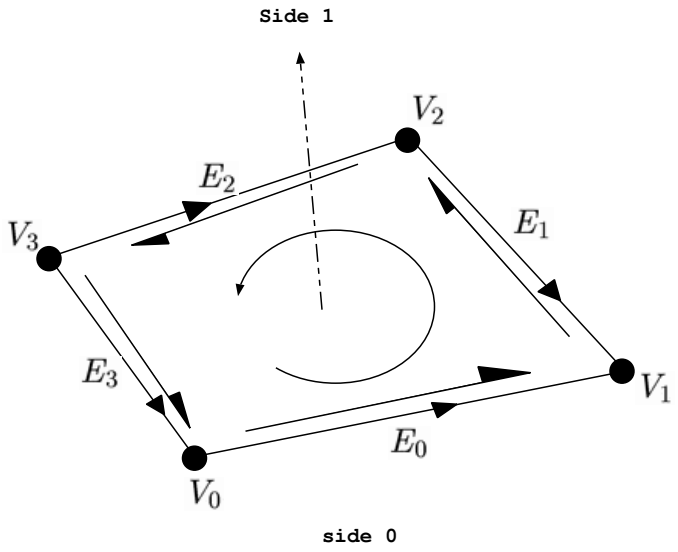


Figure 1: Face definition

***Set_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 1, 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.

***Set_ptr* MF_AdjFaces(*MFace_ptr* mface):** Set 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.

***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;

***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.

***Set_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.

***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.

***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. If 'dir' is 1, the coordinates are returned

with a ccw ordering while looking down the face normal; if 'dir' is 0, they are returned with a cw ordering (See Figure 1).

3.6 Mesh Region Object

***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.

***void* MR_Delete(*MRegion_ptr* mregion):** Delete the region. Deletes all topological information embedded in the edge.

***void* MR_Set_GEntity(*MRegion_ptr* mregion, GEntity_ptr gent):** Set the geometric model entity on which the edge is classified.

***void* MR_Set_GEntDim(*MRegion_ptr* mregion, *int* gdim):** Set the dimension of the geometric model entity on which the edge is classified.

***void* MR_Set_GEntID(*MRegion_ptr* mregion, *int* gid):** Set the ID of the geometric model entity on which the edge is classified.

***void* MR_Set_ID(*MRegion_ptr* mregion, *int* id):** Explicitly set ID of an edge and overwrite the ID set by the **MR_New** function. Does not check for duplication of region IDs.

***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 *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.

***void* MR_Set_Vertices(*MRegion_ptr* mregion, *int* nv, *MVertex_ptr* *mvertices):** Set the vertices of the region. This function is relevant for reduced representations only. For standard elements, the vertices must be ordered as indicated in Appendix B. This function does not apply for defining general regions since there cannot be any implicit ordering.

***void* MR_Replace_Face(*MRegion_ptr* mregion, *MFace_ptr* mface, *MFace_ptr* nuface, *int* dir):** Replace a face of the region with another edge. 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.

***void* MR_Replace_Vertex(*MRegion_ptr* mregion, *MVertex_ptr* mvertex, *MVertex_ptr* nuvertex):** Replace a vertex of a region with another vertex. This function is relevant only for reduced representations in MSTK.

***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.

***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.

***Mesh_ptr* MR_Mesh(*MRegion_ptr* mregion):** Returns the mesh that the region belongs to.

***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.

***Set_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 B. For non-standard elements the set is unordered.

***Set_ptr* MR_Edges(*MRegion_ptr* mregion):** Return the unordered set of edges of a region.

***Set_ptr* MR_Faces(*MRegion_ptr* mregion):** Returns the set of faces of a region.

***Set_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, 'ment-ity'. 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 B. For non-standard elements, the ordering is arbitrary.

3.7 Generic Entity Object

The following functions operate on generic mesh entities of type *MEntity_ptr*. This implies that variables of type *MVertex_ptr*, *MEdge_ptr*, *MFace_ptr*, *MRegion_ptr* can all be passed in place of *MEntity_ptr* variables in the following functions.

***int* MEnt_ID(*MEntity_ptr* mentity):** Returns the ID of a generic entity.

***int* MEnt_Dim(*MEntity_ptr* mentity):** Returns the topological dimension or type of generic entity.

***Mesh_ptr* MEnt_Mesh(*MEntity_ptr* mentity):** Returns the mesh that the entity belongs to.

***int* MEnt_GEntDim(*MEntity_ptr* mentity):** Returns the dimension of the geometric model entity that the entity is classified on.

***GEntity_ptr* MEnt_GEntity(*MEntity_ptr* mentity):** Returns a pointer or handle to geometric model entity that the entity is classified on.

3.8 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.

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 **Set_Mark(*Set_ptr* list, *int* mkr):** Mark a set of entities with given marker.

void **Set_Unmark(*Set_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.

3.9 Mesh Modification

***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.

***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 2. If 'f1' has 'n1' edges and 'f2' has 'n2' edges, then the new face has ('n1'+'n2'-2) edges.

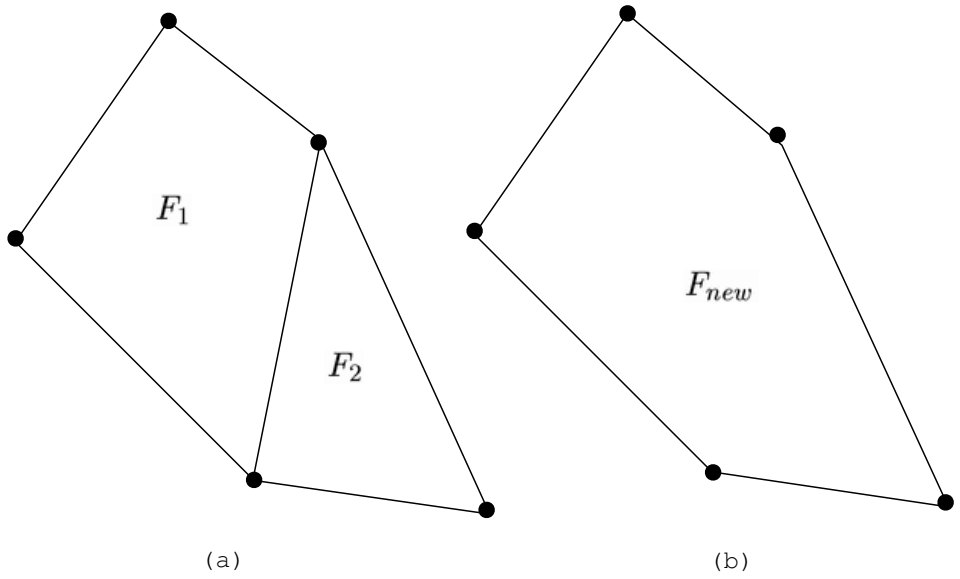


Figure 2: Joining two faces (a) Two faces F_1 and F_2 sharing a common edge (b) New pentagonal face F_{new} created by eliminating the common edge.

3.10 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* Set_PrintID(*Set_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.

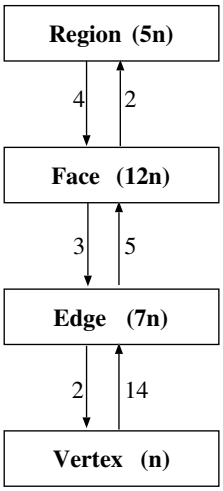
***void* ME_Print(*MEdge_ptr* e, int lev):** Debugging utility to print information about a mesh edge, **e**. The argument **lev** controls the level of detail of the information printed. **lev** = 0 prints the minimum information, i.e., edge pointer, its ID and the IDs of its two vertices. If **lev** = 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

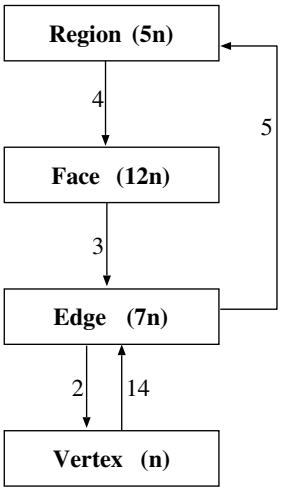
prints classification information for the edge (if available), i.e., ID and dimension of the model entity that the face is on. Also, a signed list of the edges of the face is printed. If **lev** > 1, the function prints detailed downward and upward adjacency information for the face, i.e., information 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. **lev** $= 0$ prints the minimum information, i.e., region pointer and its ID. If **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 **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.

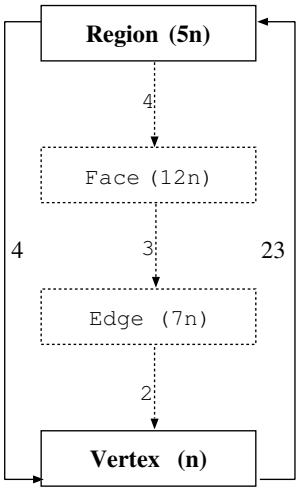
A Mesh Representation Types in MSTK



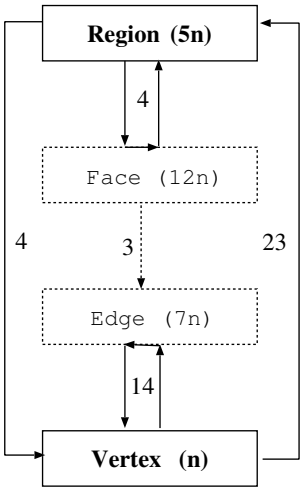
Representation F1



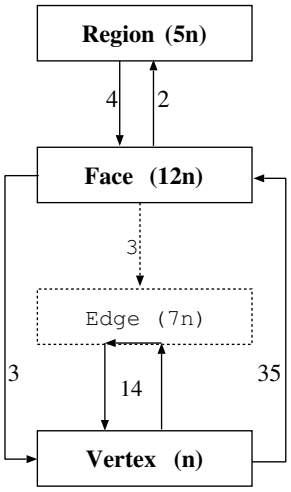
Representation F4



Representation R1

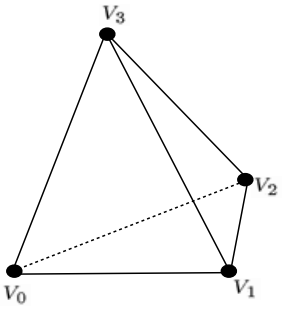


Representation R2

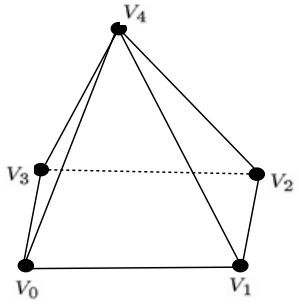


Representation R4

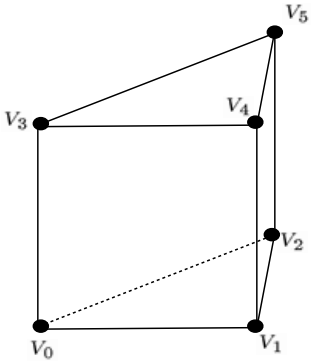
B Conventions for Vertex, Edge Numbering in Standard Region Types



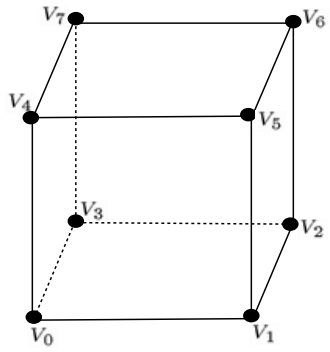
(a)
Tetrahedron



(b)
Pyramid



(c)
Triangular Prism



(d)
Hexahedron

C MSTK File Format

C.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_1 - 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*

 # 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

*# **NOT IMPLEMENTED***

*# **VERTEX ATTRIBUTES***
 # int NVA - Number of Vertex attributes
#
*# char *VA_name_1 - Name of first vertex attribute*

 # int VA_type_1 - Type of first vertex attribute
 # int VA_dim_1 - Dimension of first vertex attribute
#
*# char *VA_name_2 - Name of second vertex attribute*
 # int VA_type_2 - Type of second vertex attribute
 # int VA_dim_2 - Dimension of first vertex attribute
#
 # . . .
#
*# char *VA_name_NVA - Name of NVA'th vertex attribute*
 # int VA_type_NVA - Type of NVA'th vertex attribute
 # int VA_dim_NVA - Dimension of NVA'th vertex attribute
#
 # VA_type can be 1 (int), 2 (double), 3 (string)
 # VA_dim = 1 for scalars, VA_dim = length of vector for vector
 # VA_dim can only be 1 when VA_type is string

NVA
VA_name_1 VA_type_1 VA_dim_1
VA_name_2 VA_type_2 VA_dim_2
.
VA_dim_NVA VA_type_NVA VA_dim_2

 # For each vertex attribute record, set of attribute values
 # E.G., there are 3 attributes for each vertex:
 # a scalar int, a vector of 3 doubles and a string

VA_*int* VA_double_1 VA_double_2 VA_double_3 VA_string
VA_*int* VA_double_1 VA_double_2 VA_double_3 VA_string
.
.
.
 # Repeated NV times

EDGE ATTRIBUTES
 # Similar to Vertex attribute description

NEA
EA_name_1 EA_type_1 EA_dim_1
EA_name_2 EA_type_2 EA_dim_2
.
EA_dim_NEA EA_type_NEA EA_dim_2

 # For each edge attribute record, set of attribute values
 # E.G., a scalar int, a scalar double and a string

EA_*int* EA_double EA_string
EA_*int* EA_double EA_string
. . .
 # Repeated NE times

FACE ATTRIBUTES
 # Similar to Vertex attribute description

NFA
FA_name_1 FA_type_1 FA_dim_1
FA_name_2 FA_type_2 FA_dim_2
.
FA_dim_NFA FA_type_NEA FA_dim_2

 # For each face attribute record, set of attribute values
 # E.G., a vector of 2 doubles and a string

FA_double_1 FA_double_2
FA_double_1 FA_double_2
. . .
 # Repeated NF times

REGION ATTRIBUTES
Similar to Vertex attribute description

NRA
RA_name_1 RA_type_1 RA_dim_1
RA_name_2 RA_type_2 RA_dim_2
.
RA_dim_NRA RA_type_NRA RA_dim_NRA

For each Region attribute record, set of attribute values
E.G., a vector of 3 ints

RA_int_1 RA_int_2 RA_int_3
RA_int_1 RA_int_2 RA_int_3
. . .
Repeated NR times