



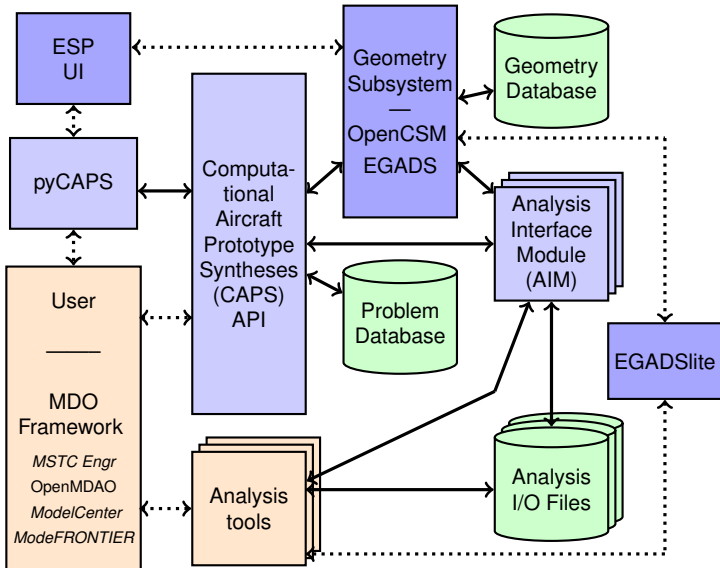
Computational Aircraft Prototype Syntheses

AIM Development

For ESP Rev 1.26

Bob Haimes Marshall Galbraith
haimes@mit.edu galbramc@mit.edu
Aerospace Computational Design Lab
Massachusetts Institute of Technology

Note: Sections in **red** are changes in CAPS from Revision 1.24.



Object-based Not *Object Orientated*

- Like *egos* in EGADS
- Pointer to a C structure – allows for a function-based API
- Treated as *blind pointers* (i.e., not meant to be dereferenced)
Header info used to determine how to dereference the *pointer*
- API Functions
 - Returns an *int* error code or CAPS_SUCCESS
 - Usually have one (or more) input Objects
 - Can have an output Object (usually at the end of the argument list)
- Can interface with multiple compiled languages

See \$ESP_ROOT/doc/CAPSapi.pdf

Problem Object

The Problem is the top-level *container* for a single mission. It maintains a single set of interrelated geometric models, analyses to be executed, connectivity and data associated with the run(s), which can be both multi-fidelity and multidisciplinary. There can be multiple Problems in a single execution of CAPS and each Problem is designed to be *thread safe* allowing for multi-threading of CAPS at the highest level.

Value Object

A Value Object is the fundamental data container that is used within CAPS. It can represent *inputs* to the Analysis and Geometry subsystems and *outputs* from both. Also Value Objects can refer to *mission* parameters that are stored at the top-level of the CAPS database. The values contained in any *input* Value Object can be bypassed by the *linkage* connection to another Value (or *DataSet*) Object of the same *shape*. Attributes are also cast to temporary (*User*) Value Objects.

Analysis Object

The Analysis Object refers to an instance of running an analysis code. It holds the *input* and *output* Value Objects for the instance and a directory path in which to execute the code (though no explicit execution is initiated). Multiple various analyses can be utilized and multiple instances of the same analysis can be handled under the same Problem.

Bound Object

A Bound is a logical grouping of BRep Objects that all represent the same entity in an engineering sense (such as the “outer surface of the wing”). A Bound may include BRep entities from multiple Bodies; this enables the passing of information from one Body (for example, the aero OML) to another (the structures Body).

Dimensionally:

- 1D – Collection of Edges
- 2D – Collection of Faces

VertexSet Object

A VertexSet is a *connected* or *unconnected* group of locations at which discrete information is defined. Each *connected* VertexSet is associated with one Bound and a single *Analysis*. A VertexSet can contain more than one DataSet. A *connected* VertexSet can refer to 2 differing sets of locations. This occurs when the solver stores it's data at different locations than the vertices that define the discrete geometry (i.e. cell centered or non-isoparametric FEM discretizations). In these cases the solution data is provided in a different manner than the geometric.

DataSet Object

A DataSet is a set of engineering data associated with a VertexSet. The rank of a DataSet is the (user/pre)-defined number of dependent values associated with each vertex; for example, scalar data (such as *pressure*) will have rank of one and vector data (such as *displacement*) will have a rank of three. Values in the DataSet can either be deposited there by an application or can be computed (via evaluations, data transfers or sensitivity calculations).

Object	SubTypes	Parent Object
capsProblem	Parametric, Static	
capsValue	GeometryIn, GeometryOut, Parameter, User	capsProblem, capsValue
capsAnalysis		capsProblem
capsValue	AnalysisIn, AnalysisOut, AnalysisDynO	capsAnalysis
capsBound		capsProblem
capsVertexSet	Connected, Unconnected	capsBound
capsDataSet	FieldOut, FieldIn, User, GeomSens, TessSens, Builtin	capsVertexSet

Body Objects are EGADS Objects (egos)

See `$ESP_ROOT/include/capsTypes.h` for the correct capitalization

Filtering the active CSM Bodies occurs at two different stages, once in the CAPS framework, and once in the AIMs. The filtering in the CAPS framework creates sub-groups of Bodies from the CSM stack that are passed to the specified AIM. Each AIM instance is then responsible for selecting the appropriate Bodies from the list it has received.

The filtering is performed by using two Body attributes: “capsAIM” and “capsIntent”.

Filtering within AIM Code

Each AIM can adopt it's own filtering scheme for down-selecting how to use each Body it receives. The “capsIntent” string is accessible to the AIM, but it is for information only.

CSM AIM targeting: “capsAIM”

The CSM script generates Bodies which are designed to be used by specific AIMs. The AIMs that the Body is designed for is communicated to the CAPS framework via the “capsAIM” string attribute. This is a semicolon-separated string with the list of AIM names. Thus, the CSM author can give a clear indication to which AIMs should use the Body. For example, a body designed for a CFD calculation could have:

```
ATTRIBUTE capsAIM $su2AIM;fun3dAIM;cart3dAIM
```

CAPS AIM Instantiation: “capsIntent”

The “capsIntent” Body attribute is used to disambiguate which AIM instance should receive a given Body targeted for the AIM. An argument to `caps_makeAnalysis` accepts a semicolon-separated list of keywords when an AIM is instantiated in CAPS/pyCAPS. Bodies from the “capsAIM” selection with a matching string attribute “capsIntent” are passed to the AIM instance. The attribute “capsIntent” is a semicolon-separated list of keywords. If the string to `caps_makeAnalysis` is **NUL**L, all Bodies with a “capsAIM” attribute that matches the AIM name are given to the AIM instance.

- Hides all of the individual Analysis details (and peculiarities)
 - Individual plugin functions *translate* from the Analysis' perspective back and forth to CAPS
 - Provides a direct connection to BRep geometry and attribution through EGADS
- Outside the CAPS Object infrastructure
 - Use of C structures
 - AIM Utility library (with the *context* embedded in `aimInfo`)

Update Notes (from Rev 1.19):

- ➊ Changing directories within an AIM function is no longer needed. When an AIM function is invoked, you will be in the correct location. Therefore the path has been removed from the argument list of many AIM functions. This includes `aimPreAnalysis`, `aimExecute`, `aimPostAnalysis`, `aimCalcOutput` and `aimTransfer`.
- ➋ There is no longer an AIM parent/child relationship. This is now accomplished via linking AnalysisOut Values of the *parent* to AnalysisIn Values of the *child*.
- ➌ During restart only “Post” is executed at the last use of the AIM instance.
- ➍ AIM specific storage is no longer indexed by the instance and is held internally.

Large Mesh IO

The meshing AIMs used to hold onto the grid information in memory and pass a pointer on to the CFD AIMs that write out a mesh file during solver preAnalysis. This is not the best use of resources and limits the ability for CAPS to perform its overall mission.

In order to have the meshing AIM know what kind of file the downstream solver AIM requires there needs to be information “passed” from the solver AIM to the meshing AIM. This is accomplished through the linkage itself. An AIM utility function has been added that returns the info for linked (solver) AIMs to aid in knowing what files to write in aimPostAnalysis. After the files have been written from PostAnalysis, the memory must be freed up.

The mesh writer is specified by using the Value structure member: `meshWriter`. This is filled in the link target (solver) AnalysisIn Value Object, which will allow for the upstream (meshing) AIM knowledge about how the mesh is to be written. The string contains the name of the so/DLL to be loaded for the writing. The meshing AIM accesses this information via the AIM utility function `aim_writeMeshes`.

Analysis Dynamic Value Objects

- After successful AIM preAnalysis invocation, all existing Analysis Dynamic Output Objects that are stored in the instance are deleted (and those associated mirrored restart files)
- AIM postAnalysis is the only place where Analysis Dynamic Output Objects can be created (see `aim_makeDynamicOutput`)
- They should not be created (i.e., they will already exist) if the **restart** flag is set
- After successful postAnalysis (and not at restart), the created Dynamic Output Objects are given the serial number of postAnalysis (and are written for restart)
- If postAnalysis errors, any created Dynamic Output Objects are deleted

Analysis Execution Calling Sequences

- `aimUpdateState` is always called before `aimDiscr`, `aimPreAnalysis` or `aimPostAnalysis`
- `aimDiscr` may be called before or after `aimPreAnalysis` or `aimPostAnalysis`
- `aimPreAnalysis` is always called before `aimExecute` or `aimPostAnalysis` (unless doing a restart/continuation)
- `aimPostAnalysis` is called right after `aimUpdateState` when CAPS is restarting (the *restart* argument is set), or if `aimPostAnalysis` is the first live function with continuation.

Only `aimPreAnalysis` and/or `aimPostAnalysis` (not a restart) should write to the Analysis directory.

- An AIM plugin is required for each Analysis code at:
 - a specific *intent*
 - a specific *mode* (i.e., where the inputs may be different)
- AIMs can “talk” to each other
 - AIM outputs of one AIM instance can be linked to inputs of another AIM instance
 - Communication is accomplished via pointers
- Dynamically loaded at runtime – extendibility and extensibility
 - Windows Dynamically Loaded Libraries (name .dll)
 - LINUX Shared Objects (name .so)
 - MAC Bundles, CAPS uses the so file extension
- Plugin names must be unique – loaded by the name
- † indicates memory handled by CAPS in the following functions
i.e., CAPS will free these memory blocks when necessary

The **capsValue** Structure is simply the data found within a CAPS Value Object. `aimInputs` and `aimOutputs` must fill the structure with the *type*, *form* and optionally *units* of the data. `aimInputs` also sets the default value(s) in the *vals* member. The structure's members listed below must be filled (most have defaults).

Value Type – no default

The value *type* can be one of:

```
enum capsValueType {Boolean, Integer, Double, String, Tuple, Pointer, DoubleDeriv, PointerMesh};
```

Notes:

- 1 The `Pointer/PointerMesh` types are only supported at the AIM level to communicate between AIMS. Linkages should be used from *AnalysisOut* to *AnalysisIn* to make the connection. The `units` member of the Value Structure must match for a successful link.
- 2 `DoubleDeriv` is a `Double` with optional derivatives (*AnalysisOut* & *GeometryOut* only)

The tuple structure

```
typedef struct {  
    char *name;           /* the name */  
    char *value;          /* the value for the pair */  
} capsTuple;
```

Shape of the Value – 0 is the default

dim can be one of:

- 0 scalar only
- 1 vector or scalar
- 2 scalar, vector or 2D array

Value Dimensions – 1 is the default

nrow and *ncol* set the dimension of the Value. If both are 1 this has a `scalar` shape. If either *nrow* or *ncol* are one then the shape is `vector`. If both are greater than 1 then this represents a 2D array of values.

Other enumerated constants

```
enum capsFixed      {Change, Fixed};  
enum capsNull       {NotAllowed, NotNull, IsNull, IsPartial};  
enum capstMethod    {Copy, Integrate, Average};
```


Varying Length – the default is “Fixed”

The member *lfixed* indicates whether the length of the Value is allowed to change.

Varying Shape – the default is “Fixed”

The member *sfixed* indicates whether the *shape* of the Value is allowed to change.

Can Value be NULL? – the default is “NotAllowed”

The member *nullVal* indicates whether the Value is or can be **NULL**
Options are found in `enum capsNULL`

A Note on String Storage

Multiple Strings are not stored as a list of pointers, but as a contiguous block of memory where each individual string is zero terminated.

capsValue Member Usage Notes

- *sfixed* & *dim*

If the shape is “Fixed” then *nrow* and *ncol* must fit that shape (or a lesser dimension). [Note that the length can change if *lfixed* is “Change”.] If *sfixed* is “Change” then you change *dim* before changing *nrow* and *ncol* to a higher dimension than the current setting.

- *lfixed* & *nrow/ncol*

If the length is “Fixed” then all updates of the Value(s) must match in both *nrow* and *ncol* (which presumes a “Fixed” shape).

- *nullVal* & *nrow/ncol*

nrow and *ncol* should remain at their values even if the Value is **NULL** to maintain the dimension (and possibly length) when “Fixed”. To indicate a **NULL** all that is necessary is to set *nullVal* to “IsNull”. The actual allocated storage can remain in the *vals* member or set to **NULL**.

- Use `EG_alloc` to allocate any memory required for the *vals* member.

```
/*
 * structure for derivative data w/ CAPS Value structure
 *   only used with "real" (double) data and
 *   only with GeometryOut, AnalysisOut or AnalysisDynO Value Objects
 */

typedef struct {
    char    *name;                /* the derivative with respect to */
                                   /* including optional [n] or [n,m] for vectors/arrays */
    int     rank;                 /* the number of members in the derivative */
    double *dot;                 /* the dot values -- rank*length in length */
} capsDot;

/*
 * structure for CAPS object -- VALUE
 */

typedef struct {
    int     type;                /* value type -- capsvType */
    int     length;              /* number of values */
    int     dim;                 /* the dimension */
    int     nrow;                /* number of rows */
    int     ncol;                /* the number of columns */
}
```

AIM Plugin Functions

- Registration & Declaring Inputs / Outputs
- Pre-Analysis, Analysis Execution & Retrieving Output
Write and read files – or – use Analyses' APIs if available
- Discrete Support – Interpolation & Integration
- Data Transfers

Initialization Information for the AIM

```
icode = aimInitialize(int qFlag, const char *uSys, void *aimInfo,
                    void **instStore, int *major, int *minor,
                    int *nIn, int *nOut, int *nFields,
                    char ***fnames, int **franks, int **fInOut)
```

qFlag -1 indicates a query and not a new analysis instance (0 or greater)

uSys a pointer to a character string declaring the unit system – can be **NULL**

aimInfo the AIM context – **NULL** if **qFlag == -1**

instStore a returned pointer to a block of memory to be associated with this AIM instance may be returned as **NULL** if no AIM state data is required

major the returned AIM major version number

minor the returned AIM minor version number

nIn the returned number of Inputs (minimum of 1)

nOut the returned number of possible Outputs

nFields the returned number of fields to responds to for DataSet filling

fnames a returned pointer to a list of character strings with the field/DataSet names †

franks a returned pointer to a list of ranks associated with each field †

fInOut a returned pointer to a list of field flags (FIELDIN - input, FIELDOUT - output) †

icode integer return code

Return Analysis Inputs

```
icode = aimInputs(void *instStore, void *aimInfo, int index,  
                  char **ainame, capsValue *defval)
```

- instStore** the AIM *instance* storage – **NULL** if called from caps_getInput
- aimInfo** the AIM context – **NULL** if called from caps_getInput
- index** the Input index [1-nIn]
- ainame** a returned pointer to the returned Analysis Input variable name
- defval** a pointer to the filled default value(s) and units – any allocated memory will be freed
- icode** integer return code

Return Analysis Outputs

```
icode = aimOutputs(void *instStore, void *aimInfo, int index,  
                   char **aoname, capsValue *form)
```

- instStore** the AIM *instance* storage – **NULL** if called from caps_getOutput
- aimInfo** the AIM context – **NULL** if called from caps_getOutput
- index** the Output index [1-nOut]
- aoname** a returned pointer to the returned Analysis Output variable name
- form** a pointer to the Value Shape & Units information – to be filled
any actual values stored are ignored/freed
- icode** integer return code

Set or Update the AIM's Internal State

```
icode = aimUpdateState(void *instStore, void *aimInfo,  
                        capsValue *inputs)
```

instStore the AIM *instance* storage

aimInfo the AIM context (used by the Utility Functions)

inputs the complete suite of Analysis inputs (nIn in length)

icode integer return code

Notes: This function is always called first in the execution sequence (before `aimDiscr`, `aimPreAnalysis` or `aimPostAnalysis`). It should not write into the Analysis directory.

Parse Input data & Generate Input File(s)

```
icode = aimPreAnalysis(const void *instStore, void *aimInfo,  
                       capsValue *inputs)
```

instStore the AIM *instance* storage

aimInfo the AIM context (used by the Utility Functions)

inputs the complete suite of Analysis inputs (nIn in length)

icode integer return code

Execute Analysis – Optional

```
icode = aimExecute(const void *instStore, void *aimInfo, int *state)
```

instStore the AIM *instance* storage

aimInfo the AIM context (used by the Utility Functions)

state the returned status (0 - done, 1 - running) – currently unused

icode integer return code

Note: if this function exists it is an indication that the AIM can auto-execute.

Processing after the Analysis is run

```
icode = aimPostAnalysis(void *instStore, void *aimInfo, int restart,  
                        capsValue *inputs)
```

instStore the AIM *instance* storage

aimInfo the AIM context (used by the Utility Functions)

restart restart state (0 - normal, 1 - restart invocation)

inputs the complete suite of Analysis inputs – for restart (nIn in length)

icode integer return code

Note: this function gets called by `caps_postAnalysis`, implicitly during `caps_execute`, during lazy execution (if auto-exec) and while restarting (only for the last invocation of an instance) to populate any internal state information (and should not write into the Analysis directory).

Free up any memory the AIM has stored

```
void aimCleanup(void *instStore)
```

instStore the block of memory associated with a particular instance

Note:

- Called a number of times, once for each instance

Calculate/Retrieve Output Information

```
icode = aimCalcOutput(void *instStore, void *aimInfo, int index,  
                      capsValue *val)
```

instStore the AIM *instance* storage

aimInfo the AIM context (used by the Utility Functions)

index the Output index [1-nOut] for this single result

val a pointer to the capsValue data to fill – CAPS will free any allocated memory

icode integer return code

Note:

- Called in a *lazy* manner, only when the output is needed (and after the Analysis is run)

Discrete Structure – Used to define a VertexSet

The CAPS *Discrete* data structure holds the spatial discretization information for a Bound. It defines reference positions for the location of the vertices that support the geometry and optionally the positions for the data locations (if these differ). This structure can contain a homogeneous or heterogeneous collection of element types and optionally specifies match positions for conservative data transfers.

EGADS Tessellation Object

- Used to specify the discretization of the entire Body
- Requires triangles
- Can be constructed from an external mesh generator
 - Look at `EG_initTessBody`, `EG_setTessEdge`, `EG_setTessFace` & `EG_statusTessBody`
 - Set in CAPS by invoking `aim_newTess`

```

/* defines the element discretization type by the number of reference positions
* (for geometry and optionally data) within the element.
* simple tri: nref = 3; ndata = 0; st = {0.0,0.0, 1.0,0.0, 0.0,1.0}
* simple quad: nref = 4; ndata = 0; st = {0.0,0.0, 1.0,0.0, 1.0,1.0, 0.0,1.0}
* internal triangles are used for the in/out predicates and represent linear
* triangles in [u,v] space.
* ndata is the number of data reference positions, which can be zero for simple
* nodal or isoparametric discretizations.
* match points are used for conservative transfers. Must be set when data
* and geometry positions differ, specifically for discontinuous mappings.
* For example:

```

```

*
*      2
*     /\
*    /\
*   /\
*  0-----1
*
*      neighbors
*      tri-side  vertices
*      0         1 2
*      1         2 0
*      2         0 1
*
*      4
*     /\
*    5  3
*   /\  /\
*  6
* /\  /\
*0----1----2
*
*      neighbors
*      side      vertices
*      0         1 2
*      1         2 3
*      2         3 4
*      3         4 5
*      4         5 0
*      5         0 1
*
*      nref = 7
*
*      6
*     3---.---2
*    |       |
*   7.   8   .5
*    |       |
*   0---.---1
*      4
*
*      neighbors
*      quad-side  vertices
*      0         1 2
*      1         2 3
*      2         3 4
*      3         4 0
*      4         0 1
*
*      nref = 9
*
*      3-----2
*     |       |
*     |       |
*     |       |
*    0-----1
*
*      neighbors
*      side      vertices
*      0         1 2
*      1         2 3
*      2         3 4
*      3         4 0
*      4         0 1
*
*      nref = 5

```

```
*/  
  
typedef struct {  
    int    nref;           /* number of geometry reference points */  
    int    ndata;          /* number of data ref points -- 0 data at ref */  
    int    nmat;           /* number of match points (0 -- match at  
                           geometry reference points) */  
  
    int    ntri;           /* number of triangles to represent the elem */  
    double *gst;           /* [s,t] geom reference coordinates in the  
                           element -- 2*nref in length */  
  
    double *dst;           /* [s,t] data reference coordinates in the  
                           element -- 2*ndata in length */  
  
    double *matst;         /* [s,t] positions for match points - NULL  
                           when using reference points (2*nmat long) */  
  
    int    *tris;          /* the triangles defined by geom reference indices  
                           (bias 1) -- 3*ntri in length */  
  
    int    nseg;           /* number of element segments (sides) */  
    int    *segs;          /* the element segments by reference indices  
                           (bias 1) -- 2*nsegs in length */  
}  
capsEleType;
```

You will usually have only a small number of element types.

```
/*
 * defines the element discretization for geometric and optional data
 * positions.
 *
 */

typedef struct {
    int    tIndex;           /* the element type index (bias 1) */
    int    eIndex;          /* element owning index -- dim 1 Edge, 2 Face */
    int    *gIndices;       /* local indices (bias 1) geom ref positions,
                           tess index -- 2*nref in length */
    int    *dIndices;       /* the vertex indices (bias 1) for data ref
                           positions -- ndata in length or NULL */

    union {
        int tq[2];          /* tri or quad (bias 1) for ntri <= 2 */
        int *poly;          /* the multiple indices (bias 1) for ntri > 2 */
    } eTris;                /* triangle indices that make up the element */
} capsElement;
```

See AIAA paper 2014-0294 on the website in Publications for a complete write-up (AIAApaper2014-0294.pdf).

```
/*
 * defines a discretized collection of Elements for a body
 *
 * specifies the connectivity based on a collection of Element Types and the
 * elements referencing the types.
 *
 */

typedef struct {
    ego            tess;           /* tessellation object associated with the
                                   discretization */
    int            nElems;         /* number of Elements */
    capsElement    *elems;         /* the Elements (nElems in length) */
    int            *gIndices;      /* memory storage for elemental gIndices */
    int            *dIndices;      /* memory storage for elemental dIndices */
    int            *poly;          /* memory storage for elemental poly */
    int            globalOffset;   /* tessellation global index offset across bodies */
} capsBodyDiscr;
```

```

/*
 * defines a discretized collection of Bodies
 *
 * nPoints refers to the number of indices referenced by the geometric positions
 * in the element which may be different from nVerts which is the number of
 * positions used for the data representation in the element. For simple nodal
 * or isoparametric discretizations, nVerts is zero and verts is set to NULL.
 */
typedef struct {
    int          dim;           /* dimensionality [1-3] */
    void         *instStore;    /* analysis instance storage */
    void         *aInfo;        /* AIM info */
                                /* below handled by the AIMS: */
    int          nVerts;        /* number data ref positions or unconnected */
    double       *verts;        /* data ref positions -- NULL if same as geom */
    int          *celem;        /* 2*nVerts (body, element) containing vert or NULL */
    int          nDtris;        /* number of triangles to plot data */
    int          *dtris;        /* NULL for NULL verts -- indices into verts */
    int          nDsegs;        /* number of segs (sides) to plot data mesh */
    int          *dsegs;        /* NULL for NULL verts -- indices into verts */
    int          nPoints;       /* number of entries in the geom positions */
    int          nTypes;        /* number of Element Types */
    capsEleType  *types;        /* the Element Types (nTypes in length) */
    int          nBodys;        /* number of Body discretizations */
    capsBodyDiscr *bodys;       /* the Body discretizations (nBodys in length) */
    int          *tessGlobal;   /* tessellation indices to this local space
                                2*nPoints in len (bodys index, global tess index) */
    void         *ptrm;         /* pointer for optional AIM use */
} capsDiscr;

```

See \$ESP_ROOT/doc/capsDiscr.pdf for a more complete description.

Fill-in the Discrete data for a Bound Object – Optional

```
icode = aimDiscr(char *bname, capsDiscr *discr)
```

bname the Bound name

Note: all of the BRep entities are examined for the attribute **capsBound**. Any that match **bname** must be included when filling this **capsDiscr**.

discr the Discrete structure to fill

Note: the AIM *instance*, AIM *info* pointer and the dimensionality have been filled in before this function is invoked.

icode integer return code

Frees up pointer in the Discrete Structure – Optional

```
void aimFreeDiscrPtr(void *ptrm)
```

ptrm the optional pointer in the Discrete Structure that needs to be freed
will not be called if the pointer is already **NULL**

Return Element in the *Mesh* – Optional

```
icode = aimLocateElement(capsDiscr *discr, double *params,  
                        double *param, int *bIndex, int *eIndex,  
                        double *bary)
```

- discr** the input Discrete Structure
- params** the input global *parametric* space (at all of the *geometry* support positions)
rank is the dimensionality (t for 1D, $[u, v]$ for 2D and $[x, y, z]$ for 3D)
- param** the input requested parametric position in **params** (dimensionality in length)
- bIndex** the returned body index in **discr** where the position was found (1 bias)
- eIndex** the returned element index in **discr** where the position was found (1 bias)
- bary** the resultant Barycentric/reference position in the element **eIndex**
- icode** integer return code

Data Associated with the Discrete Structure – Optional

```
icode = aimTransfer(capsDiscr *discr, const char *fname, int npts,  
                   int rank, double *data, char **units)
```

discr the input Discrete Structure

fname the field name to that corresponds to the fill

npts the number of points to be filled

rank the rank of the data

data a pointer associated with the data to be filled ($\text{rank} \times \text{npts}$ in length)

units the returned pointer to the string declaring the units †
return **NULL** to indicate unitless values

icode integer return code

Fills in the DataSet Object

Interpolation on the Bound – Optional

```
icode = aimInterpolation(capsDiscr *discr, const char *name,  
                        int bIndex, int eIndex, double *bary,  
                        int rank, double *data, double *result)  
icode = aimInterpolateBar(capsDiscr *discr, const char *name,  
                        int bIndex, int eIndex, double *bary,  
                        int rank, double *r_bar, double *d_bar)
```

discr the input Discrete Structure

name a pointer to the input DataSet name string

bIndex the input target body index (1 bias) in the Discrete Structure

eIndex the input target element index (1 bias) in the Discrete Structure

bary the input Barycentric/reference position in the element eIndex

rank the input rank of the data

data values at the data (or geometry) positions

result the filled in results (rank in length)

r_bar input $d(\text{objective})/d(\text{result})$

d_bar returned $d(\text{objective})/d(\text{data})$

icode integer return code

Forward and *reverse differentiated* functions

Element Integration on the Bound – Optional

```
icode = aimIntegration(capsDiscr *discr, const char *name,  
                      int bIndex, int eIndex, int rank,  
                      double *data, double *result)  
icode = aimIntegrateBar(capsDiscr *discr, const char *name,  
                       int bIndex, int eIndex, int rank,  
                       double *r_bar, double *d_bar)
```

- discr** the input Discrete Structure
- name** a pointer to the input DataSet name string
- bIndex** the input target body index (1 bias) in **discr**
- eIndex** the input target element index (1 bias) in **discr**
- rank** the input rank of the data
- data** values at the data (or geometry) positions – **NULL** length/area/volume of element
- result** the filled in results (**rank** in length)
- r_bar** input $d(\text{objective})/d(\text{result})$
- d_bar** returned $d(\text{objective})/d(\text{data})$
- icode** integer return code

Forward and *reverse differentiated* functions

AIM Helper Functions

- provides useful functions for the AIM programmer
- gives access to CAPS Object data
- provides a dynamically loadable writer interface for dealing with large meshes
- note that all function names begin with `aim_`
- if any of these functions are used, then the library must be included (`libaimUtil.a/aimUtil.lib`) in the AIM so/DLL build

Get Problem root

```
icode = aim_getRootPath(void *aimInfo, const char **fullPath)
```

aimInfo the AIM context

fullPath the file path to find the root of the Problem/Phase directory structure
if on Windows it will contain the drive

icode integer return code

Note: All other uses of *path* is relative to this point.

Get absolute file name in Problem/Phase directory

```
icode = aim_file(void *aimInfo, const char *rPath, char *aPath)
```

aimInfo the AIM context

rPath a path filename relative to the Problem/Phase directory structure

aPath returned absolute path filename in the Problem/Phase directory structure (length
PATH_MAX)

icode integer return code

Get CAPS revision

```
void aim_capsRev(int *major, int *minor)
```

major the returned major revision

minor the returned minor revision number

Relative path file open

```
FILE *fp = aim_fopen(void *aimInfo, const char *rPath,  
                     const char *mode)
```

aimInfo the AIM context

rPath the relative path filename in the Problem/Phase directory structure

mode specifies the mode used for the file open

fp the returned FILE pointer

Create relative path directory

```
icode = aim_mkdir(void *aimInfo, const char *rPath)
```

aimInfo the AIM context

rPath the relative path directory in the Problem/Phase directory structure

icode integer return code

Execute a command in the AIMs path

```
icode = aim_system(void *aimInfo, const char *rpath, const char *cmd)
```

aimInfo the AIM context

rpath the relative path from the Analysis' directory or **NULL** (in the Analysis path)

cmd the command to execute in a shell

icode integer return code

Check if relative path file exists

```
icode = aim_isFile(void *aimInfo, const char *rPath)
```

aimInfo the AIM context

rPath the relative path filename in the Problem/Phase directory structure

icode CAPS_SUCCESS if the file exists, CAPS_NOTFOUND otherwise

Check if relative path directory exists

```
icode = aim_isDir(void *aimInfo, const char *rPath)
```

aimInfo the AIM context

rPath the relative path filename in the Problem/Phase directory structure

icode CAPS_SUCCESS if the directory exists, CAPS_NOTFOUND otherwise

Copy a file

```
icode = aim_cpFile(void *aimInfo, const char *src, const char *dst)
```

aimInfo the AIM context

src the absolute path filename to copy

dst the path/filename (may be “”) in the Problem/Phase/AIM specific directory structure where the file is copied to

icode integer return code

Make a relative symbolic Link

```
icode = aim_symlink(void *aimInfo, const char *src, const char *dst)
```

aimInfo the AIM context

src the absolute path filename to link to

dst the path/filename (may be “” or **NULL**) in the Problem/Phase/AIM specific directory structure where the relative link is made

icode integer return code

Notes:

- 1 On Windows this simply calls `aim_cpFile`
- 2 **dst** must not exist

Relative path within a Problem/Phase directory

```
icode = aim_relPath(void *aimInfo, const char *src, const char *dst,  
                    char *relPath)
```

aimInfo the AIM context

src a filename in a Problem/Phase/AIM specific directory

dst the path/filename (may be “”) in the Problem/Phase/AIM specific directory structure

relPath the relative path from **dst** to **src**

icode integer return code

Is this Analysis Directory a Link?

```
icode = aim_fileLink(void *aimInfo, char *srcPath)
```

aimInfo the AIM context

srcPath the returned full filename of the source directory (length PATH_MAX)
can be **NULL** if this information is not required

icode integer return code

CAPS_NOTFOUND indicates the analysis directory is not a CAPS link

Remove a relative path directory

```
icode = aim_rmDir(void *aimInfo, const char *rPath)
```

aimInfo the AIM context

rPath the relative path directory in the Problem/Phase/AIM directory structure

icode integer return code

Note: Wildcards * and/or ? may be used in **rPath**

Remove a relative path file

```
icode = aim_rmFile(void *aimInfo, const char *rPath)
```

aimInfo the AIM context

rPath the relative path file in the Problem/Phase/AIM directory structure

icode integer return code

Note: Returns success even if the **rPath** file does not exist

Get Bodies

```
icode = aim_getBodies(void *aimInfo, const char **intent, int *nBody,  
                     ego **bodies)
```

aimInfo the AIM context

intent the returned pointer to the capsIntent string used to filter the Bodies

nBody the returned number of EGADS Body Objects that match the **intent**

bodies the returned pointer to a list of EGADS Body/Node Objects

icode integer return code

Is Node Body

```
icode = aim_isNodeBody(ego body, double *xyz)
```

body the EGADS Body Objects to query

xyz the returned XYZ of the Node (if a Node Body)

icode integer return code

Unit conversion

```
icode = aim_convert(void *aimInfo, const int count  
                    const char *inUnits, double *inValue,  
                    const char *outUnits, double *outValue)
```

aimInfo the AIM context

count length of *inValue* and *outValue*

inUnits the pointer to the string declaring the source units

inValue array of values to be converted

outUnits the pointer to the string declaring the desired units

outValue array of returned converted value (may be same pointer as *inValue*)

icode integer return code

Unit inversion

```
icode = aim_unitInvert(void *aimInfo, const char *inUnits,  
                       char **outUnits)
```

aimInfo the AIM context

inUnits the pointer to the string declaring units

outUnits the returned string units = 1/*inUnits* (freeable)

icode integer return code

Unit multiplication

```
icode = aim_unitMultiply(void *aimInfo, const char *inUnits1,  
                        const char *inUnits2, char **outUnits)
```

aimInfo the AIM context

inUnits1 the pointer to the string declaring left units

inUnits2 the pointer to the string declaring right units

outUnits the returned string units = inUnits1*inUnits2 (freeable)

icode integer return code

Unit division

```
icode = aim_unitDivision(void *aimInfo, const char *inUnits1,  
                        const char *inUnits2, char **outUnits)
```

aimInfo the AIM context

inUnits1 the pointer to the string declaring numerator units

inUnits2 the pointer to the string declaring denominator units

outUnits the returned string units = inUnits1/inUnits2 (freeable)

icode integer return code

Unit raise to a power

```
icode = aim_unitRaise(void *aimInfo, const char *inUnits,  
                      const int power, char **outUnits)
```

aimInfo the AIM context

inUnits the pointer to the string declaring units

outUnits the returned string units = inUnits ^ power (freeable)

icode integer return code

Unit Offset

```
icode = aim_unitOffset(void *aimInfo, const char *inUnits,  
                       const double offset, char **outUnits)
```

aimInfo the AIM context

inUnits the pointer to the string declaring units

offset offset to add to inUnits

outUnits the returned string units = inUnits @ offset (freeable)

icode integer return code

Check if two unit strings are convertible

```
icode = aim_unitConvertible(void *aimInfo, const char *unit1,  
                           const char *unit2)
```

aimInfo the AIM context

unit1 string pointer declaring units

unit2 string pointer declaring units

icode integer return code

Retrieve capsLength length unit attribute from bodies

```
icode = aim_capsLength(void *aimInfo, const char **lengthUnit)
```

aimInfo the AIM context

lengthUnit the returned string length unit of the bodies

icode integer return code

Name to Index lookup

```
icode = aim_getIndex(void *aimInfo, const char *name,  
                    enum capssType stype)
```

aimInfo the AIM context

name the pointer to the string specifying the name to look-up
NULL returns the total number of members in the subtype

stype GEOMETRYIN, GEOMETRYOUT, ANALYSISIN, ANALYSISOUT or
ANALYSISDYN0

icode index (1 bias) or negative integer return code

Index to Name lookup

```
icode = aim_getName(void *aimInfo, int index, enum capssType stype,  
                  const char **name)
```

aimInfo the AIM context

index the index to use (1 bias)

stype GEOMETRYIN, GEOMETRYOUT, ANALYSISIN, ANALYSISOUT or
ANALYSISDYN0

name the returned pointer to the string specifying the name

icode integer return code

Get GeometryIn Type

```
icode = aim_getGeomInType(void *aimInfo, int index)
```

aimInfo the AIM context
index the index of GEOMETRYIN (1 bias)
icode integer return code – 0 is Design, 1 is Configuration, 2 is Constant

Get Discretization State

```
icode = aim_getDiscrState(void *aimInfo, const char *bname)
```

aimInfo the AIM context
bname the Bound name
icode integer return code – CAPS_SUCCESS is clean

Get Value Structure

```
icode = aim_getValue(void *aimInfo, int index, enum capsType type, capsValue **value)
```

aimInfo the AIM context
index the index to use (1 bias)
type GEOMETRYIN, GEOMETRYOUT, ANALYSISIN, ANALYSISOUT or ANALYSISDYN
value the returned pointer to the capsValue structure

Initialize Value Structure

```
icode = aim_initValue(capsValue *value)
```

value a pointer to the capsValue structure
sets the initial state of the structure as if aimOutput has been invoked

icode integer return code

Free Value Structure

```
icode = aim_freeValue(capsValue *value)
```

value a pointer to the capsValue structure
frees pointers in value and calls aim_initValue to rest

icode integer return code

Create Dynamic Output Value Object

```
icode = aim_makeDynamicOutput(void *aimInfo, const char *dynObjName,  
                              capsValue *value)
```

aimInfo the AIM context

dynObjName the Name to give the Dynamic Output Object
must be unique for Dynamic Objects in this AIM instance

value the value structure used to create the Dynamic Value Object
the contents are copied into the capsAnalysis structure therefore any pointers in value
become “owned” by CAPS

icode integer return code

These functions are used to manage Dynamic Output Value Objects and can only be used from within `aimPostAnalysis`

Get AnalysisIn State WRT the Analysis

```
icode = aim_newAnalysisIn(void *aimInfo, int index)
```

aimInfo the AIM context

index the index to use (1 bias)

icode integer return code

Register a New Tessellation

```
icode = aim_newTess(void *aimInfo, ego tess)
```

aimInfo the AIM context

tess the EGADS Tessellation Object to register

icode integer return code

Notes:

- 1 If the Body associated with **tess** already has a registered Tessellation Object, the previous tessellation **ego** will be deleted
- 2 Any Tessellation Object registered will be deleted by CAPS before a Geometry regeneration
- 3 If the Body associated with **tess** is not on the OpenCSM stack, the Body Object will be deleted when the Tessellation Object is cleaned up (i.e., CAPS takes ownership of the Body from the AIM)

Get Geometry State WRT the Analysis

```
icode = aim_newGeometry(void *aimInfo)
```

aimInfo the AIM context

icode CAPS_SUCCESS for new, CAPS_CLEAN if not regenerated since last here

Get the number of instances in the Analysis

```
icode = aim_numInstance(void *aimInfo)
```

aimInfo the AIM context

icode Error code (negative) or the number of instances

Get the instance index for the Analysis

```
icode = aim_getInstance(void *aimInfo)
```

aimInfo the AIM context

icode Error code (negative) or the Instance index (Bias 0)

Get Discretization Structure

```
icode = aim_getDiscr(void *aimInfo, const char *bname, capsDiscr **discr)
```

aimInfo the AIM context

bname the Bound name

discr pointer to the returned Discrete structure

icode integer return code

Get Data from Existing DataSet

```
icode = aim_getDataSet(capsDiscr *discr, const char *dname,  
                      enum capsdMethod *method, int *npts,  
                      int *rank, double **data, char **units)
```

discr the input Discrete Structure

dname the requested DataSet name

method the returned method used for data transfers

npts the returned number of points in the DataSet

rank the returned rank of the DataSet

data a returned pointer to the data within the DataSet

units the unit string associated with the data within the DataSet

icode integer return code

Note: may only be called from aimPreAnalysis

Get Bound Names

```
icode = aim_getBounds(void *aimInfo, int *nBname, char ***bnames)
```

aimInfo the AIM context

nBname returned number of Bound names

bnames returned pointer to list of Bound names (freeable)

icode integer return code

Get Unit System

```
icode = aim_unitSys(void *aimInfo, char **unitSys)
```

aimInfo the AIM context

unitSys a returned pointer to a character string declaring the unit system – can be **NULL**

icode integer return code

Clear AIM's directory

```
icode = aim_clear(void *aimInfo)
```

aimInfo the AIM context

icode integer return code

Get Value Attributes

```
icode = aim_valueAttrs(void *aimInfo, int index, enum capsType type,  
                      int *nValue, char ***names, capsValue **values)
```

aimInfo the AIM context

index the index to use (1 bias)

stype GEOMETRYIN, GEOMETRYOUT, ANALYSISIN, ANALYSISOUT or
ANALYSISDYNO

nValue returned number of attributes

names the returned names – nValue in length (freeable)

values the returned pointer to the capsValue structures – nValue in length (freeable)

icode integer return code

Note: use `EG_freeAttrs` to free up the memory.

Get Analysis (our) Attributes

```
icode = aim_analysisAttrs(void *aimInfo, int *nValue, char ***names,  
                           capsValue **values)
```

aimInfo the AIM context

nValue returned number of attributes

names the returned names – nValue in length (freeable)

values the returned pointer to the capsValue structures – nValue in length (freeable)

icode integer return code

Note: use `EG_freeAttrs` to free up the memory.

Free Attribute storage

```
void aim_freeAttrs(int nValue, char **names, capsValue *values)
```

aimInfo the AIM context

nValue the number of attributes

names the names to be freed – nValue in length

values the pointer to the capsValue structures – nValue in length

Setup for Sensitivities

```
icode = aim_setSensitivity(void *aimInfo, const char *GIname,  
                          int *irow, int *icol)
```

aimInfo the AIM context

GIname the pointer to the string that matches the *Geometry Input* Parameter name

irow the parameter row to use – 1 bias

icol the parameter column to use – 1 bias

icode integer return code

Notes:

- 1 **aim_newTess** must have been invoked sometime before calling this function to set the tessellations for the Bodies of interest
- 2 Call **aim_setSensitivity** before call(s) to **aim_getSensitivity**.

Get Sensitivities based on Tessellation Components

```
icode = aim_getSensitivity(void *aimInfo, ego tess, int ttype,  
                           int index, int *npts, double **dxyz)
```

aimInfo the AIM context

tess the EGADS Tessellation Object

ttype topological type – 0 - NODE, *Tessellation Sensitivities*: 1 - EDGE, 2 - FACE
Geometric Sensitivities: -1 - EDGE, -2 - FACE

index the index in the Body (associated with the tessellation) based on the *type*

npts the returned number of sensitivities (number of tessellation points)

dxyz a pointer to the returned sensitivities – 3*npts in length (*freeable*)

icode integer return code

Note:

- Call `aim_setSensitivity` before call(s) to `aim_getSensitivity`

Get Global Tessellation Sensitivities

```
icode = aim_tessSensitivity(void *aimInfo, const char *name,  
                           int irow, int icol, ego tess, int *npts,  
                           double **dxyz)
```

- aimInfo** the AIM context
- name** the pointer to the string that matches the *Geometry Input* Parameter name
- irow** the parameter row to use – 1 bias
- icol** the parameter column to use – 1 bias
- tess** the EGADS Tessellation Object
- npts** the returned number of sensitivities (number of global vertices)
- dxyz** a pointer to the returned sensitivities – 3*npts in length (*freeable*)
- icode** integer return code

Notes:

- 1 Used to get the tessellation sensitivities for the entire Tessellation Object
- 2 The number of points is the global number of vertices in the tessellation

Set Step Size for Sensitivities

```
icode = aim_setStepSize(void *aimInfo, double step)
```

aimInfo the AIM context

step the step size used for subsequent AIM-based sensitivity calculations
minus indicates defaulting to CAPS, 0.0 is for analytic, positive sets the finite difference step size

icode integer return code

Get Step Size for Sensitivities

```
icode = aim_getStepSize(void *aimInfo, double *step)
```

aimInfo the AIM context

step the step size used for subsequent AIM-based sensitivity calculations
minus indicates defaulting to CAPS, 0.0 is for analytic, positive sets the finite difference step size

icode integer return code

These functions should only be used for debugging

Function Status MACRO

```
AIM_STATUS(void *aimInfo, int status, ...)
```

aimInfo the AIM context

status return status from a function

... printf type format string and data

Notes:

- 1 Tracks file, line, and function name backtrace information – if **status** < CAPS_SUCCESS
- 2 Includes “goto cleanup” if **status** < CAPS_SUCCESS

Pseudo Code Examples

```
status = myfunc1(aimInfo, arg1, arg2);  
AIM_STATUS(aimInfo, status)
```

```
status = myfunc2(aimInfo, arg1, arg2);  
AIM_STATUS(aimInfo, status, "myfunc2 args %d, %d", arg1, arg2)
```

Function Status MACRO with NOTFOUND exception

```
AIM_NOTFOUND (void *aimInfo, int status, ...)
```

aimInfo the AIM context

status return status from a function

... printf type format string and data

Notes:

- 1 Tracks file, line, and function name backtrace information – if **status** < CAPS_SUCCESS and **status** != CAPS_NOTFOUND and **status** != EGADS_NOTFOUND
- 2 Includes “goto cleanup” if the check fails

Pseudo Code Examples

```
status = myfunc1(aimInfo, arg1, arg2);  
AIM_NOTFOUND(aimInfo, status)
```

```
status = myfunc2(aimInfo, arg1, arg2);  
AIM_NOTFOUND(aimInfo, status, "myfunc2 args %d, %d", arg1, arg2)
```


ANALYSISIN Error Message MACRO

```
AIM_ANALYSISIN_ERROR(void *aimInfo, enum index, const char *format,  
                    ...)
```

aimInfo the AIM context

index index of ANALYSISIN

format printf format string

... printf data

Note: Tracks file, line, and function name backtrace information

Pseudo Code Examples

```
mach = inputs[Mach-1].vals.real;  
if (mach < 0) {  
    AIM_ANALYSISIN_ERROR(aimInfo, Mach,  
                        "Mach = %f must be >= 0\n", mach);  
    status = CAPS_BADVALUE;  
    goto cleanup;  
}
```

Error Message MACRO

```
AIM_ERROR(void *aimInfo, const char *format, ...)
```

aimInfo the AIM context
format printf format string
... printf data

Note: Tracks file, line, and function name backtrace information

Message Add Line MACRO

```
AIM_ADDLINE(void *aimInfo, const char *format, ...)
```

aimInfo the AIM context
format printf format string
... printf data

Pseudo Code Examples

```
status = aim_getBodies(aimInfo, &nBody, &bodies);
AIM_STATUS(aimInfo, status)

If (nBody != 1) {
    AIM_ERROR(aimInfo, "Only one body expected, but nBody = %d", nBody);
    AIM_ADDLINE(aimInfo, "This aim can only work with one body");
    status = CAPS_BADVALUE;
    goto cleanup;
}
```

Warning Message MACRO

```
AIM_WARNING(void *aimInfo, const char *format, ...)
```

aimInfo the AIM context

format printf type format string

... printf data

Notes:

- 1 Tracks file, line, and function name backtrace information
- 2 Use AIM_ADDLINE to add additional lines

Pseudo Code Examples

```
status = aim_getBodies(aimInfo, &nBody, &bodies);  
AIM_STATUS(aimInfo, status)
```

```
If (nBody > 1) {  
    AIM_WARNING(aimInfo, "Only one body will be used, but nBody = %d", nBody);  
    AIM_ADDLINE(aimInfo, "This aim only uses one body");  
}
```

Informational Message MACRO

```
AIM_INFO(void *aimInfo, const char *format, ...)
```

aimInfo the AIM context

format printf type format string

... printf data

Notes:

- 1 Tracks file, line, and function name backtrace information
- 2 Use AIM_ADDLINE to add additional lines

Remove Error Message

```
aim_removeError(void *aimInfo)
```

aimInfo the AIM context

Pseudo Code Example

```
status = myfunc3(aimInfo, arg1, arg2);  
if (status == CAPS_BADVALUE) {  
    aim_removeError(aimInfo);  
    /* Resolve CAPS_BADVALUE error */  
} else {  
    AIM_STATUS(aimInfo, status);  
}
```

Memory Allocation MACROs

AIM_ALLOC(**void** *ptr, **size_t** size, **type**, **void** *aimInfo, **int** status)

AIM_REALL(**void** *ptr, **size_t** size, **type**, **void** *aimInfo, **int** status)

ptr pointer assigned allocation (must be **NULL** for AIM_ALLOC)

size number of **type** allocations

type data type for the allocation

aimInfo the AIM context

status function return status

Notes:

- 1 Tracks file, line, and function name backtrace information
- 2 Includes “goto cleanup” on error and sets **status** = EGADS_MALLOC

Free Memory

AIM_FREE(**void** *ptr)

ptr frees pointer memory and sets **ptr** = **NULL**

String Duplication MACRO

```
AIM_STRDUP(char *ptr, const char *str, void *aimInfo, int status)
```

ptr pointer assigned allocation (must be **NULL**)

str string for duplication

aimInfo the AIM context

status function return status

Notes:

- 1 Tracks file, line, and function name backtrace information
- 2 Includes “goto cleanup” on error and sets **status** = EGADS_MALLOC

Enum Name Creation MACRO

```
char *AIM_NAME (enum Name)
```

Name enumeration

Notes: Converts enumeration Index “Name” to a string and returns a duplicate string

NULL Check MACRO

```
AIM_NOTNULL(char *ptr, void *aimInfo, int status)
```

ptr pointer checked

aimInfo the AIM context

status function return status

Notes: If **ptr == NULL**, sets **status = CAPS_NULLVALUE** and then “goto cleanup”

Pseudo Code Example

```
enum aimInputs {  
    Mach = 1,           /* index is 1-based */  
    NUMINPUT = Mach     /* Total number of inputs */  
};  
...  
if (index == Mach) {  
    *ainame = AIM_NAME(Mach);  
    ...  
}  
AIM_NOTNULL(*ainame, aimInfo, status);
```

Initialize capsBodyDiscr Pointer

```
void aim_initBodyDiscr(capsBodyDiscr *discBody)
    discBody pointer to initialize
```

Linear Triangle/Quad Element Type with Nodal Data

```
icode = aim_nodalTriangleType(capsEleType *eetype)
icode = aim_nodalQuadType(capsEleType *eetype)
    eetype element type pointer to fill
    icode integer return code
```

Linear Triangle/Quad Element Type with Cell Data

```
icode = aim_cellTriangleType(capsEleType *eetype)
icode = aim_cellQuadType(capsEleType *eetype)
    eetype element type pointer to fill
    icode integer return code
```


Return Element in a Linear *Mesh*

```
icode = aim_locateElement(capsDiscr *discr, double *params,  
                        double *param, int *eIndex, int *bIndex,  
                        double *bary)
```

- discr** the input Discrete Structure
- params** the input global *parametric* space (at all of the *geometry* support positions)
rank is the dimensionality (t for 1D, $[u, v]$ for 2D and $[x, y, z]$ for 3D)
- param** the input requested parametric position in **params** (dimensionality in length)
- bIndex** the returned body index in **discr** where the position was found (1 bias)
- eIndex** the returned element index in **discr** where the position was found (1 bias)
- bary** the resultant Barycentric/reference position in the element **eIndex**
- icode** integer return code

Interpolation on the Bound in a Linear *Mesh*

```
icode = aim_interpolation(capsDiscr *discr, const char *name,  
                          int bIndex, int eIndex, double *bary,  
                          int rank, double *data, double *result)  
icode = aim_interpolateBar(capsDiscr *discr, const char *name,  
                           int bIndex, int eIndex, double *bary,  
                           int rank, double *r_bar, double *d_bar)
```

- discr** the input Discrete Structure for a Linear *Mesh*
- name** a pointer to the input DataSet name string
- bIndex** the input target body index (1 bias) in the Discrete Structure
- eIndex** the input target element index (1 bias) in the Discrete Structure
- bary** the input Barycentric/reference position in the element **eIndex**
- rank** the input rank of the data
- data** values at the data (or geometry) positions
- result** the filled in results (**rank** in length)
- r_bar** input $d(\text{objective})/d(\text{result})$
- d_bar** returned $d(\text{objective})/d(\text{data})$
- icode** integer return code

Forward and *reverse differentiated* functions

Element Integration on the Bound in a Linear *Mesh*

```
icode = aim_integration(capsDiscr *discr, const char *name,  
                        int bIndex, int eIndex, int rank,  
                        double *data, double *result)  
icode = aim_integrateBar(capsDiscr *discr, const char *name,  
                         int bIndex, int eIndex, int rank,  
                         double *r_bar, double *d_bar)
```

- discr** the input Discrete Structure for a Linear *Mesh*
name a pointer to the input DataSet name string
bIndex the input target body index (1 bias) in **discr**
eIndex the input target element index (1 bias) in **discr**
rank the input rank of the data
data values at the data (or geometry) positions – **NULL** length/area/volume of element
result the filled in results (**rank** in length)
r_bar input $d(\text{objective})/d(\text{result})$
d_bar returned $d(\text{objective})/d(\text{data})$
icode integer return code

Forward and *reverse differentiated* functions

AIM meshWriter Structures and Functions

- Structures filled by an AIM mesh generation
- Functions for initializeing and filling the structures
- The library (libaimMesh.a/aimMesh.lib) must be included in the AIM so/DLL build

Dynamically loading the mesh writer

The meshing AIM dynamically loads the appropriate so/DLL to output the mesh file in its default location. If the mesh data is memory resident during postAnalysis, it needs be written to disk and freed. The mesh writer shared object/DLL needs to contain only the entry points: `meshExtension` & `meshWrite` (see below).

aimMesh Structure

The complete representation of a mesh

```
typedef struct {  
    aimMeshData *meshData;  
    aimMeshRef *meshRef;  
} aimMesh;
```

meshData represents the mesh coordinates and connectivity

meshRef mapping of the boundary mesh vertexes to the interior vertexes

A mesh generation AIM is responsible for filling the complete [aimMesh](#) Structure, which is passed to a `meshWriter` shared library, which is responsible for writing the data to disk. Only the `meshRef` pointer is passed via a link to an analysis AIM.

aimMeshData Structure

Represents the Cartesian coordinates and element connectivity of the mesh

```
typedef double aimMeshCoords[3];
typedef int    aimMeshIndices[2];
typedef struct {
    int          dim;           /* Physical dimension: 2D or 3D */
    int          nVertex;       /* total number of vertices in the mesh */
    aimMeshCoords *verts;       /* the xyz coordinates of the vertices
                                nVertex in length */
    int          nElemGroup;     /* number of element groups */
    aimMeshElemGroup *elemGroups; /* element groups -- nElemGroup in length */
    int          nTotalElems;    /* total number of elements */
    aimMeshIndices *elemMap;     /* group,elem map in original element ordering
                                nTotalElems in length -- can be NULL */
} aimMeshData;
```

dim must be 2 or 3 to represent the number Physical dimensions used in verts.
nVertex number of coordinates

verts Coordinates stored as $verts[iv][d]$ for $iv \in [0, nVertex)$ and $d \in [0, dim)$.

nElemGroup number of element groups

elemGroups group of elements with all the same type (nElemGroups in length)

nTotalElems total number of elements in the mesh

elemMap The original element ordering (*nTotalElems* in length). $elemMap[ie][0]$ is the 0-based element group index into *elemGroups*, and $elemMap[ie][1]$ is 0-based index of the element in the group.

aimMeshElemGroup Structure

Represents a group of elements of the same type

```
typedef struct {
    char          *groupName; /* name of group or NULL */
    int           ID;         /* Group ID */
    enum aimMeshElem elementTopo; /* Element topology */
    int           order;      /* order of the element (1 - Linear) */
    int           nPoint;     /* number of points defining an element */
    int           nElems;     /* number of elements in the group */
    int           *elements;  /* Element-to-vertex connectivity (1-based)
                               nElem*nPoint in length */
} aimMeshElemGroup;
```

groupName group identifier that may be non-unique

ID group identifier that may be non-unique

elementTopo is one of:

```
enum aimMeshElem {aimUnknownElem, aimLine, aimTri, aimQuad, aimTet,
                  aimPyramid, aimPrism, aimHex};
```

order polynomial degree of element

nPoint number of points in an element

nElems number of elements the group

elements Element-to-vertex (1-based) connectivity nElem*nPoint in length

aimMeshRef Structure

Represents the boundary of a mesh and a reference to the full mesh

```
typedef struct {  
    enum aimMeshType type;      /* type of mesh referenced */  
    int nmap;                   /* number of EGADS Tessellation Objects */  
    aimMeshTessMap *maps;       /* the EGADS Tess Object and map to mesh verts */  
    int nbnd;                   /* number of boundary groups */  
    aimMeshBnd *bnds;           /* boundary group info */  
    char *fileName;             /* full path name (no extension) for grids */  
    int _delTess;               /* internal use only, whether tess/body ego are deleted */  
} aimMeshRef;
```

type is one of:

```
enum aimMeshType {aimUnknownMeshType, aimAreaMesh,  
                  aimSurfaceMesh, aimVolumeMesh};
```

nmap number of mappings from the boundary to the interior

maps boundary to the interior mapping

nbnd number of boundary groups

bnds boundary group information

fileName absolute path to the full mesh file name without the extension

_delTess Internal usage that should not be modified

aimMeshTessMap Structure

Represents the a boundary mesh and it's mapping to the interior

```
typedef struct {  
    ego tess;          /* the EGADS Tessellation Objects (contains Body) */  
    int *map;          /* the mapping between Tessellation vertices and  
                        mesh vertices -- tess verts in length */  
} aimMeshTessMap;
```

- tess** an EGADS tessellation of the boundary
- map** mapping from global tessellation vertices to the interior mesh vertices. Use EG_statusTessBody to get the length.

aimMeshBnd Structure

Represents the a boundary group information

```
typedef struct {  
    char *groupName;  /* name of group or NULL */  
    int ID;           /* Group ID */  
} aimMeshBnd;
```

- groupName** a name associated with a boundary group
- ID** an identifier associated with the group

Mesh writer entry points

The following two functions are required for each dynamically loaded mesh writer. They allow the AIM mesh writer interface the ability to complete the filenames and to output the meshes. This is dynamically loadable so that new (or custom) mesh writer can be easily attached to a CAPS session.

```
const char *extension = meshExtension()
```

extension the file extension used for this writer

```
icode = meshWrite(void *aimInfo, aimMesh *mesh)
```

aimInfo the AIM context

mesh the mesh data structure that will be written

icode integer return code

Delete previous meshes

```
icode = aim_deleteMeshes(void *aimInfo, aimMeshRef *meshRef)
```

aimInfo the AIM context

meshRef the pointer to the Mesh Reference Structure

icode integer return code

This should be called during the mesh writing preAnalysis to cleanup mesh files from previous invocations of the AIM instance. This is required because if the mesh file already exists, it is not (re)written in `aim_writeMeshes`.

Query mesh existence

```
icode = aim_queryMeshes(void *aimInfo, int index, aimMeshRef *meshRef)
```

aimInfo the AIM context

index the AnalysisOut Value index to query

meshRef the pointer to the Mesh Reference Structure

icode integer return code

This call returns `CAPS_SUCCESS` if the mesh file already exists and no others are needed, if positive then this is the number of file types that need to be written via calling `aim_writeMeshes`.

Write meshes

```
icode = aim_writeMeshes(void *aimInfo, int index,  
                        enum capsType stype, aimMesh *mesh)
```

aimInfo the AIM context

index the AnalysisOut Value index to write

stype ANALYSISIN or ANALYSISOUT

mesh the pointer to the Mesh Structure

icode integer return code

If meshes need to be output (see `aim_queryMeshes`), the mesh data must be populated and then written out by calling this function.

For stype = ANALYSISIN:

This calls `writeMesh` for each name specified by the list of strings in the analysis value. The suffix "Writer" is appended to each name.

For stype = ANALYSISOUT:

This calls `writeMesh` for each linked solver Analysis Input (as specified in the linkage).

After this call the memory allocated to fill **mesh** should be freed.

Initialize aimMeshRef

```
icode = aim_initMeshRef( aimMeshRef *meshRef)
```

meshRef the aimMeshRef instance for member data initialization

icode integer return code

Free aimMeshRef

```
icode = aim_freeMeshData( aimMeshRef *meshRef)
```

meshRef the aimMeshRef instance to free member data

icode integer return code

Initialize aimMeshBnd

```
icode = aim_initMeshBnd( aimMeshBnd *meshBnd)
```

meshBnd the aimMeshBnd instance for member data initialization

icode integer return code

Initialize aimMeshData

```
icode = aim_initMeshData( aimMeshData *meshData)
```

meshData the aimMeshData instance for member data initialization

icode integer return code

Free aimMeshData

```
icode = aim_freeMeshData( aimMeshData *meshData)
```

meshData the aimMeshData instance to free member data

icode integer return code

Element topological dimension

```
dim = aim_elemTopoDim( enum aimMeshElem topo )
```

topo the aimMeshElem element type

dim topological dimension of the element type: 1, 2 or 3

Add element group to aimMeshData

```
icode = aim_addMeshElemGroup( void *aimInfo, const char *groupName,  
                               int ID, enum aimMeshElem elementTopo,  
                               int order, int nPoint,  
                               aimMeshData *meshData)
```

aimInfo the AIM context
groupName the name of the group (may be **NULL**)
ID an integer group ID
order the degree of the polynomial for the elements
nPoint number of points in the element
meshData the aimMeshData where the element group is added
icode integer return code

Add element group to aimMeshData

```
icode = aim_addMeshElem( void *aimInfo, int nElems,  
                         aimMeshElemGroup *elemGroup)
```

aimInfo the AIM context
nElems number of elements to add to the element group
elemGroup the aimMeshElemGroup where the elements are added
icode integer return code

Write meshRef to disk

```
icode = aim_storeMeshRef( void *aimInfo, const aimMeshRef *meshRef,  
                          const char *mesheextension)
```

aimInfo the AIM context

meshRef the aimMeshRef instance written to disk

mesheextension the mesh extension used by the analysis AIM

icode integer return code

Note: This function should be called by an analysis AIM during preAnalysis to store a meshRef instance for mesh morphing.

Load aimMeshRef from disk

```
icode = aim_loadMeshRef( void *aimInfo, aimMeshRef *meshRef )
```

aimInfo the AIM context

meshRef the aimMeshRef instance fill from disk

icode integer return code

Note: This function should be called by an analysis AIM during preAnalysis to load a meshRef instance for mesh morphing.

Morph a meshRef

```
icode = aim_morphMeshUpdate( void *aimInfo, aimMeshRef *meshRef,  
                             , int numBody, ego *bodies)
```

aimInfo the AIM context
meshRef the aimMeshRef instance to be updated
numBody number of bodies
bodies ego list of new bodies (*numBody* in length)
icode integer return code

Note: The tessellation objects in *meshRef* are mapped to *bodies* and the boundary to interior mapping is updated.