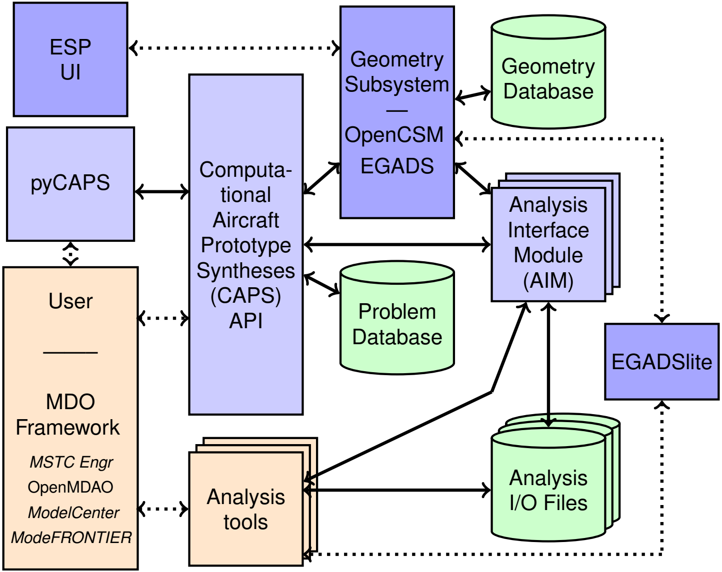
Computational Aircraft Prototype Syntheses
AIM Development

Enhanced CAPS (EnCAPS) Specification
For ESP Rev 1.19

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

CAPS Infrastructure in ESP



CAPS Objects

Object-based Not *Object Orientated*

- Like egos in `EGADS`
- Pointer to a C structure – allows for an 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

CAPS Definitions

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.

CAPS Definitions

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

CAPS Definitions

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).

CAPS Objects

Object	SubTypes	Parent Object
capsProblem	Parametric, Static	
capsValue	GeometryIn, GeometryOut, Branch, Parameter, User	capsProblem, capsValue
capsAnalysis		capsProblem
capsValue	AnalysisIn, AnalysisOut	capsAnalysis, capsValue
capsBound		capsProblem
capsVertexSet	Connected, Unconnected	capsBound
capsDataSet	User, Analysis, Interpolate, Conserve, Builtin, Sensitivity	capsVertexSet

Body Objects are EGADS Objects (egos)

CAPS Body Filtering

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.

CAPS Body Filtering

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_load` 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_load` is NULL, all Bodies with a “capsAIM” attribute that matches the AIM name are given to the AIM instance.

Analysis Interface & Meshing – Intro 1/2

- 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:

1. 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`.
2. 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*.
3. During restart only "Post" is executed at the last use of the AIM.
4. AIM specific storage is no longer indexed by the instance and is held internally.

Analysis Interface & Meshing – Intro 2/2

- 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 be hierarchical
  - Parent Analysis Objects specified at CAPS Analysis load
  - Parent and child AIMs can directly communicate
- Dynamically loaded at runtime – extendibility and extensibility

Windows	Dynamically Loaded Libraries (`name.dll`)
LINUX	Shared Objects (`name.so`)
MAC	*Bundles*, CAPS will use 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

capsValue Structure 1/6

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 capsvType {Boolean, Integer, Double, String, Tuple, Pointer, DoubleDeriv};
```

Notes:

1. The `Pointer` type is 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;
```

capsValue Structure 2/6

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};
```

capsValue Structure 3/6

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 Structure 4/6

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.

capsValue Structure 5/6

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

capsValue Structure 6/6

```
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 */
  int          lfixed;         /* length is fixed -- capsFixed */
  int          sfixed;         /* shape is fixed -- capsFixed */
  int          nullVal;        /* NULL handling -- capsNull */
  int          pIndex;         /* parent index */
  int          gInType;        /* 0 -- normal, 1 -- OCSM_CFGPMTR */
  union {
    int        integer;        /* single int -- length == 1 */
    int        *integers;      /* multiple ints */
    double     real;           /* single double -- length == 1 */
    double     *reals;         /* multiple doubles */
    char       *string;        /* character string (no single char) */
    capsTuple  *tuple;         /* tuple (no single tuple) */
    void       *AIMptr;        /* single pointer only */
  } vals;
  union {
    int        ilims[2];       /* integer limits */
    double     dlims[2];       /* double limits */
  } limits;
  char         *units;         /* the units -- "PATH" for strings converts slashes */
  capsObject   *link;          /* the linked object (or NULL) */
  int          linkMethod;     /* the link method -- capstMethod */
  int          *partial;       /* NULL or vector/array element NULL handling */
  int          ndot;           /* the number of derivatives */
  capsDot      *dots;          /* the derivatives associated with the Value */
} capsValue;
```

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

AIM – Registration/Initialization

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

AIM – Initialization

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

AIM – PreAnalysis & Execute

Parse Input data & Optionally Generate Input File(s)

```
icode = aimPreAnalysis(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(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)
- **icode** integer return code

AIM – Query & PostAnalysis

Check on running Analysis – Optional

```
icode = aimCheck(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)
- **icode** integer return code

Processing after the Analysis is run – No longer Optional

```
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

AIM – Termination & Output Parsing

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)

AIM – Discrete Structure 1/6

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

- Now a requirement
- Requires triangles
- Can be constructed from an external mesh generator
  - Look at `EG_initTessBody`, `EG_setTessEdge`, `EG_setTessFace` & `EG_statusTessBody`
  - Made understood 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 referece 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:
 *                        neighbors                          neighbors
 *       2          tri-side   vertices          4         side    vertices
 *      / \             0        1 2            / \          0        1 2
 *     /   \            1        2 0           5   3         1        2 3
 *    /     \           2        0 1          /  6  \        2        3 4
 *   0-------1                               /       \       3        4 5
 *                                          0----1----2      4        5 0
 *                        neighbors                          5        0 1
 *   3-------2      quad-side  vertices             nref = 7
 *   |       |          0        1 2
 *   |       |          1        2 3            6              neighbors
 *   |       |          2        3 0        3---.---2    quad-side  vertices
 *   0-------1          3        0 1        |       |        0        1 2
 *                                         7.   8   .5       1        2 3
 *                        neighbors         |       |        2        3 0
 *   4-------3        side     vertices     0---.---1        3        0 1
 *   |       |          0        1 2            4
 *   |       2          1        2 3
 *   |       |          2        3 4                nref = 9
 *   0-------1          3        4 0
 *                      4        0 1
 *       nref = 5
```

AIM – Discrete Structure 3/6

```
 */

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 */
} capsEleType;
```

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

AIM – Discrete Structure 4/6

```
/*
 * 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).

AIM – Discrete Structure 5/6

```
/*
 * 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 */
} capsBodyDiscr;
```

AIM – Discrete Structure 6/6

```
/*
 * defines a discretized collection of Bodies
 *
 * specifies the dimensionality, vertices, Element Types, and body discretizations.
 *
 * 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          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.

AIM – Discrete Support

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

Free the Discrete data for a Bound Object – Obsolete

```
icode = aimFreeDiscr(capsDiscr *discr)
```

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

AIM – Data Transfers

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 (`rank*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

AIM – Data Transfers

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(objective)/d(result)
d_bar	returned d(objective)/d(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(objective)/d(result)
d_bar	returned d(objective)/d(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
- 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

AIM Utility Library – Path handling

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 file name in Problem/Phase directory

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

- aimInfo: the AIM context
- rPath: the relative path filename in the Problem/Phase directory structure
- aimFile: the returned file name in the root structure of the Problem/Phase (length `PATH_MAX`)
- icode: integer return code

AIM Utility Library – Path handling

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

AIM Utility Library – Path handling

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

Execute a command in the AIMs path

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

aimInfo	the AIM context
command	the command to execute in a shell
icode	integer return code

AIM Utility Library – Body handling

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

AIM Utility Library – Units

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 invertion

```
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

AIM Utility Library – Units

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

AIM Utility Library – Units

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

AIM Utility Library – Conversions

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 or ANALYSISOUT
- **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 or ANALYSISOUT
- **name** the returned pointer to the string specifying the name
- **icode** integer return code

AIM Utility Library

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 capssType stype,
                     capsValue **value)
```

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

AIM Utility Library

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 – replaces `aim_setTess`

```
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)

AIM Utility Library

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)

AIM Utility Library

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

AIM Utility Library

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 capssType stype,
                       int *nValue, char ***names, capsValue **values)
```

aimInfo	the AIM context
index	the index to use (1 bias)
stype	GEOMETRYIN, GEOMETRYOUT, ANALYSISIN or ANALYSISOUT
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.

AIM Utility Library – Attributes

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

AIM Utility Library – Attributes

Get Value Attributes

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

- **aimInfo** the AIM context
- **index** the index to use (1 bias)
- **stype** GEOMETRYIN, GEOMETRYOUT, ANALYSISIN or ANALYSISOUT
- **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)

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)

AIM Utility Library – Sensitivities

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`.

AIM Utility Library – Sensitivities

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

AIM Utility Library – Error Handling

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, cleanup)

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

AIM Utility Library – Error Handling

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;
}
```

AIM Utility Library – Error Handling

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");
}
```

AIM Utility Library – Error Handling

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);
}
```

AIM Utility Library – Memory

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

AIM Utility Library – Memory

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

AIM Utility Library – Memory

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);
```

AIM Utility Library – Data Transfers

Initialize `capsBodyDiscr` Pointer

```
void aim_initBodyDiscr(capsBodyDiscr *discBody)
```

discBody	pointer to initialize

Linear Triangle/Quad Element Type with Nodal Data

```
icode = aim_nodalTriangleType(capsEleType *eletype)
icode = aim_nodalQuadType(capsEleType *eletype)
```

eletype	element type pointer to fill
icode	integer return code

Linear Triangle/Quad Element Type with Cell Data

```
icode = aim_cellTriangleType(capsEleType *eletype)
icode = aim_cellQuadType(capsEleType *eletype)
```

eletype	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

AIM Utility Library – Data Transfers

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(objective)/d(result)
d_bar	returned d(objective)/d(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(objective)/d(result)
- **d_bar** returned d(objective)/d(data)
- **icode** integer return code

Forward and *reverse differentiated* functions