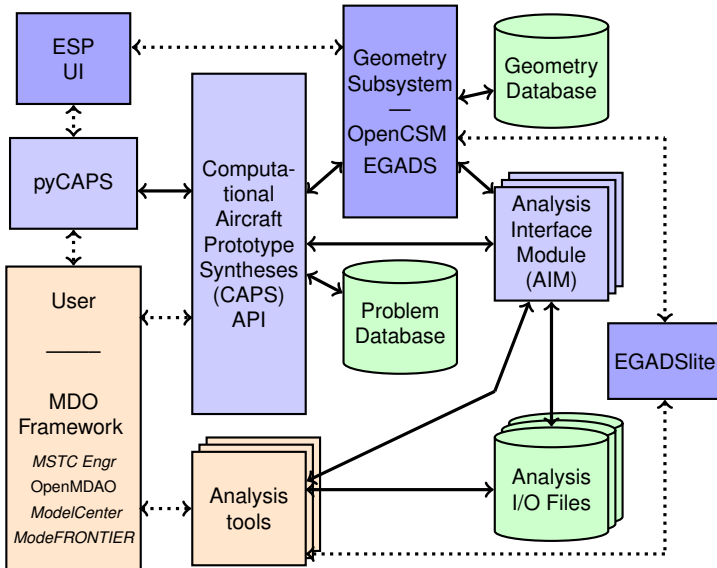




Computational Aircraft Prototype Syntheses: The CAPS API for ESP Rev 1.28

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.



Changing Thrusts Beginning at Rev 1.19

CAPS was originally designed to run concurrently with an MDO framework. This has turned out to be rarely the method of execution. In addition there were always issues in restarting from where the runs left off (due to the amount of state info stored in AIMs, the difficulty in getting to the correct place in the control program and the scattering of files). Also if MDO frameworks are not used, then additional execution support is required within the CAPS environment. So the enhancements include:

- Restarting runs the same script (or control program) *recycling* previous data.
- AIM reload. The AIMs ended up maintaining too much internal *state*, which made restarting almost impossible (requiring either rerunning or writing out the state). The AIMs need recasting not to hold on to extraneous data.
- A file structure where the *Problem Database* contains all of the *Analysis I/O Files* (seen in the block diagram on the previous slide).
- Better support for Analysis execution, which embraces asynchronous CAPS running when the Analysis is not run directly in the AIM.
- More emphasis on tracking data and decisions during the session.
- Enhanced handling of derivatives from both geometry construction and analysis output.
- Removal of Value Object of Value Objects.

Variable Dimension GeometryIn Value Objects

Now that OpenCSM supports the ability to change the size of its *Design* and *Configuration Parameters* (GeometryIn Value Objects), this complicates dealing with derivatives associated with these inputs. This is because the meaning and use of rows and columns are now malleable. There are now internal *slots* for derivatives with respect to GeometryOut Value Objects, which are internally *registered* when `caps_getDot` is called. This is done via specifying which row/column is in play. The same is true for DataSet Objects, which request sensitivity information.

Note that when a changing a GeometryIn Value Object that effects the size of other GeometryIn Value Objects:

- 1 You can get which other GeometryIn Value Objects are effected when calling `caps_setValue` (see `nGIVAL` and `GIVALS`).
- 2 Any GeometryOut Value *slots* associated with changed size GeometryIn Objects are invalidated and removed. These would need to get reregistered if still needed.
- 3 Any DataSets associated with the changed-size GeometryIn Value Objects are also removed and need to be reinstated if still required.

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 (*sub*)*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
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.

capsLength

This string Attribute must be applied to an EGADS Body to indicate the length units used in the geometric construction.

capsBound

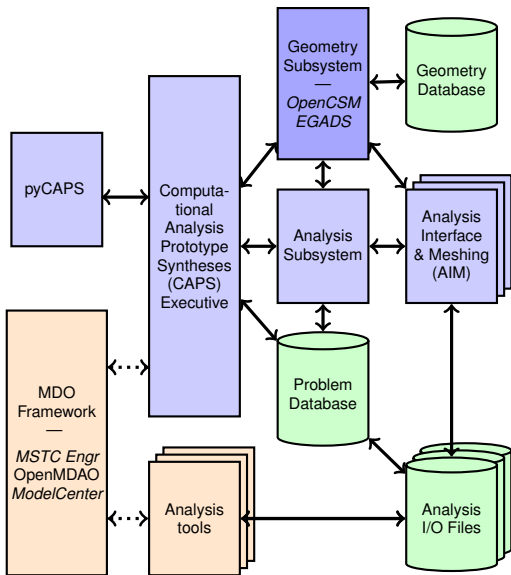
This string Attribute must be applied to EGADS BRep Objects to indicate which CAPS Bound(s) are associated with the geometry. A entity can be assigned to multiple Bounds by having the Bound names separated by a semicolon. Face examples could be “Wing”, “Wing;Flap”, “Fuselage”, and etc.

Note: Bound names should not cross dimensional lines.

capsGroup

This string Attribute can be applied to EGADS BRep Objects to assist in grouping geometry into logical sets. A geometric entity can be assigned to multiple groups in the same manner as the capsBound attribute.

Note: CAPS does not internally use this, but is suggested of classifying geometry.



Setup (or read) the Problem:

- Initialize Problem with *csm* (or *static*) file
GeomIn and GeomOut parameters
- Specify *mission* parameters
- Make Analysis instances
AnalysisIn and AnalysisOut params
- Create *Bounds*, *VetrexSets* & *DataSets*
- Establish linkages between parameters

Run the Problem:

- Adjust the appropriate parameters
- Regenerate Geometry (if *dirty* – *lazy*)
- Call for Analysis Input file generation
- AIM Execute runs each *solver*
- Inform CAPS that an Analysis has run
fills AnalysisOut, AnalysisDynO Objects & *DataSets* (*lazy*)
- Generate *Objective Function*

CAPS Execution Phases

CAPS has 4 fundamental modes for starting the session:

- Scratch – This is for development (and not production). It will remove any existing data in the *Scratch* directory of the Problem's path.
- Initial – This *phase* is started by a call to `caps_open` that points to a nonexistent directory. The initialization can either be from a CSM, geometry file, an OpenCSM or EGADS Model.
- Continuation – This occurs when CAPS has not fully completed a *phase* either do to an interruption or not reaching `caps_close` (where the *phase* is marked as completed). In this case the CAPS application or pyCAPS script can be run from the beginning, but *recycling* of results is used to quickly get to the position where the *phase* terminated.
- Starting from a completed *phase*. There are options for ignoring the deletion markers on Objects, read-only and reloading the CSM file.

This is controlled by the Problem Object's initialization using `caps_open`.

CAPS Directory Structure

At the top level **prName** (of `caps_open`) you will find *phase* sub-directories. Note that *Scratch* is not as protected as the others.

In each *phase* subdirectory you may see:

- `capsCSMFiles` – A directory containing the CSM/UDC files used for reloading the geometry – must include the file *capsCSMLoad*.
Can be generated by a call to `caps_phaseNewCSM` (see page 18).
- `capsRestart.cpc` – A CSM saved state file – or –
- `capsRestart.egads` – An EGADS saved geometry file (for nonparametric runs).
- `capsRestart` – This subdirectory contains the CAPS restart data.
- `capsClosed` – An indication that the *phase* has been closed (`caps_close` has been called marking completion).
- `capsLock` – A flag that another application is using this subdirectory.
- `AIMnames` – any number of directories each related to an AIM instance in the running CAPS Problem.

CAPS Modes of Analysis Execution

There are 3 different ways that Analyses can be executed:

- **Manual** – This is the default mode. It requires a call to `caps_preAnalysis` (page 59), the execution of the solver (use `caps_system` – page 59 if the execution is performed via the command line) and then `caps_postAnalysis`, see page 60.
- **By the AIM** – If the AIM can execute the Analysis (noted by the return argument **exec** from either `caps_queryAnalysis` – page 52 or `caps_makeAnalysis` – page 56) use `caps_execute` (page 53) to perform “pre”, “exec” and “post”.
- **Automatic** – Again if the AIM does the Analysis execution (see above) and the flag **exec** was set for *auto-exec* on input when instantiating the AIM using `caps_makeAnalysis` (page 56) then the Analysis is triggered automatically when data associated with the AIM is retrieved. This happens during invocations of `caps_getData` (page 66) or `caps_getValue` (page 34).

The Python CAPS API is built on `ctypes` and mirrors the C/C++ API

Methods have similar names and arguments, which are ordered consistently when possible (optional arguments are placed last)

C-arrays with strides are `lists` of `tuples`

Import statement: `from pyCAPS import caps`

Main API classes: `caps.capsObj` `caps.c_capsObj`

- `c_capsObj` is a `ctypes` struct for C function arguments of C `capsObj` type
- Python class `capsObj` wrap a `c_capsObj` and implement CAPS API
 - The wrapped `c_capsObj` is automatically deleted when a Python class is created from a `caps` method

Note: this is not pyCAPS but mostly a one-to-one wrapping of the C/C++ API

See `$ESP_ROOT/doc/CAPS/html/pyCAPShtml/index.html` or

`$ESP_ROOT/doc/CAPS/pdf/pyCAPS.pdf` for the full pyCAPS documentation

Get CAPS revision

```
caps_revision(int *major, int *minor)  
imajor, iminor = caps.revision()
```

major the returned major revision

minor the returned minor revision number

Check State of CAPS Problem Phase

```
icode = caps_phaseState(const char *prNm, const char *phNm, int *bts)  
bts = caps.phaseState(prNm, phNm)
```

prNm the path ending with the CAPS problem name

phNm the queried *phase* name (**NULL** is equivalent to *Scratch*)

bts the returned state (additive): 1 – locked, 2 – closed, 4 – no capsRestart directory

icode the integer return code

Setup for new Phase changing the CSM file

```
icode = caps_phaseNewCSM(const char *prName, const char *phName,  
                        const char *csm)  
    caps.phaseNewCSM(prName, phName, csm)
```

prName the path ending with the CAPS problem name

phName the new *phase* name

csm the CSM file to use in the new *phase* – for caps_open **flag** = 5

icode the integer return code

The above functions may be called before CAPS *proper* is started via the invocation of caps_open

Open CAPS Problem Phase

```
icode = caps_open(const char *prName, const char *phName, int flag,
                  void *ptr, int outLevel, capsObj *problem,
                  int *nErr, capsErrs **errs)
```

```
problem = caps.open(prName, phName, flag, ptr, outLevel=1)
```

prName the path ending with the CAPS problem name

if exists the stored data initializes the problem, otherwise the directory is created

phName the current *phase* name (**NULL** is equivalent to *Scratch*)

flag 0 – **ptr** is a filename, 1 – **ptr** is an OpenCSM Model Structure, 2 – **ptr** is a Model **ego**,

3 – **ptr** is the starting *phase* name, 4* – continuation (**ptr** can be **NULL**),

5 – **ptr** is the starting *phase* name with reloading of the CSM/UDC files †,

6 – **ptr** is the starting *phase* name but does not remove Objects marked for deletion,

7 – Open the existing **phName** in read-only mode (**ptr** can be **NULL**)

ptr input path/filename (**flag** == 0) – based on file extension:

*.csm initialize the project using the specified OpenCSM file

*.egads initialize the project based on the static geometry

– or – pointer to OpenCSM/EGADS Model – left open after caps_close

outLevel 0 - minimal, 1 - standard (default), 2 - debug

problem the returned CAPS problem Object

nErr the returned number of errors generated – 0 means no errors

errs the returned CAPS error structure – **NULL** with no errors

icode the integer return code

Notes: * A continuation can only occur on the same setup as initialized (ESP rev, version of OpenCASCADE and machine architecture)

† These files must be placed in the capsCSMFiles subdirectory (of the empty Phase directory) before calling caps_open

Specify a Call-back for Broken Links

```
icode = caps_brokenLink(void (*callBack) (capsObj problem, capsObj obj,  
                                     enum capstMethod tmethod, char *name,  
                                     enum capsstType stype))
```

callBack the function to be called when links are found to be broken – or –
NULL to remove an existing call-back

problem the almost complete reloaded Problem Object

obj is the existing Object that has lost its link (either source or target –
see **stype**)

tmethod the transfer method used for the broken link

name the name of the lost Value Object

stype the subtype of the lost Value Object

icode the integer return code

This is only needed if `caps_open` is invoked with **flag** as 5 or there are deleted Parameter Value Objects, Bounds and/or Analysis Objects (note that this must be called before `caps_open`).

If there are existing links that are broken due to the changes in the objects then the function **callBack** is invoked for each broken link during `caps_open`.

Note that this is not *thread safe* for multi-thread/multi-Problem situations. If you wish to have different call-backs per Problem initialization you will need to ensure the calls to `caps_open` are sequential.

Do not use CAPS signal handling

```
caps_externSignal()
```

Must be called before `caps_open`. Calling program is responsible for invoking `caps_rmLock()` on any abort, which deletes the `capsLock` file.

Get Problem root

```
icode = caps_getRootPath(const capsObj problem, const char **fullPath)  
fullPath = problem.getRootPath()
```

problem the input CAPS Problem Object

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.

Close CAPS Problem

```
icode = caps_close(capsObj problem, int complete, const char *phName)  
del problem or problem.close(complete = 0, phName = None)
```

- problem** the input CAPS problem is written to disk and closed; memory cleanup is performed
- complete** -1 – remove the *phase*, 0 – the *phase* is left open, 1 – the *phase* is completed
- phName** Phase Name of the Scratch phase is closed as complete
- icode** the integer return code

Notes: If caps_open was initialized with an OpenCSM or EGADS Model, it is left open. All Analyses must be past *Post* to be complete.

Information about an Object

```
icode = caps_info(capsObj object, char **name, enum capsoType *otype,  
                  enum capssType *stype, capsObj *link,  
                  capsObj *parent, capsOwn *last)
```

```
name, otype, stype, link, parent, last = object.info()
```

object the input CAPS Object

name the returned Object name pointer (if any)

otype the returned Object type: Problem, Value, Analysis, Bound, VertexSet, DataSet

stype the returned subtype (depending on **otype**)

link the returned linkage Value Object (**NULL** – no link)

parent the returned parent Object (**NULL** for a Problem or an Attribute generated User Value)

last the returned last owner to *touch* the Object

icode integer return code, can be 1 indicating the Object is marked for deletion

Number of Children in a Parent Object

```
icode = caps_size(capsObj object, enum capsObjType type,  
                 enum capsObjType subtype, int *size, int *nErr,  
                 capsErrors **errs)
```

```
size = object.size(type, subtype)
```

object the input CAPS Object

type the data type to size: Bodies, Attributes, Value, Analysis, Bound, VertexSet, DataSet

subtype the subtype to size (depending on type)

size the returned size

nErr the returned number of errors generated – 0 means no errors

errs the returned CAPS error structure – **NULL** with no errors

icode integer return code

Mark an Object for Deletion

```
icode = caps_markForDelete(capsObj object)  
object.markForDelete()
```

object the Object to be deleted in the next Phase

Note: only Value Objects of subtype Parameter, Analysis and Bound Objects may be deleted! Value Objects of subtype User are automatically removed at Phase closure.

icode integer return code

Get Child by Index

```
icode = caps_childByIndex(capsObj object, enum capsoType type,  
                          enum capssType sty, int ind, capsObj *child)  
child = object.childByIndex(type, sty, ind)
```

object the input parent Object

type the Object type to return: Value, Analysis, Bound, VertexSet, DataSet

sty the subtype to find (depending on type)

ind the index [1-**size**]

child the returned CAPS Object

icode integer return code

Get Child by Name

```
icode = caps_childByName(capsObj object, enum capsoType type,  
                        enum capssType stype, const char *name,  
                        capsObj *child, int *nErr, capsErrs **errs)  
child = object.childByName(type, stype, name)
```

object the input parent Object

type the Object type to return: Value, Analysis, Bound, VertexSet, DataSet

stype the subtype to find (depending on type)

name a pointer to the index character string

child the returned CAPS Object

nErr the returned number of errors generated – 0 means no errors

errs the returned CAPS error structure – NULL with no errors

icode integer return code

Set Verbosity Level

```
icode = caps_outLevel(capsObj problem, int outLevel)  
oldOutLevel = problem.outLevel(outLevel)
```

problem the CAPS problem object

outLevel 0 - minimal, 1 - standard (default), 2 - debug

icode the integer return code / old outLevel

Get Body by index

```
icode = caps_bodyByIndex(capsObj obj, int index, ego *body,  
                        char **unit)  
body = obj.bodyByIndex(index)
```

obj the input CAPS Problem or Analysis Object

index the index [1-**size**] – see caps_size, page 24

body the returned EGADS Body Object ([egads.ego](#))

units pointer to the string declaring the length units – **NULL** for unitless values

icode integer return code

Get Error Information

```
icode = caps_errorInfo(capsErrs *errors, int eindex, capsObj *errObj,  
                      int *eType, int *nLines, char ***lines)  
lines = errors.info()  
errors the input CAPS Error structure  
eindex the index into errors (1 bias)  
errObj the offending CAPS Object  
eType the returned error type (CINFO, CWARN, CERROR or CSTAT)  
nLines the returned number of comment lines to describe the error  
lines a pointer to a list of character strings with the error description  
icode integer return code
```

Free Error Structure

```
icode = caps_freeError(capsErrs *errors)  
del errors  
errors the CAPS Error structure to be freed  
icode integer return code
```

Write Geometry Parameter File

```
icode = caps_writeParameters(const capsObj problem, char *fileName)  
    problem.writeParameters(fileName)
```

problem the input CAPS Problem Object

fileName the name of the parameter file to write

icode integer return code

Note: This outputs an OpenCSM Design Parameter file.

Read Geometry Parameter File

```
icode = caps_readParameters(const capsObj problem, char *fileName)  
    problem.readParameters(fileName)
```

problem the input CAPS Problem Object

fileName the name of the parameter file to read

icode integer return code

Note: This reads an OpenCSM Design Parameter file and overwrites (makes *dirty*) the current state for the GeometryIn Values in the file.

Write out Geometry

```
icode = caps_writeGeometry(capsObj obj, int flag, const char *fName,  
                           int *nErr, capsErrs **errs)  
obj.writeGeometry(fileName, flag = 1)
```

obj the input CAPS Problem/Analysis Object

flag the write flag: **0** – no additional output, **1** – also write Tessellation Objects for EGADS output (only for Analysis Objects)

fName the name of the file to write – typed by extension (case insensitive):

iges/igs – IGES File

step/stp – STEP File

brep – OpenCASCADE File

egads – EGADS file (which includes attribution)

nErr the returned number of errors generated – **0** means no errors

errs the returned CAPS error structure – **NULL** with no errors

icode integer return code

Note: The *EGADS Tessellation Objects* used by the Analysis Object are written in the EGADS output file along with the geometry of the Bodies.

Get History of an Object

```
icode = caps_getHistory(capsObj obj, int *nhist, capsOwn **hist)
hist = obj.getHistory()
```

obj the input CAPS Object

nhist the returned length of the history list

hist the returned pointer to the list of History entities (**nhist** in length)

icode integer return code

Set the Intent Phrase for History tracking

```
icode = caps_intentPhrase(capsObj problem, int nLines, char **lines)
problem.intentPhrase(lines)
```

problem the CAPS Problem Object to set the phrase

nLines the number of comment lines to describe the intent phrase
can be 0 to unset any phrase

lines a pointer to a list of character strings with the description
can be **NULL** if **nLines** is 0

icode integer return code

Get Owner Information

```
icode = caps_ownerInfo(const capsObj problem, const capsOwn owner,  
                      char **phase, char **pname, char **pID,  
                      char **userID, int *nLines, char ***lines,  
                      short *datetime, CAPSLONG *sNum)  
    pname, pID, userID, lines, datetime, sNum = owner.info()
```

problem the CAPS Problem Object

owner the input CAPS Owner structure

phase the returned Phase Name when this entry was generated (can be **NULL**)

pname the returned pointer to the process name

pID the returned pointer to the process ID

userID the returned pointer to the user ID

nLines the returned number of comment lines to describe the intent phrase

lines a returned pointer to a list of character strings with the description

datetime the filled date/time stamp info – 6 in length:
year, month, day, hour, minute, second

sNum the sequence number (always increasing)

icode integer return code

Create A Value Object

```

icode = caps_makeValue(capsObj problem, const char *vname,
                      enum capsType stype, enum capsVType vtype,
                      int nrow, int ncol, const void *data,
                      int *partial, const char *units, capsObj *val)
val = problem.makeValue(vname, stype, data)

```

problem the input CAPS Problem Object where the Value to to reside

vname the Value Object name to be created

stype the Object subtype: Parameter or User

vtype the value data type:

0	Boolean	2	Double	4	String Tuple
1	Integer	3	String		

nrow number of rows

ncol number of columns – *Value length = nrow * ncol*

data pointer to the appropriate block of memory

must be a pointer to a contiguous block of memory for strings (each zero terminated)

must be a pointer to a *capsTuple* structure(s) when **vtype** is a Tuple

partial integer vector/array containing specific *ntype* indications

units string pointer declaring the units for **vtype 2** – **NULL** for unitless values
if **vtype** is **3** and **units** is “PATH” – slashes are converted automatically

val the returned CAPS Value Object

icode integer return code

Retrieve Values

```
icode = caps_getValue(capsObj val, enum capsvType *vtype, int *nrow,
                      int *ncol, const void **data,
                      const int **partial, const char **units,
                      int *nErr, capsErrs **errs)
```

```
data = val.getValue()
```

val the input Value Object

vtype the returned data type:

0	Boolean	2	Double	4	String Tuple	6	Double w/ Deriv
1	Integer	3	String	5	AIM pointer		

nrow returned number of rows

ncol returned number of columns – *Value length = nrow * ncol*

data a filled pointer to the appropriate block of memory (**NULL** – don't fill)

Can use `caps_childByIndex` (page 25) to get Value Objects

partial a returned integer vector/array containing specific `ntype` indications

NULL is returned except for `ntype` is 'partial' – filled with 'not NULL' or 'is NULL'

units the returned pointer to the string declaring the units

if **vtype** is 3 and **units** "PATH" – slashes are converted automatically

nErr the returned number of errors generated (Analysis Out) – 0 means no errors

errs the returned CAPS error structure (Analysis Out) – **NULL** with no errors

icode integer return code

Use the structure *capsTuple* when casting **data** if a Tuple (4)

Reset A Value Object

```
icode = caps_setValue(capsObj val, enum capsvType vtype, int nrow,
                     int ncol, const void *data, const int *partial,
                     const char *units, int *nErr, capsErrs **errs)
```

```
val.setValue(data)
```

val the input CAPS Value Object (not for GeometryOut, AnalysisOut or AnalysisDynO)

vtype the data type:

0	Boolean	2	Double	4	String Tuple
1	Integer	3	String	5	AIM pointer

nrow number of rows

ncol number of columns – *Value length* = **nrow** * **ncol**

data pointer to the appropriate block of memory used to reset the values; must point to a contiguous block of memory for *Value length* strings (each zero terminated)

partial an integer vector/array of *Value length* containing specific **ntype** indications ignored for length = 1 or **ntype** is 'NULL invalid' – may be NULL if non-NULL **ntype** is set to 'partial' – must be filled with 'not NULL' or 'is NULL' See caps_getValueProp

units the string declaring the units for **data**

nErr the returned number of errors generated (Geometry In) – 0 means no errors

errs the returned CAPS error structure (Geometry In) – NULL with no errors

icode integer return code

Get Valid Value Range

```
icode = caps_getLimits(capsObj val, capsvType *vtype,
                      const void **limits, const char **units)
```

See the Appendix on Limits

val the input Value Object
vtype the data type:
 -2 Doubles | -1 Integers | 1 Integer | 2 Double
limits an returned pointer to a block of memory containing the valid range
 [2 or 2*nrow*ncol*sizeof(vtype) in length] – or – NULL if not yet filled
units a string units of the limits
icode integer return code

Note: use caps_getValue or caps_getValueSize if **nrow** and/or **ncol** are needed.

Retrieve the Value's Size

```
icode = caps_getValueSize(capsObj val, int *nrow, int *ncol)
nrow, ncol = val.getValueSize()
```

val the input Value Object
nrow returned number of rows
ncol returned number of columns – *Value length = nrow * ncol*
icode integer return code

Note: this does not possibly initiate auto-execution like caps_getValue.

Set Valid Value Range

```
icode = caps_setLimits(capsObj val, capsvType vtype, void *limits,
                      const char *units, int *nErr, capsErrs **errs)
```

See the Appendix on Limits

- val** the input Value Object (only for the User & Parameter subtypes)
- vtype** the data type of the limits pointer:

-2	Doubles		-1	Integers		1	Integer		2	Double
----	---------	--	----	----------	--	---	---------	--	---	--------
- limits** a pointer to the appropriate block of memory which contains the minimum and maximum range allowed (2 or 2*nrow*ncol in length)
- units** a string units of the limits
- nErr** the returned number of errors generated – 0 means no errors
- errs** the returned CAPS error structure – NULL with no errors
- icode** integer return code

Note: use caps_getValue or caps_getValueSize if nrow and/or ncol are needed.

Get Value Properties

```
icode = caps_getValueProps(capsObj val, int *dim, int *gInType,
                           enum capsFixed *lfix, enum capsFixed *sfix,
                           enum capsNull *ntype)
```

```
dim, pmtr, lfix, sfix, ntype = val.getValueProps()
```

val the input Value Object

dim the returned dimensionality:

0 scalar only

1 vector or scalar

2 scalar, vector or 2D array

gInType the returned type: **0** – GeometryIn type → OCSM_DESPMTR (or not GeomIn),

1 – GeometryIn type → OCSM_CFGPMTR,

2 – GeometryIn type → OCSM_CONPMTR

lfix **0** – the length(s) can change, **1** – the length is fixed

sfix **0** – the Shape can change, **1** – Shape is fixed

ntype **0** – NULL invalid, **1** – not NULL, **2** – is NULL, **3** – partial NULL

icode integer return code

Set Value Properties

```
icode = caps_setValueProps(capsObj val, int dim, enum capsFixed lfix,  
                           enum capsFixed sfix, enum capsNull ntype,  
                           int *nErr, capsErrs **errs)
```

```
val.setValueProps(dim, lfix, sfix, ntype)
```

val the input Value Object (only for the User & Parameter subtypes)

dim the dimensionality:

0 scalar only

1 vector or scalar

2 scalar, vector or 2D array

lfix **0** – the length(s) can change, **1** – the length is fixed

sfix **0** – the Shape can change, **1** – Shape is fixed

ntype **0** – NULL invalid, **1** – not NULL, **2** – is NULL

nErr the returned number of errors generated – **0** means no errors

errs the returned CAPS error structure – **NULL** with no errors

icode integer return code

Units conversion

```
icode = caps_convertValue(capsObj val, double inVal,  
                           const char *inUnit, double *outVal)  
val.convertValue(inVal, inUnit)
```

val a Value Object

inVal the source value to be converted

inUnit the pointer to the string declaring the source units

outVal the returned converted value in the units of the **val** Value Object

icode integer return code

Free memory in Value Structure

```
caps_freeValue(capsValue *value)  
del value
```

value a pointer to the Value structure to be cleaned up

Transfer Values

```
icode = caps_transferValues(capsObj src, enum capstMethod tmethod,  
                           capsObj dst, int *nErr, capsErrs **errs)  
dst.transferValues(tmethod, src)
```

src the source input Value Object (not for Tuple vtypes) – or –
DataSet Object

tmethod 0 – copy, 1 – integrate, 2 – weighted average – (1 & 2 only for DataSet **src**)

dst the destination Value Object to receive the data

Notes:

- Must not be GeometryOut, AnalysisOut or AnalysisDynO
- Shapes must be compatible
- Overwrites any Linkage

nErr the returned number of errors generated – 0 means no errors

errs the returned CAPS error structure – **NULL** with no errors

icode integer return code

Establish Linkage between Value Objects

```
icode = caps_linkValue(capsObj link, enum capstMethod tmethod,  
                      capsObj trgt, int *nErr, capsErrs **errs)  
trgt.linkValue(link, tmethod)
```

link linking Value Object (not for AnalysisDynO, User subtype or Tuple vtype)
– or – DataSet Object

tmethod 0 – copy, 1 – integrate, 2 – weighted average – (1 & 2 only for DataSet **link**)

trgt the target Value Object which will get its data from **link**

Notes:

- Must not be GeometryOut, AnalysisOut or AnalysisDynO
- Shapes must be compatible
- **link** = **NULL** – removes any Linkage

nErr the returned number of errors generated – 0 means no errors

errs the returned CAPS error structure – **NULL** with no errors

icode integer return code

Note: circular linkages are not allowed!

Set and use OpenCSM Finite-Difference Step Size

```
icode = caps_setStepSize(capsObj val, const double *sizes)
      val.setStepSizeSize(sizes) [See the Appendix on StepSize]
      val the input CAPS Value Object (GeometryIn/DESPMTR types only)
      sizes the FD step sizes for each Value member (nrow*ncol in length)
             a zero indicates use analytic derivatives; can be NULL – set all to zero
      icode integer return code
```

Get the OpenCSM Finite-Difference Step Size

```
icode = caps_getStepSize(capsObj val, const double **sizes)
      sizes = val.getStepSizeSize() [See the Appendix on StepSize]
      val the input CAPS Value Object (GeometryIn/DESPMTR types only)
      sizes the returned FD step sizes for each Value member (nrow*ncol in length)
             a zero indicates use analytic derivatives; can be NULL – all set to zero
      icode integer return code
```

Should only be used for debugging purposes or if OpenCSM uses Finite Differences and the default step is poor for the design parameter at-hand

Get a list of Derivatives available

```
icode = caps_hasDeriv(capsObj val, int *ndot, char ***names,  
                      int *nErr, capsErrs **errs)  
names = val.hasDeriv()
```

val the input CAPS Value Object (*DoubleDeriv* type only)

ndot the returned length of the number of dots available

names the returned pointer to the list of derivative names (**ndot** in length – freeable)

nErr the returned number of errors generated – **0** means no errors

errs the returned CAPS error structure – **NULL** with no errors

icode integer return code

DoubleDeriv types only exist for GeometryOut and certain AnalysisOut as well as AnalysisDynO Value Objects

Get Derivative values

```
icode = caps_getDeriv(capsObj val, const char *name, int *len,  
                      int *len_wrt, double **deriv, int *nErr,  
                      capsErrs **errs)
```

```
deriv = val.getDeriv(name)
```

val the input CAPS Value Object (*DoubleDeriv* type only)

name the input name of the derivative

len the returned rows of the deriv (the length of the Value Object)

len_wrt the returned columns of deriv (length of the w.r.t. Value Object)

deriv the returned pointer to the derivative information (**len** x **len_wrt** in length)

nErr the returned number of errors generated – **0** means no errors

errs the returned CAPS error structure – **NULL** with no errors

icode integer return code

DoubleDeriv types only exist for GeometryOut and certain AnalysisOut as well as AnalysisDynO Value Objects.

For 2D Value Object or w.r.t. Value Object the indexing is flattened where the column index has no stride (i.e. $irow * ncol + icol$).

Convert value between units

See Appendix Python Units

```
icode = caps_convert(int count, const char *inUnit, double *inVal,  
                    const char *outUnit, double *outVal)
```

count length of **inVal** and **outUnit** arrays

inUnit a string representing the units of **inVal**

inVal the input values to be converted

outUnit a string representing the desired units of **outVal**

outVal the output values in units of **outUnit** (may be same pointer as **inVal**)

icode integer return code

Multiply units

See Appendix Python Units

```
icode = caps_unitMultiply(const char *unitL, const char *unitR,  
                        char **outUnit)
```

unitL a input string representing units

unitR a input string representing units

outUnit a string representing the resulting units from multiplying **unitL** and **unitR**

icode integer return code

Divide units

See Appendix Python Units

```
icode = caps_unitDivide(const char *unitL, const char *unitR,  
                        char **outUnit)
```

unitL a input string representing units

unitR a input string representing units

outUnit a string representing the resulting units from dividing **unitL** and **unitR**

icode integer return code

Raise units

See Appendix Python Units

```
icode = caps_unitRaise(const char *unit, int power, char **outUnit)
```

unit a input string representing units

power power to raise **unit**

outUnit a string representing the resulting units from raising **unit** to **power**

icode integer return code

Root units

See Appendix Python Units

```
icode = caps_unitRoot(const char *unit, int root, char **outUnit)
```

unit a input string representing units

root power to raise **unit**

outUnit a string representing the resulting units from raising **unit** to $1/\text{root}$

icode integer return code

Invert units

See Appendix Python Units

```
icode = caps_unitInvert(const char *unit, char **outUnit)
```

unit a input string representing units

outUnit a string representing the resulting units from inverting **unit**

icode integer return code

Offset units

See Appendix Python Units

```
icode = caps_unitOffset(const char *unit, double off, char **outUnit)
```

unit a input string representing units

off offset to apply to **unit**

outUnit a string representing the resulting units from offsetting **unit** by **off**

icode integer return code

Valid unit string

See Appendix Python Units

```
icode = caps_unitParse(const char *unit)
```

unit a input string representing units

icode integer return code (CAPS_SUCCESS if valid, CAPS_UNITERR otherwise)

Valid unit conversion

See Appendix Python Units

```
icode = caps_unitConvertible(const char *unitL, const char *unitR)
```

unitL a input string representing units

unitR a input string representing units

icode integer return code (CAPS_SUCCESS **unitL** is convertible to **unitR**, CAPS_UNITERR otherwise)

Unit comparison

See Appendix Python Units

```
icode = caps_unitCompare(const char *unitL, const char *unitR,  
                        int *compare)
```

unitL a input string representing units

unitR a input string representing units

compare signed difference between **unitL** and **unitR**

icode integer return code

Get Attribute by name

```
icode = caps_attrByName(capsObj object, char *name, capsObj *attr)  
attr = object.attrByName(name)
```

object any CAPS Object

name a string referring to the Attribute name

attr the returned User Value Object
will be deleted at the end of the *phase*

icode integer return code

Get Attribute by index

```
icode = caps_attrByIndex(capsObj object, int index, capsObj *attr)  
attr = object.attrByIndex(index)
```

object any CAPS Object

index the index (bias 1) to the list of Attributes

attr the returned User Value Object – Attribute name is the Value Object name
will be deleted at the end of the *phase*

icode integer return code

Set an Attribute

```
icode = caps_setAttr(capsObj object, const char *name, capsObj attr)
object.setAttr(attr, name=None)
```

object any CAPS Object

name a string referring to the Attribute name – **NULL**: use name in **attr**
Note: an existing Attribute of this name is overwritten with the new value

attr the Value Object containing the attribute
2D arrays and Tuples are not supported; 1D arrays will have rows only

icode integer return code

Delete an Attribute

```
icode = caps_deleteAttr(capsObj object, char *name)
object.deleteAttr(name)
```

object any CAPS Object

name a string referring to the Attribute to delete
NULL deletes all attributes attached to the Object

icode integer return code

Query Analysis – Does not ‘load’ or create an object

```
icode = caps_queryAnalysis(capsObj problem, const char *aname,  
                           int *nIn, int *nOut, int *exec)  
nIn, nOut, execute = problem.queryAnalysis(aname)
```

problem a CAPS Problem Object

aname the Analysis (and AIM plugin) name

nIn the returned number of Inputs

nOut the returned number of Outputs

exec returned execution flag: **0** – no execution, **1** – aimExecute exists (can auto-exec)

icode integer return code

Note: this causes the the DLL/Shared-Object to be loaded (if not already resident)

Execute Geometry Build or Analysis

```
icode = caps_execute(capsObj object, int *status, int *nErr,  
                    capsErrs **errors)  
object.execute()
```

- object** the Analysis or Problem Object
a *Geometry*-only regen is forced when this is a Problem Object
for an Analysis Object that has aimExecute this runs aimPreAnalysis,
aimExecute and aimPostAnalysis
- status** the returned status (0 – done, 1 – running)
currently unused – always returns 0
- nErr** the returned number of errors generated – 0 means no errors
- errors** the returned CAPS error structure – NULL with no errors
- icode** integer return code

Get Bodies

```
icode = caps_getBodies(capsObj aobj, int *nBody, ego **bodies,  
                      int *nErr, capsErrs **errs)  
bodies = aobj.getBodies()
```

- aobj** the Analysis Object
- nBody** the returned number of EGADS Body Objects that match the Analysis' intent
- bodies** the returned pointer to a list of EGADS Body/Node Objects (length – **nBody**)
- nErr** the returned number of errors generated – **0** means no errors
- errors** the returned CAPS error structure – **NULL** with no errors
- icode** integer return code

Get Tessellations

```
icode = caps_getTessels(capsObj aobj, int *nTessel, ego **tessels,  
                      int *nErr, capsErrs **errs)  
tessels = aobj.getTessels()
```

- aobj** the Analysis Object
- nTessel** the returned number of EGADS Tessellation Objects
- tessels** the returned pointer to a list of EGADS Tessellations (length – **nTessel**)
- nErr** the returned number of errors generated – **0** means no errors
- errors** the returned CAPS error structure – **NULL** with no errors
- icode** integer return code

Query Analysis Input Information

```
icode = caps_getInput(capsObj problem, const char *aname, int index,  
                      char **ainame, capsValue *default)
```

Not implemented yet

problem a CAPS Problem Object

aname the Analysis (and AIM plugin) name

index the Input index [1-nIn]

ainame a pointer to the returned Analysis Input variable name (use EG_free to free memory)

default a pointer to the filled default value(s) and units – use caps_freeValue to cleanup

Query Analysis Output Information

```
icode = caps_getOutput(capsObj problem, const char *aname, int index,  
                       char **aoname, capsValue *form)
```

Not implemented yet

problem a CAPS Problem Object

aname the Analysis (and AIM plugin) name

index the Output index [1-nOut]

aoname a pointer to the returned Analysis Output variable name (use EG_free)

form a pointer to the Value Shape & Units information – returned
use caps_freeValue to cleanup

Create a new Analysis Object

```
icode = caps_makeAnalysis(capsObj problem, const char *aname,
                          const char *name, const char *uSys,
                          char *intent, int *exec, capsObj *analysis,
                          int *nErr, capsErrs **errs)

analysis = problem.makeAnalysis(aname, name, uSys=None,
                                intent=None, execute=1)
```

problem a CAPS Problem Object

aname the Analysis (AIM plugin) name

name the unique supplied name for this instance (can be **NULL**)

uSys pointer to string describing the unit system to be used by the AIM (can be **NULL**)
see specific AIM documentation for a list of strings for which the AIM will respond

intent the *intent* character string used to pass Bodies to the AIM, **NULL** – no filtering

exec the execution flag: On input **0** – no auto-exec, **1** – allow for auto-exec

On output **0** – no AIM execution, **1** – aimExecute exists

analysis the resultant Analysis Object

nErr the returned number of errors generated – **0** means no errors

errors the returned CAPS error structure – **NULL** with no errors

icode integer return code

Note: If **exec** is returned as **1** then `aimPreAnalysis`, `aimExecute` and `aimPostAnalysis` automatically run when `caps_execute` (page 53) is called. When **exec** is input (and output) as **1** the analysis can run in a *lazy* manner when there is a request for an AIM output or data transfer.

Initialize Analysis from another Analysis Object

```
icode = caps_dupAnalysis(capsObj from, const char *name, capsObj *obj)  
obj = from.dupAnalysis(name)
```

- from** an existing CAPS Analysis Object
- name** the name of the duplicate Analysis Object
- obj** the resultant Analysis Object
- icode** integer return code

Get Dirty Analysis Object(s)

```
icode = caps_dirtyAnalysis(capsObj obj int *nAobj, capsObj **aobjs)  
aobjs = obj.dirtyAnalysis()
```

- obj** a CAPS Problem, Bound or Analysis Object
- nAobjs** the returned number of *dirty* Analysis Objects
- aobjs** a returned pointer to the list of *dirty* Analysis Objects (*freeable*)
- icode** integer return code

Note: Listed from most *stale* to most recent – the order in which to execute.

Get Info about an Analysis Object

```
icode = caps_analysisInfo(capsObj aobj, char **dir, char **uSys,  
                           int *major, int *minor, char **intent,  
                           int *nfields, char ***fnames, int **frank,  
                           int **fInOut, int *exec, int *status)  
dir, uSys, major, minor, intent, fnames, franks, fInOut,  
execute, status = aobj.analysisInfo()
```

- aobj** the input Analysis Object
- dir** a returned pointer to the string specifying the directory for file I/O
name (or **aname** augmented with the instance number) of caps_makeAnalysis
- uSys** returned pointer to string describing the unit system used by the AIM (can be **NULL**)
- major** the returned AIM major version number
- minor** the returned AIM minor version number
- intent** the returned pointer to the *intent* character string used to pass Bodies to the AIM
- nfields** the returned number of fields for DataSet filling
- fnames** a returned pointer to a list of character strings with the field/DataSet names
- frank** 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)
- exec** returned execution flag: **0** – no AIM execution, **1** – aimExecute exists, **2** – auto-exec
- status** **0** – up to date, **1** – *dirty* Analysis inputs, **2** – *dirty* Geometry inputs
3 – both Geometry & Analysis inputs are *dirty*, **4** – new geometry,
5 – *post Analysis* required, **6** – Execution & *post Analysis* required
- icode** integer return code

Generate Analysis Inputs

```
icode = caps_preAnalysis(capsObj analysis, int *nErr, capsErrs **errs)  
analysis.preAnalysis()
```

- analysis** the Analysis Object – use `caps_execute` (page 53) for *auto-exec* Objects
Also use `caps_execute` to perform a *Geometry*-only regen
- nErr** the returned number of errors generated – 0 means no errors
- errs** the returned CAPS error structure – **NULL** with no errors
- icode** integer return code

Execute the Command Line String

```
icode = caps_system(capsObj aobj, const char *rpath, const char *cmd)  
analysis.system(cmd, rpath=None)
```

- aobj** the Analysis Object
- rpath** the relative path from the Analysis' directory or **NULL** (in the Analysis path)
- cmd** the command line string to execute
- icode** integer return code

Notes:

- 1 only needed when explicitly executing the appropriate analysis solver (*i.e.*, not using the AIM)
- 2 should be invoked after `caps_preAnalysis` and before `caps_postAnalysis`
- 3 this must be used instead of the OS *system* call to ensure that journaling properly functions

Mark Analysis as Run

```
icode = caps_postAnalysis(capsObj analysis, int *nErr,  
                          capsErrs **errors)  
analysis.postAnalysis()
```

analysis the Analysis Object – use `caps_execute` (page 53) for *auto-exec* Objects

nErr the returned number of errors generated – **0** means no errors

errors the returned CAPS error structure – **NULL** with no errors

icode integer return code

Note: this clears all Analysis Output Objects to force reloads/recomputes

Create a Bound

```
icode = caps_makeBound(capsObj problem, int dim, const char *bname  
                      capsObj *bound)
```

```
bound = problem.makeBound(dim, bname)
```

problem the CAPS Problem Object

dim the dimensionality of the Bound (1 – 3)

bname the character string associated with “capsBound” attribute on bodies

bound the returned new CAPS Bound Object

Get Information about a Bound

```
icode = caps_boundInfo(capsObj bound, enum capsState *state, int *dim,  
                      double *plims)
```

```
state, dim, plims = bound.boundInfo()
```

bound the CAPS Bound Object

state the returned Bound state:

-1 Open

0 Empty & Closed

1 single BRep entity

2 multiple BRep entities

-2 multiple BRep entities – Error in reparameterization!

dim the returned dimensionality of the Bound (1 – 3)

plims the filled parameterization limits (2 values when **dim** is 1, 4 when **dim** is 2)

Make a VertexSet

```
icode = caps_makeVertexSet(capsObj bound, capsObj analysis,  
                           const char *vname, capsObj *vset,  
                           int *nErr, capsErrs **errs)
```

```
vset = bound.makeVertexSet(analysis, vname=None)
```

bound an input *open* CAPS Bound Object

analysis the Analysis Object (**NULL** – Unconnected)

vname a character string naming the VertexSet (can be **NULL** for a Connected VertexSet)

vset the returned VertexSet Object

nErr the returned number of errors generated – **0** means no errors

errs the returned CAPS error structure – **NULL** with no errors

Get Info about a VertexSet

```
icode = caps_vertexSetInfo(capsObj vset, int *nGpts, int *nDpts,  
                           capsObj *bound, capsObj *analysis)
```

```
nGpts, nDpts, bound, analysis = vset.vertexSetInfo()
```

vset the VertexSet Object

nGpts the returned number of *Geometry* points in the VertexSet

nDpts the returned number of point *Data* positions in the VertexSet

bound the returned associated Bound Object

analysis the returned associated Analysis Object (**NULL** – Unconnected)

Fill an Unconnected VertexSet

```
icode = caps_fillUnVertexSet(capsObj vset, int npts, double *xyzs)  
vset.fillUnVertexSet(xyzs)
```

vset the input Unconnected VertexSet Object
npts the number of points in the VertexSet
xyzs the point positions (3***npts** in length)
icode integer return code

Close a Bound

```
icode = caps_closeBound(capsObj bound)  
bound.closeBound()
```

bound an input *open* CAPS Bound Object to close
icode integer return code

Output a VertexSet for Plotting/Debugging

```
icode = caps_outputVertexSet(capsObj vset, const char *filename)  
vset the VertexSet Object
```

filename the VertexSet filename (should have the extension “.vs”)

The CAPS application **vVS** can be used to interactively view the file generated by this function.

This is now deprecated because CAPS viewing has been integrated!

DataSet Naming Conventions

- Multiple DataSets in a Bound can have the same Name
- Allows for automatic data transfers
- One *source* (from either *FieldOut* or *User Methods*)
- Reserved Names:

DSet Name	rank	Meaning	Comments
xyz	3	<i>Geometry</i> Positions	
xyzd	3	<i>Data</i> Positions	Not for vertex-based discretizations
param*	1/2	t or [u,v] data for <i>Geometry</i> Positions	
paramd*	1/2	t or [u,v] for <i>Data</i> Positions	Not for vertex-based discretizations
<i>GeomIn</i> *	3	Sensitivity for the <i>Geometry</i> Input <i>GeomIn</i>	can have [<i>irow</i> , <i>icol</i>] in name

* Note: not valid for 3D Bounds

Create a DataSet

```
icode = caps_makeDataSet(capsObj vset, const char *dname,
                        enum capsftype ftype, int rank,
                        capsObj *dset, int *nErr, capsErrs **errs)
dset = vset.makeDataSet(dname, dmethod, rank=0)
```

- vset** the VertexSet Object – associated Bound must be *open*
- dname** a pointer to a string containing the name of the DataSet (i.e., *pressure*)
- ftype** the type of data field: (FieldIn, FieldOut, GeomSens, TessSens, User)
- rank** the rank of the data for a User field (e.g., 1 – scalar, 3 – vector), ignored otherwise
- dset** the returned DataSet Object
- nErr** the returned number of errors generated – 0 means no errors
- errs** the returned CAPS error structure – **NULL** with no errors

Get DataSet Information

```
icode = caps_dataSetInfo(capsObj dset, enum capsftype *ftype,
                        capsObj *link, enum capsdMethod *dmethod)
ftype, link, dmethod = dset.dataSetInfo()
```

- dset** the input DataSet Object
- ftype** the returned type of data field: (FieldIn, FieldOut, BuiltIn, GeomSens, TessSens, User)
- link** the returned linked DataSet Object (for **ftype** of FieldIn) – can be **NULL**
- dmethod** the returned linked DataSet Method (only valid for **ftype** of FieldIn)

Get Data from a DataSet

```
icode = caps_getData(capsObj dset, int *npt, int *rank, double **data,  
                    char **units, int *nErr, capsErrs **errs)
```

```
data = dset.getData()
```

dset the DataSet Object

npt the returned number of points in the DataSet

rank the returned rank of the data (e.g., 1 – scalar, 3 – vector)

data the returned pointer to the data (**rank*****npts** in length)

units the returned pointer to the string declaring the units

nErr the returned number of errors generated – 0 means no errors

errs the returned CAPS error structure – NULL with no errors

icode integer return code

Establish Linkage between DataSet Objects

```
icode = caps_linkDataSet(capsObj link, enum capsdMethod dmethod,  
                        capsObj trgt, int *nErr, capsErrors **errs)  
trgt.linkDataSet(link, dmethod)
```

- link** linking DataSet Object, must be FieldOut
- dmethod** 0 – Interpolate, 1 – Conserve
- trgt** the target DataSet Object which will get its data from **link**, must be FieldIn or User
- nErr** the returned number of errors generated – 0 means no errors
- errs** the returned CAPS error structure – **NULL** with no errors

Initialize DataSet for cyclic/incremental startup

```
icode = caps_initDataSet(capsObj dset, int rank, double *startup,  
                        int *nErr, capsErrors **errs)  
dset.initDataSet(startup)
```

- dset** the DataSet Object (Field type must be FieldIn)
- rank** the rank of the data (e.g., 1 – scalar, 3 – vector)
- startup** the pointer to the constant *startup* data (**rank** in length)
- nErr** the returned number of errors generated – 0 means no errors
- errs** the returned CAPS error structure – **NULL** with no errors

Note: invocations of `caps_getData` and `aim_getDataSet` will return this data (and a length of 1) until properly filled.

Get DataSet Objects by Name

```
icode = caps_getDataSets(capsObj bound, const char *dname, int *nobj,  
                        capsObj **dsets)
```

dsets = bound.getDataSets(dname)

bound an input CAPS Bound Object

dname a pointer to a string containing the name of the DataSet

nobj the returned number of Objects with the name

dsets a returned pointer to the list of DataSet Objects (*freeable*)

Put User Data into a DataSet

```
icode = caps_setData(capsObj dset, int nverts, int rank, double *data,  
                   const char *units, int *nErr, capsErrs **errs)
```

dset.setData(data)

dset the DataSet Object

nverts the number of points in data – must match declared **npts**

rank the rank of the data – must match declared **rank** (e.g., 1 – scalar, 3 – vector)

data a pointer to the data (**rank*nverts** in length)

units the pointer to the string declaring the units

nErr the returned number of errors generated – 0 means no errors

errs the returned CAPS error structure – **NULL** with no errors

Get Triangulations for a 2D VertexSet

```
icode = caps_getTriangles(capsObj vst, int *nGtris, int **Gtris,  
                          int *nGsegs, int **Gsegs, int *nDtris,  
                          int **Dtris, int *nDsegs, int **Dsegs)  
Gtris, Gsegs, Dtris, Dsegs = vst.getTriangles()
```

vst the input CAPS Connected VertexSet Object

nGtris the returned number of *Geometry*-based Triangles

Gtris the returned pointer to a list of indices (bias 1) referencing *Geometry*-based points (3***nGtris** in length) – *freeable*

nGsegs the returned number of *Geometry*-based element mesh segments

Gsegs the returned pointer to a list of indices (bias 1) referencing *Geometry*-based points (2***nGsegs** in length) – *freeable*

nDtris the returned number of *Data*-based Triangles (0 if discretization is vertex based)

Dtris the returned pointer to a list of indices (bias 1) referencing *Data*-based points (3***nDtris** in length) – *freeable*

nDsegs the returned number of *data*-based element mesh segments

Dsegs the returned pointer to a list of indices (bias 1) referencing *data*-based points (2***nDsegs** in length) – *freeable*

icode integer return code

CAPS_SUCCESS	0	CAPS_SHAPEERR	-322
CAPS_BADRANK	-301	CAPS_LINKERR	-323
CAPS_BADDSETNAME	-302	CAPS_MISMATCH	-324
CAPS_NOTFOUND	-303	CAPS_NOTPROBLEM	-325
CAPS_BADINDEX	-304	CAPS_RANGEERR	-326
CAPS_NOTCHANGED	-305	CAPS_DIRTY	-327
CAPS_BADTYPE	-306	CAPS_HIERARCHERR	-328
CAPS_NULLVALUE	-307	CAPS_STATEERR	-329
CAPS_NULLNAME	-308	CAPS_SOURCEERR	-330
CAPS_NULLOBJ	-309	CAPS_EXISTS	-331
CAPS_BADOBJECT	-310	CAPS_IOERR	-332
CAPS_BADVALUE	-311	CAPS_DIRERR	-333
CAPS_PARAMBNDERR	-312	CAPS_NOTIMPLEMENT	-334
CAPS_NOTCONNECT	-313	CAPS_EXECERR	-335
CAPS_NOTPARMTRIC	-314	CAPS_CLEAN	-336
CAPS_READONLYERR	-315	CAPS_BADINTENT	-337
CAPS_FIXEDLEN	-316	CAPS_NOTNEEDED	-339
CAPS_BADNAME	-317	CAPS_NOSENSITVITY	-340
CAPS_BADMETHOD	-318	CAPS_NOBODIES	-341
CAPS_CIRCULARLINK	-319	CAPS_JOURNAL	-342
CAPS_UNITERR	-320	CAPS_JOURNALERR	-343
CAPS_NULLBLIND	-321	CAPS_FILELINKERR	-344

The Population of the VertexSets

Bounds needed to be fully populated (i.e., the VertexSets need to be filled for all analyses) before they can be used. This is due to the requirement to have all points available to ensure that there is a single UV space (either by construction or by re-parameterization). As a result, the meshing information for an AIM maybe required prior to calling the `aimPreAnalysis`.

The VertexSets are filled with calls the AIM to fill the `aimDiscr` structure (basically the VertexSet), which means the meshing information must be available via a link or generated in `aimDiscr`.

NOTE: An analysis AIM that supports `aimDiscr` and also generates meshes “on the fly” must be able to generate meshes and call `aim_newTess` from either `aimDiscr` or `aimPreAnalysis` (whenever and wherever the mesh gets generated).

Fluid/Structure Interaction Pseudocode

```

caps_makeAnalysis egadsTess aim -> msobj
caps_makeAnalysis TetGen aim -> mfobj
caps_makeAnalysis fluids aim -> fobj
caps_makeAnalysis structures -> sobj
caps_makeBound "srf" -> bobj
caps_makeVertexSet(bobj, fobj) -> vfobj
caps_makeVertexSet(bobj, sobj) -> vsobj
caps_makeDataSet(vfobj, "Pressure", FieldOut) -> dpfobj
caps_makeDataSet(vsobj, "Pressure", FieldIn ) -> dpsobj
caps_makeDataSet(vsobj, "Displace", FieldOut) -> ddsobj
caps_makeDataSet(vfobj, "Displace", FieldIn ) -> ddfobj
caps_linkDataSet(dpfobj, Conserve, dpsobj)
caps_linkDataSet(ddsobj, Conserve, ddfobj)
caps_initDataSet(ddfobj, 3, zeros)          /* Note #1 */
caps_closeBound(bobj)

caps_execTue(msobj)                        /* generate structures mesh */
caps_execute(mfobj)                       /* generate fluids mesh */

for (iter = 0; iter < nIter; iter++) {
    caps_preAnalysis(fobj)
    /* execute fluids analysis */
    caps_postAnalysis(fobj)

    caps_preAnalysis(sobj)
    /* execute structures analysis */
    caps_postAnalysis(sobj)
}

```


Pseudocode Notes

The fluids AIM requires the “Displace” values during its “pre” phase, just as the structural analysis AIM requires “Pressure” (i.e., loads) during its “pre” phase to fill in all the inputs.

- 1 `caps_initDataSet` gets called to set the first displacement data to zeros, in that no structural analysis will have been run at start, but is needed by the fluids.
- 2 The lines in **red** and will mark Analysis *dirty* when the DataSet is filled.

caps_analysisInfo	58	caps_getInput	55	caps_phaseState	17
caps_attrByIndex	50	caps_getLimits	36	caps_postAnalysis	60
caps_attrByName	50	caps_getOutput	55	caps_preAnalysis	59
caps_bodyByIndex	27	caps_getRootPath	21	caps_queryAnalysis	52
caps_boundInfo	61	caps_getStepSize	43	caps_readParameters	29
caps_brokenLink	20	caps_getTessels	54	caps_revision	17
caps_childByIndex	25	caps_getTriangles	69	caps_rmLock	21
caps_childByName	26	caps_getValueProps	38	caps_setAttr	51
caps_close	22	caps_getValue	34	caps_setData	68
caps_closeBound	63	caps_getValueSize	36	caps_setLimits	37
caps_convertValue	40	caps_hasDeriv	44	caps_setStepSize	43
caps_convert	46	caps_info	23	caps_setValueProps	39
caps_dataSetInfo	65	caps_initDataSet	67	caps_setValue	35
caps_deleteAttr	51	caps_intentPhrase	31	caps_size	24
caps_dirtyAnalysis	57	caps_linkDataSet	67	caps_system	59
caps_dupAnalysis	57	caps_linkValue	42	caps_transferValues	41
caps_errorInfo	28	caps_makeAnalysis	56	caps_unitCompare	49
caps_externSignal	21	caps_makeBound	61	caps_unitConvertible	49
caps_execute	53	caps_makeDataSet	65	caps_unitDivide	47
caps_fillUnVertexSet	63	caps_makeValue	33	caps_unitMultiply	46
caps_freeError	28	caps_makeVertexSet	62	caps_unitInvert	48
caps_freeValue	40	caps_markForDelete	24	caps_unitOffset	48
caps_getBodies	54	caps_open	19	caps_unitParse	48
caps_getData	66	caps_outLevel	27	caps_unitRaise	47
caps_getDataSets	68	caps_outputVertexSet	63	caps_unitRoot	47
caps_getDeriv	45	caps_ownerInfo	32	caps_vertexSetInfo	62
caps_getHistory	31	caps_phaseNewCSM	18	caps_writeGeometry	30
				caps_writeParameters	29

Python API get/set Limits

The CAPS C API for `caps_getLimits` and `caps_setLimits` does not provide the size of the limits array, and instead C API developers are supposed to combine these calls with `caps_getValueSize` if the size of the Value Object is unknown. However, **Python** lists require the size of the array. Hence, the CAPS Python API for `caps_getLimits/caps_setLimits` requires two C API calls which are journaled. Since this breaks the one-to-one nature of the bindings described here, the following functions are used instead. Implementation of these functions are akin to the C functions that follow.

Get Valid Value Range

```
limits = val.getLimitsSize()
```

val the Value Object

limits a returned list containing the valid range

Set Valid Value Range

```
val.setLimitsSize(limits)
```

val the Value Object

limits the list of limits

```
int
caps_setLimitsSize(capsObj object, enum capsvType vtype, int nrow, int ncol,
                  void *limits, const char *units, int *nErr, capsErrs **errs)
{
    int status, valnrow, valncol;

    status = caps_getValueSize(object, &valnrow, &valncol);
    if (status != CAPS_SUCCESS) return status;

    /* check the shape of the limits array to make sure it matches the value */
    if (limits != NULL) {
        if ((nrow == 1) && (ncol == 1)) {
            /* A single value can be assigned to all entries */
            vtype = abs(vtype);
        } else if (valnrow == 1 || valncol == 1) {
            if ((nrow != 1) && (ncol != 1) &&
                (valnrow*valncol > 1)) return CAPS_SHAPEERR;
            if (nrow*ncol != valnrow*valncol) return CAPS_SHAPEERR;
            vtype = -abs(vtype);
        } else {
            if (nrow != valnrow) return CAPS_SHAPEERR;
            if (ncol != valncol) return CAPS_SHAPEERR;
            vtype = -abs(vtype);
        }
    }

    return caps_setLimits(object, vtype, limits, units, nErr, errs);
}
```

```
int
caps_getLimitsSize(const capsObj object, enum capsvType *vtype, int *nrow,
                  int *ncol, const void **limits, const char **units)
{
    int status;

    if (ncol == NULL) return CAPS_NULLVALUE;
    if (nrow == NULL) return CAPS_NULLVALUE;

    status = caps_getLimits(object, vtype, limits, units);
    if (status != CAPS_SUCCESS) return status;

    if (*vtype > 0) {
        *nrow = 1;
        *ncol = 1;
    } else {
        status = caps_getValueSize(object, nrow, ncol);
        if (status != CAPS_SUCCESS) return status;
        *vtype = -*vtype;
    }

    return status;
}
```

Python API get/set StepSize

The CAPS C API for `caps_getStepSize` and `caps_setStepSize` does not provide the size of the sizes array, and instead C API developers are supposed to combine these calls with `caps_getValueSize` if the size of the Value Object is unknown. However, **Python** lists require the size of the array. Since this breaks the one-to-one nature of the bindings described here, the following functions are used instead. Implementation of these functions are akin to the C functions that follow.

Get the OpenCSM Finite-Difference Step Size

```
sizes = val.stepSize
```

val the input CAPS Value Object (*GeometryIn*/DESPMTR types only)

sizes the FD step sizes for each Value member (**nrow**×**ncol** matrix (e.g. list of lists))
a zero indicates use analytic derivatives; can be **None** – set all to zero

Set and use OpenCSM Finite-Difference Step Size

```
val.stepSize = sizes
```

val the input CAPS Value Object (*GeometryIn*/DESPMTR types only)

sizes the returned FD step sizes for each Value member (**nrow**×**ncol** matrix (e.g. list of lists))
a zero indicates use analytic derivatives; can be **None** – all set to zero

```
int
caps_setStepSizeSize(capsObj object, int nrow, int ncol, double *sizes)
{
    int status, valnrow, valncol;
    /* check the shape of the sizes array to make sure it matches the value */
    if (sizes != NULL) {
        status = caps_getValueSize(object, &valnrow, &valncol);
        if (status != CAPS_SUCCESS) return status;
        if (nrow != valnrow) return CAPS_SHAPEERR;
        if (ncol != valncol) return CAPS_SHAPEERR;
    }
    return caps_setStepSize(object, sizes);
}

int
caps_getStepSizeSize(const capsObj object, int *nrow, int *ncol, const double **sizes)
{
    int status;
    if (ncol == NULL) return CAPS_NULLVALUE;
    if (nrow == NULL) return CAPS_NULLVALUE;
    status = caps_getStepSize(object, sizes);
    if (status != CAPS_SUCCESS) return status;
    if (*sizes == NULL) {
        *nrow = *ncol = 0;
    } else {
        status = caps_getValueSize(object, nrow, ncol);
        if (status != CAPS_SUCCESS) return status;
    }
    return status;
}
```

Python API Units

This **Python** API uses the exposed CAPS unit manipulation functions to be consistent with internal use of units in CAPS. Similar to the Pint¹ Python package, this API defines these classes:

`caps.Unit`

`caps.Quantity`

where `caps.Unit` defines a unit which can be manipulated with standard operator, and `caps.Quantity` represents a value with units. This API is designed to work with these classes as the C API uses the optional **units** string. The best way to extract a value from a `caps.Quantity` is to divide it out by its units.

Unit Manipulation

```
kg = caps.Unit("kg")
m  = caps.Unit("m")
s  = caps.Unit("s")
```

```
Newton = kg*m/s**2
```

Value from Quantity

```
m = caps.Unit("m")
ft = caps.Unit("ft")

q = 10 * m      # Make a Quantity

assert(10 == q/m)
assert(10 == q.value())
assert(q.convert(ft).value() == q/ft)
```

¹<https://pint.readthedocs.io>