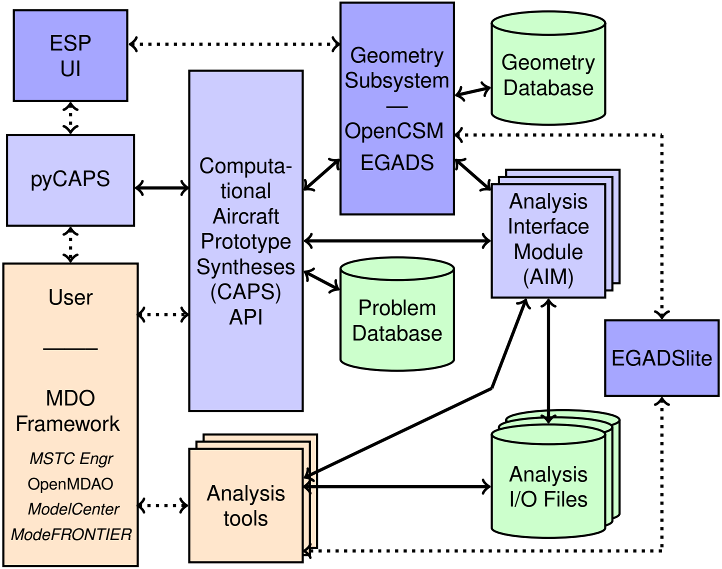
Computational Aircraft Prototype Syntheses: The CAPS API for ESP Rev 1.24

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 1.23.

CAPS Infrastructure in ESP



CAPS Enhancements

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.

CAPS Enhancements

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.

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 *(sub)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, 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

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

Other Reserved CAPS Attribute names

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.

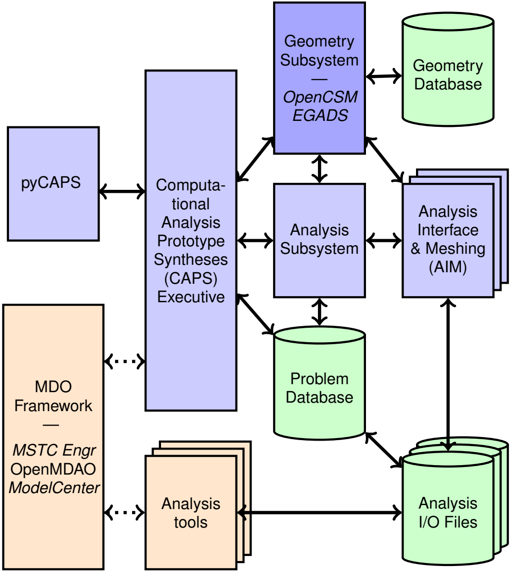
Note: Bound names should not cross dimensional lines.

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.

CAPS Execution



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

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* subdirectories. 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 Execution

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).

CAPS Python API

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

CAPS API – Information

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

CAPS API – Information

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 capssType 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.

CAPS API – Utilities

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.

CAPS API – Utilities

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

CAPS API – Utilities

Number of Children in a Parent Object

```
icode = caps_size(capsObj object, enum capsoType type,
                  enum capssType stype, int *size, int *nErr,
                  capsErrs **errs)
        size = object.size(type, stype)
```

- **object** the input CAPS Object
- **type** the data type to size: Bodies, Attributes, Value, Analysis, Bound, VertexSet, DataSet
- **stype** 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

CAPS API – Utilities

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

CAPS API – Utilities

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

CAPS API – Utilities

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

CAPS API – I/O

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.

CAPS API – Owner/History

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

CAPS API – Owner/History

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

CAPS API – Value Object

Create A Value Object

```
icode = caps_makeValue(capsObj problem, const char *vname,
                       enum capssType 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

CAPS API – Value Object

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)

CAPS API – Value Object

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

CAPS API – Value Object

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`.

CAPS API – Value Object

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

CAPS API – Value Object

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

CAPS API – Value Object

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

CAPS API – Value Object

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

CAPS API – Value Object

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!

CAPS API – Value Object / Derivatives

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

CAPS API – Value Object / Derivatives

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

CAPS API – Value Object / Derivatives

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).

CAPS API – Units

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

CAPS API – Units

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

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

CAPS API – Units

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)

CAPS API – Units

Valid unit conversion

See Appendix Python Units

```
icode = caps_unitConvertable(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

CAPS API – Attributes

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

CAPS API – Attributes

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

CAPS API – Analysis

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

CAPS API – Analysis

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

CAPS API – Analysis

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.

CAPS API – Analysis

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

CAPS API – Analysis

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

CAPS API – Analysis

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

CAPS API – Analysis Data

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)

CAPS API – Analysis Data

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)

CAPS API – Analysis Data

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!

CAPS API – Analysis Data

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	*Geometry* Positions	
xyzd	3	*Data* Positions	Not for vertex-based discretizations
param*	1/2	t or [u,v] data for *Geometry* Positions	
paramd*	1/2	t or [u,v] for *Data* Positions	Not for vertex-based discretizations
*GeomIn**	3	Sensitivity for the Geometry Input *GeomIn*	can have *[irow, icol]* in name

* Note: not valid for 3D Bounds

CAPS API – Analysis Data

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)

CAPS API – Analysis Data

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

CAPS API – Analysis Data

Establish Linkage between DataSet Objects

```
icode = caps_linkDataSet(capsObj link, enum capsdMethod dmethod,
                         capsObj trgt, int *nErr, capsErrs **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, capsErrs **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.

CAPS API – Analysis Data

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

CAPS API – Analysis Data

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 Return Codes

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

Bounds and the use of Intermediate Results

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).

Bounds and the use of Intermediate Results

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)
}
```

Bounds and the use of Intermediate Results

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.

API index

CAPS API – Appendix Limits

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

CAPS API – Appendix 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);
}
```

CAPS API – Appendix Limits

```
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;
}
```

CAPS API – Appendix StepSize

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

CAPS API – Appendix StepSize

```
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 Pint[1] 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