CFD General Notation System

http://www.cgns.org

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ANSYS/ICEM CFD

Presentation Overview

- What is CGNS ?
- History of CGNS
- CGNS Steering Committee
- ISO-STEP Standard
- HDF5 Interface
- User Base
- CGNS Main Features
- Current Release (Version 2.3)
- Extensions (Version 2.4 beta)
- CGNS Tools
- Detailed Node Descriptions
- Example
- Conclusions

What is CGNS ?

- CFD General Notation System
  - Principal target is the data normally associated with compressible viscous flow (i.e. Navier-Stokes)
  - Applicable to computational field physics in general with augmentation of the data definitions and storage conventions
- Objectives
  - Provide a general, portable and extensible standard for the storing and retrieval of CFD analysis data
  - Offer seamless communication of CFD analysis data between sites, applications and system architectures
  - Eliminate the overhead costs due to file translation and multiplicity of data sets in various formats
  - Provide free, open software – GNU Lesser General Public License

What is CGNS ?

- Advanced Data Format (ADF)
  - Software that performs the I/O operations
  - Directed graph based on a single data structure (the ADF node)
  - Defines how data is organized in the storage media.
- Standard Interface Data Structures (SIDS)
  - Collection of conventions and definitions that defines the intellectual content of CFD-related data.
  - Independent of the physical file format
- SIDS to ADF Mapping
  - Defines how the SIDS is represented in ADF
- CGNS Mid-Level Library (MLL)
  - High level Application Programming Interface (API) which conforms closely to the SIDS
  - Built on top of ADF and does not perform any direct I/O operation

History of CGNS

- 1994-1995:
  - Series of meetings between Boeing and NASA addressing means of improving technology transfer from NASA to Industry: The main impediment to technology transfer is the disparity of file formats.
- 1995-1998:
  - Development of the CGNS System (SIDS, ADF) at Boeing Seattle, under NASA Contract with participation from:
    - Boeing Commercial Aircraft Group, Seattle
    - NASA Ames/Langley/Lewis Research Centers
    - Boeing St-Louis (former McDonnell Douglas Corporation)
    - Arnold Engineering Development Center, for the NPARC Alliance
    - Wright-Patterson Air Force Base
    - ICEM CFD Engineering Corporation

History of CGNS

- 1997-1998:
  - Development of the CGNS Mid-level Library.
  - Institution of the CGNS website (http://www.cgns.org)
  - first release of the CGNS software and documentation.
- 1999-2001:
  - CGNS Steering Committee created as a subcommittee of the AIAA CFD Committee on Standards
  - Version 2.0 of CGNS library released
    - Added moving grids and time-dependent data
  - ISO-STEP standardization process undertaken by Boeing
  - CGNStalk mailing list created at NASA Glenn

History of CGNS

- 2002:
  - CGNS becomes a AIAA Recommended Practice
  - Version 2.1 of CGNS library released
    - Added support for user-defined arrays, chemistry and links
- 2003:
  - Source code moved under CVS at SourceForge (http://sourceforge.net/projects/cgns/)
  - Version 2.2 of CGNS library released
    - Added axisymmetry, rotating coordinates, connectivity and boundary condition properties
- 2004:
  - HDF5 interface to CGNS released
  - Version 2.3 (current stable version) released
    - I/O times speed up by an order of magnitude

CGNS Steering Committee

- Public forum made up of international representatives from government, industry and academia
- Responsibilities
  - Maintain the software, documentation and CGNS web site
  - Ensure a free distribution of the software and documentation
  - Promote the acceptance of the CGNS standard
- Organization
  - Meets at a minimum of once a year
  - Represented by an elected ChairPerson
    - currently Chris Rumsey of NASA Langley
  - Governs by consensus
  - Welcomes participation of all parties, members or not

CGNS Steering Committee

- Membership – 20 organizations
  - NASA Ames
  - NASA Langley
  - NASA Glenn
  - Boeing Commercial
  - Boeing – Rocketdyne
  - Boeing Integrated Defense Systems
  - Pratt & Whitney
  - ICEM CFD Engineering
  - Fluent, Inc.
  - Rolls-Royce Allison
  - US Air Force / AEDC
  - CD ADAPCO
  - Intelligent Light
  - Pointwise
  - Aerospatiale Matra Airbus
  - NUMECA
  - ONERA
  - Stanford University
  - Utah State University
  - ANSYS CFX

ISO-STEP Standard

- AP 237 – Fluid Dynamics
  - Top-level standard which defines the data types and structures used throughout the field of fluid dynamics
  - Need to extend ISO-STEP for binary data (currently ASCII only)
- Part 110 – Computational Fluid Dynamics
  - Defines the data types and structures unique to CFD
- Part 52 – Mesh-based Topology
  - Defines structured and unstructured grids including topology and element connectivity
- Part 53 – Numerical Analysis
  - Defines links to product data management structures and configuration control for numerical analysis

ISO-STEP Standard

- Approval process
  - A proposal must past 6 stages or “gates” to become a standard.
  - Passage through each “gate” requires a specified number of votes from the 17 P-Member countries. There are CGNS users in each of these countries.
  - Proposals are cancelled after 2 years if progress is not shown
  - AP 237 is at “gate” 3 (Committee Draft)
  - Parts 110, 52, and 53 are at “gate” 4 (Draft International Std)
- Current status
  - Standardization effort is stalled due to lack of funds.
  - ISO-STEP has decided to merge AP 237 with AP 209 (finite element analysis) because there is a high degree of common content. Effort is being lead by Keith Hunten of Lockheed Martin

HDF5 Interface

- Implementation
  - Fully implemented at the ADF level – no change to MLL
- Advantages
  - Used in many applications
  - Parallel I/O using MPI
  - Faster access through linked files
- Disadvantages
  - File sizes are 2 to 3 times larger
  - I/O times are generally 2 to 3 times slower, but may be up to a order of magnitude for a large number of nodes
- Current Status
  - HDF5 Task Force set up to further evaluate implementation
  - Added as option to CGNS with conversion routines

User Base

- Registered Users
  - 591 users from more than 25 countries
- CGNStalk (as of May 2003)
  - 153 participants from 20 different countries and at least 63 different organizations
- SourceForge (last 2 years)
  - Average of 20 page views and 7.5 downloads per day
- Known implementations
  - 13 commercial, 9 government, 5 industry, 3 academia

CGNS Main Features

- Hierarchical data structure: quickly traversed and sorted, no need to process irrelevant data
- Complete and explicit problem description
- Standardized naming conventions
- Unlimited internal documentation, and application specific data
- Layered so that much of the data structures are optional
- ADF database: universal and self describing
- Based on a single data structure called an ADF node
- The data may encompass several files through the use of links
- Portable ANSI C software, with complete Fortran and C interfaces
- Files stored in compact C binary format
- Complete and architecture independent API

Current Release (Version 2.3)

- Grid coordinates and elements
  - 1D, 2D and 3D support (physical and cell dimensions)
  - Any number of structured and/or unstructured zones
  - Cartesian, cylindrical and spherical coordinates systems
  - Linear and higher-order elements (22 predefined element types)
  - 2D axisymmetry
- Grid connectivities
  - 1-to-1 abutting, mismatched abutting, and overset (chimera)
  - Connectivity properties (average and periodic interfaces)
- Boundary conditions
  - Simple or complex boundary conditions with predefined identifiers
  - Any number of Dirichlet or Neumann conditions may be specified globally or locally on a boundary condition patch
  - Boundary patch normals, area and wall function properties

Current Release (Version 2.3)

- Governing flow equations
  - General class of flow equations
  - Gas, viscosity, thermal conductivity, thermal relaxation, chemistry, turbulence, and turbulence closure models
- Solutions
  - Vertex, cell, face or edge centered with rind (ghost points/cells)
  - Any number of solution variables
  - Predefined identifiers for solution variables
  - Generic discrete data (not typically part of the solution)
- Time-dependent flows
  - Time-accurate or non-time-accurate
  - Rotating, rigid motion or arbitrary motion grids
  - Storage of base and/or zone iterative data

Current Release (Version 2.3)

- Physical data
  - Data class: dimensional, normalized, or non-dimensional
  - Data conversion factors
  - Dimensional units: mass, length, time, temperature and angle
  - Dimensional exponents: powers of base units
- Auxiliary data
  - Global and/or local convergence history
  - Reference state variables
  - Gravity and global integral data
  - Arbitrary user-defined data
  - Textual data for documentation and annotations

Current Release (Version 2.3)

- Families
  - Provides a level of indirection to allow mesh to geometry associations
  - Boundary conditions may be applied on families
  - Links mesh surfaces to one or more CAD entities

Extensions (Version 2.4 beta)

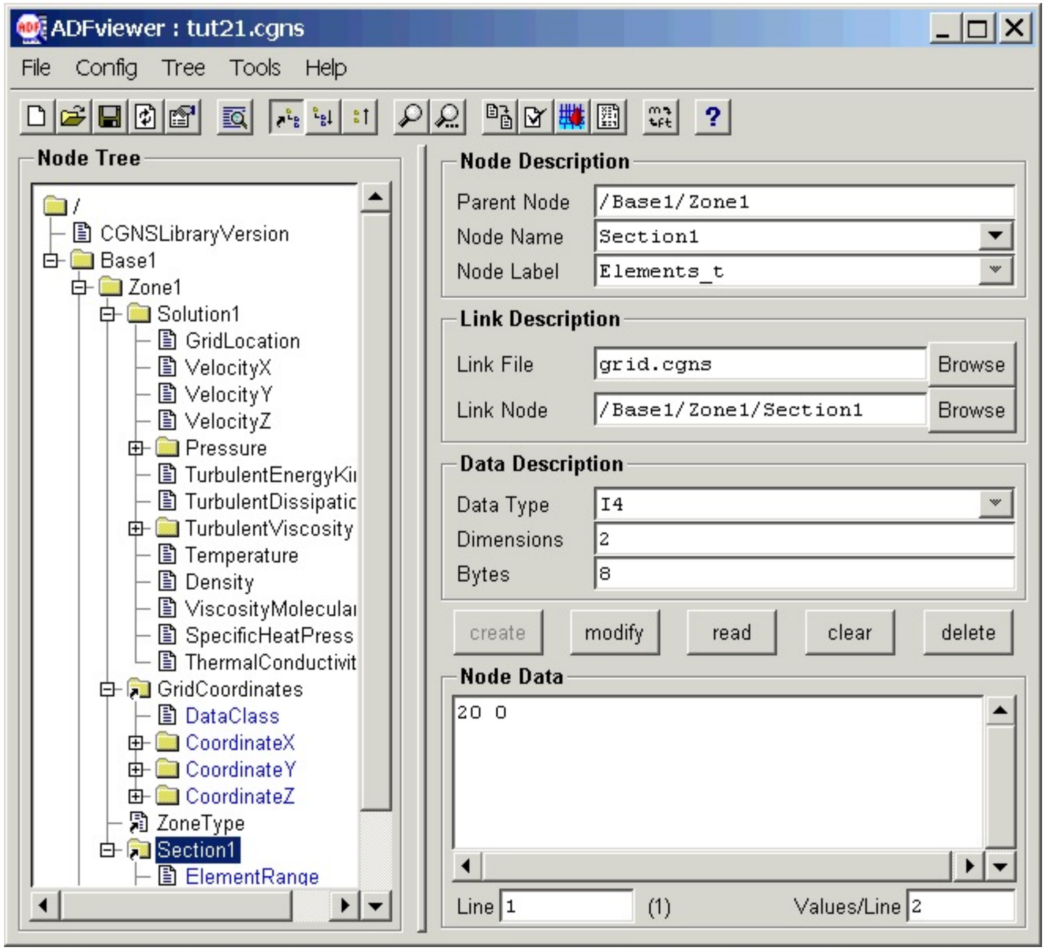
- Units
  - Electric current, amount of a substance, and luminous intensity added to the base units
- Electromagnetics
  - Electric field, magnetic field and electrical conductivity models added to the governing flow equations
  - Voltage, electric and magnetic field strengths, current density, electrical conductivity, Lorenz force and Joule heating added to list of solution identifiers
- Families
  - Rotating coordinates and complex boundary conditions added to the family specification

Extensions (Version 2.4 beta)

- Boundary conditions
  - Allow for specification of boundary condition data at a location different than that of the patch specification
- User-defined data
  - Allows recursive user-defined data
  - Family names and point set specification added
- 1-to-1 connectivities
  - Periodic and average interface properties added
- Partial read and write
  - Partial read and write for grid coordinates, elements and solution variable added

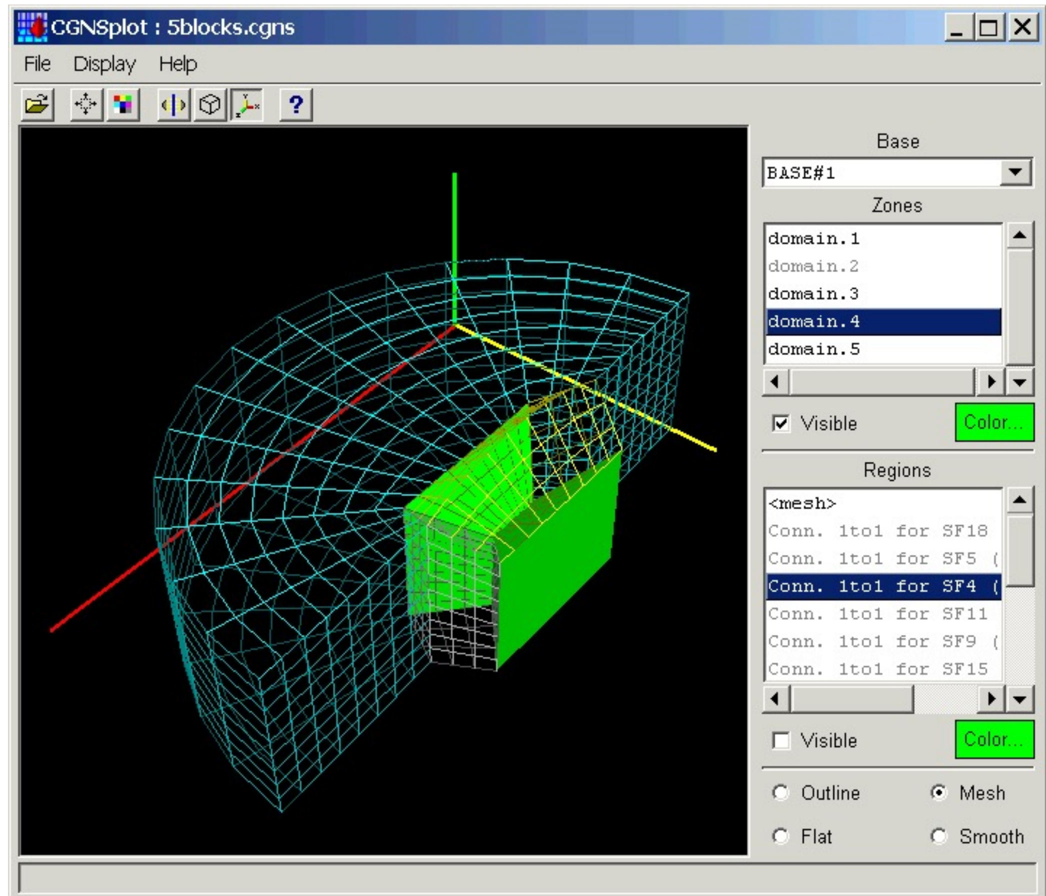
CGNS Tools

- ADFviewer
  - Views and/or edits ADF/CGNS files.
  - May create, delete or modify nodes
  - Nodes are displayed in a Windows-like collapsible tree
  - Additional utilities may be accessed from the menus
  - Configurable menus
  - Written in Tcl/Tk



CGNS Tools

- CGNSplot
  - Viewer for CGNS files
  - Displays zones, element sets, connectivities, and boundary conditions
  - Written in Tcl/Tk with OpenGL
  - Runs standalone, or may be called from ADFviewer



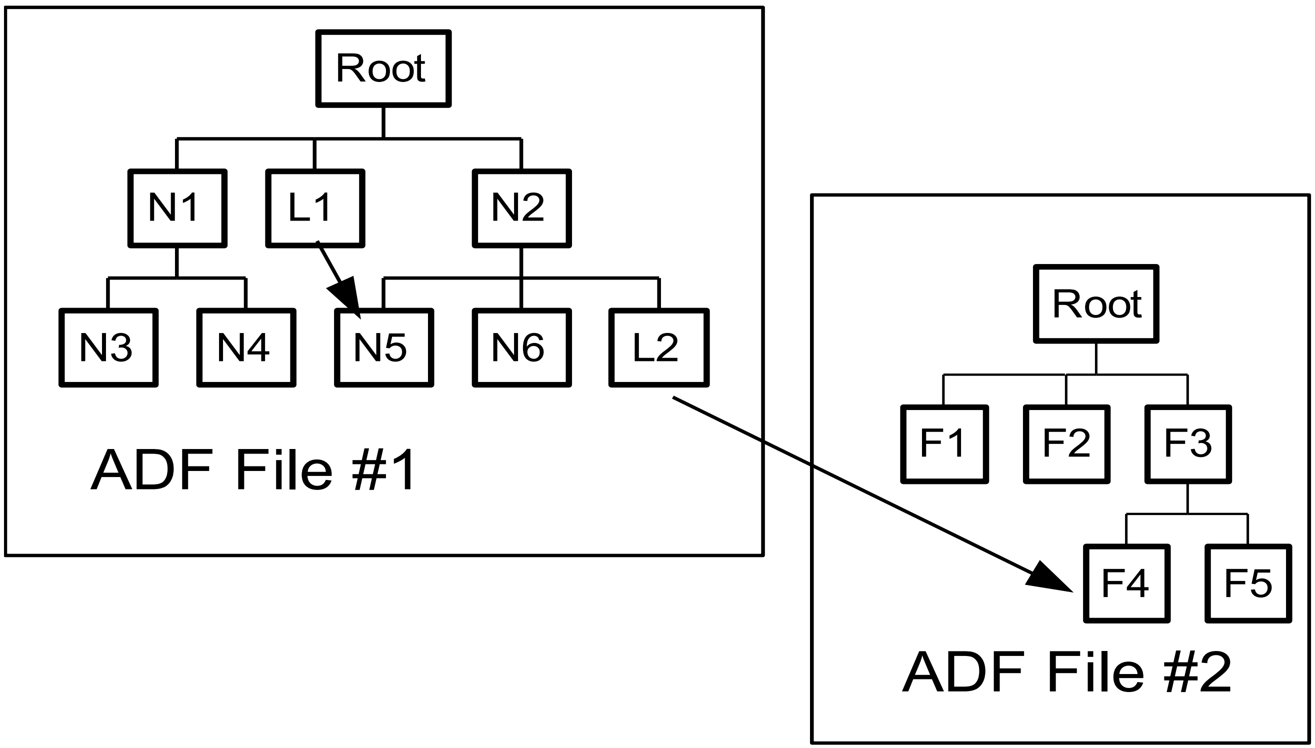
CGNS Tools

- File conversion
  - Convert Patran, PLOT3D and Tecplot files to CGNS
  - Convert CGNS files to PLOT3D and Tecplot
- CGNS file manipulation
  - Data conversion utilities for modifying the solution location (vertex or cell-center), solution variables (primitive or conservative), and data class (dimensional or normalized)
  - Subset extraction and interpolation
- CGNS bindings
  - Tcl/Tk interface to ADF and MLL
  - PyCGNS: Python interface to ADF and MLL
  - ADFM: in memory representation of ADF trees
  - CGNS++: C++ interface to ADF and MLL

CGNS Tools

- Other utilities
  - *CGNScheck*: checks CGNS files for valid data and conformance to the SIDS
  - *ADFlist*: lists ADF/CGNS file tree structure and node data
  - *ADF_Edit*: command-line based interactive browser/editor for ADF/CGNS files
  - *CGNS_readhist*: reads a CGNS file and writes convergence history to a formatted file.
  - *FTU (File Transfer Utility)*: converts to and from PLOT3D, and has a text-based menu allowing the manipulation of a CGNS base
  - *CGNS Viewer*: ADF/CGNS file editor/viewer with a GUI using the GTK+ library

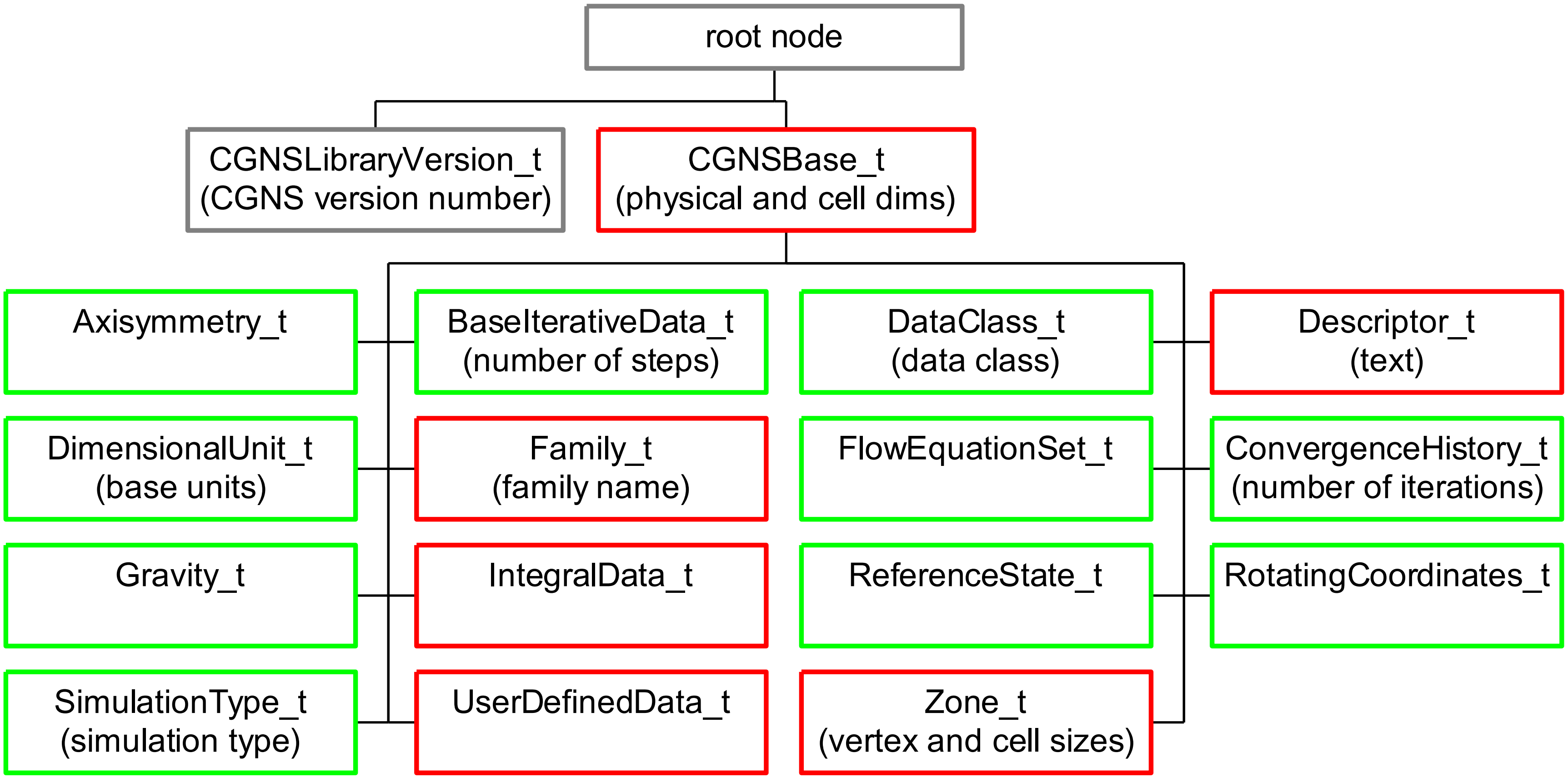
ADF Core


Root
N1
L1
N2
N3
N4
N5
N6
L2
ADF File #1
Root
F1
F2
F3
F4
F5
ADF File #2

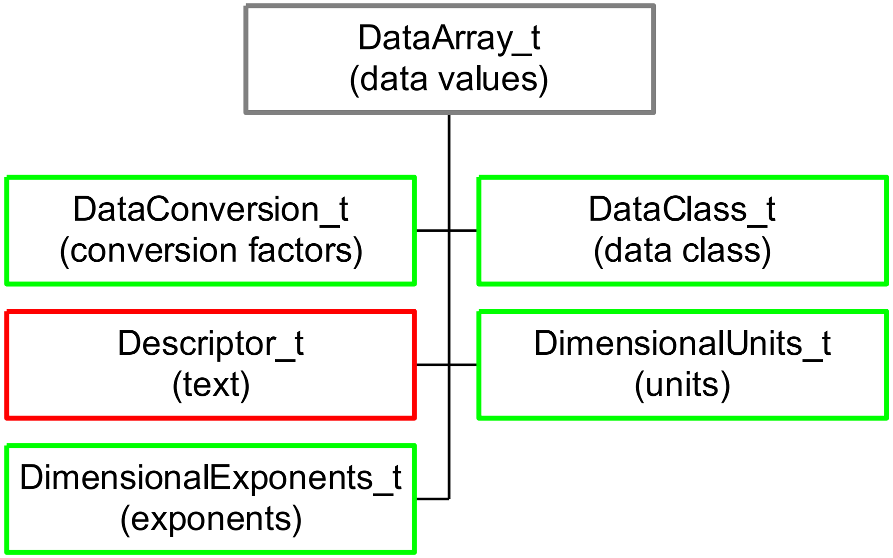
ADF Node Content

- ID: A unique identifier to access a node within a file.
- Name: A character field used to name the node. It must be unique for a given parent.
- Label: A character field used to described the type of information contained in the node.
- Data type: A character field specifying the type of data (e.g. real, complex) associated with the node.
- Number of dimensions: The dimensionality of the data.
- Dimensions: An integer vector containing the number of elements within each dimension.
- Data: The data associated with the node.
- Number of sub-nodes: The number of children directly attached to a node.
- Name of sub-nodes: The list of children names.

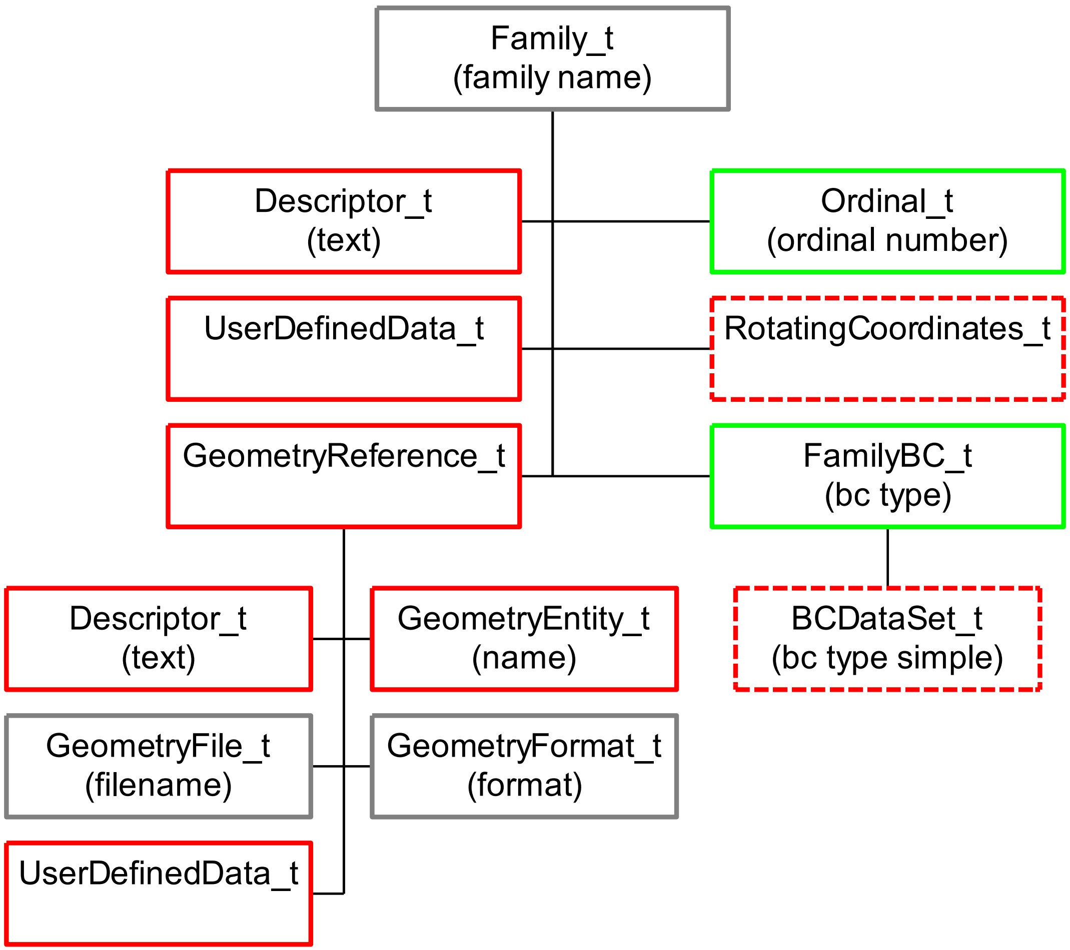
Top Level Structure



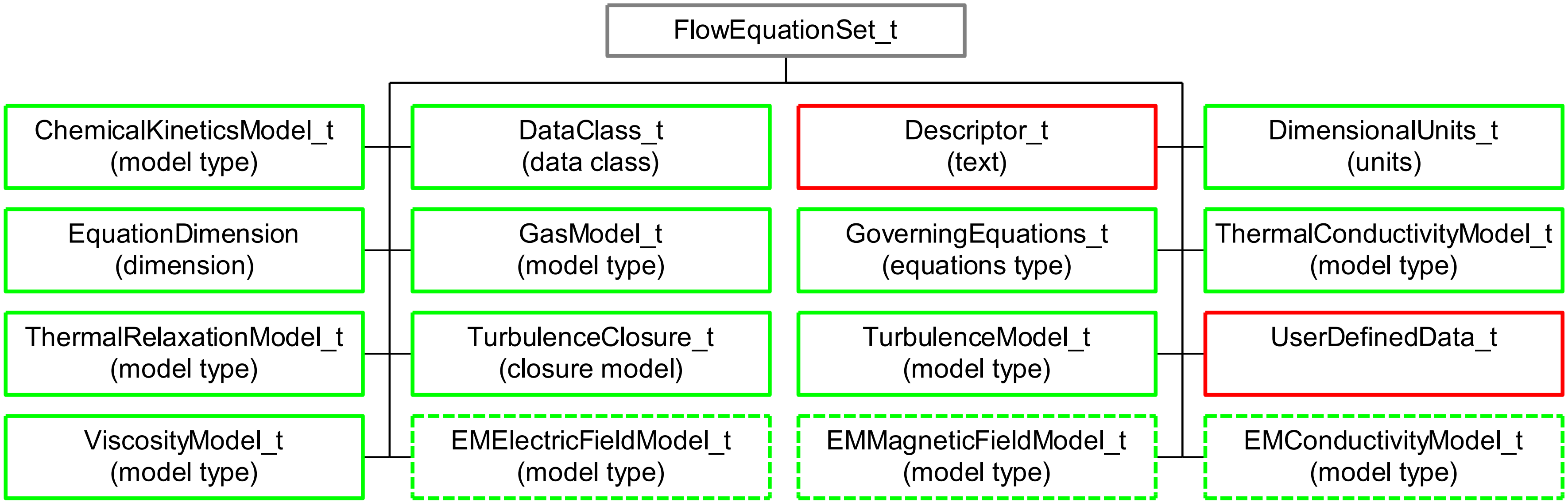
DataArray_t Node



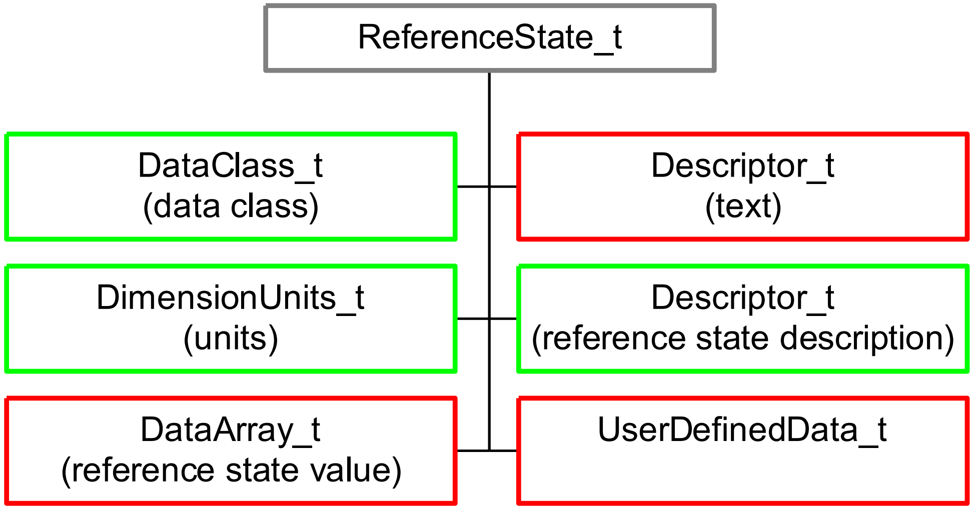
Family_t Node



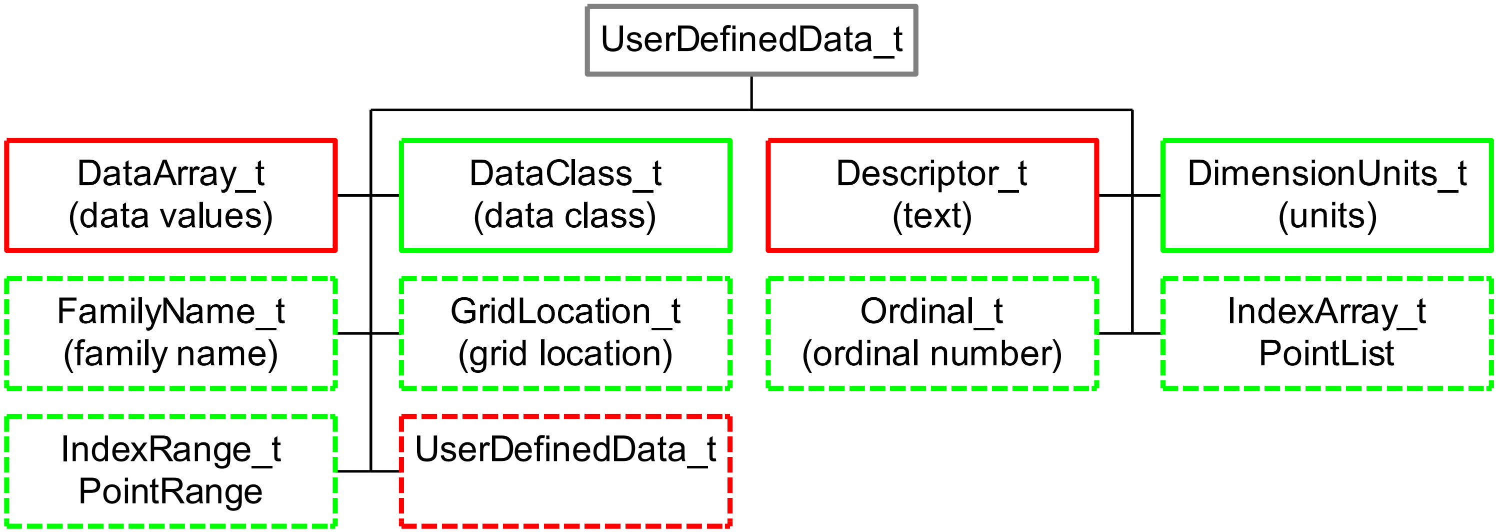
FlowEquationSet_t Node



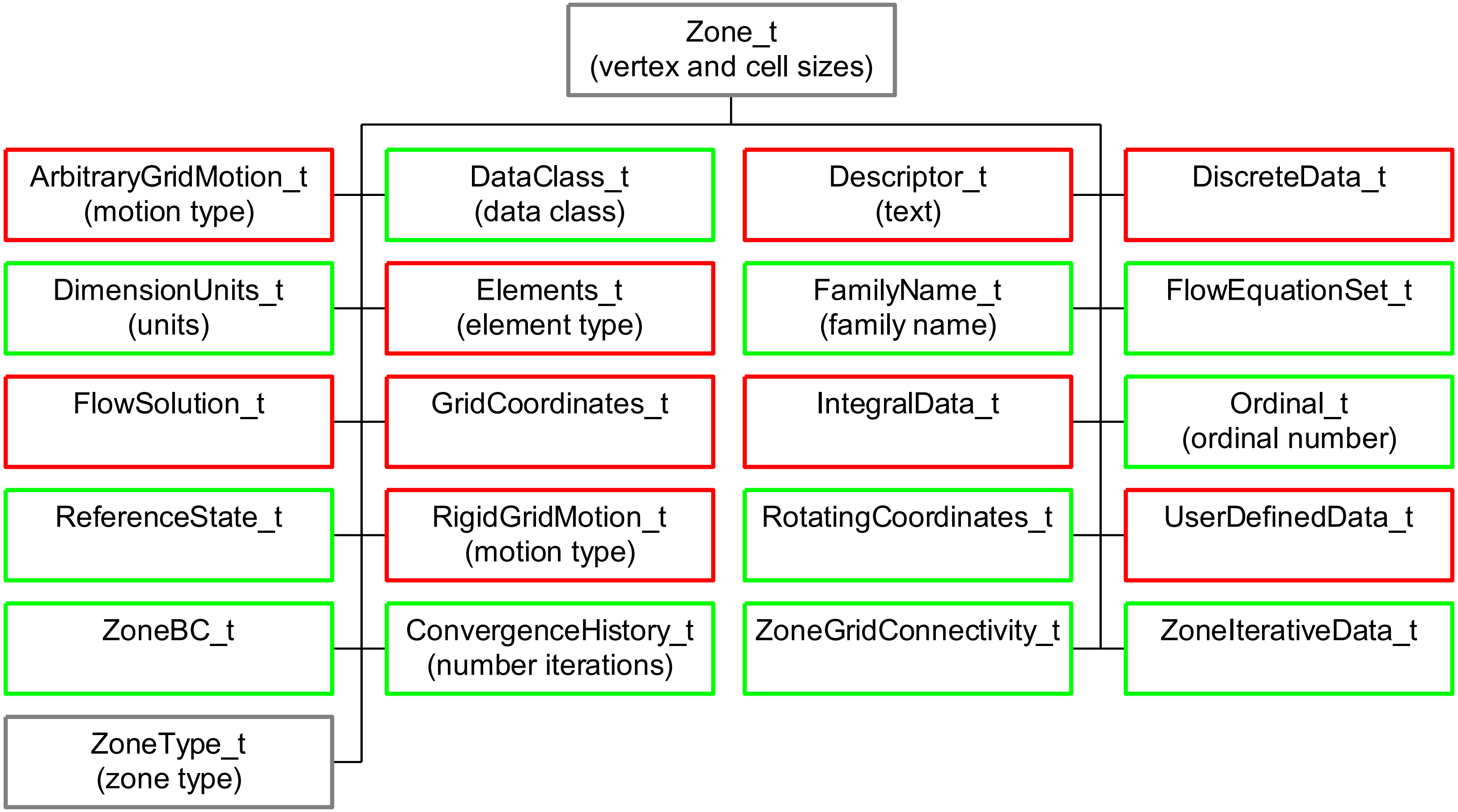
ReferenceState_t Node



UserDefinedData_t Node

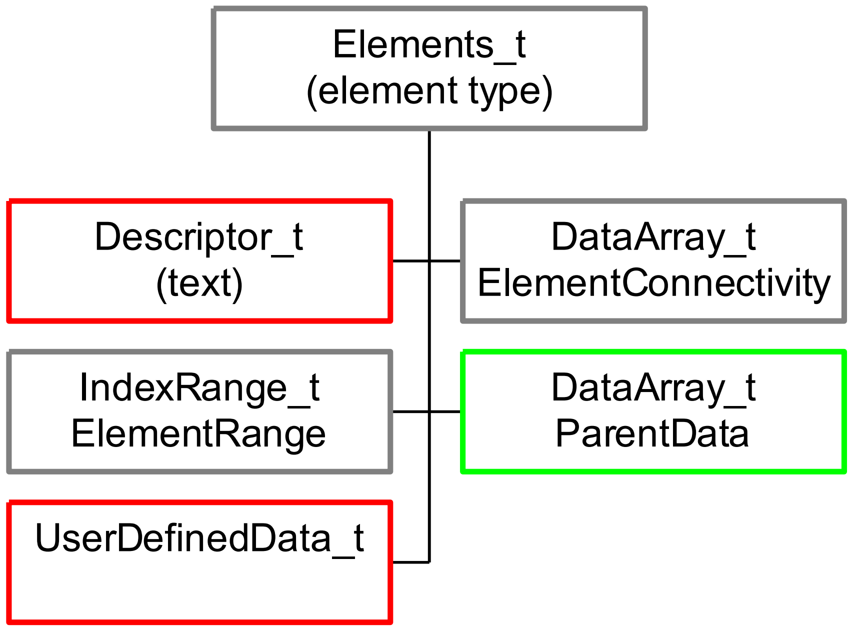


Zone_t Node

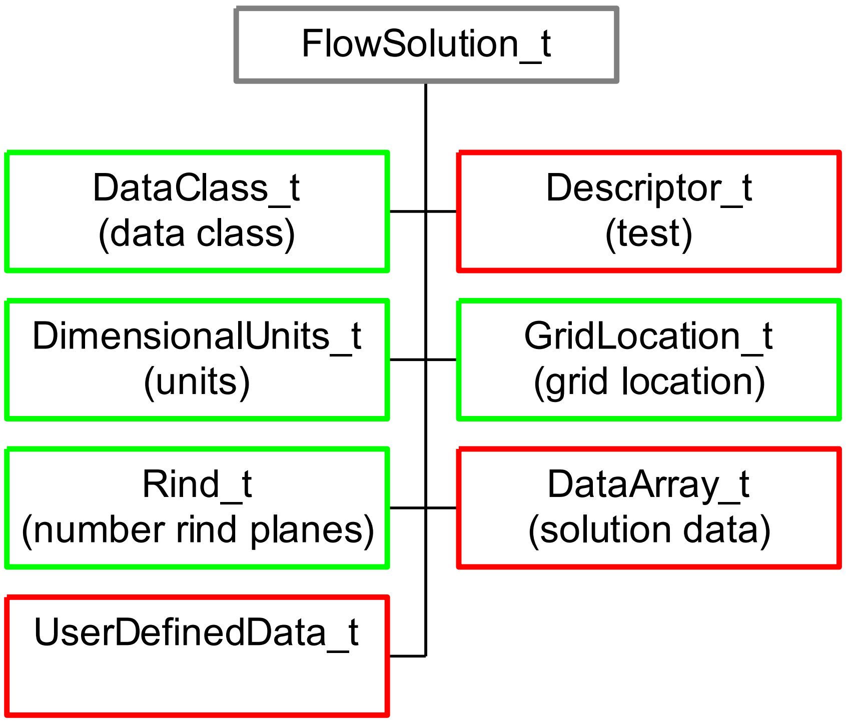


Zone_t
(vertex and cell sizes)
ArbitraryGridMotion_t
(motion type)
DataClass_t
(data class)
Descriptor_t
(text)
DiscreteData_t
DimensionUnits_t
(units)
Elements_t
(element type)
FamilyName_t
(family name)
FlowEquationSet_t
FlowSolution_t
GridCoordinates_t
IntegralData_t
Ordinal_t
(ordinal number)
ReferenceState_t
RigidGridMotion_t
(motion type)
RotatingCoordinates_t
UserDefinedData_t
ZoneBC_t
ConvergenceHistory_t
(number iterations)
ZoneGridConnectivity_t
ZoneIterativeData_t
ZoneType_t
(zone type)

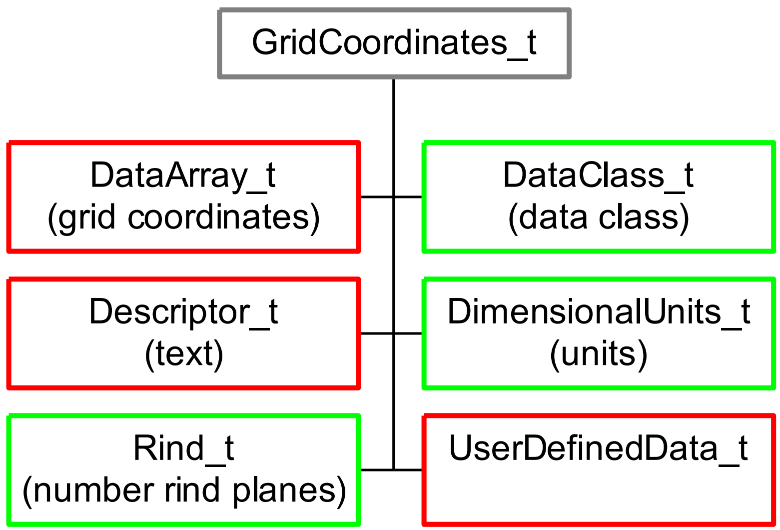
Elements_t Node



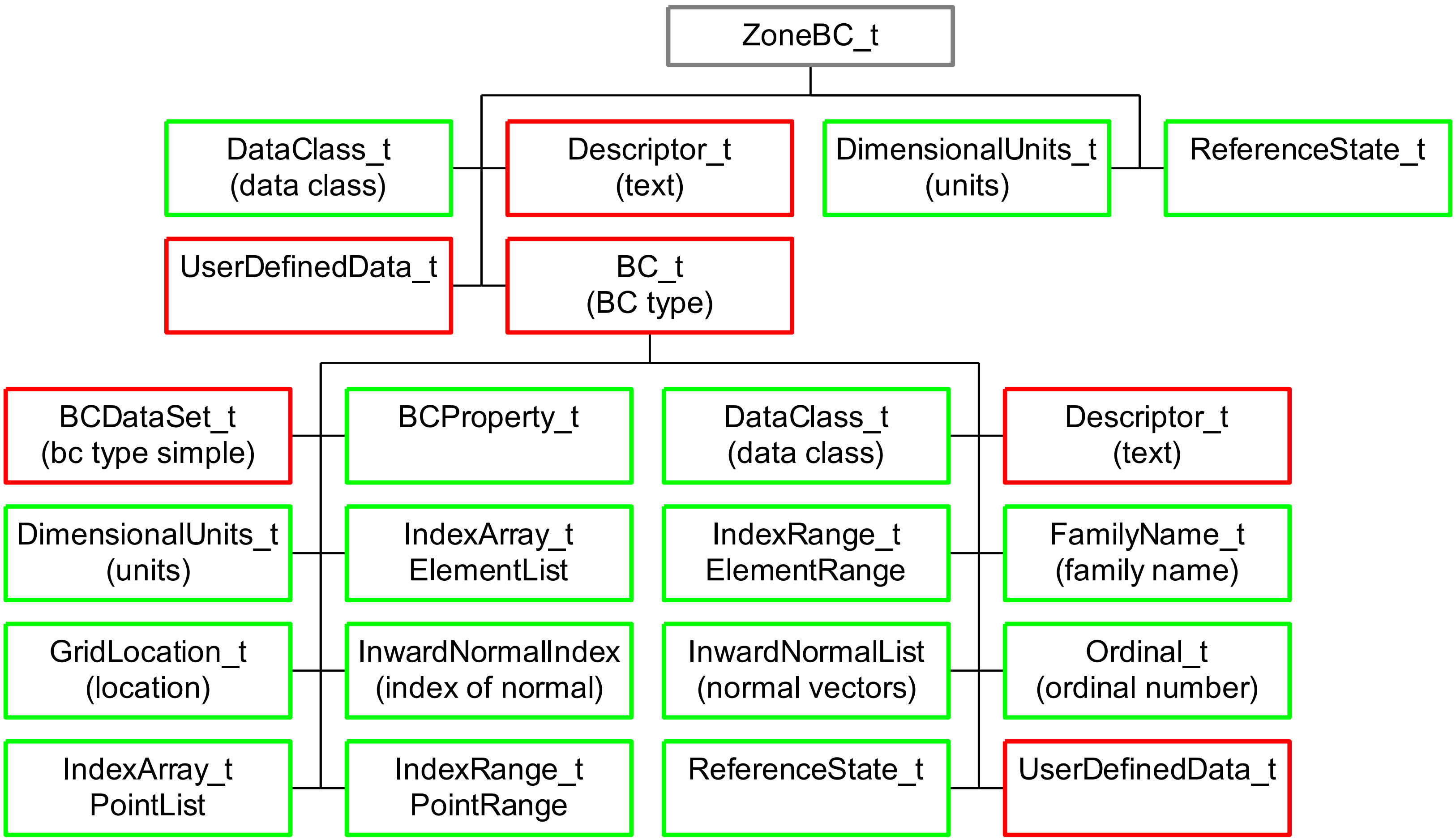
FlowSolution_t Node



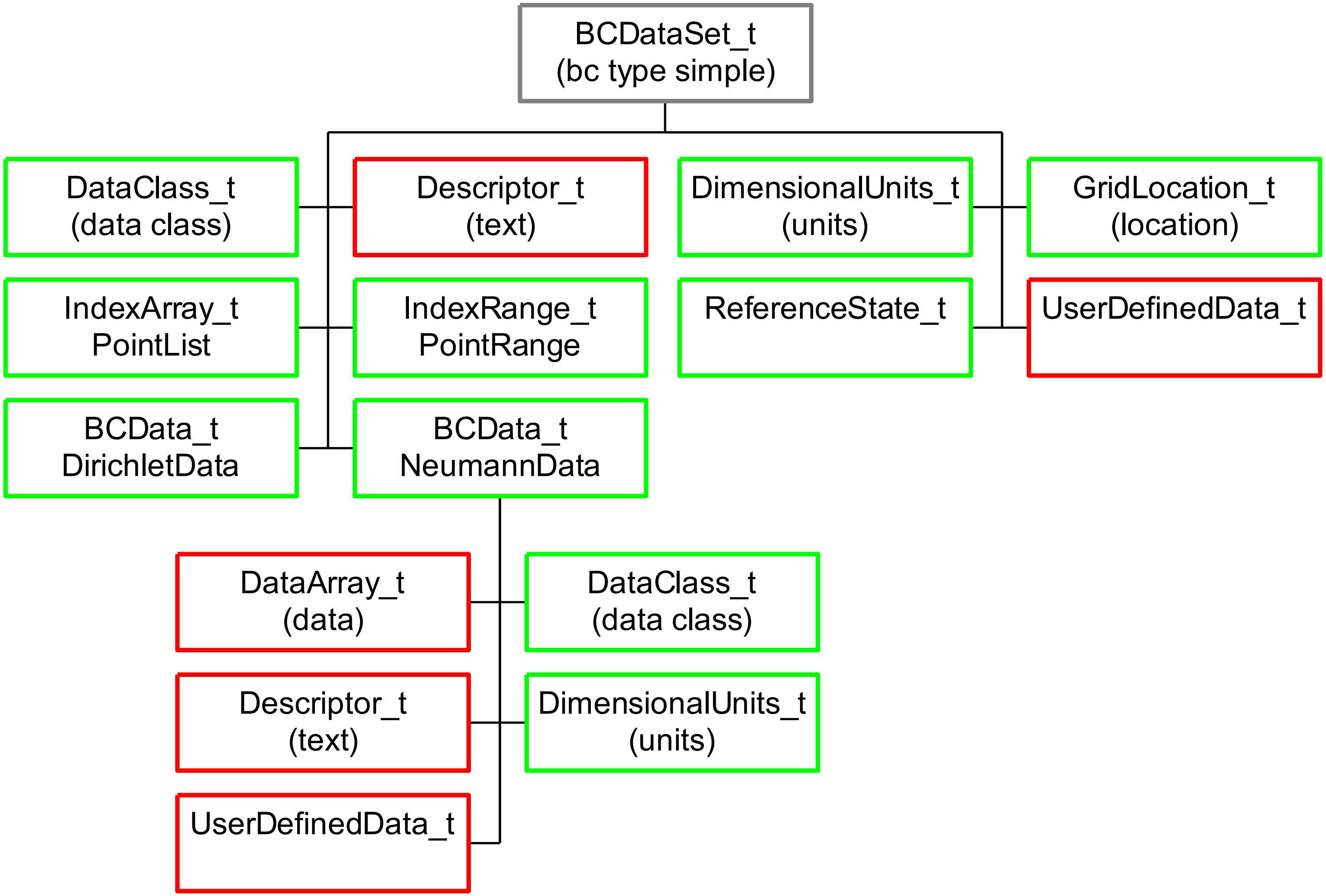
GridCoordinates_t Node



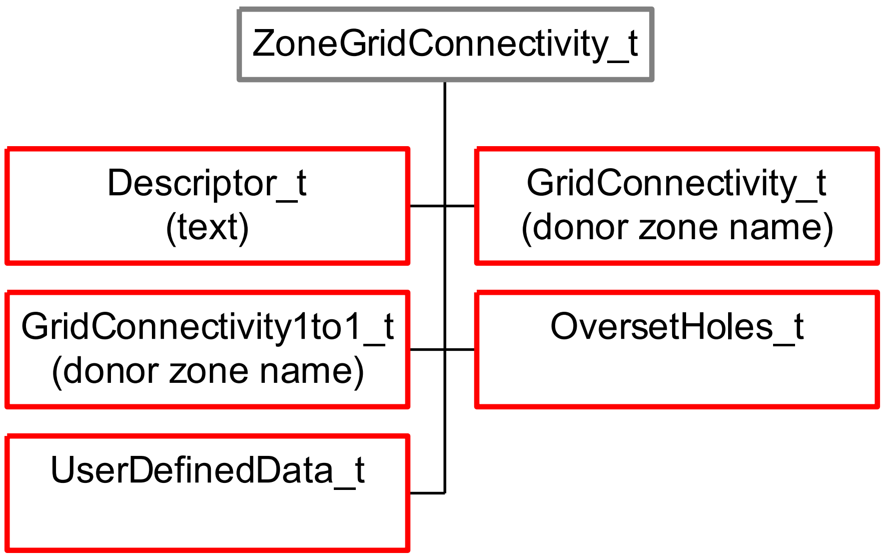
ZoneBC_t Node



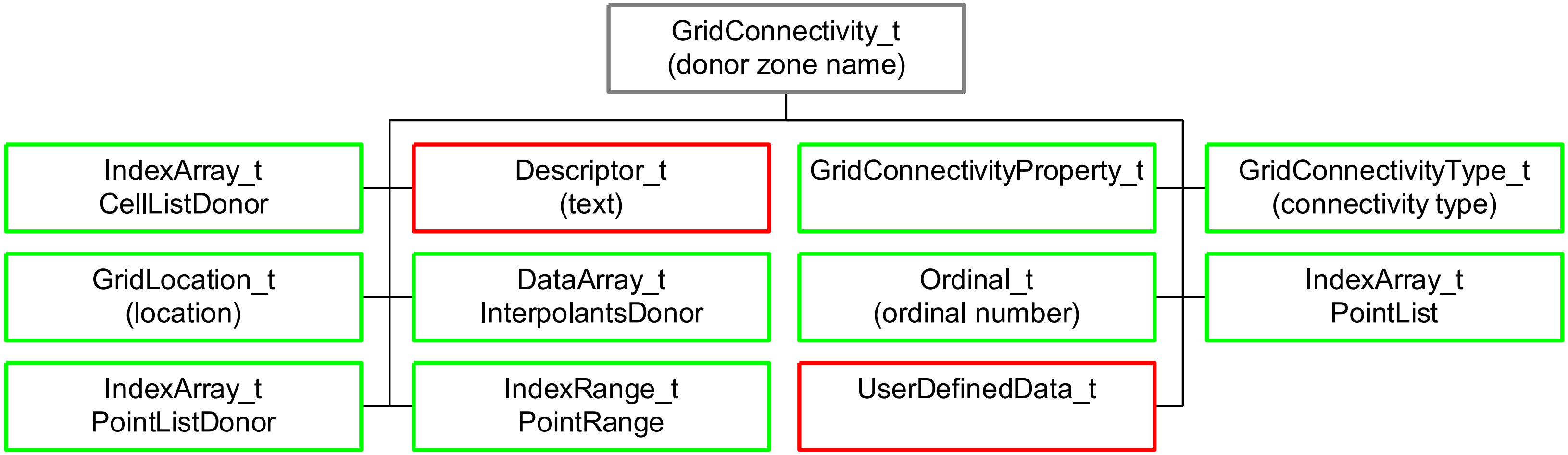
BCDataSet_t Node



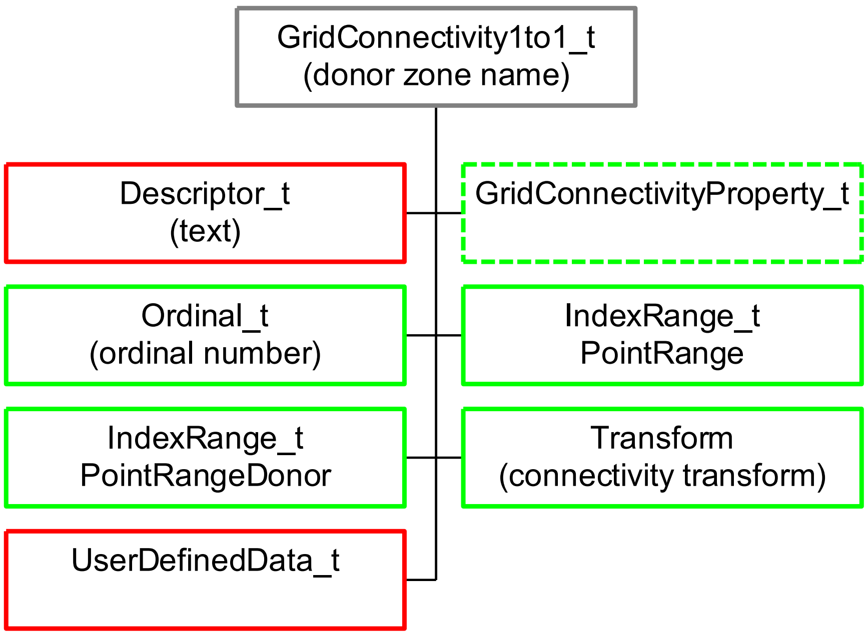
ZoneGridConnectivity_t Node



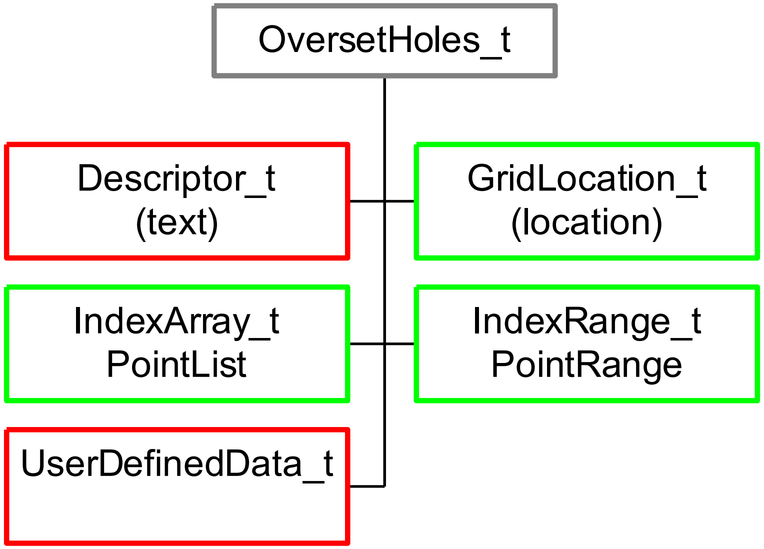
GridConnectivity_t Node



GridConnectivity1to1_t Node

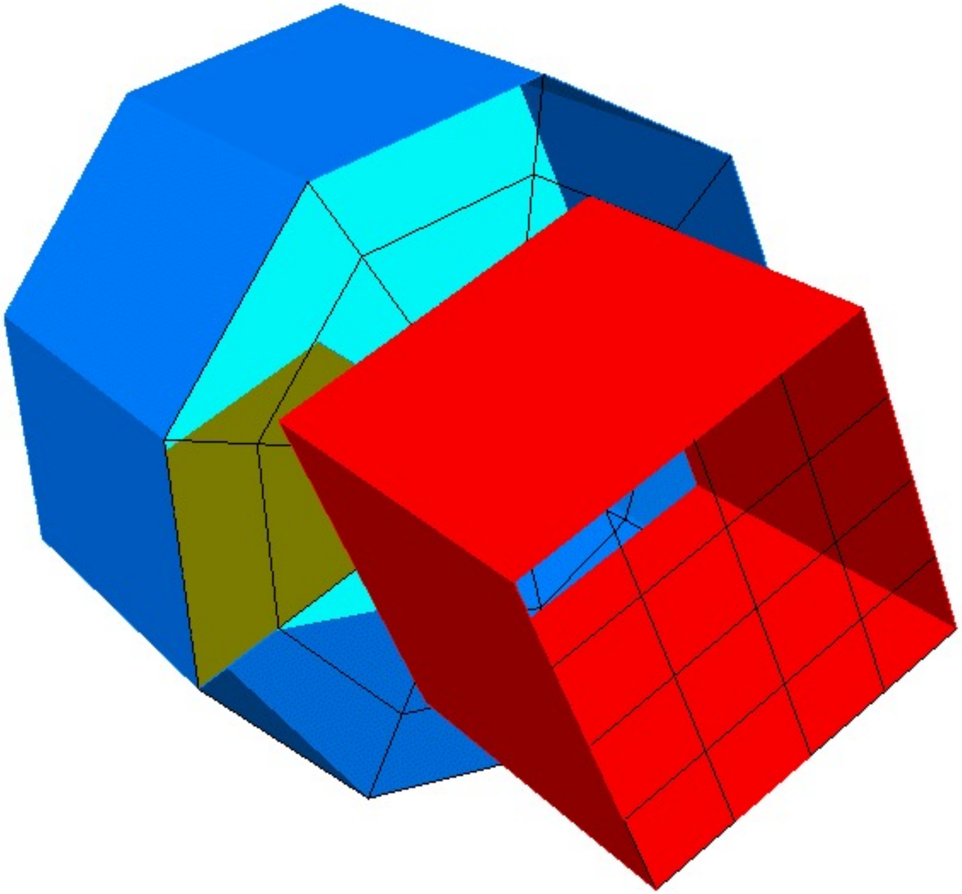


OversetHoles_t Node



Example

- Structured cylinder attached to unstructured cube



Example - Code

```
unlink("example.cgns");
cg_open("example.cgns", MODE_WRITE, &cgfile);
cg_base_write(cgfile, "Mismatched", CellDim, PhyDim,
     &cgbase);
cg_goto(cgfile, cgbase, "end");
cg_descriptor_write("Descriptor", "Mismatched Grid");
cg_dataclass_write(Dimensional);
cg_units_write(Kilogram, Meter, Second, Kelvin,
     Radian);
/*----- zone 1 is unstructured cube -----*/
cg_zone_write(cgfile, cgbase, "UnstructuredZone",
    size, Unstructured, &cgzone);
/* write coordinates */
cg_coord_write(cgfile, cgbase, cgzone, RealSingle,
     "CoordinateX", xcoord, &cgcoord);
cg_coord_write(cgfile, cgbase, cgzone, RealSingle,
     "CoordinateY", ycoord, &cgcoord);
cg_coord_write(cgfile, cgbase, cgzone, RealSingle,
     "CoordinateZ", zcoord, &cgcoord);
/* write elements and faces */
cg_section_write(cgfile, cgbase, cgzone, "Elements",
     HEXA_8, 1, num_element, 0, elements, &cgsect);
cg_section_write(cgfile, cgbase, cgzone, "Faces",
     QUAD_4, num_element+1, num_element+num_face, 0,
     faces, &cgsect);
cg_parent_data_write(cgfile, cgbase, cgzone, cgsect,
     parent);
/* write inflow and wall BCs */
cg_boco_write(cgfile, cgbase, cgzone, "Inlet",
     BCInflow, ElementRange, 2, range, &cgbc);
cg_boco_write(cgfile, cgbase, cgzone, "Walls", BCWall,
     PointList, n, pts, &cgbc);
```

```
/*----- zone 2 is structured cylinder -----*/
cg_zone_write(cgfile, cgbase, "StructuredZone", size,
     Structured, &cgzone);
/* write coordinates */
cg_coord_write(cgfile, cgbase, cgzone, RealSingle,
     "CoordinateR", xcoord, &cgcoord);
cg_coord_write(cgfile, cgbase, cgzone, RealSingle,
     "CoordinateTheta", ycoord, &cgcoord);
cg_coord_write(cgfile, cgbase, cgzone, RealSingle,
     "CoordinateZ", zcoord, &cgcoord);
/* write outlet and wall BCs */
cg_boco_write(cgfile, cgbase, cgzone, "Outlet",
     BCOutflow, PointRange, 2, range, &cgbc);
cg_boco_write(cgfile, cgbase, cgzone, "Walls", BCWall,
     PointList, n/3, pts, &cgbc);
/* periodic 1to1 connectivity */
cg_1to1_write(cgfile, cgbase, 2, "Periodic",
     "StructuredZone", range, d_range, transform,
     &cgconn);
/*----- zone 1 -> zone 2 connectivity -----*/
cg_conn_write(cgfile, cgbase, 1, "Unstructured ->
     Structured", Vertex, Abutting, PointRange, 2, pts,
     "StructuredZone", Structured, CellListDonor,
     Integer, n/3, d_pts, &cgconn);
cg_goto(cgfile, cgbase, "Zone_t", 1,
     "ZoneGridConnectivity_t", 1,
     "GridConnectivity_t", cgconn, "end");
cg_array_write("InterpolantsDonor", RealSingle, 2, dims,
     interp);
/*----- zone 2 -> zone 1 connectivity similar -----*/
/* close file */
cg_close(cgfile);
```

Example - Node Tree

```
ADF MotherNode
  +-CGNSLibraryVersion
  +-Mismatched
    +-Descriptor
    +-DataClass
    +-DimensionalUnits
    +-UnstructuredZone
    | +-ZoneType
    | +-GridCoordinates
    | | +-CoordinateX
    | | +-CoordinateY
    | | +-CoordinateZ
    | +-Elements
    | | +-ElementRange
    | | +-ElementConnectivity
    | +-Faces
    | | +-ElementRange
    | | +-ElementConnectivity
    | | +-ParentData
    | +-ZoneBC
    | | +-Inlet
    | | | +-ElementRange
    | | +-Walls
    | |   +-PointList
    | +-ZoneGridConnectivity
    |   +-Unstructured -> Structured
    |     +-GridConnectivityType
    |     +-PointRange
    |     +-CellListDonor
    |     +-InterpolantsDonor
    +-StructuredZone
      +-ZoneType
      +-GridCoordinates
      | +-CoordinateR
      | +-CoordinateTheta
      | +-CoordinateZ
      +-ZoneGridConnectivity
      | +-Periodic
      | | +-Transform
      | | +-PointRange
      | | +-PointRangeDonor
      | +-Structured -> Unstructured
      |   +-GridConnectivityType
      |   +-PointList
      |   +-CellListDonor
      |   +-InterpolantsDonor
      +-ZoneBC
        +-Outlet
        | +-PointRange
        +-Walls
          +-PointList
```

Conclusions

- Why should I use CGNS ?
  - CGNS is a well-established, stable format with world-wide acceptance, use and support
  - Provides seamless communication of data between applications, sites, and system architectures
  - Supported by most commercial visualization and CFD vendors
  - Extensible and flexible – easily adapted to other fields of computational physics through specification in the SIDS
  - Backwards compatible with previous versions – forwards compatible within the major release number
  - Allows new software development to focus on functionality and reliability rather than data I/O, storage and compatibility
- Want more information ?
  - http://www.cgns.org