CFD General Notation System (CGNS)

Tutorial Session

Agenda

- 7:00-7:30 Introduction, overview, and basic usage
  C. Rumsey (NASA Langley)
- 7:30-7:50 Usage for structured grids
  B. Wedan (ANSYS – ICEM)
- 7:50-8:10 Usage for unstructured grids
  E. van der Weide (Stanford University)
- 8:20-8:40 HDF5 usage and parallel implementation
  T. Hauser (Utah State University)
- 8:40-9:00 Python and in-memory CGNS trees
  M. Poinot (ONERA)
- 9:00-9:30 Discussion and question/answer period

CFD General Notation System (CGNS)

Introduction, overview, and basic usage

Christopher L. Rumsey

NASA Langley Research Center

Chair, CGNS Steering Committee

Outline

- Introduction
- Overview of CGNS
  - What it is
  - History
  - How it works, and how it can help
  - The future
- Basic usage
  - Getting it and making it work for you
  - Simple example
  - Aspects for data longevity

Introduction

- CGNS provides a general, portable, and extensible standard for the storage and retrieval of CFD analysis data
- Principal target is data normally associated with computed solutions of the Navier-Stokes equations & its derivatives
- But applicable to computational field physics in general (with augmentation of data definitions and storage conventions)

What is CGNS?

- Standard for defining & storing CFD data
  - Self-descriptive
  - Machine-independent
  - Very general and extendable
  - Administered by international steering committee
- AIAA recommended practice (AIAA R-101-2002)
- In process of becoming part of international ISO standard
- Free and open software
- Well-documented
- Discussion forum: cgnstalk@lists.nasa.gov
- Website: http://www.cgns.org

History

- CGNS was started in the mid-1990s as a joint effort between NASA, Boeing, and McDonnell Douglas
  - Under NASA's Advanced Subsonic Technology (AST) program
- Arose from need for common CFD data format for improved collaborative analyses between multiple organizations
  - Existing formats, such as PLOT3D, were incomplete, cumbersome to share between different platforms, and not self-descriptive (poor for archival purposes)
- Initial development was heavily influenced by McDonnell Douglas' "Common File Format", which had been in use since 1989
- Version 1.0 of CGNS released in May 1998

History, cont'd

- After AST funding ended in 1999, CGNS steering committee was formed
  - Voluntary public forum
  - International members from government, industry, academia
  - Formally became a sub-committee of AIAA Committee on Standards in 2000
- Initial efforts by Boeing to make CGNS an international ISO-STEP standard (1999-2002)
  - Stalled due to lack of funding
  - Instead, the existing ISO standard AP209 (finite element solid mechanics) is being rewritten (AP209E2) to include CGNS as well as an integrated engineering analysis framework (headed by Lockheed-Martin)

CGNS cfd data standard

Steering committee

- CGNS Steering committee is a public forum
- Responsibilities include (1) maintaining software, documentation, and website, (2) ensuring free distribution, and (3) promoting acceptance
- Current steering committee make-up (20 members):

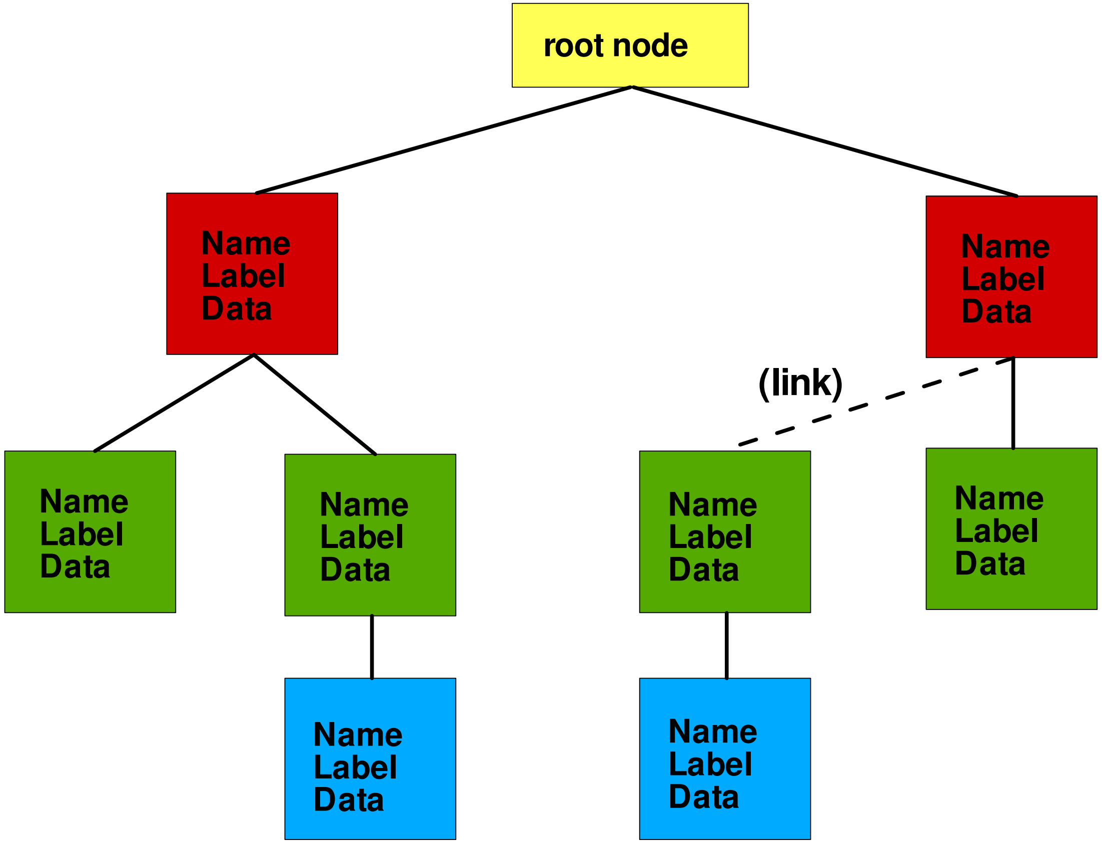
ADAPCO
ANSYS-CFX
Aerospatiale Matra Airbus
Boeing – IDS/PW
Boeing Commercial
Boeing IDS
Fluent
ANSYS-ICEM
Intelligent Light
NASA Glenn
NASA Langley
ONERA
Pacific NW Laboratory
Pointwise
Pratt & Whitney
Pratt & Whitney – Rocketdyne
Rolls-Royce Allison
Stanford University
U.S. Air Force / AEDC
Utah State University

CGNS main features

- Hierarchical data structure : quickly traversed and sorted, no need to process irrelevant data
- Files stored in compact C binary format
- Layered so that many of the data structures are optional
- ADF or HDF5 database: universal and self-describing
- Data may encompass multiple files through the use of links
- Portable ANSI C software, with complete Fortran and C interfaces
- Architecture-independent application programming interface (API) – written as a mid-level library (MLL)

CGNS
cfd data standard

CGNS File Layout



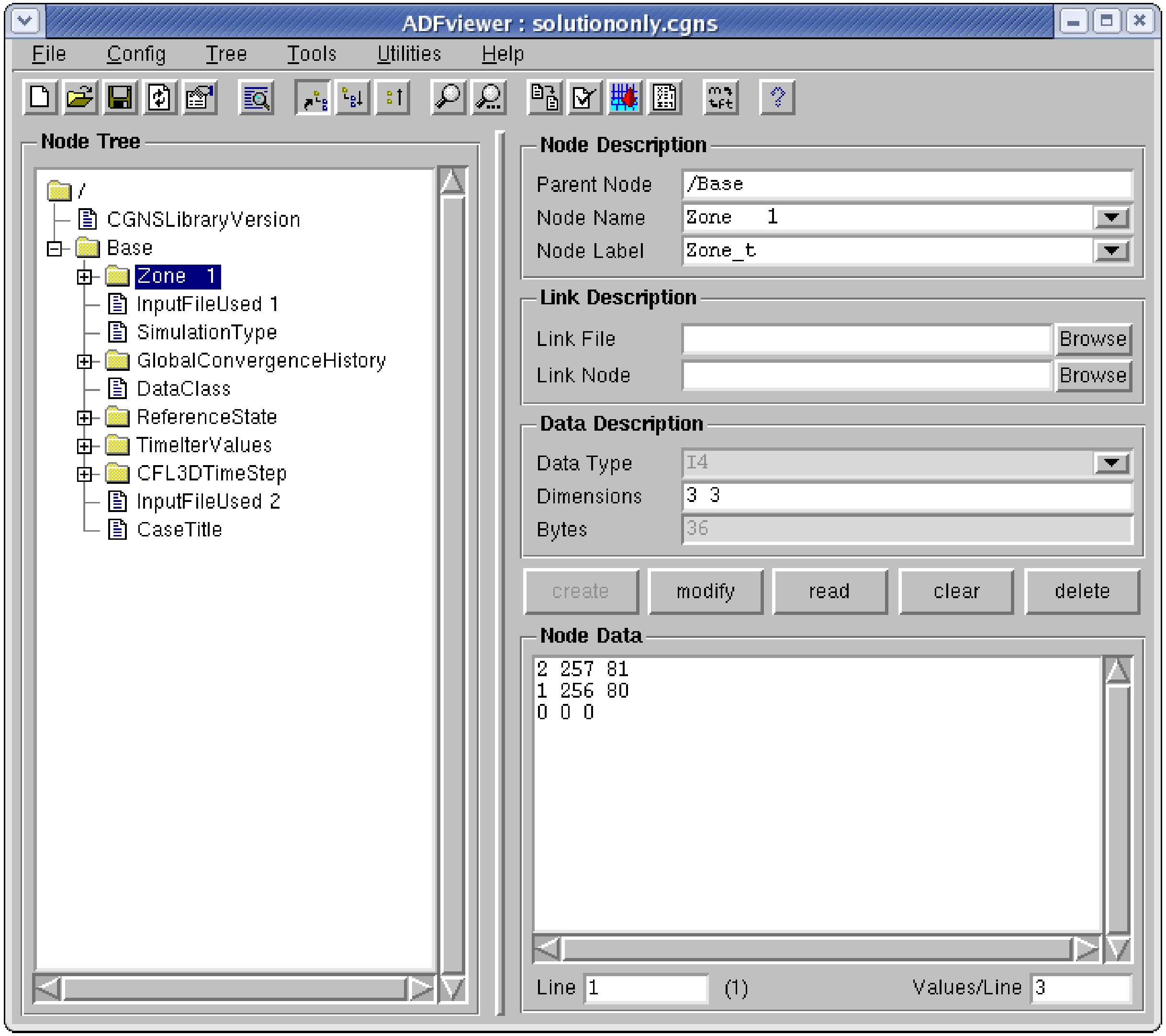
Makeup of CGNS

- Standard Interface Data Structures (SIDS) is the core of CGNS – defines the intellectual content
  - Defines what goes in the “boxes” and how they are organized
- Original low level implementation is Advanced Data Format (ADF)
  - Basic direct I/O operations
  - Software has no knowledge of data structure or contents
  - Tree-based (nodal parent/child) structure
- Low level implementation is migrating toward HDF5 format
  - HDF5 is already available as an option
  - HDF5 is well-supported (NCSA) , widely used, and has parallel I/O capability
  - This will be the official recommended format, although ADF will also continue to be supported, and MLL will translate between the two
- Mid-level library (MLL) is currently available for C and Fortran
  - This is what most users employ
  - Software has some knowledge of SIDS
  - C++ and Python extensions also available

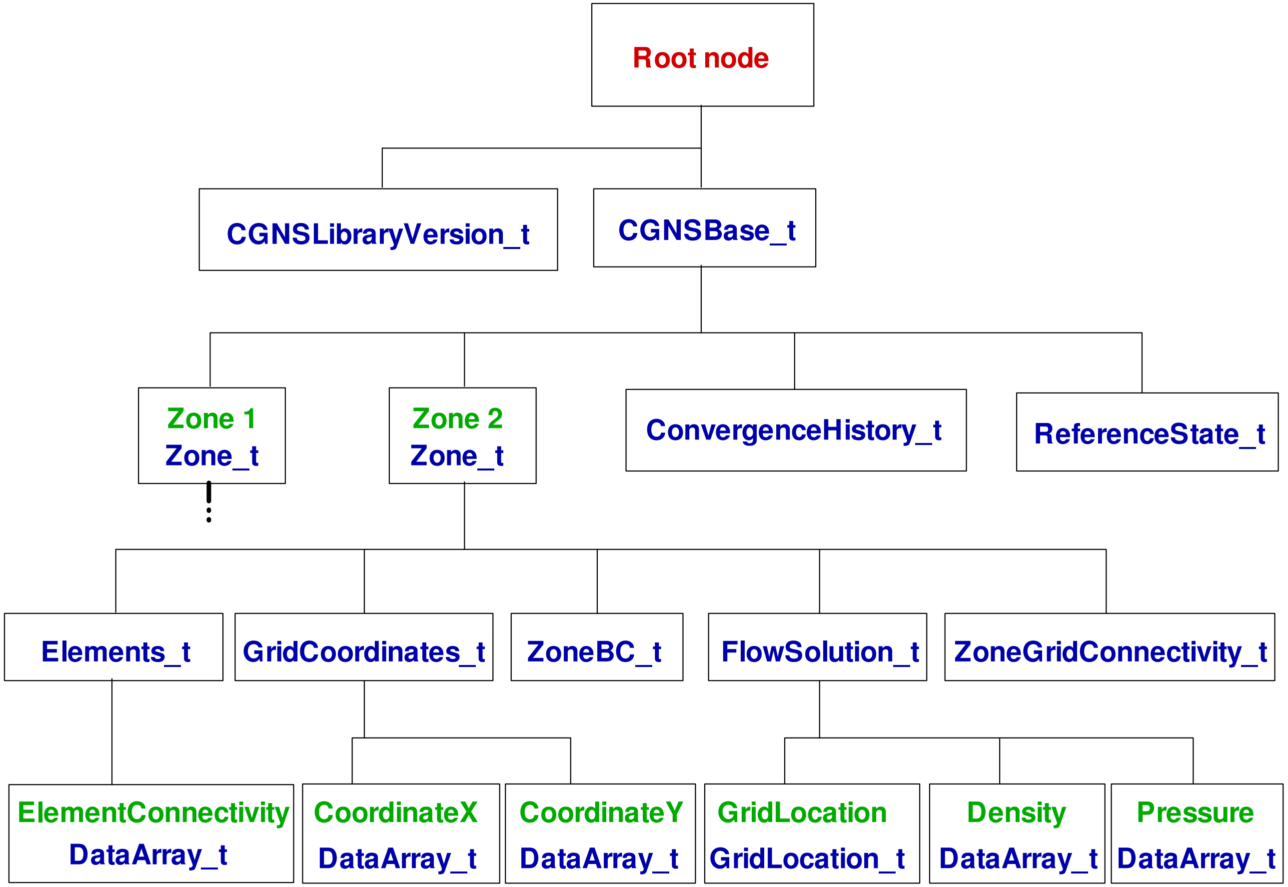
How CGNS works

- Users must download the CGNS software
  - This includes ADF software (basic I/O operations in binary format)
  - Also includes MLL software (for ease of implementation)
  - Users wishing to use HDF5 instead of ADF must download this separately (MLL will work with either ADF or HDF5)
- Users are encouraged to use the MLL to read and write their data (helps ensure CGNS-compatibility)
- Files are portable across computer platforms
- Tools (such as adfviewer) allow user to "see" what is in the CGNS file
- Many commercial pre- and post-processing software support CGNS format

Typical view of CGNS file using ADFVIEWER



Typical CGNS file



Cons and Pros

- Cons
  - Although there are rules, there are also many options and a certain amount of freedom
    - Example: GridLocation = Vertex vs. CellCenter
    - Example: data can be stored dimensional or nondimensional
    - Example: optional use of Rind cells
  - This flexibility places more responsibility on the CGNS reader to figure out how to make use of what is in the file
  - Attempted balance between too rigid and too flexible
- Pros
  - As more people use it, more tools get developed to handle the flexibility
  - Can be as simple as storing only “grid + flow solution”, or as complex as storing <u>everything</u> needed to run/describe a case
  - Longevity and infinite extensibility

How CGNS can help you

- Improves longevity (archival quality) of data
  - Self-descriptive (more on this later)
  - Machine-independent
- Easy to share data files between sites
  - Eliminates need to translate between different data formats
  - Rigorous standard means less ambiguity about what the data means
- Saves time and money
  - For example, easy to set-up CFD runs because files include grid coordinates, connectivity, and BC information
- Easily extendible to include additional types of data
  - Solver-specific or user-specific data can easily be written & read – file remains CGNS-compliant (others can still read it!)
  - Once defined & agreed upon, new data standards can be added

Status/where CGNS is headed

- Latest version is 2.4
- As of Aug 2005, the CGNSTalk mailing list had 161 participants from 21 different countries and at least 80 different organizations
- Over 11,000 CGNS downloads from SourceForge over last 3 years (average of 408 per month over last 1 year)
- Many people have expressed interest in CGNS from outside of the traditional aerodynamics community
  - E.g., computational physiology, electromagnetics
- Parallel I/O (through HDF5) will be available soon
- CGNS is already in many widely-used commercial visualization products, e.g., Tecplot, Fieldview, ICEM-CFD (reader for Paraview being worked)
- Continuous process: approval and implementation of extensions for handling new capabilities

Getting CGNS

- Go to http://www.cgns.org and follow instructions
  - Or go directly to http://www.SourceForge.net
  - You can get the official released version (currently 2.4), or use CVS to keep up with the latest fixes
  - E.g.: cgnslib_2.4-4.tar.gz (or cgnslib_2.4-4.zip for Windows)
  - Follow instructions in README file to compile
- Also highly recommended (from same place):
  - cgnstools (tools for viewing/editing)
  - CGNS Users Guide (practical entry-level manual for getting started with CGNS – includes simple source codes)

Basics of using CGNS

- Simple example: opening, closing, writing, & reading Base
- Aspects for data longevity
  - Boundary conditions
  - Convergence history
  - Descriptor nodes
  - Data & equation descriptions
  - Flowfield variables

Opening/closing file & writing Base

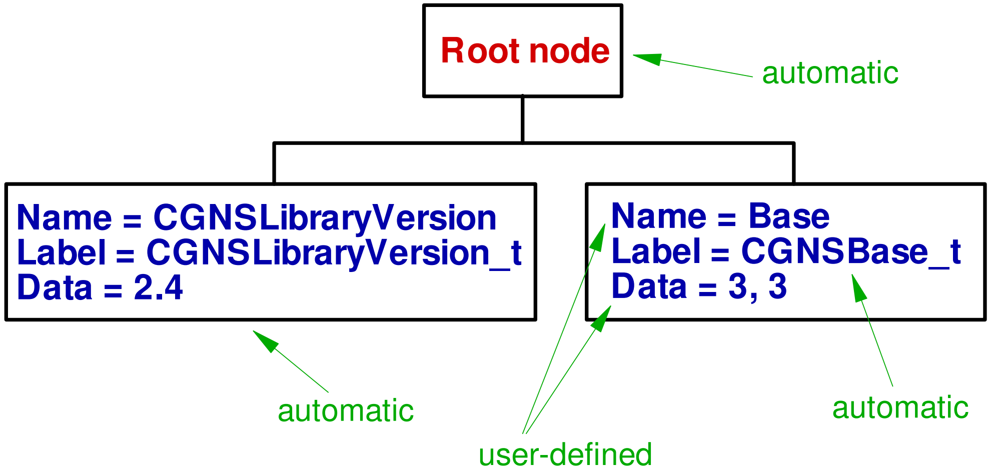
- C

```
cg_open("grid.cgns", MODE_WRITE, &indexf);
basename="Base";
icelldim=3;  /* dimensionality of cell (3 for volume cell) */
iphysdim=3;  /* number of coordinates (3 for 3-D) */
cg_base_write(indexf, basename, icelldim, iphysdim, &indexb);
    ……..
cg_close(indexf);
```

- Fortran

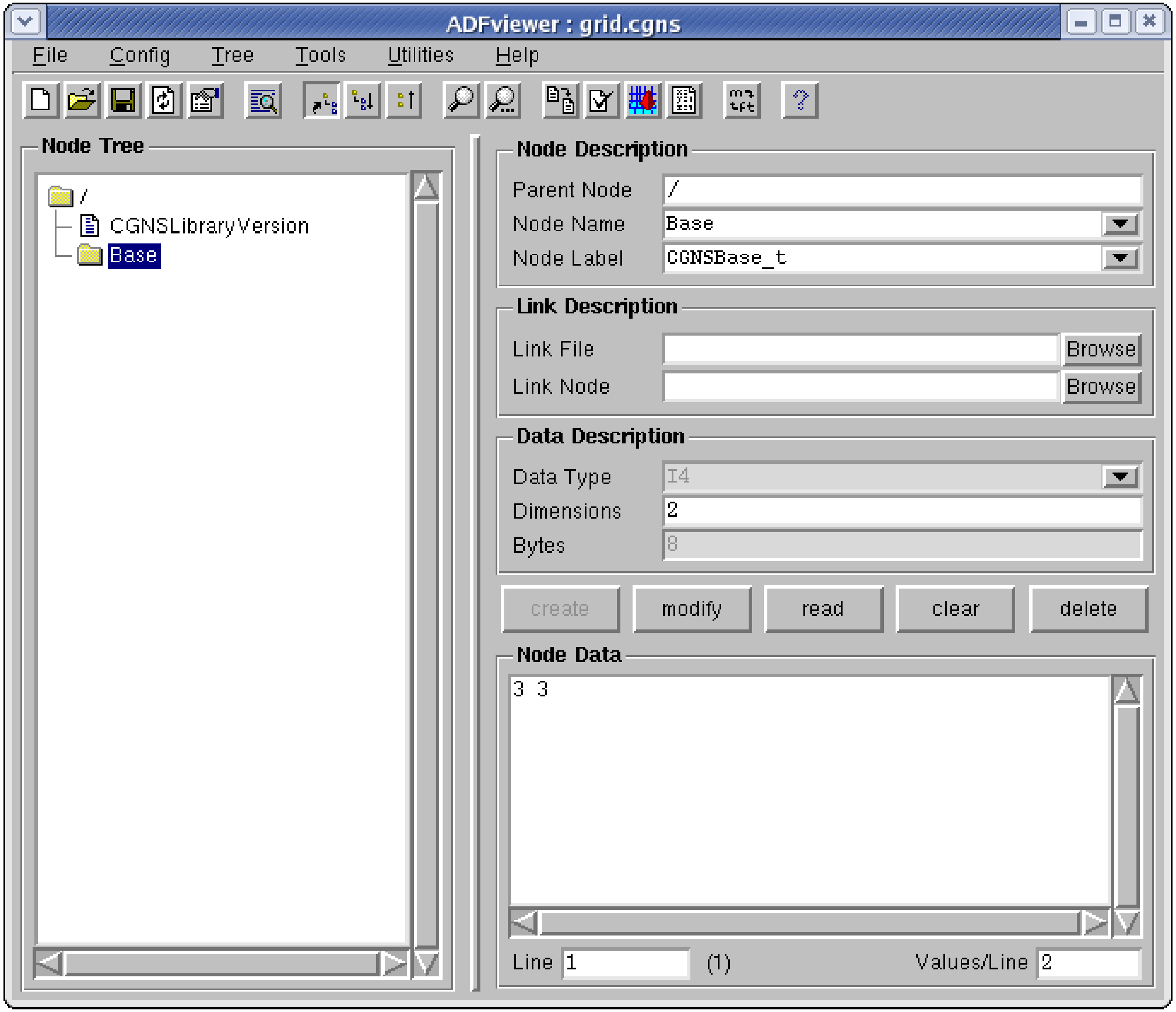
```
call cg_open_f('grid.cgns', MODE_WRITE, indexf, ier)
basename='Base'
icelldim=3
iphysdim=3
call cg_base_write_f(indexf, basename, icelldim, iphysdim, indexb, ier)
    ……..
call cg_close_f(indexf, ierr)
```

What the file looks like…



Notes: icelldim = dimensionality of cell (2 for face, 3 for volume)
iphysdim = no. of coordinates required to define a node position (1 for 1-D, 2 for 2-D, 3 for 3-D)

What the file looks like in adfviewer…



Reading the Base

- C

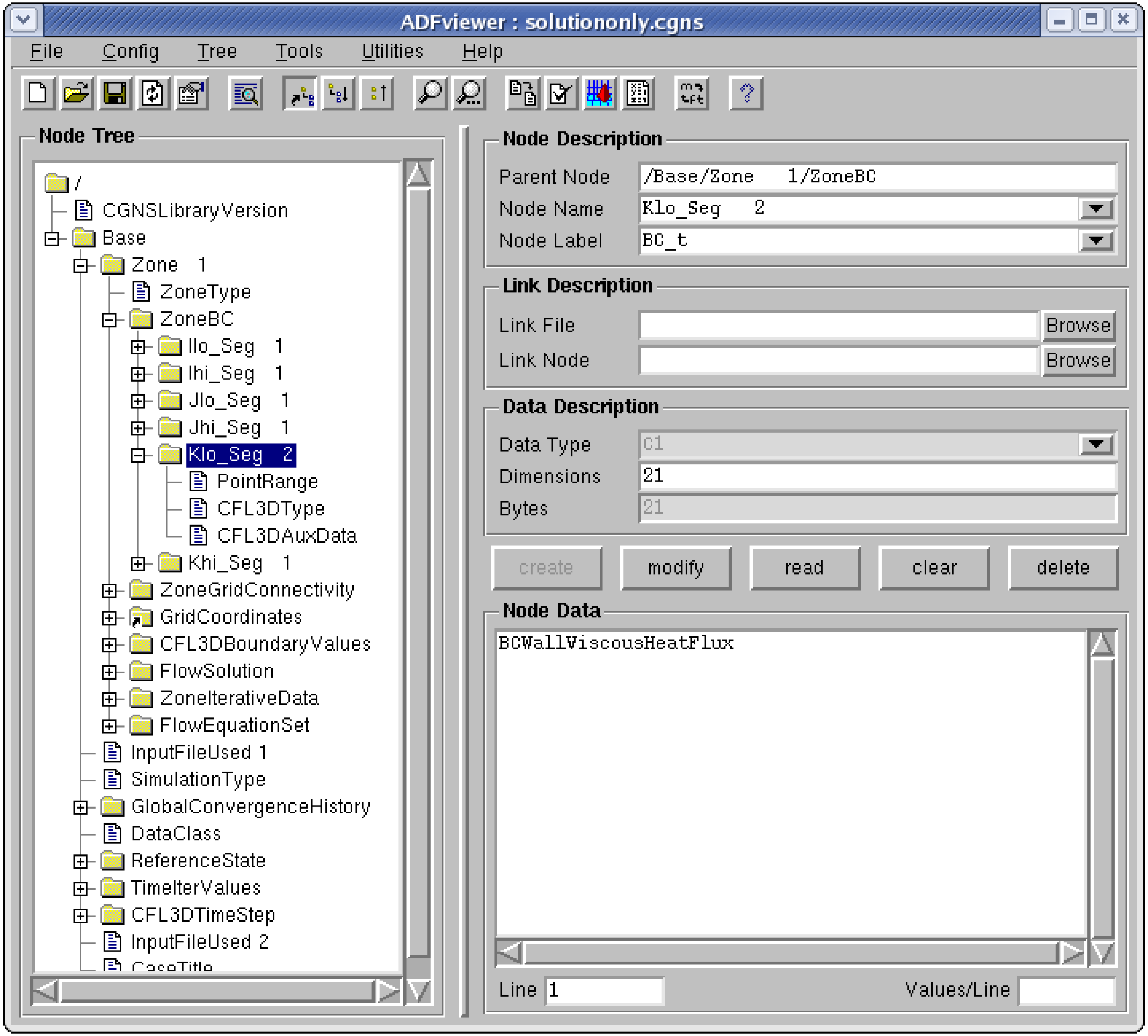
```
cg_open("grid.cgns", MODE_READ, &indexf);
cg_nbases(indexf, &nbases);
for (i=1; i <= nbases; i++)
    {cg_base_read(indexf, i, basename, &icelldim, &iphysdim);}
cg_close(indexf);
```

- Fortran

```
call cg_open_f('grid.cgns', MODE_READ, indexf, ier)
call cg_nbases_f(indexf, nbases, ier)
do i=1,nbases
    call cg_base_read_f(indexf, i, basename, icelldim, iphysdim, ier)
enddo
call cg_close_f(indexf, ier)
```

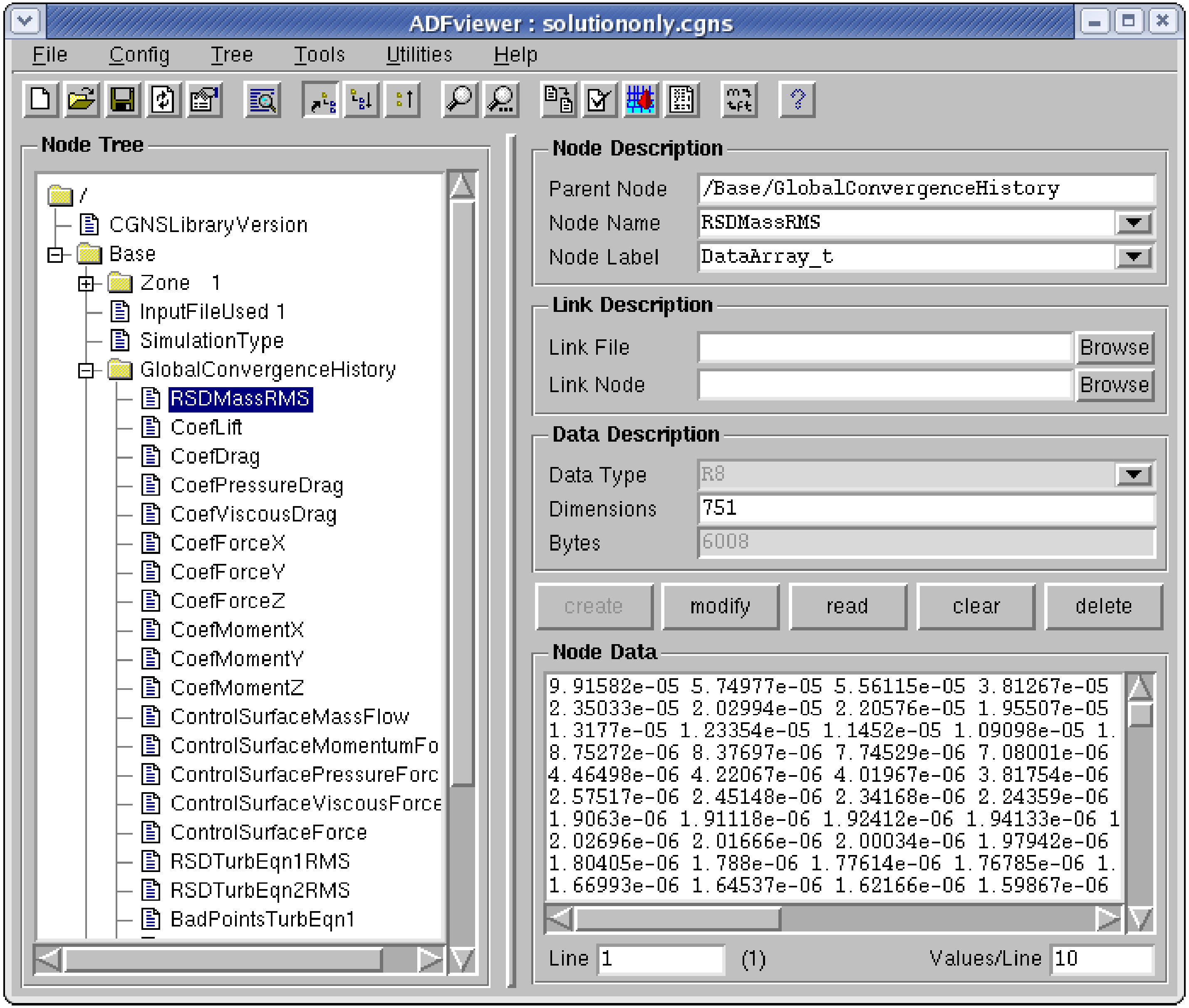
Aspects for data longevity
boundary conditions

- BCs are included in the CGNS file
- Including BCs makes it easier for someone else to duplicate the same flow conditions
- Eliminates doubt as to how the solution was run, when later looking at the file
- BCs can be simple or have high level of detail
  - Minimum: list of points and their BC type (name)
  - Can also include Dirichlet or Neumann-type data


ADFviewer : solutiononly.cgns
File
Config
Tree
Tools
Utilities
Help
Node Tree
/
CGNSLibraryVersion
Base
Zone 1
ZoneType
ZoneBC
Ilo_Seg 1
Ihi_Seg 1
Jlo_Seg 1
Jhi_Seg 1
Klo_Seg 2
PointRange
CFL3DType
CFL3DAuxData
Khi_Seg 1
ZoneGridConnectivity
GridCoordinates
CFL3DBoundaryValues
FlowSolution
ZoneIterativeData
FlowEquationSet
InputFileUsed 1
SimulationType
GlobalConvergenceHistory
DataClass
ReferenceState
TimeIterValues
CFL3DTimeStep
InputFileUsed 2
Node Description
Parent Node
/Base/Zone 1/ZoneBC
Node Name
Klo_Seg 2
Node Label
BC_t
Link Description
Link File
Browse
Link Node
Browse
Data Description
Data Type
C1
Dimensions
21
Bytes
21
create
modify
read
clear
delete
Node Data
BCWallViscousHeatFlux
Line
1
Values/Line

Aspects for data longevity
convergence history

- GlobalConvergenceHistory tracks history of residual(s), forces, moments, etc.
- Part of a complete record of the flow solution, easily readable by others


ADFviewer : solutiononly.cgns
File Config Tree Tools Utilities Help
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Base
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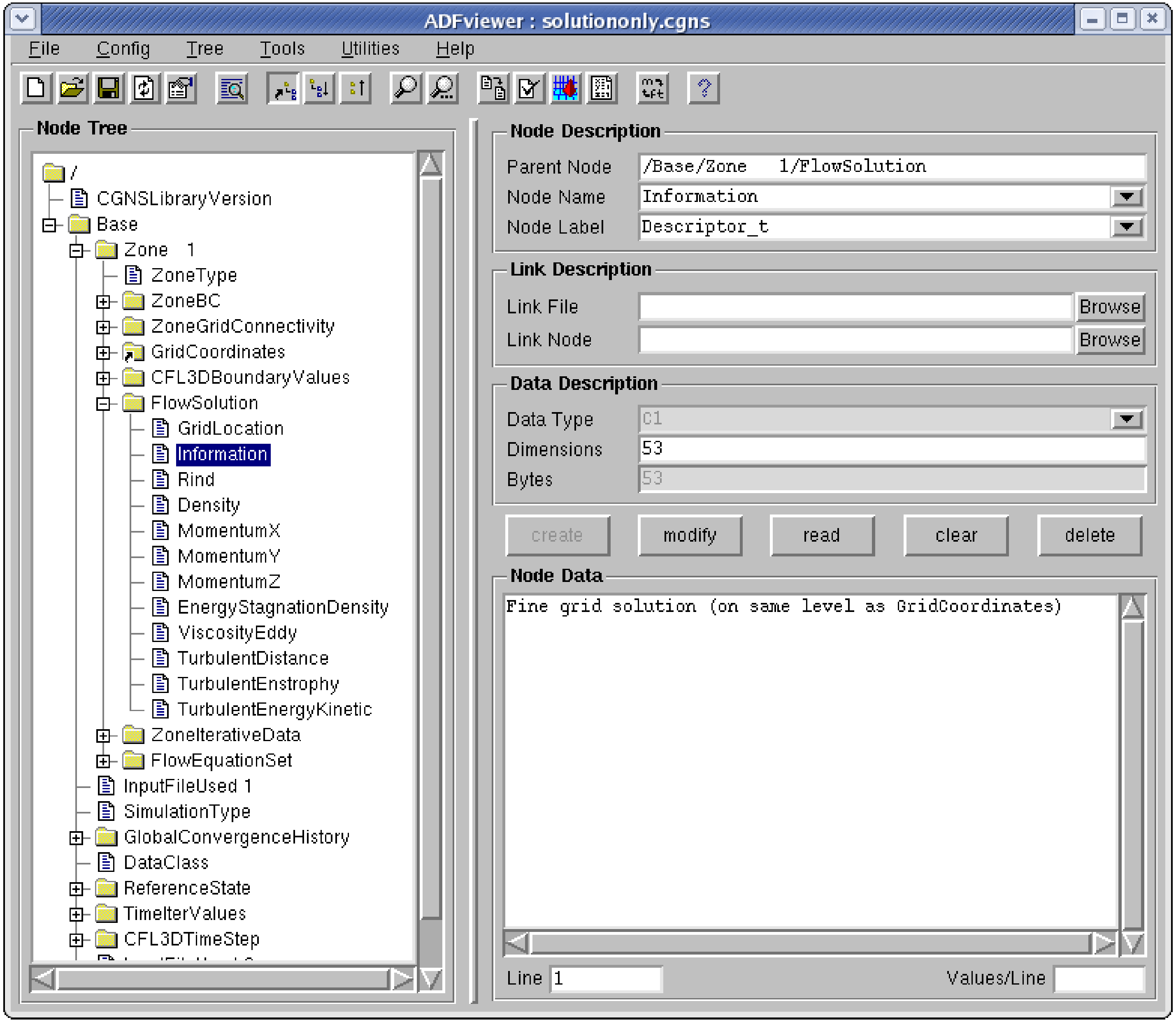
InputFileUsed 1
SimulationType
GlobalConvergenceHistory
RSDMassRMS
CoefLift
CoefDrag
CoefPressureDrag
CoefViscousDrag
CoefForceX
CoefForceY
CoefForceZ
CoefMomentX
CoefMomentY
CoefMomentZ
ControlSurfaceMassFlow
ControlSurfaceMomentumFo
ControlSurfacePressureForc
ControlSurfaceViscousForce
ControlSurfaceForce
RSDTurbEqn1RMS
RSDTurbEqn2RMS
BadPointsTurbEqn1
Node Description
Parent Node /Base/GlobalConvergenceHistory
Node Name RSDMassRMS
Node Label DataArray_t
Link Description
Link File Browse
Link Node Browse
Data Description
Data Type R8
Dimensions 751
Bytes 6008
create modify read clear delete
Node Data
9.91582e-05 5.74977e-05 5.56115e-05 3.81267e-05
2.35033e-05 2.02994e-05 2.20576e-05 1.95507e-05
1.3177e-05 1.23354e-05 1.1452e-05 1.09098e-05 1.
8.75272e-06 8.37697e-06 7.74529e-06 7.08001e-06
4.46498e-06 4.22067e-06 4.01967e-06 3.81754e-06
2.57517e-06 2.45148e-06 2.34168e-06 2.24359e-06
1.9063e-06 1.91118e-06 1.92412e-06 1.94133e-06 1
2.02696e-06 2.01666e-06 2.00034e-06 1.97942e-06
1.80405e-06 1.788e-06 1.77614e-06 1.76785e-06 1.
1.66993e-06 1.64537e-06 1.62166e-06 1.59867e-06
Line 1 (1) Values/Line 10

Aspects for data longevity
descriptor nodes

- Allow user to add notes, descriptions, important factors associated with the particular run, etc.
- As part of the permanent record, descriptor nodes make the file potentially more useful/meaningful in the future
- Full inclusion of flow solver input deck(s) is particularly useful
- Eliminates doubt as to how the solution was run, when later looking at the file


ADFviewer : solutiononly.cgns
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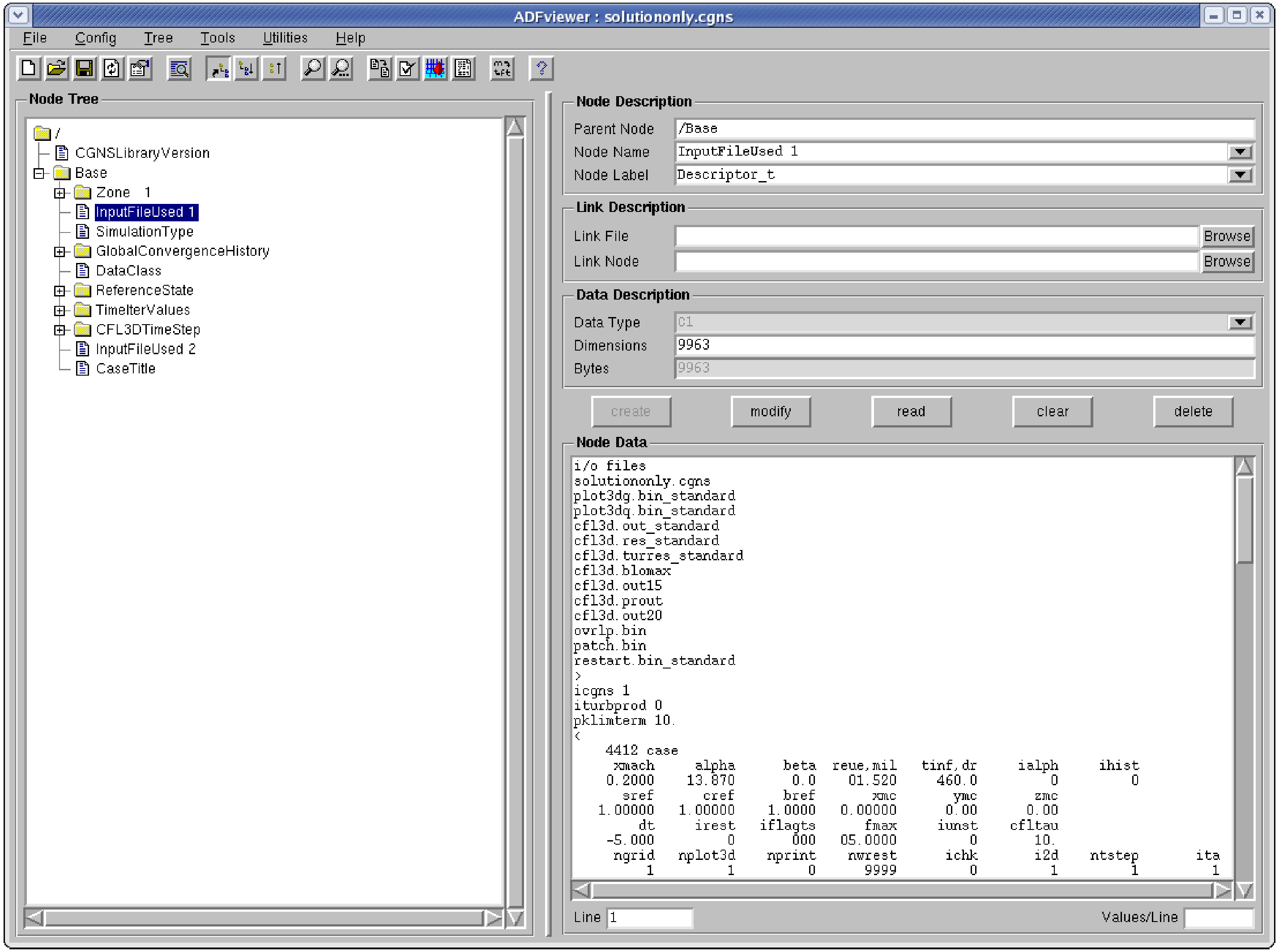
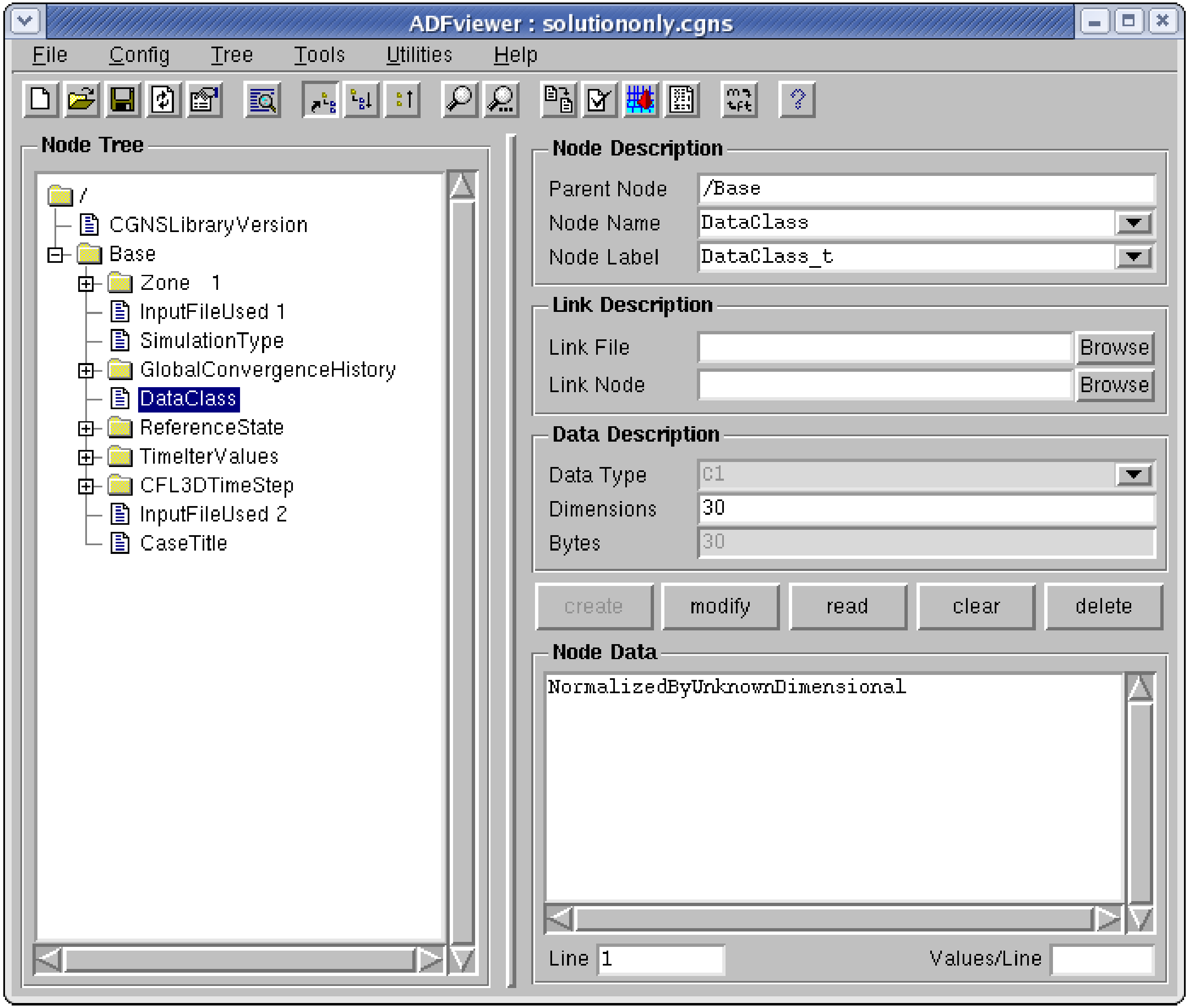
Base
Zone 1
ZoneType
ZoneBC
ZoneGridConnectivity
GridCoordinates
CFL3DBoundaryValues
FlowSolution
GridLocation
Information
Rind
Density
MomentumX
MomentumY
MomentumZ
EnergyStagnationDensity
ViscosityEddy
TurbulentDistance
TurbulentEnstrophy
TurbulentEnergyKinetic
ZoneIterativeData
FlowEquationSet
InputFileUsed 1
SimulationType
GlobalConvergenceHistory
DataClass
ReferenceState
TimeIterValues
CFL3DTimeStep
Node Description
Parent Node
/Base/Zone 1/FlowSolution
Node Name
Information
Node Label
Descriptor_t
Link Description
Link File
Browse
Link Node
Browse
Data Description
Data Type
C1
Dimensions
53
Bytes
53
create
modify
read
clear
delete
Node Data
Fine grid solution (on same level as GridCoordinates)
Line
1
Values/Line



CGNS
cfd data standard

Aspects for data longevity
data & equation descriptions

- Documents the dimensionality & units (or normalization) of the data
- Reference state and flow solution method become part of permanent record
- Eliminates doubt as to what the variables represent and how the solution was run, when later looking at the file


ADFviewer : solutiononly.cgns
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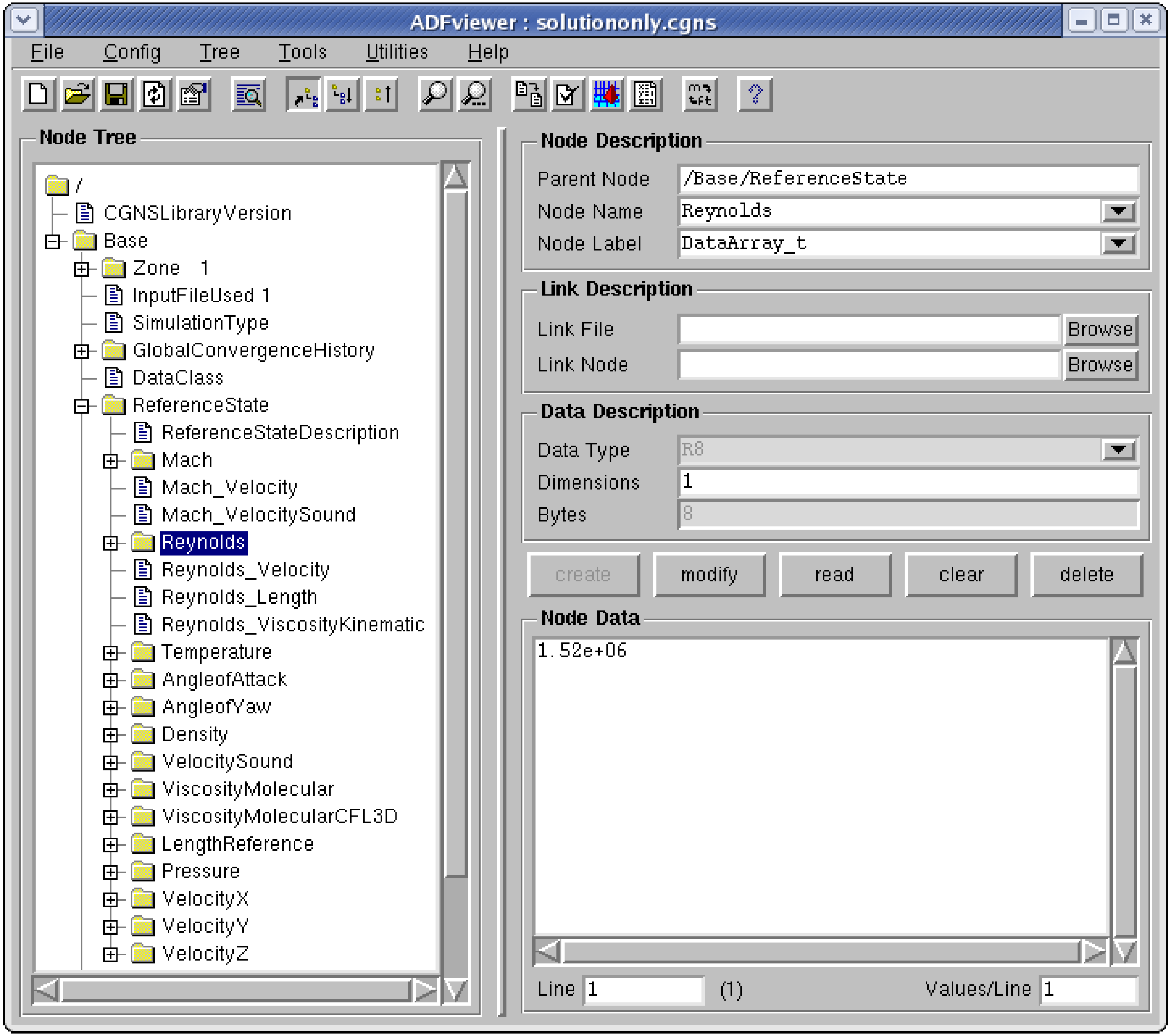
Base
Zone 1
InputFileUsed 1
SimulationType
GlobalConvergenceHistory
DataClass
ReferenceState
TimeIterValues
CFL3DTimeStep
InputFileUsed 2
CaseTitle
Node Description
Parent Node
/Base
Node Name
DataClass
Node Label
DataClass_t
Link Description
Link File
Browse
Link Node
Browse
Data Description
Data Type
C1
Dimensions
30
Bytes
30
create
modify
read
clear
delete
Node Data
NormalizedByUnknownDimensional
Line
1
Values/Line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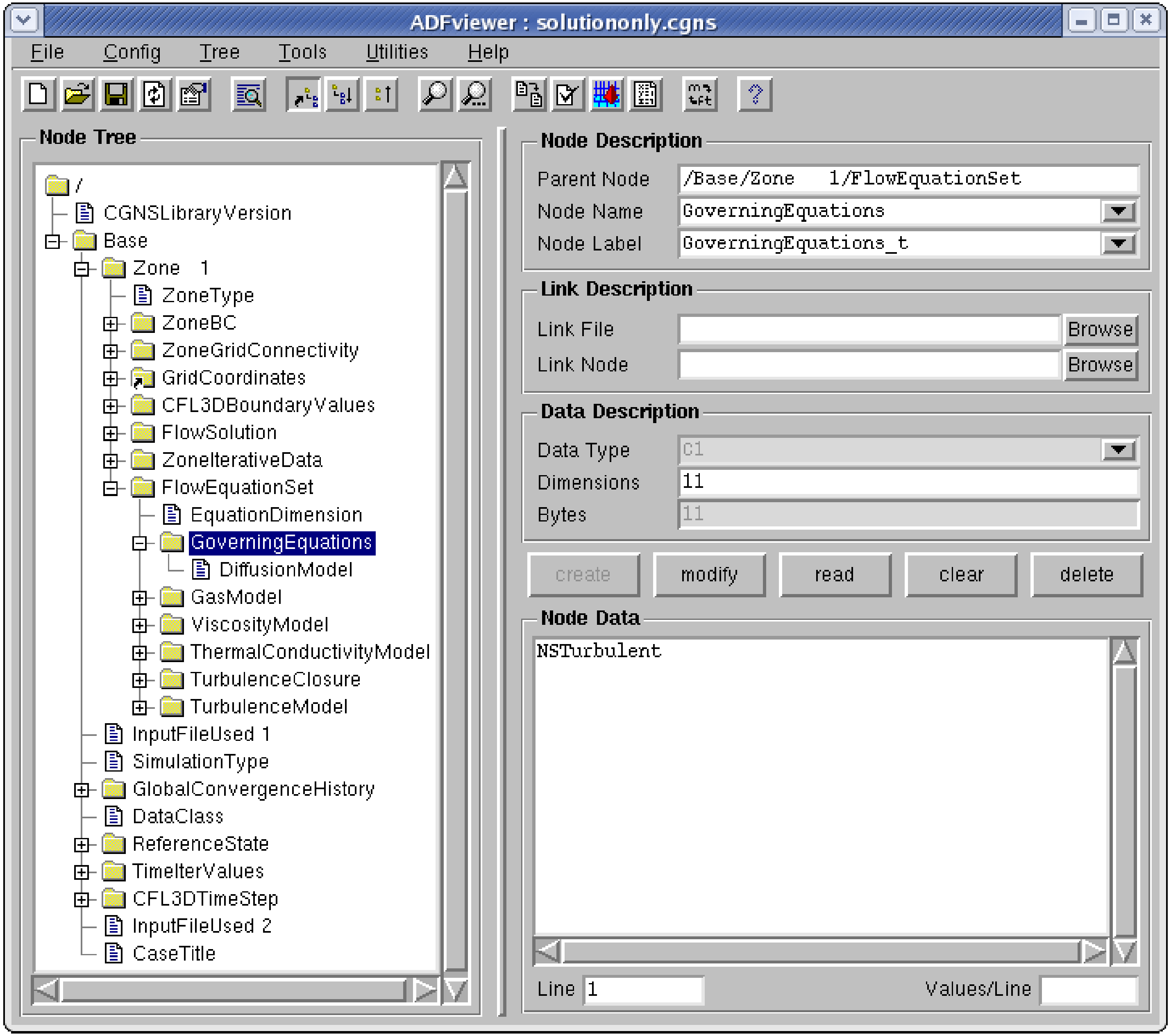
Base
Zone 1
InputFileUsed 1
SimulationType
GlobalConvergenceHistory
DataClass
ReferenceState
ReferenceStateDescription
Mach
Mach_Velocity
Mach_VelocitySound
Reynolds
Reynolds_Velocity
Reynolds_Length
Reynolds_ViscosityKinematic
Temperature
AngleofAttack
AngleofYaw
Density
VelocitySound
ViscosityMolecular
ViscosityMolecularCFL3D
LengthReference
Pressure
VelocityX
VelocityY
VelocityZ
Node Description
Parent Node
/Base/ReferenceState
Node Name
Reynolds
Node Label
DataArray_t
Link Description
Link File
Browse
Link Node
Browse
Data Description
Data Type
R8
Dimensions
1
Bytes
8
create
modify
read
clear
delete
Node Data
1.52e+06
Line
1
(1)
Values/Line
1


ADFviewer : solutiononly.cgns
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CGNSLibraryVersion
Base
Zone 1
ZoneType
ZoneBC
ZoneGridConnectivity
GridCoordinates
CFL3DBoundaryValues
FlowSolution
ZoneIterativeData
FlowEquationSet
EquationDimension
GoverningEquations
DiffusionModel
GasModel
ViscosityModel
ThermalConductivityModel
TurbulenceClosure
TurbulenceModel
InputFileUsed 1
SimulationType
GlobalConvergenceHistory
DataClass
ReferenceState
TimeIterValues
CFL3DTimeStep
InputFileUsed 2
CaseTitle
Node Description
Parent Node
/Base/Zone 1/FlowEquationSet
Node Name
GoverningEquations
Node Label
GoverningEquations_t
Link Description
Link File
Browse
Link Node
Browse
Data Description
Data Type
C1
Dimensions
11
Bytes
11
create
modify
read
clear
delete
Node Data
NSTurbulent
Line
1
Values/Line

Aspects for data longevity
flowfield variables

- As many flowfield variables as desired can be stored; for example:
  - Conserved and/or primitive variables
  - Plus all turbulence quantities, eddy viscosity, distance functions, species mass fractions, or other flowfield quantities of interest
- Eliminates having to go back and restart or reconstruct when you want to obtain non-standard quantities

CGNS cfd data standard

Some final comments

- A CGNS file can be as full or as sparse as you want to make it
  - The fuller it is, the more complete and archival the file
  - Always easy to read only the parts you want
- Easy to build CGNS into existing processes
  - Start by writing only the "basic" elements of CGNS file (e.g., grid, flow solution, connectivity, and BCs) as a postprocessing file for flow visualization
  - Gradually add to completeness of file
  - Eventually, CGNS file can replace your restart file, if desired

Conclusions

- 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 many commercial visualization and CFD vendors
- Extensible and flexible – easily adapted to other fields of computational physics through specification in the SIDS
- Backward compatible with previous versions; forward compatible within major release numbers
- Allows new software development to focus on important matters, rather than on time-consuming data I/O, storage, and compatibility issues

Conclusions, cont'd

- CGNS is the best thing since sliced bread!

Auxiliary slides

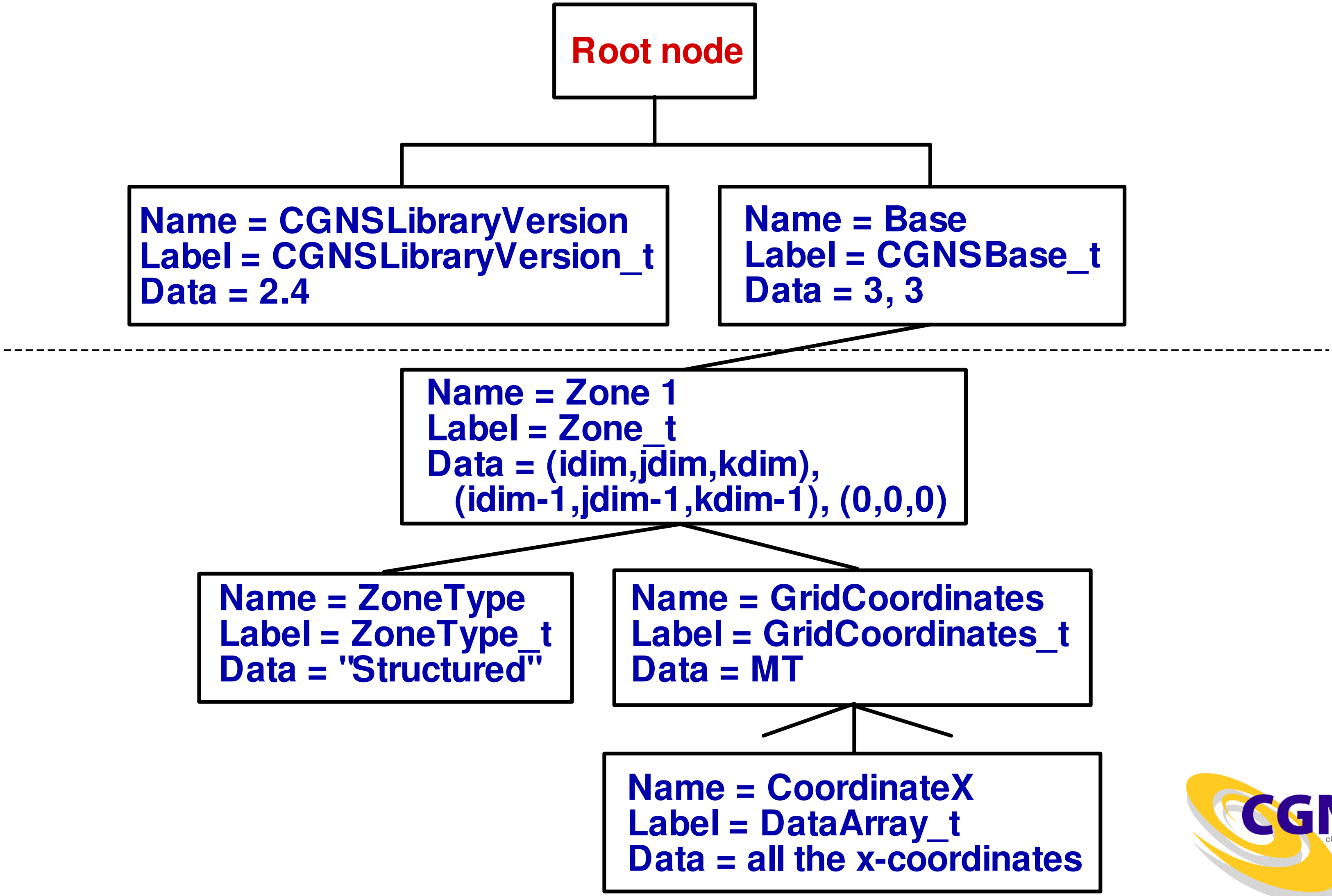
Writing structured grids

```
double x[kdim][kdim][idim], y[kdim][jdim][idim], z[kdim][jdim][idim];
int isize[3][3];
strcpy(zonename,"Zone 1");
/* vertex size (structured grid example) */
isize[0][0]=idim;
isize[0][1]=jdim;
isize[0][2]=kdim;
/* cell size (structured grid example) */
isize[1][0]=isize[0][0]-1;
isize[1][1]=isize[0][1]-1;
isize[1][2]=isize[0][2]-1;
/* boundary vertex size (always zero for structured) */
isize[2][0]=0;
isize[2][1]=0;
isize[2][2]=0;
```

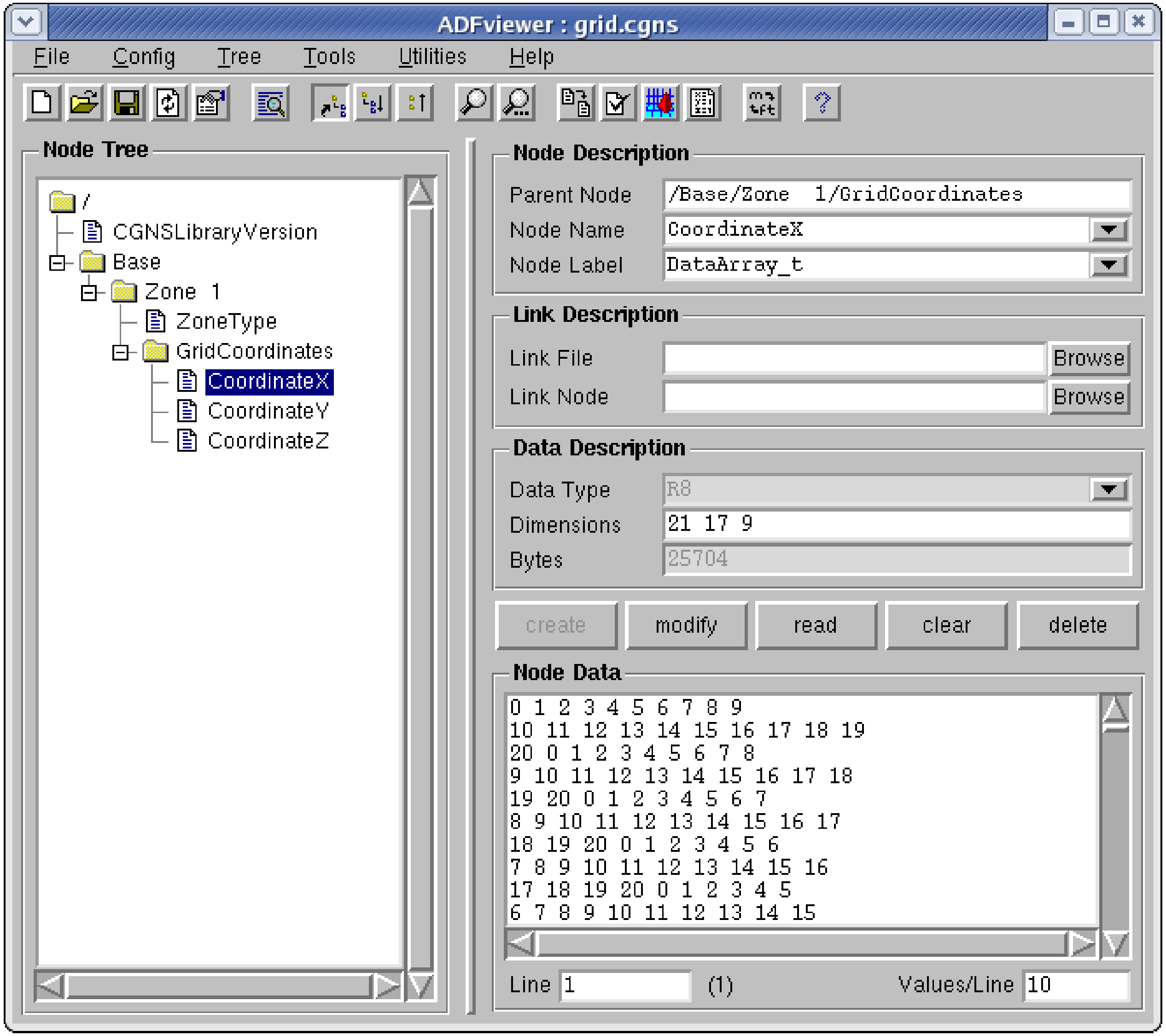
Writing structured grids (cont'd)

```
/* create zone */
cg_zone_write(indexf, indexb, zonename, isize[0], Structured, &indexz);
/* write grid coordinates */
cg_coord_write(indexf, indexb, indexz, RealDouble, "CoordinateX", x,
    &indexcx);
cg_coord_write(indexf, indexb, indexz, RealDouble, "CoordinateY", y,
    &indexcy);
cg_coord_write(indexf, indexb, indexz, RealDouble, "CoordinateZ", z,
    &indexcz);
```

What the file looks like…



What the file looks like in adfviewer…



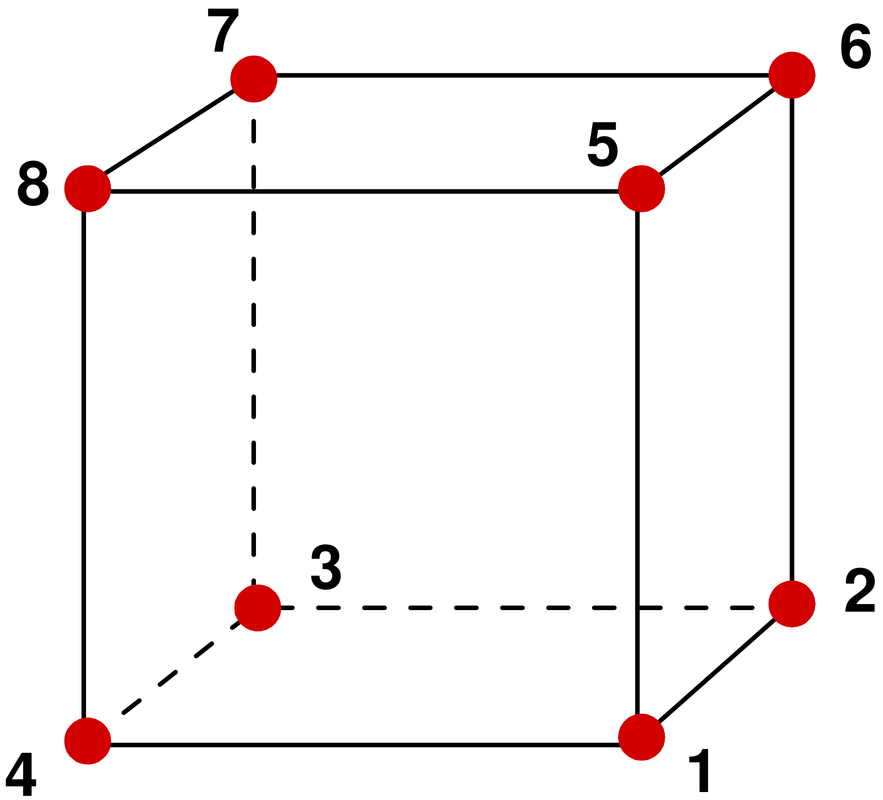
Writing unstructured grids

```
/* this is an example for HEXA_8 (cube-like) elements
double x[maxnodes], y[maxnodes], z[maxnodes];
int isize[3], ielem[maxelem][8];
strcpy(zonename,"Zone 1");
/* vertex size (unstructured grid example) */
isize[0]=inodedim;
/* cell size (unstructured grid example) */
isize[1]=icelldim;
/* boundary vertex size (zero if elements not sorted) */
isize[2]=ivbdy;
```

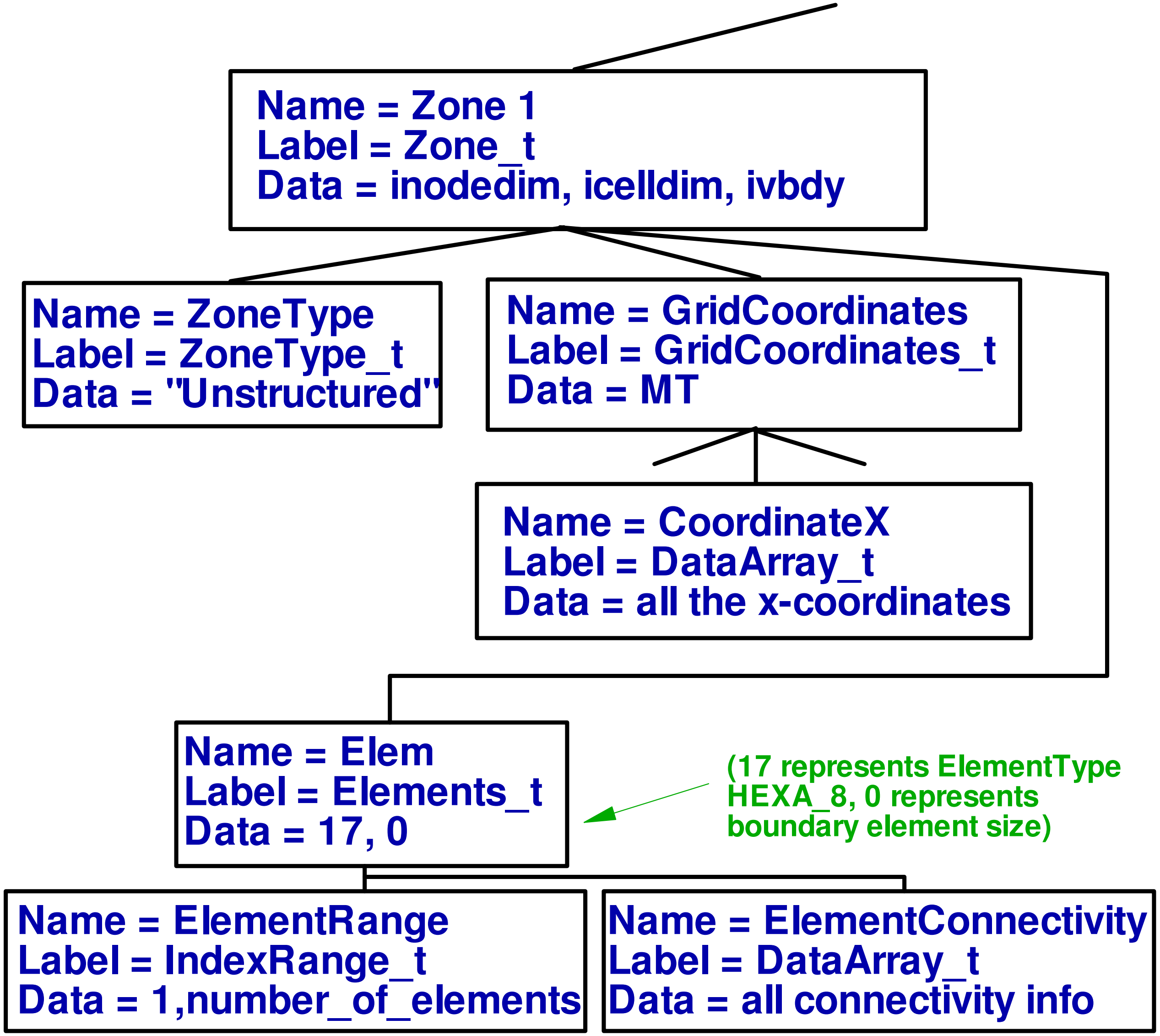
Writing unstructured grids (cont'd)

```
/* create zone */
cg_zone_write(indexf, indexb, zonename, isize, Unstructured, &indexz);
/* write grid coordinates */
cg_coord_write(indexf, indexb, indexz, RealDouble, “CoordinateX”, x,
    &indexcx);
cg_coord_write(indexf, indexb, indexz, RealDouble, “CoordinateY”, y,
    &indexcy);
cg_coord_write(indexf, indexb, indexz, RealDouble, “CoordinateZ”, z,
    &indexcz);
/* write element connectivity */
cg_section_write(indexf, indexb, indexz, “Elem”, HEXA_8, nelem_start,
    nelem_end, nbdyelem, ielem[0], &indexe);
```

Element connectivity for HEXA_8



What the file looks like… (below Base)



What the file looks like in adfviewer…