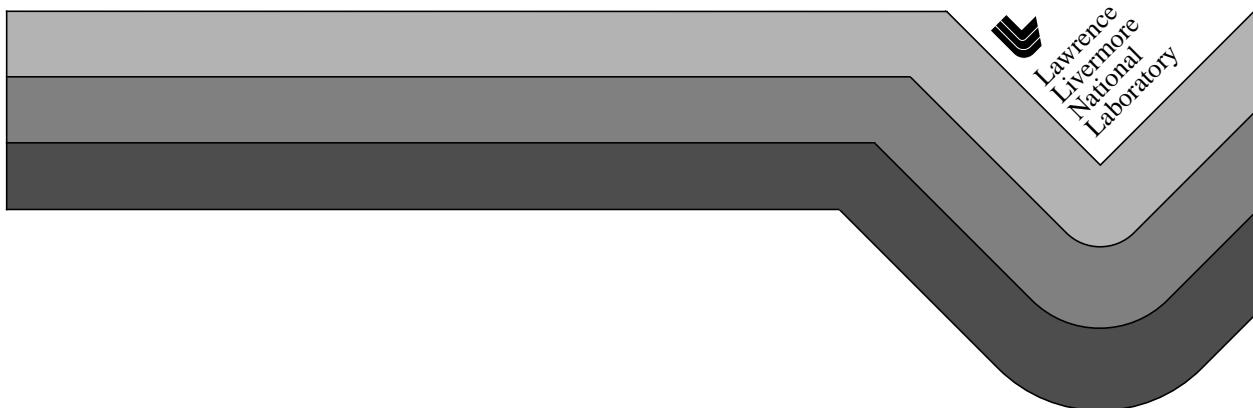


Getting Data Into VisIt

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Chapter 1 Introduction

1.0 Overview

VisIt is a free, open source, platform independent, distributed, parallel, visualization tool for visualizing data defined on two- and three-dimensional structured and unstructured meshes. VisIt's plug-in architecture allows it to perform a wide variety of plotting and data processing operations, and also allows VisIt to import data from many different data formats.

This manual explains in detail how to get your data into VisIt, concentrating on three main strategies: writing compatible files, writing a new plug-in for VisIt, or instrumenting a simulation code. In addition to providing the how-to's of getting your data into VisIt, this manual also presents reasons for why you might choose one strategy over another.

This manual is geared towards someone who wants to visualize and analyze data using VisIt. VisIt reads a large number of file formats so users of some existing simulation software will be able to use VisIt right away. This manual is for the user who has data files that VisIt does not read, or who wants to directly access data from a homegrown simulation code. Whichever the case, this manual assumes familiarity with computer programming since all of the covered approaches for getting data into VisIt require some programming. The examples in this manual are written primarily using the C and C++ programming languages, though relevant examples for the Fortran and Python languages are also included.

2.0 Manual chapters

This manual is broken down into the following chapters:

Chapter title	Chapter description
Introduction	This chapter.
Creating compatible files	Describes how to store data into file formats that VisIt already reads.
Creating compatible files II Advanced topics	Describes how to store metadata to boost VisIt's performance and also covers more exotic types of data that can be stored into file formats that VisIt already reads.
Creating a database reader plug-in	Describes how to create a new database reader plug-in for VisIt so it can read your own data file format.
Instrumenting simulation codes	Describes how to instrument your simulation code so VisIt can directly access its data without the need to write files.

3.0 Manual conventions

This manual uses the following conventions:

Element	All GUI elements, like windows, menus, and buttons will use bold helvetica .
Chapters	All references to other chapters will use Bold Times .
<i>Documents</i>	All document or file names will be <i>italicized</i> .

4.0 Strategies

Often, the first strategy to consider when trying to get your data into VisIt is creating data files using a data format that VisIt can already read. This is usually the simplest method for getting data into VisIt as it can be accomplished by adding a new I/O module to your simulation code or it can be achieved by creating an external data conversion utility.

Changing your simulation code to write out data that VisIt can read is sometimes not an option. For example, you might not have the simulation's source code or perhaps there is

too much risk involved in changing the source code. In addition, you might have gigabytes of archived data that you've written using your simulation's native data format and now you want to visualize that data in VisIt. If any of these cases apply to your situation then you might want to consider writing a database reader plug-in for VisIt so VisIt can natively understand your simulation code's data format.

If you want to maintain your current data format but you don't want to write a database reader plug-in for VisIt, you have another option: instrument the simulation code. VisIt provides a modestly sized library that contains C-Language functions that you can use to instrument your simulation code. When a simulation code is instrumented, VisIt can connect to it and access any of the arrays that you expose. This approach lets VisIt visualize the data from your simulation code directly without the need to write files.

5.0 Picking a strategy

The strategy you use to get your data into VisIt depends on your situation. The following table indicates reasons when you might pick one strategy over another.

Strategy	Reasons when to use
Create compatible files	<ul style="list-style-type: none"> You have access to your simulation code's source code and one of VisIt's supported file formats can express your data. You can write a conversion utility and don't mind using it to copy the existing data into a new data format.
Write a database reader plug-in	<ul style="list-style-type: none"> You have written a lot of data files using your own data format or a format that VisIt does not read. Changing the simulation's source code is not an option. VisIt's supported file formats can't fully capture your data's structure or content. Your data format is already supported in another visualization application.
Instrument simulation code	<ul style="list-style-type: none"> You want to use VisIt to inspect your data as it is calculated. You don't want to change your simulation code so it writes a different data format. Your simulation code is written in the C, C++, or Fortran programming languages.

The following table indicates reasons why you would *not* pick one of the given strategies.

Strategy	Reason to <i>not</i> use
Create compatible files	<ul style="list-style-type: none">• You don't want to change or are unable to change your simulation's source code• You don't want to replicate data in another data format, taking up more storage.• Your data format is already supported in another visualization application
Write a database reader plug-in	<ul style="list-style-type: none">• Developing a VisIt database reader plug-in can be difficult, though this manual aims to lessen the difficulties.• You need to run VisIt on several platforms and you don't want to build the plug-in on all of those platforms.• You don't want to maintain a VisIt plug-in. Note that you could donate the plug-in to the VisIt development team.
Instrument simulation code	<ul style="list-style-type: none">• You don't want to change or are unable to change your simulation's source code.• Your simulation code is not written in C, C++, or Fortran.

After examining the above tables, you probably have a pretty good idea of which strategy will work best for getting your data into VisIt. The following chapters will provide details on how best to get your data into VisIt using each of the recommended strategies.

6.0 Definition of terms

This section defines some of the terms that will be used to describe data structures that VisIt can visualize. These terms are defined here because many branches of science that might use VisIt to visualize and analyze data have their own terms. It is hoped that adding

the definition of terms here will reduce ambiguity when different types of data are covered in later chapters.

Term	Definition
Curvilinear mesh	A curvilinear mesh is a mesh composed entirely of quadrilateral or hexahedral cells. Furthermore, the mesh is constructed such that all zones exist in a logically contiguous brick having NX zones in the X dimension, NY zones in the Y dimension, and in the case of 3-D: NZ zones in the Z dimension. Each node in the mesh requires an explicitly provided coordinate value.
Domain	A domain is a unit of work that corresponds to a piece of the mesh that is handled by a given processor when running in parallel. Meshes are often split into multiple pieces, or domains, that can be assigned to different processors in order to handle larger simulations.
Ghost zone	A ghost zone is a zone on the boundaries of domains and it is used to ensure that each domain knows the data value on the other side of the domain boundary so operations requiring continuity do not give rise to discontinuities at domain boundaries.
Material	A physical material such as air or steel that is assigned to various zones in a mesh to indicate the types of materials that make up the simulated model. Zones that contain more than one material are said to be “mixed” since their compositions are determined by a set of volume fractions of various materials in the zone.
Mesh	A mesh is a structure composed of zones.
Node	A mathematical point. Nodes are used to describe the coordinates for zones that make up a mesh.
Node-centered	Node-centered is a term that applies to data stored on a mesh; it means that there is one data value for each node in the mesh and that values in the zone are created by interpolating data from the nodes.
Point mesh	A mesh consisting of a set of locations, or points, in space. These nodes are not connected.

Term	Definition
Rectilinear mesh	A rectilinear mesh is a mesh composed entirely of quadrilateral or hexahedral cells that are all the same shape. Furthermore, the mesh is constructed such that all zones exist in a contiguous brick having NX zones in the X dimension, NY zones in the Y dimension, and in the case of 3-D: NZ zones in the Z dimension. The coordinates for the nodes are supplied as lists of NX, NY, or NZ elements from which the full complement of nodes can be created.
Time step	Simulations proceed by calculating their state at the current time and then making adjustments that are needed to advance the state of the simulation to the next time. This is done in an iterative cycle. One iteration of the simulation is called a time step.
Unstructured mesh	An unstructured mesh consists of a set of nodes and a set of zones. The set of zones may consist of many different zone types such as triangles, quadrilaterals, tetrahedra, hexahedra, prisms, pyramids, or other polyhedra. Adjacent zones share the same nodes and the nodes are represented as a shape type identifier and a list of the nodes that comprise the zone.
Zone-centered	Zone-centered is a term that applies to data stored on a mesh; it means that there is one data value for each zone in the mesh.
Zone/Cell	Zone and Cell are used interchangeably in this document. A zone is a shape that unites one or more nodes into a connected structure where the nodes are the vertices of the connected structure. Point meshes can have nodes as zones. 1-D meshes contain zones that are lines that connect nodes. 2-D meshes contain 2-D shapes such as triangles and quadrilaterals that connect nodes together. 3-D meshes contain volumetric polyhedra such as: tetrahedrons, hexahedrons, prisms, pyramids, etc.

Chapter 2 Creating compatible files

1.0 Overview

This chapter elaborates on how to create files that VisIt can read. The two main methods of creating files that VisIt can read are: creating a conversion utility and altering a simulation code to write out its data in a new file format. This chapter discusses the merits of each approach so you can decide which is best for your situation. Once you settle on an approach, you can elect to write out Silo files from C or Fortran, or you can write out VTK files from any programming language. If you decide to write out VTK files, this chapter presents examples for doing so in C and Python.

2.0 Creating a conversion utility or extending a simulation

Creating files using a data format that VisIt can read is often the easiest strategy for getting your data into VisIt. You can change your simulation code to natively write its data to a format that VisIt can read, such as Silo or VTK. Alternatively, you can create a conversion utility to post-process your data files into a format that VisIt can read. Both of these approaches have their pros and cons and, fortunately, the programming done to achieve either is essentially the same.

Approach	Pros	Cons
Modify simulation code	•Data is in a format that can be immediately visualized	•Depending on the simulation code's implementation language, there may not be a binding to a suitable I/O library.

Approach	Pros	Cons
Create conversion utility	<ul style="list-style-type: none"> • Simulation code does not have to be changed 	<ul style="list-style-type: none"> • Replicates data on disk • Extra step is required to visualize simulation data • Utility must be maintained • Utility must read data from file before it can be written to new data format.

The chief differences between the two approaches arise in where the new code is located. When changing a simulation code, you will most likely add a new I/O module that can dump out your simulation's data for the purpose of visualization. When creating a conversion utility, you are creating a stand-alone program that you have to run on the data after the simulation has completed.

A very simple simulation code's main loop might look like the example below. The purpose of the simple pseudocode listing is to point out where you might want to add additional routines that can write your data to files compatible with VisIt. You might want to provide a switch that tells your program to write data files that VisIt can read in addition to your regular data format. Alternatively, you might opt to just write files that are compatible with VisIt.

```
/* SIMPLE SIMULATION SKELETON */
void write_vis_dump()
{
    if(write_data_for_visit)
        /* Add your code to write VisIt data files here. */
    else
        write_vis_dump_using_regular_format();
}
int main(int argc, char **argv)
{
    read_input_deck();
    do
    {
        simulate_one_timestep();
        write_vis_dump();
    } while(!simulation_done());
    return 0;
}
```

If you choose to write a conversion utility, a pseudocode skeleton might look something like this:

```
/* SIMPLE CONVERSION UTILITY SKELETON */
void write_to_visit_format(const char *, MeshAndData *)
{
    /* Add your code to write a VisIt data file here. */
```

```
}

void convert_file(const char *filename)
{
    struct MeshAndData data;
    char newfilename[1024];
    read_data_from_regular_format(filename, &data);
    create_visit_filename(filename, newfilename);
    write_to_visit_format(newfilename, &data);
    free_data(&data);
}
int main(int argc, char *argv[])
{
    for(int i = 1; i < argc; ++i)
        convert_file(argv[i]);
    return 0;
}
```

3.0 Survey of database reader plug-ins

VisIt provides database reader plug-ins for over one hundred different file formats. You can find a table listing the supported formats and links to more information at http://www.visitusers.org/index.php?title=Detailed_list_of_file_formats_VisIt_supports. This chapter will talk briefly about some simple file formats before covering the Silo and VTK file formats. Silo and VTK will be covered much more extensively because they are two of the most general formats and they are capable of describing a wide variety of different data constructs.

Silo is a C-language library with a well-defined application programming interface (API) for writing out the types of objects in which most simulations are interested (e.g. meshes, variables). Silo files can be written to two different underlying file structures: HDF5 and PDB; both are self-describing, platform independent, binary file formats. If you write a file on one platform using the Silo library, it can be read by the Silo library on any other platform. Silo bindings also exist for the Fortran and Python programming languages. For more information, see the *Silo User's Guide*.

The VTK file format is written by various C++ classes in VTK (Visualization Tool Kit) and is most often stored in ASCII text files. The VTK file format does, more recently, support an XML-based file format, which includes support for binary data and compression. However, this manual will provide example code to write data into VTK's legacy ASCII format. The example code will use VisIt's `visit_writer` library to demonstrate creating VTK files without using the VTK library itself so the applications will be very lightweight.

3.1 BOV file format

As mentioned earlier, VisIt can read over one hundred file formats and this manual will mainly concentrate on two of them. There are other file formats that might be useful to

you depending on how you have written your data files. For example, if you have written your data as a binary file consisting of 1 variable on a NX*NY*NZ rectilinear mesh then it is possible that you can use VisIt's BOV ("Brick of Values") database reader plug-in and not have to do any data conversion.

VisIt's BOV database reader plug-in is used to read data out of a binary file containing just the data values. If your data file was written using code resembling the following code fragments then you might be able to use VisIt's BOV database reader plug-in.

Listing 2-1: bov.c: C-Language example for creating data that the BOV plug-in can read.

```
/* Example C code */
float data[NZ][NY][NX];
FILE *fp = fopen("bov.values", "wb");
fwrite((void *)data, sizeof(float), NX*NY*NZ, fp);
fclose(fp);
```

Listing 2-2: fbov.f: Fortran language example for creating data that the BOV plug-in can read.

```
c Example Fortran code
      real values(NX, NY, NZ)
      open (unit=output, file='fbov.values', status='replace',
. form='unformatted')
      write(output) values
      close (output)
```

Files written in this manner will need an auxiliary data header text file stored along side of the real data file to contain information such as the dimensions of the data and its type and endian representation. If this sounds like what you write from your simulation code then you should try using the BOV reader. Before trying to open the data using VisIt's BOV database reader plug-in, you will have to write a BOV-compatible header file to accompany your data files so VisIt knows how to read the binary data file.

Note that it is also possible to create a BOV header file that describes a set of binary brick of value files. This is useful when you have multiple processors each writing their own data files but you need to view them as a whole within VisIt. When you need this functionality, you can provide a filename with wildcards for using the DATA_FILE keyword. For example, you could add "DATA_FILE: file%04d.dat" to the BOV header file to make VisIt treat all files matching the *file%04d.dat* pattern as separate domains within the BOV dataset.

Example BOV header file:

```
TIME: 1.23456
DATA_FILE: file0000.dat
# The data size corresponds to NX,NY,NZ in the above example code.
DATA_SIZE: 10 10 10
```

```
# Allowable values for DATA_FORMAT are: BYTE,SHORT,INT,FLOAT,DOUBLE
DATA_FORMAT: FLOAT
VARIABLE: what_I_call_the_data
# Endian representation of the computer that created the data.
# Intel is LITTLE, many other processors are BIG.
DATA_ENDIAN: LITTLE
# Centering refers to how the data is distributed in a cell. If you
# give "zonal" then it's 1 data value per zone. Otherwise the data
# will be centered at the nodes.
CENTERING: zonal
# BRICK_ORIGIN lets you specify a new coordinate system origin for
# the mesh that will be created to suit your data.
BRICK_ORIGIN: 0. 0. 0.
# BRICK_SIZE lets you specify the size of the brick.
BRICK_SIZE: 10. 10. 10.
```

Additional BOV options:

```
# BYTE_OFFSET: is optional and lets you specify some number of
# bytes to skip at the front of the file. This can be useful for
# skipping the 4-byte header that Fortran tends to write to files.
# If your file does not have a header then DO NOT USE BYTE_OFFSET.
BYTE_OFFSET: 4

# DIVIDE_BRICK: is optional and can be set to "true" or "false".
# When DIVIDE_BRICK is true, the BOV reader uses the values stored
# in DATA_BRICKLETS to divide the data into chunks that can be
# processed in parallel.
DIVIDE_BRICK: true

# DATA_BRICKLETS: is optional and requires you to specify 3 integers
# that indicate the size of the bricklets to create when you have
# also specified the DIVIDE_BRICK option. The values chosen for
# DATA_BRICKLETS must be factors of the numbers used for DATA_SIZE.
DATA_BRICKLETS: 5 5 5

# DATA_COMPONENTS: is optional and tells the BOV reader how many
# components your data has. 1=scalar, 2=complex number, 3=vector,
# 4 and beyond indicate an array variable. You can use "COMPLEX"
# instead of "2" for complex numbers. When your data consists of
# multiple components, all components for a cell or node are written
# sequentially to the file before going to the next cell or node.
DATA_COMPONENTS: 1
```

Take the above example BOV header file template and save it to a new text file with a “.bov” file extension. Next, edit the file and change some of the values to make it relevant to the data file that you want to open. Once you’ve completed editing the “.bov” file, open it in VisIt. If you see that the **Plots menu** is enabled and the **Mesh** and **Pseudocolor** plot menus are enabled then you are halfway to success. If you can create a Pseudocolor plot, click the **Draw** button, and have VisIt process your data until there is a picture in the visualization window then this approach works for you and you can repeat it for your other data files. If the picture is not quite what you expected then you can fine-tune the values in

the “.bov” file until you get the picture that you want to see. The most common cause of errors is failing to set the DATA_SIZE and DATA_FORMAT keywords to the right values for your data file.

For large data files, you will want to add DATA_BRICKLETS and DIVIDE_BRICK keywords to your BOV file. When these keywords are present, they instruct the BOV reader to dynamically read smaller pieces of the BOV data file into different domains that VisIt can process in parallel (when you use a parallel installation of VisIt). When used with DIVIDE_BRICK, DATA_BRICKLETS allows you to specify the size of a bricklet. The values used for the bricklet size divide evenly into the total data size that you provided with the DATA_SIZE keyword.

3.2 X-Y Curve file format

VisIt is used to examine and analyze a wide variety of data in 2D and 3D on many different types of meshes. In addition to those capabilities, VisIt can also visualize and process 1D curves, sometimes known as X-Y plots. VisIt’s Lineout mode can extract data from a higher dimensional dataset and draw the resulting data as an X-Y plot, or a Curve plot as it is known in VisIt terms. VisIt can also import X-Y data and use it to create Curve plots. The Curve file format, which is barely more than a list of X-Y pairs, is outlined below:

```
#curve1name
x0 y0
x1 y1
x2 y2
...
#curve2name
xn yn
xn1 yn1
...
```

As shown in the example Curve file, the Curve file format can contain data for more than 1 set of X-Y pairs. The name of each pair is indicated in a ‘#’ comment line. The X-Y pairs follow until the end of the file or until a new curve is declared using another ‘#’ comment line. If you write data to the Curve file format then the file extension should be “.curve” to ensure that VisIt recognizes it as a Curve file.

3.3 Plain text ASCII files

Many software programs, including VisIt, can read tables of numeric text. These files are called plain text ASCII files and they contain columns of numbers separated by whitespace or commas. When VisIt reads plain text ASCII files, you can specify some read options that determine how VisIt presents the data for plotting. This is necessary because of the myriad of ways that data can be stored in tabular form. For example, VisIt provides options to treat the table as data values on a 2D mesh, or as columns of 1D particle data.

3.4 NETCDF files

NETCDF is a library that allows codes to write self-describing array data to a binary file. This format is very popular in the climate research community and VisIt provides a NETCDF reader. Since NETCDF files are for array data only, they lack a mechanism to represent higher level constructs such as meshes in the file. As a result, many simulation codes write out their mesh data as a set of arrays whose relationship is understood by the simulation code. The relationship between arrays is known as a convention. Conventions present a problem for other software that is not aware of the conventions used to store the data. VisIt's NETCDF reader is aware of a few conventions for specific simulation codes and it attempts to implement a subset of the CF convention for climate data. Any other NETCDF files that VisIt's reader cannot associate with a particular convention are treated generically by VisIt's "basic" NETCDF reader. The basic NETCDF reader serves up data as independent 1D, 2D, 3D (possibly time-varying) arrays. If you write your data using the NETCDF library, VisIt will usually be able to present it in a suitable fashion.

3.5 HDF5 files

HDF5 format is a binary format that allows codes to write hierarchical, self-describing array data to a file. More information on HDF5 is available at <http://www.hdfgroup.org/HDF5>. As with NETCDF, HDF5 is mainly a format for storing arrays though it does permit storing structures and more complex data types. Simulation codes mainly use HDF5 to store the independent arrays that make up their data model. This means that while the data arrays are described by the file, the relationships between them are not. Libraries such as Silo are built on top of HDF5 to provide these semantics.

VisIt takes a slightly different approach with HDF5 than it does for NETCDF in that each "flavor", or HDF5 convention, is read by a separate HDF5 reader plugin. The NETCDF reader incorporates all of the NETCDF readers into a single plugin. Many of the HDF5 reader plugins are for specific simulation codes and some are more general, attempting to provide a generic view of the HDF5 data. Finally, some HDF5 readers such as VisSchema and XDMF use an auxiliary XML file to describe how various arrays in the HDF5 file are assembled into higher level constructs such as meshes. If you use HDF5 to store your data, chances are that you will be able to create an XML file that tells the VisSchema or XDMF reader how to read your file in the manner that you intended when you stored the data. For more information on creating an XML file for the XDMF reader, see http://www.xdmf.org/index.php/XDMF_Model_and_Format.

4.0 Writing Silo files

If you are writing a conversion utility or if you have a simulation code written in C, C++, or Fortran then writing out Silo files is a good choice for getting your data into VisIt. This section will illustrate how to use the Silo library to write out various types of scientific data. Since the Silo library provides bindings for multiple languages, including C, Fortran,

and Python, the source code examples that demonstrate a particular topic will be given in more than 1 programming language, when appropriate. One goal of this section is to provide examples that are complete enough so that they can be readily adapted into working source code. In fact, most of the examples in this chapter are available as working programs in the accompanying “Getting your data into VisIt” code distribution. This section will not necessarily explain all of the various arguments to function calls in the Silo library. You can refer to the *Silo User’s Guide* for more information.

4.1 Using the Silo library

VisIt is always built with support for reading Silo databases so Silo can be a good file format in which to store your data. This subsection includes information about using Silo such as including the appropriate header files and linking with the Silo library.

4.1.1 Including Silo

When using any library in a program, you must tell the compiler about the symbols provided by the library. Here is what you need to include in your source code in order to use Silo:

C-Language:

```
#include <silo.h>
```

Fortran language:

```
include "silo.inc"
```

4.1.2 Linking with Silo

Before you can build a program that uses Silo, you must locate the Silo include files and the Silo library. Silo is not distributed as part of the VisIt source code or binary installations so you must obtain it separately unless you are developing on the Windows platform. A link to the most up-to-date version of the Silo library’s source code can be found on the VisIt Web site at <http://www.llnl.gov/visit/source.html>.

Once you download the Silo source code, building and installing it is usually only a matter of running its *configure* script and running *make*. You can even use the *build_visit* script from the VisIt Web site to build Silo with support for HDF5. An example command line to build Silo with support for HDF5 is:

```
./build_visit --console --no-visit --no-thirdparty \
--thirdparty-path /usr/local \
--silo --hdf5 --szip
```

After you’ve configured, built, and installed the Silo library, your program will have to be built against the Silo library. Building against the Silo library is usually accomplished by a simple adaptation of your *Makefile* and the inclusion of *silo.h* in your C-language source

code. If you used build_visit to install Silo and its dependant libraries in */usr/local* then you would add the following to your *Makefile*, adjusting the values for the install location, versions, and PLATFORM accordingly:

```
PLATFORM=i386-apple-darwin10_gcc-4.2

SZIP_DIR=/usr/local/szip/2.1/${PLATFORM}
SZIP_CPPFLAGS=-I$(SZIP_DIR)/include
SZIP_LDFLAGS=-L$(SZIP_DIR)/lib
SZIP_LIBS=-lsz

HDF5_DIR=/usr/local/hdf5/1.8.4/${PLATFORM}
HDF5_CPPFLAGS=-I$(HDF5_DIR)/include $(SZIP_CPPFLAGS)
HDF5_LDFLAGS=-L$(HDF5_DIR)/lib $(SZIP_LDFLAGS)
HDF5_LIBS=-lhdf5 $(SZIP_LIBS) -lz

SILO_DIR=/usr/local/silo/4.6.2/${PLATFORM}
SILO_CPPFLAGS=-I$(SILO_DIR)/include $(HDF5_CPPFLAGS)
SILO_LDFLAGS=-L$(SILO_DIR)/lib $(HDF5_LDFLAGS)
SILO_LIBS=-lsiloh5 $(HDF5_LIBS) -lm

LDFLAGS=$(LDFLAGS) $(SILO_LDFLAGS)
LIBS=$(SILO_LIBS)
CPPFLAGS=$(CPPFLAGS) $(SILO_CPPFLAGS)
```

If your *Makefile* does not use CPPFLAGS then you might try adding the *-I* include directives to CFLAGS, F77FLAGS, or whichever make variables are relevant for your *Makefile*.

4.1.3 Using Silo on Windows

When you build an application using the Silo library on Windows, you can use the precompiled Silo DLL and import library that comes with the VisIt source code distribution for Windows. The VisIt 2.0.0 source code distribution for Windows is called visitdev2.0.0.exe. Other versions of VisIt would, of course, include a different version number in the filename. When you install the VisIt source code distribution for Windows, you get all of VisIt's project files, include files, and source code. In addition, certain precompiled libraries such as Silo are included.

If you want to build an application against the Silo library provided with VisIt, add the path to *silo.h* to your project file. If you build using a source code distribution for VisIt 2.0.0 that was installed in the default location, the path would be:

C:\VisItDev2.0.0\include\silo.

After setting the Silo include directory to your project file, make sure that the Silo's import library is in your linker path. You can add C:\VisItDev2.0.0\lib\Release our C:\VisItDev2.0.0\lib\Debug to your project to ensure that your linker can find Silo's import library. Next, add *silohdf5.lib* to the list of libraries that are linked with your program. That should be enough to get your program to build.

Before running your program, be sure to copy *silohdf5.dll*, *hdf5dll.dll*, *sziplib.dll*, and *zlib.dll* from *C:\VisItDev2.0.0\bin\Release* or *C:\VisItDev2.0.0\bin\Debug* (depending on whether your program is compiled with debugging information) into the directory where your program will execute. Note that you must configure your program to use a Multithreaded DLL version of the Microsoft runtime library or using the precompiled Silo library may result in fatal errors.

4.2 Inspecting Silo files

Silo includes a command line utility called *browser* that can access the contents of Silo files. To run *browser*, type “*browser*” into a terminal window followed by the name of a Silo file that you want to inspect. Once the *browser* application opens the Silo file, type “*ls*” to see the contents of the Silo file. From there, typing the name of any of the objects shown in the object listing will print information about that object to the console.

4.3 Silo files and parallel codes

Before we delve into examples about how to use the Silo library, let’s first examine how parallel simulation codes process their data in a distributed-memory environment. Many parallel simulation codes will divide the entire simulated mesh into submeshes, called domains, which are assigned to processors that calculate the fields of interest on their domain. Often, the most efficient I/O strategy for the simulation code is to make each processor write its domain to a separate file. The examples that follow assume parallel simulations will write 1 file per processor. It is possible for multiple processors to append their data to a single Silo file but it requires synchronization and that technique is beyond the scope of the examples that will be presented.

4.4 Creating a new Silo file

The first step to saving data to a Silo file is to create the file and obtain a handle that will be used to reference the file. The handle will be passed to other Silo function calls in order to add new objects to the file. Silo creates new files using the `DBCreate` function, which takes the name of the new file, access modes, a descriptive comment, and the underlying file type as arguments.

In addition to being a library, Silo is a self-describing data model, which can be implemented on top of many different underlying file formats. Silo includes drivers that allow it to read data from several different file formats, the most important of which are: PDB (A legacy LLNL file format) format, and HDF5 format. Silo files stored in HDF5 format often provide performance advantages so the following code to open a Silo file will create HDF5-based Silo files. You tell Silo to create HDF5-based Silo files by passing the

DB_HDF5 argument to the DBCreate function. If your Silo library does not have built-in HDF5 support then you can pass DB_PDB instead to create PDB-based Silo files.

Listing 2-3: basic.c: C-Language example for creating a new Silo file.

```
#include <silo.h>
#include <stdio.h>
int
main(int argc, char *argv[])
{
    DBfile *dbfile = NULL;
    /* Open the Silo file */
    dbfile = DBCreate("basic.silo", DB_CLOBBER, DB_LOCAL,
                      "Comment about the data", DB_HDF5);
    if(dbfile == NULL)
    {
        fprintf(stderr, "Could not create Silo file!\n");
        return -1;
    }
    /* Add other Silo calls here. */
    /* Close the Silo file. */
    DBClose(dbfile);
    return 0;
}
```

Listing 2-4: fbasic.f: Fortran language example for creating a new Silo file..

```
program main
implicit none
include "silo.inc"
integer dbfile, ierr
c The 11 and 22 arguments represent the lengths of strings
ierr = dbcreate("fbasic.silo", 11, DB_CLOBBER, DB_LOCAL,
. "Comment about the data", 22, DB_HDF5, dbfile)
if(dbfile.eq.-1) then
    write (6,*) 'Could not create Silo file!\n'
    goto 10000
endif
c Add other Silo calls here.
c Close the Silo file.
ierr = dbcclose(dbfile)
10000 stop
end
```

In addition to using the DBCreate function, the previous examples also use the DBClose function. The DBClose function ensures that all data is written to the file and then closes the Silo file. You must call the DBClose function when you want to close a Silo file or your file may not be complete.

4.5 Dealing with time

Silo files are a flexible container for storing many types of data. Silo's ability to store data hierarchically in directories can allow you to store multiple time states of your simulation data within a single data file. However, since Silo is primarily an I/O library for storing files that contain a single time step's worth of data, VisIt only recognizes one time state per Silo file. Consequently, when writing out data, programs that use Silo will write a new Silo file for each time step. By convention, the new file will contain an index indicating either the simulation cycle or a simple integer counter.

Listing 2-5: time.c: C-Language example for dealing with time.

```
/* SIMPLE SIMULATION SKELETON */
void write_vis_dump(int cycle)
{
    DBfile *dbfile = NULL;
    /* Create a unique filename for the new Silo file*/
    char filename[100];
    sprintf(filename, "output%04d.silo", cycle);
    /* Open the Silo file */
    dbfile = DBCreate(filename, DB_CLOBBER, DB_LOCAL,
                      "simulation time step", DB_HDF5);
    /* Add other Silo calls to write data here. */
    /* Close the Silo file. */
    DBClose(dbfile);
}
int main(int, char **)
{
    int cycle = 0;
    read_input_deck();
    do
    {
        simulate_one_timestep();
        write_vis_dump(cycle);
        cycle = cycle + 1;
    } while(!simulation_done());
    return 0;
}
```

The above code listing will write out Silo files with names such as: *output0000.silo*, *output0001.silo*, *output0002.silo*, ... Each file contains the data from a particular simulation time state. It may seem like the data are less related because they are stored in different files but the fact that the files are related in time is subtly encoded in the name of each of the files. When VisIt recognizes a pattern in the names of the files such as “*output????.silo*”, in this case, VisIt automatically groups the files into a time-varying database. If you choose names for your Silo files that cannot be grouped by recognizing a numeric pattern in the trailing part of the file name then you must use a *.visit* file to tell

VisIt that your files are related in time. For more information about `.visit` files, consult the *VisIt User's Manual*.

4.6 Option lists

Many of Silo's more complex functions accept an auxiliary argument called an option list. An option list is a list of option/value pairs and it is used to specify additional metadata about the data being stored. Each Silo function that accepts an option list has its options enumerated in the *Silo User's Manual*. This manual will cover only a subset of available options. Option lists need not be passed to the Silo functions that do support them. In fact, most of the source code examples in this manual will pass `NULL` instead of passing a pointer to an option list. Omitting the option list from the Silo function call in this way is not harmful; it only means that certain pieces of additional metadata will not be stored with the data.

Option lists are created using the `DBMakeOptlist` function. Once an option list object is created, you can add options to it using the `DBAddOption` function. Option lists are freed using the `DBFreeOptlist` function.

4.6.1 Cycle and time

We've established that a notion of time can be encoded into filenames using ranges of numbers in each filename. VisIt can use the numbers in the names of related files to guess cycle number, a metric for how many times a simulation has iterated. It is possible to use Silo's option list feature to directly encode the cycle number and the simulation time into the stored data.

Listing 2-6: optlist.c: C-Language example for saving cycle and time using an option list..

```
/* Create an option list to save cycle and time values. */
int cycle = 100;
double dtime = 1.23456789;
DBOptlist *optlist = DBMakeOptlist(2);
DBAddOption(optlist, DBOPT_DTIME, &time);
DBAddOption(optlist, DBOPT_CYCLE, &cycle);
/* Write a mesh using the option list. */
DBPutQuadmesh(dbfile, "quadmesh", coordnames, coords, dims, ndims,
    DB_FLOAT, DB_COLLINEAR, optlist);
/* Free the option list. */
DBFreeOptlist(optlist);
```

Listing 2-7: foplist.f: Fortran language example for saving cycle and time using an option list..

```
c Create an option list to save cycle and time values.
integer cycle /100/
double precision dtime /1.23456789/
integer err, ierr, optlistid
err = dbmkoptlist(2, optlistid)
```

```

        err = dbaddiopt(optlistid, DBOPT_CYCLE, cycle)
        err = dbadddopt(optlistid, DBOPT_DTIME, dtime)
c Write a mesh using the option list.
        err = dbputqm(dbfile, "quadmesh", 8, "xc", 2,
        . "yc", 2, "zc", 2, x, y, DB_F77NULL, dims, ndims,
        . DB_FLOAT, DB_COLLINEAR, optlistid, ierr)
c Free the option list.
        err = dbfreeoptlist(optlistid)

```

4.7 Writing a rectilinear mesh

A rectilinear mesh is a 2D or 3D mesh where all coordinates are aligned with the axes. Each axis of the rectilinear mesh can have different, non-uniform spacing, allowing for details to be concentrated in certain regions of the mesh. Rectilinear meshes are specified by lists of coordinate values for each axis. Since the mesh is aligned to the axes, it is only necessary to specify one set of X and Y values to generate all of the coordinates for the entire mesh. Figure 2-8 contains an example of a 2D rectilinear mesh. The Silo function call to write a rectilinear mesh is called DBPutQuadmesh.

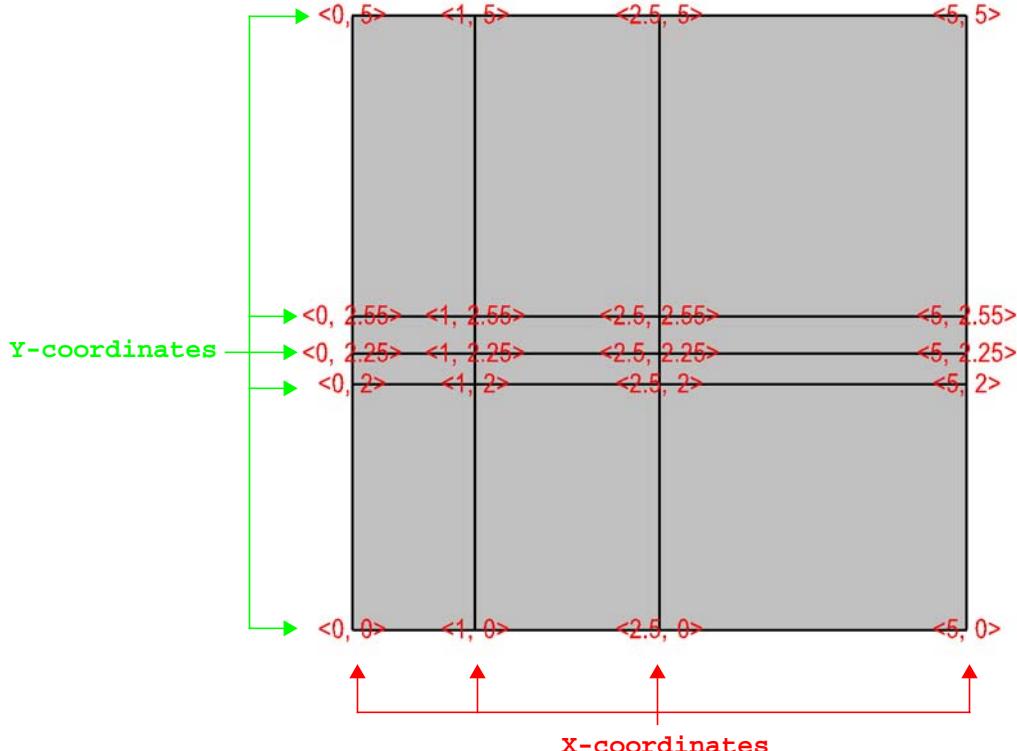


Figure 2-8: Rectilinear mesh and its X,Y node coordinates.

Listing 2-9: rect2d.c: C-Language example for writing a 2D rectilinear mesh.

```
/* Write a rectilinear mesh. */
float x[] = {0., 1., 2.5, 5.};
float y[] = {0., 2., 2.25, 2.55, 5.};
int dims[] = {4, 5};
int ndims = 2;
float *coords[] = {x, y};
DBPutQuadmesh(dbfile, "quadmesh", NULL, coords, dims, ndims,
    DB_FLOAT, DB_COLLINEAR, NULL);
```

Listing 2-10: frect2d.f: Fortran language example for writing a 2D rectilinear mesh.

```
c Write a rectilinear mesh
integer err, ierr, dims(2), ndims, NX, NY
parameter (NX = 4)
parameter (NY = 5)
real x(NX), y(NY)
data dims/NX, NY/
data x/0., 1., 2.5, 5./
data y/0., 2., 2.25, 2.55, 5./
ndims = 2
err = dbputqm (dbfile, "quadmesh", 8, "xc", 2,
. "yc", 2, "zc", 2, x, y, DB_F77NULL, dims, ndims,
. DB_FLOAT, DB_COLLINEAR, DB_F77NULL, ierr)
```

The previous code examples demonstrate how to write out a 2D rectilinear mesh using Silo’s DBPutQuadmesh function (called dbputqm in Fortran). There are three pieces of important information passed to the DBPutQuadmesh function. The first important piece information is the name of the mesh being created. The name that you choose will be the name that you use when writing a variable to a Silo file and also the name that you will see in VisIt’s plot menus when you want to create a Mesh plot in VisIt. After the name, you provide the coordinate arrays that contain the X and Y point values that ultimately form the set of X,Y coordinate pairs that describe the mesh. The C-interface to Silo requires that you pass pointers to the coordinate arrays in a single pointer array. The Fortran interface to Silo requires you to pass the names of the coordinate arrays, followed by the actual coordinate arrays, with a value of DB_F77NULL for any arrays that you do not use. The final critical pieces of information that must be passed to the DBPutQuadmesh function are the dimensions of the mesh, which correspond to the number of nodes, or coordinate values, along the mesh in a given dimension. The dimensions are passed in an array, along with the number of dimensions, which must be 2

or 3. Figure 2-11 shows an example of a 3D rectilinear mesh for the upcoming code examples.

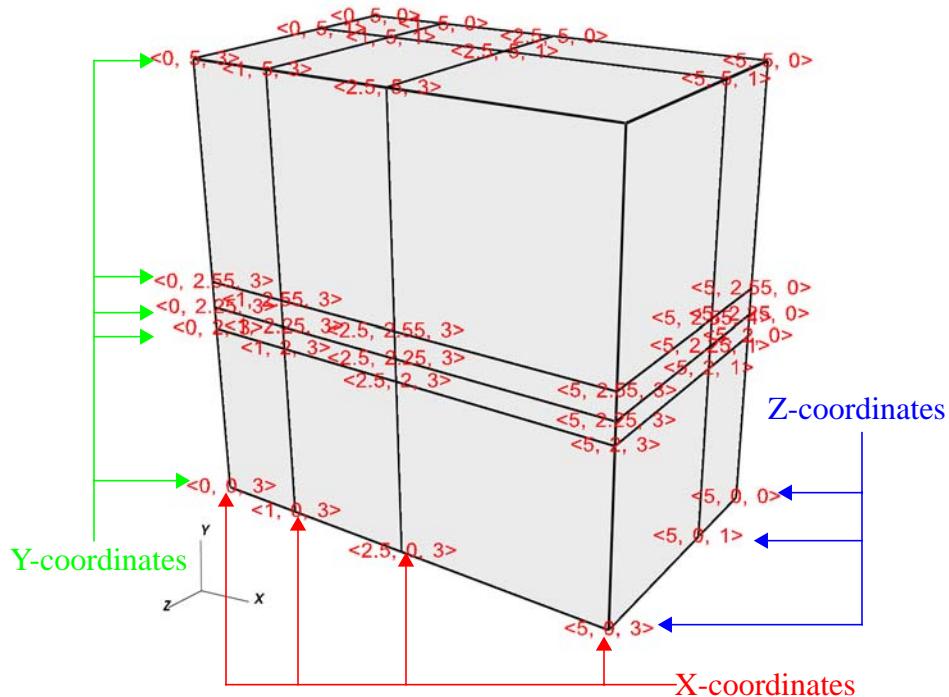


Figure 2-11: Rectilinear mesh and its X,Y,Z coordinates

Listing 2-12: rect3d.c: C-Language example for writing a 3D rectilinear mesh.

```
/* Write a rectilinear mesh. */
float x[] = {0., 1., 2.5, 5.};
float y[] = {0., 2., 2.25, 2.55, 5.};
float z[] = {0., 1., 3.};
int dims[] = {4, 5, 3};
int ndims = 3;
float *coords[] = {x, y, z};
DBPutQuadmesh(dbfile, "quadmesh", NULL, coords, dims, ndims,
    DB_FLOAT, DB_COLLINEAR, NULL);
```

Listing 2-13: frect3d.f: Fortran language example for writing a 3D rectilinear mesh.

```
integer err, ierr, dims(3), ndims, NX, NY, NZ
parameter (NX = 4)
parameter (NY = 5)
parameter (NZ = 3)
real x(NX), y(NY), z(NZ)
data x/0., 1., 2.5, 5./
```

```

data y/0., 2., 2.25, 2.55, 5./
data z/0., 1., 3./
ndims = 3
data dims/NX, NY, NZ/
err = dbputqm (dbfile, "quadmesh", 8, "xc", 2,
. "yc", 2, "zc", 2, x, y, z, dims, ndims,
. DB_FLOAT, DB_COLLINEAR, DB_F77NULL, ierr)

```

4.8 Writing a curvilinear mesh

A curvilinear mesh is similar to a rectilinear mesh. The main difference between the two mesh types is how coordinates are specified. Recall that in a rectilinear mesh, the coordinates are specified individually for each axis and only a small subset of the nodes in the mesh are provided. The coordinate arrays are used to assemble a point for each node in the mesh. In a curvilinear mesh, you must provide an X,Y,Z value for every node in the mesh. Providing the coordinates for every point explicitly allows you to specify more complex geometries than are possible using rectilinear meshes. Note how the mesh coordinates on the mesh in Figure 2-14 allow it to assume shapes that are not aligned to the coordinate axes.

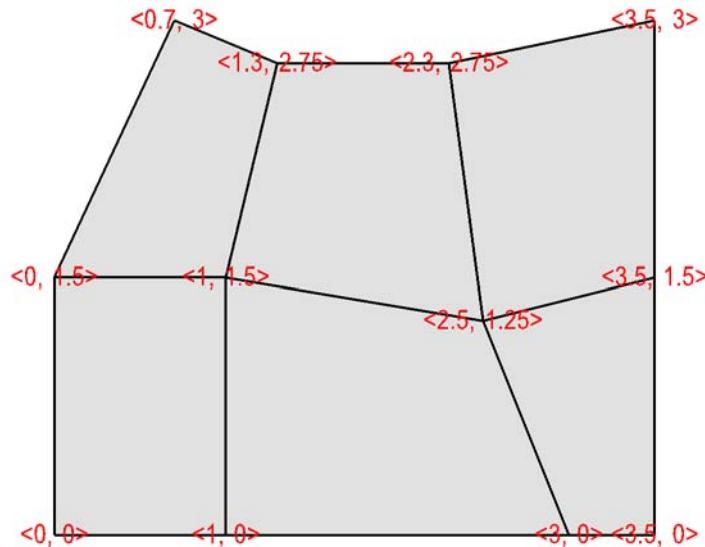


Figure 2-14: Curvilinear mesh and its X,Y node coordinates

The fine line between a rectilinear mesh and a curvilinear mesh comes down to how the coordinates are specified. Silo dictates that the coordinates be specified with an array of X-

coordinates, an array of Y-coordinates, and an optional array of Z-coordinates. The difference, of course, is that in a curvilinear mesh, there are explicit values for each node's X,Y,Z points. Silo uses the same DBPutQuadmesh function to write out curvilinear meshes. The coordinate arrays are passed the same as for the rectilinear mesh, though the X,Y,Z arrays now point to larger arrays. You can pass the DB_NONCOLLINEAR flag to the DBPutQuadmesh function in order to indicate that the coordinate arrays contain values for every node in the mesh.

Listing 2-15: curv2d.c: C-Language example for writing a 2D curvilinear mesh.

```
/* Write a curvilinear mesh. */
#define NX 4
#define NY 3
float x[NY][NX] = {{0., 1., 3., 3.5}, {0., 1., 2.5, 3.5},
{0.7, 1.3, 2.3, 3.5}};
float y[NY][NX] = {{0., 0., 0., 0.}, {1.5, 1.5, 1.25, 1.5},
{3., 2.75, 2.75, 3.}};
int dims[] = {NX, NY};
int ndims = 2;
float *coords[] = {(float*)x, (float*)y};
DBPutQuadmesh(dbfile, "quadmesh", NULL, coords, dims, ndims,
DB_FLOAT, DB_NONCOLLINEAR, NULL);
```

Listing 2-16: fcurv2d.f: Fortran language example for writing a 2D curvilinear mesh.

```
c Write a curvilinear mesh.
integer err, ierr, dims(2), ndims, NX, NY
parameter (NX = 4)
parameter (NY = 3)
real x(NX,NY), y(NX,NY)
data x/0., 1., 3., 3.5,
.      0., 1., 2.5, 3.5,
.      0.7, 1.3, 2.3, 3.5/
data y/0., 0., 0., 0.,
.      1.5, 1.5, 1.25, 1.5,
.      3., 2.75, 2.75, 3./
ndims = 2
data dims/NX, NY/
err = dbputqm (dbfile, "quadmesh", 8, "xc", 2,
."yc", 2, "zc", 2, x, y, DB_F77NULL, dims, ndims,
.DB_FLOAT, DB_NONCOLLINEAR, DB_F77NULL, ierr)
```

Figure 2-17 shows a simple 3D curvilinear mesh that is 1 cell thick in the Z-dimension. The number of cells in a dimension is 1 less than the number of nodes in the same dimension. As you increase the number of nodes in the Z-dimension, you must also add

more X and Y coordinate values because the X,Y,Z values for node coordinates must be fully specified for a curvilinear mesh.

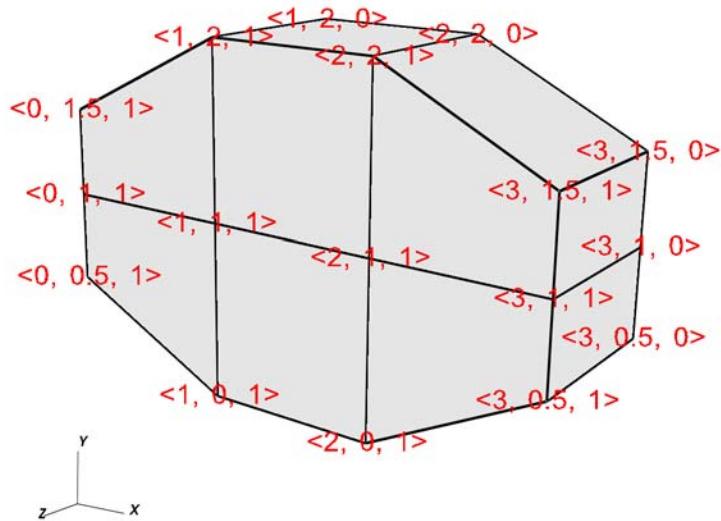


Figure 2-17: 3D Curvilinear mesh and its X,Y,Z coordinates

Listing 2-18: curv3d.c: C-Language example for writing a 3D curvilinear mesh.

```
/* Write a curvilinear mesh. */
#define NX 4
#define NY 3
#define NZ 2
float x[NZ][NY][NX] = {
    {{0.,1.,2.,3.},{0.,1.,2.,3.}, {0.,1.,2.,3.}},
    {{0.,1.,2.,3.},{0.,1.,2.,3.}, {0.,1.,2.,3.}}
};
float y[NZ][NY][NX] = {
    {{0.5,0.,0.,0.5},{1.,1.,1.,1.}, {1.5,2.,2.,1.5}},
    {{0.5,0.,0.,0.5},{1.,1.,1.,1.}, {1.5,2.,2.,1.5}}
};
float z[NZ][NY][NX] = {
    {{0.,0.,0.,0.},{0.,0.,0.,0.},{0.,0.,0.,0.}},
    {{1.,1.,1.,1.},{1.,1.,1.,1.},{1.,1.,1.,1.}}
};
int dims[] = {NX, NY, NZ};
int ndims = 3;
float *coords[] = {(float*)x, (float*)y, (float*)z};
DBPPutQuadmesh(dbfile, "quadmesh", NULL, coords, dims, ndims,
```

```
DB_FLOAT, DB_NONCOLLINEAR, NULL);
```

Listing 2-19: fcurv3d.f: Fortran language example for writing a 3D curvilinear mesh.

```
c Write a curvilinear mesh
integer err, ierr, dims(3), ndims, NX, NY, NZ
parameter (NX = 4)
parameter (NY = 3)
parameter (NZ = 2)
real x(NX,NY,NZ), y(NX,NY,NZ), z(NX,NY,NZ)
data x/0.,1.,2.,3., 0.,1.,2.,3., 0.,1.,2.,3.,
. 0.,1.,2.,3., 0.,1.,2.,3., 0.,1.,2.,3./
data y/0.5,0.,0.,0.5, 1.,1.,1.,1., 1.5,2.,2.,1.5,
. 0.5,0.,0.,0.5, 1.,1.,1.,1., 1.5,2.,2.,1.5/
data z/0.,0.,0.,0., 0.,0.,0.,0., 0.,0.,0.,0.,
. 1.,1.,1.,1., 1.,1.,1.,1., 1.,1.,1.,1./
ndims = 3
data dims/NX, NY, NZ/
err = dbputqm (dbfile, "quadmesh", 8, "xc", 2,
. "yc", 2, "zc", 2, x, y, z, dims, ndims,
. DB_FLOAT, DB_NONCOLLINEAR, DB_F77NULL, ierr)
```

4.9 Writing a point mesh

A point mesh is a set of 2D or 3D points where the nodes also constitute the cells in the mesh. Silo provides the DBPutPointmesh function so you can write out particle systems represented as point meshes.

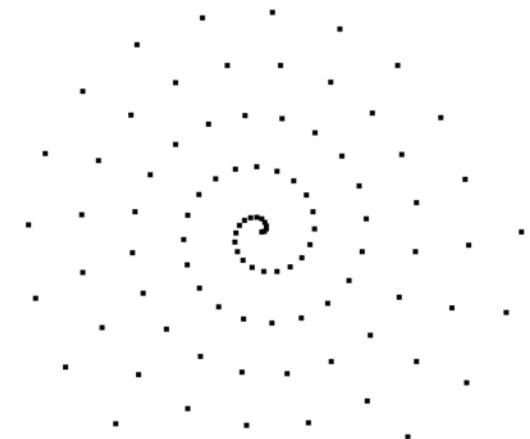


Figure 2-20: 2D point mesh

Listing 2-21: point2d.c: C-Language example for writing a 2D point mesh.

```

/* Create some points to save. */
#define NPTS 100
int i, ndims = 2;
float x[NPTS], y[NPTS];
float *coords[] = {(float*)x, (float*)y};
for(i = 0; i < NPTS; ++i)
{
    float t = ((float)i) / ((float)(NPTS-1));
    float angle = 3.14159 * 10. * t;
    x[i] = t * cos(angle);
    y[i] = t * sin(angle);
}
/* Write a point mesh. */
DBPutPointmesh(dbfile, "pointmesh", ndims, coords, NPTS,
    DB_FLOAT, NULL);

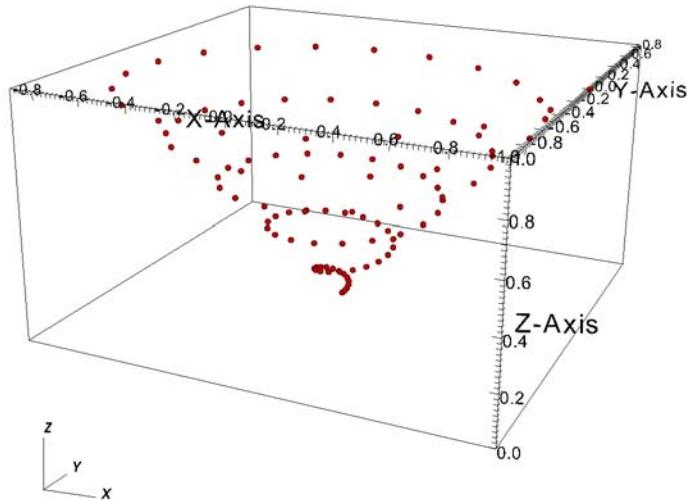
```

Listing 2-22: fpoint2d.f: Fortran language example for writing a 2D point mesh.

```

c Create some points to save.
integer err, ierr, i, ndims, NPTS
parameter (NPTS = 100)
real x(NPTS), y(NPTS), t, angle
do 10000 i = 0,NPTS-1
    t = float(i) / float(NPTS-1)
    angle = 3.14159 * 10. * t
    x(i+1) = t * cos(angle);
    y(i+1) = t * sin(angle);
10000 continue
ndims = 2
c Write a point mesh.
err = dbputpm (dbfile, "pointmesh", 9, ndims, x, y,
    . DB_F77NULL, NPTS, DB_FLOAT, DB_F77NULL, ierr)

```

**Figure 2-23:** 3D point mesh

Writing a 3D point mesh is very similar to writing a 2D point mesh with the exception that for a 3D point mesh, you must specify a Z-coordinate. Figure 2-23 shows what happens when we extend our 2D point mesh example into 3D.

Listing 2-24: point3d.c: C-Language example for writing a 3D point mesh.

```
/* Create some points to save. */
#define NPTS 100
int i, ndims = 3;
float x[NPTS], y[NPTS], z[NPTS];
float *coords[] = { (float*)x, (float*)y, (float*)z };
for(i = 0; i < NPTS; ++i)
{
    float t = ((float)i) / ((float)(NPTS-1));
    float angle = 3.14159 * 10. * t;
    x[i] = t * cos(angle);
    y[i] = t * sin(angle);
    z[i] = t;
}
/* Write a point mesh. */
DBPutPointmesh(dbfile, "pointmesh", ndims, coords, NPTS,
               DB_FLOAT, NULL);
```

Listing 2-25: fpoint3d.f: Fortran language example for writing a 3D point mesh.

```

c Create some points to save
integer err, ierr, i, ndims, NPTS
parameter (NPTS = 100)
real x(NPTS), y(NPTS), z(NPTS), t, angle
do 10000 i = 0,NPTS-1
    t = float(i) / float(NPTS-1)
    angle = 3.14159 * 10. * t
    x(i+1) = t * cos(angle);
    y(i+1) = t * sin(angle);
    z(i+1) = t
10000 continue
ndims = 3
c Write a point mesh
err = dbputpm (dbfile, "pointmesh", 9, ndims, x, y, z,
. NPTS, DB_FLOAT, DB_F77NULL, ierr)

```

4.10 Writing an unstructured mesh

Unstructured meshes are collections of different types of zones and are useful because they can represent more complex mesh geometries than structured meshes can. This section explains the Silo functions that are used to write out an unstructured mesh.

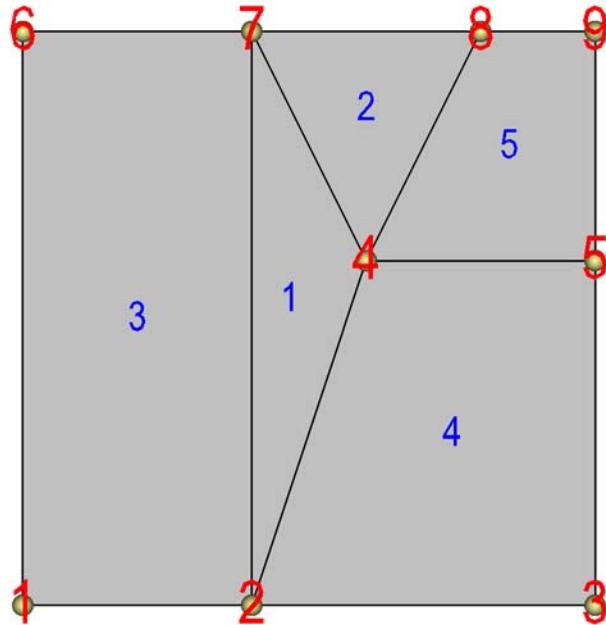


Figure 2-26: 2D unstructured mesh composed of triangles and quadrilaterals. The node numbers are labelled red and the zone numbers are labelled blue.

Silo supports the creation of 2D unstructured meshes composed of triangles, quadrilaterals, and polygonal cells. However, VisIt splits polygonal cells into triangles. Unstructured meshes are specified in terms of a set of nodes and then a zone list consisting

of lists of nodes, called connectivity information, that make up the zones in the mesh. When creating connectivity information, be sure that the nodes in your zones are specified so that when you iterate over the nodes in the zone that a counter-clockwise pattern is observed. Silo provides the DBPutZonelist function to store out the connectivity information. The coordinates for the unstructured mesh itself is written out using the DBPutUcdmesh function.

Listing 2-27: ucd2d.c: C-Language example for writing a 2D unstructured mesh.

```
/* Node coordinates */
float x[] = {0., 2., 5., 3., 5., 0., 2., 4., 5.};
float y[] = {0., 0., 0., 3., 3., 5., 5., 5., 5.};
float *coords[] = {x, y};
/* Connectivity */
int nodelist[] = {
    2,4,7, /* tri zone 1 */
    4,8,7, /* tri zone 2 */
    1,2,7,6, /* quad zone 3 */
    2,3,5,4, /* quad zone 4 */
    4,5,9,8 /* quad zone 5 */
};
int lnodelist = sizeof(nodelist) / sizeof(int);
/* shape type 1 has 3 nodes (tri), shape type 2 is quad */
int shapesize[] = {3, 4};
/* We have 2 tris and 3 quads */
int shapcounts[] = {2, 3};
int nshapetypes = 2;
int nnodes = 9;
int nzones = 5;
int ndims = 2;
/* Write out connectivity information. */
DBPutZonelist(dbfile, "zonelist", nzones, ndims, nodelist, lnodelist,
    1, shapesize, shapcounts, nshapetypes);
/* Write an unstructured mesh. */
DBPutUcdmesh(dbfile, "mesh", ndims, NULL, coords, nnodes, nzones,
    "zonelist", NULL, DB_FLOAT, NULL);
```

Listing 2-28: fucd2d.f: Fortran language example for writing a 2D unstructured mesh.

```
integer err, ierr, ndims, nshapetypes, nnodes, nzones
c Node coordinates
real x(9) /0., 2., 5., 3., 5., 0., 2., 4., 5./
real y(9) /0., 0., 0., 3., 3., 5., 5., 5., 5./
c Connectivity
integer LNODELIST
parameter (LNODELIST = 18)
integer nodelist(LNODELIST) /2,4,7,
. 4,8,7,
. 1,2,7,6,
. 2,3,5,4,
. 4,5,9,8/
```

```

c Shape type 1 has 3 nodes (tri), shape type 2 is quad
    integer shapesize(2) /3, 4/
c We have 2 tris and 3 quads
    integer shapecounts(2) /2, 3/
    nshapetypes = 2
    nnodes = 9
    nzones = 5
    ndims = 2
c Write out connectivity information.
    err = dbputzl(dbfile, "zonelist", 8, nzones, ndims, nodelist,
    . LNODELIST, 1, shapesize, shapecounts, nshapetypes, ierr)
c Write an unstructured mesh
    err = dbputum(dbfile, "mesh", 4, ndims, x, y, DB_F77NULL,
    . "X", 1, "Y", 1, DB_F77NULL, 0, DB_FLOAT, nnodes, nzones,
    . "zonelist", 8, DB_F77NULL, 0, DB_F77NULL, ierr)

```

3D unstructured meshes are created much the same way as 2D unstructured meshes are created. The main difference is that whereas in 2D, you use triangles and quadrilateral zone types, in 3D, you use hexahedrons, pyramids, prisms, and tetrahedrons to compose your mesh. The procedure for creating the node coordinates is the same with the exception that 3D meshes also require a Z-coordinate. The procedure for creating the zone list (connectivity information) is the same except that you specify cells using a larger number of nodes because they are 3D. The order in which the nodes are specified is also more important for 3D shapes because if the nodes are not given in the right order, the zones can become tangled. The proper zone ordering for each of the four supported 3D zone shapes is shown in Figure 2-29.

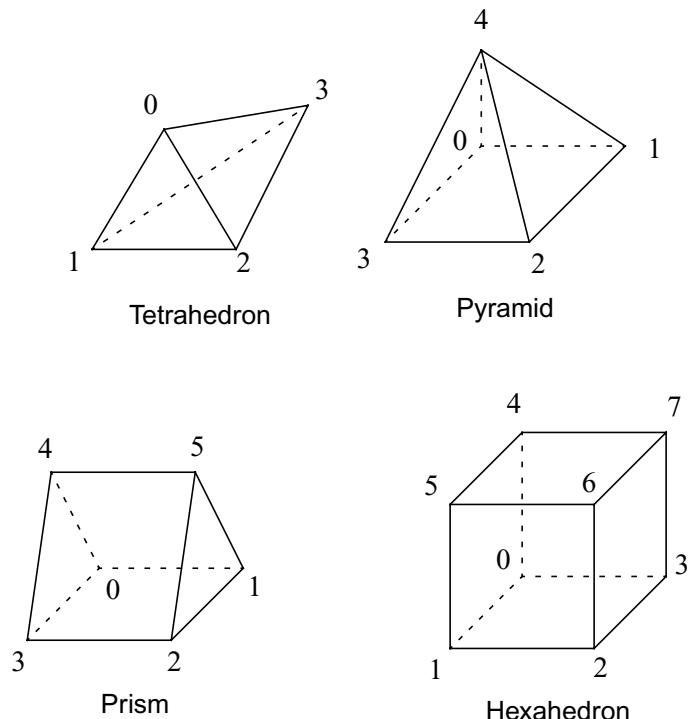


Figure 2-29: Node ordering for Silo's 3D unstructured zone types

Figure 2-30 shows an example of a simple 3D unstructured mesh consisting of 2 hexahedrons, 1 pyramid, 1 prism, and 1 tetrahedron.

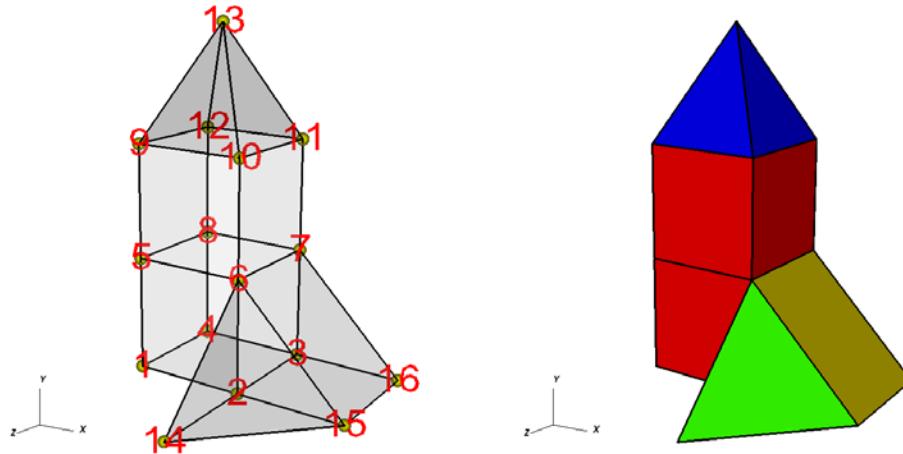


Figure 2-30: Node numbers on the left and the mesh, colored by zone type, on the right.
Hexahedrons (red), Pyramid (blue), Prism (yellow), Tetrahedron (green).

Listing 2-31: ucd3d.c: C-Language example for writing a 3D unstructured mesh.

```

/* Node coordinates */
float x[] = {0.,2.,2.,0.,0.,2.,2.,0.,0.,2.,2.,0.,1.,2.,4.,4.};
float y[] = {0.,0.,0.,0.,2.,2.,2.,2.,4.,4.,4.,4.,6.,0.,0.,0.};
float z[] = {2.,2.,0.,0.,2.,2.,0.,0.,2.,2.,0.,0.,1.,4.,2.,0.};
float *coords[] = {x, y, z};
/* Connectivity */
int nodelist[] = {
    1,2,3,4,5,6,7,8, /* hex,      zone 1 */
    5,6,7,8,9,10,11,12, /* hex,      zone 2 */
    9,10,11,12,13, /* pyramid, zone 3 */
    2,3,16,15,6,7, /* prism,   zone 4 */
    2,15,14,6, /* tet,     zone 5 */
};
int lnodelist = sizeof(nodelist) / sizeof(int);
/* shape type 1 has 8 nodes (hex) */
/* shape type 2 has 5 nodes (pyramid) */
/* shape type 3 has 6 nodes (prism) */
/* shape type 4 has 4 nodes (tet) */
int shapesize[] = {8,5,6,4};
/* We have 2 hex, 1 pyramid, 1 prism, 1 tet */
int shapcounts[] = {2,1,1,1};
int nshapetypes = 4;
int nnodes = 16;
int nzones = 5;
int ndims = 3;
/* Write out connectivity information. */
DBPutZonelist(dbfile, "zonelist", nzones, ndims, nodelist, lnodelist,

```

```

    1, shapesize, shapecounts, nshapetypes);
/* Write an unstructured mesh. */
DBPutUcdmesh(dbfile, "mesh", ndims, NULL, coords, nnodes, nzones,
"zonelist", NULL, DB_FLOAT, NULL);

```

Listing 2-32: fucd3d.f: Fortran language example for writing a 3D unstructured mesh.

```

integer err, ierr, ndims, nzones
integer NSHAPETYPES, NNODES
parameter (NSHAPETYPES = 4)
parameter (NN = 16)
c Node coordinates
real x(NN) /0.,2.,2.,0.,0.,2.,2.,0.,0.,2.,2.,0.,1.,2.,4.,4./
real y(NN) /0.,0.,0.,0.,2.,2.,2.,2.,4.,4.,4.,4.,6.,0.,0.,0./
real z(NN) /2.,2.,0.,0.,2.,2.,0.,0.,2.,2.,0.,0.,1.,4.,2.,0./
c Connectivity
integer LNODELIST
parameter (LNODELIST = 31)
integer nodelist(LNODELIST) /1,2,3,4,5,6,7,8,
. 5,6,7,8,9,10,11,12,
. 9,10,11,12,13,
. 2,3,16,15,6,7,
. 2,15,14,6/
c Shape type 1 has 8 nodes (hex)
c Shape type 2 has 5 nodes (pyramid)
c Shape type 3 has 6 nodes (prism)
c Shape type 4 has 4 nodes (tet)
integer shapesize(NSHAPETYPES) /8, 5, 6, 4/
c We have 2 hex, 1 pyramid, 1 prism, 1 tet
integer shapecounts(NSHAPETYPES) /2, 1, 1, 1/
nzones = 5
ndims = 3
c Write out connectivity information.
err = dbputz1(dbfile, "zonelist", 8, nzones, ndims, nodelist,
. LNODELIST, 1, shapesize, shapecounts, NSHAPETYPES, ierr)
c Write an unstructured mesh
err = dbputum(dbfile, "mesh", 4, ndims, x, y, z,
. "X", 1, "Y", 1, "Z", 1, DB_FLOAT, NN, nzones,
. "zonelist", 8, DB_F77NULL, 0, DB_F77NULL, ierr)

```

4.10.1 Adding axis labels and axis units

It is possible to add additional annotations to your meshes that you store to Silo files using Silo’s option list mechanism. This subsection covers how to change the axis titles and units that will be used when VisIt plots your mesh. By default, VisIt uses “X-Axis”, “Y-Axis”, and “Z-Axis” when labelling the coordinate axes. You can override the default labels using an option list. Option lists are created with the DBMakeOptlist function and freed with the DBFreeOptlist function. All of the Silo functions for writing meshes that we’ve demonstrated so far can accept option lists that contain custom axis labels and units. Refer to the *Silo User’s Manual* for more information on addition options that can be passed via option lists.

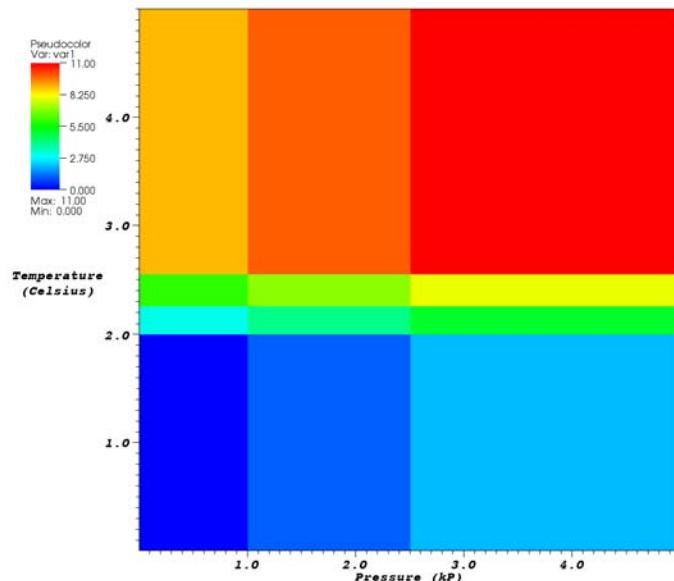


Figure 2-33: Custom mesh labels and units along the X and Y axes

Adding customized labels and units for a mesh by using option lists ensures that VisIt uses your customized labels and units instead of the default values. Figure 2-33 shows how the labels and units in the previous examples show up in VisIt’s visualization window.

Listing 2-34: rect2d.c: C-Language example for associating new axis labels and units with a mesh.

```
/* Create an option list to contain labels and units. */
DBOptlist *optlist = DBMakeOptlist(4);
DBAddOption(optlist, DBOPT_XLABEL, (void *)"Pressure");
DBAddOption(optlist, DBOPT_XUNITS, (void *)"kP");
DBAddOption(optlist, DBOPT_YLABEL, (void *)"Temperature");
DBAddOption(optlist, DBOPT_YUNITS, (void *)"Degrees Celsius");
/* Write a quadmesh with an option list. */
DBPutQuadmsh(dbfile, "quadmesh", NULL, coords, dims, ndims,
             DB_FLOAT, DB_COLLINEAR, optlist);
/* Free the option list. */
DBFreeOptlist(optlist);
```

Listing 2-35: frect2d.f: Fortran language example for associating new axis labels and units with a mesh

```
c Create an option list to contain labels and units.
```

```

integer err, ierr, optlistid
err = dbmkoptlist(4, optlistid)
err = dbaddcopt(optlistid, DBOPT_XLABEL, "Pressure", 8)
err = dbaddcopt(optlistid, DBOPT_XUNITS, "kP", 2)
err = dbaddcopt(optlistid, DBOPT_YLABEL, "Temperature", 11)
err = dbaddcopt(optlistid, DBOPT_YUNITS, "Celsius", 7)
c Write a quadmesh with an option list.
err = dbputqm (dbfile, "quadmesh", 8, "xc", 2,
. "yc", 2, "zc", 2, x, y, DB_F77NULL, dims, ndims,
. DB_FLOAT, DB_COLLINEAR, optlistid, ierr)
c Free the option list
err = dbfreeoptlist(optlistid)

```

4.11 Writing a scalar variable

Silo provides several different functions for writing variables; one for each basic type of mesh: quadmesh (rectilinear and curvilinear), unstructured mesh, and point mesh. Each of these functions can be used to write either zone-centered or node-centered data. This section concentrates on how to write scalar variables; vector and tensor variable components can be written as scalar variables and reassembled into vectors and tensors using expressions, covered on page 47. This section's code examples use the rectilinear, curvilinear, point, and unstructured meshes that have appeared in previous code examples.

4.11.1 Zone centering vs. Node centering

VisIt supports two types of variable centering: zone-centering and node-centering. A variable's centering indicates how its values are attached to the mesh on which the variable is defined. When a variable is zone-centered, each zone is assigned a single value. If you were to plot a zone-centered value in VisIt, each zone would be drawn using a uniform color and picking anywhere in the zone would yield the same value. Arrays containing values that are to be zone-centered on a mesh must contain the same number of elements as there are zones in the mesh. Node-centered arrays, on the other hand, contain a value for every node in the mesh. When you plot a node-centered value in VisIt, VisIt

interpolates the values from the nodes across the zone's surface, usually producing a smooth gradient of values across the zone.

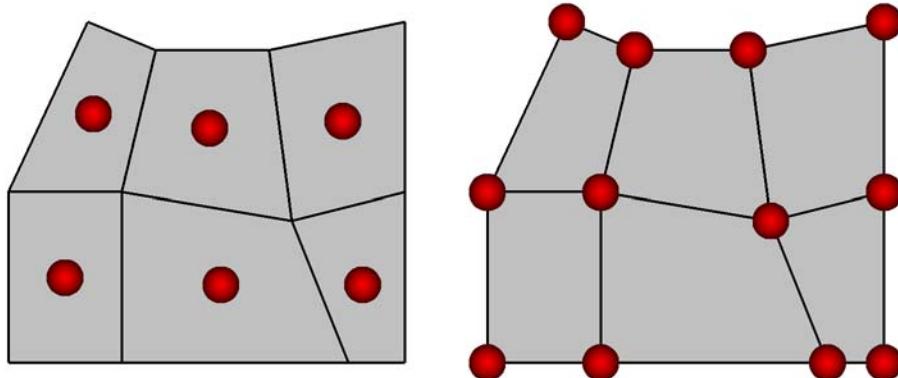


Figure 2-36: Zone-centering (left) and Node-centering (right)

4.11.2 API Commonality

Each of the provided functions for writing scalar variables does have certain arguments in common. For example, all of the functions must be provided the name of the variable to write out. The name that you pick is the name that will appear in VisIt's plot menus (see Figure 2-37). Be careful when you pick your variable names because you should avoid characters that include: punctuation marks, and spaces. Variable names should only contain letters and numbers and they should begin with a letter. These guidelines are in place to assure that your data files will have the utmost compatibility with VisIt's expression language, which is defined in the *VisIt User's Manual*.

All variables must be defined on a mesh. If you examine the code examples in this section, each Silo function that writes out a variable will be passed the name of the mesh on which the variable is to be defined.

Each of the Silo function calls will accept a pointer to the array that contains the variable's data. The data can be stored in several internal formats: `char`, `short`, `int`, `long`, `float`, and `double`. Since Silo's variable writing functions use a pointer to pass the data, you can pass a pointer that points to data in any of the mentioned types. In addition, you must pass a flag that indicates to Silo the type of data stored in the array whose address you've passed.

Most of the remaining arguments to Silo’s variable writing functions are specific to the types of meshes on which the variable is defined so the rest of this section will provide examples for writing out variables that are defined on various mesh types.

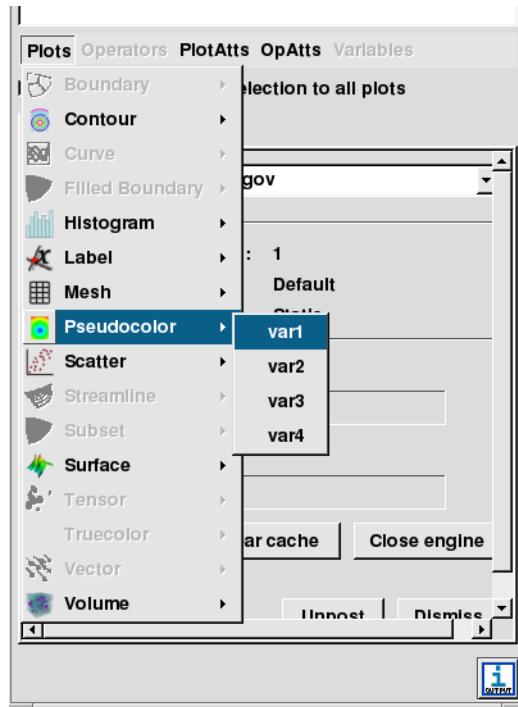


Figure 2-37: Variables in VisIt’s plot menus

4.11.3 Rectilinear and curvilinear meshes

Recall from sections “Writing a rectilinear mesh” on page 20 and “Writing a curvilinear mesh” on page 23 that the procedure for creating rectilinear and curvilinear meshes was similar and the chief difference between the two mesh types was in how their coordinates were specified. While a rectilinear mesh’s coordinates could be specified quite compactly as separate X,Y,Z arrays made up of unique values along a coordinate axis, the curvilinear mesh required X,Y,Z coordinate arrays that contained the X,Y,Z values for every node in the mesh. Regardless of how the coordinates were specified, both mesh types contain $(NX-1)*(NY-1)*(NZ-1)$ zones and $NX*NY*NZ$ nodes. This means that the code to write a variable on a rectilinear mesh will be identical to the code to write a zone-centered variable on a curvilinear mesh! Silo provides the `DBPutQuadvar1` function to write scalar variables for both rectilinear and curvilinear meshes,

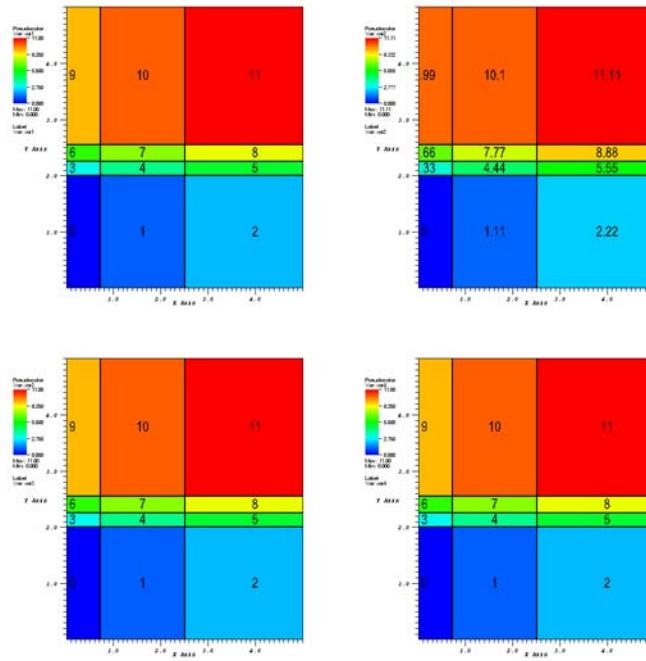


Figure 2-38: Zone-centered variables. Clock-wise from upper left, float, double-precision, integer, char

Listing 2-39: quadvar2d.c: C-Language example for writing zone-centered variables.

```
/* The data must be (NX-1) * (NY-1) since it is zonal. */
float var1[] = {
    0., 1., 2.,
    3., 4., 5.,
    6., 7., 8.,
    9., 10., 11.
};
double var2[] = {
    0.00, 1.11, 2.22,
    3.33, 4.44, 5.55,
    6.66, 7.77, 8.88,
    9.99, 10.1, 11.11
};
int var3[] = {
    0, 1, 2,
    3, 4, 5,
    6, 7, 8,
    9, 10, 11
};
char var4[] = {
    0, 1, 2,
    3, 4, 5,
```

```

    6, 7, 8,
    9, 10, 11
};

/* Note dims are 1 less than mesh's dims in each dimension. */
int dims[]={3, 4};
int ndims = 2;
DBPutQuadvar1(dbfile, "var1", "quadmesh", var1, dims,
    ndims, NULL, 0, DB_FLOAT, DB_ZONECENT, NULL);
/* Write a double-precision variable. */
DBPutQuadvar1(dbfile, "var2", "quadmesh", (float*)var2, dims,
    ndims, NULL, 0, DB_DOUBLE, DB_ZONECENT, NULL);
/* Write an integer variable */
DBPutQuadvar1(dbfile, "var3", "quadmesh", (float*)var3, dims,
    ndims, NULL, 0, DB_INT, DB_ZONECENT, NULL);
/* Write a char variable */
DBPutQuadvar1(dbfile, "var4", "quadmesh", (float*)var4, dims,
    ndims, NULL, 0, DB_CHAR, DB_ZONECENT, NULL);

```

Listing 2-40: fquadvar2d.f: Fortran language example for writing zone-centered variables.

```

integer err, ierr, dims(2), ndims, NX, NY, ZX, ZY
parameter (NX = 4)
parameter (NY = 5)
parameter (ZX = NX-1)
parameter (ZY = NY-1)
real           var1(ZX,ZY)
double precision var2(ZX,ZY)
integer         var3(ZX,ZY)
character       var4(ZX,ZY)
data var1/0., 1., 2.,
. 3., 4., 5.,
. 6., 7., 8.,
. 9., 10., 11./
data var2/0.,1.11,2.22,
. 3.33, 4.44, 5.55,
. 6.66, 7.77, 8.88,
. 9.99, 10.1, 11.11/
data var3/0,1,2,
. 3, 4, 5,
. 6, 7, 8,
. 9, 10, 11/
data var4/0,1,2,
. 3, 4, 5,
. 6, 7, 8,
. 9, 10, 11/
data dims/ZX, ZY/
ndims = 2
err = dbputqvl(dbfile, "var1", 4, "quadmesh", 8, var1, dims,
. ndims, DB_F77NULL, 0, DB_FLOAT, DB_ZONECENT, DB_F77NULL, ierr)
c Write a double-precision variable
err = dbputqvl(dbfile, "var2", 4, "quadmesh", 8, var2, dims,
. ndims, DB_F77NULL, 0, DB_DOUBLE, DB_ZONECENT,
. DB_F77NULL, ierr)

```

```

c Write an integer variable
err = dbputqvl(dbfile, "var3", 4, "quadmesh", 8, var3, dims,
    . ndims, DB_F77NULL, 0, DB_INT, DB_ZONECENT, DB_F77NULL, ierr)
c Write a char variable
err = dbputqvl(dbfile, "var4", 4, "quadmesh", 8, var4, dims,
    . ndims, DB_F77NULL, 0, DB_CHAR, DB_ZONECENT, DB_F77NULL, ierr)

```

Both of the previous code examples produce a data file with 4 different scalar arrays as shown in Figure 2-38. Note that in both of the previous code examples, the same DBPutQuadvar1 function (or dbputqvl in Fortran) function was used to write out data arrays of differing types.

The DBPutQuadvar1 function can also be used to write out node centered variables. There are two differences that you must observe when writing a node-centered variable as opposed to writing a zone-centered variable. First, the data array that you pass to the DBPutQuadvar1 function must be larger by 1 in each of its dimensions and you must pass DB_NODECENT instead of DB_ZONECENT.

Listing 2-41: quadvar2d.c: C-Language example for writing node-centered variables.

```

/* The data must be NX * NY since it is nodal. */
#define NX 4
#define NY 5
float nodal[] = {
    0., 1., 2., 3.,
    4., 5., 6., 7.,
    8., 9., 10., 11.,
    12., 13., 14., 15.,
    16., 17., 18., 19.
};
/* Nodal variables have same #values as #nodes in mesh */
int dims[]={NX, NY};
int ndims = 2;
DBPutQuadvar1(dbfile, "nodal", "quadmesh", nodal, dims,
    ndims, NULL, 0, DB_FLOAT, DB_NODECENT, NULL);

```

Listing 2-42: fquadvar2d.f: Fortran language example for writing node-centered variables.

```

c The data must be NX * NY since it is nodal.
integer err, ierr, dims(2), ndims, NX, NY
parameter (NX = 4)
parameter (NY = 5)
real    nodal(NX, NY)
data dims/NX, NY/
data nodal/0., 1., 2., 3.,
. 4., 5., 6., 7.,
. 8., 9., 10., 11.,
. 12., 13., 14., 15.,
. 16., 17., 18., 19./

```

```

ndims = 2
c Nodal variables have same #values as #nodes in mesh
err = dbputqvl(dbfile, "nodal", 5, "quadmesh", 8, nodal,
. dims, ndims, DB_F77NULL, 0, DB_FLOAT, DB_NODECENT,
. DB_F77NULL, ierr)

```

Writing variables to 3D curvilinear and rectilinear meshes follows the same basic rules as writing variables for 2D meshes. For zone-centered variables, you must have $(NX-1)*(NY-1)*(NZ-1)$ data values and for node-centered variables, you must have $NX*NY*NZ$ data values. Figure 2-43 shows what the data values look like for the Silo files produced by the examples to come.

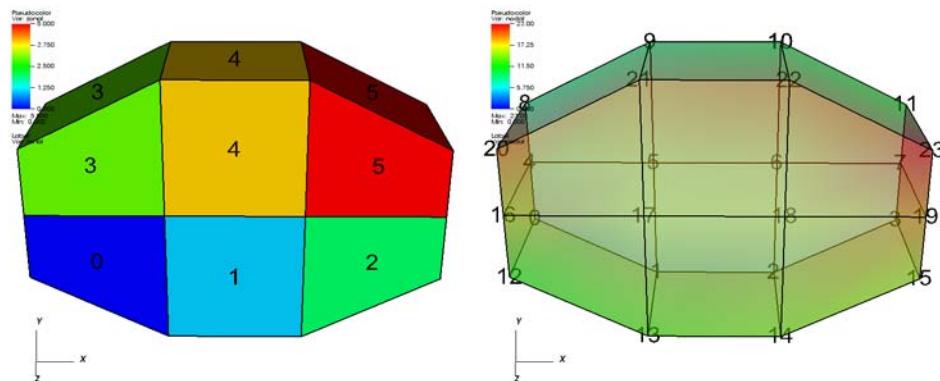


Figure 2-43: Zone-centered variable in 3D and a node-centered variable in 3D (shown with a partially transparent plot)

Listing 2-44: quadvar3d.c: C-Language example for writing variables on a 3D mesh.

```

#define NX 4
#define NY 3
#define NZ 2
/* Write a zone-centered variable. */
void write_zonecent_quadvar(DBfile *dbfile)
{
    int i, dims[3], ndims = 3;
    int ncells = (NX-1)*(NY-1)*(NZ-1);
    float *data = (float *)malloc(sizeof(float)*ncells);
    for(i = 0; i < ncells; ++i)
        data[i] = (float)i;
    dims[0] = NX-1; dims[1] = NY-1; dims[2] = NZ-1;
    DBPutQuadvar1(dbfile, "zonal", "quadmesh", data, dims,
                  ndims, NULL, 0, DB_FLOAT, DB_ZONECENT, NULL);
    free(data);
}
/* Write a node-centered variable. */

```

```

void write_nodecent_quadvar(DBfile *dbfile)
{
    int i, dims[3], ndims = 3;
    int nnodes = NX*NY*NZ;
    float *data = (float *)malloc(sizeof(float)*nnodes);
    for(i = 0; i < nnodes; ++i)
        data[i] = (float)i;
    dims[0] = NX; dims[1] = NY; dims[2] = NZ;
    DBPutQuadvar1(dbfile, "nodal", "quadmesh", data, dims,
                  ndims, NULL, 0, DB_FLOAT, DB_NODECENT, NULL);
    free(data);
}

```

Listing 2-45: fquadvar3d.f: Fortran language example for writing variables on a 3D mesh.

```

c Write a zone-centered variable.
subroutine write_zonecent_quadvar(dbfile)
implicit none
integer dbfile
include "silo.inc"
integer err, ierr, dims(3), ndims, i,j,k,index, ZX,ZY,ZZ
parameter (ZX = 3)
parameter (ZY = 2)
parameter (ZZ = 1)
integer zonal(ZX, ZY, ZZ)
data dims/ZX, ZY, ZZ/
index = 0
do 10020 k=1,ZZ
do 10010 j=1,ZY
do 10000 i=1,ZX
    zonal(i,j,k) = index
    index = index + 1
10000 continue
10010 continue
10020 continue
ndims = 3
err = dbputqvl(dbfile, "zonal", 5, "quadmesh", 8, zonal, dims,
. ndims, DB_F77NULL, 0, DB_INT, DB_ZONECENT, DB_F77NULL, ierr)
end
c Write a node-centered variable.
subroutine write_nodecent_quadvar(dbfile)
implicit none
integer dbfile
include "silo.inc"
integer err, ierr, dims(3), ndims, i,j,k,index, NZ, NY, NZ
parameter (NX = 4)
parameter (NY = 3)
parameter (NZ = 2)
real nodal(NX, NY, NZ)
data dims/NX, NY, NZ/
index = 0
do 20020 k=1,NZ
do 20010 j=1,NY

```

```

        do 20000 i=1,NX
            nodal(i,j,k) = float(index)
            index = index + 1
20000 continue
20010 continue
20020 continue
    ndims = 3
    err = dbputqvl(dbfile, "nodal", 5, "quadmesh", 8, nodal, dims,
. ndims, DB_F77NULL, 0, DB_FLOAT, DB_NODECENT, DB_F77NULL, ierr)
end

```

4.11.4 Point meshes

Point meshes, which were meshes composed of a set of points can, like other mesh types, have values associated with each point. Silo provides the DBPutPointVar1 function that you can use to write out a scalar variable stored on a point mesh. Nodes and the zones are really the same thing in a point mesh so you can consider zone-centered scalars to be the same thing as node-centered scalars.

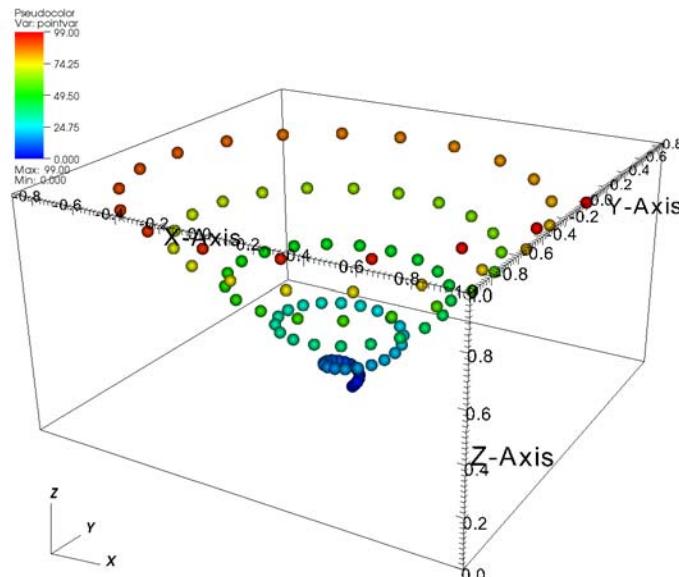


Figure 2-46: Scalar variable defined on a point mesh

Listing 2-47: pointvar3d.c: C-Language example for writing variables on a 3D point mesh.

```

/* Create some values to save. */
int i;
float var[NPTS];

```

```

for(i = 0; i < NPTS; ++i)
    var[i] = (float)i;
/* Write the point variable. */
DBPutPointvar1(dbfile, "pointvar", "pointmesh", var, NPTS,
    DB_FLOAT, NULL);

```

Listing 2-48: fpointvar3d.f: Fortran language example for writing variables on a 3D point mesh.

```

c Create some values to save.
integer err, ierr, i, NPTS
parameter (NPTS = 100)
real var(NPTS)
do 10010 i = 1,NPTS
    var(i) = float(i-1)
10010 continue
c Write the point variable
err = dbputpvl(dbfile, "pointvar", 8, "pointmesh", 9,
. var, NPTS, DB_FLOAT, DB_F77NULL, ierr)

```

4.11.5 Unstructured meshes

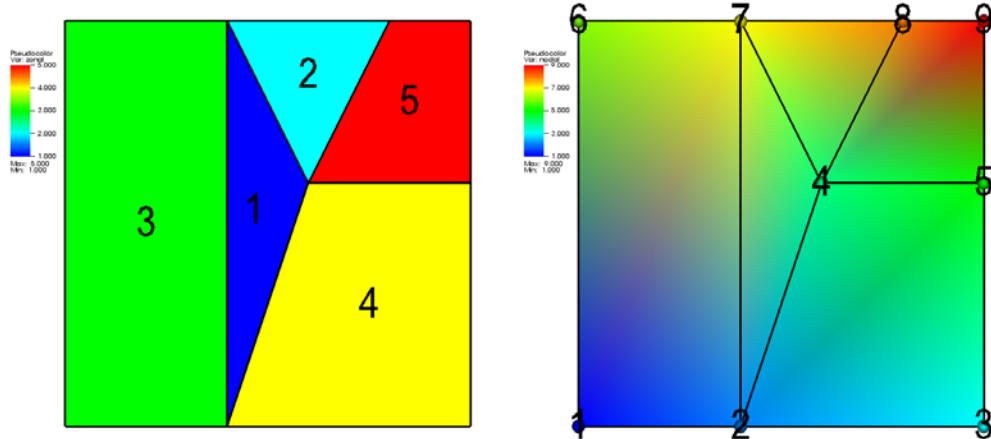


Figure 2-49: A 2D unstructured mesh with a zonal variable (left) and a nodal variable (right).

Writing a variable on an unstructured mesh is done following a procedure similar to that for writing a variable on a point mesh. As with other mesh types, a scalar variable defined on an unstructured grid can be zone-centered or node-centered. If the variable is zone-centered then the data array required to store the variable on the unstructured mesh must be a 1-D array with the same number of elements as the mesh has zones. If the variable to be stored is node-centered then the array containing the variable must be a 1-D array with the same number of elements as the mesh has nodes. Thinking of the data array as a 1-D array simplifies indexing since the number used to identify a particular node is the same

index that would be used to access data in the variable array (assuming 0-origin in C and 1-origin in Fortran). Since the data array is always 1-D for an unstructured mesh, the code to store variables on 2D and 3D unstructured meshes is identical. Figure 2-49 shows a 2D unstructured mesh with both zonal and nodal variables. Silo provides the DBPutUcdvar1 function for writing scalar variables on unstructured meshes.

Listing 2-50: ucdvar2d.c: C-Language example for writing variables on an unstructured mesh.

```
float nodal[] = {1.,2.,3.,4.,5.,6.,7.,8.,9.};
float zonal[] = {1.,2.,3.,4.,5.};
int nnodes = 9;
int nzones = 5;
/* Write a zone-centered variable. */
DBPutUcdvar1(dbfile, "zonal", "mesh", zonal, nzones, NULL, 0,
    DB_FLOAT, DB_ZONECENT, NULL);
/* Write a node-centered variable. */
DBPutUcdvar1(dbfile, "nodal", "mesh", nodal, nnodes, NULL, 0,
    DB_FLOAT, DB_NODECENT, NULL);
```

Listing 2-51: fucdvar2d.f: Fortran language example for writing variables on an unstructured mesh.

```
integer err, ierr, NNODES, NZONES
parameter (NNODES = 9)
parameter (NZONES = 5)
real nodal(NNODES) /1.,2.,3.,4.,5.,6.,7.,8.,9./
real zonal(NZONES) /1.,2.,3.,4.,5./
c Write a zone-centered variable.
err = dbputuv1(dbfile, "zonal", 5, "mesh", 4, zonal, NZONES,
    . DB_F77NULL, 0, DB_FLOAT, DB_ZONECENT, DB_F77NULL, ierr)
c Write a node-centered variable.
err = dbputuv1(dbfile, "nodal", 5, "mesh", 4, nodal, NNODES,
    . DB_F77NULL, 0, DB_FLOAT, DB_NODECENT, DB_F77NULL, ierr)
```

4.11.6 Adding variable units

All of the examples for writing scalar variables presented so far have focused on the basics of writing a variable array to a Silo file. Silo's option list mechanism allows a variable object to be annotated with various extra information. In the case of scalar variables, the option list passed to DBPutQuadvar1 and DBPutUcdvar1 can contain the units that describe the variable being stored. Refer to the *Silo User's Manual* for a complete list of the options accepted by the DBPutQuadvar1 and DBPutUcdvar1 functions. When a scalar variable has associated units, the units appear in the variable legend in VisIt's visualization window (see Figure 2-52).

If you want to add units to the variable that you write, you must create an option list to pass to the function writing your variable. You may recall that option lists are created with the DBMakeOptlist function and freed with the DBFreeOptlist function. In order to add units to the option list, you must add the DBOPT_UNITS option.

Listing 2-53: ucdvar2d.c: C-Language example for writing a variables with units.

```
/* Create an option list and add "g/cc" units to it. */
DBOptlist *optlist = DBMakeOptlist(1);
DBAddOption(optlist, DBOPT_UNITS, (void*)"g/cc");
/* Write a variable that has units. */
DBPutUcdvar1(dbfile, "zonal", "mesh", zonal, nzones, NULL, 0,
    DB_FLOAT, DB_ZONECENT, optlist);
/* Free the option list. */
DBFreeOptlist(optlist);
```

Listing 2-54: fucdvar2d.f: Fortran language example for writing a variables with units.

```
c Create an option list and add "g/cc" units to it.
integer err, optlistid
err = dbmkoptlist(1, optlistid)
err = dbaddcopt(optlistid, DBOPT_UNITS, "g/cc", 4)
c Write a variable that has units.
err = dbputuvl(dbfile, "zonal", 5, "mesh", 4, zonal, NZONES,
    . DB_F77NULL, 0, DB_FLOAT, DB_ZONECENT, optlistid, ierr)
c Free the option list.
err = dbfreeoptlist(optlistid)
```

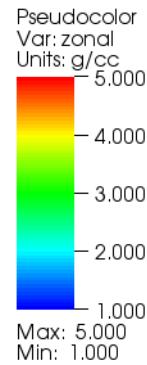


Figure 2-52: Plot legend with units

4.12 Single precision vs. Double precision

After having written some variables to a Silo file, you've no doubt learned that you can pass a pointer to data of many different representations and precisions (char, int, float, double, etc.). When you pass data to a Silo function, you also must pass a flag that tells Silo how to interpret the data stored in your data array. For example, if you have single precision floating point data then you would tell Silo to traverse the data as such using the DB_FLOAT type flag in the function call to DBPutQuadvar1. Many of the functions in the Silo library require a type flag to indicate the type of data being passed to Silo. In fact, even the functions to write mesh coordinates can accept different data types. This means that you can use double-precision to specify your mesh coordinates, which can be immensely useful when dealing with very large or very small objects.

Listing 2-55: C-Language example for writing a mesh with double-precision coordinates.

```
/* The x,y arrays contain double-precision coordinates. */
double x[NY][NX], y[NY][NX];
int dims[] = {NX, NY};
int ndims = 2;
/* Note that x,y pointers are cast to float to conform to API. */
float *coords[] = {(float*)x, (float*)y};
/* Tell Silo that the coordinate arrays are actually doubles. */
DBPutQuadmesh(dbfile, "quadmesh", NULL, coords, dims,
    DB_DOUBLE, DB_NONCOLLINEAR, NULL);
```

4.13 Writing expressions

You can plot derived quantities in VisIt by creating expressions that involve variables from your database. Sometimes, it is useful to include expression definitions in your Silo file so they are available to VisIt without you first having to create them. Silo provides the DBPutdefvars function so you can write your expressions to a Silo file. Expression names should be valid VisIt expression names, as defined in the *VisIt User's Manual*. Likewise, the expression definitions should contain only expressions that are supported by the VisIt expression language.

While VisIt's expression language can be useful for calculating a multitude of expressions, it can be particularly useful for grouping vector or tensor components into vector and tensor variables. If you store vector or tensor components as scalar variables in your Silo file then you can easily create expressions that assemble the components into real vector or tensor variables without significantly increasing your file's storage requirements. Writing out vector and tensor variables as expressions involving scalar variables also prevents you from having to use more complicated Silo functions in order to write out the vector or tensor data.

Listing 2-56: defvars.c: C-Language example for writing out expression definitions.

```
/* Write some expressions to the Silo file. */
const char *names[] = {"velocity", "speed"};
const char *defs[] = {"{xc,yc,zc}", "magnitude(velocity)"};
int types[] = {DB_VARTYPE_VECTOR, DB_VARTYPE_SCALAR};
DBPutDefvars(dbfile, "defvars", 2, names, types, defs, NULL);
```

Listing 2-57: fdefvars.f: Fortran language example for writing out expression definitions.

```
integer err, ierr, types(2), lnames(2), ldefs(2)
integer numexpressions, oldlen
c Initialize some 20 character length strings
character*20 names(2) //velocity           ,
. 'speed'          /
character*20 defs(2)  //'{xc,yc,zc}'      ,
. 'magnitude(velocity)' /
c Store the length of each string
data lnames/8, 5/
data ldefs/10, 19/
data types/DB_VARTYPE_VECTOR, DB_VARTYPE_SCALAR/
c Set the maximum string length to 20 since that's how long
c our strings are
oldlen = dbget2dstrlen()
err = dbset2dstrlen(20)
c Write out the expressions
numexpressions = 2
err = dbputdefvars(dbfile, "defvars", 7, numexpressions,
. names, lnames, types, defs, ldefs, DB_F77NULL, ierr)
c Restore the previous value for maximum string length
err = dbset2dstrlen(oldlen)
```

In the previous Fortran example for writing expressions, there are more functions involved than just the `dbputdefvars` function. It is critical to set the maximum 2D string length for strings in the Silo library, using the `dbset2dstrlen` function, so the Fortran interface to Silo will be able to correctly traverse the string data passed to it from Fortran. In the previous example, we used 20 characters for both the expression names and definitions. We call `dbset2dstrlen` to set the maximum allowable 2d string length to 20 characters before we pass our arrays of 20 character strings to the `dbputdefvars` function. In addition, we must also pass valid lengths for the expression name and definition strings. The lengths should be at least 1 character long but no longer than the maximum allowable string length, which we set to 20 characters in the example program. Passing valid string lengths is important so the expressions that you save to your file do not contain any extra characters, such as trailing spaces.

4.14 Creating a master file for parallel

When a parallel program saves out its data files, often the most efficient method of I/O is for each processor to write its own piece of the simulation, or domain, to its own Silo file.

If each processor writes its own Silo file then no communication or synchronization must take place to manage access to a shared file. However, once the simulation has completed, there are many files and all of them are required to reconstitute the simulated object.

Plotting each domain file in VisIt would be very tedious so Silo provides functions to create what is known as a “master file”, which is a top-level file that effectively unifies all of the domain files into a whole. When you open a master file in VisIt and plot variables out of it, all domains are plotted.

Master files contain what are known as multimeshes, multivars, and multimaterials. These objects are lists of filenames that contain the appropriate domain variable. They also contain some meta-information about each of the domains that helps VisIt perform better in parallel. Strategies for using metadata to improve VisIt’s I/O performance will be covered shortly.

4.14.1 Creating a multimesh

A multimesh is an object that unites smaller domain-sized meshes into a whole mesh. The multimesh object contains a list of the filenames that contain a piece of the named mesh. When you tell VisIt to plot a multimesh, VisIt reads the named mesh in all of the required domain files and processes the mesh in each file, to produce the entire mesh.

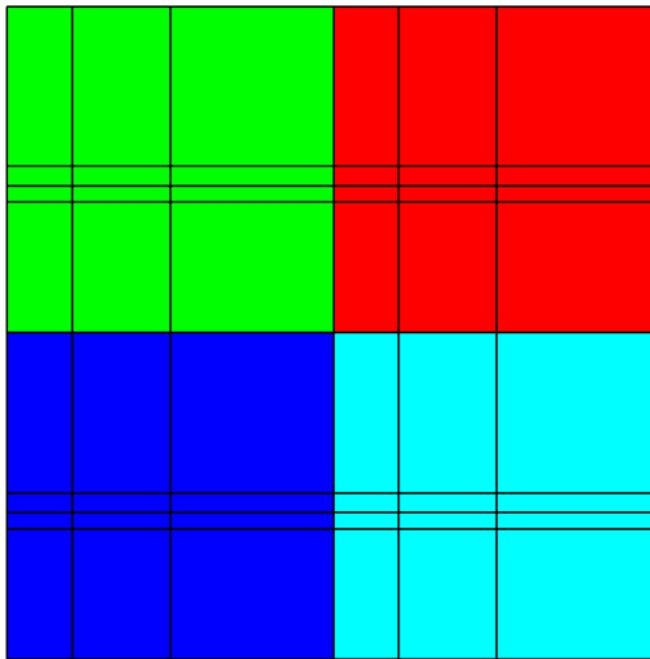


Figure 2-58: Multimesh colored by its domain number

The following example, shown in Figure 2-58, uses the mesh from the 2D rectilinear mesh example program and repeats it as 4 domains. Note that the mesh forming the domains is translated in X and Y so that the edges are shared. In the given example, the meshes that make up the entire mesh are stored in separate Silo files: *multimesh.1*, *multimesh.2*,

multimesh.3, and *multimesh.4*. The mesh and any data that may be defined on it is stored in those files. Remember that storing pieces of a single mesh is commonplace when parallel processes write their own file. Plotting each of the smaller files individually in VisIt is not necessary when a master file has been generated since plotting the multimesh object from the master file will cause VisIt to plot each of its constituent meshes. The code that follows shows how to use Silo's DBPutMultimesh function to write out a multimesh object that reassembles meshes from many domain files into a whole mesh.

The list of meshes or items in a multi-object generally take the form: *path:item* where *path* is the file system path to the item and *item* is the name of the object being referenced. Note that the path may be specified as a relative or absolute path using names valid for the file system containing the master file. However, we strongly recommend using only relative paths so the master file does not reference directories that exist only on one file system. Using relative paths makes the master files much more portable since they allow the data files to be moved. The path may also refer to subdirectories within the file being referenced since Silo files may contain directories that help to organize related data. The following examples assume that the domain files will exist in the same directory as the master file since the path includes only the names of the domain files.

Listing 2-59: multimesh.c: C-Language example for writing a multimesh.

```
void write_masterfile(void)
{
    DBfile *dbfile = NULL;
    char **meshnames = NULL;
    int dom, nmesh = 4, *meshtypes = NULL;
    /* Create the list of mesh names. */
    meshnames = (char **)malloc(nmesh * sizeof(char *));
    for(dom = 0; dom < nmesh; ++dom)
    {
        char tmp[100];
        sprintf(tmp, "multimesh.%d:quadmesh", dom);
        meshnames[dom] = strdup(tmp);
    }
    /* Create the list of mesh types. */
    meshtypes = (int *)malloc(nmesh * sizeof(int));
    for(dom = 0; dom < nmesh; ++dom)
        meshtypes[dom] = DB_QUAD_RECT;
    /* Open the Silo file */
    dbfile = DBCreate("multimesh.root", DB_CLOBBER, DB_LOCAL,
                      "Master file", DB_HDF5);
    /* Write the multimesh. */
    DBPutMultimesh(dbfile, "quadmesh", nmesh, meshnames,
                   meshtypes, NULL);
    /* Close the Silo file. */
    DBClose(dbfile);
    /* Free the memory*/
    for(dom = 0; dom < nmesh; ++dom)
        free(meshnames[dom]);
    free(meshnames);
```

```

        free(meshTypes);
    }
}

```

Listing 2-60: fmultimesh.f: Fortran language example for writing a multimesh.

```

subroutine write_master()
implicit none
include "silo.inc"
integer err, ierr, dbfile, nmesh, oldlen
character*20 meshnames(4) /'multimesh.1:quadmesh',
.                                'multimesh.2:quadmesh',
.                                'multimesh.3:quadmesh',
.                                'multimesh.4:quadmesh'/
integer lmeshnames(4) /20,20,20,20/
integer meshTypes(4) /DB_QUAD_RECT, DB_QUAD_RECT,
.                                DB_QUAD_RECT, DB_QUAD_RECT/
c Create a new silo file
err = dbcreate("multimesh.root", 14, DB_CLOBBER, DB_LOCAL,
. "multimesh root", 14, DB_HDF5, dbfile)
if(dbfile.eq.-1) then
    write (6,*) 'Could not create Silo file!\n'
    return
endif
c Set the maximum string length to 20 since that's how long our
c strings are
oldlen = dbget2dstrlen()
err = dbset2dstrlen(20)
c Write the multimesh object.
nmesh = 4
err = dbputmmesh(dbfile, "quadmesh", 8, nmesh, meshnames,
. lmeshnames, meshTypes, DB_F77NULL, ierr)
c Restore the previous value for maximum string length
err = dbset2dstrlen(oldlen)
c Close the Silo file
err = dbclose(dbfile)
end

```

Sometimes it can be advantageous to have each processor write its files to a unique subdirectory (e.g. proc-0, proc-1, proc-2, ...). You can also choose for each processor to write its files to a common directory so all files for a given time step are contained in a single place (e.g. cycle0000, cycle0001, cycle0002, ...). Generally, you will want to tailor your strategy to the strengths of your file system to spread the demands of writing files across as many I/O nodes as possible in order to increase throughput. The organization strategies mentioned so far are only suggestions and you will have to determine the optimum method for storing domain files on your computer system. Moving your domain files to subdirectories can make it easier to navigate your file system and can provide benefits later such as VisIt not having to check permissions, etc on so many files. Code to

create the list of mesh names where each processor writes its data to a different subdirectory that contains all files for a given time step might look like the following:

```
int cycle = 100;
for(dom = 0; dom < nmesh; ++dom)
{
    char tmp[100];
    sprintf(tmp, "proc-%d/multimesh.%04d:quadmesh", dom, cycle);
    meshnames[dom] = strdup(tmp);
}
```

4.14.2 Creating a multivar

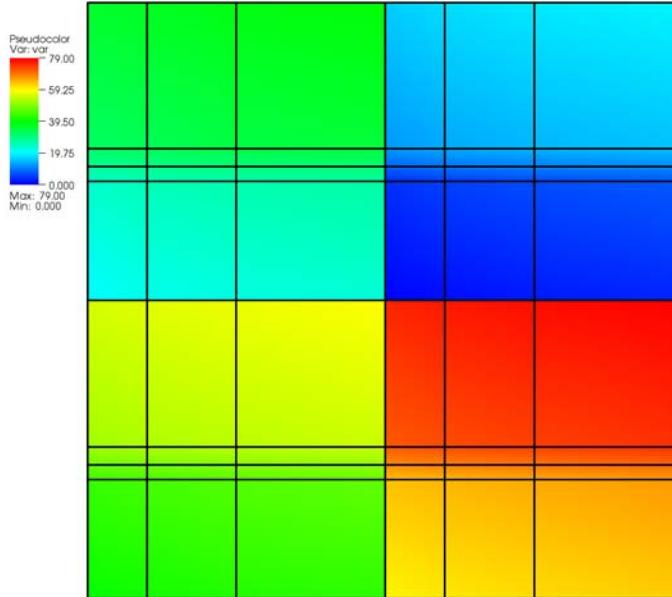


Figure 2-61: Multivar displayed on its multimesh

A multivar object is the variable equivalent of a multimesh object. Like the multimesh object, a multivar object contains a list of filenames that make up the variable represented by the multivar object. Silo provides the DBPutMultivar function for writing out multivar objects.

Listing 2-62: multivar.c: C-Language example for writing a multivar.

```
void write_multivar(DBfile *dbfile)
{
```

```

char **varnames = NULL;
int dom, nvar = 4, *vartypes = NULL;
/* Create the list of var names. */
varnames = (char **)malloc(nvar * sizeof(char *));
for(dom = 0; dom < nvar; ++dom)
{
    char tmp[100];
    sprintf(tmp, "multivar.%d:var", dom);
    varnames[dom] = strdup(tmp);
}
/* Create the list of var types. */
vartypes = (int *)malloc(nvar * sizeof(int));
for(dom = 0; dom < nvar; ++dom)
    vartypes[dom] = DB_QUADVAR;
/* Write the multivar. */
DBPutMultivar(dbfile, "var", nvar, varnames, vartypes, NULL);
/* Free the memory*/
for(dom = 0; dom < nvar; ++dom)
    free(varnames[dom]);
free(varnames);
free(vartypes);
}

```

Listing 2-63: fmultivar.f: Fortran language example for writing a multivar.

```

subroutine write_multivar(dbfile)
implicit none
include "silo.inc"
integer err, ierr, dbfile, nvar, oldlen
character*20 varnames(4) /'multivar.1:var      ', 
.                           'multivar.2:var      ', 
.                           'multivar.3:var      ', 
.                           'multivar.4:var      '
integer lvarnames(4) /14,14,14,14/
integer vartypes(4) /DB_QUADVAR,DB_QUADVAR,
.                      DB_QUADVAR,DB_QUADVAR/
c Set the maximum string length to 20 since that's how long
c our strings are
oldlen = dbget2dstrlen()
err = dbset2dstrlen(20)
c Write the multivar.
nvar = 4
err = dbputmvar(dbfile, "var", 3, nvar, varnames, lvarnames,
. vartypes, DB_F77NULL, ierr)
c Restore the previous value for maximum string length
err = dbset2dstrlen(oldlen)
end

```

4.14.3 EMPTY contributions

During the course of a calculation, sometimes only a subset of processors will contribute data. This means that they will not write data files. When some processors do not write data files, creating your multi-objects can become more complicated. Note that because of how VisIt represents its domain subsets, etc, you will want to keep the number of filenames in a multi-object equal to the number of processors that you are using (the maximum number of domains that you will generate). If the length of the list varies over time then VisIt's subsetting controls may not behave as expected. To keep things simple, if you have N processors that write N files, you will always want N entries in your multi-objects. If a processor does not contribute any data, insert the "EMPTY" keyword into the multi-object in place of the path and variable. The "EMPTY" keyword allows the size of the multi-object to remain fixed over time even as the number of processors that contribute data changes. Keeping the size of the multi-object fixed over time ensures that VisIt's subsetting controls will continue to function as expected. Note that if you use the "EMPTY" keyword in a multivar object then the same entry in the multimesh object for the variable must also contain the "EMPTY" keyword.

Listing 2-64: C-Language example using the EMPTY keyword.

```
/* Processors 3,4 did not contribute so use EMPTY. */
char *meshnames[] = {"proc-1/file000/mesh", "proc-2/file000/mesh",
    "EMPTY", "EMPTY"};
int meshtypes[] = {DB_QUAD_RECT, DB_QUAD_RECT,
    DB_QUAD_RECT, DB_QUAD_RECT};
int nmesh = 4;
/* Write the multimesh. */
DBPutMultimesh(dbfile, "mesh", nmesh, meshnames, meshtypes, NULL);
```

5.0 Writing VTK files

VTK (Visualization Toolkit) files provide a simple, flexible way to import data into VisIt. VTK files can be written in human-readable ASCII form or in binary form. VTK files may also be created in the legacy VTK file format or in their newer XML-based format. The human-readable ASCII form for legacy VTK files is described in the *VTK File Formats* document found on the Web at <http://public.kitware.com/VTK/pdf/file-formats.pdf>. You can create code in any language to write data to the VTK file format if you follow the format guidelines in the *VTK File Formats* document.

In order to simplify the creation of legacy VTK files, which can be susceptible to formatting mistakes, VisIt provides the `visit_writer` library. The `visit_writer` library is implemented in C and can be called from the C, C++, and Python programming languages. The `visit_writer` library provides a handful of easy-to-use functions for producing VTK files. This section will show how to use the `visit_writer` library to create VTK files that can be used to import data into VisIt.

5.1 Getting started with visit_writer

The `visit_writer` library is included in source code form in VisIt's source code distribution. The C-version of the library consists of 2 files called `visit_writer.c` and `visit_writer.h` that are stored in the `tools/writer` directory of VisIt's source code tree.

5.1.1 Using visit_writer in C programs

When you use the `visit_writer` library, you can include the `visit_writer.c` file directly in the list of source files for your project. Source files that use functions from the `visit_writer` library must include the `visit_writer.h` header file. The `visit_writer` library has no external dependencies so no additional libraries are required to link programs that use the `visit_writer` library, provided the `visit_writer.c` source code file was included in the project.

5.1.2 Using visit_writer in Python programs

The Python version of the `visit_writer` library is implemented as a Python extension module, which is a dynamically loaded executable file containing the `visit_writer` functions. The compiled `visit_writer` extension module is not currently distributed in VisIt's binary distributions so you will have to build it before you can use it in your Python programs. Fortunately, building the `visit_writer` module is easy if you allow Python to build it for you. To begin, open a terminal window and cd into VisIt's source code tree and then into the `tools/writer` directory. Next, type the following Python code into a file called `setup.py`:

```
from distutils.core import setup, Extension
module1 = Extension('visit_writer',
    include_dirs= ['./'],
    sources = ['visit_writer.c', 'py_visit_writer.c'])
setup (name = 'visit_writer',
    version = '1.0',
    description = 'This module lets us write VTK files.',
    ext_modules = [module1])
```

Once you have created the `setup.py` file, run the following command in your terminal window to build the `visit_writer` Python extension module.

```
python setup.py build
```

Once Python builds the `visit_writer` extension module, you can install it by running the following command:

```
python setup.py install
```

After the `visit_writer` module has been built and installed, it should be available when you run Python. To test whether the module was successfully installed, run python and type: `import visit_writer` at the Python prompt. If Python does not complain then the module was successfully built and loaded. Whenever you want to use the `visit_module` in

your Python scripts, you must first issue the `import visit_writer` directive. If you want to find out more information about a particular `visit_writer` function once you've imported the `visit_writer` module, you can type: `print visit_writer.__doc__` to make Python print out the documentation string for the `visit_writer` module.

5.2 Regular meshes with data

A regular mesh, or Cartesian mesh, is an implicit mesh in which all zones have the same size and are axis-aligned (see Figure 2-65). Furthermore, in this context, all zones are squares or cubes with a side length of 1. The extents are determined by the number of zones in each dimension. A regular mesh is a type of rectilinear mesh where the zones are not permitted to differ in size. The `visit_writer` library provides the `write_regular_mesh` function for writing out regular meshes and data to VTK files.

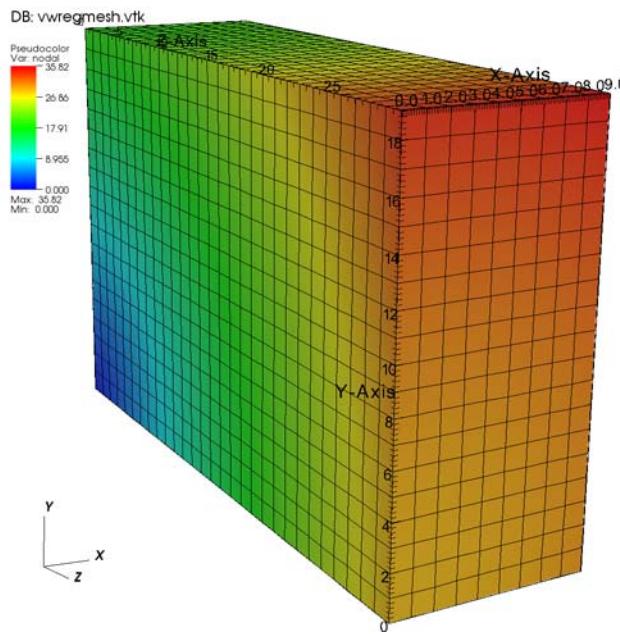


Figure 2-65: Regular mesh with data created using `visit_writer`

Listing 2-66: `vwregmesh.c`: C-Language example for writing a regular mesh with data.

```
#include <visit_writer.h>
#include <math.h>

int main(int argc, char *argv[])
{
#define NX 10
#define NY 20
```

```

#define NZ 30
    int i,j,k, index = 0;
    int dims[] = {NX, NY, NZ};
    int nvars = 2;
    int vardims[] = {1, 1};
    int centering[] = {0, 1};
    const char *varnames[] = {"zonal", "nodal"};
    float zonal[NZ-1][NY-1][NX-1], nodal[NZ][NY][NX];
    float *vars[] = {(float *)zonal, (float *)nodal};
    /* Create zonal variable */
    for(k = 0; k < NZ-1; ++k)
        for(j = 0; j < NY-1; ++j)
            for(i = 0; i < NX-1; ++i, ++index)
                zonal[k][j][i] = (float)index;
    /* Create nodal variable. */
    for(k = 0; k < NZ; ++k)
        for(j = 0; j < NY; ++j)
            for(i = 0; i < NX; ++i)
                nodal[k][j][i] = sqrt(i*i + j*j + k*k);
    /* Use visit_writer to write a regular mesh with data. */
    write_regular_mesh("vwregmesh.vtk", 0, dims, nvars, vardims,
                       centering, varnames, vars);
    return 0;
}

```

Listing 2-67: vwregmesh.py: Python language example for writing a regular mesh with data.

```

import visit_writer, math
NX = 10
NY = 20
NZ = 30
# Create a zonal variable
zonal = []
index = 0
for k in range(NZ-1):
    for j in range(NY-1):
        for i in range(NX-1):
            zonal = zonal + [index]
            index = index + 1
# Create a nodal variable
nodal = []
for k in range(NZ):
    for j in range(NY):
        for i in range(NX):
            nodal = nodal + [math.sqrt(i*i + j*j + k*k)]
# Use visit_writer to write a regular mesh with data.
dims = (NX, NY, NZ)
vars = ("zonal", 1, 0, zonal), ("nodal", 1, 1, nodal)
visit_writer.WriteRegularMesh("vwregmesh2.vtk", 0, dims, vars)

```

5.3 Rectilinear meshes with data

Recall from “Writing a rectilinear mesh” on page 20 that a rectilinear mesh is a 2D or 3D mesh where all coordinates are aligned with the axes and coordinates along each axis can have different, non-uniform spacing. The `visit_writer` library provides the `write_rectilinear_mesh` function for writing rectilinear meshes. The following code examples will use the same 2D and 3D rectilinear meshes that were used for the Silo examples.

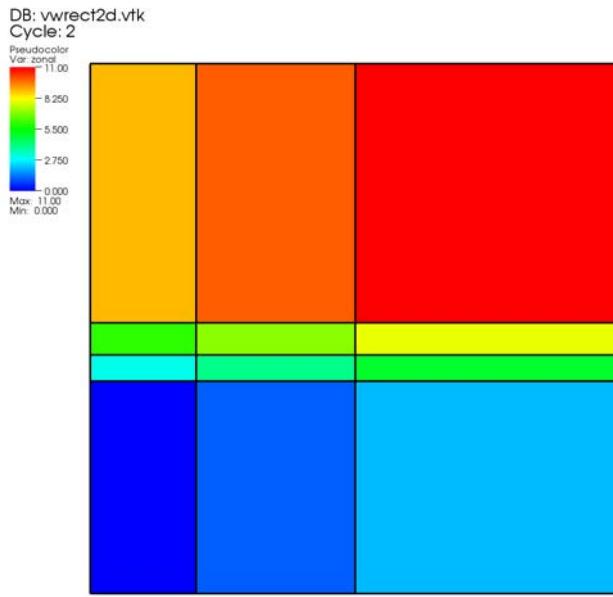


Figure 2-68: 2D rectilinear mesh with zonal variable

Listing 2-69: `vwrect2d.c`: C-Language example for writing a rectilinear mesh with data.

```
#include <visit_writer.h>

int main(int argc, char *argv[])
{
#define NX 4
#define NY 5
    /* Rectilinear mesh coordinates. */
    float x[] = {0., 1., 2.5, 5.};
    float y[] = {0., 2., 2.25, 2.55, 5.};
    float z[] = {0.};
    int dims[] = {NX, NY, 1};
    int ndims = 2;
    /* Zonal and Nodal variable data. */
    float zonal[NY-1][NX-1], nodal[NY][NX];
```

```

/* Info about the variables to pass to visit_writer. */
int nvars = 2;
int vardims[] = {1, 1};
int centering[] = {0, 1};
const char *varnames[] = {"zonal", "nodal"};
float *vars[] = {(float*)zonal, (float*)nodal};

/* Create a zonal variable. */
int i,j,index = 0;
for(j = 0; j < NY-1; ++j)
    for(i = 0; i < NX-1; ++i, ++index)
        zonal[j][i] = (float)index;

/* Create a nodal variable. */
index = 0;
for(j = 0; j < NY; ++j)
    for(i = 0; i < NX; ++i, ++index)
        nodal[j][i] = (float)index;

/* Pass the data to visit_writer to write a VTK file.*/
write_rectilinear_mesh("vwrect2d.vtk", 0, dims, x, y, z, nvars,
vardims, centering, varnames, vars);

return 0;
}

```

Listing 2-70: vwrect2d.py: Python language example for writing a rectilinear mesh with data.

```

import visit_writer

NX = 4
NY = 5
x = (0., 1., 2.5, 5.)
y = (0., 2., 2.25, 2.55, 5.)
z = 0.

# Create a zonal variable
zonal = []
index = 0
for j in range(NY-1):
    for i in range(NX-1):
        zonal = zonal + [index]
        index = index + 1

# Create a nodal variable
nodal = []
index = 0
for j in range(NY):
    for i in range(NX):
        nodal = nodal + [index]
        index = index + 1

```

```
vars = (("zonal", 1, 0, zonal), ("nodal", 1, 1, nodal))
visit_writer.WriteRectilinearMesh("vwrect2d.vtk", 0, x, y, z, vars)
```

5.4 Curvilinear meshes with data

A curvilinear mesh is similar to a rectilinear mesh; the main difference between the two mesh types is how coordinates are specified. Recall that in a rectilinear mesh, the coordinates are specified individually for each axis and only a small subset of the nodes in the mesh are provided. In a curvilinear mesh, you must provide an X,Y,Z value for every node in the mesh. The `visit_writer` library provides the `write_curvilinear_mesh` function to write out curvilinear meshes and any variables defined on them. Figure 2-71 shows an example of a 3D curvilinear mesh with a zonal variable.

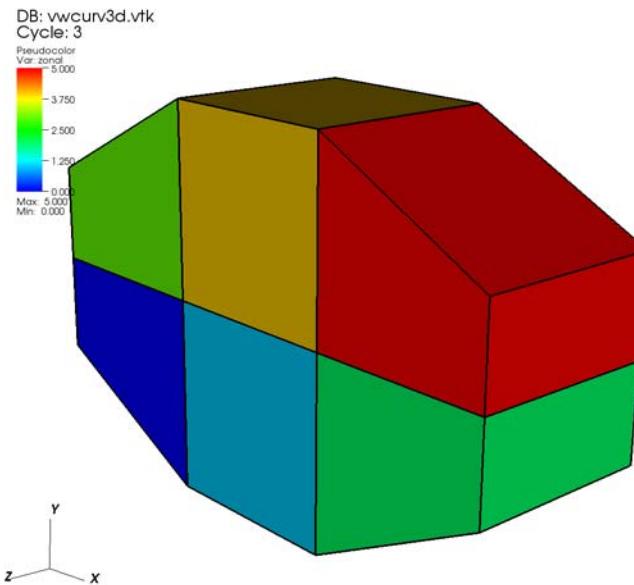


Figure 2-71: 3D curvilinear mesh with zonal variable

Listing 2-72: vwcurv3d.c: C-Language example for writing a curvilinear mesh with data.

```
#include <visit_writer.h>

#define NX 4
#define NY 3
#define NZ 2

int main(int argc, char *argv[])
{
```

```

/* Curvilinear mesh points stored x0,y0,z0,x1,y1,z1,...*/
float pts[] = {0, 0.5, 0, 1, 0, 0, 2, 0, 0,
               3, 0.5, 0, 0, 1, 0, 1, 1, 0,
               2, 1, 0, 3, 1, 0, 0, 1.5, 0,
               1, 2, 0, 2, 2, 0, 3, 1.5, 0,
               0, 0.5, 1, 1, 0, 1, 2, 0, 1,
               3, 0.5, 1, 0, 1, 1, 1, 1, 1,
               2, 1, 1, 3, 1, 1, 0, 1.5, 1,
               1, 2, 1, 2, 2, 1, 3, 1.5, 1
};
int dims[] = {NX, NY, NZ};
/* Zonal and nodal variable data. */
float zonal[NZ-1][NY-1][NX-1], nodal[NZ][NY][NX];
/* Info about the variables to pass to visit_writer. */
int nvars = 2;
int vardims[] = {1, 1};
int centering[] = {0, 1};
const char *varnames[] = {"zonal", "nodal"};
float *vars[] = {(float *)zonal, (float *)nodal};
int i,j,k, index = 0;

/* Create zonal variable */
for(k = 0; k < NZ-1; ++k)
    for(j = 0; j < NY-1; ++j)
        for(i = 0; i < NX-1; ++i, ++index)
            zonal[k][j][i] = (float)index;

/* Create nodal variable. */
index = 0;
for(k = 0; k < NZ; ++k)
    for(j = 0; j < NY; ++j)
        for(i = 0; i < NX; ++i, ++index)
            nodal[k][j][i] = index;

/* Pass the data to visit_writer to write a binary VTK file. */
write_curvilinear_mesh("vwcurv3d.vtk", 1, dims, pts, nvars,
                      vardims, centering, varnames, vars);

return 0;
}

```

Listing 2-73: vwcurv3d.py: Python language example for writing a curvilinear mesh with data.

```

import visit_writer

NX = 4
NY = 3
NZ = 2

# Curvilinear mesh points stored x0,y0,z0,x1,y1,z1,...
pts = (0, 0.5, 0, 1, 0, 0, 2, 0, 0,
       3, 0.5, 0, 0, 1, 0, 1, 1, 0,

```

```
2, 1, 0, 3, 1, 0, 0, 1.5, 0,
1, 2, 0, 2, 2, 0, 3, 1.5, 0,
0, 0.5, 1, 1, 0, 1, 2, 0, 1,
3, 0.5, 1, 0, 1, 1, 1, 1, 1,
2, 1, 1, 3, 1, 1, 0, 1.5, 1,
1, 2, 1, 2, 2, 1, 3, 1.5, 1)

# Create a zonal variable
zonal = []
index = 0
for k in range(NZ-1):
    for j in range(NY-1):
        for i in range(NX-1):
            zonal = zonal + [index]
            index = index + 1

# Create a nodal variable
nodal = []
index = 0
for k in range(NZ):
    for j in range(NY):
        for i in range(NX):
            nodal = nodal + [index]
            index = index + 1

# Pass data to visit_writer to write a binary VTK file.
dims = (NX, NY, NZ)
vars = (("zonal", 1, 0, zonal), ("nodal", 1, 1, nodal))
visit_writer.WriteCurvilinearMesh("vwcurv3d.vtk", 0, dims, pts, vars)
```

5.5 Point meshes with data

A point mesh is a set of 2D or 3D points where the nodes also constitute the cells in the mesh. The `visit_writer` library provides the `write_point_mesh` function to write out point meshes and data to VTK files.

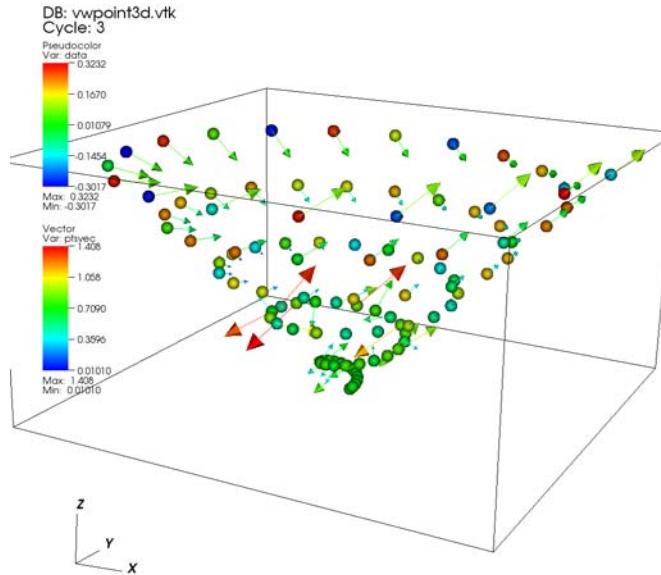


Figure 2-74: Point mesh with scalar data and vector data

Listing 2-75: vwpoin3d.c: C-Language example for writing a point mesh with data.

```
#include <visit_writer.h>

#define NPTS 100

int main(int argc, char *argv[])
{
    /* Create some points and data to save. */
    int i;
    float pts[NPTS][3], data[NPTS];
    int nvargs = 2;
    int vardims[] = {1, 3};
    const char *varnames[] = {"data", "ptsvec"};
    float *vars[] = {(float *)pts, data};

    for(i = 0; i < NPTS; ++i)
    {
        /* Make a point. */
        float t = ((float)i) / ((float)(NPTS-1));
        float angle = 3.14159 * 10. * t;
        pts[i][0] = sin(angle);
        pts[i][1] = cos(angle);
        pts[i][2] = t;
        data[i] = sin(2. * angle) + 0.5;
    }
}
```

```
        pts[i][0] = t * cos(angle);
        pts[i][1] = t * sin(angle);
        pts[i][2] = t;
        /* Make a scalar */
        data[i] = t * cos(angle);
    }

    /* Pass the mesh and data to visit_writer. */
    write_point_mesh("vwpoint3d.vtk", 1, NPTS, (float*)pts, nvars,
                     vardims, varnames, vars);

    return 0;
}
```

Listing 2-76: vwpoint3d.py: Python language example for writing a point mesh with data.

```
import visit_writer, math
NPTS = 100
pts = []
data = []
for i in range(NPTS):
    # Make a point
    t = float(i) / float(NPTS-1)
    angle = 3.14159 * 10. * t
    pts = pts + [t * math.cos(angle), t * math.sin(angle), t]
    # Make a scalar
    data = data + [t * math.cos(angle)]

    # Pass the mesh and data to visit_writer.
    vars = (("data", 1, 1, pts), ("ptsvec", 3, 1, pts))
    visit_writer.WritePointMesh("vwpoint3d.vtk", 1, pts, vars)
```

5.6 Unstructured meshes with data

Unstructured meshes are collections of different types of zones and are useful because they can represent more complex mesh geometries than the structured meshes can. Unstructured meshes are specified using the cell types and node orderings listed in “Writing an unstructured mesh” on page 29. This section explains how to use the `visit_writer` library’s `write_unstructured_mesh` function to write out unstructured meshes and data.

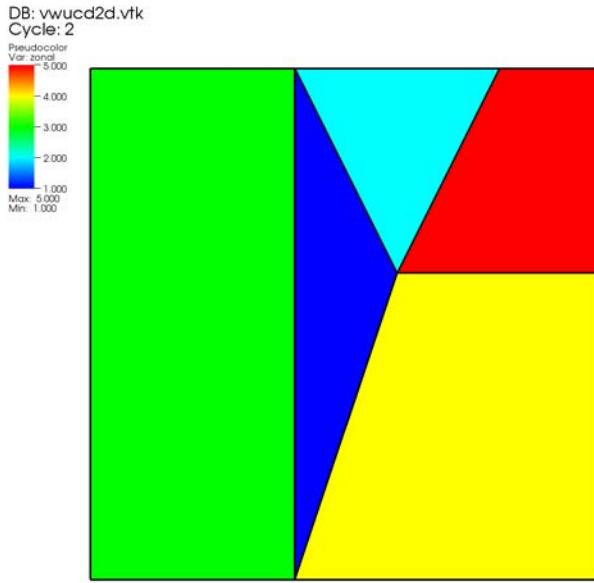


Figure 2-77: 2D unstructured mesh with zonal variable

Listing 2-78: vwrucd2d.c: C-Language example for writing an unstructured mesh with data.

```
#include <visit_writer.h>

int main(int argc, char *argv[])
{
    /* Node coordinates */
    int nnodes = 9;
    int nzones = 5;
    float pts[] = {0., 0., 0., 2., 0., 0., 5., 0., 0.,
                   3., 3., 0., 5., 3., 0., 0., 5., 0.,
                   2., 5., 0., 4., 5., 0., 5., 5., 0.};

    /* Zone types */
    int zonetypes[] = {VISIT_TRIANGLE, VISIT_TRIANGLE,
                       VISIT_QUAD, VISIT_QUAD, VISIT_QUAD};

    /* Connectivity */
    int connectivity[] = {
        1,3,6,    /* tri zone 1. */
        3,7,6,    /* tri zone 2. */
        0.,1,6,5, /* quad zone 3. */
        1,2,4,3,  /* quad zone 4. */
        3,4,8,7   /* quad zone 5. */
    };
}
```

```
/* Data arrays */
float nodal[] = {1,2,3,4,5,6,7,8,9};
float zonal[] = {1,2,3,4,5};

/* Info about the variables we're passing to visit_writer. */
int nvars = 2;
int vardims[] = {1, 1};
int centering[] = {0, 1};
const char *varnames[] = {"zonal", "nodal"};
float *vars[] = {zonal, nodal};

/* Pass the mesh and data to visit_writer. */
write_unstructured_mesh("vwucd2d.vtk", 1, nnodes, pts, nzones,
    zonetypes, connectivity, nvars, vardims, centering,
    varnames, vars);

    return 0;
}
```

Listing 2-79: vwucd2d.py: Python language example for writing an unstructured mesh with data.

```
import visit_writer

# Node coordinates
pts = (0., 0., 0., 2., 0., 0., 5., 0., 0.,
       3., 3., 0., 5., 3., 0., 0., 5., 0.,
       2., 5., 0., 4., 5., 0., 5., 0., 0.)

# Connectivity
connectivity = (
    (visit_writer.triangle, 1,3,6),
    (visit_writer.triangle, 3,7,6),
    (visit_writer.quad, 0,1,6,5),
    (visit_writer.quad, 1,2,4,3),
    (visit_writer.quad, 3,4,8,7)
)

# Data arrays
nodal = (1,2,3,4,5,6,7,8,9)
zonal = (1,2,3,4,5)

# Pass the data to visit_writer
vars = (("zonal", 1, 0, zonal), ("nodal", 1, 1, nodal))
visit_writer.WriteUnstructuredMesh("vwucd2d.vtk", 1, pts,
    connectivity, vars)
```

5.7 Creating a master file for parallel (.visit file)

The `visit_writer` library creates legacy VTK files and the legacy VTK file format has no mechanism for storing more than a single mesh. Furthermore, legacy VTK files have

no concept of a master file or of multi-objects like Silo uses to unite domains into a whole. Fortunately, VisIt provides a construct called a .visit file that addresses this shortcoming. A .visit file is a text file, ending with the “.visit” extension, that contains the names of domain files that make up the whole. A .visit file can be created to group files for any file format that VisIt can read. Your parallel program can still write individual VTK files and you can create a .visit file before visualizing the files so VisIt knows to open all of the relevant files as opposed to you creating plots of each individual file. The following code example lists what a .visit file looks like if you have 4 VTK domain files that contain the same variables and all of them are to be plotted at once.

```
!NBLOCKS 4
proc-0.vtk
proc-1.vtk
proc-2.vtk
proc-3.vtk
```

The .visit file can be used for indicating which VTK files are part of a time-varying database in addition to indicating how to reassemble domain files into a whole. In the previous example, there were 4 domain files and only 1 time step. If you want to have more than 1 time step, just add more files to the list. The !NBLOCKS directive tells VisIt that every block of 4 files are related in a single time step. If you had two time steps then your .visit file might look like this:

```
!NBLOCKS 4
proc-0.0000.vtk
proc-1.0000.vtk
proc-2.0000.vtk
proc-3.0000.vtk
proc-0.0001.vtk
proc-1.0001.vtk
proc-2.0001.vtk
proc-3.0001.vtk
```


1.0 Overview

This chapter elaborates on some of the advanced topics involved in creating files that VisIt can read. Most applications should be able to write out all of their data using information contained in the previous chapter. This chapter introduces advanced topics such as incorporating metadata to accelerate VisIt’s performance as well as some less common data representations. Many of the examples in this chapter use the Silo library, which was introduced in the previous chapter. For more information on getting started with the Silo library, see “Writing Silo files” on page 13.

2.0 Writing vector data

The components of vector data are often stored to files as individual scalar variables and VisIt uses an expression to compose the scalars back into a vector field. If you use the Silo library, you can always choose instead to store your vector data as a multi-component variable. The previous chapter provided several examples that use the Silo library to write scalar variables on rectilinear, curvilinear, point, and unstructured meshes. The functions that were used to write the scalars were simplified forms of the functions that are used to write vector data. The scalar functions that were used to write data for a specific mesh type as well as the vector function equivalents are listed in the following table:

Mesh type	Scalar function	Vector function
Rectilinear mesh	DBPutQuadvar1	DBPutQuadvar
Curvilinear mesh	DBPutQuadvar1	DBPutQuadvar
Point mesh	DBPutPointvar1	DBPutPointvar

Mesh type	Scalar function	Vector function
Unstructured mesh	DBPutUcdvar1	DBPutUcdvar

The differences between a scalar function and a vector function are small. In fact, the argument lists for a scalar function and a vector function are nearly identical in the Silo library's C-Language interface. The chief difference is that the vector functions take two additional arguments and the meaning of one existing argument is modified. The first new argument is an integer indicating the number of components contained by the variable to be written. The next difference is that you must pass an array of pointers to character strings that represent the names of each individual component. Finally, the argument that was used to pass the data to the DBPutQuadvar1 function, now in the DBPutQuadvar function, accepts an array of pointers to the various arrays that contain the variable components. For more complete information on each of the arguments to the functions that Silo uses to write multi-component data, refer to the *Silo User's Manual*.

Listing 3-1: vectorvar.c: C-Language example for writing vector data using Silo.

```

int i, dims[3], ndims = 3;
int nnodes = NX*NY*NZ;
float *comp[3];
char *varnames[] = {"nodal_comp0", "nodal_comp1", "nodal_comp2"};
comp[0] = (float *)malloc(sizeof(float)*nnodes);
comp[1] = (float *)malloc(sizeof(float)*nnodes);
comp[2] = (float *)malloc(sizeof(float)*nnodes);
for(i = 0; i < nnodes; ++i)
{
    comp[0][i] = (float)i; /*vector component 0*/
    comp[1][i] = (float)i; /*vector component 1*/
    comp[2][i] = (float)i; /*vector component 2*/
}
dims[0] = NX; dims[1] = NY; dims[2] = NZ;
DBPutQuadvar(dbfile, "nodal", "quadmesh",
    3, varnames, comp, dims,
    ndims, NULL, 0, DB_FLOAT, DB_NODECENT, NULL);
free(comp[0]);
free(comp[1]);
free(comp[2]);

```

Silo's Fortran interface does not provide functions to write out multi-component data such as vectors. If you use the Fortran interface to Silo, you will have to write out the vector components as separate scalar variables and then write an expression to your Silo file that composes the components into a single vector variable.

Listing 3-2: fvectorvar.f: Fortran-Language example for writing vector data using Silo.

```
subroutine write_nodecent_quadvar(dbfile)
```

```

implicit none
integer dbfile
include "silo.inc"
integer err, ierr, dims(3), ndims,i,j,k,index,NX,NY,NZ
parameter (NX = 4)
parameter (NY = 3)
parameter (NZ = 2)
real    comp0(NX,NY,NZ), compl(NX,NY,NZ), comp2(NX,NY,NZ)
data dims/NX,NY,NZ/
index = 0
do 20020 k=1,NZ
do 20010 j=1,NY
do 20000 i=1,NX
    comp0(i,j,k) = float(index)
    compl(i,j,k) = float(index)
    comp2(i,j,k) = float(index)
    index = index + 1
20000 continue
20010 continue
20020 continue
ndims = 3
err = dbputqvl(dbfile, "n_comp0", 11, "quadmesh", 8, comp0,
. dims, ndims, DB_F77NULL, 0, DB_FLOAT, DB_NODECENT, DB_F77NULL,
. ierr)
err = dbputqvl(dbfile, "n_compl", 11, "quadmesh", 8, compl,
. dims, ndims, DB_F77NULL, 0, DB_FLOAT, DB_NODECENT, DB_F77NULL,
. ierr)
err = dbputqvl(dbfile, "n_comp2", 11, "quadmesh", 8, comp2,
. dims, ndims, DB_F77NULL, 0, DB_FLOAT, DB_NODECENT, DB_F77NULL,
. ierr)
end

subroutine write_defvars(dbfile)
implicit none
integer dbfile
include "silo.inc"
integer      err, ierr, types(2), lnames(2), ldefs(2), oldlen
c Initialize some 20 character length strings
character*40 names(2)  '//zonalvec
.           ' //nodalvec
.           character*40 defs(2)  '//{z_comp0,z_compl,z_comp2}  ',
.           ' {n_comp0,n_compl,n_comp2}  '
c Store the length of each string
data lnames/8, 8/
data ldefs/37, 37/
data types/DB_VARTYPE_VECTOR, DB_VARTYPE_VECTOR/
c Set the maximum string length to 40 since that's how long our
c strings are
oldlen = dbget2dstrlen()
err = dbset2dstrlen(40)
c Write out the expressions
err = dbputdefvars(dbfile, "defvars", 7, 2, names, lnames,
. types, defs, ldefs, DB_F77NULL, ierr)
c Restore the previous value for maximum string length

```

```
err = dbset2dstrlen(olddlen)
end
```

3.0 Adding metadata for performance boosts

VisIt incorporates several performance boosting strategies that make use of metadata, if it is available. Most of the metadata applies to increasing parallel performance by reducing the amount of I/O and subsequent processing that is required. The I/O reductions are realized by not reading in and processing domains that will contribute nothing to the final image on the screen. In order to prevent domains from being read in, your multi-objects must have associated metadata for each of the domains that they contain. When a Silo multi-object contains metadata about all of its constituent domains, VisIt can make work-saving decisions since it knows the properties of each domain without having to read in the data for each domain.

This section explains how to add metadata to your Silo multi-objects using option lists. Metadata attached to multi-objects allow VisIt to determine important data characteristics such as data extents or the spatial extents of the mesh without having to first read and process all domains. Such knowledge allows VisIt to restrict the number of domains that are processed, thus reducing the amount of work and the time required to display images on your screen.

3.1 Writing data extents

Providing data extents can help VisIt only read in and process those domains that will contribute to the final image. Many types of plots and operators use data extents for each domain, when they are provided, to perform a simple upfront test to determine if a domain contains the values which will be used. If a domain is not needed then VisIt will not read that domain because it is known beforehand that the domain does not contain the desired value.

An example of a plot that uses data extents in order to save work is VisIt's Contour plot. The Contour plot creates contours (lines or surfaces where the data has the same value) through a dataset. Consider the example shown in Figure 3-3, where the entire mesh and scalar field are divided into four smaller domains where the data extents of each domain are stored to the file so VisIt can perform optimizations. Before the Contour plot executes, it tells VisIt the data values for which it will make contours. Suppose that that you wanted to see the areas where the value in the scalar field are equal to 11.5. The Contour plot takes that 11.5 contour value and compares it to the data extents for all of the domains to see which domains will be needed. If a domain will not be needed then VisIt will make no further effort to read the domain or process it, thus saving work and making the plot appear on the screen faster than it could if the data extents were not available in the file

metadata. In the above example, the value of 11.5 is only present in domain 3, which means that the Contour plot will only return a result if it processes data from domain 3.

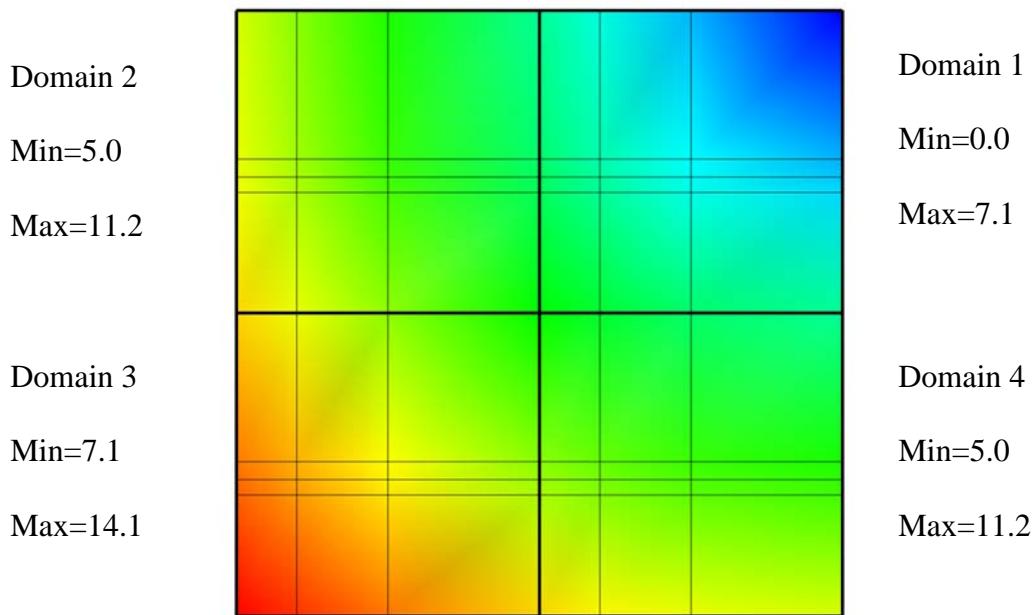


Figure 3-3: Example Mesh and Pseudocolor plots with the data extents for each domain of the Pseudocolor plot's scalar variable.

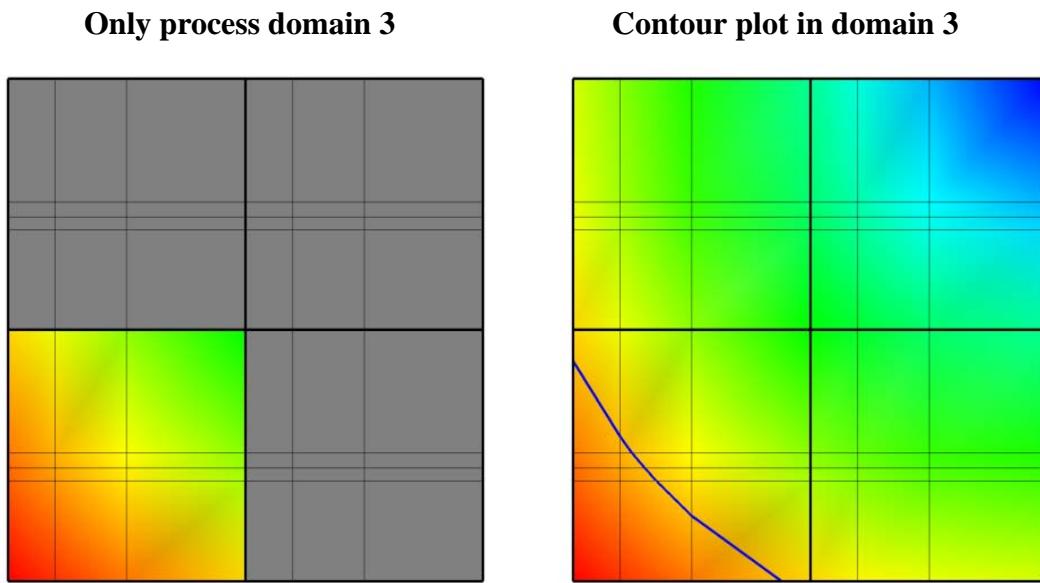


Figure 3-4: Only process domain 3 (left) to yield the Contour plot of value 11.5 (right).

The other domains are not processed in this case because they do not contain the required value of 11.5. After the comparisons have been made, VisIt knows which domains will

have to be processed and it can divide the set of domains (just domain 3 in this case) that will contribute to the visualization among processors so they can execute the plot and return data to VisIt's viewer where it can be displayed.

To add the data extents for each processor to the metadata using Silo, you must add the data extents to the option list that you pass to the DBPutMultivar function call. Having the data extents for each domain readily available in the Multivar object ensures that VisIt will have enough information to determine which domains will be necessary for operations such as Contour without having to read all of the data to determine which domains contribute to the visualization. The data extents must be stored in a double precision array that has enough entries to accommodate the min and max values for each domain in the multivar object. The layout of the min and max values within that array are as follows: min_dom1, max_dom1, min_dom2, max_dom2, . . . , min_domN, max_domN

Listing 3-5: dataextents.c: C-Language example for writing data extents using Silo.

```
const int two = 2;
double extents[NDOMAINS][2];
DBOptlist *optlist = NULL;
/* Calculate the per-domain data extents for this variable. */
/* Write the multivar. */
optlist = DBMakeOptlist(2);
DBAddOption(optlist, DBOPT_EXTENTS_SIZE, (void *)&two);
DBAddOption(optlist, DBOPT_EXTENTS, (void *)extents);
DBPutMultivar(dbfile, "var", nvar, varnames, vartypes, optlist);
DBFreeOptlist(optlist);
```

Listing 3-6: fdataextents.f: Fortran language example for writing data extents using Silo.

```
double precision extents(2,NDOMAINS)
integer err, optlist
c Calculate the per-domain data extents for this variable.
c Write the multivar.
err = dbmkoptlist(2, optlist)
err = dbaddiopt(optlist, DBOPT_EXTENTS_SIZE, 2)
err = dbaddir(optlist, DBOPT_EXTENTS, extents)
err = dbputmvar(dbfile, "var", 3, nvar, varnames, lvarnames,
. vartypes, optlist, ierr)
err = dbfreeoptlist(optlist)
```

3.2 Writing spatial extents

If you provide spatial extents for each domain in your database then VisIt can use that information during spatial data reduction operations, such as slicing, to reduce the number of domains that must be read from disk and processed.

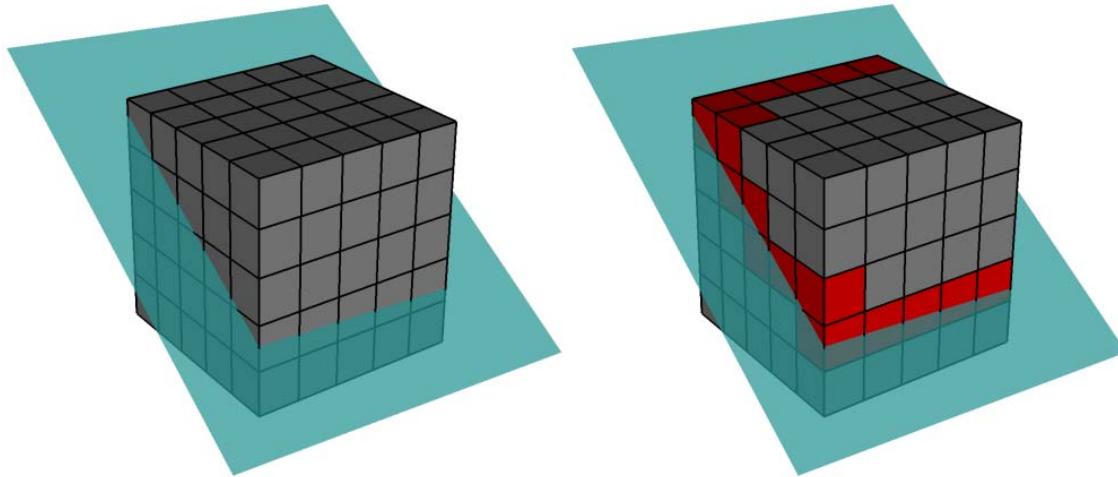


Figure 3-7: Only the red domains need to be processed to compute the slice plane if spatial extents are provided.

Spatial extents for a domain contain the minimum and maximum values of the coordinates within that domain, also called the domain's bounding box. The spatial extents must be stored in a double precision array that has enough entries to accommodate the min and max coordinate values for each domain in the multimesh object. The layout of the min and max values within that array for 3D domains are as follows: `xmin_dom1, ymin_dom1, zmin_dom1, xmax_dom1, ymax_dom1, zmax_dom1, ..., xmin_domN, ymin_domN, zmin_domN, xmax_domN, ymax_domN, zmax_domN`. In the event that you have 2D domains then you can omit the z-components of the min and max values and tell Silo that there are 4 values per min/max tuple instead of the 6 values required to specify min and max values for 3D domains.

Listing 3-8: `spatialextents.c`: C-Language example for writing 3D spatial extents using Silo.

```

const int six = 6;
double spatial_extents[NDOMAINS][6];
DBoptlist *optlist = NULL;
/* Calculate the per-domain spatial extents for this mesh. */
for(int i = 0; i < NDOMAINS; ++i)
{
    spatial_extents[i][0] = xmin; /* xmin for i'th domain */
    spatial_extents[i][1] = ymin; /* ymin for i'th domain */
    spatial_extents[i][2] = zmin; /* zmin for i'th domain */
}

```

```

        spatial_extents[i][3] = xmin; /* xmax for i'th domain */
        spatial_extents[i][4] = ymax; /* ymax for i'th domain */
        spatial_extents[i][5] = zmax; /* zmax for i'th domain */
    }
/* Write the multimesh. */
optlist = DBMakeOptlist(2);
DBAddOption(optlist, DBOPT_EXTENTS_SIZE, (void *)&six);
DBAddOption(optlist, DBOPT_EXTENTS, (void *)spatial_extents);
DBPutMultimesh(dbfile, "mesh", nmesh, meshnames, meshtypes, optlist);
DBFreeOptlist(optlist);

```

Listing 3-9: fspatialextents.f: Fortran language example for writing 3D spatial extents using Silo.

```

double precision spatial_extents(6,NDOMAINS)
integer optlist, err, dom
c Calculate the per-domain spatial extents for this mesh.
do 10000 dom=1,NDOMAINS
    spatial_extents(1,dom) = xmin
    spatial_extents(2,dom) = ymin
    spatial_extents(3,dom) = zmin
    spatial_extents(4,dom) = xmin
    spatial_extents(5,dom) = ymax
    spatial_extents(6,dom) = zmax
10000 continue
c Write the multimesh
err = dbmkoptlist(2, optlist)
err = dbaddiopt(optlist, DBOPT_EXTENTS_SIZE, 6)
err = dbaddir(optlist, DBOPT_EXTENTS, spatial_extents)
err = dbputmmesh(dbfile, "quadmesh", 8, nmesh, meshnames,
. lmeshnames, meshtypes, optlist, ierr)
err = dbfreeoptlist(optlist)

```

4.0 Ghost zones

Ghost zones are zones external to a domain, which correspond to zones in an adjacent domain. Ghost zones allow VisIt to ensure continuity between domains containing zone-centered data, making surfaces such as Contour plots continuous across domain boundaries instead of creating surfaces with ugly gaps at the domain boundaries. Ghost zones also allow VisIt to remove internal surfaces from the visualized data for plots such as Pseudocolor, which only wants to keep the surfaces that are external to the model. Removing internal surfaces results in fewer primitives that must be rendered on the graphics card and that increases interactivity with plots. See Figure 3-10 for examples of the problems that ghost zones allow VisIt to fix.

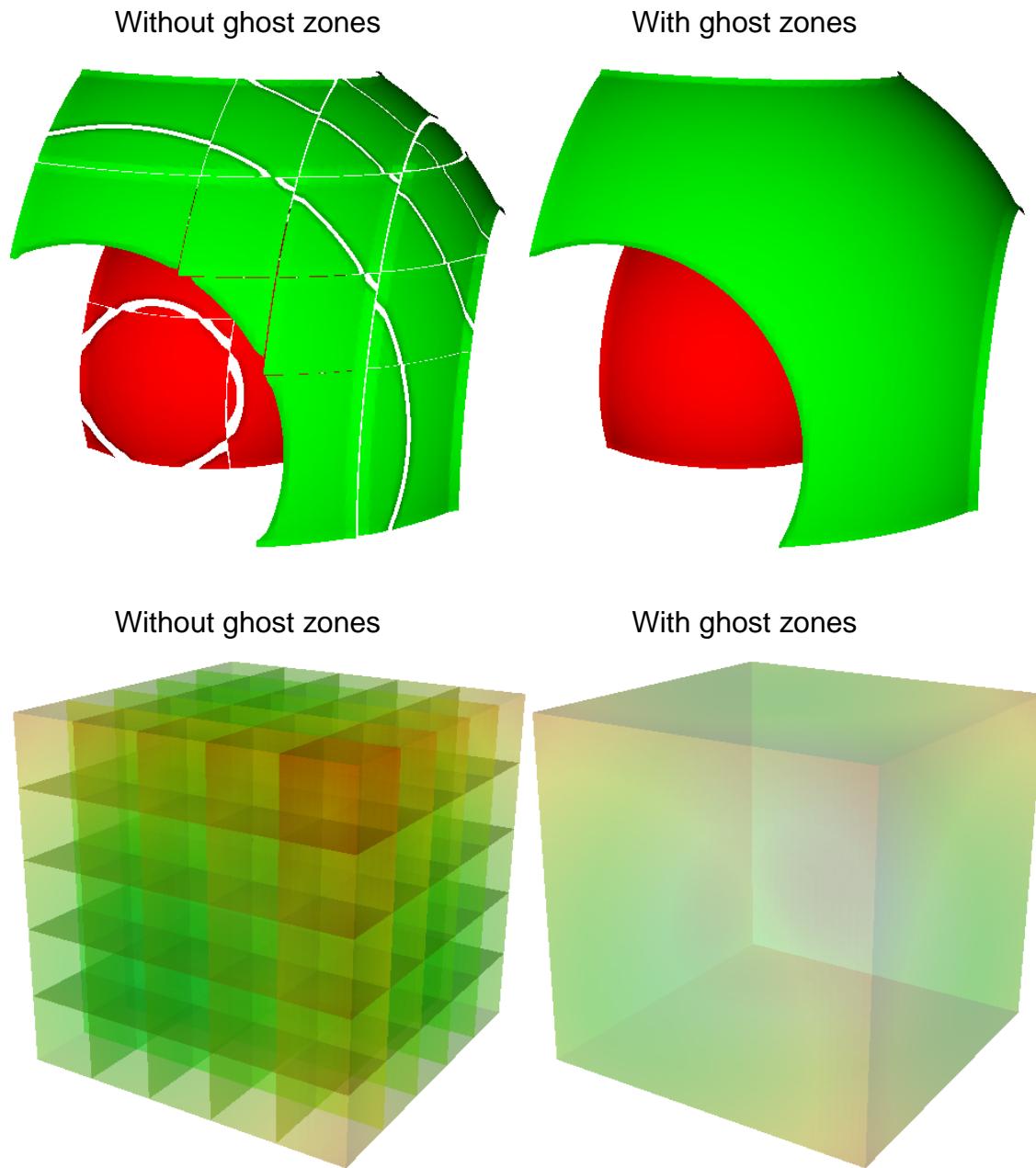


Figure 3-10: VisIt can use ghost zones to ensure continuity and to remove internal surfaces

Ghost zones can be stored into the database so VisIt can read them when the data is visualized. Ghost zones can also be created on-the-fly for structured (rectilinear and curvilinear) meshes if multimesh adjacency information is provided. This section will show how to write ghost zones to the file. If you are interested in providing multimesh adjacency information so you can write smaller files and so VisIt can automatically create ghost zones then refer to the documentation for the `DBPutMultimeshadj` function in the *Silo User's Guide*.

4.1 Writing ghost zones to your files

You can write ghost zones to your files using the Silo library or you can instead write a multimesh adjacency object, covered in the *Silo User's Guide*, that VisIt can use to automatically create ghost zones. This section will cover how to use the Silo library to store ghost zones explicitly in your files.

The first step in creating ghost zones is to add a layer of zones around the mesh in each domain of your database where a domain boundary exists. Each zone in the layer of added ghost zones must match the location and have the same data value as the zone in the domain that it is meant to mirror in order for VisIt to be able to successfully use ghost zones to remove domain decomposition artifacts. This means that you must change your code for writing out meshes and variables so your meshes have an addition layer of zones for each domain boundary that is internal to the model. Your variables must also contain valid data values in the ghost zones since providing a domain with knowledge of the data values of its neighboring domains is the entire point of adding ghost zones. Note that you should not add ghost zones on the surface of a domain where the surface is external to the model. When ghost zones are erroneously added to external surfaces of the model, VisIt removes the external faces and this can cause plots to be invisible.

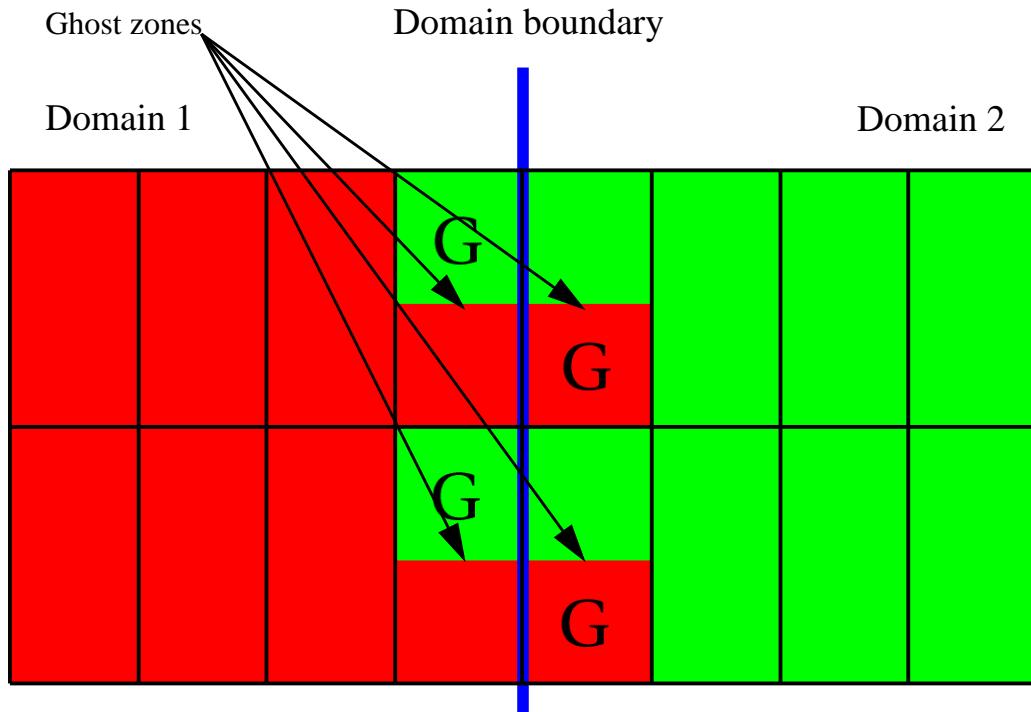


Figure 3-11: The zones that are both red and green are real zones in one domain and ghost zones in another.

Figure 3-11 shows two domains: domain1 (red) and domain2 (green). The boundary between (blue) the two domains is the interface that would exist between the domains if there were no ghost zones. When you add a layer of ghost zones, each domain intrudes a

little into the other domain's bounding box so the zones in one domain's layer of ghost zones match the zones in the other domain's external layer of zones. Of course, domains on both sides of the domain boundary have ghost zones to assure that the VisIt will know the proper zone-centered data values whether it approaches the domain boundary from the left or from the right. The first row of cells on either side of the domain boundary are ghost zones. For example, if you look at the upper left zone containing the "G" for ghost zone, the "G" is drawn in the green part of the zone, while the red part of the zone contains no "G". This means that the zone in question is a zone in domain1, the red domain, but that domain2 has a zone that exactly matches the location and values of the zone in the red domain. The corresponding zone in domain2 is a ghost zone.

Listing 3-12: spatialextents.c: C-Language example for writing a 3D, domain-decomposed rectilinear mesh without ghost zones.

```

/* Create each of the domain meshes. */
int dom = 0, xdom, ydom, zdom;
for(zdom = 0; zdom < NZDOMS; ++zdom)
for(ydom = 0; ydom < NYDOMS; ++ydom)
for(xdom = 0; xdom < NXDOMS; ++xdom, ++dom)
{
    float xc[NX], yc[NY], zc[NZ];
    float *coords[] = {xc, yc, zc};
    int index = 0;
    float xstart, xend, ystart, yend, zstart, zend;
    int xzones, yzones, zzones, nzones;
    int xnodes, ynodes, znodes;

    /* Create a new directory. */
    char dirname[100];
    sprintf(dirname, "Domain%03d", dom);
    DBMkDir(dbfile, dirname);
    DBSetDir(dbfile, dirname);

    /* Determine default start, end coordinates */
    xstart = (float)xdom * XSIZE;
    xend   = (float)(xdom+1) * XSIZE;
    xzones = NX-1;
    ystart = (float)ydom * YSIZE;
    yend   = (float)(ydom+1) * YSIZE;
    yzones = NY-1;
    zstart = (float)zdom * ZSIZE;
    zend   = (float)(zdom+1) * ZSIZE;
    zzones = NZ-1;

    xnodes = xzones + 1;
    ynodes = yzones + 1;
    znodes = zzones + 1;

    /* Create the mesh coordinates. */
    for(i = 0; i < xnodes; ++i)
    {

```

```

        float t = (float)i / (float)(xnodes-1);
        xc[i] = (1.-t)*xstart + t*xend;
    }
    for(i = 0; i < ynodes; ++i)
    {
        float t = (float)i / (float)(ynodes-1);
        yc[i] = (1.-t)*ystart + t*yend;
    }
    for(i = 0; i < znodes; ++i)
    {
        float t = (float)i / (float)(znodes-1);
        zc[i] = (1.-t)*zstart + t*zend;
    }
    /* Write a rectilinear mesh. */
    dims[0] = xnodes;
    dims[1] = ynodes;
    dims[2] = znodes;
    DBPutQuadmesh(dbfile, "quadmesh", NULL, coords, dims, ndims,
                  DB_FLOAT, DB_COLLINEAR, NULL);

    /* Go back to the top directory. */
    DBSetDir(dbfile, "..");
}

```

Once you have changed your mesh-writing code to add a layer of ghost zones, where appropriate, you must indicate that the extra layer of zones are ghost zones. If you use Silo's DBPutQuadmesh function to write your mesh, you can indicate which zones are ghost zones by adding DBOPT_LO_OFFSET and DBOPT_HI_OFFSET to pass arrays containing high and low zone index offsets in the option list. If you are adding ghost zones to an unstructured mesh, you would instead adjust the lo_offset and hi_offset arguments that you pass to the DBPutZonelist2 function. The next code listing shows the additions made in order to support ghost zones in a domain-decomposed rectilinear mesh. The additions are underlined.

Listing 3-13: ghostzonesinfile.c: C-Language example for writing a 3D, domain-decomposed rectilinear mesh with ghost zones.

```

/* Determine the size of a zone. */
float cx, cy, cz;
cx = XSIZE / (float)(NX-1);
cy = YSIZE / (float)(NY-1);
cz = ZSIZE / (float)(NZ-1);
/* Create each of the domain meshes. */
int dom = 0, xdom, ydom, zdom;
for(zdom = 0; zdom < NZDOMS; ++zdom)
    for(ydom = 0; ydom < NYDOMS; ++ydom)
        for(xdom = 0; xdom < NXDOMS; ++xdom, ++dom)
    {
        float xc[NX], yc[NY], zc[NZ];
        float *coords[] = {xc, yc, zc};

```

```

int index = 0;
float xstart, xend, ystart, yend, zstart, zend;
int xzones, yzones, zzones, nzones;
int xnodes, ynodes, znodes;
int hi_offset[3], lo_offset[3];
DBOptlist *optlist = NULL;

/* Create a new directory. */
char dirname[100];
sprintf(dirname, "Domain%03d", dom);
DBMkdir(dbfile, dirname);
DBSetDir(dbfile, dirname);

/* Determine default start, end coordinates */
xstart = (float)xdom * XSIZE;
xend = (float)(xdom+1) * XSIZE;
xzones = NX-1;
ystart = (float)ydom * YSIZE;
yend = (float)(ydom+1) * YSIZE;
yzones = NY-1;
zstart = (float)zdom * ZSIZE;
zend = (float)(zdom+1) * ZSIZE;
zzones = NZ-1;

/* Set the starting hi/lo offsets. */
lo_offset[0] = 0;
lo_offset[1] = 0;
lo_offset[2] = 0;
hi_offset[0] = 0;
hi_offset[1] = 0;
hi_offset[2] = 0;

/* Adjust the start and end coordinates based on whether
* or not we have ghost zones.
*/
if(xdom > 0)
{
    xstart -= cx;
    lo_offset[0] = 1;
    ++xzones;
}
if(xdom < NXDOMS-1)
{
    xend += cx;
    hi_offset[0] = 1;
    ++xzones;
}
if(ydom > 0)
{
    ystart -= cy;
    lo_offset[1] = 1;
    ++yzones;
}
if(ydom < NYDOMS-1)
{
    yend += cy;
    hi_offset[1] = 1;
    ++yzones;
}
if(zdom > 0)
{
    zstart -= cz;
    lo_offset[2] = 1;
    ++zzones;
}
if(zdom < NZDOMS-1)
{
    zend += cz;
    hi_offset[2] = 1;
    ++zzones;
}

```

```

{
    yend += cy;
    hi_offset[1] = 1;
    ++yzones;
}
if(zdom > 0)
{
    zstart -= cz;
    lo_offset[2] = 1;
    ++zzones;
}
if(zdom < NZDOMS-1)
{
    zend += cz;
    hi_offset[2] = 1;
    ++zzones;
}

xnodes = xzones + 1;
ynodes = yzones + 1;
znodes = zzones + 1;

/* Create the mesh coordinates. */
for(i = 0; i < xnodes; ++i)
{
    float t = (float)i / (float)(xnodes-1);
    xc[i] = (1.-t)*xstart + t*xend;
}
for(i = 0; i < ynodes; ++i)
{
    float t = (float)i / (float)(ynodes-1);
    yc[i] = (1.-t)*ystart + t*yend;
}
for(i = 0; i < znodes; ++i)
{
    float t = (float)i / (float)(znodes-1);
    zc[i] = (1.-t)*zstart + t*zend;
}
/* Write a rectilinear mesh. */
dims[0] = xnodes;
dims[1] = ynodes;
dims[2] = znodes;
optlist = DBMakeOptlist(2);
DBAddOption(optlist, DBOPT_HI_OFFSET, (void *)hi_offset);
DBAddOption(optlist, DBOPT_LO_OFFSET, (void *)lo_offset);
DBPutQuadmesh(dbfile, "quadmesh", NULL, coords, dims, ndims,
              DB_FLOAT, DB_COLLINEAR, optlist);
DBFreeOptlist(optlist);

/* Go back to the top directory. */
DBSetDir(dbfile, "..");
}

```

There are two changes to the code in the previous listing that allow it to write ghost zones. First of all, the code calculates the size of a zone in the `cx`, `cy`, `cz` variables and then uses those sizes along with the location of the domain within the model to determine which domain surfaces will receive a layer of ghost zones. The layer of ghost zones is added by altering the start and end locations of the coordinate arrays as well as incrementing the number of zones and nodes in the dimensions that will have added ghost zones. The knowledge of which surfaces get a layer of ghost zones is recorded in the `lo_offset` and `hi_offset` arrays. By setting `lo_offset[0]` to 1, Silo knows that the first layer of zones in the X dimension will all be ghost zones. Similarly, by setting `high_offset[0]` to 1, Silo knows that the last layer of zones in the X dimension are ghost zones. The `lo_offset` and `hi_offset` arrays are associated with the mesh by adding them to the option list that is passed to the `DBPPutQuadmesh` function. The example program `fghostzonesinfile.f` demonstrates how to add ghost zones to a file using Silo's Fortran interface.

5.0 Materials

Many simulations use materials to define the composition of regions so the response of the materials can be taken into account during the calculation. Materials are represented as a list of integers with associated material names such as: "steel". Each zone in the mesh gets one or more material numbers to indicate its composition. When a zone has a single material number, it is said to be a "clean zone". When there is more than one material number in a zone, it is said to be a "mixed zone". When zones are mixed, they have a list of material numbers and a list of volume fractions (floating point numbers that sum to one) that indicate how much of each material is contained in a zone. VisIt provides the FilledBoundary and Boundary plots for plotting materials and VisIt provides the **Subset** window so you can selectively turn off certain materials.

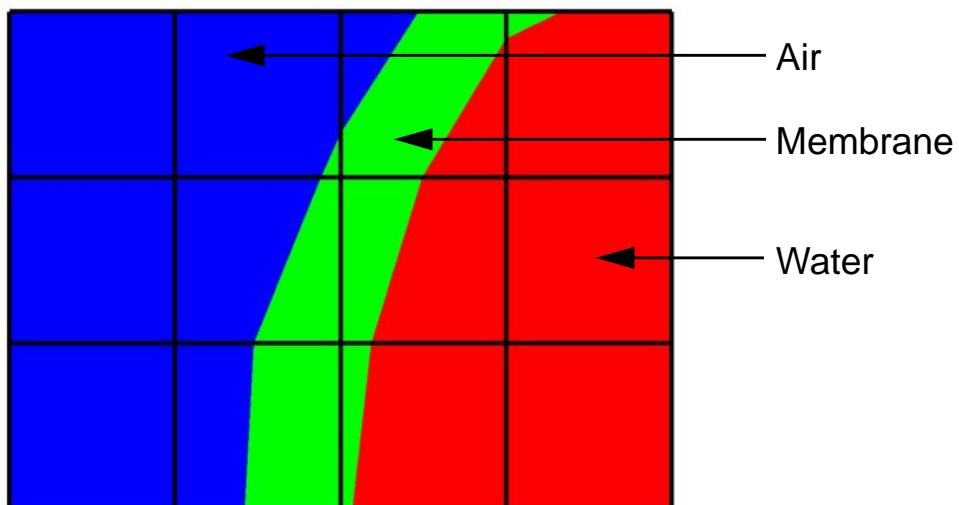


Figure 3-14: A mesh with both clean and mixed material zones

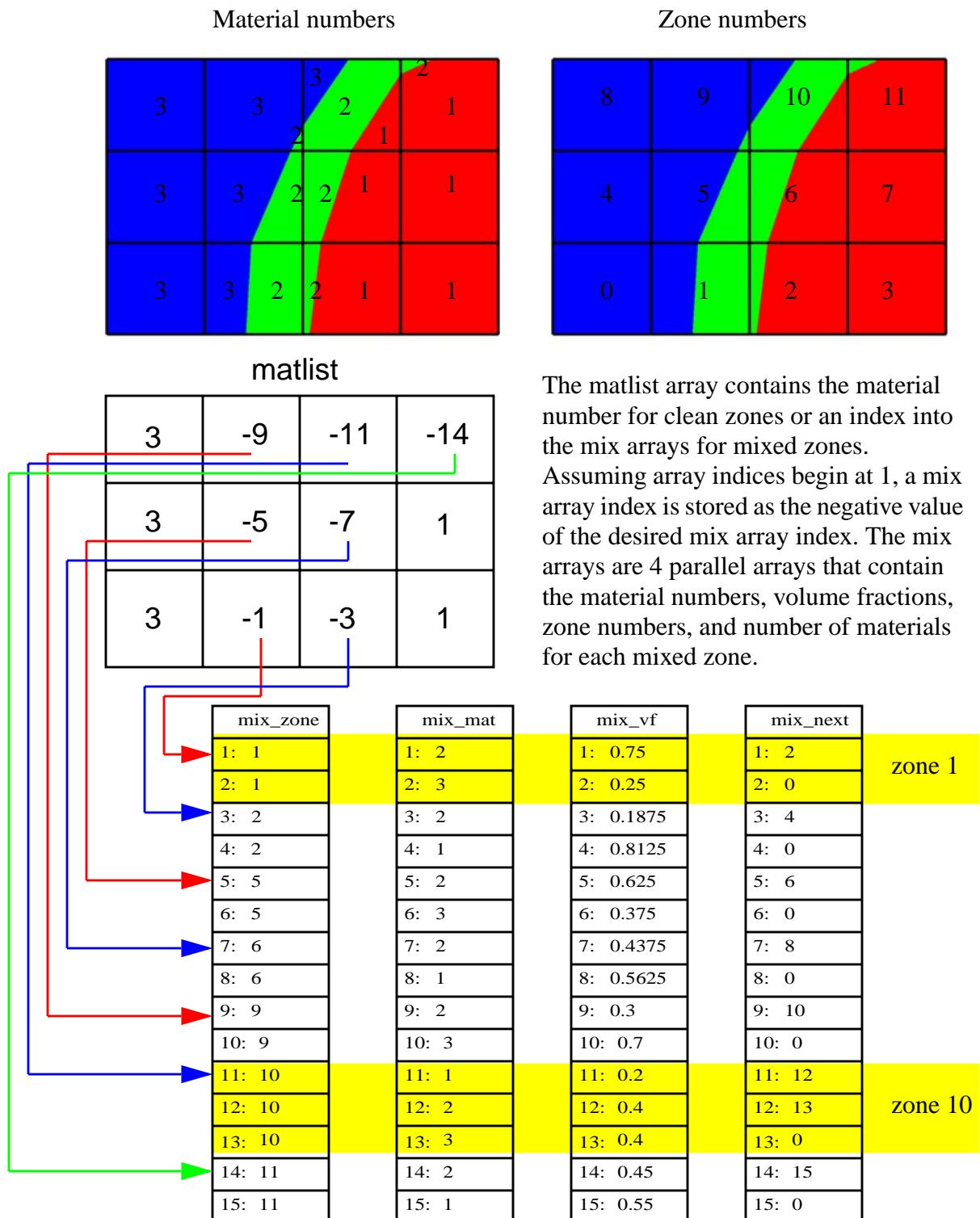


Figure 3-15: Mixed material example

The plot of the material object shown in Figure 3-14 and Figure 3-15 contains three materials: “Water” (1), “Membrane” (2), and “Air” (3). Materials use a `matlist` array to indicate which zone are clean and which are mixed. The `matlist` array is a zone-centered array of integers that contain the material numbers for the materials in the zone. If a zone has only one material then the `matlist` array entry for that zone will contain the material number of the material that fills the zone. If a zone contains more than one material then the `matlist` array entry for that zone will contain an index into the mixed material arrays. Indices into the mixed material arrays are equal to the negative value of the desired mixed material array entry. When creating your mixed material arrays, assume that array indices for the mixed material arrays begin at 1. When you begin assigning material information into the mixed material arrays, use one array index per material in the mixed material zone. The index that you use for the beginning index for the next mixed material zone is the current index minus the number of materials in the current zone. Study the `matlist` array in Figure 3-15. The first mixed material zone is zone 1 and since it is mixed, instead of containing a material number, the `matlist` array for zone 1 contains the starting index into the mixed material arrays, or -1. If you negate the -1, you arrive at index 1, which is the starting index for zone 1 in the mixed material arrays. Since zone 1 will contain two materials, we use indices 1 and 2 in the mixed material arrays to store information for zone 1. The next available array for other zones wanting to add mixed materials to the mixed material arrays is element 3. Thus, when zone 2, which is also a mixed zone, needs to have its information added to the mixed material arrays, you store -3 into the `matlist` array to indicate that zone 2’s values begin at zone 3 in the mixed material arrays.

The mixed material arrays are a set of 4 parallel arrays: `mix_zone`, `mix_mat`, `mix_vf`, and `mix_next`. All of the arrays have the number of elements but that number varies depending on how many mixed zones there are in the material object. The `mix_zone` array contains the index of the zone that owns the material information for the current array element. That is, if you examine element 14 in the `mix_zone` array, you will know that element 14 in all of the mixed material arrays contain information about zone 11.

The `mix_mat` array contains the material numbers of the materials that occupy a zone. Material numbers correspond to the names of materials (e.g. 1 = Water) and should begin at 1 and increment from there. The range of material numbers used may contain gaps without causing any problems in VisIt. However, if you create databases that have many domains that vary over time, you’ll want to make sure that each domain has the same list of materials at every time step. It is not necessary to use a material number in the `matlist` array or in the mixed material arrays in order to include it in a material object. Look at element 11 in the `mix_mat` array in Figure 3-15. Element 11 contains material 1, element 12 contains material 2, and element 13 contains material 3. Since those three material numbers are supposed to all be present in zone 10, they are all added to the `mix_mat` array. The same array elements in the `mix_vf` array record the amount of each material in zone 10. The values in the `mix_vf` array for zone 10 are: 0.2, 0.4, 0.4 and those numbers mean that 20% of zone 10 is filled with material 1, 40% is filled with material 2, and 40% is filled with material 3. Note that all of the numbers for a zone in the `mix_vf` array must sum to 1., or 100%.

The `mix_next` array contains indices to the next element in the mixed material arrays that contains values for the mixed material zone under consideration. The `mix_next` array allows you to construct a linked-list of material numbers for a zone within the mixed material arrays. This means that the information for one zone's mixed materials could be scattered through the mixed material arrays but in practice the mixed material information for one zone is usually contiguous within the mixed material arrays. The `mix_next` array contains the next index to use within the mixed material arrays or it contains a zero to indicate that no more information for the zone is available.

To write materials to a Silo file, you use the `DBPutMaterial` function. The `DBPutMaterial` function is covered in the *Silo User's Guide* but it is worth noting here that it can be called to write either mixed materials or clean materials. The examples so far have illustrated the more complex case of writing out mixed materials. You can pass the `matlist` array and the mixed material arrays to the `DBPutMaterial` function or, in the case of writing clean materials, you can pass only the `matlist` array and `NULL` for all of the mixed material arrays. Note that when you write clean materials, your `matlist` array will contain only the numbers of valid materials. That is, the `matlist` array does not contain any negative mixed material array indices when you write out clean material objects.

Listing 3-16: mixedmaterials.c: C-Language example for writing mixed materials using Silo.

```
/* Material arrays */
int nmats = 2, mdims[2];
int matnos[] = {1,2,3};
char *matnames[] = {"Water", "Membrane", "Air"};
int matlist[] = {
    3, -1, -3, 1,
    3, -5, -7, 1,
    3, -9, -11, -14
};
float mix_vf[] = {
    0.75,0.25,      0.1875,0.8125,
    0.625,0.375,   0.4375,0.56250,
    0.3,0.7,        0.2,0.4,0.4,      0.45,0.55
};
int mix_zone[] = {
    1,1,  2,2,
    5,5,  6,6,
    9,9,  10,10,10,  11,11
};
int mix_mat[] = {
    2,3,  2,1,
    2,3,  2,1,
    2,3,  1,2,3,  2,1
};
int mix_next[] = {
    2,0,  4,0,
    6,0,  8,0,
    10,0, 12,13,0,  15,0
```

```

};

int mixlen = 15;

/* Write out the material */
mdims[0] = NX-1;
mdims[1] = NY-1;
optlist = DBMakeOptlist(1);
DBAddOption(optlist, DBOPT_MATNAMES, matnames);
DBPutMaterial(dbfile, "mat", "quadmesh", nmats, matnos, matlist,
    mdims, ndims, mix_next, mix_mat, mix_zone, mix_vf, mixlen,
    DB_FLOAT, optlist);
DBFreeOptlist(optlist);

```

Listing 3-17: fmixedmaterials.f: Fortran language example for writing mixed materials using Silo.

```

subroutine write_mixedmaterial(dbfile)
implicit none
integer dbfile
include "silo.inc"
integer NX, NY
parameter (NX = 5)
parameter (NY = 4)
integer err, ierr, optlist, ndims, nmats, mixlen
integer mdims(2) /NX-1, NY-1/
integer matnos(3) /1,2,3/

integer matlist(12) /3, -1, -3, 1,
. 3, -5, -7, 1,
. 3, -9, -11, -14/

real mix_vf(15) /0.75,0.25,      0.1875,0.8125,
. 0.625,0.375,     0.4375,0.56250,
. 0.3,0.7,          0.2,0.4,0.4,      0.45,0.55/

integer mix_zone(15) /1,1,   2,2,
. 5,5,   6,6,
. 9,9,   10,10,10,  11,11/

integer mix_mat(15) /2,3,   2,1,
. 2,3,   2,1,
. 2,3,   1,2,3,   2,1/

integer mix_next(15) /2,0,   4,0,
. 6,0,   8,0,
. 10,0,  12,13,0,  15,0/

ndims = 2
nmats = 3
mixlen = 15
c Write out the material
err = dbputmat(dbfile, "mat", 3, "quadmesh", 8, nmats, matnos,
. matlist, mdims, ndims, mix_next, mix_mat, mix_zone, mix_vf,
. mixlen, DB_FLOAT, DB_F77NULL, ierr)

```

end



Chapter 4

Creating a database reader plug-in

1.0 Overview

This chapter shows how to extend VisIt by writing a new database reader plug-in so you can use VisIt to access data files that you have already generated. Writing a database reader plug-in has several advantages over other approaches to importing data into VisIt such as writing a conversion program. First of all, if VisIt can natively read your file format then there is no need to convert files and consume extra disk space. Converting files may not even be possible if the data files are prohibitively large. Secondly, plug-ins offer the advantage of not having to alter a complex simulation code to write out data that VisIt can read. New plug-ins are free to read the simulation code's native file format. While many approaches to importing data into VisIt require new, specialized, code, when you write a database plug-in, the code that you write is external to your simulation and it is not a converter that you have to maintain. There is no doubt that there is some maintenance involved in writing a database reader plug-in for VisIt but there is always the option of contributing your plug-in back into the VisIt source code tree where the code maintenance burden is shared among the developer community.

This chapter first reviews the VisIt architecture and describes where plug-ins fit into that scheme. After plug-ins are discussed, the steps that you must follow in order to create a plug-in are outlined. After covering the basics, you can dive into the section that covers how to implement your plug-in. Finally, once you have a working plug-in, you can add advanced features.

2.0 Structure of VisIt

VisIt is a parallel, distributed application that consists of four component processes that work in tandem to produce your visualizations. The two components that you may already

be familiar with are the client and the viewer. VisIt has GUI, Python interface, and Java clients that control the visualization operations performed by the viewer, which is the central state repository and graphics rendering component. The other components, which are not immediately visible, are the database server and the compute engine. The database server (sometimes called the meta-data server) is responsible for browsing the file system and letting you know which files can be opened. Once you decide on a file to open, the database server attempts to open that file, loading an appropriate database reader plug-in to do so. Once the database server has opened a file, it sends file metadata such as the list of available variables to the client and the viewer. The compute engine comes into play when you want to create a plot to process your data into a form that can be rendered on the screen. The compute engine, like the database server, loads a plug-in to read a data file and does the actual work of reading the problem-sized data from the file and translating it into Visualization Toolkit (VTK) objects that VisIt can process. Once the data has been read, it is fed through the visualization pipeline and returned to the viewer component where it can be displayed.

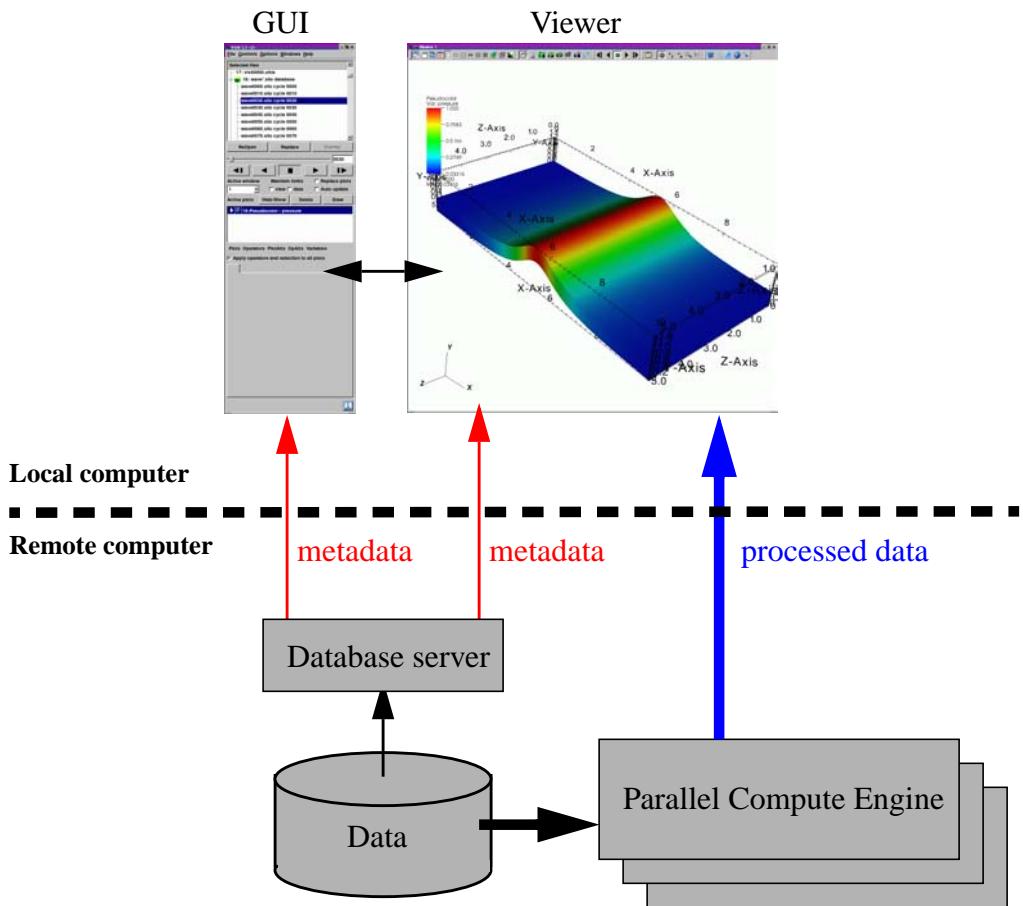


Figure 4-1: VisIt's architecture

2.1 plug-ins

VisIt supports three types of plug-ins: plot plug-ins, operator plug-ins, and database reader plug-ins. This chapter explores database reader plug-ins as a method of importing data from new file formats into VisIt. A database reader plug-in is made of three shared libraries, which are dynamically loaded by the appropriate VisIt components when data from a file must be read. The VisIt components involved in reading data from a file are the database server and the compute engine. Each database reader plug-in has a database server component, a compute engine component, and an independent component, for a total of three shared libraries (`libM`, `libE`, `libI`).

The independent plug-in component, or `libI` plug-in component, is a very lightweight shared library containing little more than the name and version of a plug-in as well as the file extensions that should be associated with it. When the database server and compute engine initialize at runtime, one of their first actions is to scan VisIt's plug-in directories for available `libI` plug-ins and then load all of the `libI` plug-ins to assemble an internal list of known plug-ins along with the table of file extensions for each file.

When VisIt needs to open a file, the filename is first passed to the database server, which tries to extract a file extension from the end of the filename so an appropriate plug-in can be selected from the list of available plug-ins. Once one or more matches are made, the database factory object in the database server loads the `libM` plug-in component for the first plug-in in the list of matching plug-ins. The `libM` plug-in component is the piece of the plug-in used by the database server and it is used to read the metadata from the file in question. If the plug-in cannot open the file then it should throw an exception to make the database factory attempt to open the file using the next matching plug-in. If there are no plug-ins that match the file's file extension then a default database plug-in is used. If that plug-in cannot open the file then VisIt issues an error message. Once the `libM` plug-in has read the metadata from the file, that information is sent to the VisIt clients where it can be used to populate variable menus, etc.

When you add a plot in VisIt and click the **Draw** button, the first step that the compute engine takes to process your request is to open the file that contains the data. The procedure for opening the file that contains the data in the compute engine is the same as that for the database server. In fact, the same database factory code is used internally. However, the database factory in the compute engine loads the `libE` plug-in component. The `libE` and `libM` plug-in components are essentially the same except that, when possible, database server plug-in components do less work. Both the `libE` and `libM` plug-in components contain code to read a file's metadata and both contain code to read variables and create meshes. The difference between the two plug-in types is that the code to read the variables and create meshes is only called from the `libE` plug-in component.

3.0 Starting your plug-in

Now that you know the basics of how VisIt uses database reader plug-ins in order to read different types of files, it is time to begin your plug-in. This section explains the different interfaces available for coding your plug-in and also covers the steps involved to create your plug-in code skeleton and run it for the first time.

3.1 Picking a database reader plug-in interface

Database reader plug-ins have 4 possible interfaces, which affect how files are mapped to plug-in file format objects. The 4 possible interfaces are shown in the table below:

	SD	MD
ST	STSD - Single time state per file and it contains just 1 domain.	STMD - Single time state per file but each file contains multiple domains.
MT	MTSD - Multiple time states per file and each file contains just 1 domain	MTMD - Multiple time states per file and each file contains multiple domains.

In order to pick which plug-in interface is most appropriate for your particular file format, you must consider how your file format treats time and domains. If your file format contains multiple time states in each file then you have an MT file format; otherwise you have an ST file format. If your file format comes from a parallel simulation then you will often have some type of domain decomposition, which breaks up the entire simulation into smaller pieces called domains that are divided among processors. If your simulation has domains and the domains are written to a single file then you have an MD file format; otherwise, if your simulation processors wrote out their own files then you have an SD file format. When you consider both how your file format deals with time and how it deals with domains, you should be able to select which plug-in interface you will need when you write your database reader plug-in.

3.2 Using XMLEDit

Once you pick which database interface you will use to write your database plug-in, the next step is to use VisIt's XMLEDit tool to get started with some interface definitions. XMLEDit is a graphical application that lets you create an XML file that describes some of the basic attributes for your database reader plug-in. The XML file contains information such as the name of the plug-in, its version, which interface is used, the plug-in's list of file extensions, and any additional libraries or source code files that need to be included in the plug-in in order to build it.

To get started with building your plug-in, the first step is to create a source code directory to contain all of the files that will be created to generate your plug-in. It is best that the directory name be the name of your file format or the name of your simulation. Once you have created a directory for your plug-in files, you can run VisIt's XMLEDit program. To start XMLEDit on UNIX systems where VisIt is installed, open a command window and type `xmledit`. On Windows systems, XMLEDit should be available in the **Start** menu under VisIt's plug-in development options.

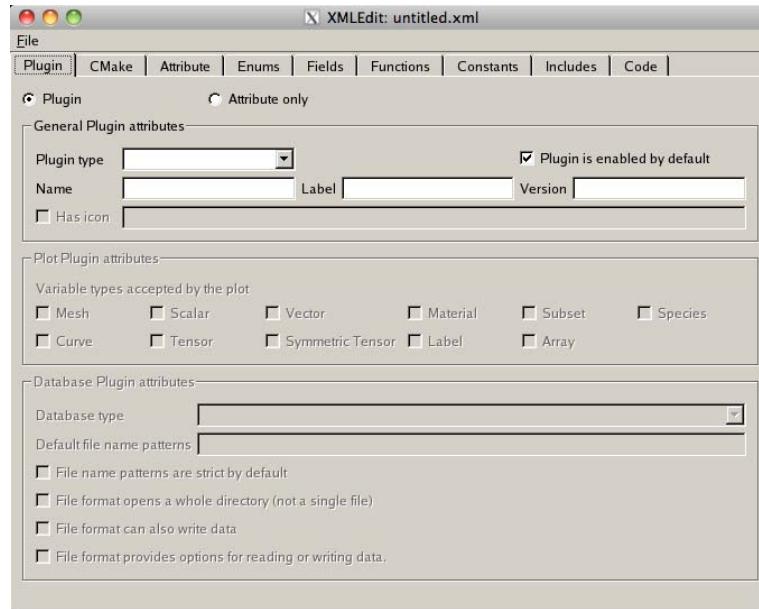


Figure 4-2: XMLEDit plug-in tab

Once XMLEDit is active you can see that it has a number of tabs that are devoted to various aspects of plug-in development. Most of the tabs are used for developing plot and operator plug-ins only so this section will focus on the actions that you need to take to create your database reader plug-in. First of all, you must type the name of your plug-in into the **Name** text field. The name should match the name of the source code directory that you created - be sure that you pick a name that can be used inside of C++ class names since the name is used to help generate the plug-in code skeleton that will form the basis of your database reader plug-in. Next, type in a label into the **Label** text field. The label for a database plug-in can contain a longer identifier that will be displayed when VisIt uses your plug-in to read files. The label may contain spaces and punctuation. Next, enter the version of your plug-in into the **Version** text field. The version for initial development should be: *1.0*. Now, choose *Database* from the **Plugin type** combo box to tell XMLEDit that you want to build a database reader plug-in. Once you choose *Database* for your plug-

in type, some additional options will become enabled. You can ignore these options for now since they contain reasonable default values.

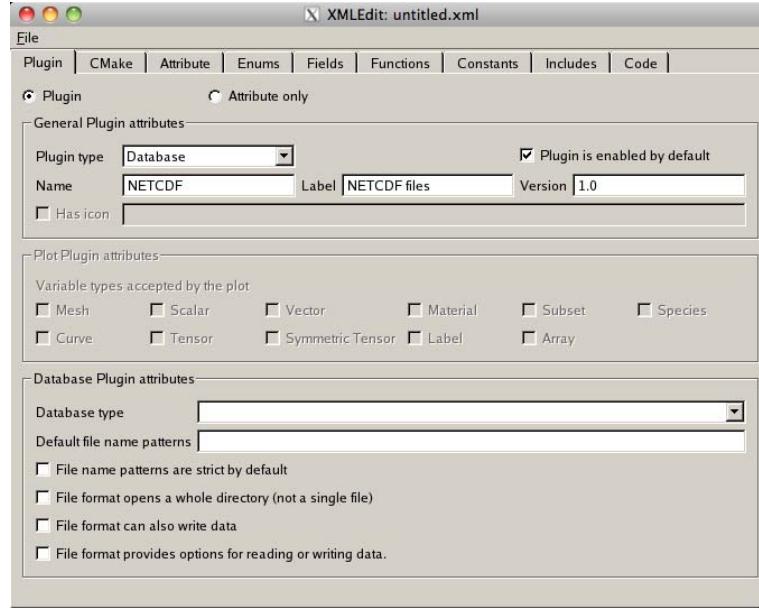


Figure 4-3: XMLEdit plug-in tab with plug-in name and type selected

The next step in creating your database plug-in using XMLEdit is to set the database type to *STSD*, *STMD*, *MTSD*, *MTMD* by selecting one of those options from the **Database type** combo box. Note that it is possible to instead choose to create a fully custom

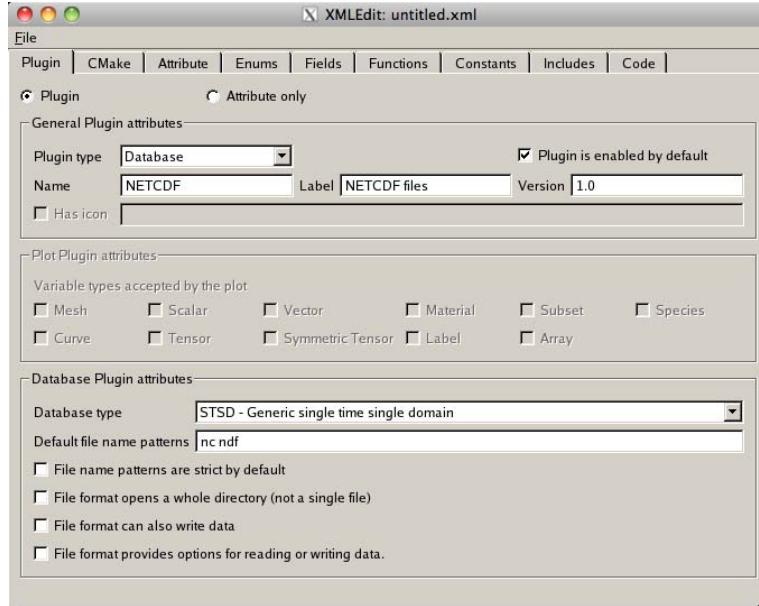


Figure 4-4: XMLEdit plug-in tab with database type and extensions selected

database type but do not choose that option since most formats do not need that level of customizeability. Once you have selected a database type for your plug-in, type in the list of file formats that you want to associate with your plug-in. You can enter as many space-delimited file extensions as you want.

The information that you entered is the minimum amount of information required to create your database reader plug-in. Save your XMLEdit session to an XML file by selecting **Save** from the **File** menu. Be sure to use the same name as you used for the directory name that will contain your plug-in files and also be sure to save your XML file to that directory. At this point, you can skip ahead to generating your plug-in code skeleton or you can continue adding options to your XML file.

3.2.1 CMake options

VisIt uses cmake for its build system and for the build systems of its plugins. XMLEdit contains controls on its CMake tab that allow you to add options to your XML file that will influence how your plug-in code is built when you go to compile it. For example, the CMake tab includes options that allow you to specify compiler options such as **CXXFLAGS**, **LDFLAGS**, and **LIBS**.

Adding options to these fields can be particularly useful if your plug-in uses an external library such as NETCDF or HDF5. If you are using a library that VisIt provides (NETCDF, HDF5, CGNS, Silo, etc.) then you can use special predefined cmake variables that VisIt's build defines to locate those libraries. For example, you could use `${NETCDF_INCLUDE_DIR}` , `${NETCDF_LIBRARY_DIR}` , `${NETCDF_LIB}` to reference the include directory, library directory, and library name for the NETCDF library. Just substitute another capitalized library name for NETCDF to use variables for other I/O libraries. It is better to use these cmake variables for libraries that VisIt provides to ensure that your plugin is linked against the right libraries.

If you are using a library that VisIt does not support, you can add the include file and library file locations to ensure that the compiler will know where to look for your external library when your plug-in is built. Be sure to use `-I/path/to/include` in the **CXXFLAGS** when you want to add include directories for your plugin. Use `-L/path/to/lib` in the **LDFLAGS** when you want to add link directories for your plugin. Finally, add the name of the library (e.g. netcdf instead of -lnetcdf) in the **LIBS** when you need to link against additional libraries.

You can also add extra files to the `libE` and `libM` plug-ins by adding a list of files to the **Engine files** and **MDServer files** text fields, respectively. If you change any of these options, shown in Figure 4-5, be sure to save your XML file before quitting XMLEDit.

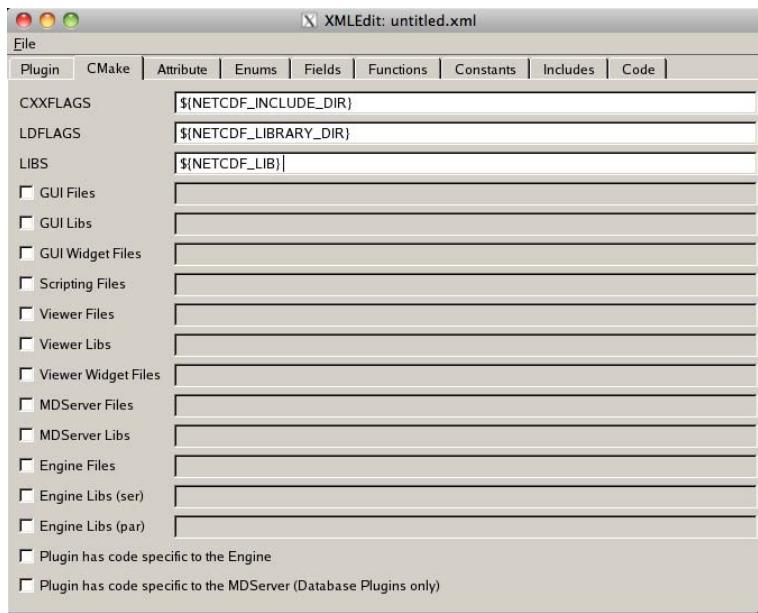


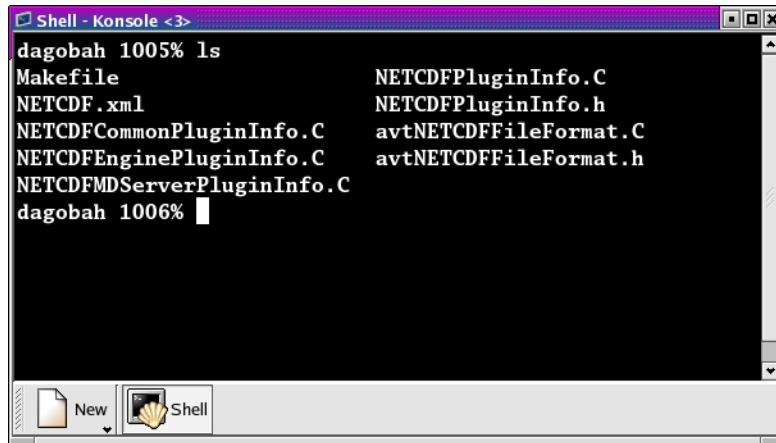
Figure 4-5: XMLEDit CMake tab with compiler options and additional files specified.

3.3 Generating a plug-in code skeleton

Once you save your work from XMLEDit, you will find an XML file containing the options that you provided in the directory where you store your plug-in files. VisIt provides more XML tools to generate the necessary code skeleton for your plug-in. The important tools when building a database plug-in are: `xml2cmake`, `xml2info`, `xml2plugin`. The `xml2plugin` program is actually a script that automates calling the required `xml2*` programs. In order to generate your plug-in code skeleton, open a command window, go to the directory containing your XML file, and run `xml2plugin`. On UNIX systems, the command that you will run is:

```
xml2plugin -clobber FILE.xml
```

Be sure to replace *FILE.xml* with the name of your own XML file. Once you run the `xml2plugin` program, if you look in your directory, you will see several new files.



```
dagobah 1005% ls
Makefile           NETCDFPluginInfo.C
NETCDF.xml         NETCDFPluginInfo.h
NETCDFCommonPluginInfo.C  avtNETCDFFileFormat.C
NETCDFEnginePluginInfo.C  avtNETCDFFileFormat.h
NETCDFMDServerPluginInfo.C
dagobah 1006%
```

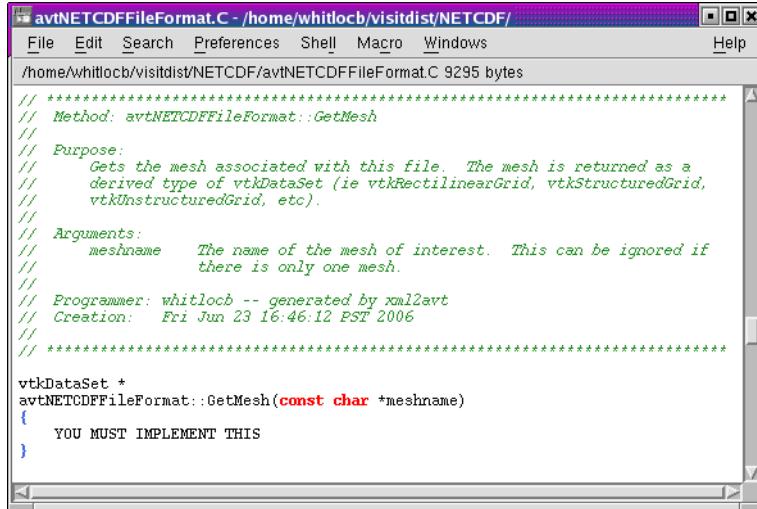
Figure 4-6: Files generated by `xml2plugin`

For database reader plug-ins, there are essentially three classes of files that `xml2plugin` creates. First of all, `xml2plugin` creates the plug-in code skeleton, which includes the plug-in entry points that are used to load the plug-in dynamically at runtime. These files have “*Info*” in their name and they are generated by the `xml2info` program. If you change the name, version, or file extensions that your plug-in uses then you should re-run `xml2info` instead of running `xml2plugin`. The next set of files are the AVT file format source and header files. The AVT file format source code files are C++ source code files that you will complete using new code to read your file format. Finally, `xml2cmake`, created a `CmakeLists.txt` file that `cmake` can use to generate a build system for your plug-in. If you run “`cmake .`” at the command prompt and you are on a UNIX system such as Linux or MacOS X, `cmake` will generate a `Makefile` for your plug-in. In that case, all you have to do in order to build your plug-in is type: `make` at the command prompt.

3.4 Building your plug-in

So far, we have created an XML file using the `XMLEdit` program and then used the XML file with VisIt’s XML tools to generate plug-in source code. The static portions of the generated source code is complete but there are still some pieces that you need to write yourself in order to make VisIt read your data files. The automatically generated files that are called `avtXXXXFileFormat.C` and `avtXXXXFileFormat.h`, where `XXXX` is the name of your plug-in, are incomplete. These two AVT files contain a derived class of one of the STSD, STMD, MTSD, MTMD file format classes that VisIt provides for reading different file types. Your job is to fill in the missing code in the methods for the AVT classes so they can read data from your file format and translate that data into VTK objects. By default, the AVT files contain some messages in the source code like “*YOU MUST IMPLEMENT*

THIS", which are meant to prevent the source code from compiling and to call attention to areas of the plug-in that you need to implement (See Figure 4-7).



The screenshot shows a terminal window titled "avtNETCDFFileFormat.C - /home/whitlocb/visitdist/NETCDF". The code is a C++ file named "avtNETCDFFileFormat.C". It contains several comments in green, including a purpose statement and arguments. A red error message at the bottom reads "YOU MUST IMPLEMENT THIS".

```
// ****
// Method: avtNETCDFFileFormat::GetMesh
//
// Purpose:
//   Gets the mesh associated with this file. The mesh is returned as a
//   derived type of vtkDataSet (ie vtkRectilinearGrid, vtkStructuredGrid,
//   vtkUnstructuredGrid, etc).
//
// Arguments:
//   meshname    The name of the mesh of interest. This can be ignored if
//               there is only one mesh.
//
// Programmer: whitlocb -- generated by xml2avt
// Creation:  Fri Jun 23 16:46:12 PST 2006
//
vtkDataSet *
avtNETCDFFileFormat::GetMesh(const char *meshname)
{
    YOU MUST IMPLEMENT THIS
}
```

Figure 4-7: Example of a “YOU MUST IMPLEMENT THIS” message

The first step in building a plug-in is to make sure that the automatically generated source code compiles. Open the AVT files and look for instances of the “*YOU MUST IMPLEMENT THIS*” message and, when you find them, write down a note of where they appear. Comment out each of the messages in the C++ source code and add “return 0 ;” statements (See Figure 4-8). By commenting out the offending messages, the automatically generated source code will compile when you attempt to compile the plug-in. You will also have a list of some of the plug-in methods that you will have to write later when you really begin developing your plug-in.

Once you have changed the AVT files so there are no stray messages about implementing a plug-in feature, go back to your command terminal and type “cmake -DCMAKE_BUILD_TYPE:STRING=Debug” so cmake will generate a build system for your plug-in. The generated build system is most commonly a Makefile, allowing you to use the make command for your system (commonly make or gmake). The make command takes the automatically generated Makefile that was generated by cmake and starts building your plug-in against the installed version of VisIt. If you encounter compilation errors, such as syntax errors, then you most likely need to make further changes to your AVT files before trying to build your plug-in. A good C++ language reference can help you understand the types of errors that may be printed to your command window in the event that you have not successfully changed the AVT files. If your source code seems to compile but fails due to missing libraries such as NETCDF or HDF5 then you can edit your XML file so it points to the right library installation locations. Note that if you edit your XML file, you will need to regenerate the CMakeLists.txt file using xml2cmake. It is also a good idea that you remove the

CMakeCache.txt file before rerunning cmake if you have changed the path to any libraries in your XML file.

```

avtNETCDFFileFormat.C - /home/whitlocb/visitdist/NETCDF/
File Edit Search Preferences Shell Macro Windows Help
/home/whitlocb/visitdist/NETCDF/avtNETCDFFileFormat.C line 199, col 13, 9311 bytes
// ****
// Method: avtNETCDFFileFormat::GetMesh
//
// Purpose:
//   Gets the mesh associated with this file.  The mesh is returned as a
//   derived type of vtkDataSet (ie vtkRectilinearGrid, vtkStructuredGrid,
//   vtkUnstructuredGrid, etc).
//
// Arguments:
//   meshname    The name of the mesh of interest.  This can be ignored if
//               there is only one mesh.
//
// Programmer: whitlocb -- generated by xml2avt
// Creation: Fri Jun 23 16:46:12 PST 2006
// ****

vtkDataSet *
avtNETCDFFileFormat::GetMesh(const char *meshname)
{
    //YOU MUST IMPLEMENT THIS
    return 0;
}

```

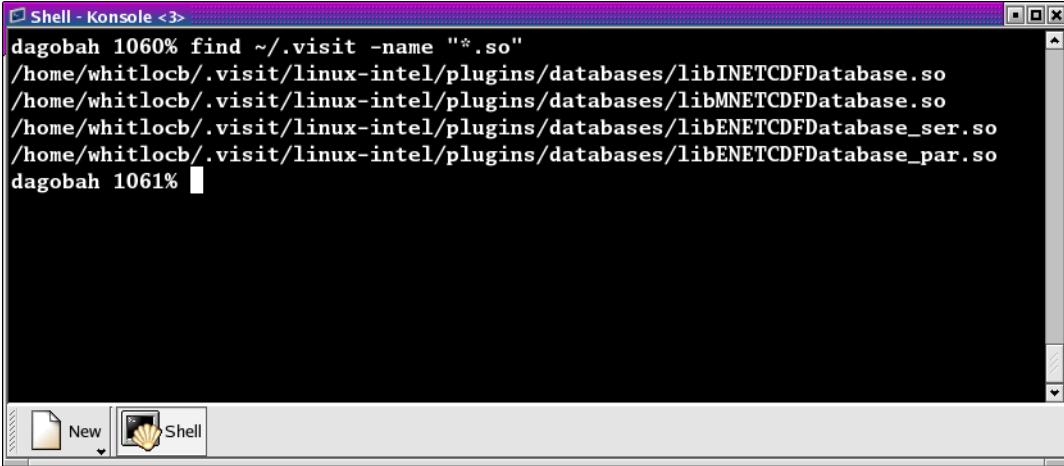
Figure 4-8: Example of corrections made to a “YOU MUST IMPLEMENT THIS” message needed to make the source code compile

Once your plug-in is built, it will be stored in a platform-specific subdirectory of the `.visit` directory in your home directory (`~/ .visit`). If you type: `find ~/ .visit -name “*.so”` into your command window, you will be able to locate the `libE`, `libI`, and `libM` files that make up your compiled plug-in (see Figure 4-9). If you develop for MacOS X, you should substitute `“*.dylib”` for `“*.so”` in the previous command because shared libraries on MacOS X have a `“.dylib”` file extension instead of a `“.so”` file extension. Note that when a parallel compute engine is available in the installed version of VisIt, you will get two `libE` plug-ins; one with a `_ser` suffix and one with a `_par` suffix. The `libE` files that have a `_ser` suffix are loaded by the serial compute engine and the `_par libE` file is loaded by the parallel compute engine and may contain parallel function calls, such as calls to the MPI library.

When VisIt’s database server and compute engine execute, they look in your `~/ .visit` directory for available plug-ins and load any that are available. This means that even if you build plug-ins against the installed version of VisIt, it will still be able to find your private plug-ins.

It is recommended that while you develop your plug-ins, you only install them in your `~/ .visit` directory so other VisIt users will not be affected. However, if you develop your plug-in on MacOS X, you will have to make sure that your plug-ins are installed publicly so that they can be loaded at runtime. You can also choose to install your plug-ins publicly once you have completed development. To install plug-ins publicly, first remove the files that were installed to your `~/ .visit` directory by typing the `make clean` command in your command window. Next, re-run the `xml2cmake` program like this: `xml2cmake -public -clobber FILE.xml`. Adding the `-public` argument on

the command line causes make to install your plug-in files publicly so all VisIt users can access them. Don't forget to rerun cmake after running `xml2cmake`.



```
dagobah 1060% find ~./visit -name "*.so"
/home/whitlocb/.visit/linux-intel/plugins/databases/libINETCDFDatabase.so
/home/whitlocb/.visit/linux-intel/plugins/databases/libMNETCDFDatabase.so
/home/whitlocb/.visit/linux-intel/plugins/databases/libENETCDFDatabase_ser.so
/home/whitlocb/.visit/linux-intel/plugins/databases/libENETCDFDatabase_par.so
dagobah 1061%
```

Figure 4-9: Files are created in the .visit directory when a plug-in is built.

3.5 Calling your plug-in for the first time

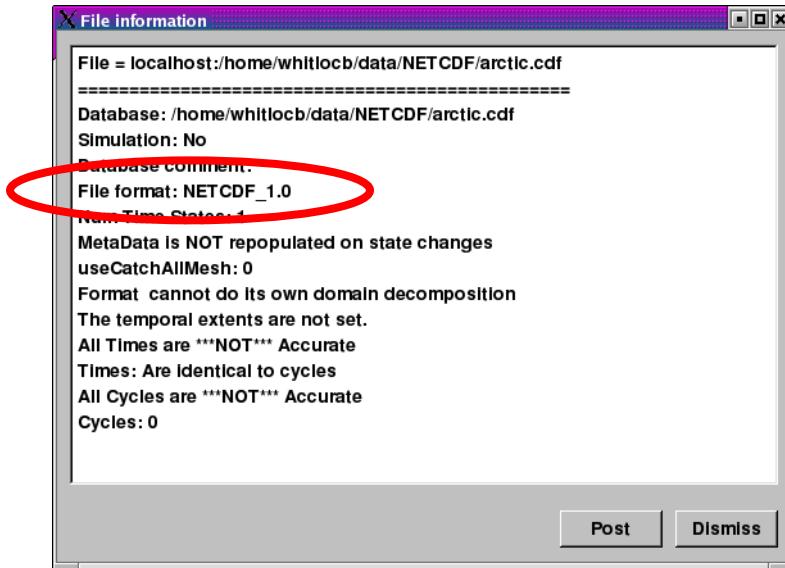


Figure 4-10: File Information window confirming use of your plug-in.

Once you have completed building your plug-in for the first time, all that you need to do is run VisIt and try to open one of your files. When you open one of your files, the database server should match the file extension of the file that you tried to open with the list of file extensions that your plug-in accepts, causing your plug-in to be loaded and used for opening the file. You can verify that VisIt used your plug-in by opening the **File**

Information window (see Figure 4-10) in the VisIt GUI and looking for the name of your plug-in in the listed information.

Note that at this stage, the database server should be properly loading your database reader plug-in but since no code to actually read your files has yet been added to the AVT source code files, no plottable meshes or variables will be available.

4.0 Implementing your plug-in

Now that you have built a working plug-in framework, you are ready to begin adding code to your plug-in that will make it capable of opening your file format, reading data, and translating that data into VTK objects. This section explores the details of writing the AVT code for your database reader plug-in, providing necessary background and then diving into specific topics such as how to return data for a particular mesh type. **Before starting, remember that building a plug-in is an incremental process and you should proceed in small steps, saving your work, building, and testing your plug-in each step of the way.**

4.1 Required plug-in methods

Most of the code in a VisIt database plug-in is automatically generated and, for the most part, the only code that you need to modify is the AVT code. The AVT code contains a class definition and implementation for a derived type of the STSD, STMD, MTSD, or MTMD file format classes and your job as a plug-in developer is to write the required methods for your derived file format class so that VisIt can read your file. There are many methods in the file format class interface that you can override to make your plug-in perform specialized operations. The only methods that you absolutely must implement are

the `PopulateDatabaseMetaData`, `GetMesh`, `GetVar`, and `GetVectorVar` methods. The purpose of each of these plug-in methods is listed in the following table.

Method	Purpose
<code>PopulateDatabaseMetaData</code>	VisIt calls the <code>PopulateDatabaseMetaData</code> method when file metadata is needed. File metadata is returned in a pass-by-reference <code>avtDatabaseMetaData</code> object. File metadata consists of the list of names of meshes, scalar variables, vector variables, tensor variables, label variables, array variables, expressions, cycles, and times contained in the file. These lists of variables and meshes let VisIt know the names of the objects that can be plotted from your file. The metadata is used primarily to populate the plot menus in the GUI and viewer components. The <code>PopulateDatabaseMetaData</code> method is called by both the <code>libM</code> and <code>libE</code> plug-ins.
<code>GetMesh</code>	VisIt calls the <code>GetMesh</code> method in a <code>libE</code> plug-in when it needs to plot a mesh. This method is the first method to return “problem-sized” data, meaning that the mesh data can be as large as the data in your file. The <code>GetMesh</code> method must return a mesh object in the form of one of the VTK dataset objects (<code>vtkRectilinearGrid</code> , <code>vtkStructuredGrid</code> , <code>vtkUnstructuredGrid</code> , <code>vtkPolyData</code>)
<code>GetVar</code>	VisIt calls the <code>GetVar</code> method in a <code>libE</code> plug-in when it needs to read a scalar variable. Like the <code>GetMesh</code> method, this method returns “problem-sized” data. <code>GetVar</code> reads data values from the file format, possibly performing calculations to alter the data, and stores the data into a derived type <code>vtkDataArray</code> object such as <code>vtkFloatArray</code> or <code>vtkDoubleArray</code> . If your file format does not need to return scalar data then you can leave the “ <code>return 0 ;</code> ” implementation that you added in order to get your plug-in to build.

Method	Purpose
GetVectorVar	VisIt calls the GetVectorVar method in a libE plug-in when it needs to read a vector or tensor variable. GetVectorVar performs the same function as GetVar but returns vtkFloatArray or vtkDoubleArray objects that have more than one value per tuple. A tuple is the equivalent of a value associated with a zone or node but it can store more than one value. If your file format does not need to return scalar data then you can leave the “return 0;” implementation that you added in order to get your plug-in to build.

4.2 Debugging your plug-in

Before beginning to write code for your plug-in, you should know a few techniques for debugging your plug-in since debugging VisIt can be tricky because of its distributed architecture.

4.2.1 Debugging logs

The first method debugging in VisIt is by using VisIt’s debug logs. When you run `visit` on the command line, you can optionally add the `-debug 5` arguments to make VisIt write out debugging logs. The number of debugging logs can be 1, 2, 3, 4, or 5, with debugging log 5 being the most detailed. When VisIt’s components are told to run with debugging logs turned on, each component writes a set of debugging logs. For example, the database server component will write `A.mdserver.1.vlog`, `A.mdserver.2.vlog`, ..., `A.mdserver.5.vlog` debugging logs if you pass `-debug 5` on the VisIt command line. Subsequent runs of VisIt will prepend ‘B’ then ‘C’, and so on. If you don’t want that behavior, you may add `-clobber_vlogs` to VisIt’s command line arguments. Since you are writing a database reader plug-in, you will want to look at the `A.mdserver*.vlog` and `A.engine*.vlog` files since those components load your `libM` and `libE` plug-ins.

The debugging logs will contain information written to them by the debugging statements in VisIt’s source code. If you want to add debugging statements to your AVT code then you can use the `debug1`, `debug2`, `debug3`, `debug4`, or `debug5` streams as shown in the next code listing.

Listing 4-11: `debugstream.C`: C++-Language example for using debug streams.

```
// NOTE - This code incomplete and is for example purposes only.

// Include this header for debug streams.
#include <DebugStream.h>
```

```
vtkDataSet *
avtXXXXFileFormat::GetMesh(const char *meshname)
{
    // Write messages to different levels of the debug logs.
    debug1 << "Hi from avtXXXXFileFormat::GetMesh" << endl;

    debug4 << "Many database plug-ins prefer debug4" << endl;

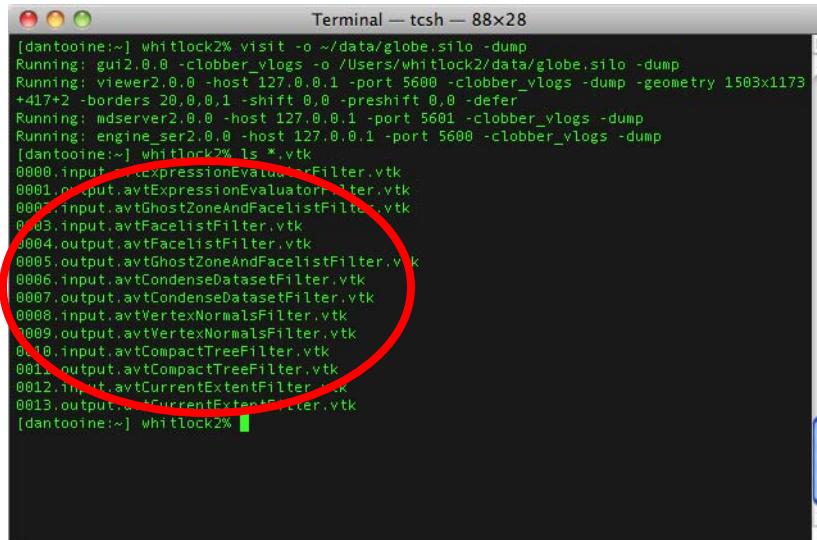
    debug5 << "Lots of detail from avtXXXXFileFormat::GetMesh"
        << endl;

    return 0;
}
```

4.2.2 Dumping VTK objects to disk

In addition to the `-debug` argument, VisIt also supports a `-dump` argument. The `-dump` argument tells VisIt's compute engine to write VTK files containing the data for every stage of the pipeline execution so you can view the changes to the data made by each AVT filter. While this option is more useful when writing plots and operators, you can use it to examine the data at the beginning of the pipeline since, at that stage, the data will contain the VTK object that was created by your database reader plug-in.

When you run VisIt with the `-dump` argument, many VTK files will be created since the data is saved at every stage in the execution of VisIt's data processing pipeline. Each VTK filename begins with a number indicating the order of the filter in the pipeline that saved the data. The list of files created by using the `-dump` argument is shown in Figure 4-12.



```
Terminal — tcsh — 88x28
[dantooine:~] whitlock2% visit -o ~/data/globe.silo -dump
Running: gui2.0.0 -clobber_vlogs -o /Users/whitlock2/data/globe.silo -dump
Running: viewer2.0.0 -host 127.0.0.1 -port 5600 -clobber_vlogs -dump -geometry 1503x1173
+417+2 -borders 20,0,0,1 -shift 0,0 -preshift 0,0 -defer
Running: mdserver2.0.0 -host 127.0.0.1 -port 5601 -clobber_vlogs -dump
Running: engine_ser2.0.0 -host 127.0.0.1 -port 5600 -clobber_vlogs -dump
[dantooine:~] whitlock2% ls *.vtk
0000.input_avtExpressionEvaluatorFilter.vtk
0001.output_avtExpressionEvaluatorFilter.vtk
0002.input_avtGhostZoneAndFacelistFilter.vtk
0003.input_avtFacelistFilter.vtk
0004.output_avtFacelistFilter.vtk
0005.output_avtGhostZoneAndFacelistFilter.vtk
0006.input_avtCondenseDatasetFilter.vtk
0007.output_avtCondenseDatasetFilter.vtk
0008.input_avtVertexNormalsFilter.vtk
0009.output_avtVertexNormalsFilter.vtk
0010.input_avtCompactTreeFilter.vtk
0011.output_avtCompactTreeFilter.vtk
0012.inp_avtCurrentExtentFilter.vtk
0013.output_avtCurrentExtentFilter.vtk
[dantooine:~] whitlock2%
```

Figure 4-12: Output of running with the `-dump` command line argument

4.3 Opening your file

When VisIt receives a list of files to open, it tries to determine which plug-in should be loaded to access the data in those files. The match is performed by comparing the file extension of the files against the known file extensions or patterns for all database reader plug-ins. Each plug-in in the list of matches is loaded and VisIt creates instances of the plug-in's AVT file format classes that are then used to access the data in the files. If the plugin's file format classes can be successfully constructed then VisIt tries to get the file's metadata. It is very important that your file format's constructor do as little work as possible, and try at all costs to avoid opening the files. Remember, VisIt could be creating a long list of your file format objects and opening the file in the constructor will really slow down the process of opening a file. It is better to instead add a boolean initialized member to your class and an `Initialize` method that reads the file to check its contents. Then override the `ActivateTimestep` method for your file format class and call your `Initialize` method from it. We make `Initialize` its own method so we can call it from other methods such as `GetMesh` or `GetVar` just in case.

In the event that your `Initialize` method cannot open the file if the file is not the right type, or if it contains errors, or if it cannot be accessed for some other reason, the constructor must throw an `InvalidDBTypeException` exception. When the `InvalidDBTypeException` exception is thrown, VisIt's database factory catches the exception and then tries to open the file with the next matching plug-in. This procedure continues until the file is opened by a suitable plug-in or the file cannot be opened at all.

Listing 4-13: invaliddbtype.C: C++-Language example for identifying a file.

```
// NOTE - This code incomplete and is for example purposes only.

#include <InvalidDBTypeException.h>

avtXXXXFileFormat::avtXXXXFileFormat(const char *filename)
: avtSTSDFileFormat(filename)
{
    initialized = false;
}

// Override this method in your reader
void
avtXXXXFileFormat::ActivateTimestep()
{
    Initialize();
}

// Provide this method in your reader
void
avtXXXXFileFormat::Initialize()
{
    if(!initialized)
```

```
{  
    bool okay = false;  
  
    // Open the file specified by the filename argument here using  
    // your file format API. See if the file has the right things in  
    // it. If so, set okay to true.  
    YOU MUST IMPLEMENT THIS  
  
    // If your file format API could not open the file then throw  
    // an exception.  
    if (!okay)  
    {  
        EXCEPTION1(InvalidDBTypeException,  
        "The file could not be opened");  
    }  
  
    initialized = true;  
}  
}
```

If your database reader plug-in uses a unique file extension then you have the option of deferring any file opens until later when metadata is required. This is the preferred approach because VisIt may create many instances of your file format class and doing less work in the constructor makes opening files faster.

Once you decide whether your file format can defer opening a file or whether it must open the file in the constructor, you can begin adding code to your AVT class. Since opening files can be a costly operation, you might want to open a file and keep it open if you have a random access file format. If you open a file in one method and want to keep the file open so it is available to multiple plug-in methods, you will need to add a new class member to your AVT class to contain the handle to your open file. If your file format consists of sequential text then you might consider reading the file once and keeping the data in memory in a format that you can conveniently translate into VTK objects. Both approaches require the addition of a new class member - either a handle to the file or a pointer to data that was read from the file.

4.4 Returning file metadata

Once you have decided how your plug-in will manage access to the file that it must read, the next step in writing your database reader plug-in is to implement the `PopulateDatabaseMetaData` method. The `PopulateDatabaseMetaData` method is called by VisIt's database infrastructure when information about a file's meshes and variables must be obtained. The `PopulateDatabaseMetaData` method is usually called only the first time that a file format's metadata is being read, though some time-varying formats can have time-varying metadata, which requires that `PopulateDatabaseMetaData` is called each time VisIt requests data for a new time state. However, most file formats call `PopulateDatabaseMetaData` once.

The `PopulateDatabaseMetaData` method arguments can vary, depending on whether your file format is STSD, STMD, MTSD, or MTMD but in all cases the first argument is an `avtDatabaseMetaData` object. The `avtDatabaseMetaData` object is a class that is pervasively used in VisIt; it contains information about the files that you plot such as the number of domains, times, meshes, and variables that the files can provide. When you implement your plug-in's `PopulateDatabaseMetaData` method, you must populate the `avtDatabaseMetaData` object with the list of meshes and variables, etc. that you want VisIt to be able to plot. You can hard-code a fixed list of meshes and variables if your file format always contains the same entities or you can open your file and provide a dynamic list of meshes and variables. This section covers how to add meshes and various variable types to the `avtDatabaseMetaData` object so your file format's data will be exposed in VisIt. For a complete listing of the `avtDatabaseMetaData` object's methods, see the `avtDatabaseMetaData.h` header file. It is worth noting that the following code examples create metadata objects and manually add them to the metadata object instead of using convenience functions. This is done because the convenience functions used in automatically generated plug-in code do not provide support for less often used metadata settings such as units and labels.

4.4.1 Returning mesh metadata

In order for you to be able to plot any data from your file format, your database reader plug-in must add at least one mesh to the `avtDatabaseMetaData` object that is passed into the `PopulateDatabaseMetaData` method. Adding information about a mesh to the `avtDatabaseMetaData` object is done by creating an `avtMeshMetaData` object, populating its important members, and adding it to the `avtDatabaseMetaData`. At a minimum, each mesh must have a name, spatial dimension, topological dimension, and a mesh type. The mesh's name is the identifier that will be displayed in VisIt's plot menus and it is also the name that will be passed later on into the plug-in's `GetMesh` method.

The spatial dimension attribute corresponds to how many dimensions are needed to specify the coordinates for the points that make up your mesh. If your mesh exists in a 2D plane then choose 2, otherwise choose 3. Note that when you create the points for your mesh later in the `GetMesh` method, you will always create points that contain X,Y,Z points.

The topological dimension attribute describes the number of logical dimensions used by your mesh, regardless of the dimension of the space that it sits in. For example, you may have a planar surface of triangles sitting in 3D space. Such a mesh would be topologically 2D even though it sits in 3D space. The rule of thumb that VisIt follows is that if your

mesh's cells are points then you have a mesh that is topologically 0D, lines are 1D, surfaces are 2D, and volumes are 3D. This point is illustrated in Figure 4-14.

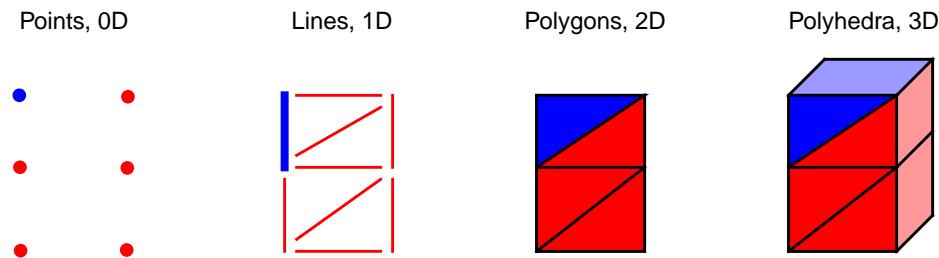


Figure 4-14: Topological dimensions. One zone is highlighted blue.

Once you have set the other basic attributes for your mesh object, consider which type of mesh you have. VisIt supports several different mesh types and the value that you provide in the metadata allows VisIt to tailor how it applies filters that process your data. If you have a mesh composed entirely of particles then choose AVT_POINT_MESH. If you have a structured mesh where the coordinates are specified by small vectors of values for each axis and the rest of the coordinates are implied then you probably have a rectilinear mesh and you should choose AVT_RECTILINEAR_MESH. If you have a structured mesh and every node has its own specific location in space then you probably have a curvilinear mesh and you should choose AVT_CURVILINEAR_MESH. If you have a mesh for which you specify a large list of nodes and then create cells using indices into that list of nodes then you probably have an unstructured mesh and you should choose AVT_UNSTRUCTURED_MESH for the mesh type. If you have a mesh that adaptively refines then choose AVT_AMR_MESH. Finally, if your mesh is specified using shapes such as cones and spheres that are unioned or differenced using boolean operations then you have a constructive solid geometry mesh and you should choose AVT_CSG_MESH for your mesh's mesh type.

If your mesh consists of multiple domains then you will need to set the number of domains into the numBlocks member of the `avtMeshMetaDataTable` object. Remember that the number of domains tells VisIt how many pieces make up your mesh and it is especially important to specify this number if your plug-in is derived from an MD file format interface. You may also choose to tell VisIt what the domains are called for your file format. Some file formats use the word: “domains” while others use “brick” or “block”. If you choose to set the name that VisIt uses for domains then that term will be used in parts of VisIt’s GUI such as the **Subset** window. Set the `blockPieceName` member of the `avtMeshMetaDataTable` object to a suitable term that describes a domain in the context of your simulation code. Alternatively, you can provide proper names by providing a vector of strings containing the names by setting the `blockNames` member.

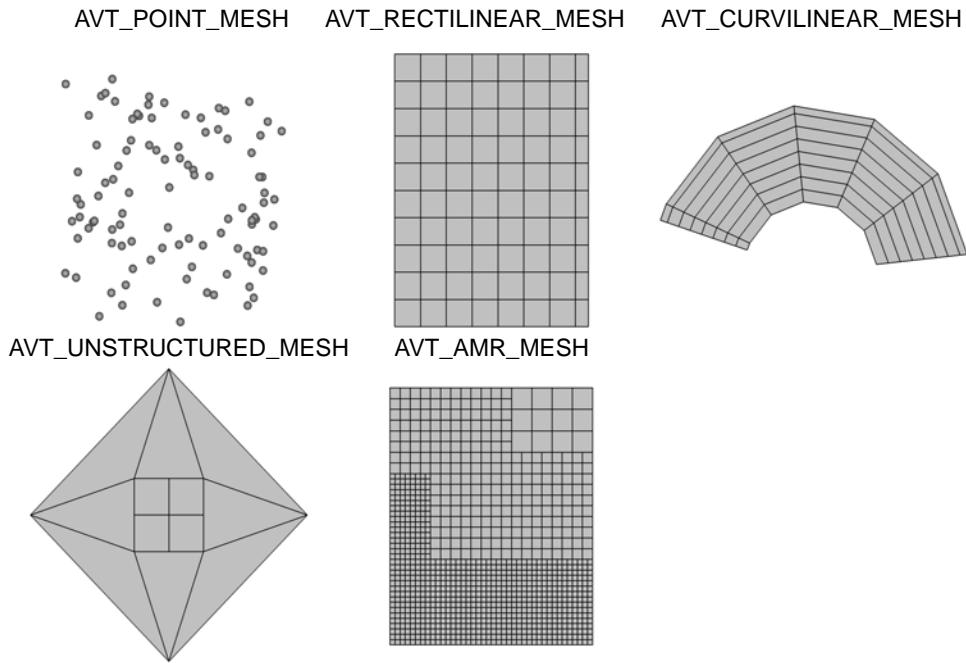


Figure 4-15: AVT mesh types (AVT_CSG_MESH not pictured).

Now that the most important attributes of the `avtMeshMetaData` object have been specified, you can add extra information such as the names or units of the coordinate dimensions. Once all attributes are set to your satisfaction, you must add the `avtMeshMetaData` object to the `avtDatabaseMetaData` object.

Listing 4-16: meshmetadata.C: C++-Language example for returning mesh metadata.

```
// NOTE - This code incomplete and is for example purposes only.

void
avtXXXXFileFormat::PopulateDatabaseMetaData(avtDatabaseMetaData *md)
{
    // Add a point mesh to the metadata. Note that this example will
    // always expose a mesh called "particles" to VisIt. A real
    // plug-in may want to read a list of meshes from the data
    // file.
    avtMeshMetaData *mmd = new avtMeshMetaData;
    mmd->name = "particles";
    mmd->spatialDimension = 3;
    mmd->topologicalDimension = 0;
    mmd->meshType = AVT_POINT_MESH;
    mmd->numBlocks = 1;
    md->Add(mmd);
```

```
    // Add other objects to the metadata object.  
}
```

4.4.2 Returning scalar metadata

Once you have exposed a mesh to VisIt by adding mesh metadata to the `avtDatabaseMetaData` object, you can add scalar field metadata to the metadata. A scalar field is a set of floating point values defined for all cells or nodes of a mesh. You can expose as many scalar variables as you want on any number of meshes. The list of scalar fields that a plug-in exposes is often determined by the data file being processed. Like mesh metadata, scalar metadata requires a name so the scalar can be added to VisIt's menus. The name that you choose is the same name that later is passed to the `GetVar` plug-in method. Once you select a name for your scalar variable, you must indicate the name of the mesh on which the variable is defined by setting the `meshName` member of the `avtScalarMetaData` object. Once you have set the name and `meshName` members, you can set the centering member. The centering member of the `avtScalarMetaData` object can be set to `AVT_NODECENT` or `AVT_ZONECENT`, indicating that the data is defined on the nodes or at the zone centers, respectively. If you want to indicate units that are associated with the scalar variable, set the `hasUnits` member to `true` and set the `units` string to the appropriate unit names.

Listing 4-17: `scalarmetadata.C`: C++-Language example for returning scalar metadata.

```
// NOTE - This code incomplete and is for example purposes only.  
  
void  
avtXXXXFileFormat::PopulateDatabaseMetaData(avtDatabaseMetaData *md)  
{  
    // Add a mesh called "mesh" to the metadata object.  
  
    // Add a scalar to the metadata. Note that this plug-in will  
    // always expose a scalar called "temperature" to VisIt. A real  
    // plug-in may want to read a list of scalars from the data  
    // file.  
    avtScalarMetaData *smd = new avtScalarMetaData;  
    smd->name = "temperature";  
    smd->meshName = "mesh";  
    smd->centering = AVT_ZONECENT;  
    smd->hasUnits = true;  
    smd->units = "Celsius";  
    md->Add(smd);  
  
    // Add other objects to the metadata object.  
}
```

4.4.3 Returning vector metadata

The procedure for returning vector metadata is similar to that for returning scalar metadata. In fact, if you change the object type that you create from `avtScalarMetaData` to `avtVectorMetaData` then you are almost done. After you set the basic vector metadata attributes, you must set the `varDim` member to 2 if you have a 2-component vector or 3 if you have a 3-component vector.

Listing 4-18: vectormetadata.C: C++-Language example for returning vector metadata.

```
// NOTE - This code incomplete and is for example purposes only.

void
avtXXXXFileFormat::PopulateDatabaseMetaData(avtDatabaseMetaData *md)
{
    // Add a mesh called "mesh" to the metadata object.

    // Add a vector to the metadata. Note that this plug-in will
    // always expose a vector called "velocity" to VisIt. A real
    // plug-in may want to read a list of vectors from the data
    // file.
    avtVectorMetaData *vmd = new avtVectorMetaData;
    vmd->name = "velocity";
    vmd->meshName = "mesh";
    vmd->centering = AVT_ZONECENT;
    vmd->hasUnits = true;
    vmd->units = "m/s";
    vmd->varDim = 3;
    md->Add(vmd);

    // Add other objects to the metadata object.
}
```

4.4.4 Returning material metadata

Like the other types of mesh variables that we have seen so far, a material is defined on a specific mesh. However, unlike the other variables types, materials can be used to name regions of the mesh and can also be used by VisIt to break the mesh down into smaller pieces that can be turned on and off using the **Subset** window. Material metadata is stored in an `avtMaterialMetaData` object and it consists of: the name of the material object, the mesh on which it is defined, the number of materials, and the names of the materials. If you had a material called “mat1” defined on “mesh” and “mat1” was composed of: “Steel”, “Wood”, “Glue”, and “Air” then the metadata object needed to expose “mat1” to VisIt would look like the following code listing:

Listing 4-19: materialmetadata.C: C++-Language example for returning material metadata.

```
// NOTE - This code incomplete and is for example purposes only.

void
avtXXXXFileFormat::PopulateDatabaseMetaData(avtDatabaseMetaData *md)
{
    // Add a mesh called "mesh" to the metadata object.

    // Add a material to the metadata. Note that this plug-in will
    // always expose a material called "mat1" to VisIt. A real
    // plug-in may want to use from the data file to construct
    // a material.
    avtMaterialMetaData *matmd = new avtMaterialMetaData;
    matmd->name = "mat1";
    matmd->meshName = "mesh";
    matmd->numMaterials = 4;
    matmd->materialNames.push_back("Steel");
    matmd->materialNames.push_back("Wood");
    matmd->materialNames.push_back("Glue");
    matmd->materialNames.push_back("Air");
    md->Add(matmd);

    // Add other objects to the metadata object.
}
```

4.4.5 Returning expressions

VisIt provides support for defining expressions to calculate new data based on the data in your file. VisIt provides the **Expression** window in the GUI for managing expression definitions. It can be convenient for users in certain fields, where custom expressions are used frequently, to store the expression definitions directly in the file format or to encode the custom expressions directly in the file metadata so they are always available when a given file is visualized. VisIt's `avtDatabaseMetaData` object can contain custom expressions. Thus you can add custom expressions to the `avtDatabaseMetaData` object inside of your database reader plug-in. Custom expressions are added to the `avtDatabaseMetaData` object by creating `Expression` (defined in `Expression.h`) objects and adding them by calling the `avtDatabaseMetaData::AddExpression` method. The `Expression` object lets you provide the name and definition of an expression as well as the expression's expected return type (scalar, vector, tensor, etc.) and whether the expression should be hidden from the user. Hidden expressions can be useful if you build a complex expression that makes use of smaller sub-expressions that do not need to be exposed in the VisIt user interface.

Listing 4-20: `expressionmetadata.C`: C++-Language example for returning expression metadata.

```
// NOTE - This code incomplete and is for example purposes only.

#include <Expression.h>
```

```

void
avtXXXXFileFormat::PopulateDatabaseMetaData(avtDatabaseMetaData *md)
{
    // Add a mesh called "mesh" to the metadata object.

    // Add scalars to the metadata object.

    // Add expression definitions to the metadata object.
    Expression *e0 = new Expression;
    e0->SetName("speed");
    e0->SetDefinition("{u,v,w}");
    e0->SetType(Expression::VectorMeshVar);
    e0->SetHidden(false);
    md->AddExpression(e0);

    Expression *e1 = new Expression;
    e1->SetName("density");
    e1->SetDefinition("mass/volume");
    e1->SetType(Expression::ScalarMeshVar);
    e1->SetHidden(false);
    md->AddExpression(e1);

    // Add other objects to the metadata object.
}

```

4.5 Returning a mesh

Once your database reader plug-in can successfully return metadata about one or more meshes, you can proceed to implementing your plug-in's GetMesh method. When you make a plot in VisIt, the plot is set up using the file metadata returned by your plug-in. When you click the **Draw** button in the VisIt GUI, it causes a series of requests that make the compute engine load your libE plug-in and call its GetMesh method with the name of the mesh being used by the plot as well as the time state and domain numbers (MT or MD formats only).

A database reader plug-in's job is to read relevant data from a file format and translate the data into a VTK object that VisIt can process. The GetMesh method's job is to read the mesh information from the file and create a VTK object that describes the mesh in the data file. VisIt can process many different mesh types (See Figure 4-15 on page 109) and you can return different types of VTK objects that best describe your mesh type. This section gives example code to show how you would take data read from your file format and turn it into VTK objects that describe your mesh. The details of reading data from your file format are omitted from the example code listings because those details change for each file format. The central message in this section is how to use data from a file format to construct different mesh types.

4.5.1 Determining which mesh to return

The GetMesh method is always passed a string containing the name of the mesh that should be returned from the plug-in. If your file format only ever has one mesh then you can ignore the meshname argument. However, if your file format can contain more than one mesh then you should check the name of the requested mesh before returning a VTK object so you create and return the correct mesh.

Listing 4-21: getmesh1.C: C++ Language example for which mesh to return in GetMesh.

```
// NOTE - This code incomplete and is for example purposes only.

#include <InvalidVariableException.h>

vtkDataSet *
avtXXXXFileFormat::GetMesh(const char *meshname)
{
    // Determine which mesh to return.
    if (strcmp(meshname, "mesh") == 0)
    {
        // Create a VTK object for "mesh"
        return mesh;
    }
    else if (strcmp(meshname, "mesh2") == 0)
    {
        // Create a VTK object for "mesh2"
        return mesh2;
    }
    else
    {
        // No mesh name that we recognize.
        EXCEPTION1(InvalidVariableException, meshname);
    }

    return 0;
}
```

If your database reader plug-in is derived from one of the MT or MD file format interfaces then the GetMesh method will have, in addition to the meshname argument, either a timestate argument, domain argument, or both. These extra arguments are both integers that VisIt passes to your plug-in so your plug-in can select the right mesh for the specified time state or domain. If your GetMesh method accepts a timestate argument then you can use it to return the mesh for the specified time state, which is in the range [0, NTS - 1], where NTS is the number of time states that your plug-in returned from its GetNTimesteps method. The range for the domain argument, if it is present, is [0,NDOMS - 1] where NDOMS is the number of domains that your file format added to the numBlocks member in the avtMeshMetaData object corresponding to the mesh named by the meshname argument.

4.5.2 Rectilinear meshes

A rectilinear mesh is a 2D or 3D mesh where all coordinates are aligned with the axes. Each axis of the rectilinear mesh can have different, non-uniform spacing, allowing for details to be concentrated in certain regions of the mesh. Rectilinear meshes are specified by lists of coordinate values for each axis. Since the mesh is aligned to the axes, it is only necessary to specify one set of X, Y, and Z values to generate all of the coordinates for the entire mesh.

Once you read the X,Y, and Z coordinates from your data file, you can use them to assemble a `vtkRectilinearGrid` object. The procedure for creating a

`vtkRectilinearGrid` object and returning it from `GetMesh` is shown in the next code listing. The underlined portions of the code listing indicate incomplete code that you must replace with code to read values from your file format. The first such piece requires you to read the number of dimensions for your mesh from the file format and store the value into the `ndims` variable. Once you have done that, read the number of nodes in each of the X,Y,Z dimensions and store those values in the `dims` array. Finally, fill in the code for reading the X coordinate values into the `xarray` array and do the same for the Y and Z coordinate arrays. Once you have replaced the underlined code portions with code that reads values from your file format, your plug-in should be able to return a valid `vtkRectilinearGrid` object once you rebuild it.

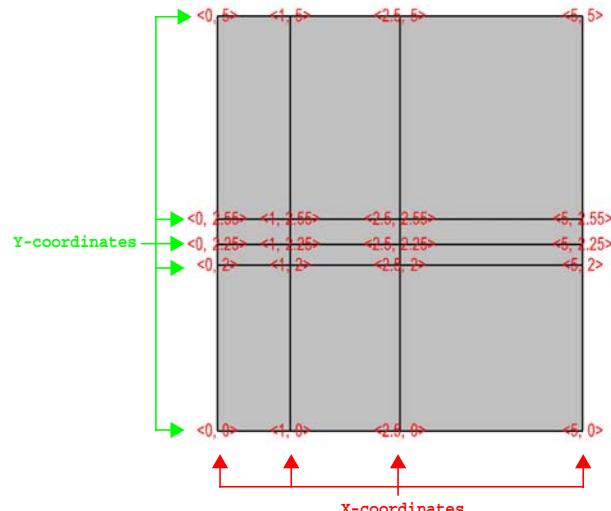


Figure 4-22: Rectilinear mesh and its X,Y node coordinates.

Listing 4-23: `getmesh_rect.C`: C++ Language example for creating `vtkRectilinearGrid` in `GetMesh`.

```
// NOTE - This code incomplete and requires underlined portions
// to be replaced with code to read values from your file format.

#include <vtkFloatArray.h>
#include <vtkRectilinearGrid.h>

vtkDataSet *
avtXXXfileFormat::GetMesh(const char *meshname)
{
    int ndims = 2;
    int dims[3] = {1,1,1};
    vtkFloatArray *coords[3] = {0,0,0};

    // Read the ndims and number of X,Y,Z nodes from file.
    ndims = NUMBER OF MESH DIMENSIONS;
```

```
dims[0] = NUMBER OF NODES IN X-DIMENSION;
dims[1] = NUMBER OF NODES IN Y-DIMENSION;
dims[2] = NUMBER OF NODES IN Z-DIMENSION, OR 1 IF 2D;

// Read the X coordinates from the file.
coords[0] = vtkFloatArray::New();
coords[0]->SetNumberOfTuples(dims[0]);
float *xarray = (float *)coords[0]->GetVoidPointer(0);
READ dims[0] FLOAT VALUES INTO xarray

// Read the Y coordinates from the file.
coords[1] = vtkFloatArray::New();
coords[1]->SetNumberOfTuples(dims[1]);
float *yarray = (float *)coords[1]->GetVoidPointer(0);
READ dims[1] FLOAT VALUES INTO yarray

// Read the Z coordinates from the file.
coords[2] = vtkFloatArray::New();
if(ndims > 2)
{
    coords[2]->SetNumberOfTuples(dims[2]);
    float *zarray = (float *)coords[2]->GetVoidPointer(0);
    READ dims[2] FLOAT VALUES INTO zarray
}
else
{
    coords[2]->SetNumberOfTuples(1);
    coords[2]->SetComponent(0, 0, 0.);
}

//
// Create the vtkRectilinearGrid object and set its dimensions
// and coordinates.
//
vtkRectilinearGrid *rgrid = vtkRectilinearGrid::New();
rgrid->SetDimensions(dims);
rgrid->SetXCoordinates(coords[0]);
coords[0]->Delete();
rgrid->SetYCoordinates(coords[1]);
coords[1]->Delete();
rgrid->SetZCoordinates(coords[2]);
coords[2]->Delete();

return rgrid;
}
```

4.5.3 Curvilinear meshes

Curvilinear meshes are structured meshes as are rectilinear meshes. Whereas in a rectilinear mesh, a small set of independent X,Y,Z coordinate arrays are used to generate the coordinate values for each node in the mesh, in a curvilinear mesh, the node coordinates are explicitly given for each node in the mesh. This means that the sizes of the X,Y,Z coordinate arrays in a curvilinear mesh are all $NX*NY*NZ$ where NX is the number of nodes in the X-dimension, NY is the number of nodes in the Y-dimension, and NZ is the number of nodes in the Z-dimension. Providing the coordinates for every node permits you to create more complex geometries than are possible using rectilinear meshes (See Figure 4-24).

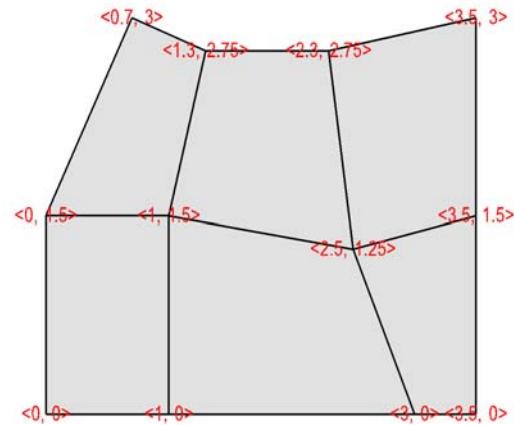


Figure 4-24: Curvilinear mesh and its X,Y node coordinates

Curvilinear meshes are created using the `vtkStructuredGrid` class. The next code listing shows how to create a `vtkStructuredGrid` object once you have read the required information from your file format. The underlined portions of the code listing indicate incomplete code that you will need to replace with code that can read data from your file format. First, read the number of dimensions for your mesh from the file format and store the value into the `ndims` variable. Once you have done that, read the number of nodes in each of the X,Y,Z dimensions and store those values in the `dims` array. Finally, fill in the code for reading the X coordinate values into the `xarray` array and do the same for the Y and Z coordinate arrays. Once you have replaced the underlined code portions with code that reads values from your file format, your plug-in should be able to return a valid `vtkStructuredGrid` object once you rebuild it

Listing 4-25: `getmesh_curv.C`: C++ Language example for creating `vtkStructuredGrid` in GetMesh.

```
// NOTE - This code incomplete and requires underlined portions
// to be replaced with code to read values from your file format.

#include <vtkPoints.h>
#include <vtkStructuredGrid.h>

vtkDataSet *
avtXXXfileFormat::GetMesh(const char *meshname)
{
    int ndims = 2;
    int dims[3] = {1,1,1};
```

```
// Read the ndims and number of X,Y,Z nodes from file.
ndims = NUMBER OF MESH DIMENSIONS;
dims[0] = NUMBER OF NODES IN X-DIMENSION;
dims[1] = NUMBER OF NODES IN Y-DIMENSION;
dims[2] = NUMBER OF NODES IN Z-DIMENSION, OR 1 IF 2D;
int nnodes = dims[0]*dims[1]*dims[2];

// Read the X coordinates from the file.
float *xarray = new float[nnodes];
READ nnodes FLOAT VALUES INTO xarray

// Read the Y coordinates from the file.
float *yarray = new float[nnodes];
READ nnodes FLOAT VALUES INTO yarray

// Read the Z coordinates from the file.
float *zarray = 0;
if(ndims > 2)
{
    zarray = new float[nnodes];
    READ dims[2] FLOAT VALUES INTO zarray
}

//
// Create the vtkStructuredGrid and vtkPoints objects.
//
vtkStructuredGrid *sgrid = vtkStructuredGrid::New();
vtkPoints         *points = vtkPoints::New();
sgrid->SetPoints(points);
sgrid->SetDimensions(dims);
points->Delete();
points->SetNumberOfPoints(nnodes);

//
// Copy the coordinate values into the vtkPoints object.
//
float *pts = (float *) points->GetVoidPointer(0);
float *xc = xarray;
float *yc = yarray;
float *zc = zarray;
if(ndims == 3)
{
    for(int k = 0; k < dims[2]; ++k)
        for(int j = 0; j < dims[1]; ++j)
            for(int i = 0; i < dims[0]; ++i)
            {
                *pts++ = *xc++;
                *pts++ = *yc++;
                *pts++ = *zc++;
            }
}
else if(ndims == 2)
{
    for(int j = 0; j < dims[1]; ++j)
```

```

        for(int i = 0; i < dims[0]; ++i)
        {
            *pts++ = *xc++;
            *pts++ = *yc++;
            *pts++ = 0.;
        }
    }

    // Delete temporary arrays.
    delete [] xarray;
    delete [] yarray;
    delete [] zarray;

    return sgrid;
}

```

4.5.4 Point meshes

Point meshes are collections of particle positions that can be displayed in VisIt as points or small glyphed icons. Point meshes can be returned from the GetMesh method as vtkUnstructuredGrid objects that contain the locations of the points and connectivity composed entirely of vertex cells.

The next code listing shows how to create a vtkUnstructuredGrid object once you have read the required information from your file format. The underlined portions of the code listing indicate incomplete code that you will need to replace with code that can read data from your file format. First, read the number of dimensions for your mesh from the file format and store the value into the `ndims` variable. Next, read the number of points that make up the point mesh into the `nnodes` variable. Finally, fill in the code for reading the X coordinate values into the `xarray` array and do the same for the Y and Z coordinate arrays. Once you have replaced the underlined code portions with code that reads values from your file format, your plug-in should be able to return a valid vtkUnstructuredGrid object once you rebuild it.

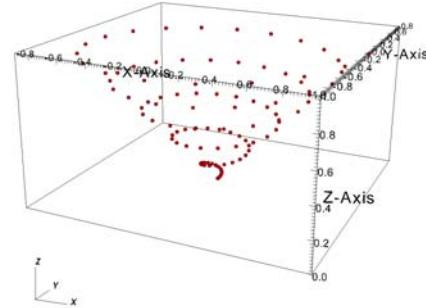


Figure 4-26: 3D point mesh

Listing 4-27: getmesh_point.C: C++ Language example for returning a point mesh from GetMesh.

```

// NOTE - This code incomplete and requires underlined portions
// to be replaced with code to read values from your file format.

#include <vtkPoints.h>
#include <vtkUnstructuredGrid.h>

```

```
vtkDataSet *
avtXXXFileFormat::GetMesh(const char *meshname)
{
    int ndims = 2;
    int nnodes;

    // Read the ndims and number of nodes from file.
ndims = NUMBER OF MESH DIMENSIONS;
nnodes = NUMBER OF NODES IN THE MESH;

    // Read the X coordinates from the file.
    float *xarray = new float[nnodes];
READ nnodes FLOAT VALUES INTO xarray

    // Read the Y coordinates from the file.
    float *yarray = new float[nnodes];
READ nnodes FLOAT VALUES INTO yarray

    // Read the Z coordinates from the file.
    float *zarray = 0;
    if(ndims > 2)
    {
        zarray = new float[nnodes];
READ dims[2] FLOAT VALUES INTO zarray
    }

    //
    // Create the vtkPoints object and copy points into it.
    //
    vtkPoints *points = vtkPoints::New();
    points->SetNumberOfPoints(nnodes);
    float *pts = (float *) points->GetVoidPointer(0);
    float *xc = xarray;
    float *yc = yarray;
    float *zc = zarray;
    if(ndims == 3)
    {
        for(int i = 0; i < nnodes; ++i)
        {
            *pts++ = *xc++;
            *pts++ = *yc++;
            *pts++ = *zc++;
        }
    }
    else if(ndims == 2)
    {
        for(int i = 0; i < nnodes; ++i)
        {
            *pts++ = *xc++;
            *pts++ = *yc++;
            *pts++ = 0.;
        }
    }
}
```

```

// Create a vtkUnstructuredGrid to contain the point cells.
//
vtkUnstructuredGrid *ugrid = vtkUnstructuredGrid::New();
ugrid->SetPoints(points);
points->Delete();
ugrid->Allocate(nnodes);
vtkIdType onevertex;
for(int i = 0; i < nnodes; ++i)
{
    onevertex = i;
    ugrid->InsertNextCell(VTK_VERTEX, 1, &onevertex);
}

// Delete temporary arrays.
delete [] xarray;
delete [] yarray;
delete [] zarray;

return ugrid;
}

```

4.5.5 Unstructured meshes

Unstructured meshes are collections of cells of various geometries that are specified using indices into an array of points. When you write your GetMesh method, if your mesh is best described as an unstructured mesh then you can return a vtkUnstructuredGrid object.

Like some of the other mesh objects, the vtkUnstructuredGrid object also uses a vtkPoints object to contain its node array. In addition to the vtkPoints array, the vtkUnstructuredGrid object maintains a list of cells whose connectivity is determined by setting the cell type to one of VTK's predefined unstructured cell types (VTK_VERTEX, VTK_LINE, VTK_TRIANGLE, VTK_QUAD, VTK_TETRA, VTK_PYRAMID, VTK_WEDGE, and VTK_HEXAHEDRON), shown in Figure 4-29. When you add a cell using one of the predefined unstructured cell types, you must also provide a list of node indices that are

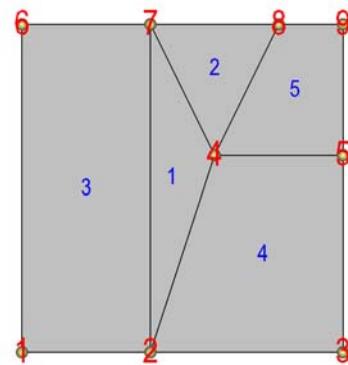


Figure 4-28: 2D unstructured mesh composed of triangles and quadrilaterals. The node numbers are labelled red and the cell numbers are labelled blue.

used as the nodes for the cell. The number of nodes that each cell contains is determined by its cell type.

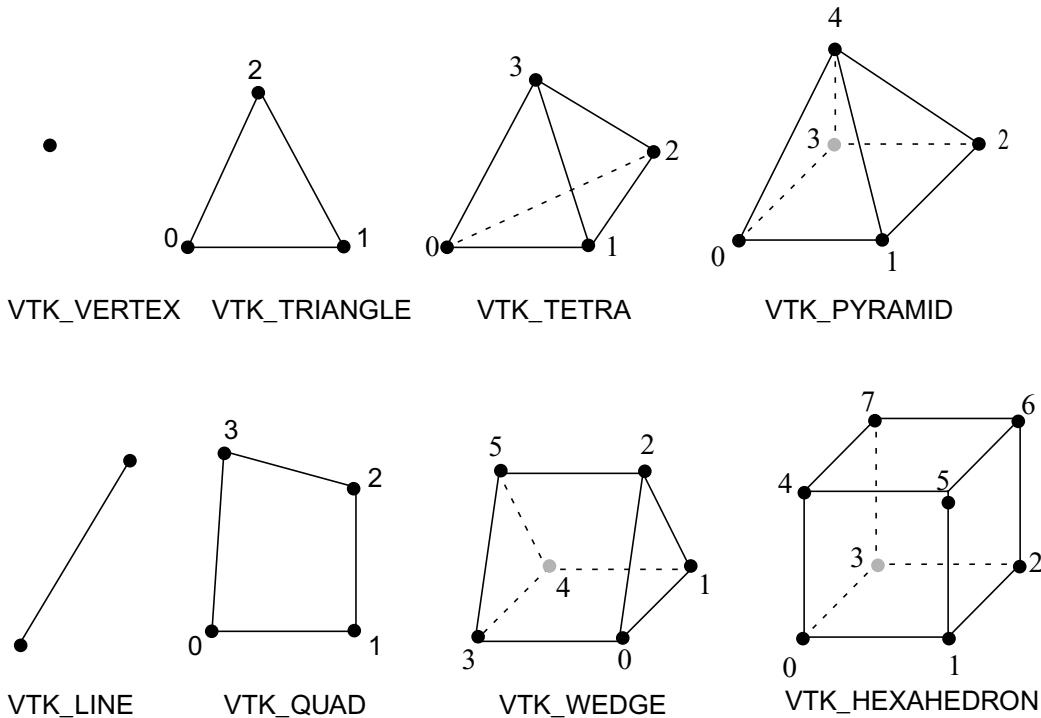


Figure 4-29: Node ordering for some VTK unstructured cell types

The next code listing shows how to create a `vtkUnstructuredGrid` object. The connectivity for an unstructured grid can be stored in a file format using a myriad of different approaches. The example code assumes that the connectivity will be stored in an integer array that contains the information for each cell, beginning with the cell type for the first cell, followed by a list of node indices that are used in the cell. After that, the cell type for the second cell appears, followed by its node indices, and so on. For example, if you wanted to store connectivity for cells 1 and 2 in the example shown in Figure 4-28 then the connectivity array would contain: [VTK_TRIANGLE, 2, 4, 7, VTK_TRIANGLE, 4, 8, 7, ...]. Note that the node indices in the example begin at one so the example code will subtract one from all of the node indices to ensure that they begin at zero, the starting index for the `vtkPoints` array.

Listing 4-30: `getmesh_ugrid.C`: C++ Language example for returning an unstructured mesh from GetMesh.

```
// NOTE - This code incomplete and requires underlined portions
// to be replaced with code to read values from your file format.

#include <vtkPoints.h>
#include <vtkUnstructuredGrid.h>
#include <InvalidVariableException.h>
```

```
vtkDataSet *
avtXXXFileFormat::GetMesh(const char *meshname)
{
    int ndims = 2;
    int nnodes, ncells, origin = 1;

    // Read the ndims, nnodes, ncells, origin from file.
    ndims = NUMBER OF MESH DIMENSIONS;
    nnodes = NUMBER OF NODES IN THE MESH;
    ncells = NUMBER OF CELLS IN THE MESH;
    origin = GET THE ARRAY ORIGIN (0 or 1);

    // Read the X coordinates from the file.
    float *xarray = new float[nnodes];
    READ nnodes FLOAT VALUES INTO xarray

    // Read the Y coordinates from the file.
    float *yarray = new float[nnodes];
    READ nnodes FLOAT VALUES INTO yarray

    // Read the Z coordinates from the file.
    float *zarray = 0;
    if(ndims > 2)
    {
        zarray = new float[nnodes];
        READ dims[2] FLOAT VALUES INTO zarray
    }

    // Read in the connectivity array. This example assumes that
    // the connectivity will be stored: type, indices, type,
    // indices, ... and that there will be a type/index list
    // pair for each cell in the mesh.
    int *connectivity = 0;
    ALLOCATE connectivity ARRAY AND READ VALUES INTO IT.

    //
    // Create the vtkPoints object and copy points into it.
    //
    vtkPoints *points = vtkPoints::New();
    points->SetNumberOfPoints(nnodes);
    float *pts = (float *) points->GetVoidPointer(0);
    float *xc = xarray;
    float *yc = yarray;
    float *zc = zarray;
    if(ndims == 3)
    {
        for(int i = 0; i < nnodes; ++i)
        {
            *pts++ = *xc++;
            *pts++ = *yc++;
            *pts++ = *zc++;
        }
    }
}
```

```
    else if(ndims == 2)
    {
        for(int i = 0; i < nnodes; ++i)
        {
            *pts++ = *xc++;
            *pts++ = *yc++;
            *pts++ = 0.;
        }
    }

    // Delete temporary arrays.
    delete [] xarray;
    delete [] yarray;
    delete [] zarray;

    //

    // Create a vtkUnstructuredGrid to contain the point cells.
    //
    vtkUnstructuredGrid *ugrid = vtkUnstructuredGrid::New();
    ugrid->SetPoints(points);
    points->Delete();
    ugrid->Allocate(ncells);
    vtkIdType verts[8];
    int *conn = connectivity;
    for(int i = 0; i < ncells; ++i)
    {
        int fileCellType = *conn++;
        // You file's cellType will likely not match so you
        // will have to translate fileCellType to a VTK
        // cell type.
        int cellType = MAP fileCellType TO VTK CELL TYPE.

        // Determine number of vertices for each cell type.
        if(cellType == VTK_VERTEX)
            nverts = 1;
        else if(cellType == VTK_LINE)
            nverts = 2;
        else if(cellType == VTK_TRIANGLE)
            nverts = 3;
        else if(cellType == VTK_QUAD)
            nverts = 4;
        else if(cellType == VTK_TETRA)
            nverts = 4;
        else if(cellType == VTK_PYRAMID)
            nverts = 5;
        else if(cellType == VTK_WEDGE)
            nverts = 6;
        else if(cellType == VTK_HEXAHEDRON)
            nverts = 8;
        else
        {
            delete [] connectivity;
            ugrid->Delete();
            // Other cell type - need to add a case for it.
        }
    }
}
```

```

    // In the meantime, throw exception or if you
    // know enough, skip the cell.
    EXCEPTION0(InvalidVariableException, meshname);
}

// Make a list of node indices that make up the cell.
for(int j = 0; j < nverts; ++j)
    verts[j] = conn[j] - origin;
conn += nverts;

// Insert the cell into the mesh.
ugrid->InsertNextCell(cellType, nverts, verts);
}

delete [] connectivity;

return ugrid;
}

```

The previous code listing shows how to create an unstructured mesh in a `vtkUnstructuredGrid` object. The code listing contains underlined portions that you must replace with working code to read the relevant data from your file format. The first instance of code that must be replaced are the lines that read `ndims`, `nnodes`, `ncells`, and `origin` from the file format. The `ndims` variable should contain 2 or 3, depending on whether your data is 2D or 3D. The `nnodes` variable should contain the number of nodes that are used in the set of vertices that describe your unstructured mesh. The `ncells` variable should contain the number of cells that will be added to your unstructured mesh. The `origin` variable should contain 0 or 1, depending on whether your connectivity indices begin at 0 or 1. Once you have set those variables to the appropriate values, you must read in the X, Y, and Z coordinate arrays from the file format and store the values into the `xarray`, `yarray`, and `zarray` array variables. If your file format keeps X,Y,Z values together in a single array then you may be able to read the coordinate values directly into the `vtkPoint` object's memory, skipping the step of copying the X,Y,Z coordinate components into the `vtkPoint` object.

After reading in the coordinate values from your file format, unstructured meshes require two more changes to the code in the listing. The next change requires you to allocate memory for a `connectivity` array, which stores the type of cells and the nodes indices of the nodes that are used in the cells. The final change that you must make to the source code in the listing is located further down in the loop that adds cells to the `vtkUnstructuredGrid` object. The cell type read from your file format will most likely not use the same enumerated type values that VTK uses for its cell types (`VTK_VERTEX`, `VTK_LINE`, ...) so you will need to add code to translate from your cell type designation to VTK cell type numbers. After making the necessary changes and rebuilding your plug-in, your plug-in's `GetMesh` method should be capable of returning a valid `vtkUnstructuredGrid` object for VisIt to plot.

4.6 Returning a scalar variable

Now that you can successfully create a Mesh plot of the meshes from your file format, you can focus on other types of data such as scalars. If you exposed scalar variables in your plug-in's `PopulateDatabaseMetaData` method then those variable names will appear in the plot menus for plots that can use scalar variables (e.g. the Pseudocolor plot). When you create a plot of a scalar variable and click the **Draw** button in the VisIt GUI, VisIt will tell your database reader plug-in to open your file, read the mesh, and then your plug-in's `GetVar` method will be called with the name of the variable that you want to plot. The `GetVar` method, like the `GetMesh` method, takes a variable name as an argument. When you receive the variable name in the `GetVar` method you should access your file and read out the desired variable and return it in a VTK data array such as a `vtkFloatArray` or a `vtkDoubleArray`. A `vtkFloatArray` is a VTK object that encapsulates a dynamically allocated array of a given length. The length of the array that you allocate to contain your variable must match either the number of cells in your mesh or the number of nodes in your mesh. The length is determined by the scalar variable's centering (cell-centered, node-centered).

Listing 4-31: `getvar.C`: C++ Language example for returning data from `GetVar`.

```
// NOTE - This code incomplete and requires underlined portions
// to be replaced with code to read values from your file format.

#include <vtkFloatArray.h>

vtkDataArray *
avtXXXfileFormat::GetVar(const char *varname)
{
    int nvals;
    // Read the number of values contained in the array
    // specified by varname.
    nvals = NUMBER OF VALUES IN ARRAY NAMED BY varname;

    // Allocate the return vtkFloatArray object. Note that
    // you can use vtkFloatArray, vtkDoubleArray,
    // vtkUnsignedCharArray, vtkIntArray, etc.
    vtkFloatArray *arr = vtkFloatArray::New();
    arr->SetNumberOfTuples(nvals);
    float *data = (float *)arr->GetVoidPointer(0);
    READ nvals FLOAT NUMBERS INTO THE data ARRAY.

    return arr;
}
```

In the previous code listing, there are two underlined areas that need to have code added to them in order to have a completed `GetVar` method. The first change that you must make is to add code to read the size of the array to be created into the `nvals` variable. The value that is read into the `nvals` variable must be either the number of cells in the mesh on

which the variable is defined if you have a cell-centered variable or it must be the number of nodes in the mesh. Once you have successfully set the proper value into the `nvals` variable, you can proceed to read values from your file format into the `data` array, which points to storage owned by the `vtkFloatArray` object that will be returned from the `GetVar` method. Once you have made these changes, you can rebuilt your plug-in and begin plotting scalar variables.

4.7 Returning a vector variable

If you exposed vector variables in your plug-in's `PopulateDatabaseMetaData` method then those variable names will appear in the plot menus for plots that can use vector variables (e.g. the Vector plot). When you create a plot of a vector variable and click the **Draw** button in the VisIt GUI, VisIt will tell your database reader plug-in to open your file, read the mesh, and then your plug-in's `GetVectorVar` method will be called with the name of the variable that you want to plot. The `GetVectorVar` method, like the `GetMesh` method, takes a variable name as an argument. When you receive the variable name in the `GetVectorVar` method you should access your file and read out the desired variable and return it in a VTK data array such as a `vtkFloatArray` or a `vtkDoubleArray`. A `vtkFloatArray` is a VTK object that encapsulates a dynamically allocated array of a given length. The length of the array that you allocate to contain your variable must match either the number of cells in your mesh or the number of nodes in your mesh. The length is determined by the scalar variable's centering (cell-centered, node-centered). In addition to setting the length, which like a scalar variable is tied to the number of cells or nodes, you must also set the number of vector components. In VisIt, vector variables always have three components. If the third component is not needed then all values in the third component should be set to zero.

The `GetVectorVar` code listing shows how to return a `vtkFloatArray` with multiple components from the `GetVectorVar` method. As with the code listing for `GetVar`, this code listing requires you to replace underlined portions of code with code that reads data from your file format and stores the results in the variables provided.

Listing 4-32: `getvectorvar.C`: C++ Language example for returning data from `GetVectorVar`.

```
// NOTE - This code incomplete and requires underlined portions
// to be replaced with code to read values from your file format.

#include <vtkFloatArray.h>
#include <InvalidVariableException.h>

vtkDataArray *
avtXXXfileFormat::GetVectorVar(const char *varname)
{
    int nvals, ncomps = 3;

    // Read the number of values contained in the array
    // specified by varname.
```

```
nvals = NUMBER OF VALUES IN ARRAY NAMED BY varname;
ncomps = NUMBER OF VECTOR COMPONENTS IN ARRAY NAMED BY varname;

// Read component 1 from the file.
float *comp1 = new float[nvals];
READ nvals FLOAT VALUES INTO comp1

// Read component 2 from the file.
float *comp2 = new float[nvals];
READ nvals FLOAT VALUES INTO comp2

// Read component 3 from the file.
float *comp3 = 0;
if(ncomps > 2)
{
    comp3 = new float[nvals];
    READ nvals FLOAT VALUES INTO comp3
}

// Allocate the return vtkFloatArray object. Note that
// you can use vtkFloatArray, vtkDoubleArray,
// vtkUnsignedCharArray, vtkIntArray, etc.
vtkFloatArray *arr = vtkFloatArray::New();
arr->SetNumberOfComponents(3);
arr->SetNumberOfTuples(nvals);
float *data = (float *)arr->GetVoidPointer(0);
float *c1 = comp1;
float *c2 = comp2;
float *c3 = comp3;
if(ncomps == 3)
{
    for(int i = 0; i < nvals; ++i)
    {
        *data++ = *c1++;
        *data++ = *c2++;
        *data++ = *c3++;
    }
}
else if(ncomps == 2)
{
    for(int i = 0; i < nvals; ++i)
    {
        *data++ = *c1++;
        *data++ = *c2++;
        *data++ = 0.;
    }
}
else
{
    delete [] comp1;
    delete [] comp2;
    delete [] comp3;
    arr->Delete();
    EXCEPTION1(InvalidVariableException, varname);
```

```
}

// Delete temporary arrays.
delete [] comp1;
delete [] comp2;
delete [] comp3;

return arr;
}
```

4.8 Using a VTK reader class

The implementations so far for the `GetMesh`, `GetVar`, and `GetVectorVar` plug-in methods have assumed that the database plug-in would do the work of interacting with the file format to read data into VTK form. Most of the work of reading a file and creating VTK objects from it can be handled at the VTK level if you wish. This means that it is possible to use an existing VTK reader class to read data into VisIt if you are willing to implement your plug-in methods so that they in turn call the VTK reader object's methods. See VisIt's VTK database reader plug-in for an example of how to call VTK reader objects from inside a VisIt database reader plug-in.

5.0 Advanced topics

If you've implemented your database reader plug-in using only the techniques outlined in this chapter so far then you likely have a database reader plug-in that works and correctly serves up its data to VisIt in VTK form. This part of the chapter explains some of the more advanced, though not necessarily required, techniques that you can use to enhance your plug-in. For instance, you can enhance your plug-in so it returns the correct simulation times from the data files. You can also add code to return data and spatial extents for your data, enabling VisIt to make more optimization decisions when processing files with multiple domains.

5.1 Returning cycles and times

Simulations often iterate for many thousands of cycles while they solve their systems of equations. Generally, each simulation cycle has an associated cycle number and time value. Many file formats save this information so it can be made available later to post-processing tools such as VisIt. VisIt uses cycles and times to help you navigate through time in your database by providing the same time frame of reference that your simulation used. VisIt's **File panel** can display times next to each time state in a database and can

also show the current time value as you scroll through time using the time slider. Cycle and time values for the current time state are often displayed in the visualization window.

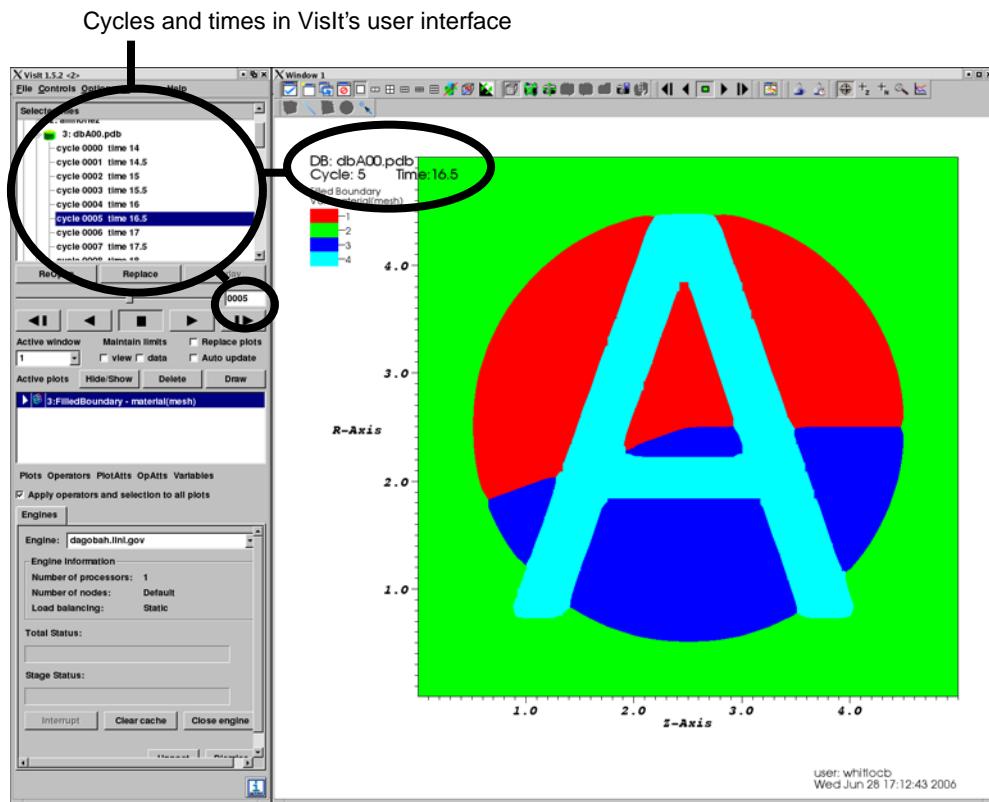


Figure 4-33: Cycles and times values are used to help you navigate through time

Returning cycle and time values from your plug-in is completely optional. In fact, returning cycle and time values for data such as CAD drawings does not make sense. Since returning cycles and times is optional in a VisIt database reader plug-in, you can choose to not implement the methods that return cycles and times. You can also implement code to return time but not cycles or vice-versa.

The mechanics of returning cycles and times are a little different depending on whether you have written an ST or an MT database reader plug-in. In any case, if your plug-in implements the methods to return cycles or times then those methods will be some of the first methods called when VisIt accesses your database reader plug-in. VisIt calls the methods to get cycles and times and if the returned values appear to be valid then they are

added to the metadata for your file so they can be returned to the VisIt clients and used to populate windows such as the **File Information** window, shown in Figure 4-34.

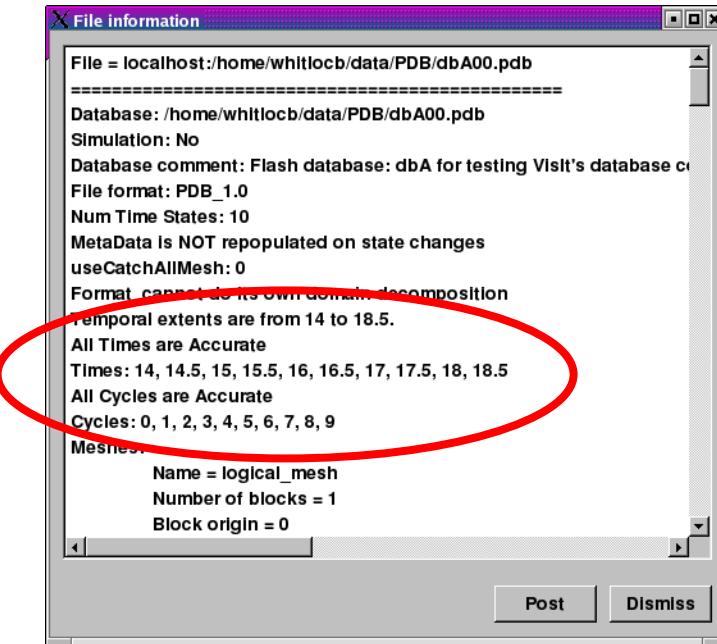


Figure 4-34: The File Information window can be used to inspect the cycles and times returned from your plug-in.

5.1.1 Returning cycles and times in an ST plug-in

When VisIt creates plug-in objects to handle a list of files using an ST plug-in, there is one plug-in object per file in the list of files. Since each plug-in object can only ever be associated with one file, the programming interface for returning cycles and times for an ST plug-in provides methods that return a single value. The methods for returning cycles and times for an ST plug-in are:

```

virtual bool      ReturnsValidCycle() const { return true; }
virtual int       GetCycle(void);
virtual bool      ReturnsValidTime() const { return true; }
virtual double    GetTime(void);

```

Implementing valid cycles and times can be done independently of one another and there is no requirement that you have to implement both or either of them, for that matter. The `ReturnsValidCycle` method is a simple method that you should expose if you plan to provide a custom `GetCycle` method in your database reader plug-in. If you provide `GetCycle` then the `ReturnsValidCycle` method should return true. The same pattern applies if you implement `GetTime` - except that you would also implement the

ReturnsValidTime method. Replace the underlined sections of code in the listing with code to read the correct cycle and time values from your file format.

Listing 4-35: cycletime_st.C: C++ Language example for returning cycles, times from ST plug-in.

```
// NOTE - This code incomplete and requires underlined portions
// to be replaced with code to read values from your file format.

int
avtXXXFileFormat::GetCycle(void)
{
    int cycle = OPEN FILE AND READ THE CYCLE VALUE;
    return cycle;
}

double
avtXXXFileFormat::GetTime(void)
{
    double dtime = OPEN FILE AND READ THE TIME VALUE;
    return dtime;
}
```

In the event that you implement the GetCycle method but no cycle value is available in the file, you can return the INVALID_CYCLE value to make VisIt discard your plug-in's cycle number and guess the cycle number from the filename. If you want VisIt to successfully guess the cycle number from the filename then you must implement the GetCycleFromFilename method.

```
int
avtXXXXFileFormat::GetCycleFromFilename(const char *f) const
{
    return GuessCycle(f);
}
```

5.1.2 Returning cycles and times in an MT plug-in

An MT database reader plug-in may return cycles and times for multiple time states so the programming interface for MT plug-ins allows you to return vectors of cycles and times. In addition, an MT database reader plug-in prefers to know upfront how many time states will be returned from the file format so in addition to GetCycles and GetTimes methods, there is a GetNTimesteps method that is among the first methods called from your database reader plug-in.

```

virtual void GetCycles(std::vector<int> &);
virtual void GetTimes(std::vector<double> &);
virtual int GetNTimesteps(void);

```

As with ST plug-ins, there is no requirement that an MT plug-in must provide a list of cycles or times. However, an MT plug-in must provide a `GetNTimesteps` method. If you are enhancing your database reader plug-in to return cycles and times then it is convenient to implement your `GetNTimesteps` method such that it just calls your `GetCycles` or `GetTimes` method and returns the length of the vector returned by those methods. This simplifies the implementation and ensures that the number of time states reported by your database reader plug-in matches the length of the cycle and time vectors returned from `GetCycles` and `GetTimes`. Replace the underlined sections of code in the listing with code to read the correct cycles and times from your file format.

Listing 4-36: cycletime_mt.C: C++ Language example for returning cycles, times from MT plug-in.

```

// NOTE - This code incomplete and requires underlined portions
// to be replaced with code to read values from your file format.

void
avtXXXFileFormat::GetCycles(std::vector<int> &cycles)
{
    int ncycles, *vals = 0;
ncycles = OPEN FILE AND READ THE NUMBER OF CYCLES;
READ ncycles INTEGER VALUES INTO THE vals ARRAY;

    // Store the cycles in the vector.
    for(int i = 0; i < ncycles; ++i)
        cycles.push_back(vals[i]);

    delete [] vals;
}

void
avtXXXFileFormat::GetTime(std::vector<double> &times)
{
    int ntimes;
    double *vals = 0;
ntimes = OPEN FILE AND READ THE NUMBER OF TIMES;
READ ntimes DOUBLE VALUES INTO THE vals ARRAY;

    // Store the times in the vector.
    for(int i = 0; i < ntimes; ++i)
        times.push_back(vals[i]);

    delete [] vals;
}

int
avtXXXXFileFormat::GetNTimesteps(void)

```

```
{  
    std::vector<double> times;  
    GetTimes(times);  
    return times.size();  
}
```

5.2 Auxiliary data

This section describes how to enable your MD database reader plug-in so it can provide auxiliary data such as data extents, spatial extents, and materials to VisIt if they are available in your file format. “Auxiliary data”, is the generic term for many types of data that VisIt’s pipeline can use to perform specific tasks such as I/O reduction or material selection. VisIt’s database reader plug-in interfaces provide a method called `GetAuxiliaryData` that you can implement if you want your plug-in to be capable of returning auxiliary data. Note however that if your plug-in is MTMD then you will have to cache your spatial and data extents in the plug-in’s variable cache in the `PopulateDatabaseMetaData` method instead of returning that information from the `GetAuxiliaryData` method. This subtle difference in how certain metadata is accessed by VisIt must be observed by an MTMD plug-in in order for it to return spatial and data extents.

The method arguments for the `GetAuxiliaryData` method may vary somewhat depending on whether your database reader plug-in is based on the STSD, STMD, MTSD, MTMD interfaces. There is an extra integer argument for the time state if your plug-in is MT and there is another integer argument for the domain if your plug-in is MD. Those differences aside, the `GetAuxiliaryData` method always accepts the name of a variable, a string indicating the type of data being requested, a pointer to optional data required by the type of auxiliary data being requested, and a return reference for a destructor function that will be responsible for freeing resources for the returned data. The variable name that VisIt passes to the `GetAuxiliaryData` method is the name of a variable such as those passed to the `GetVar` method when VisIt wants to read a variable’s data.

5.2.1 Returning data extents

When an MD database reader plug-in provides data extents for each of its domains, VisIt has enough information to make important optimization decisions in filters that support data extents. For example, if you create a Contour plot using a specific contour value, VisIt can check the data extents for each domain before any domains are read from disk and determine the list of domains that contain the desired contour value. After determining which subset of the domains will contribute to the final image, VisIt’s compute engine then reads and processes only those domains, saving work and accelerating VisIt’s computations. For a more complete explanation of data extents, see “Writing data extents” on page 72.

In the context of returning data extents, VisIt first checks a plug-in's variable cache for extents. If the desired extents are not available then VisIt calls the plug-in's GetAuxiliaryData method with the name of the scalar variable for which data extents are required and also passes AUXILIARY_DATA_DATA_EXTENTS as the type argument, indicating that the GetAuxiliaryData method is being called to obtain the data extents for the specified scalar variable. If the data extents for the specified variable are not available then the GetAuxiliaryData method should return 0. If the data extents are available then the list of minimum and maximum values for the specified variable are assembled into an interval tree structure that VisIt uses for fast comparisons of different data ranges. Once the interval tree is constructed, as shown in the code listing, the GetAuxiliaryData method must return the interval tree object and set the destructor function argument to a function that can be called to later destroy the interval tree. To add support for data extents to your database reader plug-in, copy the GetAuxiliaryData method in the code listing and replace the underlined lines of code with code that reads the required information from your file format.

Listing 4-37: dataextents.C: C++ Language example for returning data extents.

```
// NOTE - This code incomplete and requires underlined portions
// to be replaced with code to read values from your file format.

#include <avtIntervalTree.h>

// STMD version of GetAuxiliaryData.
void *
avtXXXXFileFormat::GetAuxiliaryData(const char *var,
    int domain, const char *type, void *,
    DestructorFunction &df)
{
    void *retval = 0;

    if(strcmp(type, AUXILIARY_DATA_DATA_EXTENTS) == 0)
    {
        // Read the number of domains for the mesh.
        int ndoms = READ NUMBER OF DOMAINS FROM FILE;

        // Read the min/max values for each domain of the
        // "var" variable. This information should be in
        // a single file and should be available without
        // having to read the real data.
        double *minvals = new double[ndoms];
        double *maxvals = new double[ndoms];
        READ ndoms DOUBLE VALUES INTO minvals ARRAY.
        READ ndoms DOUBLE VALUES INTO maxvals ARRAY.

        // Create an interval tree
        avtIntervalTree *itree = new avtIntervalTree(ndoms, 1);
        for(int dom = 0; dom < ndoms; ++dom)
        {
            double range[2];
            minvals[dom] = range[0];
            maxvals[dom] = range[1];
            itree->InsertRange(var, domain, range);
        }
        df = DeleteIntervalTree;
        retval = itree;
    }
}
```

```
        range[0] = minvals[dom];
        range[1] = maxvals[dom];
        itree->AddElement(dom, range);
    }
    itree->Calculate(true);

    // Delete temporary arrays.
    delete [] minvals;
    delete [] maxvals;

    // Set return values
    retval = (void *)itree;
    df = avtIntervalTree::Destruct;
}
return retval;
}
```

5.2.2 Returning spatial extents

Another type of auxiliary data that VisIt supports for MD file formats are spatial extents. When VisIt knows the spatial extents for all of the domains that comprise a mesh, VisIt can optimize operations such as the Slice operator by first determining whether the slice will intersect a given domain. The Slice operator is thus able to use spatial extents to determine which set of domains must be read from disk and processed in order to produce the correct visualization. Spatial extents are used in this way by many filters to reduce the set of domains that must be processed.

When VisIt asks the database reader plug-in for spatial extents, the `GetAuxiliaryData` method is called with its type argument set to `AUXILIARY_DATA_SPATIAL_EXTENTS`. When VisIt creates spatial extents, they are stored in an interval tree structure as they are with data extents. The main difference is the input into the interval tree. When adding information about a specific domain to the interval tree, you must provide the minimum and maximum spatial values for the domain's X, Y, and Z dimensions. The spatial extents for one domain are expected to be provided in the following order: xmin, xmax, ymin, ymax, zmin, zmax. To add support for spatial extents to your database reader plug-in, copy the `GetAuxiliaryData` method in the code listing and replace the underlined lines of code with code that reads the required information from your file format.

Listing 4-38: `spatialextents.C`: C++ Language example for returning spatial extents.

```
// NOTE - This code incomplete and requires underlined portions
// to be replaced with code to read values from your file format.

#include <avtIntervalTree.h>

// STMD version of GetAuxiliaryData.
```

```

void *
avtXXXXFileFormat::GetAuxiliaryData(const char *var,
    int domain, const char *type, void *,
    DestructorFunction &df)
{
    void *retval = 0;

    if(strcmp(type, AUXILIARY_DATA_SPATIAL_EXTENTS) == 0)
    {
        // Read the number of domains for the mesh.
        int ndoms = READ NUMBER OF DOMAINS FROM FILE;

        // Read the spatial extents for each domain of the
        // mesh. This information should be in a single
        // and should be available without having to
        // read the real data. The expected format for
        // the data in the spatialextents array is to
        // repeat the following pattern for each domain:
        // xmin, xmax, ymin, ymax, zmin, zmax.
        double *spatialextents = new double[ndoms * 6];
        READ ndoms*6 DOUBLE VALUES INTO spatialextents ARRAY.

        // Create an interval tree
        avtIntervalTree *itree = new avtIntervalTree(ndoms, 3);
        double *extents = spatialextents;
        for(int dom = 0; dom < ndoms; ++dom)
        {
            itree->AddElement(dom, extents);
            extents += 6;
        }
        itree->Calculate(true);

        // Delete temporary array.
        delete [] spatialextents;

        // Set return values
        retval = (void *)itree;
        df = avtIntervalTree::Destruct;
    }
    return retval;
}

```

5.2.3 Returning materials

Materials are another type of auxiliary data that database plug-ins can provide. A material classifies different pieces of the mesh into different named subsets that can be turned on and off using VisIt's **Subset** window. In the simplest case, you can think of a material as a cell-centered variable, or matlist, defined on your mesh where each cell contains an integer that identifies a particular material such as "Steel" or "Air". VisIt's `avtMaterial` object is used to encapsulate knowledge about materials. The `avtMaterial` object contains the matlist array and a list of names corresponding to

each unique material number in the matlist array. Materials can also be structured so that instead of providing just one material number for each cell in the mesh, you can provide multiple materials per cell with volume fractions occupied by each. So-called “mixed materials” are created using additional arrays, described in “Materials” on page 83. To add support for materials in your database reader plug-in’s GetAuxiliaryData method, replace the underlined lines in the code example with code that read the necessary values from your file format.

Listing 4-39: matclean.C: C++ Language example for returning material data.

```
// NOTE - This code incomplete and requires underlined portions
// to be replaced with code to read values from your file format.

#include <avtMaterial.h>

// STMD version of GetAuxiliaryData.
void *
avtXXXXFileFormat::GetAuxiliaryData(const char *var,
    int domain, const char *type, void *,
    DestructorFunction &df)
{
    void *retval = 0;

    if(strcmp(type, AUXILIARY_DATA_MATERIAL) == 0)
    {
        int dims[3] = {1,1,1}, ndims = 1;
        // Structured mesh case
        ndims = MESH DIMENSION, 2 OR 3;
dims[0] = NUMBER OF ZONES IN X DIMENSION;
dims[1] = NUMBER OF ZONES IN Y DIMENSION;
dims[2] = NUMBER OF ZONES IN Z DIMENSION, OR 1 IF 2D;

        // Unstructured mesh case
dims[0] = NUMBER OF ZONES IN THE MESH
ndims = 1;

        // Read the number of materials from the file. This
        // must have already been read from the file when
        // PopulateDatabaseMetaData was called.
int nmats = NUMBER OF MATERIALS;

        // The matnos array contains the list of numbers that
        // are associated with particular materials. For example,
        // matnos[0] is the number that will be associated with
        // the first material and any time it is seen in the
        // matlist array, that number should be taken to mean
        // material 1. The numbers in the matnos array must
        // all be greater than or equal to 1.
        int *matnos = new int[nmats];
READ nmats INTEGER VALUES INTO THE matnos ARRAY.

        // Read the material names from your file format or
```

```

// make up names for the materials. Use the same
// approach as when you created material names in
// the PopulateDatabaseMetaData method.
char **names = new char *[nmats];
READ MATERIAL NAMES FROM YOUR FILE FORMAT UNTIL EACH
ELEMENT OF THE names ARRAY POINTS TO ITS OWN STRING.

// Read the matlist array, which tells what the material
// is for each zone in the mesh.
int nzones = dims[0] * dims[1] * dims[2];
int *matlist = new int[nzones];
READ nzones INTEGERS INTO THE matlist array.

// Optionally create mix_mat, mix_next, mix_zone, mix_vf
// arrays and read their contents from the file format.

// Use the information to create an avtMaterial object.
avtMaterial *mat = new avtMaterial(
    nmats,
    matnos,
    names,
    ndims,
    dims,
    0,
    matlist,
    0, // length of mix arrays
    0, // mix_mat array
    0, // mix_next array
    0, // mix_zone array
    0 // mix_vf array
);

// Clean up.
delete [] matlist;
delete [] matnos;
for(int i = 0; i < nmats; ++i)
    delete [] names[i];
delete [] names;

// Set the return values.
retval = (void *)mat;
df = avtMaterial::Destruct;
}

return retval;
}

```

5.3 Returning ghost zones

Ghost zones are mesh zones that should not be visible in the visualization but may provide additional information such as values along domain boundaries. VisIt uses ghost zones for

ensuring variable continuity across domain boundaries, for removing internal domain boundary faces, and for blanking out specific zones. This section covers the code that must be added to make your database reader plug-in order for it to return ghost zones to VisIt.

5.3.1 Blanking out zones

Blanking out specific zones so they do not appear in a visualization is a common practice for creating holes in structured meshes so cells zones that overlap or tangle on top of one another can be removed from the mesh. If you want to create a mesh that contains voids where zones have been removed then you can add a special cell-centered array to your mesh before you return it from your plug-in's GetMesh method. The code in the listing can be used to remove zones from any mesh type and works by looking through a mesh-sized array containing on/off values for each zone and sets the appropriate values into the ghost zone array that gets added to the mesh object. Replace any underlined code with code that can read the necessary values from your file format.

Listing 4-40: gz_blank.C: C++ Language example for returning a mesh with blanked out zones.

```
// NOTE - This code incomplete and requires underlined portions
// to be replaced with code to read values from your file format.

#include <avtGhostData.h>
#include <vtkUnsignedCharArray.h>

vtkDataSet *
avtXXXXFormat::GetMesh(const char *meshname)
{
    // Code to create your mesh goes here.
    vtkDataSet *retval = CODE TO CREATE YOUR MESH;

    // Now that you have your mesh, figure out which cells need
    // to be removed.
    int nCells = retval->GetNumberOfCells();
    int *blanks = new int[nCells];
    READ nCells INTEGER VALUES INTO blanks ARRAY.

    // Now that we have the blanks array, create avtGhostZones.
    unsigned char realVal = 0, ghost = 0;
    avtGhostData::AddGhostZoneType(ghost,
        ZONE_NOT_APPLICABLE_TO_PROBLEM);
    vtkUnsignedCharArray *ghostCells = vtkUnsignedCharArray::New();
    ghostCells->SetName("avtGhostZones");
    ghostCells->Allocate(nCells);
    for(int i = 0; i < nCells; ++i)
    {
        if(blanks[i])
            ghostCells->InsertNextValue(realVal);
        else
            ghostCells->InsertNextValue(ghost);
    }
}
```

```

    retval->GetCellData()->AddArray(ghostCells);
    retval->SetUpdateGhostLevel(0);
    ghostCells->Delete();

    // Clean up
    delete [] blanks;

    return retval;
}

```

5.3.2 Ghost zones at the domain boundaries

When ghost zones are used to ensure continuity across domains, an extra layer of zones must be added to the mesh boundaries where the boundary is shared with another domain. Once you have done that step, the approach for providing ghost zones is the same as for blanking out cells using ghost zones if your `blanks` array contains zeroes for only the zones that appear on domain boundaries. The one minor difference is that you must substitute the `DUPLICATED_ZONE_INTERNAL_TO_PROBLEM` ghost zone type for the `ZONE_NOT_APPLICABLE_TO_PROBLEM` ghost zone type in the code example.

5.4 Parallelizing your reader

VisIt is a distributed program made up of multiple software processes that act as a whole. The software process that reads in data and processes it is the compute engine, which comes in serial and parallel versions. All of the `libE` plug-ins in VisIt also have both serial and parallel versions. The parallel `libE` plug-ins can contain specialized MPI communication to support the communication patterns needed by the algorithms used. If you want to parallelize your database reader plug-in then, in most cases, you will have to use the MD interface or convert from SD to MD. There are some SD formats that can adaptively decompose their data so each processor has work (see the ViSUS plug-in) but most database plug-ins that benefit from parallelism instead are implemented as MD plug-ins. MD plug-ins are a natural fit for the parallel compute engine because they serve data that is already decomposed into domains. Some database reader plug-ins, such as the BOV plug-in, take single domain meshes and automatically decompose them into multiple domains for faster processing on multiple processors.

Deriving your plug-in from an MD interface is useful since it naturally tells VisIt to expect data from more than one domain when reading your file format. There are a number of parallel optimizations that can be made inside of your MD database reader plug-in. For example, you might have one processor read the metadata and broadcast it to all other processors so when you visualize your data with a large number of processors, they are not all trying to read the file that contains the metadata.

VisIt's parallel compute engine can use one of two different load balancing schemes: static or dynamic. In static load balancing, each processor is assigned a fixed list of domains and each of those domains is processed one at a time in parallel visualization pipelines until

the result is computed. When static load balancing is used, the same code is executed on all processors with different data and there are more opportunities for parallel, global communication. When VisIt's parallel compute engine uses dynamic load balancing, the master process acts as an executive that assigns work as needed to each processor. When a processor needs work, it requests a domain from the executive and it processes the domain in its visualization pipeline until the results for the domain have been calculated. After that, the processor asks the executive for another domain. In dynamic load balancing, each processor can be working on very different operations so there is no opportunity to do global communication. VisIt attempts to do dynamic load balancing unless any one of the filters in its visualization pipeline requires global communication, in which case static load balancing must be used. This means that the places where global communication can occur are few.

VisIt's database plug-in interfaces provide the `ActivateTimestep` method as a location where global, parallel communication can be performed safely. If your parallel database reader needs to do parallel communication such as broadcasting metadata to all processors, or figuring out data extents in parallel then that code must be added in the `ActivateTimestep` method.

Chapter 5

Instrumenting a simulation code

1.0 Overview

Some simulation programs include a runtime graphics package, which creates visualizations of simulation results during execution. Runtime graphics have a number of advantages over writing out graphics files that can be visualized after the fact by a visualization tool. First of all, graphics files are written far less frequently than the simulation calculates its data because of time and disk space limitations. Secondly, runtime graphics packages have access to all of the variables that a simulation calculates, whereas a graphics file usually contains a small subset of the variables. Finally, by using runtime graphics, users can visualize simulation results as the simulation executes and the user can possibly intercede to change how the simulation runs.

VisIt provides a library that can be used by simulation codes in order to expose data to VisIt, allowing you to use VisIt as a runtime graphics package. This chapter explains in detail the steps required to instrument your C or Fortran simulation so that VisIt can access its data for the purpose of runtime graphics.

2.0 Architecture

Parallel simulations often use a technique called domain decomposition (see Figure 5-1) to break up the simulated problem into smaller pieces called domains. We've learned in earlier chapters how to store data from different domains in a variety of file formats such as Silo and VTK. Simulations often write out 1 domain file per processor, and VisIt

processes all of the individual domain files to produce a unified picture with contributions from all of the relevant domains.

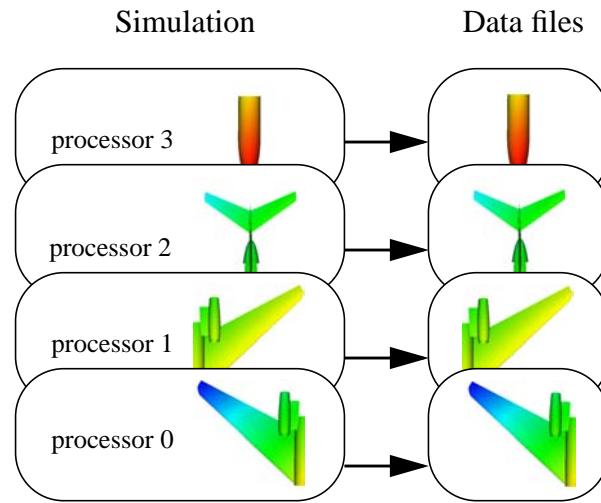


Figure 5-1: Simulation writing data files in parallel

VisIt has a distributed architecture which allows various functions to be grouped into cooperating processes. VisIt's compute engine is particularly relevant when discussing runtime graphics. The compute engine is responsible for reading data from files, generating plots from the data, and sending the plots to VisIt's viewer where the plot can be displayed. In short, VisIt's compute engine is the VisIt component that handles all of the data. Figure 5-2 depicts VisIt's compute engine reading data files in parallel.

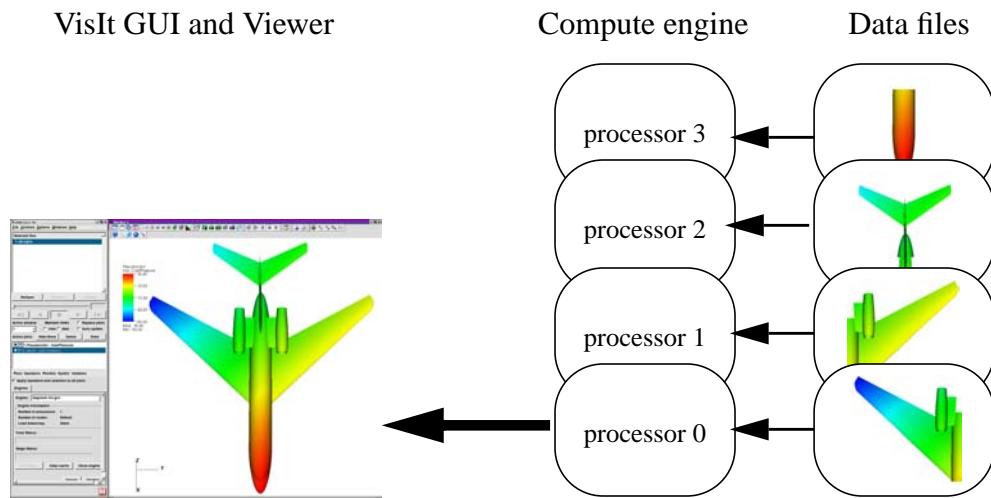


Figure 5-2: VisIt's compute engine reads data files in parallel and sends data to the viewer component.

VisIt users often import their data via files that have been written to disk, making data visualization and analysis a post-processing step. VisIt's `libsim` simulation instrumentation library can be inserted into a simulation program to make the simulation act in many ways like a VisIt compute engine. The `libsim` library, coupled with some data access code that you must write and build into your simulation, gives VisIt's data processing routines access to the simulation's calculated data without the need for the simulation to write files to disk (see Figure 5-3). An instrumented simulation may begin its processing while periodically listening for connections from an instance of VisIt using `libsim`. When `libsim` detects that VisIt wants to connect to the simulation so its data can be visualized, `libsim` loads its dynamic runtime library that contains the VisIt compute engine's data processing functions. Once the runtime is loaded, your simulation connects back to VisIt's viewer and requests for plots and data can be made as though your simulation was a regular VisIt compute engine.

When a request for data comes in from VisIt's viewer, your simulation is asked to provide data via some data access code. Data access code consists of a set of callback functions that your simulation must provide in order to serve data to VisIt. Data access code is written in the same language as your simulation program and it serves as the "glue" that allows the runtime to access your simulation's data so it can be processed and plotted in VisIt. Though the initial portion of this chapter illustrates how to integrate `libsim` routines into your simulation, much of the rest of this chapter will be devoted to writing data access code.

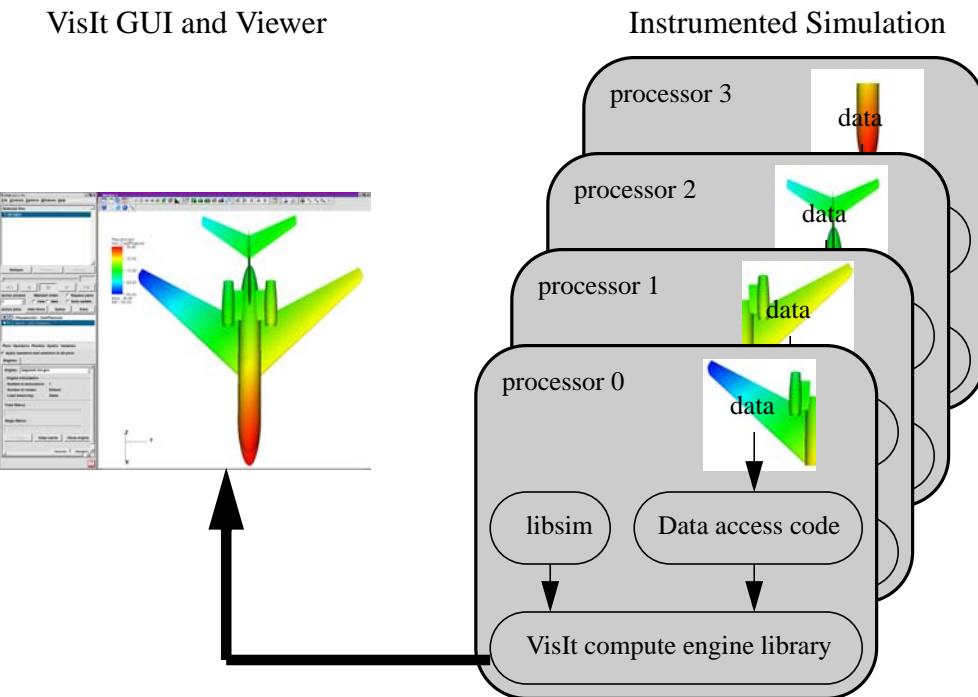


Figure 5-3: VisIt getting data from an instrumented parallel simulation

3.0 Using libsim

The first step in instrumenting a simulation so it can provide data to VisIt is to add the `libsim` library. The `libsim` library is responsible for listening for incoming VisIt connections, connecting to them, and for dynamically loading the runtime that allows the simulation to act as a VisIt compute engine. The `libsim` library can listen for input from incoming VisIt instances, establish connections to VisIt, and respond to console input or input from VisIt. As one might imagine, this implies that your simulation's main loop will need to be changed so it calls critical routines from `libsim`. Restructuring the main loop will be covered shortly. The code examples herein will start from a simple simulation skeleton that builds on itself until a working simulation is created.

3.1 Getting libsim

As of VisIt 2.0, the `libsim` library comes in two flavors: SimV1 and SimV2. SimV1 is the older version of `libsim` and is covered in previous versions of this manual. SimV2 is the newer form of `libsim` and it provides a function-based API for manipulating data instead of one based on C-structs as in SimV1. SimV2 also includes features not present in SimV1 such as support for Adaptive Mesh Refinement (AMR) meshes, Constructive Solid Geometry (CSG) meshes, material species, and many more. The remainder of this manual will target `libsim`'s SimV2 interface.

Both versions of `libsim` are located in the `libsim` directory, which is installed under the version and platform directories when VisIt is installed. There are `V1` and `V2` subdirectories for SimV1 and SimV2, respectively. For example, if you are building against a Linux/Intel version of VisIt 2.0 installed in `/usr/local/apps/visit` then the full path to the `libsim` directory would be: `/usr/local/apps/visit/2.0.0/linux-intel/libsim/V2`. The `V2` subdirectory contains `include` and `lib` directories that give you easy access to the required C and Fortran include files and static libraries.

The files that you need in order to instrument a simulation vary depending on the language that you used to write your simulation.

Language	Include files
C/C++	<code>VisItControlInterface_V2.h</code> <code>VisItDataInterface_V2.h</code>
Fortran	<code>visitfortransimV2interface.inc</code>

3.2 Building in libsim support

Before getting started, it is important to note that `libsim` is currently only available on Linux and MacOS X platforms. A Windows implementation requires additional porting and has not yet been completed.

When you write your simulation in C or C++, you must include `VisItControlInterface_V2.h` and `VisItDataInterface_V2.h` in your simulation's source file. In addition, you must add `libsimV2.a` to the list of libraries against which your program is linked. When your simulation is written in Fortran, you must also take care to include `visitfortransimV2interface.inc` in your Fortran simulation code to assure that the compiler knows the names of the functions that come from `libsim`. You must link your Fortran program against both `libsimV2.a` and `libsimV2f.a`.

Listing 5-4: Including `libsim` header file in C-Language simulation.

```
#include <VisItControlInterface_V2.h>
int main(int argc, char **argv)
{
    return 0;
}
```

Listing 5-5: Including `libsim` header file in Fortran-Language simulation.

```
program main
implicit none
include "visitfortransimV2interface.inc"
stop
end
```

Using `libsim` on UNIX platforms, such as Linux, will most likely require you to link your simulation with the dynamic loader library (`-ldl`) because `libsim` uses the system's `dlopen` function to dynamically load its runtime library.

3.3 Initialization

This section discusses the changes to the main program that are involved when instrumenting a simulation code with `libsim`. The following examples are cartoonish but they show how the main program evolves from something very simple into a main program that can serve as the skeleton of a simulation that can act as a VisIt compute engine. Once you adapt one of your programs to use `libsim`, it is easy to use that program as a template for future simulations. Additions to the example programs in this section will be underlined unless otherwise stated.

The C example programs use a struct called `simulation_data` that represents the simulation's global state and it could contain other data such as the mesh being simulated. The `simulation_data` struct is used as a proxy for your simulation's global state and

will later be used to show how the simulation state can be passed to data access callback functions. The following listing shows the contents of the `simulation_data` struct.

Listing 5-6: sim1.c: C-Language simulation example before adding libsim

```
/* SIMPLE SIMULATION SKELETON */
typedef struct
{
    int      cycle;
    double   time;
    int      runMode;
    int      done;
#ifndef PARALLEL
    int      par_rank;
    int      par_size;
#endif
} simulation_data;

void simulate_one_timestep(simulation_data *sim)
{
    /* Simulate 1 timestep. */
}
int main(int argc, char **argv)
{
    simulation_data sim;
    simulation_data_ctor(&sim);
    read_input_deck(&sim);
    do
    {
        simulate_one_timestep(&sim);
        write_vis_dump(&sim);
    } while(!sim.done);
    simulation_data_dtor(&sim);
    return 0;
}
```

3.3.1 Setting up the environment and creating a .sim2 file

The first libsim functions called when instrumenting a simulation influence the behavior of libsim's `VisItSetupEnvironment` function, which is the first required function that must be called. You may want to call other functions such as

`VisItOpenTraceFile`, `VisItSetDirectory`, or `VisItSetOptions` before calling `VisItSetupEnvironment`.

Function	Description
<code>VisItOpenTraceFile</code>	Open a trace file that contains a trace of all of SimV2's function calls. Trace files are highly recommended because they contain information about every action attempted by libsim and they are invaluable for determining the causes of various types of failure such as when VisIt can't connect to the simulation.
<code>VisItSetDirectory</code>	Set the path to the top level directory where VisIt is installed (e.g. <code>/path/to/visitdir</code>). This is the directory that contains the <code>bin/visit</code> launch script. If you don't call this function, libsim will use whichever <code>visit</code> executable is in your path.
<code>VisItSetOption</code>	Pass a string containing command line arguments to the <code>visit</code> launch script when it is invoked by <code>VisItSetupEnvironment</code> . This is useful if you need to pass a version string or some other arguments to the <code>visit</code> launch script.

After calling optional functions, the first required function that must be called when instrumenting a simulation is the `VisItSetupEnvironment` function. The `VisItSetupEnvironment` function adds important visit-related environment variables to the environment, ensuring that VisIt has the environment that it needs to find its plug-ins, etc.

Step 2 in instrumenting a simulation is to call the `VisItInitializeSocketAndDumpSimFile` function, which initializes the libsim library and writes out a `.sim2` file to your `~/.visit/simulations` directory in your home directory. A `.sim2` file is a small text file that contains details that tell VisIt how to connect to your running simulation. The `.sim2` file contains such information as the name of the computer where your simulation is running, the port that should be used to connect to the simulation, and the key that should be returned when you successfully connect to the simulation. The first argument to the

`VisItInitializeSocketAndDumpSimFile` function is the base name that will be used to construct a filename for the `.sim2` file. The name for a `.sim2` file is typically the specified file base with the time that the simulation started appended to it, allowing you to distinguish between multiple simulations that may be running concurrently. The second argument is a comment that can be used to further identify your simulation. The third argument contains the directory path to where your simulation was started, though it is

mainly reserved for future use. The fourth argument, which is optional, contains the path and name to the simulation’s input file. The fifth argument, which is also optional, contains the name of an XML user interface file that VisIt can use to create a custom user interface for controlling your simulation. The final argument is reserved and you should pass NULL.

Listing 5-7: sim2.c: C-Language simulation example including libsim initialization

```
/* SIMPLE SIMULATION SKELETON */
#include <VisItControlInterface V2.h>
void simulate_one_timestep(simulation_data *sim)
{
    /* Simulate 1 timestep. */
}
int main(int argc, char **argv)
{
    simulation_data sim;
    simulation_data_ctor(&sim);

    /* Initialize environment variables. */
    VisItSetupEnvironment();
    /* Write out .sim file that VisIt uses to connect. */
    VisItInitializeSocketAndDumpSimFile("simname",
        "Simulation Comment", "/path/to/where/sim/was/started",
        NULL, NULL, NULL);

    read_input_deck(&sim);
    do
    {
        simulate_one_timestep(&sim);
        write_vis_dump(&sim);
    } while(!sim.done);
    simulation_data_dtor(&sim);
    return 0;
}
```

3.3.2 Parallel initialization

Parallel programs often require global communication to ensure that all processors are working on the same activity. The libsim library requires periodic global communication to ensure that all processors service the same plot requests from VisIt’s viewer process. Using libsim in a parallel simulation requires a little bit of extra setup. The code in Listing 5-8 differs from the previous code listing in three important ways, each labelled in the listing using comments: *CHANGE 1*, *CHANGE 2*, *CHANGE 3*, respectively.

The first change in the code listing adds two broadcast functions that libsim will use when it needs to broadcast integers or strings. The two callback functions from the code

listing can most likely be copied directly into your simulation. Note that the callback functions are conditionally compiled since they are not needed in a serial simulation.

The second change in Listing 5-8 includes initialization of the MPI library, `par_rank`, `par_size`, and `libsim`. The `par_rank` and `par_size` integers are members of the `simulation_data` struct. Once MPI is initialized, the processor rank and size is queried and stored in `par_rank` and `par_size` so they can be used to initialize `libsim` as well as later for control flow. Various routines that we'll add in future code examples will use the `par_rank`, and `par_size` integers for control flow because processor 0 needs to behave a little differently from the rest of the processors because it communicates with VisIt's viewer. Note that the broadcast functions defined in the first change are registered with `libsim`, using `VisItSetBroadcastIntFunction` and `VisItSetBroadcastStringFunction`, so `libsim` can broadcast integers and strings among processors. Once the broadcast callbacks are installed, `par_rank` and `par_size` are used to tell `libsim` how many processors there are and whether the simulation is parallel using the `VisItSetParallel` and `VisItSetParallelRank` functions.

Listing 5-8: sim2p.c: C-Language simulation example including parallel libsim initialization

```

/* SIMPLE PARALLEL SIMULATION SKELETON */
#include <VisItControlInterface_V2.h>
#include <mpi.h>
void simulate_one_timestep(simulation_data *sim)
{
    /* Simulate 1 timestep. */
}
/* CHANGE 1 */
#ifndef PARALLEL
static int visit broadcast int callback(int *value, int sender)
{
    return MPI_Bcast(value, 1, MPI_INT, sender, MPI_COMM_WORLD);
}
static int visit broadcast string callback(char *str, int len,
    int sender)
{
    return MPI_Bcast(str, len, MPI_CHAR, sender, MPI_COMM_WORLD);
}
#endif

int main(int argc, char **argv)
{
    simulation_data sim;
    simulation_data_ctor(&sim);

    /* Initialize environment variables. */
    VisItSetupEnvironment();
    /* CHANGE 2 */
#ifndef PARALLEL
    /* Initialize MPI */

```

```
MPI_Init(&argc, &argv);
MPI_Comm_rank (MPI_COMM_WORLD, &sim.par_rank);
MPI_Comm_size (MPI_COMM_WORLD, &sim.par_size);

/* Install callback functions for global communication.*/
VisItSetBroadcastIntFunction(visit broadcast int callback);
VisItSetBroadcastStringFunction(visit broadcast string callback);
/* Tell libsim whether the simulation is parallel.*/
VisItSetParallel(sim.par_size > 1);
VisItSetParallelRank(sim.par_rank);
#endif

/* Write out .sim file that VisIt uses to connect. Only do it
 * on processor 0.
 */
/* CHANGE 3*/
if(sim.par_rank == 0)
{
    VisItInitializeSocketAndDumpSimFile("simname",
        "Simulation Comment", "/path/to/where/sim/was/started",
        NULL, NULL, NULL);
}
read_input_deck(&sim);
do
{
    simulate_one_timestep(&sim);
    write_vis_dump(&sim);
} while(!sim.done);
simulation_data_dtor(&sim);

#ifdef PARALLEL
    MPI_Finalize();
#endif

    return 0;
}
```

3.4 Restructuring the main loop

Given the example code from the previous example, the `do..while` loop that serves as the simulation's main loop can be separated out into a new function called `mainloop`. It is possible to add calls to `libsim` into an existing simulation main loop using polling but it is not as clean as restructuring the main loop.

3.4.1 Creating a mainloop function

Moving the `do..while` loop into a separate `mainloop` function will help in the next stage where additional `libsim` functions will be called. If your simulation does not have a well-defined function for simulating one time step, as in the previous example code, then

it is strongly recommended that you refactor your simulation so that code to simulate 1 time can be called from `mainloop` using either a single function or a small block of code. The next examples assume that the simulation provides a function called: `simulate_one_timestep` that can be called over and over again to perform one cycle of the simulation.

Listing 5-9: sim3.c: C-Language simulation example with a mainloop function.

```

/* SIMPLE SIMULATION SKELETON */
#include <VisItControlInterface_V2.h>
void simulate_one_timestep(simulation_data *sim)
{
    /* Simulate 1 timestep. */
}

void mainloop(simulation_data *sim)
{
    do
    {
        simulate_one_timestep(sim);
        write_vis_dump(sim);
    } while(!sim->done);
}

int main(int argc, char **argv)
{
    simulation_data sim;
    simulation_data_ctor(&sim);

    /* Initialize environment variables. */
    VisItSetupEnvironment();
    /* Write out .sim2 file that VisIt uses to connect. */
    VisItInitializeSocketAndDumpSimFile("simname",
        "Simulation Comment", "path/to/where/sim/was/started", NULL,
        NULL, NULL);

    /* Read input problem setup, geometry, data. */
    read_input_deck(&sim);

    /* Call the main loop. */
    mainloop(&sim);

    simulation_data_dtor(&sim);
    return 0;
}

```

3.4.2 Adding libsim functions to mainloop

Now that the main loop of the program has been extracted from the main piece of the simulation, we can perform an even larger change on the `mainloop` function. After

completing these changes, you will have the first simulation in the series that will be able to accept VisIt connections. It will take more changes before the simulation can provide any data to VisIt. The following code example keeps only the `do..while` loop and the call to `simulate_one_timestep`; everything else is new. The structure of the `mainloop` function will be very similar between simulations since most of the code is devoted to detecting input from VisIt using `libsim` and doing the right thing based on that input.

Listing 5-10: sim4.c: C-Language simulation example with fully instrumented mainloop function.

```
void mainloop(simulation_data *sim)
{
    int blocking, visitstate, err = 0;

    do
    {
        blocking = (sim->runMode == VISIT_SIMMODE_RUNNING) ? 0 : 1;
        /* Get input from VisIt or timeout so the simulation can run. */
        visitstate = VisItDetectInput(blocking, -1);

        /* Do different things depending on the output from
        VisItDetectInput. */
        if(visitstate <= -1)
        {
            fprintf(stderr, "Can't recover from error!\n");
            err = 1;
        }
        else if(visitstate == 0)
        {
            /* There was no input from VisIt, return control to sim. */
            simulate_one_timestep(sim);
        }
        else if(visitstate == 1)
        {
            /* VisIt is trying to connect to sim. */
            if(VisItAttemptToCompleteConnection())
                fprintf(stderr, "VisIt connected\n");
            else
                fprintf(stderr, "VisIt did not connect\n");
        }
        else if(visitstate == 2)
        {
            /* VisIt wants to tell the engine something. */
            sim->runMode = VISIT_SIMMODE_STOPPED;
            if(!VisItProcessEngineCommand())
            {
                /* Disconnect on an error or closed connection. */
                VisItDisconnect();
                /* Start running again if VisIt closes. */
                sim->runMode = VISIT_SIMMODE_RUNNING;
            }
        }
    }
```

```

    } while(!sim->done && err == 0);
}

```

There are several functions from `libsim` that are called in the new `mainloop` function. The first `libsim` function that we call is the `VisItDetectInput` function, which listens for inbound VisIt connections on a port that was allocated when `libsim` was initialized. The `VisItDetectInput` function can be called so that it blocks indefinitely, or so that it times out after a brief period. When the simulation starts up, `VisItDetectInput` is called in non-blocking mode so that it times out. When a timeout occurs, the `VisItDetectInput` function returns zero and we call the `simulate_one_timestep` function. Since the `VisItDetectInput` function will continue to time out until VisIt connects to it, this augmented main loop allows the simulation to keep iterating, while still periodically listening for inbound VisIt connections.

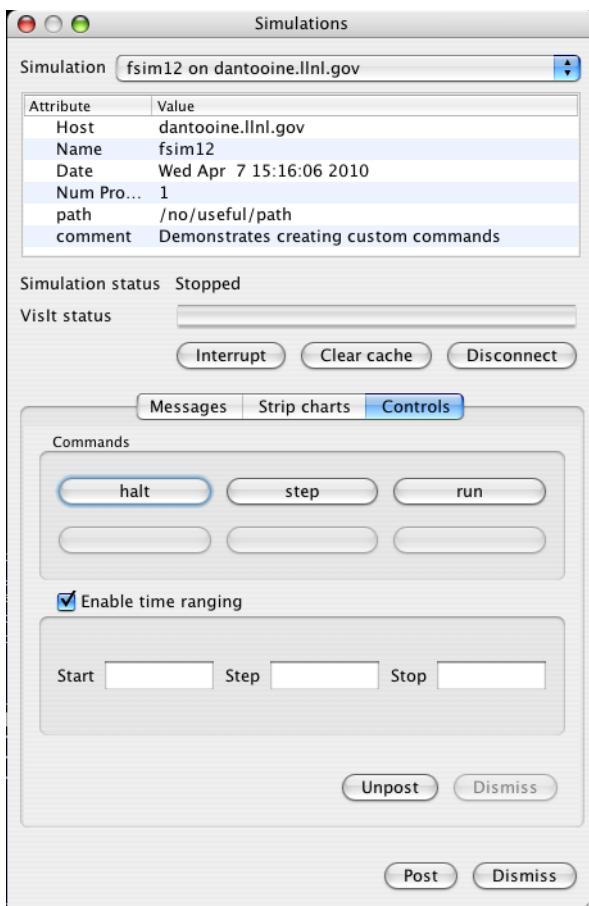


Figure 5-11: Simulation window

function. The `VisItProcessEngineCommand` function reads the commands coming from the viewer and uses them to make requests of the runtime, which ends up requesting and processing the data returned from your data access code. If the

When `VisItDetectInput` returns one, there is an inbound VisIt connection to which the simulation should try and connect. In this situation, we call the `VisItAttemptToCompleteConnection` function, which is responsible for two crucial actions. The first action is to dynamically load the simulation runtime library, which is the piece of the puzzle that allows the simulation to perform compute engine operations. After loading the runtime, the `VisItAttemptToCompleteConnection` function tries to connect back to VisIt's viewer. In the event of a successful connection, the viewer and the simulation will be connected and the simulation will appear in the GUI's **Compute Engines** and **Simulation** windows (see Figure 5-11).

When `VisItDetectInput` returns two, VisIt's viewer is sending commands to generate plots to the simulation. The simulation can handle commands from the viewer simply by calling the `VisItProcessEngineCommand`

`VisItProcessEngineCommand` function fails for any reason, it usually means that either VisIt quit or the communication link between VisIt and the simulation was severed. When the simulation can no longer communicate with VisIt, it is important for it to call `libsim`'s `VisItDisconnect` function. The `VisItDisconnect` function resets `libsim` so it is ready to once again accept a new incoming VisIt connection. Note that after calling `VisItDisconnect`, we also set the `runMode` variable to ensure that the simulation begins to again run autonomously.

3.4.3 Setting up mainloop for a parallel simulation

In VisIt's parallel compute engine, only the first processor, processor 0, communicates in any way with VisIt's viewer. When requests for plots come in, processor 0 broadcasts the requests to all of the other processors so all can begin working on the request. Instead of calling `VisItProcessEngineCommand` directly in a parallel simulation, you will have to add code to ensure that all slave processors also call `VisItProcessEngineCommand` when needed. Listing 5-12 shows how instead of calling `VisItProcessEngineCommand` directly, you can call it and broadcast the appropriate cues to other processors, ensuring they also process input from VisIt's viewer. Note that command communication also requires calling the `VisItSetSlaveProcessCallback` function and registering a slave process callback to be used in command communication.

Listing 5-12: sim4p.c: C-Language simulation example with fully instrumented parallel mainloop function.

```
#define VISIT_COMMAND_PROCESS 0
#define VISIT_COMMAND_SUCCESS 1
#define VISIT_COMMAND_FAILURE 2

/* Helper function for ProcessVisItCommand */
static void BroadcastSlaveCommand(int *command)
{
#ifdef PARALLEL
    MPI_Bcast(command, 1, MPI_INT, 0, MPI_COMM_WORLD);
#endif
}
/* Callback involved in command communication. */
void SlaveProcessCallback()
{
    int command = VISIT_COMMAND_PROCESS;
    BroadcastSlaveCommand(&command);
}
/* Process commands from viewer on all processors. */
int ProcessVisItCommand(simulation_data *sim)
{
    int command;
    if (sim->par_rank == 0)
    {
        int success = VisItProcessEngineCommand();
        if (success)
```

```

    {
        command = VISIT_COMMAND_SUCCESS;
        BroadcastSlaveCommand(&command);
        return 1;
    }
    else
    {
        command = VISIT_COMMAND_FAILURE;
        BroadcastSlaveCommand(&command);
        return 0;
    }
}
else
{
    /* Note: only through the SlaveProcessCallback callback
     * above can the rank 0 process send a VISIT COMMAND PROCESS
     * instruction to the non-rank 0 processes. */
    while (1)
    {
        BroadcastSlaveCommand(&command);
        switch (command)
        {
            case VISIT_COMMAND_PROCESS:
                VisItProcessEngineCommand();
                break;
            case VISIT_COMMAND_SUCCESS:
                return 1;
            case VISIT_COMMAND_FAILURE:
                return 0;
        }
    }
    return 1;
}

/* New function to contain the program's main loop. */
void mainloop(simulation_data *sim)
{
    int blocking, visitstate, err = 0;

    do
    {
        blocking = (sim->runMode == VISIT_SIMMODE_RUNNING) ? 0 : 1;
        /* Get input from VisIt or timeout so the simulation can run. */
        if(sim->par_rank == 0)
            visitstate = VisItDetectInput(blocking, -1);
        MPI_Bcast(visitstate, 1, MPI_INT, 0, MPI_COMM_WORLD);

        /* Do different things depending on the output from
         * VisItDetectInput. */
        if(visitstate >= -5 && visitstate <= -1)
        {
            fprintf(stderr, "Can't recover from error!\n");
            err = 1;
        }
    }
}
```

```
        }
        else if(visitstate == 0)
        {
            /* There was no input from VisIt, return control to sim. */
            simulate_one_timestep(sim);
        }
        else if(visitstate == 1)
        {
            /* VisIt is trying to connect to sim. */
            if(VisItAttemptToCompleteConnection())
            {
                fprintf(stderr, "VisIt connected\n");
                VisItSetSlaveProcessCallback(SlaveProcessCallback);
            }
            else
                fprintf(stderr, "VisIt did not connect\n");
        }
        else if(visitstate == 2)
        {
            /* VisIt wants to tell the engine something. */
            sim->runMode = VISIT_SIMMODE_STOPPED;
            if(!ProcessVisItCommand(sim))
            {
                /* Disconnect on an error or closed connection. */
                VisItDisconnect();
                /* Start running again if VisIt closes. */
                sim->runMode = VISIT_SIMMODE_RUNNING;
            }
        }
    } while(!sim->done && err == 0);
}
```

3.5 Using libsim in a Fortran simulation

So far, the examples for using libsim have been expressed in the C programming language. It is also possible to instrument Fortran simulations so they can serve their data up to VisIt. In SimV2, the function calls for instrumenting a Fortran simulation are nearly identical to the function calls used for C simulations. This subsection will list the entire code skeleton for a libsim-instrumented Fortran simulation since the transitions that evolved a simple program into one that can connect to VisIt have already been demonstrated in C. The principles for instrumenting a Fortran program are the same. If you want to inspect the intermediate steps involved in converting a simple Fortran simulation program, examine the sample programs that accompany this book.

The primary source of differences between the following code listing and the code in Listing 5-10 result from Fortran's treatment of string variables. Strings are not always null-terminated in Fortran as they are in C, so any libsim function that takes string arguments will require the length of each string argument to be passed as well. The length

argument immediately follows any string argument in the argument list of a `libsim` function.

The Fortran interface to `libsim` differs in another significant way; it requires certain functions to be defined in order to link successfully. The `libsim` library uses callback functions, or functions that must be provided by your simulation, in order to perform certain operations. Since the Fortran programming language lacks pointers, it is not possible to pass the address of a function that will perform a certain action to `libsim`. The Fortran interface to `libsim`, called `libsimf`, gets around this limitation by registering internal callback functions, which reference Fortran functions that must be provided by your simulation. The data access functions required to pass simulation data to the `libsim` runtime are handled using the same method, thus instrumenting a Fortran simulation initially requires more steps than instrumenting a C simulation. The number of steps to instrument simulations in either language is ultimately the same.

Listing 5-13: `fsim4.f`: Fortran language simulation example with fully instrumented mainloop function.

```
c-----
c Program: main
c
c-----
program main
implicit none
include "visitfortransimv2interface.inc"
ccc local variables
integer err

err = visitsetupenv()
err = visitinitializesim("fsim4", 5,
. "Fortran prototype simulation connects to VisIt", 46,
. "/no/useful/path", 15,
. VISIT_F77NULLSTRING, VISIT_F77NULLSTRINGLEN,
. VISIT_F77NULLSTRING, VISIT_F77NULLSTRINGLEN,
. VISIT_F77NULLSTIRNG, VISIT_F77NULLSTRINGLEN)
call mainloop()
stop
end

c-----
c mainloop
c-----
subroutine mainloop()
implicit none
include "visitfortransimv2interface.inc"
ccc local variables
integer visitstate, result, runflag, blocking

c   main loop
runflag = 1
do 10
```

```

if(runflag.eq.1) then
    blocking = 0
else
    blocking = 1
endif

visitstate = visitdetectinput(blocking, -1)

if (visitstate.lt.0) then
    goto 1234
elseif (visitstate.eq.0) then
    call simulate_one_timestep()
elseif (visitstate.eq.1) then
    runflag = 0
    result = visitattemptconnection()
    if (result.eq.1) then
        write (6,*) 'VisIt connected!'
    else
        write (6,*) 'VisIt did not connect!'
    endif
elseif (visitstate.eq.2) then
    runflag = 0
    if (visitprocessenginecommand().eq.0) then
        result = visitdisconnect()
        runflag = 1
    endif
endif
10    continue
1234 end

subroutine simulate_one_timestep()
c Simulate one time step
    write (6,*) 'Simulating time step'
    call sleep(1)
end

```

The above code listing lists the functions from `libsimV2f` that must be called from the program's main function and main loop for a serial simulation. When instrumenting a Fortran simulation using `libsimV2f`, you must define the following functions in order to link your program successfully:

Required subroutine/function	Argument types
<code>subroutine visitcommandcallback(cmd, lcmd, intdata, floatdata, stringdata, lstringdata)</code>	<code>character*8 cmd, stringdata</code> <code>integer lcnd, lstringdata, intdata</code> <code>real floatdata</code>
<code>integer function visitbroadcastintfunction(value, sender)</code>	<code>integer value, sender</code>

Required subroutine/function	Argument types
integer function visitbroadcaststringfunction(str, lstr, sender)	character*8 str integer lstr, sender
subroutine visitslaveprocesscallback ()	

These functions are primarily for using `libsim` with a parallel simulation but they must always be defined. Extending a parallel Fortran simulation will be covered shortly. In addition, there are functions related to data access code that must be defined in order to get your Fortran simulation to link successfully. Look at the `fsim4.f` source code file for examples of which functions must also be defined. Those additional functions will be covered later in this chapter.

3.6 Using `libsim` in a parallel Fortran simulation

A parallel Fortran simulation's `mainloop` function should look very similar to its serial counterpart in terms of how code is organized. Once you have adapted your simulation so it can be instrumented with `libsim`, it is possible to make further changes that allow each processor to serve data to VisIt in parallel. There are many changes that need to happen in order to instrument a parallel simulation so the process will be broken into stages. The changes begin with telling VisIt the number of processors and the rank of the current processor within the group before the call to the `visitinitializesim` function. You can provide this information to VisIt by calling MPI's `MPI_COMM_RANK` and `MPI_COMM_SIZE` functions and then passing the resulting rank and size data to the `visitsetparallel` and `visitsetparallelrank` functions. Once the rank and size data have been given to `libsim`, the next change is to ensure that only the master, or rank zero, process calls the `visitinitializesim` function from `libsim`. Only the master process should call the `visitinitializesim` function to ensure that only one `".sim2"` file is created.

Listing 5-14: `fscalar.f`: Fortran language simulation example for parallel initialization.

```

c-----
c Program: main
c
c-----
program main
implicit none
include "visitfortransimv2interface.inc"
include "mpif.h"
ccc local variables
integer err
ccc PARALLEL state common block
integer par_rank, par_size
common /PARALLEL/ par_rank, par_size
save /PARALLEL/

```

```
call MPI_INIT(err)

c Determine the rank and size of this MPI task so we can tell
c VisIt's libsim about it.
call MPI_COMM_RANK(MPI_COMM_WORLD, par_rank, err)
call MPI_COMM_SIZE(MPI_COMM_WORLD, par_size, err)
if(par_size.gt.1) then
    err = visitsetparallel(1)
endif
err = visitsetparallelrank(par_rank)

err = visitsetupenv()
c Have the master process write the sim file.
if(par_rank.eq.0) then
    err = visitinitializesim("fscalarp", 8,
    .   "Demonstrates scalar data access function", 40,
    .   "/no/useful/path", 15,
    .   VISIT_F77NULLSTRING, VISIT_F77NULLSTRINGLEN,
    .   VISIT_F77NULLSTRING, VISIT_F77NULLSTRINGLEN)
endif

call mainloop()

call MPI_FINALIZE(err)
stop
end
```

The next step in instrumenting a parallel Fortran simulation is to change the `mainloop` function. The first change that you must make is to ensure that only the master process calls `visitdetectinput`. Remember that only the master process talks to VisIt's viewer process so the `visitdetectinput` function should not be called by slave processes. However, the slaves need to know the instructions that came from the viewer so we must insert an MPI broadcast function to ensure that all processes get the value sent from the viewer to the master process. In addition the `visitprocessenginecommand` function must be exchanged for a function that can call `visitprocessenginecommand` on all processes. For now, let's call that new function `processvisitcommand`.

Listing 5-15: fscalarp.f: Fortran language simulation example for parallel mainloop function.

```
c-----
c mainloop
c-----
subroutine mainloop()
implicit none
#include "mpif.h"
#include "visitfortransimv2interface.inc"
ccc  functions
```

```

    integer processvisitcommand
ccc local variables
integer visitstate, result, blocking, ierr
ccc SIMSTATE common block
integer runflag, simcycle
real simtime
common /SIMSTATE/ runflag,simcycle,simtime
save /SIMSTATE/
ccc PARALLEL state common block
integer par_rank, par_size
common /PARALLEL/ par_rank, par_size
c main loop
runflag = 1
simcycle = 0
simtime = 0
do 10
  if(runflag.eq.1) then
    blocking = 0
  else
    blocking = 1
  endif

c Detect input from VisIt on processor 0 and then broadcast
c the results of that input to all processors.
  if(par_rank.eq.0) then
    visitstate = visitdetectinput(blocking, -1)
  endif
  call MPI_BCAST(visitstate,1,MPI_INTEGER,0,
. MPI_COMM_WORLD,ierr)

  if (visitstate.lt.0) then
    goto 1234
  elseif (visitstate.eq.0) then
    call simulate_one_timestep()
  elseif (visitstate.eq.1) then
    runflag = 0
    result = visitattemptconnection()
    if (result.eq.1) then
      write (6,*) 'VisIt connected!'
    else
      write (6,*) 'VisIt did not connect!'
    endif
  elseif (visitstate.eq.2) then
    runflag = 0
    if (processvisitcommand().eq.0) then
      result = visitdisconnect()
      runflag = 1
    endif
  endif
10   continue
1234 end

```

Now that you have changed the mainloop function it is time to define the processvisitcommand function. The processvisitcommand function is used by the mainloop function as a replacement for the visitprocessenginecommand function. The new processvisitcommand function must call the visitprocessenginecommand function and it must do so in a way that ensures the function is called on all processors. Since the processvisitcommand function is completely new, you will probably be able to paste it into your simulation with few changes.

Listing 5-16: fscalar.f: Fortran language simulation example for parallel processvisitcommand function.

```
c-----  
c processvisitcommand  
c-----  
  
      integer function processvisitcommand()  
      implicit none  
      include "mpif.h"  
      include "visitfortransimV2interface.inc"  
ccc      PARALLEL state common block  
      integer par_rank, par_size  
      common /PARALLEL/ par_rank, par_size  
      integer command, e, doloop, success, ret  
      integer VISIT_COMMAND_PROCESS  
      integer VISIT_COMMAND_SUCCESS  
      integer VISIT_COMMAND_FAILURE  
      parameter (VISIT_COMMAND_PROCESS = 0)  
      parameter (VISIT_COMMAND_SUCCESS = 1)  
      parameter (VISIT_COMMAND_FAILURE = 2)  
  
      if(par_rank.eq.0) then  
         success = visitprocessenginecommand()  
  
         if(success.gt.0) then  
            command = VISIT_COMMAND_SUCCESS  
            ret = 1  
         else  
            command = VISIT_COMMAND_FAILURE  
            ret = 0  
         endif  
  
         call MPI_BCAST(command,1,MPI_INTEGER,0,MPI_COMM_WORLD,e)  
      else  
         doloop = 1  
2345      call MPI_BCAST(command,1,MPI_INTEGER,0,MPI_COMM_WORLD,e)  
         if(command.eq.VISIT_COMMAND_PROCESS) then  
            success = visitprocessenginecommand()  
         elseif(command.eq.VISIT_COMMAND_SUCCESS) then  
            ret = 1  
            doloop = 0  
         else
```

```

        ret = 0
        doloop = 0
    endif
    if(doloop.ne.0) then
        goto 2345
    endif
endif
processvisitcommand = ret
end

```

The alterations to the code that have been listed thus far are nearly enough to complete the changes required for a parallel Fortran simulation to use `libsim`. The main program and the `mainloop` function have been changed to support the extra processing that needs to happen to ensure that all processors properly receive instructions from VisIt's viewer. However, there are some broadcast callback functions that must now be implemented to ensure that `libsim` can communicate with all processors. The callback functions: `visitbroadcastintfunction`, `visitbroadcaststringfunction`, and `visitslaveprocesscallback` have to date been stub functions that did not do any real work. When you instrument a parallel Fortran simulation, those callback functions need to perform broadcasts so `libsim` can properly communicate with all processors.

Listing 5-17: `fscalar.f`: Fortran language simulation example for parallel broadcast functions.

```

c-----
c visitbroadcastintfunction
c-----
integer function visitbroadcastintfunction(value, sender)
implicit none
include "mpif.h"
integer value, sender
integer IERR
call MPI_BCAST(value,1,MPI_INTEGER, sender, MPI_COMM_WORLD, ierr)
visitbroadcastintfunction = 0
end

c-----
c visitbroadcaststringfunction
c-----
integer function visitbroadcaststringfunction(str, lstr,
sender)
implicit none
include "mpif.h"
character*8 str
integer lstr, sender
integer IERR
call MPI_BCAST(str,lstr,MPI_CHARACTER, sender, MPI_COMM_WORLD,
.ierr)
visitbroadcaststringfunction = 0
end

```

```
c-----
c visitslaveprocesscallback
c-----
subroutine visitslaveprocesscallback ()
implicit none
include "mpif.h"
integer c, ierr, VISIT_COMMAND_PROCESS
parameter (VISIT_COMMAND_PROCESS = 0)
c = VISIT_COMMAND_PROCESS
call MPI_BCAST(c,1,MPI_INTEGER,0,MPI_COMM_WORLD,ierr)
end
```

After making all of these changes, your parallel Fortran simulation should be ready to run for the first time as an application to which VisIt can connect. You will not be able to extract any data from your simulation just yet but you can begin to run connected to VisIt and once you have that working you can begin to expose your data to VisIt.

3.7 Running an instrumented simulation

Once you've added `libsim` functions to your simulation and created a `mainloop` function capable of connecting to VisIt, you can run your modified simulation. The current `libsim` implementation uses the `visit` command in your path to determine where it will find the `libsim` runtime library. The `libsim` runtime library is linked to its dependent VisIt libraries and has an awareness of their location set via `-rpath`. So, assuming `libsim` is able to locate its runtime library, the other VisIt libraries on which it depends should load without issues. If you use a Linux version of VisIt 2.0.0 installed in `/usr/local/apps/visit` then use the following commands to ensure that `libsim` can find the `libsim` runtime library. However, this should only be necessary if VisIt is not in your path.

```
# Set VISIT to the directory where a version of VisIt is installed
setenv VISIT /usr/local/apps/visit/2.0.0/linux-intel
env LD_LIBRARY_PATH=$VISIT/lib VISITPLUGINDIR=$VISIT/plugins ./sim
```

If you use a different version of VisIt or run VisIt on a platform other than Linux, make the appropriate substitutions in the `VISIT` environment variable before trying to run. This is an instance where you could also call `VisItSetDirectory` in your simulation, passing `/usr/local/apps/visit` to make the proper VisIt environment be detected.

3.8 Connecting to an instrumented simulation from VisIt

Once you've successfully launched your simulation, you can attempt to connect to it using VisIt. Open a terminal window and run VisIt. When VisIt comes up, open the **File selection window** and browse to `~/.visit/simulations`, the directory where `.sim2` files are stored. You should see a file in that directory with a `.sim2` file extension. The `.sim2` file was

created by your simulation when it started and called the `VisItInitializeSocketAndDumpSimFile` function from `libsim`. The `.sim2` file contains all of the information that VisIt needs to connect to your simulation. If you open the `.sim2` file in VisIt's **Main window**, VisIt will initiate contact with your simulation.

If VisIt is unable to connect to your simulation, you might see error messages like the following from your simulation:

```
Simulating time step
Simulating time step
VisIt did not connect
Simulating time step
Simulating time step
```

Error messages such as those above appear in the terminal window where your simulation was launched. The most common problem when VisIt cannot connect to a simulation is that the simulation runtime library could not be loaded. This occurs when the environment is not set, usually due to a failure by `libsim` to automatically detect the VisIt environment. This happens most often if the `visit` command is not in your path. You can find out more about this type of failure by examining `libsim` trace files. In the event that `libsim` cannot detect the VisIt environment, you can set it explicitly using `LD_LIBRARY_PATH` and `VISITPLUGINDIR`.

At this stage in instrumenting your simulation, if it was able to successfully create a connection to VisIt then you will see the name of your simulation in the **Compute engines window** and the **Simulations window**.

4.0 Writing data access code

If you have made it this far then you probably have a simulation that has been restructured to use `libsim`. Once a simulation has been instrumented using `libsim`, it should be possible for VisIt to connect to it. Adding the code to allow VisIt to connect to your simulation is only the first part of instrumenting your simulation. The next phase in instrumenting your simulation code is adding data access code to your simulation so the simulation runtime library can access your simulation's data.

Writing data access code is much like writing a database reader plug-in. It all starts with writing a function to provide metadata to VisIt so that it knows the names of the meshes and variables that are available for plotting. After your simulation is capable of telling VisIt about its variables, the next step is to write functions that can pass your mesh or data arrays to VisIt so they can be used in plots. If your data is not in a format that VisIt readily supports, you can create a more VisIt-friendly representation of the data in the data access functions and hand it off to VisIt.

4.1 The VisIt Data Interface

VisIt relies on the VisIt Data Interface (VDI), a C header file containing the prototypes of the functions that can be called to allocate and manipulate data objects that you pass back to VisIt. These data objects contain references to your simulation data and are used to construct the data structures that VisIt uses to plot your data.

It is important to note some significant differences between SimV1 and SimV2 in case you are converting a SimV1 simulation to use SimV2. In SimV1, the VDI consisted of a set of C structs that you would allocate, fill in, and pass back to VisIt. In SimV2, the structs have been taken away and replaced with a set of functions for setting and getting properties on the various data objects. This change eliminates a classic problem where VisIt would crash when users did not properly fill out the fields of the C structure. SimV2 functions are also redirected to their real implementation which is dynamically loaded from the SimV2 runtime library. This means that the data objects are more free to change and improve in different versions of VisIt without affecting the client simulation or requiring that it relink with a new SimV2 library.

The VDI C-Language header file is called `VisItDataInterface_V2.h` and it defines the types and functions that are used when creating objects that pass data to VisIt. The header file is installed with the binary VisIt distribution. If a Linux version of VisIt 2.0.0 was installed in `/usr/local/apps/visit` then the header file would be located in `/usr/local/apps/visit/2.0.0/linux-intel/include/visit/libsim/V2/include`. Of course, the actual path depends on where VisIt was installed, the version of VisIt that was installed, and the platform.

If you are writing your simulation in Fortran then the `VisItDataInterface_V2.h` header file will be of no consequence to you. Everything you need to instrument a Fortran simulation code is located in `visitfortransimV2interface.inc`, the same file that you've already used to instrument your simulation so far. Fortran simulations follow the same paradigm as C simulations but call functions with slightly shorter names since function names in Fortran are often limited to 31 characters. When possible, the function names are either the same as in C, albeit with underscores ‘`_`’ removed, and use all lower-case letters.

4.2 How data access functions are called

VisIt data access functions are registered with libsim using special callback registration functions, defined in `VisItControlInterface_V2.h`. There is one callback registration function per data access function. In the C version of libsim, you pass the function pointer to be called when a particular data access callback function is needed. You may also pass user-defined data that will be passed to the data access callback function so the function can be aware of your application’s data without using global variables. Calling these functions is not necessary when writing Fortran simulations

because they are called already in the `simV2f` library, which imposes a requirement for specific data access callback names: `visitgetmetadata`, `visitgetmesh`, etc.

Function	Description
<code>VisItSetGetMetaData</code>	Installs callback function that returns simulation metadata.
<code>VisItSetGetMesh</code>	Installs a callback function that returns mesh data.
<code>VisItSetGetMaterial</code>	Installs a callback function that returns material data.
<code>VisItSetGetSpecies</code>	Installs a callback function that returns species data.
<code>VisItSetGetVariable</code>	Installs a callback function that returns variable data (scalars, vectors, tensors, and so on).
<code>VisItSetGetMixedVariable</code>	Installs a callback function that returns mixed variable data.
<code>VisItSetGetCurve</code>	Installs a callback function that returns curve data.
<code>VisItSetGetDomainList</code>	Installs a callback function that returns a domain list.
<code>VisItSetGetDomainBoundaries</code>	Installs a callback function that returns domain boundary information.
<code>VisItSetGetDomainNesting</code>	Installs a callback function that returns domain nesting information.

When VisIt opens the `.sim2` file corresponding to your running simulation, VisIt knows that the data will come from a simulation because the `.sim2` file is opened by the SimV2 database reader plug-in. The SimV2 plug-in is a special VisIt database reader plug-in that uses the functions in the SimV2 runtime library to access data from your simulation.

When the SimV2 runtime is loaded into your simulation and VisIt tells the simulation to make a plot, the request ends up in the SimV2 database reader plug-in. When the SimV2 plug-in wants to read metadata, for example, it invokes your simulation's metadata callback function to retrieve metadata. Once your function returns a populated metadata object, created by calling SimV2 functions, the SimV2 plug-in transcribes the metadata from your metadata object into the `avtDatabaseMetaData` object that VisIt uses. Other data access callbacks follow the same pattern.

4.3 Making data access functions available

The previous sections have established the importance of data access callback functions and the functions that register them. Now, it is time to see how and when the data access callback functions are registered. Since the data access callback function are ultimately used by the SimV2 runtime library, they cannot be registered until after VisIt connects to your simulation since that is when the SimV2 runtime is loaded. Consequently, the functions that register data access callback functions must be called after a successful call to `VisItAttemptToCompleteConnection`. In order for your simulation to return data, you must register, at a minimum, the callback functions for returning metadata. In this example, note how `VisItSetGetMetaDataTable` is called after a successful call to `VisItAttemptToCompleteConnection`.

Listing 5-18: sim5.c: C-Language example for making a data access function available.

```
#include <VisItDataInterface_V2.h>

visit_handle
SimGetMetaData(void *cbdata)
{
    visit_handle md = VISIT_INVALID_HANDLE;
    simulation_data *sim = (simulation_data *)cbdata;

    /* Create metadata with no variables. */
    if(VisIt_SimulationMetaData_alloc(&md) == VISIT_OKAY)
    {
        /* Fill in the metadata. */
    }

    return md;
}

void mainloop(simulation_data *sim)
{
    int blocking, visitstate, err = 0;

    do
    {
        blocking = (sim->runMode == VISIT_SIMMODE_RUNNING) ? 0 : 1;
        /* Get input from VisIt or timeout so the simulation can run. */
        visitstate = VisItDetectInput(blocking, -1);

        /* Do different things depending on the output from
        VisItDetectInput. */
        if(visitstate <= -1)
        {
            fprintf(stderr, "Can't recover from error!\n");
            err = 1;
        }
        else if(visitstate == 0)
        {
```

```

        /* There was no input from VisIt, return control to sim. */
        simulate_one_timestep(sim);
    }
    else if(visitstate == 1)
    {
        /* VisIt is trying to connect to sim. */
        if(VisItAttemptToCompleteConnection())
        {
            fprintf(stderr, "VisIt connected\n");
            /* Register data access callbacks */
            VisItSetGetMetaData(SimGetMetaData, (void*)sim);
        }
        else
            fprintf(stderr, "VisIt did not connect\n");
    }
    else if(visitstate == 2)
    {
        /* VisIt wants to tell the engine something. */
        sim->runMode = VISIT_SIMMODE_STOPPED;
        if(!VisItProcessEngineCommand())
        {
            /* Disconnect on an error or closed connection. */
            VisItDisconnect();
            /* Start running again if VisIt closes. */
            sim->runMode = VISIT_SIMMODE_RUNNING;
        }
    }
} while(!sim->done && err == 0);
}

```

Data access functions for Fortran simulations do not have to be made available explicitly because that is taken care of in the `simV2f` library, which defines the Fortran-callable wrapper functions for `libsim`. Instead of defining the data access function and registering it, you only need to define it. In fact, all data access functions for Fortran simulations must be defined to successfully link your simulation.

Listing 5-19: `fsim5.f`: Fortran language example for making a data access function available.

```

integer function visitgetmetadata(handle)
implicit none
integer handle
include "visitfortransimv2interface.inc"
visitgetmetadata = VISIT_INVALID_HANDLE
end

```

4.4 Data access function for metadata

The first data access function that you write should be the one that populates a metadata object. VisIt uses metadata to determine which meshes and variables are in a database and reading a database's metadata is the first thing VisIt does when accessing it. The data access function for returning metadata allocates and returns a handle to a `SimulationMetaData` object. The `SimulationMetaData` object contains lists of other metadata objects such as meshes and variables. Good starting points for a data access function that returns metadata are found in Listing 5-18 and Listing 5-19. The code listings found in this section may reproduce those listings, however, as the listings get longer, the following code listings may instead contain code fragments required to perform a particular operation. The code fragments can be included into your simulation and modified until they expose the right variables for your simulation.

4.4.1 Returning simulation state metadata

Simulation state metadata is important because it indicates the running state of the simulation as well as its cycle iteration and simulated time. The C-Language example in Listing 5-20 shows how to set the simulation state into the metadata object. .

Listing 5-20: sim6.c: C-Language example for returning simulation state metadata.

```
visit_handle SimGetMetaData(void *cbdata)
{
    visit_handle md = VISIT_INVALID_HANDLE;
    simulation_data *sim = (simulation_data *)cbdata;

    /* Create metadata with no variables. */
    if(VisIt_SimulationMetaData_alloc(&md) == VISIT_OKAY)
    {
        /* Set the simulation state. */
        if(sim->runMode == VISIT_SIMMODE_STOPPED)
            VisIt_SimulationMetaData_setMode(md, VISIT_SIMMODE_STOPPED);
        else(sim->runMode == SIM_STOPPED)
            VisIt_SimulationMetaData_setMode(md, VISIT_SIMMODE_RUNNING);
        VisIt_SimulationMetaData_setCycleTime(md, sim->cycle, sim->time);
    }
    return md;
}
```

Listing 5-21: fsim6.f: Fortran language example for returning simulation state metadata.

```
integer function visitgetmetadata()
implicit none
include "visitfortransimV2interface.inc"
ccc  SIMSTATE common block
      integer runflag, simcycle
      real simtime
      common /SIMSTATE/ runflag, simcycle, simtime
```

```

ccc local variables
integer md, err

if(visitmdsimalloc(md).eq.VISIT_OKAY) then
    err = visitmdsimsetcycletime(md, simcycle, simtime)
    if(runflag.eq.1) then
        err = visitmdsimsetmode(md, VISIT_SIMMODE_RUNNING)
    else
        err = visitmdsimsetmode(md, VISIT_SIMMODE_STOPPED)
    endif
endif
visitgetmetadata = md
end

```

4.4.2 Returning mesh metadata

If you want VisIt to plot any of your simulation's data then you must expose at least one of your simulation's meshes in the metadata. Remember that VisIt can support several different mesh types from simple point meshes all the way up to complex multi-domain unstructured meshes.

Mesh metadata is stored in the `SimulationMetaData` as a list of `MeshMetaData` objects. Each `MeshMetaData` object contains information about a mesh such as its name, type, dimensions, units, labels, etc. Note that when you create new `MeshMetaData` objects and add them to the `SimulationMetaData` object, they become associated with the `SimulationMetaData` object and you should not deallocate them. The `SimulationMetaData` object and its contents will be destroyed after you pass it back to VisIt.

It is not important to set values for all of the members in the `MeshMetaData` object so long as you do set values for the name, `meshType`, `topologicalDimension`, `spatialDimension`, and `numDomains`.

The value that you use for the mesh's name is the name that will appear in VisIt's **Plot menus** (see Figure 5-22) as well as the name that will be passed to your data access function when VisIt wants to plot your mesh. The `meshType` value specifies the mesh's type and can be any of the following values: `VISIT_MESHTYPE_RECTILINEAR`,

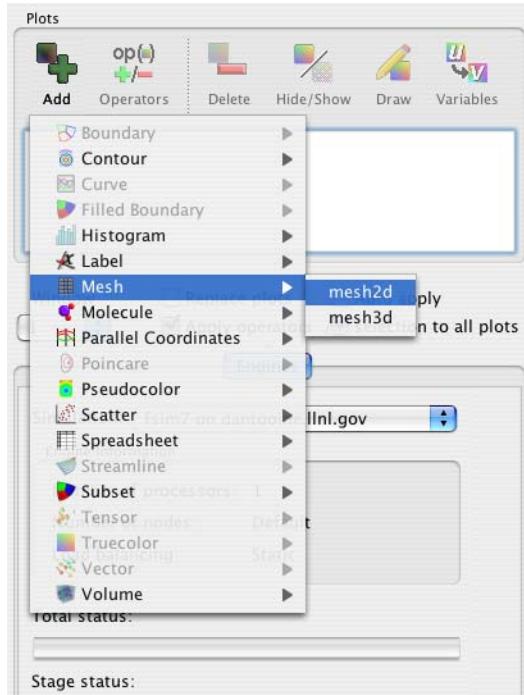


Figure 5-22: Mesh variables in the plot menu

VISIT_MESHTYPE_CURVILINEAR, VISIT_MESHTYPE_UNSTRUCTURED, VISIT_MESHTYPE_POINT, VISIT_MESHTYPE_AMR, VISIT_MESHTYPE_CSG. The topologicalDimension and spatialDimension values should be either 2 or 3, depending on whether your mesh exists in 2D or 3D. Finally, the numDomains value should be set to the total number of domains that comprise your mesh, or 1 in the case of a single domain.

Listing 5-23: sim7.c: C-Language example for returning mesh metadata.

```
visit_handle m1 = VISIT_INVALID_HANDLE;
visit_handle m2 = VISIT_INVALID_HANDLE;

/* Set the first mesh's properties.*/
if(VisIt_MeshMetaData_alloc(&m1) == VISIT_OKAY)
{
    /* Set the mesh's properties.*/
    VisIt_MeshMetaData_setName(m1, "mesh2d");
    VisIt_MeshMetaData_setMeshType(m1, VISIT_MESHTYPE_RECTILINEAR);
    VisIt_MeshMetaData_setTopologicalDimension(m1, 2);
    VisIt_MeshMetaData_setSpatialDimension(m1, 2);
    VisIt_MeshMetaData_setXUnits(m1, "cm");
    VisIt_MeshMetaData_setYUnits(m1, "cm");
    VisIt_MeshMetaData_setXLabel(m1, "Width");
    VisIt_MeshMetaData_setYLabel(m1, "Height");

    VisIt_SimulationMetaData_addMesh(md, m1);
}

/* Set the second mesh's properties.*/
if(VisIt_MeshMetaData_alloc(&m2) == VISIT_OKAY)
{
    /* Set the mesh's properties.*/
    VisIt_MeshMetaData_setName(m2, "mesh3d");
    VisIt_MeshMetaData_setMeshType(m2, VISIT_MESHTYPE_CURVILINEAR);
    VisIt_MeshMetaData_setTopologicalDimension(m2, 3);
    VisIt_MeshMetaData_setSpatialDimension(m2, 3);
    VisIt_MeshMetaData_setXUnits(m2, "cm");
    VisIt_MeshMetaData_setYUnits(m2, "cm");
    VisIt_MeshMetaData_setZUnits(m2, "cm");
    VisIt_MeshMetaData_setXLabel(m2, "Width");
    VisIt_MeshMetaData_setYLabel(m2, "Height");
    VisIt_MeshMetaData_setZLabel(m2, "Depth");

    VisIt_SimulationMetaData_addMesh(md, m2);
}
```

Apart from slight differences in the names of the functions called, the Fortran interface follows the same pattern as the C interface.

Listing 5-24: fsim7.f: Fortran language example for returning mesh metadata.

```

integer md, m1, m2, err

c Set the first mesh's properties
if(visitmdmeshalloc(m1).eq.VISIT_OKAY) then
    err = visitmdmeshsetname(m1, "mesh2d", 6)
    err = visitmdmeshsetmeshtype(m1,
        VISIT_MESHTYPE_RECTILINEAR)
    err = visitmdmeshsettopologicaldim(m1, 2)
    err = visitmdmeshsetspatialdim(m1, 2)
    err = visitmdmeshsetxunits(m1, "cm", 2)
    err = visitmdmeshsetyunits(m1, "cm", 2)
    err = visitmdmeshsetxlabel(m1, "Width", 5)
    err = visitmdmeshsetylabel(m1, "Height", 6)

    err = visitmdsimaddmesh(md, m1)
endif

c Set the second mesh's properties
if(visitmdmeshalloc(m2).eq.VISIT_OKAY) then
    err = visitmdmeshsetname(m2, "mesh3d", 6)
    err = visitmdmeshsetmeshtype(m2,
        VISIT_MESHTYPE_CURVILINEAR)
    err = visitmdmeshsettopologicaldim(m2, 3)
    err = visitmdmeshsetspatialdim(m2, 3)
    err = visitmdmeshsetxunits(m2, "cm", 2)
    err = visitmdmeshsetyunits(m2, "cm", 2)
    err = visitmdmeshsetzunits(m2, "cm", 2)
    err = visitmdmeshset xlabel(m2, "Width", 5)
    err = visitmdmeshset ylabel(m2, "Height", 6)
    err = visitmdmeshset zlabel(m2, "Depth", 5)

    err = visitmdsimaddmesh(md, m2)
endif

```

4.4.3 Returning variable metadata

Variables must be exposed via the metadata if they are to be plotted in VisIt. You need not expose all of the variables that you have; only those you want to plot in VisIt. The `SimulationMetaData` object contains a list of `VariableMetaData` objects, which contain the metadata for all of the variables that you expose to VisIt. All variable types: scalar, vector, tensor, label, array, etc. can be represented in the metadata as `VariableMetaData` objects. Specifying a variable only requires you to add a new

VariableMetaData object into the simulation metadata. You must set the name , meshName, type, and centering fields in order to create a valid object.

Listing 5-25: sim8.c: C-Language example for returning variable metadata.

```
/* Add a zonal scalar variable on mesh2d. */
if(VisIt_VariableMetaData_alloc(&vmd) == VISIT_OKAY)
{
    VisIt_VariableMetaData_setName(vmd, "zonal");
    VisIt_VariableMetaData_setMeshName(vmd, "mesh2d");
    VisIt_VariableMetaData_setType(vmd, VISIT_VARTYPE_SCALAR);
    VisIt_VariableMetaData_setCentering(vmd, VISIT_VARCENTERING_ZONE);

    VisIt_SimulationMetaData_addVariable(md, vmd);
}

/* Add a nodal scalar variable on mesh3d. */
if(VisIt_VariableMetaData_alloc(&vmd) == VISIT_OKAY)
{
    VisIt_VariableMetaData_setName(vmd, "nodal");
    VisIt_VariableMetaData_setMeshName(vmd, "mesh3d");
    VisIt_VariableMetaData_setType(vmd, VISIT_VARTYPE_SCALAR);
    VisIt_VariableMetaData_setCentering(vmd, VISIT_VARCENTERING_NODE);

    VisIt_SimulationMetaData_addVariable(md, vmd);
}
```

Listing 5-26: fsim8.f: Fortran language example for returning variable metadata.

```
c Add a zonal scalar variable on mesh2d.
if(visitmdvaralloc(vmd).eq.VISIT_OKAY) then
    err = visitmdvarsetname(vmd, "zonal", 5)
    err = visitmdvarsetmeshname(vmd, "mesh2d", 6)
    err = visitmdvarsettype(vmd, VISIT_VARTYPE_SCALAR)
    err = visitmdvarsetcentering(vmd, VISIT_VARCENTERING_ZONE)

    err = visitmdsimaddvariable(md, vmd)
endif

c Add a nodal scalar variable on mesh3d.
if(visitmdvaralloc(vmd).eq.VISIT_OKAY) then
    err = visitmdvarsetname(vmd, "nodal", 5)
    err = visitmdvarsetmeshname(vmd, "mesh3d", 6)
    err = visitmdvarsettype(vmd, VISIT_VARTYPE_SCALAR)
    err = visitmdvarsetcentering(vmd, VISIT_VARCENTERING_NODE)

    err = visitmdsimaddvariable(md, vmd)
endif
```

4.4.4 Returning curve variable metadata

As with other variable types, curve variables (X-Y plot data) must also be exposed in the metadata if they are to be plotted in VisIt. The `SimulationMetaData` object contains a list of `CurveMetaData` objects, which contain the attributes of the curve variables that will be exposed to VisIt from the simulation. The only required field that must be set in the `CurveMetaData` object is the `name` field, which specifies the name of the curve as it will be used in the **Plot list** and in your data access function.

Listing 5-27: sim9.c: C-Language example for returning curve metadata.

```
/* Add a curve variable. */
if(VisIt_CurveMetaData_alloc(&cmd) == VISIT_OKAY)
{
    VisIt_CurveMetaData_setName(cmd, "sine");
    VisIt_CurveMetaData_setXLabel(cmd, "Angle");
    VisIt_CurveMetaData_setXUnits(cmd, "radians");
    VisIt_CurveMetaData_setYLabel(cmd, "Amplitude");

    VisIt_SimulationMetaData_addCurve(md, cmd);
}
```

Listing 5-28: fsim9.f: Fortran language example for returning curve metadata.

```
c      Add a curve variable
      if(visitmdcurvealloc(cmd).eq.VISIT_OKAY) then
          err = visitmdcurvesetname(cmd, "sine", 4)
          err = visitmdcurveset xlabel(cmd, "angle", 5)
          err = visitmdcurveset xunits(cmd, "radians", 7)
          err = visitmdcurveset ylabel(cmd, "amplitude", 9)

          err = visitmdsimaddcurve(md, cmd)
      endif
```

4.4.5 Returning material metadata

In addition to the variable types mentioned so far, the `SimulationMetaData` object also contains a list of material variables. The list of material variables is stored in the `materials` member and is composed of `MaterialMetaData` objects. A `MaterialMetaData` object contains the name of the material, the mesh on which it is defined, and the list of possible material names that can be used.

Listing 5-29: sim10.c: C-Language example for returning material metadata.

```
/* Add a material */
if(VisIt_MaterialMetaData_alloc(&mat) == VISIT_OKAY)
{
    VisIt_MaterialMetaData_setName(mat, "mat");
```

```
    VisIt_MaterialMetaData_setMeshName(mat, "mesh2d");
    VisIt_MaterialMetaData_addMaterialName(mat, "Iron");
    VisIt_MaterialMetaData_addMaterialName(mat, "Copper");
    VisIt_MaterialMetaData_addMaterialName(mat, "Nickel");

    VisIt_SimulationMetaData_addMaterial(md, mat);
}.

```

Listing 5-30: fsim10.f: Fortran language example for returning material metadata.

```
c      Add a material
      if(visitmdmatalloc(mat).eq.VISIT_OKAY) then
          err = visitmdmatsetname(mat, "mat", 3)
          err = visitmdmatsetmeshname(mat, "mesh2d", 6)
          err = visitmdmataddmaterialname(mat, "Iron", 4)
          err = visitmdmataddmaterialname(mat, "Copper", 6)
          err = visitmdmataddmaterialname(mat, "Nickel", 6)

          err = visitmdsimaddmaterial(md, mat)
      endif

```

4.4.6 Returning expression metadata

VisIt allows databases to return user-defined expressions that can be plotted or used to create new expressions in the **Expressions window**. The SimulationMetaData object contains a list of ExpressionMetaData objects that each contain the information for one expression. An expression consists of an expression name, definition, and expression type. The expression definition is a string that must contain a valid VisIt expression, as defined in by the expression language documented in the *VisIt User's Manual*.

Listing 5-31: sim11.c: C-Language example for returning material metadata.

```
/* Add some expressions. */
if(VisIt_ExpressionMetaData_alloc(&emd) == VISIT_OKAY)
{
    VisIt_ExpressionMetaDataSetName(emd, "zvec");
    VisIt_ExpressionMetaDataSetDefinition(emd, "{zonal, zonal}");
    VisIt_ExpressionMetaDataSetType(emd, VISIT_VARTYPE_VECTOR);

    VisIt_SimulationMetaData_addExpression(md, emd);
}
if(VisIt_ExpressionMetaData_alloc(&emd) == VISIT_OKAY)
{
    VisIt_ExpressionMetaDataSetName(emd, "nid");
    VisIt_ExpressionMetaDataSetDefinition(emd, "nodeid(mesh3d)");
    VisIt_ExpressionMetaDataSetType(emd, VISIT_VARTYPE_SCALAR);
}
```

```

    VisIt_SimulationMetaData_addExpression(md, emd);
}

```

Listing 5-32: fsim11.f: Fortran language example for returning material metadata.

```

c      Add some expressions
if(visitmdexpralloc(emd).eq.VISIT_OKAY) then
    err = visitmdexprsetname(emd, "zvec", 4)
    err = visitmdexprsetdefinition(emd, "{zonal, zonal}", 14)
    err = visitmdexprsettype(emd, VISIT_VARTYPE_VECTOR)

    err = visitmdsimadddexpression(md, emd)
endif
if(visitmdexpralloc(emd).eq.VISIT_OKAY) then
    err = visitmdexprsetname(emd, "nid", 3)
    err = visitmdexprsetdefinition(emd, "nodeid(mesh3d)", 14)
    err = visitmdexprsettype(emd, VISIT_VARTYPE_SCALAR)

    err = visitmdsimadddexpression(md, emd)
endif

```

4.4.7 Returning simulation-defined command metadata

VisIt allows your simulation to provide the names of user-defined commands in the metadata object. When such commands appear in a simulation's metadata, it influences VisIt to create special command buttons in the **Simulations window**. When you open the **Simulations window** and click on the buttons, it causes a chain of events that ends up calling your simulation's command callback function, which then performs some action based on the name of the command being executed. These custom commands give you the opportunity to perform limited steering of your simulation from within VisIt. More advanced methods of simulation steering will be covered later in this chapter.

Examples of simple simulation commands that you might want to expose in the metadata are the “run”, “halt”, “step”. Imagine that you use VisIt to connect to your simulation and you create some plots. Once you are done analyzing a particular time step, you may want to click the “run” button in the **Simulations window** (shown in Figure 5-33) to let your simulation proceed for a while. After your simulation has advanced, you could click the “halt” button to pause it while you investigate features that have developed in the data for the simulation’s current time step.

The C-Language mainloop function that was created in Section 3.4.2 did not have support for a command callback function. The following code listing shows what the command callback function would look like for a simulation that exposes three simple commands: halt, step, and run. The code listing also shows how the command callback function is registered with libsim using the

`VisItSetCommandCallback` function. The new command callback function is registered after a successful call to `VisItAttemptToCompleteConnection` and the changes to the mainloop function are underlined.

Listing 5-34: sim12.c: C-Language example for installing a command callback function.

```

void
ControlCommandCallback(const char *cmd, const char *args,
void *cbdata)
{
    simulation_data *sim = (simulation_data *)cbdata;

    if(strcmp(cmd, "halt") == 0)
        sim->runMode = VISIT_SIMMODE_STOPPED;
    else if(strcmp(cmd, "step") == 0)
        simulate_one_timestep(sim);
    else if(strcmp(cmd, "run") == 0)
        sim->runMode = VISIT_SIMMODE_RUNNING;
}
void mainloop(simulation_data *sim)

```

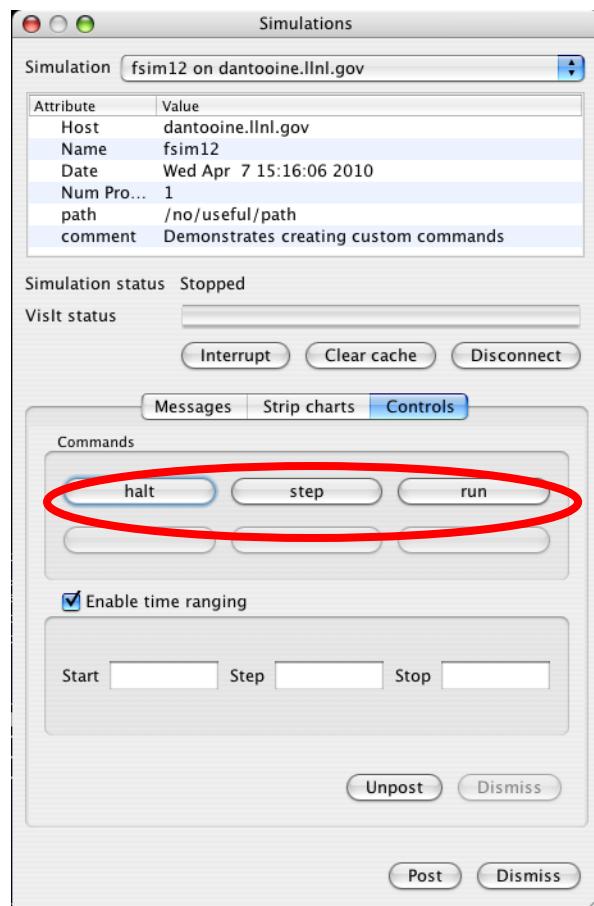


Figure 5-33: VisIt's Simulations window with custom simulation commands.

```

{
    int blocking, visitstate, err = 0;

    do
    {
        blocking = (sim->runMode == VISIT_SIMMODE_RUNNING) ? 0 : 1;
        /* Get input from VisIt or timeout so the simulation can run. */
        visitstate = VisItDetectInput(blocking, -1);

        /* Do different things depending on the output from
        VisItDetectInput. */
        if(visitstate <= -1)
        {
            fprintf(stderr, "Can't recover from error!\n");
            err = 1;
        }
        else if(visitstate == 0)
        {
            /* There was no input from VisIt, return control to sim. */
            simulate_one_timestep(sim);
        }
        else if(visitstate == 1)
        {
            /* VisIt is trying to connect to sim. */
            if(VisItAttemptToCompleteConnection())
            {
                fprintf(stderr, "VisIt connected\n");
                /* Register command callback */
                VisItSetCommandCallback(ControlCommandCallback,
                (void*)sim);
                /* Register data access callbacks */
                VisItSetGetMetaDataTable(SimGetMetaDataTable, (void*)sim);
            }
            else
                fprintf(stderr, "VisIt did not connect\n");
        }
        else if(visitstate == 2)
        {
            /* VisIt wants to tell the engine something. */
            sim->runMode = VISIT_SIMMODE_STOPPED;
            if(!VisItProcessEngineCommand())
            {
                /* Disconnect on an error or closed connection. */
                VisItDisconnect();
                /* Start running again if VisIt closes. */
                sim->runMode = VISIT_SIMMODE_RUNNING;
            }
        }
    } while(!sim->done && err == 0);
}

```

Listing 5-35: sim12.c: C-Language example for returning simulation commands in the metadata.

```
/* Add some commands. */
const char *cmd_names[] = {"halt", "step", "run"};
for(i = 0; i < sizeof(cmd_names)/sizeof(const char *); ++i)
{
    visit_handle cmd = VISIT_INVALID_HANDLE;
    if(VisIt_CommandMetaData_alloc(&cmd) == VISIT_OKAY)
    {
        VisIt_CommandMetaData_setName(cmd, cmd_names[i]);
        VisIt_SimulationMetaData_addGenericCommand(md, cmd);
    }
}
```

Since the Fortran interface, defined in the `simV2f` library, requires callbacks to be in place when the simulation is linked, the Fortran simulation examples so far have already contained a command callback function. No change is required to the `mainloop` function in the Fortran simulations because the callback is already installed. The command callback function, which is always named `visitcommandcallback` in a Fortran simulation, previously did nothing. The following code example shows how to compare the names of a command coming from a button click in VisIt's **Simulations window** with the names of the supported commands and how to perform the desired action. The Fortran interface provides the `visitstrcmp` function, which is analogous to the C-Language's `strcmp` function in order to make string comparisons easier in Fortran.

Listing 5-36: fsim12.f: Fortran language implementation of the command callback function.

```
c-----
c visitcommandcallback
c-----
      subroutine visitcommandcallback (cmd, lcmd, args, largs)
      implicit none
      character*8 cmd, args
      integer      lcmd, largs
      include "visitfortransimV2interface.inc"
ccc   SIMSTATE common block
      integer runflag, simcycle
      real simtime
      common /SIMSTATE/ runflag, simcycle, simtime
c   Handle the commands that we define in visitgetmetadata.
      if(visitstrcmp(cmd, lcmd, "halt", 4).eq.0) then
          runflag = 0
      elseif(visitstrcmp(cmd, lcmd, "step", 4).eq.0) then
          call simulate_one_timestep()
      elseif(visitstrcmp(cmd, lcmd, "run", 3).eq.0) then
          runflag = 1
      endif
```

```
end
```

Listing 5-37: fsim12.f: Fortran language example for returning simulation commands in metadata..

```

c      Add simulation commands
if(visitmdcmdalloc(cmd).eq.VISIT_OKAY) then
    err = visitmdcmdsetname(cmd, "halt", 4)
    err = visitmdsimaddgenericcommand(md, cmd)
endif
if(visitmdcmdalloc(cmd).eq.VISIT_OKAY) then
    err = visitmdcmdsetname(cmd, "step", 4)
    err = visitmdsimaddgenericcommand(md, cmd)
endif
if(visitmdcmdalloc(cmd).eq.VISIT_OKAY) then
    err = visitmdcmdsetname(cmd, "run", 3)
    err = visitmdsimaddgenericcommand(md, cmd)
endif
```

4.5 Data access function for meshes

Now that you've implemented a function to return metadata about the meshes and variables in your simulation, you can write a new data access function to return the actual mesh. Adding a new data access function means that you will be registering a new callback function as you did before to register the metadata callback function. If your simulation is written in Fortran, you must implement the `visitgetmesh` function to return your mesh's data.

VisIt deals with several mesh types and each mesh type has its own corresponding data object that represents its data. The data access function for meshes allocates a handle to one of the mesh data types, fills in the results, and returns it. This section will first show how to return the right mesh to VisIt and will then focus on passing different types of meshes back to VisIt so they can be visualized.

4.5.1 Adding a mesh data access function

Adding a mesh data access function means that you have to first write a function and call `VisItSetGetMesh` to register it with `libsim`. You must register the function after a successful call to `VisItAttemptToCompleteConnection` so it should be done at the same time you register your metadata callback. The mesh data access function takes 3 arguments if you program in C. The first argument is a domain number, which you can use to return smaller pieces of the whole mesh. The mesh name will be one of the meshes that you added to the metadata. The second argument is the name of the mesh that VisIt wants to read. The third argument is a void pointer to the user-defined data that you passed to `VisItSetGetMesh` when you registered the mesh callback function. The user-defined data should point to your data model so you can retrieve mesh data from the callback function without using global variables.

The basic procedure involved in writing a mesh data access function is to first check the incoming name against the names of the meshes that your simulation is prepared to return and when one is found, return a handle to a mesh object that contains the mesh's data. If your mesh data access routine does not recognize the name of the mesh or if there is no data for the requested domain then you can return VISIT_INVALID_HANDLE instead of returning a mesh data object.

Listing 5-38: mesh.c: C-Language example for installing a mesh data access function.

```
visit_handle VisitGetMesh(int domain, const char *name, void *data)
{
    visit_handle mesh = VISIT_INVALID_HANDLE;

    if(strcmp(name, "mesh2d") == 0)
    {
        /* Allocate a rectilinear mesh. */
        if(VisIt_RectilinearMesh_alloc(&mesh) == VISIT_OKAY)
        {
            /* Fill in the attributes of the RectilinearMesh. */
        }
    }
    else if(strcmp(name, "mesh3d") == 0)
    {
        /* Allocate a curvilinear mesh. */
        if(VisIt_CurvilinearMesh_alloc(&mesh) == VISIT_OKAY)
        {
            /* Fill in the attributes of the CurvilinearMesh. */
        }
    }

    return mesh;
}
```

Remember that when writing a Fortran simulation, all of the data access functions must be defined before you can actually link your simulation. That means that up until now, the Fortran example programs have been using a simple implementation of the visitgetmesh function, which did nothing. The rest of this section will cover how to add an appropriate, working implementation of the visitgetmesh data access function.

Listing 5-39: fmesh.f: Fortran language example of a mesh data access function.

```
c-----
c visitgetmesh
c-----
      integer function visitgetmesh(handle, domain, name, lname)
      implicit none
      character*8 name
      integer      handle, domain, lname
```

```

include "visitfortransimV2interface.inc"
integer h
h= VISIT_INVALID_HANDLE
if(visitstrcmp(name, lname, "mesh2d", 6).eq.0) then
c Create a rectilinear mesh here
    if(visitrectmeshalloc(h).eq.VISIT_OKAY) then
c fill in the mesh data
        endif
    elseif(visitstrcmp(name, lname, "mesh3d", 6).eq.0) then
c Create a curvilinear mesh here
        if(visitcurvmeshalloc(h).eq.VISIT_OKAY) then
c fill in the mesh data
            endif
        endif
    visitgetmesh = h
end

```

4.5.2 VariableData

SimV2 provides a `VariableData` object that can represent linear arrays of char, int, float, and double precision data. Each tuple in the array can consist of multiple values, or components. For example, scalar data has 1 component but 3D vector data would have 3 components that describe it. Label variable data or array variable data could have more components. The simulation provides its data to VisIt in terms of `VariableData` objects. Meshes can consist of 1 or more `VariableData` objects to specify coordinates and connectivity. The composition, type, and number of the `VariableData` objects in a mesh will vary depending on the mesh type.

`VariableData` objects all have a concept of an owner for the data arrays that they wrap. Some arrays are long-lived and change little and can be used by VisIt without making a copy. These arrays are owned by the simulation and have an owner of type `VISIT_OWNER_SIM`. Some arrays are dynamically created by the sim for the express purpose of being fed to VisIt with the intent that VisIt will free the memory associated with the `VariableData`. These arrays have an owner of type `VISIT_OWNER_VISIT` and VisIt frees the data using the C Standard Library `free()` function when the data is no longer needed. As such, any data passed to VisIt with owner type `VISIT_OWNER_VISIT` must be allocated using `malloc()`. There is a special owner case called `VISIT_OWNER_COPY` that can be used to wrap stack variables that will go out of scope. When `VISIT_OWNER_COPY` is used, it acts as a trigger to get `libsim` to copy the data passed to the `VariableData` instead of just keeping a pointer to it. The copied data is then marked with `VISIT_OWNER_VISIT` as the owner.

4.6 Rectilinear meshes

Rectilinear meshes can be returned by the mesh data access function by allocating and returning a `RectilinearMesh` object. In fact, meshes of type `AVT_AMR_MESH` in the metadata are treated as rectilinear meshes when it is time to return data to VisIt. Once

you've allocated the `RectilinearMesh` object, start initializing its members using information about the mesh. For starters, create 2 or 3 `VariableData` objects to represent the mesh's coordinate fields. You can associate the `VariableData` objects with the mesh as its coordinates by calling `VisIt_RectilinearMesh_setCoordsXY` for 2D and `VisIt_RectilinearMesh_setCoordsXYZ` for 3D.

In SimV2, the only required pieces of a `RectilinearMesh` object are the coordinates. All other fields in the mesh will be set to sensible default values. You can, however, override the default values.

You can set the `baseIndex` member, which is an offset in X,Y,Z that will be added to your mesh's zone numbers and node numbers when VisIt displays information about your mesh. You can leave these values set at zero. However, when you want to create a multi-domain mesh that has global zone and node numbers, you should set the values for `baseIndex`. Global node and zone numbers can make it easier to think of your domain-decomposed mesh as a single entity by making VisIt features such as pick return global node or zone numbers instead of per-domain node or zone numbers.

Now that you've set the values in the `RectilinearMesh` object that indicate its logical size, you can tell VisIt whether the mesh has ghost zones. The `RectilinearMesh` object indicates whether there are ghost zones by using the values stored in the `minRealIndex` and `maxRealIndex` members. These values are set by calling `VisIt_RectilinearMesh_setRealIndices`. The defaults are set to values that make sense for a mesh with no ghost zones: the minimums are all zeroes and the maximums are set to the number zones in the specified dimension minus one. If your mesh has ghost zones in any of the dimensions then be sure that you add 1 to the values stored in the `minRealIndex` array for the dimensions that have ghost zones. Also be sure to subtract 1 from the elements in the `maxRealIndex` array for the dimensions that have ghost zones..

Listing 5-40: mesh.c: C-Language example for returning a rectilinear mesh.

```
/* Simulation mesh */
float rmesh_x[] = {0., 1., 2.5, 5.};
float rmesh_y[] = {0., 2., 2.25, 2.55, 5.};
int rmesh_dims[] = {4, 5, 1};
int rmesh_ndims = 2;

visit_handle
SimGetMesh(int domain, const char *name, void *cbdata)
{
    visit_handle h = VISIT_INVALID_HANDLE;

    if(strcmp(name, "mesh2d") == 0)
    {
        if(VisIt_RectilinearMesh_alloc(&h) != VISIT_ERROR)
        {
```

```

        visit_handle hxc, hyc;
        VisIt_VariableData_alloc(&hxc);
        VisIt_VariableData_alloc(&hyc);
        VisIt_VariableData_setDataF(hxc, VISIT_OWNER_SIM, 1,
            rmesh_dims[0], rmesh_x);
        VisIt_VariableData_setDataF(hyc, VISIT_OWNER_SIM, 1,
            rmesh_dims[1], rmesh_y);
        VisIt_RectilinearMesh_setCoordsXY(h, hxc, hyc);
    }
}
return h;
}

```

The Fortran implementation of the GetMesh callback function follows the same pattern as the C implementation. The data arrays that make up the rectilinear mesh in the upcoming Fortran example are stored in a Fortran common block, making the data accessible to the `simulate_one_timestep` function and the `visitgetmesh` function. If you store your data in common blocks, it is easy to make it accessible to VisIt.

Listing 5-41: fmesh.f: Fortran language example for returning a rectilinear mesh.

```

      subroutine simulate_one_timestep()
ccc  RECTMESH common block
      integer NX, NY
      parameter (NX = 4)
      parameter (NY = 5)
      real rmx(NX), rmy(NY)
      integer rmndims(3), rmndims
      common /RECTMESH/ rmndims, rmndims, rmx, rmy
      save /RECTMESH/
c Initial rectilinear mesh
      data rmndims /2/
      data rmndims /4, 5, 1/
      data rmx/0., 1., 2.5, 5./
      data rmy/0., 2., 2.25, 2.55, 5./
c Simulate one time step
      end

c-----
c visitgetmesh
c-----
integer function visitgetmesh(handle, domain, name, lname)
implicit none
character*8 name
integer handle, domain, lname
include "visitfortransimV2interface.inc"
ccc  RECTMESH common block (shared with simulate_one_timestep)
      integer NX, NY
      parameter (NX = 4)
      parameter (NY = 5)
      real rmx(NX), rmy(NY)

```

```

        integer rmndims(3), rmndims
        common /RECTMESH/ rmndims, rmndims, rmx, rmy
ccc      local variables
        integer h, err

        h = VISIT_INVALID_HANDLE
        if(visitstrcmp(name, lname, "mesh2d", 6).eq.0) then
            if(visitrectmeshalloc(h).eq.VISIT_OKAY) then
                err = visitvardataalloc(x)
                err = visitvardataalloc(y)
                err = visitvardatasetf(x,VISIT_OWNER_SIM,1,NX,rmx)
                err = visitvardatasetf(y,VISIT_OWNER_SIM,1,NY,rmy)

                err = visitrectmeshsetcoordsxy(h, x, y)
            endif
        endif

        visitgetmesh = h
    end

```

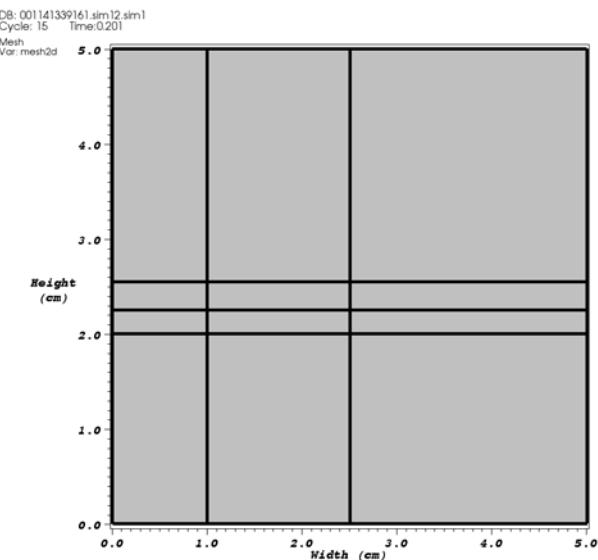


Figure 5-42: 2D rectilinear mesh returned by the previous code examples.

4.7 Curvilinear meshes

Curvilinear meshes can be passed to VisIt by allocating and returning a `CurvilinearMesh` object from your mesh data access function. The procedure for creating a curvilinear mesh is nearly the same as that for creating a rectilinear mesh. The

main difference that VisIt recognizes between the two mesh types is the size of the coordinate arrays. A curvilinear mesh must have the X,Y,Z coordinates of each node in the mesh explicitly provided, whereas most of the coordinates are implicitly defined, with only 1D arrays given for the X,Y,Z coordinates, in a rectilinear mesh. As with a rectilinear mesh, you will need to create 2 or 3 VariableData objects in which to store the coordinate data when coordinate data are separate. The size of each coordinate array will be NX*NY*NZ where NX is the number of nodes in the X dimension, NY is the number of nodes on the Y dimension, and NZ is the number of nodes in the Z dimension. Since the code for handling curvilinear meshes is so similar to that for handling rectilinear meshes, refer to Section 4.6 for more detail on setting values into the CurvilinearMesh.

Listing 5-43: mesh.c: C-Language example for returning a curvilinear mesh.

```

/* Curvilinear mesh */
float cmesh_x[2][3][4] = {
    {{0.,1.,2.,3.},{0.,1.,2.,3.}, {0.,1.,2.,3.}},
    {{0.,1.,2.,3.},{0.,1.,2.,3.}, {0.,1.,2.,3.}}
};
float cmesh_y[2][3][4] = {
    {{0.5,0.,0.,0.5},{1.,1.,1.,1.}, {1.5,2.,2.,1.5}},
    {{0.5,0.,0.,0.5},{1.,1.,1.,1.}, {1.5,2.,2.,1.5}}
};
float cmesh_z[2][3][4] = {
    {{0.,0.,0.,0.},{0.,0.,0.,0.},{0.,0.,0.,0.}},
    {{1.,1.,1.,1.},{1.,1.,1.,1.},{1.,1.,1.,1.}}
};
int cmesh_dims[] = {4, 3, 2};
int cmesh_ndims = 3;

visit_handle
SimGetMesh(int domain, const char *name, void *cbdata)
{
    visit_handle h = VISIT_INVALID_HANDLE;

    if(strcmp(name, "mesh3d") == 0)
    {
        if(VisIt_CurvilinearMesh_alloc(&h) != VISIT_ERROR)
        {
            int nn;
            visit_handle hxc, hyc, hzc;
            nn = cmesh_dims[0] * cmesh_dims[1] * cmesh_dims[2];
            VisIt_VariableData_alloc(&hxc);
            VisIt_VariableData_alloc(&hyc);
            VisIt_VariableData_alloc(&hzc);
            VisIt_VariableData_setDataF(hxc, VISIT_OWNER_SIM, 1, nn,
                (float*)cmesh_x);
            VisIt_VariableData_setDataF(hyc, VISIT_OWNER_SIM, 1, nn,
                (float*)cmesh_y);
            VisIt_VariableData_setDataF(hzc, VISIT_OWNER_SIM, 1, nn,
                (float*)cmesh_z);
        }
    }
}

```

```

        VisIt_CurvilinearMesh_setCoordsXYZ(h, cmesh_dims, hxc, hyc,
        hzc);
    }
}

return h;
}

```

The Fortran interface provides the `visitmeshcurvilinear` function to create a rectilinear mesh that can be passed back to VisIt. The `visitmeshcurvilinear` function essentially packages up the code from the C-Language example, making it possible to dynamically create a `CurvilinearMesh` object and populate its members. The data arrays that make up the curvilinear mesh in the upcoming Fortran example are stored in a Fortran common block, making the data accessible to the `simulate_one_timestep` function and the `visitgetmesh` function.

Listing 5-44: fmesh.f: Fortran language example for returning a curvilinear mesh.

```

subroutine simulate_one_timestep()
ccc CURVMESH common block
integer CNX, CNY, CNZ
parameter (CNX = 4)
parameter (CNY = 3)
parameter (CNZ = 2)
integer cmdims(3), cmndims
real cmx(CNX,CNY,CNZ), cmy(CNX,CNY,CNZ), cmz(CNX,CNY,CNZ)
common /CURVMESH/ cmdims, cmndims, cmx, cmy, cmz
save /CURVMESH/
c Curvilinear mesh data
data cmx/0.,1.,2.,3., 0.,1.,2.,3., 0.,1.,2.,3.,
. 0.,1.,2.,3., 0.,1.,2.,3., 0.,1.,2.,3./
data cmy/0.5,0.,0.,0.5, 1.,1.,1.,1., 1.5,2.,2.,1.5,
. 0.5,0.,0.,0.5, 1.,1.,1.,1., 1.5,2.,2.,1.5/
data cmz/0.,0.,0.,0., 0.,0.,0.,0., 0.,0.,0.,0.,
. 1.,1.,1.,1., 1.,1.,1.,1., 1.,1.,1.,1./
data cmndims /3/
data cmdims/CNX,CNY,CNZ/
c Simulate one time step
end
c-----
c visitgetmesh
c-----
integer function visitgetmesh(handle, domain, name, lname)
implicit none
character*8 name
integer handle, domain, lname
include "visitfortransimV2interface.inc"
ccc CURVMESH common block (shares with simulate_one_timestep)
integer CNX, CNY, CNZ
parameter (CNX = 4)

```

```

parameter (CNY = 3)
parameter (CNZ = 2)
integer cmdims(3), cmndims
real cmx(CNX,CNY,CNZ), cmy(CNX,CNY,CNZ), cmz(CNX,CNY,CNZ)
common /CURVMESH/ cmdims, cmndims, cmx, cmy, cmz
ccc local variables
integer h, x, y, z, nnodes, err

h = VISIT_INVALID_HANDLE
if(visitstrcmp(name, lname, "mesh3d", 6).eq.0) then
    if(visitcurvmeshalloc(h).eq.VISIT_OKAY) then
        err = visitvardataalloc(x)
        err = visitvardataalloc(y)
        err = visitvardataalloc(z)
        nnodes = CNX * CNY * CNZ
        err = visitvardatasetf(x,VISIT_OWNER_SIM,1,nnodes,cmx)
        err = visitvardatasetf(y,VISIT_OWNER_SIM,1,nnodes,cmy)
        err = visitvardatasetf(z,VISIT_OWNER_SIM,1,nnodes,cmz)

        err = visitcurvmeshsetcoordsxyz(h, cmdims, x, y, z)
    endif
endif
visitgetmesh = h
end

```

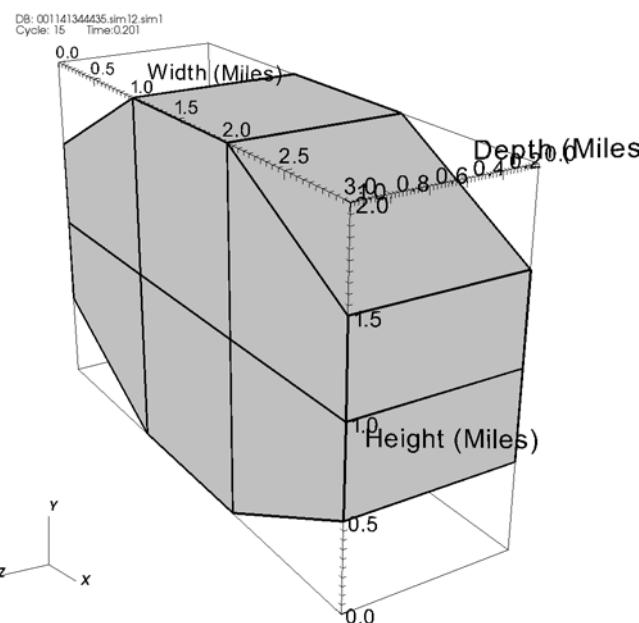


Figure 5-45: 3D curvilinear mesh returned by the previous code examples

4.8 Point meshes

Point meshes can be returned by allocating and returning a `PointMesh` object from your mesh data access function. Once you've allocated the `PointMesh` object, start initializing its members using information about the mesh. Point meshes contain relatively few elements - little more than a list of vertices. As with structured meshes, you will need to create 2 or 3 `VariableData` objects in which to store the coordinate data when coordinate data are separate. You can then associate those `VariableData` objects with the `PointMesh` object by calling `VisIt_PointMesh_setCoordsXY` or `VisIt_PointMesh_setCoordsXYZ..`

Listing 5-46: point.c: C-Language example for returning a point mesh.

```
#define NPTS          1000

/* Simulation data is stored in this structure. */
typedef struct
{
    int      cycle;
    double   time;
    int      runMode;
    int      done;

    float    angle;
    float    *x;
    float    *y;
    float    *z;
} simulation_data;

visit_handle
SimGetMesh(int domain, const char *name, void *cbdata)
{
    visit_handle h = VISIT_INVALID_HANDLE;
    /* We passed a pointer to the simulation data as user-data when we
     * registered the SimGetMesh data access callback.
     */
    simulation_data *sim = (simulation_data *)cbdata;

    if(strcmp(name, "point3d") == 0)
    {
        if(VisIt_PointMesh_alloc(&h) != VISIT_ERROR)
        {
            visit_handle hx, hy, hz;

            VisIt_VariableData_alloc(&hx);
            VisIt_VariableData_alloc(&hy);
            VisIt_VariableData_alloc(&hz);
            VisIt_VariableData_setDataF(hx, VISIT_OWNER_SIM, 1, NPTS,
                                       sim->x);
            VisIt_VariableData_setDataF(hy, VISIT_OWNER_SIM, 1, NPTS,
                                       sim->y);
```

```

        VisIt_VariableData_setDataF(hz, VISIT_OWNER_SIM, 1, NPTS,
        sim->z);
        VisIt_PointMesh_setCoordsXYZ(h, hx, hy, hz);
    }
}

return h;
}

```

The Fortran interface provides the `visitmeshpoint` function so you can create a `VisIt_PointMesh` object that can be returned to VisIt. The `visitmeshpoint` function takes 6 arguments. The first argument is an integer handle to the mesh object that was passed into the `visitgetmesh` function. The second argument allows you to set the number of dimensions that your point mesh will use: 2 or 3. The third argument lets you set the number of nodes in your point mesh. The final three REAL arguments contain the X,Y,Z coordinates, respectively.

Listing 5-47: fpoint.f: Fortran language example for returning a point mesh.

```

integer function visitgetmesh(domain, name, lname)
implicit none
character*8 name
integer domain, lname
include "visitfortransimV2interface.inc"
ccc POINTMESH common block (shared with simulate_one_timestep)
integer NPTS
parameter (NPTS = 1000)
real pmx(NPTS), pmy(NPTS), pmz(NPTS)
common /POINTMESH/ pmx, pmy, pmz
ccc local vars
integer h, hx, hy, hz, err

h = VISIT_INVALID_HANDLE
if(visitstrcmp(name, lname, "point3d", 7).eq.0) then
    if(visitpointmeshalloc(h).eq.VISIT_OKAY) then
        err = visitvardataalloc(hx)
        err = visitvardataalloc(hy)
        err = visitvardataalloc(hz)
        err = visitvardatasetf(hx, VISIT_OWNER_SIM, 1, NPTS, pmx)
        err = visitvardatasetf(hy, VISIT_OWNER_SIM, 1, NPTS, pmy)
        err = visitvardatasetf(hz, VISIT_OWNER_SIM, 1, NPTS, pmz)
        err = visitpointmeshsetcoordsxyz(h, hx, hy, hz)
    endif
endif
visitgetmesh = h
end

```

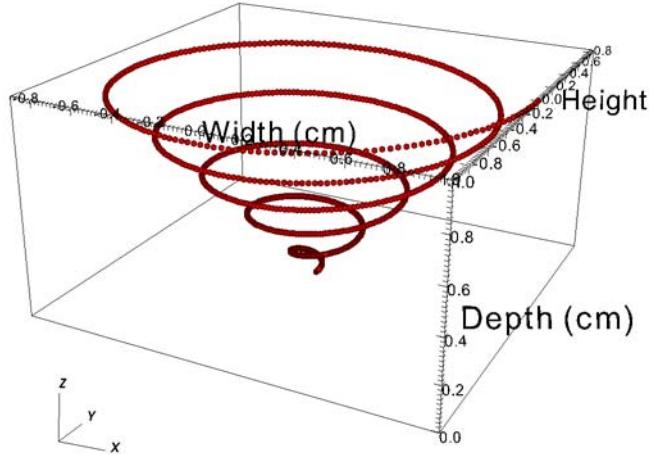


Figure 5-48: 3D point mesh returned by the previous code examples

4.9 Unstructured meshes

Unstructured meshes can be returned allocating and returning an `UnstructuredMesh` object from your mesh data access function. After allocating the `UnstructuredMesh` object, you can begin filling in its data. As with other mesh types, you must provide coordinates. This requires either 2 or 3 `VariableData` objects when the coordinates are separate. You can associate the coordinate arrays with the `UnstructuredMesh` object by calling the `VisIt_UnstructuredMesh_setCoordsXY` or `VisIt_UnstructuredMesh_setCoordsXYZ` functions.

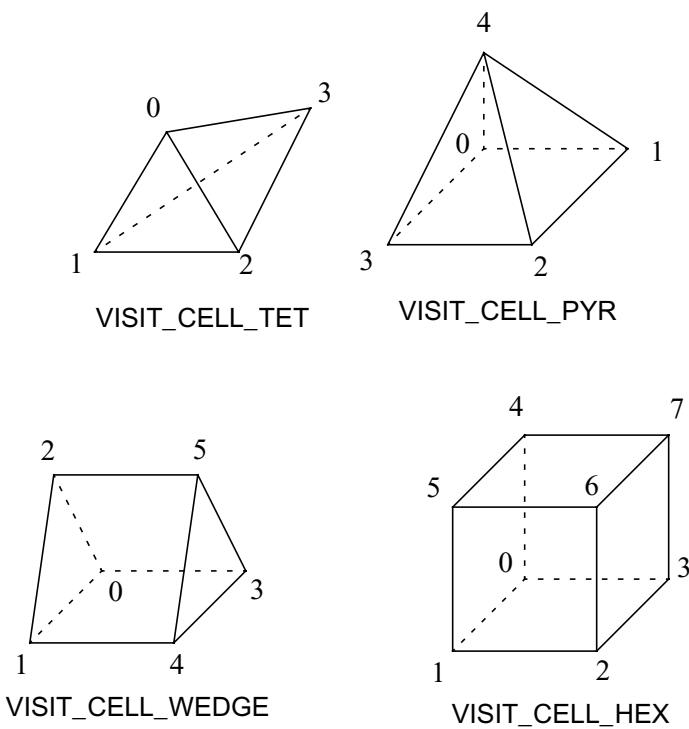


Figure 5-49: Node ordering for 3D unstructured zone types

Note that the node ordering (VTK's node ordering) is the same as for creating Silo files, except for the wedge zone type.

If your mesh has ghost zones, you can indicate their placement in the zone list by calling `VisIt_UnstructuredMesh_setRealIndices`. The function takes start and end indices of the real zones in the zone list. Zones before the start or after the end of the specified indices are treated as ghost zones. If your mesh has no ghost zones then you do not need to set anything as all zones are assumed to be real zones by default.

Listing 5-50: unstructured.c: C-Language example for returning an unstructured mesh.

```

float umx[] = {0.,2.,2.,0.,0.,2.,2.,0.,0.,2.,2.,0.,1.,2.,4.,4.};
float umy[] = {0.,0.,0.,0.,2.,2.,2.,2.,4.,4.,4.,4.,6.,0.,0.,0.};
float umz[] = {2.,2.,0.,0.,2.,2.,0.,0.,2.,2.,0.,0.,1.,4.,2.,0.};
/* Connectivity */
int connectivity[] = {
    VISIT_CELL_HEX, 0,1,2,3,4,5,6,7, /* hex,      zone 1 */
    VISIT_CELL_HEX, 4,5,6,7,8,9,10,11, /* hex,      zone 2 */
    VISIT_CELL_PYR, 8,9,10,11,12, /* pyramid, zone 3 */
    VISIT_CELL_WEDGE, 1,14,5,2,15,6, /* wedge,    zone 4 */
    VISIT_CELL_TET, 1,14,13,5 /* tet,      zone 5 */
};
int lconnectivity = sizeof(connectivity) / sizeof(int);

```

In addition to coordinates, you must also create a `VariableData` object that wraps an integer array containing the mesh connectivity. The mesh connectivity is stored as a linear array of integers in sequences that list the zone type, followed by the node indices being used for that zone. The connectivity can contain a mix of all zone types in any order. The node indices should begin at zero, even in languages where the first array element is one, such as in Fortran. This pattern is repeated until all zones in the mesh have been identified. Figure 5-49 shows the node ordering that must be used to create cells for an unstructured mesh, though polyhedral cells are not shown.

```

int umnnodes = 16;
int umnzones = 5;

visit_handle
SimGetMesh(int domain, const char *name, void *cbdata)
{
    visit_handle h = VISIT_INVALID_HANDLE;

    if(strcmp(name, "unstructured3d") == 0)
    {
        if(VisIt_UnstructuredMesh_alloc(&h) != VISIT_ERROR)
        {
            visit_handle x,y,z,conn;

            VisIt_VariableData_alloc(&x);
            VisIt_VariableData_alloc(&y);
            VisIt_VariableData_alloc(&z);
            VisIt_VariableData_setDataF(x, VISIT_OWNER_SIM, 1, umnnodes,
                                         umx);
            VisIt_VariableData_setDataF(y, VISIT_OWNER_SIM, 1, umnnodes,
                                         umy);
            VisIt_VariableData_setDataF(z, VISIT_OWNER_SIM, 1, umnnodes,
                                         umz);

            VisIt_VariableData_alloc(&conn);
            VisIt_VariableData_setDataI(conn, VISIT_OWNER_SIM, 1,
                                         lconnectivity, connectivity);

            VisIt_UnstructuredMesh_setCoordsXYZ(h, x, y, z);
            VisIt_UnstructuredMesh_setConnectivity(h, umnzones, conn);
        }
    }

    return h;
}

```

Listing 5-51: funstructured.f: Fortran language example for returning an unstructured mesh.

```

subroutine simulate_one_timestep()
implicit none
include "visitfortransiminterface.inc"
ccc UNSTRUCTURED common block (shared with visitgetmesh)
integer NNODES, NZONES, LCONN
parameter (NNODES = 16)
parameter (NZONES = 5)
parameter (LCONN = 36)
real umx(NNODES), umy(NNODES), umz(NNODES)
integer connectivity(LCONN)
common /UNSTRUCTURED/ umx, umy, umz, connectivity
save /UNSTRUCTURED/
c Data values
data umx/0.,2.,2.,0.,0.,2.,2.,0.,0.,2.,2.,0.,1.,2.,4.,4./

```

```

    data umy/0.,0.,0.,0.,2.,2.,2.,2.,4.,4.,4.,4.,6.,0.,0.,0./
    data umz/2.,2.,0.,0.,2.,2.,0.,0.,2.,2.,0.,0.,1.,4.,2.,0./
    data connectivity/VISIT_CELL_HEX, 0,1,2,3,4,5,6,7,
    . VISIT_CELL_HEX, 4,5,6,7,8,9,10,11,
    . VISIT_CELL_PYR, 8,9,10,11,12,
    . VISIT_CELL_WEDGE, 1,14,5,2,15,6,
    . VISIT_CELL_TET, 1,14,13,5/
    end

c-----
c visitgetmesh
c-----

integer function visitgetmesh(handle, domain, name, lname)
implicit none
character*8 name
integer handle, domain, lname
include "visitfortransimV2interface.inc"
ccc UNSTRUCTURED common block (shared with simulate_one_timestep)
integer NNODES, NZONES, LCONN
parameter (NNODES = 16)
parameter (NZONES = 5)
parameter (LCONN = 36)
real umx(NNODES), umy(NNODES), umz(NNODES)
integer connectivity(LCONN)
common /UNSTRUCTURED/ umx, umy, umz, connectivity
ccc local variables
integer h, x, y, z, conn, err

h = VISIT_INVALID_HANDLE
if(visitstrcmp(name, lname, "unstructured3d", 14).eq.0) then
c Create an unstructured mesh here
    if(visitucdmeshalloc(h).eq.VISIT_OKAY) then
        err = visitvardataalloc(x)
        err = visitvardataalloc(y)
        err = visitvardataalloc(z)
        err = visitvardatasetf(x,VISIT_OWNER_SIM,1,NNODES,umx)
        err = visitvardatasetf(y,VISIT_OWNER_SIM,1,NNODES,umy)
        err = visitvardatasetf(z,VISIT_OWNER_SIM,1,NNODES,umz)

        err = visitvardataalloc(conn)
        err = visitvardatasetset(conn,VISIT_OWNER_SIM,1,LCONN,
                                connectivity)
        .
        err = visitucdmeshsetcoordsxyz(h, x, y, z)
        err = visitucdmeshsetconnectivity(h, NZONES, conn)
    endif
endif
visitgetmesh = h
end

```

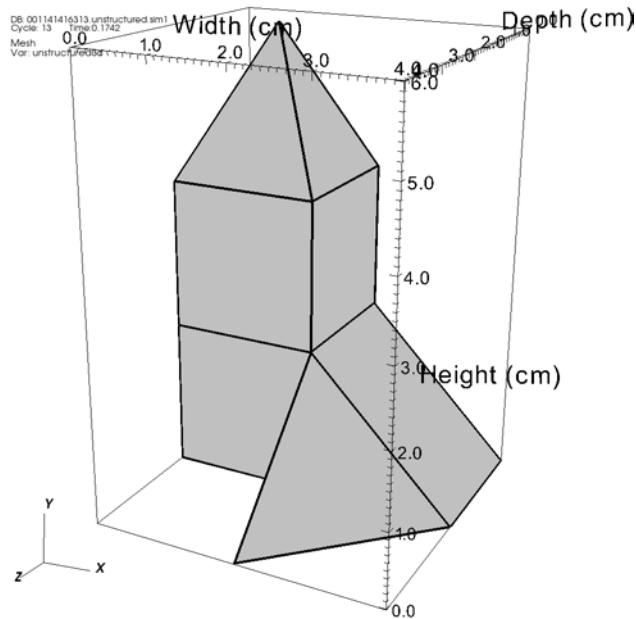


Figure 5-52: 3D unstructured mesh returned by the previous code examples

4.9.1 Polyhedral zones in an unstructured mesh

Unstructured mesh connectivity can also contain polyhedral zones, which are N-faced (where $N > 3$) solid cells that can be arbitrarily complex. Polyhedral cells can serve as a bridge in between cell types or when you split the faces of one cell that needs to connect to several adjacent cells as with an AMR level transition. VisIt breaks up polyhedral cells into tetrahedrons and pyramids, internally after they are received from the simulation. Polyhedral cells are described in the connectivity by `VISIT_CELL_POLYHEDRON`, followed by the number of faces, followed by each face. Each polyhedral face is a polygon and is represented in the connectivity by the number of nodes in the face, followed by the node indices that make up the face.

Listing 5-53: `polyhedral.c`: C-Language example for returning polyhedral zones.

```
int connectivity[] = {
    VISIT_CELL_HEX,
    0,1,5,4,3,2,6,7,
    VISIT_CELL_POLYHEDRON,
    9, /* # faces*/
    4, /*ids*/ 4,5,6,7,
    5, /*ids*/ 8,4,7,14,11,
    5, /*ids*/ 14,7,6,16,15,
    5, /*ids*/ 16,6,5,10,13,
    5, /*ids*/ 10,5,4,8,9,
    4, /*ids*/ 9,8,11,12,
```

```

    4, /*ids*/ 10,9,12,13,
    4, /*ids*/ 12,11,14,15,
    4, /*ids*/ 13,12,15,16,
VISIT_CELL_HEX,
    8,9,18,17,11,12,21,20,
VISIT_CELL_HEX,
    9,10,19,18,12,13,22,21,
VISIT_CELL_HEX,
    11,12,21,20,14,15,24,23,
VISIT_CELL_HEX,
    12,13,22,21,15,16,25,24
};

}


```

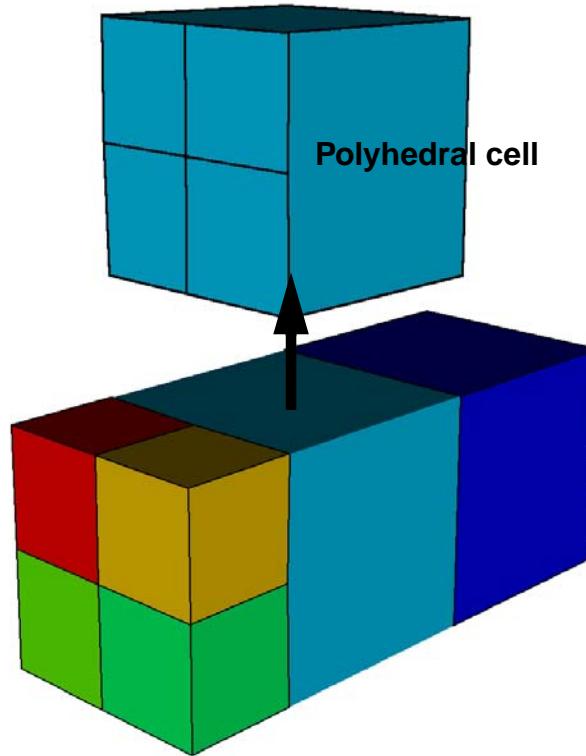


Figure 5-54: Polyhedral zone used to connect other hex zones

4.10 AMR meshes

AMR stands for adaptive mesh refinement. This term describes a structured mesh where rectangular regions of zones subdivide uniformly, by a factor, in regions of the mesh where more detail is required. The newly refined region forms a new mesh, often called a patch, that can be thought of as an overlay on top of the original coarser data. This refinement process repeats until the zones of interest are sufficiently small to capture enough detail about the phenomena being modeled. Since each refined layer overlays its parent layer, AMR refinement levels are treated hierarchically. In VisIt, each individual

patch in the hierarchy becomes a separate domain. The meshes for each domain are themselves just rectilinear meshes and can be returned as such from the mesh data access callback function.

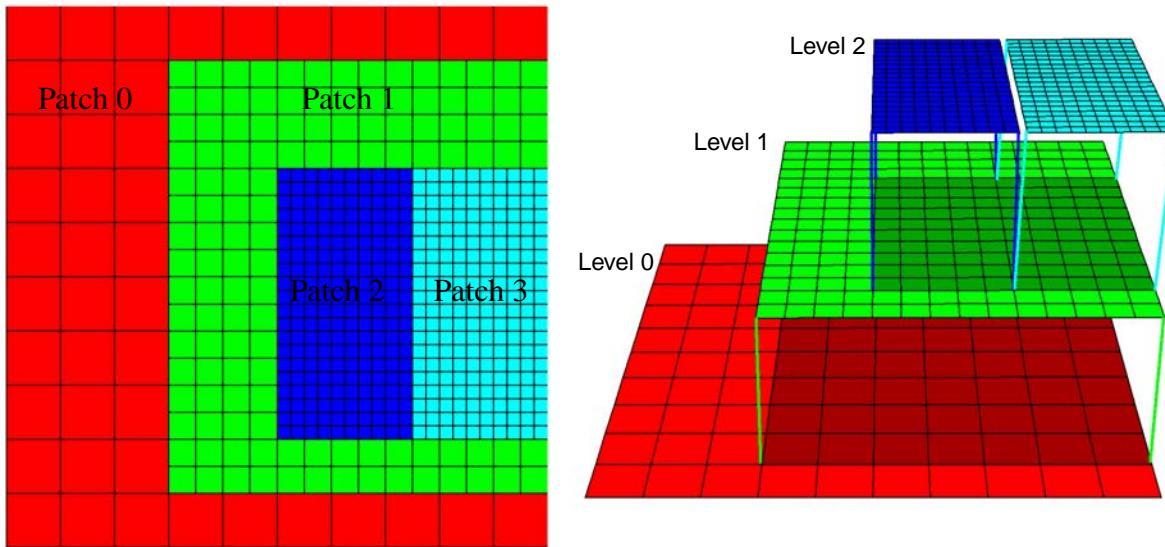


Figure 5-55: AMR mesh colored by patch number with level hierarchy shown (right)

4.10.1 Returning metadata

AMR meshes require some additional metadata to be returned. Since AMR meshes have both patches and levels those different subset concepts must be mapped to subset types that VisIt supports. Patches should be mapped to domains and levels should be mapped to groups, which in VisIt parlance, are groups of domains. You can set the number of groups by calling `VisIt_MeshMetaData_setNumGroups` in C or `visitmdmeshsetnumgroups` in Fortran. The metadata must contain the patch to level mapping for each patch, which aids VisIt in determining the AMR hierarchy. You can set the patch to level mapping for each patch by calling `VisIt_MeshMetaData_addGroupId` from C, or `visitmdmeshsetgroupids` from Fortran. The metadata code listings for setting the patch to level mapping assumes the example code has defined an integer array called `level` that contains a level number for each domain in the AMR mesh.

The metadata can also be changed to set the domain and group titles and piece names to names that better represent AMR meshes. For example, the “*Domains*” title that is eventually shown in VisIt’s **Subset** window can be changed by setting the mesh metadata’s domain title to “*Patches*”. The individual domain names can be set but we will set the domain piece name to cause all of our domains to be named “*patch0*”, “*patch1*”,

... and so on. The same type of name substitution can be done for groups so they appear in VisIt as levels.

Listing 5-56: amr.c: C-Language example for returning a AMR metadata.

```

/* Set the first mesh's properties.*/
if(VisIt_MeshMetaData_alloc(&mmd) == VISIT_OKAY)
{
    /* Set the mesh's properties.*/
    VisIt_MeshMetaData_setName(mmd, "amr");
    VisIt_MeshMetaData_setMeshType(mmd, VISIT_MESHTYPE_AMR);
    VisIt_MeshMetaData_setTopologicalDimension(mmd, 2);
    VisIt_MeshMetaData_setSpatialDimension(mmd, 2);
    VisIt_MeshMetaData_setNumDomains(mmd, NPATCHES);
    VisIt_MeshMetaData_setDomainTitle(mmd, "Patches");
    VisIt_MeshMetaData_setDomainPieceName(mmd, "patch");
    VisIt_MeshMetaData_setNumGroups(mmd, 3);
    VisIt_MeshMetaData_setGroupTitle(mmd, "Levels");
    VisIt_MeshMetaData_setGroupPieceName(mmd, "level");
    for(i = 0; i < NPATCHES; ++i)
        VisIt_MeshMetaData_addGroupId(mmd, level[i]);
    VisIt_MeshMetaData_setXUnits(mmd, "cm");
    VisIt_MeshMetaData_setYUnits(mmd, "cm");
    VisIt_MeshMetaData_setXLabel(mmd, "Width");
    VisIt_MeshMetaData_setYLabel(mmd, "Height");

    VisIt_SimulationMetaData_addMesh(md, mmd);
}

```

Listing 5-57: famr.f: Fortran-Language example for returning AMR metadata.

```

c      Add a 2D AMR mesh
      if(visitmdmeshalloc(mmd).eq.VISIT_OKAY) then
          err = visitmdmeshsetname(mmd, "amr", 3)
          err = visitmdmeshsetmeshtype(mmd, VISIT_MESHTYPE_AMR)
          err = visitmdmeshsettopologicaldim(mmd, 2)
          err = visitmdmeshsetspatialdim(mmd, 2)
          err = visitmdmeshsetnumdomains(mmd, 4)
          err = visitmdmeshsetdomaintitle(mmd, "patches", 7)
          err = visitmdmeshsetdomainpieceName(mmd, "patch", 5)
          err = visitmdmeshsetnumgroups(mmd, 3)
          err = visitmdmeshsetgroupTitle(mmd, "levels", 6)
          err = visitmdmeshsetgroupPieceName(mmd, "level", 5)
          do 1400 i=1,NPATCHES
              err = visitmdmeshsetgroupids(mmd, level(i))
1400 continue
          err = visitmdmeshsetxunits(mmd, "cm", 2)
          err = visitmdmeshsetyunits(mmd, "cm", 2)
          err = visitmdmeshset xlabel(mmd, "Width", 5)
          err = visitmdmeshset ylabel(mmd, "Height", 6)
          err = visitmdsimaddmesh(md, mmd)

```

```
endif
```

4.10.2 Domain nesting

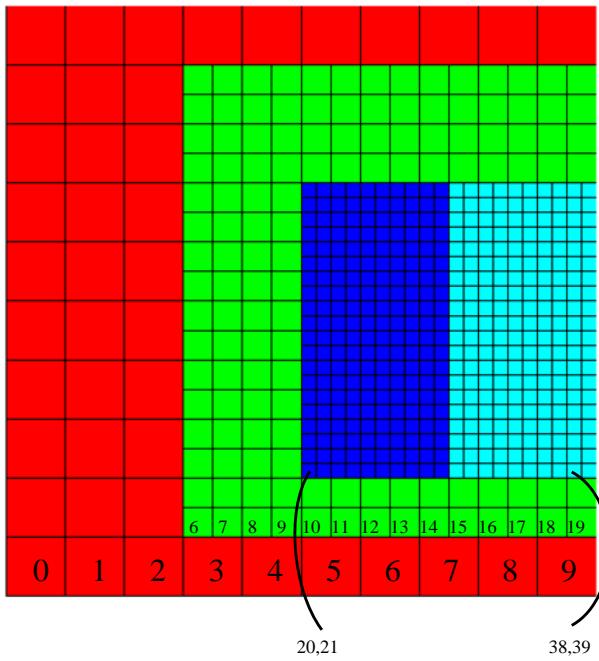


Figure 5-58: AMR mesh zone indexing

The real trick to AMR meshes is telling VisIt how to hierarchically group them so VisIt will treat them as AMR meshes. Part of this is achieved by indicating the level for each patch in the metadata. Since AMR meshes contain multiple levels of detail that will be handled simultaneously, any given place on the mesh could be several levels thick. VisIt avoids this by skipping out regions of coarser patches where more-resolved patches are available. The resulting AMR data consist of a single surface of data at varying resolutions. In order to perform this operation, VisIt uses ghost zones to skip over zones where finer data exist. Consequently, VisIt must know how patches nest within one another. For this

purpose, `libsim` provides the `DomainNesting` object. The `DomainNesting` object is returned by a separate data access callback function that can be registered using the `VisItSetGetDomainNesting` function.

The `DomainNesting` object contains the refinement ratios for each level as well as per-patch IJK indices for each patch. The IJK indices are specified relative to the level in which the patch exists and a patch must be contained within its parent patch. Our example AMR mesh has 3 levels and 4 patches. Patch 0, which is in level 0 is a 10x10 rectilinear grid whose zone indices range 0:9 in both I and J. Patch 1 is in level 1 in the AMR hierarchy so its possible I and J ranges, were it to cover all of its parent patch, are both 0:19 since there is a refinement ratio of 2 in both I and J. This means that each successive level in the AMR mesh will have 2x the number of cells in I and J. The refinement ratio is customizable on a per-level basis and can differ for I and J. Taking the refinement ratio into account, you can see that level 2 would have twice the number of zones as level 1, for a zone range of 0:39. In general, the smallest possible index for a level is 0 though this value can't always be used if patches are refined offset to their parent's origin. The largest possible index is $NX * \text{ratio}_x^{\text{level}} - 1$ for I and $NY * \text{ratio}_y^{\text{level}} - 1$ for J where NX, NY are the number of zones in the level₀ mesh.

Back to the example program, the zone indices for the 4 patches are:

Patch	min I	max I	min J	max J
0	0	9	0	9
1	6	19	2	17
2	20	29	8	27
3	30	39	8	27

The example program stores the I indices in the `rmxext` array, stored min followed by max on a per patch basis. J indices are stored the same way in the `rmyext` array. The `level` array stores the level to which each patch belongs. The `cpatch` array stores a list of child patches for each patch with no child patches designated as -1. The `ncpatch` array contains the number of child patches for each patch.

The first step in initializing a `DomainNesting` object is to set the number of patches, levels, and dimensions into it using the

`VisIt_DomainNesting_set_dimensions` or

`visitdnestingsetdimensions` functions. Next, set the refinement level for each level in the AMR hierarchy using the

`VisIt_DomainNesting_set_levelRefinement` or

`visitdnestingsetlevelrefinement` functions. Note that levels must start their numbering at zero. The next step is to specify the domain nesting for each patch in the AMR hierarchy. The domain nesting is specified using the patch's min and max I,J,K values stored in an integer array. The list of child patches for the current patch is also given as part of the domain nesting information. Domain nesting information for a patch is recorded using the `VisIt_DomainNesting_set_nestingForPatch` and `visitdnestingsetnestingforpatch` functions. Like level numbers, patch numbers begin at zero.

Listing 5-59: amr.c: C-Language example for returning domain nesting.

```

/* AMR mesh */
#define NPATCHES 4
float rmx[NPATCHES][2]    = {{0., 10.}, {3., 10.}, {5., 7.5}, {7.5,
10.}};
float rmy[NPATCHES][2]    = {{0., 10.}, {1., 9.}, {2., 7.}, {2., 7.}};
int  rmxext[NPATCHES][2] = {{0,9}, {6,19}, {20,29}, {30,39}};
int  rmyext[NPATCHES][2] = {{0,9}, {2,17}, {8,27}, {8,27}};
int  level[NPATCHES]     = {0, 1, 2, 2};
int  ncpatch[NPATCHES]   = {1,2,0,0};
int  cpatch[NPATCHES][2] = {{1,-1},{2,3},{-1,-1},{-1,-1}};

visit_handle
SimGetDomainNesting(const char *name, void *cbdata)
{

```

```

visit_handle h = VISIT_INVALID_HANDLE;

if(VisIt_DomainNesting_alloc(&h) != VISIT_ERROR)
{
#define XMIN 0
#define YMIN 1
#define ZMIN 2
#define XMAX 3
#define YMAX 4
#define ZMAX 5
    int i, dom, nlevels = 3;
    int ratios[3] = {2,2,1}, ext[6]={0,0,0,0,0,0}, patch[2]={0,0};

    VisIt_DomainNesting_set_dimensions(h, NPATCHES, nlevels, 2);

    VisIt_DomainNesting_set_levelRefinement(h, 0, ratios);
    VisIt_DomainNesting_set_levelRefinement(h, 1, ratios);
    VisIt_DomainNesting_set_levelRefinement(h, 2, ratios);

    for(dom = 0; dom < NPATCHES; ++dom)
    {
        ext[XMIN] = rmxext[dom][0];
        ext[YMIN] = rmyext[dom][0];
        ext[ZMIN] = 0;
        ext[XMAX] = rmxext[dom][1];
        ext[YMAX] = rmyext[dom][1];
        ext[ZMAX] = 0;
        for(i = 0; i < ncpatch[dom]; ++i)
            patch[i] = cpatch[dom][i];
        VisIt_DomainNesting_set_nestingForPatch(h, dom, level[dom],
            patch, ncpatch[dom], ext);
    }
}

return h;
}

```

Listing 5-60: famr.f: Fortran-Language example for returning domain nesting.

```

c-----
c visitgetdomainnesting
c-----
integer function visitgetdomainnesting(name, lname)
implicit none
character*8 name
integer      lname
include "visitfortransimV2interface.inc"
ccc   AMRMESH common block
integer NPATCHES
parameter (NPATCHES = 4)
real rmx(2, NPATCHES), rmy(2, NPATCHES)
integer rmxext(2, NPATCHES), rmyext(2, NPATCHES)

```

```

        integer level(NPATCHES), ncpatch(NPATCHES)
        integer cpatch(2, NPATCHES)
        common /AMRMESH/ rmx,rmmy,rmxext,rmmyext,level,ncpatch,cpatch
ccc  AMRMESH data
        data rmx/0., 10., 3., 10., 5., 7.5, 7.5, 10./
        data rmmy/0., 10., 1., 9., 2., 7., 2., 7./
        data rmxext/0,9, 6,19, 20,29, 30,39/
        data rmmyext/0,9, 2,17, 8,27, 8,27/
        data level/0, 1, 2, 2/
        data ncpatch/1,2,0,0/
        data cpatch/1,-1,2,3,-1,-1,-1,-1/
ccc local vars
        integer XMIN,YMIN,ZMIN,XMAX,YMAX,ZMAX
        parameter (XMIN = 1)
        parameter (YMIN = 2)
        parameter (ZMIN = 3)
        parameter (XMAX = 4)
        parameter (YMAX = 5)
        parameter (ZMAX = 6)
        integer h, i, err, dom, ratios(3), ext(6), patch(2)
        data ratios/2,2,1/
        data ext/0,0,0,0,0,0/
        data patch/0,0/

        if(visitdnestingalloc(h).eq.VISIT_OKAY) then
            err = visitdnestingsetdimensions(h, 4, 3, 2)

            err = visitdnestingsetlevelrefinement(h, 0, ratios)
            err = visitdnestingsetlevelrefinement(h, 1, ratios)
            err = visitdnestingsetlevelrefinement(h, 2, ratios)

            do 1800 dom = 1,4
                ext(XMIN) = rmxext(1, dom)
                ext(YMIN) = rmmyext(1, dom)
                ext(ZMIN) = 0
                ext(XMAX) = rmxext(2, dom)
                ext(YMAX) = rmmyext(2, dom)
                ext(ZMAX) = 0
                do 1700 i=1,ncpatch(dom)
                    patch(i) = cpatch(i, dom)
1700            continue
                    err = visitdnestingsetnestingforpatch(h,dom-1,level(dom),
                        patch, ncpatch(dom), ext)
                .
                1800        continue
                endif
                visitgetdomainnesting = h
            end

```

4.11 CSG meshes

VisIt supports Constructive Solid Geometry (CSG) meshes. CSG meshes are defined by volumetric regions that are combined using boolean operators. By combining regions in various ways, one can arrive at very complex geometries using a very compact description. The first step in creating a CSG mesh is to create the set of boundaries that will be used to create regions. A boundary is a primitive or an analytical surface such as a plane, cone, sphere, or cylinder. Each boundary is described by a set of coefficients. Once a boundary has been defined, it is turned into a region by instancing it using a unary OUTER or INNER operator. The instanced region defines a volume that is either inside or outside of the boundary. Once the region is defined, it can be combined with other regions using boolean operators such as INTERSECT (and) or UNION (or). Once a final region has been defined, it can be promoted to a “zone”, which is the CSG term for what VisIt considers a domain.

4.11.1 CSG boundaries

CSG boundaries are primitives and analytical surfaces that define the shape of regions used in boolean operations. Boundaries are described by a set of coefficients appended to an array. The types of boundaries that can be used in VisIt’s CSG meshes, as well as their coefficients, are described in the following tables. The names of the boundary types contain a suffix that suggests the coefficients required by the boundary.

Suffix	Meaning
G	generalized form (n values, depends on type)
P	Point (3 values x,y,z in 3D. 2 values x,y in 2D)
N	Normal (3 values Nx,Ny,Nz in 3D. 2 values Nx,Ny in 2D)
R	Radius (1 value)
A	Angle (1 value in degrees)
L	Length (1 value)
X	X-intercept (1 value)
Y	Y-intercept (1 value)
Z	Z-intercept (1 value)
K	Arbitrary integer (1 value)
F	Planar face defined by point-normal (6 values)

Boundary	Description
VISIT_CSG_QUADRIC_G	General quadric with 10 coefficients for $x^2, y^2, z^2, xy, yz, xz, x, y, z, 1$
VISIT_CSG_SPHERE_PR	Sphere defined by 4 coefficients: center point and radius
VISIT_CSG_PLANE_X	Plane $X=$ constant with 1 coefficient
VISIT_CSG_PLANE_Y	Plane $Y=$ constant with 1 coefficient
VISIT_CSG_PLANE_Z	Plane $Z=$ constant with 1 coefficient
VISIT_CSG_PLANE_PN	Plane with 6 coefficients: origin, normal
VISIT_CSG_PLANE_PPP	Plane with 9 coefficients. The plane is specified by 3 points in the plane.
VISIT_CSG_CYLINDER_PNLR	Cylinder with 8 coefficients: point, normal, length, radius
VISIT_CSG_CYLINDER_PPR	Cylinder with 7 coefficients: 2 points that make up the endpoints and a radius perpendicular to the defined line segment.
VISIT_CSG_CONE_PNLA	Cone with 8 coefficients: point, normal, length, angle
VISIT_CSG_CONE_PPA	Cone with 7 coefficients: 2 points that make up the endpoints and an angle that opens up from one of the endpoints.

Note that there are more boundary types defined in the *VisItInterfaceTypes_V2.h* header file which are not yet actually implemented in VisIt. Only the boundary types in the table are implemented. This leaves out some commonly-used convenient primitives such as hexahedra. Hexahedrons in particular can be created using 6 VISIT_CSG_PLANE_PN planes: 2 for the X direction, 2 for the Y direction, and 2 for the Z direction. The X planes can isolate a range of X values, Y planes can isolate Y values, and Z planes can isolate Z values using an INTERSECT operation. Then the X and Y regions can be intersected and the resulting region can be intersected with the Z region to yield a hexahedron.

4.11.2 CSG operators

CSG meshes are produced by defining regions and combining them using various operators. The table below contains a list of the most common operators as well as their usage. Regions are encoded by storing operators and operands into 3 parallel arrays: typeflags, left, and right. By parallel arrays, we mean that an index in one array corresponds to an index in the other arrays as well. The typeflags array contains the operator being used in the operation. The left array contains the index of a boundary or the index of a region. The same is true for the right array unless the operator being used is a

unary operator, in which case the entry in the right array will contain -1. Suppose the typeflags, left, right arrays already contain region definitions in indices 0 and 1 and we want to take their union to produce a new region in index 2. We would insert VISIT_CSG_UNION into typeflags[2], 0 into left[2], and 1 into right[2].

Operator	Type	Description
VISIT_CSG_INNER	unary	Turn a boundary into a region where the volume is enclosed by the boundary.
VISIT_CSG_OUTER	unary	Turn a boundary into a region where the volume exists outside of the boundary.
VISIT_CSG_UNION	binary	Boolean OR operator. Combine 2 regions into a new region that is the union of both regions.
VISIT_CSG_INTERSECT	binary	Boolean AND operator. Create a new region that is the intersection of both regions.
VISIT_CSG_DIFF	binary	Subtract one region from another.
VISIT_CSG_COMPLIMENT	unary	Boolean NOT operator. Create a new region that occupies the opposite volume from the input region.

4.11.3 Creating a CSG mesh

Creation of a CSG mesh is a three step process. First, you must create the boundaries that will be used to build up the regions on which you'll operate. Second, you instantiate the regions using the boundaries and perform operations on them to arrive at a final shape. Third, you take the final shapes and add their region numbers into a zone list so each region can function as a separate domain in VisIt.

Boundaries are created by populating the boundary type and coefficient arrays. The type array contains the types of the boundaries. The coefficient array contains the coefficients for each boundary with one appended into the array after another. For example if you wanted to add a VISIT_CSG_SPHERE_PR boundary to the CSG definition, you would add VISIT_CSG_SPHERE_PR to the first element in the type array then you would add a point (3 values) and a radius (1 value) to elements 0,1,2,3 in the coefficients array. The next boundary's type would go into element 1 in the type array and its coefficients would begin at element 4 in the coefficients array.

After boundaries have been created, they must be turned into regions. To turn a boundary into a region, you must add the index of the boundary into the left array and -1 into the right array while adding either the VISIT_CSG_INNER or VISIT_CSG_OUTER operators into the operators array. All of these values are added at the same element index in their respective arrays. Once a region has been defined, it can be operated on by the

various CSG operators by adding its region index into the left or right arrays and adding a CSG operator in the operators array.

Each completed region can be promoted to a CSG zone, which means that VisIt will plot it as a domain. The entire CSG mesh can be composed of one or more zones but the CSG description must always contain the definitions of all CSG zones to ensure that it gets discretized properly. CSG meshes having more than one zone will be operated on in parallel by VisIt.

4.11.4 CSG example

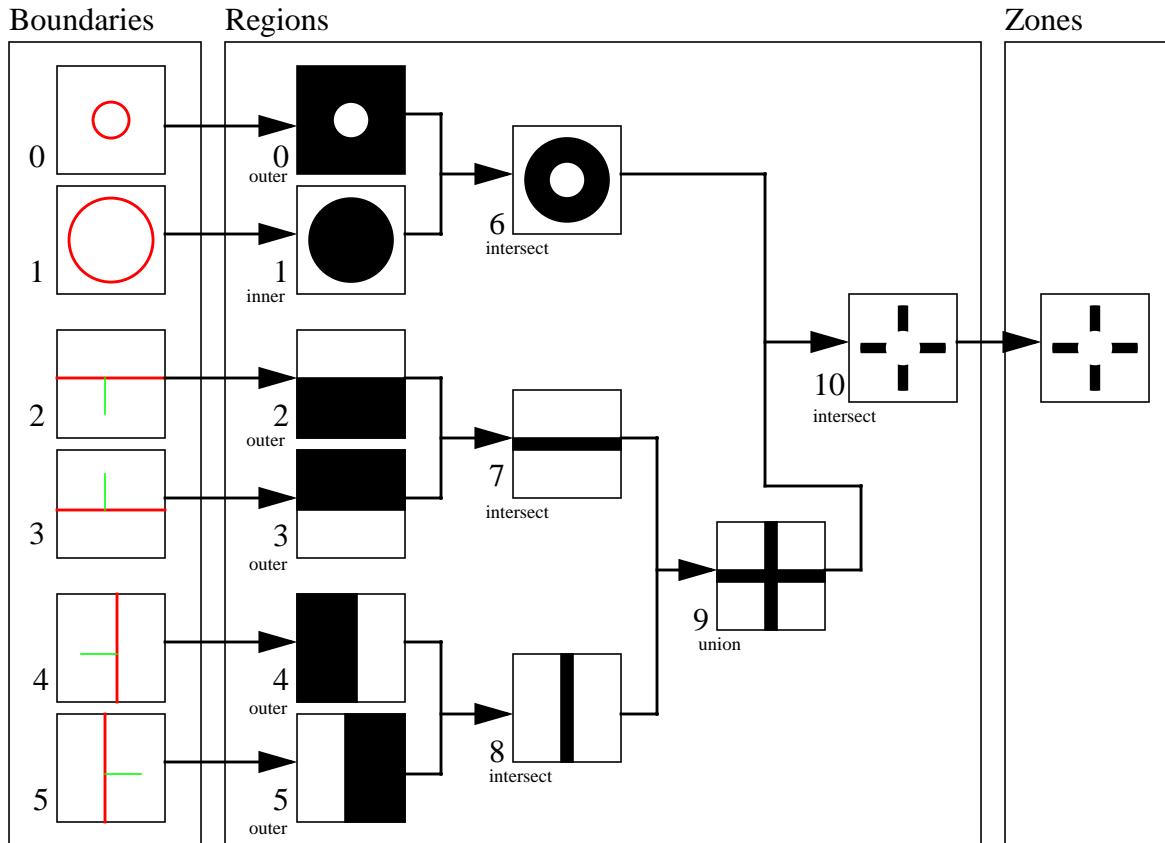


Figure 5-61: CSG boundaries, regions, and zones

The CSG example depicted in Figure 5-61 shows a washer and inside (intersecting) of that washer is another vertical washer which rotates in the simulation. The example is shown with 2D graphics for simplicity. In the simulation, all of the boundaries are 3D. The rotation of the vertical washer is achieved by altering the plane origin and normal for boundaries 4 and 5. The washers are created by a hierarchy of CSG operations. Operations 0 through 5 create regions from boundaries. Operation 6 intersects regions 0 and 1 to create a hollow sphere. Operations 7 intersects regions 2 and 3 to create a slab, as does operation 8. Operation 9 unites two slabs to form an extruded “plus sign”. Operation 10

intersects the hollow sphere from operation 6 and the plus sign from operation 9 to produce the two washers of our final shape, shown in Figure 5-62.

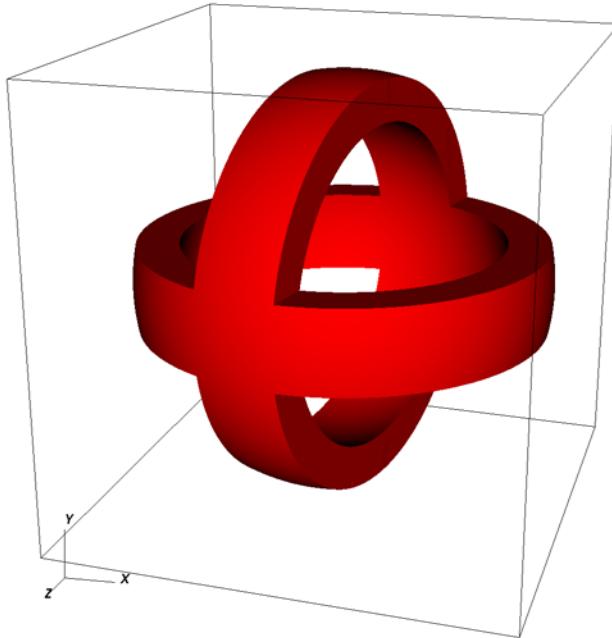


Figure 5-62: CSG mesh example

The code needed to produce the CSG mesh in this example is shown in the following code listing.

Listing 5-63: csg.c: C-Language example for returning a CSG mesh.

```
***** CSG Mesh variables *****/
double csg_extents[] = {-11., -11., -11., 11., 11., 11.};

/* CSG Boundaries */
int csg_bound_types[] = {
    VISIT_CSG_SPHERE_PR,
    VISIT_CSG_SPHERE_PR,
    VISIT_CSG_PLANE_PN,
    VISIT_CSG_PLANE_PN,
    VISIT_CSG_PLANE_PN,
    VISIT_CSG_PLANE_PN
};

float csg_bound_coeffs[] = {
    0., 0., 0., 8.,           /* sphere 1*/
    0., 0., 0., 10.,          /* sphere 2*/
    0., 2., 0., 0., -1., 0., /* plane 1 point, normal*/
    0., -2., 0., 0., 1., 0., /* plane 2 point, normal*/
    2., 0., 0., -1., 0., 0., /* plane 3 point, normal*/
    -2., 0., 0., 1., 0., 0.  /* plane 4 point, normal*/
};
```

```

int csg_num_bound_coeffs = sizeof(csg_bound_coeffs) / sizeof(float);
int csg_num_bound_types = sizeof(csg_bound_types) / sizeof(int);

/* CSG Regions */
int csg_region_operations[] =
{
    VISIT_CSG_OUTER,           /* 0: outside of inner sphere */
    VISIT_CSG_INNER,           /* 1: inside of outer sphere */
    VISIT_CSG_OUTER,           /* 2: plane 1 */
    VISIT_CSG_OUTER,           /* 3: plane 2 */
    VISIT_CSG_OUTER,           /* 4: plane 3 */
    VISIT_CSG_OUTER,           /* 5: plane 4 */
    VISIT_CSG_INTERSECT,       /* 6: intersection of sphere 0,1 */
    VISIT_CSG_INTERSECT,       /* 7: intersection of planes 1,2 */
    VISIT_CSG_INTERSECT,       /* 8: intersection of planes 3,4 */
    VISIT_CSG_UNION,           /* 9 add the 2 blocks together */
    VISIT_CSG_INTERSECT       /* 10: intersect shell with slabs*/
};

/* index          0   1   2   3   4   5   6   7   8   9   10*/
int csg_leftids[] = { 0, 1, 2, 3, 4, 5, 0, 2, 4, 7, 6};
int csg_rightids[] = {-1, -1, -1, -1, -1, -1, 1, 3, 5, 8, 9};
int csg_num_region_operations = sizeof(csg_region_operations) /
sizeof(int);

/* CSG Zones */
int csg_zonelist[] = {10};
int csg_nzones = sizeof(csg_zonelist) / sizeof(csg_zonelist[0]);

/********************************************* CSG Mesh variables *****/
visit_handle
SimGetMesh(int domain, const char *name, void *cbdata)
{
    visit_handle h = VISIT_INVALID_HANDLE;

    if(strcmp(name, "csg") == 0)
    {
        if(VisIt_CSGMesh_alloc(&h) != VISIT_ERROR)
        {
            visit_handle typeflags, leftids, rightids, zonelist;
            visit_handle boundaryTypes, boundaryCoeffs;

            /* Fill in the CSG mesh's data values. */
            VisIt_VariableData_alloc(&boundaryTypes);
            VisIt_VariableData_setDataI(boundaryTypes, VISIT_OWNER_SIM,
                1, csg_num_bound_types, csg_bound_types);
            VisIt_CSGMesh_setBoundaryTypes(h, boundaryTypes);

            VisIt_VariableData_alloc(&boundaryCoeffs);
            VisIt_VariableData_setDataF(boundaryCoeffs, VISIT_OWNER_SIM,
                1, csg_num_bound_coeffs, csg_bound_coeffs);
            VisIt_CSGMesh_setBoundaryCoeffs(h, boundaryCoeffs);

            /* Set the extents */
        }
    }
}

```

```

    VisIt_CSGMesh_setExtents(h, csg_extents, csg_extents+3);

    /* Set the regions */
    VisIt_VariableData_alloc(&typeflags);
    VisIt_VariableData_setDataI(typeflags, VISIT_OWNER_SIM,
        1, csg_num_region_operations, csg_region_operations);

    VisIt_VariableData_alloc(&leftids);
    VisIt_VariableData_setDataI(leftids, VISIT_OWNER_SIM,
        1, csg_num_region_operations, csg_leftids);

    VisIt_VariableData_alloc(&rightids);
    VisIt_VariableData_setDataI(rightids, VISIT_OWNER_SIM,
        1, csg_num_region_operations, csg_rightids);

    VisIt_CSGMesh_setRegions(h, typeflags, leftids, rightids);

    /* Set the zonelist */
    VisIt_VariableData_alloc(&zonelist);
    VisIt_VariableData_setDataI(zonelist, VISIT_OWNER_SIM,
        1, 1, csg_zonelist);
    VisIt_CSGMesh_setZonelist(h, zonelist);
}

return h;
}

```

4.12 Interleaved coordinates

All of the mesh examples so far have used separate coordinate arrays for the X, Y, and Z coordinates. For certain mesh types, it is also possible to provide coordinates using one array that contains all XY or XYZ coordinates, an approach called interleaved coordinates. Interleaved coordinates are specified in an array like this for 2D:

$x_0, y_0, x_1, y_1, \dots, x_n, y_n$ and like this for 3D: $x_0, y_0, z_0, x_1, y_1, z_1, \dots, x_n, y_n, z_n$. The mesh objects that support interleaved coordinates have functions for providing interleaved coordinates and these functions can be called instead of the typical functions that specify XY or XYZ coordinates. The coordinates are passed to these functions as a single `VariableData` object with 2 or 3 components, depending on the mesh's dimensionality.

Mesh type	Function
Curvilinear	<pre> int VisIt_CurvilinearMesh_setCoords2(visit_handle obj, int dims[2], visit_handle coords); int VisIt_CurvilinearMesh_setCoords3(visit_handle obj, int dims[3], visit_handle coords); </pre>

Mesh type	Function
Point	int VisIt_PointMesh_setCoords(visit_handle obj, visit_handle coords);
Unstructured	int VisIt_UnstructuredMesh_setCoords(visit_handle obj, visit_handle coords);

4.13 Data access function for variables

This chapter has so far shown how to instrument a simulation code so VisIt can connect to it and read out meshes so they can be plotted. This section will illustrate how to add a data access function that lets VisIt access your simulation’s variable data. Reading variable data requires a new data access function. In this case, you will register a new data access function by calling the `VisItSetGetVariable` function. If your simulation is written in Fortran, you must implement the `visitgetvariable` function to return your simulation’s variable data. This section will show how to return your simulation’s variable data so they can be visualized with VisIt.

4.13.1 Returning a simulation’s data array

The data access function for variables returns a `VariableData` object, which was introduced in Section 4.5.2. The `VariableData` object is a simple wrapper the array that you want to return and includes a little information about the array, including its type, number of components, number of tuples, and which program owns the array data. The owner flag indicates whether or not VisIt will be responsible for freeing the variable data array when it is no longer needed. If you pass `VISIT_OWNER_SIM` then VisIt will never free the data because the simulation owns the variable’s memory. If you pass `VISIT_OWNER_VISIT` then VisIt will free the variable’s memory when it is no longer needed. `VISIT_OWNER_COPY` is a convenience owner type that makes it easy to pass stack data to VisIt since it copies the data that were passed so they can be freed later by VisIt.

Returning variable data is as simple as returning an array with number of components set to 1 and the number of tuples set to the array length. Other types of variables such as vectors or tensors will have their component count increased to 2 or 3 for vectors, 9 for tensors, and any number greater than 1 for array data or label data. Data are stored in the array such that data for each tuple are stored before data for the next tuple appears in the array: (*tuple0comp0, tuple0comp1, tuple0comp2, tuple1comp0, tuple1comp1, tuple1comp2, ...*). The C interface for `libsim` provides different functions for setting different types of data into a `VariableData` object. The functions are called: `VisIt_VariableData_setDataC` for character data, `VisIt_VariableData_setDataI` for integer data,

VisIt_VariableData_setDataF for float data, and
 VisIt_VariableData_setDataD for double precision data.

Listing 5-64: scalar.c: C-Language example for returning a variable.

```

int    rmesh_dims[] = {4, 5, 1};
float zonal[] = {1.,2.,3.,4.,5.,6.,7.,8.,9.,10.,11.,12.};
int cmesh_dims[] = {4, 3, 2};
double nodal[2][3][4] = {
    {{1.,2.,3.,4.},{5.,6.,7.,8.},{9.,10.,11.,12.}},
    {{13.,14.,15.,16.},{17.,18.,19.,20.},{21.,22.,23.,24.}}
};
visit_handle
SimGetVariable(int domain, const char *name, void *cbdata)
{
    visit_handle h = VISIT_INVALID_HANDLE;
    int nComponents = 1, nTuples = 0;

    if(VisIt_VariableData_alloc(&h) == VISIT_OKAY)
    {
        if(strcmp(name, "zonal") == 0)
        {
            nTuples = (rmesh_dims[0]-1) * (rmesh_dims[1]-1);
            VisIt_VariableData_setDataF(h, VISIT_OWNER_SIM, nComponents,
                nTuples, zonal);
        }
        else if(strcmp(name, "nodal") == 0)
        {
            nTuples = cmesh_dims[0] * cmesh_dims[1] *
                cmesh_dims[2];
            VisIt_VariableData_setDataD(h, VISIT_OWNER_SIM, nComponents,
                nTuples, (double*)nodal);
        }
    }
    return h;
}

```

The Fortran interface provides the visitvardatasetc, visitvardataseti, visitvardatasetf, and visitvardatasetd functions for passing your simulation's scalar data back to VisIt. The functions behave the same as their C equivalents.

Listing 5-65: fscalar.f: Fortran language example for returning a variable.

```

c-----
c visitgetvariable
c-----
      integer function visitgetvariable(handle, domain, name, lname)
      implicit none
      character*8 name

```

```

        integer      handle, domain, lname
        include "visitfortransimV2interface.inc"
ccc  RECTMESH data
        integer NX, NY
        parameter (NX = 4)
        parameter (NY = 5)
        integer rmdims(3)
        real zonal(NX-1,NY-1)
ccc  CURVMESH data
        integer CNX, CNY, CNZ
        parameter (CNX = 4)
        parameter (CNY = 3)
        parameter (CNZ = 2)
        integer cmdims(3)
        double precision nodal(CNX,CNY,CNZ)
ccc  local vars
        integer h, nvals, err
ccc  Data
        data rmdims /4, 5, 1/
        data zonal/1.,2.,3.,4.,5.,6.,7.,8.,9.,10.,11.,12./
        data cmdims/CNX,CNY,CNZ/
        data nodal/1.,2.,3.,4.,5.,6.,7.,8.,9.,10.,11.,12.,13.,14.,15.,
. 16.,17.,18.,19.,20.,21.,22.,23.,24./

        h = VISIT_INVALID_HANDLE
        if(visitstrcmp(name, lname, "zonal", 5).eq.0) then
c A zonal variable has 1 less value in each dimension as there
c are nodes. Send back REAL data.
            if(visitvardataalloc(h).eq.VISIT_OKAY) then
                nvals = (rmdims(1)-1) * (rmdims(2)-1)
                err = visitvardatasetf(h, VISIT_OWNER_SIM,1,nvals,zonal)
            endif
        elseif(visitstrcmp(name, lname, "nodal", 5).eq.0) then
c A nodal variable has the same number values in each dimension
c as there are nodes. Send back DOUBLE PRECISION data.
            if(visitvardataalloc(h).eq.VISIT_OKAY) then
                nvals = cmdims(1) * cmdims(2)* cmdims(3)
                err = visitvardatasetd(h, VISIT_OWNER_SIM,1,nvals,nodal)
            endif
        endif

        visitgetvariable = h
end

```

The variable data access functions in the previous examples build on some of the earlier mesh data access function examples, specifically the examples that returned rectilinear and curvilinear meshes. The zonal variable returned in the examples in this section return data defined on the “mesh2d” rectilinear mesh. The nodal variable returned in the

examples in this section return data on the “mesh3d” curvilinear mesh. Examples of both variables are shown in Figure 5-66.

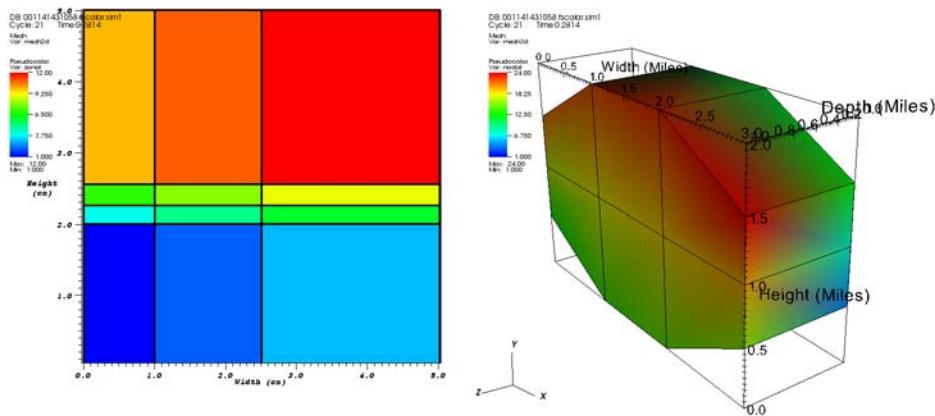


Figure 5-66: Examples of scalar variables returned by a variable data access function.

4.14 Data access function for curves

This section illustrates how to add a data access function that lets VisIt access your simulation’s curve data. Reading curve data requires a new data access function, which is registered using the `VisitSetGetCurve` function. If your simulation is written in Fortran, you must implement the `visitgetcurve` function to return your simulation’s curve data.

The data access function for curves returns a `CurveData` object, which simply contains handles to 2 `VariableData` objects that contain the coordinates. This section shows how to create a data access function for curves so your simulation’s curve data are available in VisIt.

4.14.1 Adding a curve data access function

Adding a curve data access function means that you have to first write a function and pass it to `VisitSetGetCurve`. If you program in C, the curve data access function takes the name of a curve object and a user-defined pointer as arguments. The basic procedure for returning curve data is to first check the incoming name against the names of the curves that your simulation is prepared to return and when one is found, return it to VisIt in a `CurveData` object. If your curve data access routine does not recognize the name of the curve then you can return `VISIT_INVALID_HANDLE` instead of returning a `CurveData` object.

Listing 5-67: `curve.c`: C-Language example for installing a curve data access function.

```
visit_handle
```

```

SimGetCurve(const char *name, void *cbdata)
{
    int h = VISIT_INVALID_HANDLE;
    simulation_data *sim = (simulation_data *)cbdata;

    if(strcmp(name, "sine") == 0)
    {
        if(VisIt_CurveData_alloc(&h) != VISIT_ERROR)
        {
            visit_handle hxc, hyc;

            /* Give the arrays to VisIt. VisIt will free them. */
            VisIt_VariableData_alloc(&hxc);
            VisIt_VariableData_alloc(&hyc);
            VisIt_VariableData_setDataF(hxc, VISIT_OWNER_SIM, 1, NPTS,
                sim->x);
            VisIt_VariableData_setDataF(hyc, VISIT_OWNER_SIM, 1, NPTS,
                sim->y);
            VisIt_CurveData_setCoordsXY(h, hxc, hyc);
        }
    }

    return h;
}

```

In order to return curve data from a Fortran simulation, you must implement the `visitgetcurve` function. The function takes 2 arguments: the name of the curve and the length of that name string, respectively. As in the C interface, the `visitgetcurve` function must check the incoming names against the names of the curves that the simulation has exposed to VisIt via metadata. You can use the `visitstrcmp` function to match the incoming name against the names of the known curves.

Listing 5-68: fcurve.f: Fortran language example of a curve data access function.

```

c-----
c visitgetcurve
c-----
      integer function visitgetcurve(name, lname)
      implicit none
      character*8 name
      integer      lname
      include "visitfortransimV2interface.inc"
ccc   CURVE common block
      integer NPTS
      parameter (NPTS = 10000)
      real pmx(NPTS), pmy(NPTS)
      common /CURVE/ pmx, pmy
ccc   local vars
      integer h, hx, hy, err

```

```

h = VISIT_INVALID_HANDLE
if(visitstrcmp(name, lname, "sine", 4).eq.0) then
    if(visitcurvedataalloc(h).eq.VISIT_OKAY) then
        err = visitvardataalloc(hx)
        err = visitvardataalloc(hy)
        err = visitvardatasetf(hx, VISIT_OWNER_SIM, 1, NPTS, pmx)
        err = visitvardatasetf(hy, VISIT_OWNER_SIM, 1, NPTS, pmy)
        err = visitcurvedatasetcoordsxy(h, hx, hy)
    endif
endif
visitgetcurve = h
end

```

Both of the code examples for returning curve data produce a sine curve (code to set X,Y values for the sine curve is not shown), shown in Figure 5-69.

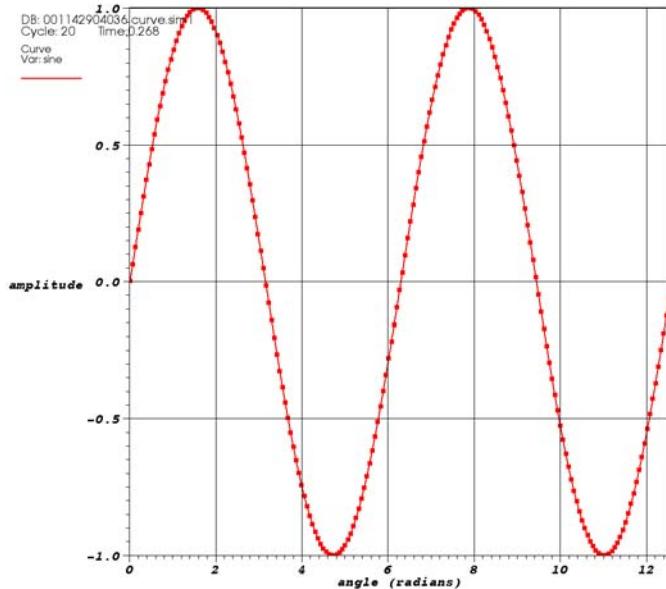


Figure 5-69: Sine curve produced by the curve data access function example programs.

4.15 Data access function for materials

This section illustrates how to add a data access function that lets VisIt access your simulation's material data. Reading material data requires a new data access function, which is registered using the `VisItSetGetMaterial` function. If your simulation is

written in Fortran, you must implement the `visitgetmaterial` function to return your simulation's material data.

The data access function for materials returns a `MaterialData` object, which contains a list of material names as well as material data for each cell in your mesh. The number of cells in the mesh is specified using the `VisIt_MaterialData_appendCells` function, which also tells SimV2 to expect you to add material information to the `MaterialData` object using functions that add material data on a per cell basis. Note that `MaterialData` objects are populated per cell to prevent errors that are common when providing all of the data in bulk. Material names are assigned a material number using the `VisIt_MaterialData_addMaterial` function. The material number that is returned must be used to identify the material in subsequent function calls that provide material data about cells. Cells which contain a single material are known as clean cells while cells with more than one material are known as mixed cells. The `VisIt_MaterialData_addCleanCell` function is used to add the data for clean cells and the `VisIt_MaterialData_addMixedCell` function is used to add data for mixed cells. In the case of mixed cells, a list of material ids (as returned from `VisIt_MaterialData_addMaterial`) and their relative volume fractions are passed. The volume fractions indicate a percentage of the cell occupied by a given material.

Listing 5-70: material.c: C language example of a material data access function.

```

visit_handle
SimGetMaterial(int domain, const char *name, void *cbdata)
{
    visit_handle h = VISIT_INVALID_HANDLE;

    /* Allocate a VisIt_MaterialData */
    if(VisIt_MaterialData_alloc(&h) == VISIT_OKAY)
    {
        int i, j, m, cell = 0, arrlen = 0;
        int nmats, cellmat[10], matnos[3]={1,2,3};
        float cellmatvf[10];

        /* The matlist table indicates the material numbers that are
         * found in each cell. Every 3 numbers indicates the material
         * numbers in a cell. A material number of 0 means that the
         * material entry is not used.
        */
        int matlist[NY-1][NX-1][3] = {
            {{3,0,0},{2,3,0},{1,2,0},{1,0,0}},
            {{3,0,0},{2,3,0},{1,2,0},{1,0,0}},
            {{3,0,0},{2,3,0},{1,2,3},{1,2,0}}
        };

        /* The mat_vf table indicates the material volume fractions
         * that are found in a cell.
        */
        float mat_vf[NY-1][NX-1][3] = {
    
```

```

{{1.,0.,0.},{0.75,0.25,0.}, {0.8125,0.1875, 0.},{1.,0.,0.}},
{{1.,0.,0.},{0.625,0.375,0.},{0.5625,0.4375,0.}, {1.,0.,0.}},
{{1.,0.,0.},{0.3,0.7,0.}, {0.2,0.4,0.4}, {0.55,0.45,0.}}
};

/* Tell the object we'll be adding cells to it using add*Cell
functions */
visIt_MaterialData_appendCells(h, (NX-1)*(NY-1));

/* Fill in the VisIt_MaterialData */
visIt_MaterialData_addMaterial(h, matNames[0], &matnos[0]);
visIt_MaterialData_addMaterial(h, matNames[1], &matnos[1]);
visIt_MaterialData_addMaterial(h, matNames[2], &matnos[2]);

for(j = 0; j < NY-1; ++j)
{
    for(i = 0; i < NX-1; ++i, ++cell)
    {
        nmats = 0;
        for(m = 0; m < 3; ++m)
        {
            if(matlist[j][i][m] > 0)
            {
                cellmat[nmats] = matnos[matlist[j][i][m] - 1];
                cellmatvf[nmats] = mat_vf[j][i][m];
                nmats++;
            }
        }
        if(nmats > 1)
            VisIt_MaterialData_addMixedCell(h, cell, cellmat,
            cellmatvf, nmats);
        else
            VisIt_MaterialData_addCleanCell(h, cell, cellmat[0]);
    }
}
return h;
}

```

Apart from using some functions with slightly different names, the Fortran version of a material data access function is nearly identical to the C version. The algorithm for adding material data is the same. First, call `visitmatdataappendcells` to allocate a number of cells for the material data. Next, get a material id for the material name using the `visitmatdataaddmat` function. Finally, build up per cell material information

and add it to the `MaterialData` object using the `visitmatdataaddmixedcell` and `visitmatdataaddcleancell` functions.

Listing 5-71: fmaterial.f: Fortran language example of a material data access function.

```

c-----
c visitgetmaterial
c-----
integer function visitgetmaterial(domain, name, lname)
implicit none
character*8 name
integer domain, lname
include "visitfortransimV2interface.inc"
ccc  RECTMESH
integer NX, NY
parameter (NX = 5)
parameter (NY = 4)

c The matlist table indicates the material numbers that are found in
c each cell. Every 3 numbers indicates the material numbers in a cell.
c A material number of 0 means that the material entry is not used.
integer matlist(3, NX-1, NY-1)
data matlist/3,0,0,2,3,0,1,2,0,1,0,0,
.           3,0,0,2,3,0,1,2,0,1,0,0,
.           3,0,0,2,3,0,1,2,3,1,2,0/
c The mat_vf table indicates the material volume fractions that are
c found in a cell.
real mat_vf(3, NX-1, NY-1)
data mat_vf/1.,0.,0.,0.75,0.25,0.,0.8125,0.1875, 0.,1.,0.,0.,
. 1.,0.,0.,0.625,0.375,0.,0.5625,0.4375,0.,1.,0.,0.,
. 1.,0.,0.,0.3,0.7,0.,0.2,0.4,0.4,0.55,0.45,0./

c Size the material object so it has the right dimensions (equal to
c the number of cells in the mesh. Unstructured grids would have
c /ncells,1,1/ size for the material. That means that the cellid array
c would have one linear index in its first element.
integer err, I, J, m, cellid, nmats, h
integer matno(3), cellmat(3)
real cellmatvf(3)
h = VISIT_INVALID_HANDLE
err = visitmatdataalloc(h)
err = visitmatdataappendcells(h, (NX-1) * (NY-1))
err = visitmatdataaddmat(h, "Water", 5, matno(1))
err = visitmatdataaddmat(h, "Membrane", 8, matno(2))
err = visitmatdataaddmat(h, "Air", 3, matno(3))

cellid = 0
do 2020 J=1,NY-1
do 2010 I=1,NX-1
nmats = 0
do 2000 m=1,3
if(matlist(m,I,J).gt.0) then
    nmats = nmats + 1

```

```

        cellmat(nmats) = matno(matlist(m,I,J))
        cellmatvf(nmats) = mat_vf(m,I,J)
    endif
2000 continue
    if(nmats.gt.1) then
        err = visitmatdataaddmixedcell(h,
. cellid, cellmat, cellmatvf, nmats)
    else
        err = visitmatdataaddcleancell(h,
. cellid, cellmat)
    endif
    cellid = cellid + 1
2010 continue
2020 continue

visitgetmaterial = h
end

```

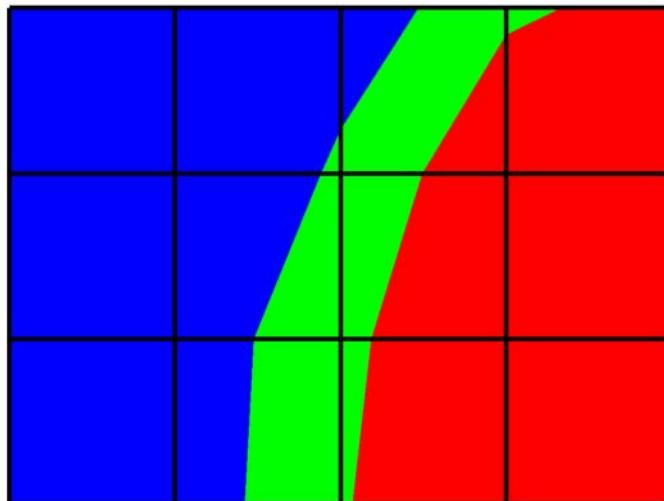


Figure 5-72: Material data returned from data access function

4.16 Data access function for the domain list

The domain list is an object that tells VisIt how many domains there are in your simulation and to which processors they belong. Domain lists are used by VisIt's load balancer to assign work to various processors when running in parallel. The domain list data access

function must be provided if your parallel simulation is to provide data to VisIt. Since most parallel simulations only ever process a single domain's worth of data, the domain list will almost always contain a single domain, though the total number of domains is free to change. Note that you must provide a domain list when you run a parallel simulation so VisIt's load balancer can retrieve domains from the appropriate simulation processors. Serial simulations do not need to implement a domain list callback function.

If you program in C and you are writing a parallel simulation then you must create a new function and register it using the `VisItSetGetDomainList` function. Most of the time, a simulation will have only a single domain per processor so the domain list will consist of just the rank of the processor within the global communicator.

Listing 5-73: C-Language example for returning a domain list.

```
visit_handle
SimGetDomainList(const char *name, void *cbdata)
{
    int par_size, par_rank;
    visit_handle h = VISIT_INVALID_HANDLE;

    MPI_Comm_rank(MPI_COMM_WORLD, &par_rank);
    MPI_Comm_size(MPI_COMM_WORLD, &par_size);

    if(VisIt_DomainList_alloc(&h) != VISIT_ERROR)
    {
        visit_handle hdl;

        VisIt_VariableData_alloc(&hdl);
        VisIt_VariableData_setDataI(hdl, VISIT_OWNER_COPY, 1, 1,
        par_rank);
        VisIt_DomainList_setDomains(h, par_size, hdl);
    }
    return h;
}
```

If you use the Fortran interface then you must implement the `visitgetdomainlist` function. The `visitgetdomainlist` function is called when VisIt needs the number and distribution of the domains in use by your simulation. You can provide this information by creating a `DomainList` object using the `visitdomainlistalloc` function, and setting data into it using `visitdomainlistsetdomains`. The domain list data consists of a `VariableData` object that wraps an array of integers. In the case where each processor has a single domain, you need only create wrap an array that contains 1 value: the rank of the current processor.

Listing 5-74: fscalar.f: Fortran language example for returning a domain list.

```
c-----
c visitgetdomainlist
```

```
c-----  
      integer function visitgetdomainlist()  
      implicit none  
      include "visitfortransimV2interface.inc"  
ccc  PARALLEL state common block  
      integer par_rank, par_size  
      common /PARALLEL/ par_rank, par_size  
ccc  local vars  
      integer h, dl, err  
  
c   Tell VisIt that there are as many domains as processors and this  
c   processor just has one of them.  
      h = VISIT_INVALID_HANDLE  
      if(visitdomainlistalloc(h).eq.VISIT_OKAY) then  
          if(visitvardataalloc(dl).eq.VISIT_OKAY) then  
              err = visitvardataseti(dl, VISIT_OWNER_SIM, 1, 1,  
.                  par_rank)  
              err = visitdomainlistsetdomains(h, par_size, dl)  
          endif  
      endif  
      visitgetdomainlist = h  
  
      end
```

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