

Remote Visualization Tool PBVR (v1.09)
User Guide

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Revision Record

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1.04	2015.3.31	-	Release
1.05	2015.5.18	5.2	Parameter file function is added on Server
		5.4.2	File button is added on MainPanel
		5.4.6	Particle data output function is added
1.06a	2015.10.30	5.4.2	CROP panel is enabled for Mac
		5.4.3	Histogram function is added on Transfer Function Editor
		5.4.5	Image file production function is updated (file output directory, key frame animation)
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		2	The package is updated including serial versions and PBVR Filter for VTK is added
		3.4	Data formats and parameter files are extended including STL, PLOT3D, and VTK
		4.2	A new command line option “-pd” is added, “-plimit” is modified, and “-sl” is removed
		5.2	A new command line option “-pd” is added, “-plimit” is modified, “-sl” is removed, and “-pin” is extended up to “-pin10”
		5.4.5	Particle panel is added
		6.4	An example of particle integration is added
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		5.4.2	Transfer Function Editor, Particle Panel and Animation Control Panel buttons are added to Main Panel.
1.09	2017.3.2	4.2	New command line options “-Bs”, “-Be” and “-Bd” are added.
		4.2.1	A usage of command line option “-vin” is extended for multiple pfi files.
		4.2.2	Added about processing of distributed files.

		5.2	<ul style="list-style-type: none"> - Number of panels that opened when client started is changed. - Command line option “-vin” is extended for multiple pfi files.
		5.4.2	<ul style="list-style-type: none"> - Following three buttons are added on MainPanel. “Transfer Function Editor” , “Particle Panel”, and “Animation Control Panel”. - A checkbox “no-repeat sampling until Transfer Functions be edited” is added on MainPanel, and following three buttons are added on MainPanel. “Legend Panel”, “Coordinate Panel”, and “Viewer Control Panel”. - Display Particle Number is added.
		5.4.3	“Transfer Function Editor” is activated from MainPanel, and close button is added.
		5.4.3.3	An action when NaN appears by the arithmetic processing of function editor is added.
		5.4.5	“Particle panel” is activated from MainPanel, and close button is added.
		5.4.6	“Animation Control Panel” is activated from MainPanel, and close button is added.
		5.4.7	“Legend panel” is added.
		5.4.8	“Coordinate panel” is added.
		5.4.9	“Viewer Control panel” is added.

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1 Introduction

1.1 Overview

This document is a user guide for Particle Based Volume Rendering (PBVR), a remote visualization system developed at the Center for Computational Science & e-Systems in Japan Atomic Energy Agency. PBVR provides high-speed remote visualization of large-scale volume data by making use of the KVS library, and by employing the particle-based rendering algorithm from the Koyamada Visualization Laboratory in Kyoto University. PBVR consists of the following three components.

- 1) PBVR Filter
PBVR Filter reads volume data and divides it into sub-volumes, each of which becomes the unit to be processed in parallel visualization.
- 2) PBVR Server
PBVR Server receives the sub-volumes and applies parallel visualization with PBVR's particle generation method.
- 3) PBVR Client
PBVR Client renders the particle data as images using Open GL.

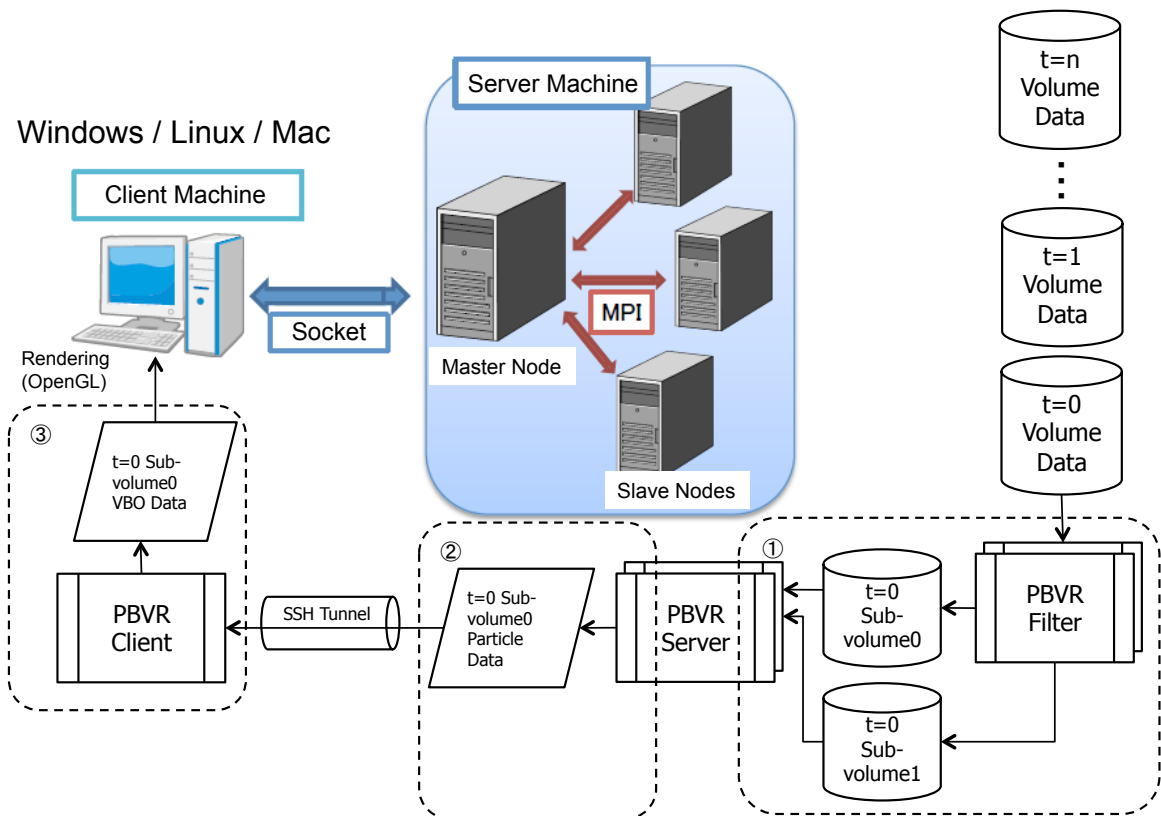


Figure 1 The system configuration of PBVR

1.2 System Requirements

The system is verified for the following platforms and compilers.

●PBVR Filter

Platform	Compiler	Library
Linux 64bit	gcc version 4.4.6	VTK*4
Mac 64bit *2	gcc version 4.8.2	VTK*4
Windows 64bit*3	Visual Studio 2013	VTK*4
K Computer	Fujitsu Compiler	
FX10	Fujitsu Compiler	
ICEX	Intel Compiler 15.0.3	

●PBVR Server

Platform	Compiler	Library
Linux 64bit	g++ version 4.4.6	KMATH_RANDOM, NTL *1
Mac 64bit *2	g++ version 4.8.2	
Windows 64bit*3	Visual Studio 2013	Visual C++ runtime component
K Computer	Fujitsu Compiler	KMATH_RANDOM, NTL *1
FX10	Fujitsu Compiler	KMATH_RANDOM, NTL *1
ICEX	Intel Compiler 15.0.3	KMATH_RANDOM, NTL *1

●PBVR Client

Platform	Compiler	Library
Linux 64bit	g++ version 4.4.6	OpenGL, GLUT
Mac 64bit *2	g++ version 4.8.2	OpenGL, GLUT
Windows 64bit*3	Visual Studio 2013	OpenGL, GLUT, Visual C++ runtime component

- *1. KMATH_RANDOM is a high-performance pseudorandom number generator library, which was developed at RIKEN Advanced Institute for Computational Science. Installing KMATH_RANDOM further requires the NTL library.
- *2. The current version was verified on Marverics, Yosemite, and El Capitan. On Macs, OpenMP is not available for the default gcc that is shipped with Xcode. To use the load modules or to compile the source code, install a newer version of gcc that works with OpenMP. The prebuilt binaries were compiled with gcc48 installed through MacPorts. To obtain this gcc version, run the following commands with root privilege in the terminal'.
port install gcc48
port select --set gcc mp-gcc48
- *3. The current version was verified on Windows 7, 8.1, and 10. The Visual c++ runtime component is needed on Windows without Visual Studie 2013.

*4. VTK6.0 or later is needed for compiling PBVR Filter for VTK data.

2 Installation

PBVR consists of a load module package and a source code package. The following sections show how to install each package.

2.1 Installation of Prebuilt Binaries

2.1.1 PBVR Filter

PBVR Filter is implemented in C and is shipped with two versions. One is an MPI+OpenMP version for massively parallel computing, and the other is an OpenMP version for thread parallel computing. The following table lists the load modules of the load module package. Choose the suitable load modules, and copy them to a directory that is specified in PATH environment variable. When the copying operation finishes, the installation is complete.

Table 1 List of load modules for PBVR Filter.

Platform	Parallelization	Name of load module
Linux 64bit	Serial	pbvr_filter_linux pbvr_filter_linux_vtk*2
	OpenMP	pbvr_filter_linux_omp pbvr_filter_linux_omp_vtk*2
	MPI+OpenMP	pbvr_filter_linux_mpi_omp pbvr_filter_linux_mpi_omp_vtk*2
Mac 64bit	Serial	pbvr_filter_mac pbvr_filter_mac_vtk*2
	OpenMP	pbvr_filter_mac_omp pbvr_filter_mac_omp_vtk*2
Windows 64bit	Serial	pbvr_filter.exe pbvr_filter_vtk.exe
	OpenMP	pbvr_filter_omp.exe pbvr_filter_omp_vtk.exe
K Computer *1	OpenMP	pbvr_filter_k_omp
	MPI+OpenMP	pbvr_filter_k_mpi_omp
FX10 *1	OpenMP	pbvr_filter_fx10_omp
	MPI+OpenMP	pbvr_filter_fx10_mpi_omp
ICEX	OpenMP	pbvr_filter_icex_omp
	MPI+OpenMP	pbvr_filter_icex_mpi_omp

*1. The load modules for supercomputers are used only in computing nodes. Therefore, for login nodes and post-processing nodes with Linux, use the load modules built for Linux.

*2. VTK library is needed for compiling PBVR Filter for VTK data.

2.1.1.1 Installation of PBVR Filter for VTK data

In compiling and installing PBVR Filter for VTK data, VTK6.0 or later is required. Refer the VTK website (<http://www.vtk.org/>) for the installation of the VTK library. In the installation, the following options should be chosen on CMake-gui.

- 1) turn on BUILD_SHARED_LIBS option.
- 2) Choose "Release" for CMAKE_BUILD_TYPE option.
- 3) Set the VTK installation directory to CMAKE_INSTALL_PREFIX.

On each environment, PBVR Filter is compiled as follows.

Installation in Linux and Mac

Execute the following compilation commands.

```
$ export VTK_VERSION=n.n
$ export VTK_LIB_PATH=/usr/local/lib
$ export VTK_INCLUDE_PATH=/usr/local/include/vtk-n.n
$ make -f makefile.linux vtk
```

Here, n.n denotes the version of the VTK library , and each path should be modified depending on the VTK installation directory.

Installation in Windows

Set the following environment variables with
Control Panel -> System -> Property -> Environment.

<i>Variable</i>	<i>Value</i>
VTK_LIB	d:\environments\vtk\lib
VTK_VERSION	n.n
VTK_INCLUDE_PATH	d:\environments\vtk\include\vtk-n.n

Here, n.n denotes the version of the VTK library , and each path should be modified depending on the VTK installation directory.

2.1.2 PBVR Server

PBVR Server is implemented in C++ and is shipped in three versions, a serial processing version, an OpenMP version for thread parallel computing, and an MPI+OpenMP version for massively parallel computing. The following table lists the load modules of the load module package. Choose the suitable load modules, and copy them to a directory that is specified in PATH environment variable. When the copying operation finishes, the installation is complete.

Table 2 List of load modules for PBVR Server

Platform	Parallelization	Name of load module
Linux 64bit	Serial	pbvr_server_linux
	OpenMP	pbvr_server_linux_omp
	MPI+OpenMP	pbvr_server_linux_mpi_omp
Mac 64bit	Serial	pbvr_server_mac
	OpenMP	pbvr_server_mac_omp
Windows 64bit	Serial	pbvr_server.exe
	OpenMP	pbvr_server_omp.exe
K Computer *1	OpenMP	pbvr_server_k_omp
	MPI+OpenMP	pbvr_server_k_mpi_omp
FX10 *1	OpenMP	pbvr_server_fx10_omp
	MPI+OpenMP	pbvr_server_fx10_mpi_omp
ICEX	OpenMP	pbvr_server_icex_omp
	MPI+OpenMP	pbvr_server_icex_mpi_omp

*1. The load modules for supercomputers are used only in computing nodes. Therefore, if the login nodes and the post-processing nodes are on Linux servers, use the load modules that are compiled for Linux.

2.1.3 PBVR Client

PBVR Client is implemented in C++ and makes use of OpenGL. The following table lists the load modules stored in the *client* directory of the load module package. Choose the suitable load modules, and copy them to a directory that is specified in PATH environment variable.

Table 2 List of load modules for PBVR Client

Platform	Parallelization	Name of load module
Linux 64bit	pthread	pbvr_client_linux
Mac 64bit	pthread	pbvr_client_mac
Windows 64bit *1	pthread	pbvr_client.exe

*1. For the Windows version, copy also 'glut32.dll' to the destination directory.

2.2 Installation from Source Code

Uncompress the source code package to an arbitrary directory and compile it using pbvr.conf and Makefile in PBVR/ directory. The pbvr.conf specifies a setting of make and compile PVBR Filter, PBVR Server, and PBVR Client. The source code package is composed as follows.

Table 3 Components of source code package

Directory • File	Detail
PBVR/	
KMATH/	Pseudorandom number generator library KMATH
KVS/	Visualization library KVS
glui/	Widget library for GUI
FunctionParser/	Function editor library
Common/	Common library for protocol, communication and others
Filter/	PBVR Filter programs
Server/	PBVR Server programs
Client/	PBVR Client programs
arch/	Compilation setting files
pbvr.conf *1	Configuration setting file
Makefile *1	Make file for PBVR/ directory

*1. In Windows, VisualStudio solution file pbvr.sln is used instead of pbvr.conf and Makefile.

By changing values in pbvr.conf in the following table, specify the functions to install.

Table 4 List of variables of pbvr.conf

Variable	Value	Detail
PBVR_MACHINE	String	Compilation setting files under arch/
PBVR_MAKE_FILTER	0 or 1	Select 1 for support of PBVR Filter
PBVR_MAKE_CLIENT	0 or 1	Select 1 for support of PBVR Client
PBVR_MAKE_SERVER	0 or 1	Select 1 for support of PBVR Server
PBVR_SUPPORT_KMATH	0 or 1	Select 1 for support of KMATH (Server only)*1
PBVR_SUPPORT_VTK	0 or 1	Select 1 for support of PBVR VTK (Filter only)

*1. In Windows and Mac, KMATH is unavailable, and TynyMT is used.

For PBVR_MACHINE, specify the compilation setting file under arch/ directory listed in the following table.

Table 5 List of compilation setting files

Filename	Detail
Makefile_machine_gcc	Serial compilation using gcc
Makefile_machine_gcc_omp	OpenMP compilation using gcc
Makefile_machine_gcc_mpi_omp	MPI+OpenMP compilation using gcc
Makefile_machine_intel	Serial compilation using intel
Makefile_machine_intel_omp	OpenMP compilation using intel
Makefile_machine_intel_mpi_omp	MPI+OpenMP compilation using intel
Makefile_machine_fujitsu	Serial compilation using fujitsu
Makefile_machine_fujitsu_omp	OpenMP compilation using fujitsu
Makefile_machine_fujitsu_mpi_omp	MPI+OpenMP compilation using fujitsu
Makefile_machine_icex	Serial compilation using icex
Makefile_machine_icex_omp	OpenMP compilation using icex
Makefile_machine_icex_mpi_omp	MPI+OpenMP compilation using icex

The following list shows the supported environments for the compilation setting files.

Table 6 List of supported environment

File name	Environments					
	Linux	Mac	ICEX	FX10	K*2	K(Pre/Post)
Makefile_machine_gcc	◎	◎	–	–	–	○
Makefile_machine_gcc_omp	◎	◎	–	–	–	○
Makefile_machine_gcc_mpi_omp	◎	–	–	–	–	○
Makefile_machine_intel	○	–	–	–	–	○
Makefile_machine_intel_omp	○	–	–	–	–	○
Makefile_machine_intel_mpi_omp	○	–	–	–	–	○
Makefile_machine_fujitsu	–	–	–	○	○	–
Makefile_machine_fujitsu_omp	–	–	–	○	○	–
Makefile_machine_fujitsu_mpi_omp	–	–	–	○	○	–
Makefile_machine_icex	–	–	○	–	–	–
Makefile_machine_icex_omp	–	–	○	–	–	–
Makefile_machine_icex_mpi_omp	–	–	○	–	–	–

*1. ◎ means the support of PBVR Filter, Server, and Client. ○ means the support of PBVR Filter and Server.

*2. Use Pre/Post node in case of Client/Server mode on K computer.

Installation

2.2.1 Installation in Linux and Mac

In Linux and Mac, build the source code and install it as follows.

- 1) Edit pbvr.conf under PBVR/ directory depending on your environment.

The following example shows the variables for building OpenMP versions of PBVR Client, PBVR Filter, and PBVR Server using gcc compiler.

#Example of pbvr.conf

<pre>PBVR_MACHINE=Makefile_machine_gcc_omp PBVR_MAKE_CLIENT=1 PBVR_MAKE_FILTER=1 PBVR_MAKE_SERVER=1 PBVR_SUPPORT_KMATH=0</pre>
--

- 2) Compile under PBVR/ directory as follows.

\$make

Following load modules are generated under PBVR/ directory.

PBVR Filter: Filter/pbvr_filter

PBVR Server: Server/pbvr_server

PBVR Client: Client/pbvr_client

- 3) Copy the generated load modules to an arbitrary directory that is specified in PATH environment variable.

2.2.2 Installation in Windows

In Windows, uncompress the source code package and build the source code as follows.

- 1) Install GLUT

- i) Download *glut-3.7.6-bin_x64.zip(64bit)* from the link below.

<http://ktm11.eng.shizuoka.ac.jp/lesson/modeling.html>

- ii) Extract the following files:

glut.h

glut32.lib

glut32.dll

- 2) Extract **server** on a Windows machine that has Visual Studio 2013.
- 3) Open pbvr.sln with Visual Studio 2013.
- 4) Choose **Release** and **x64** from the pull-down list as shown in Figure 2.

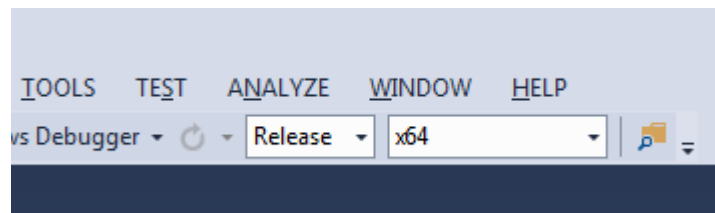


Figure 2 Build configuration of Visual Studio 2013

5) Go to the menu **Build > Build Solution**.

The load module pbvr_filter.exe, pbvr_server.exe, and pbvr_client.exe are created under ~~¥¥x64¥~~Release.

3 PBVR Filter

3.1 Overview

PBVR Filter is independent from the PBVR system. PBVR Filter divides time-series volume data that will become the input of parallel processing in PBVR Server. In addition, PBVR Filter generates Sub-volume data for the purpose of visualization. The data decomposition is based on the octree model. PBVR Filter divides structured grid data and unstructured grids data into user-specified octree regions in order to generate the input files of parallel processing by PBVR Server.

3.2 Data Decomposition Model

As shown in Figure 3, the octree data structure divides each edge of a cuboid in half, recursively. Therefore, each cuboid has eight child cuboids while each child cuboid has a single parent cuboid.

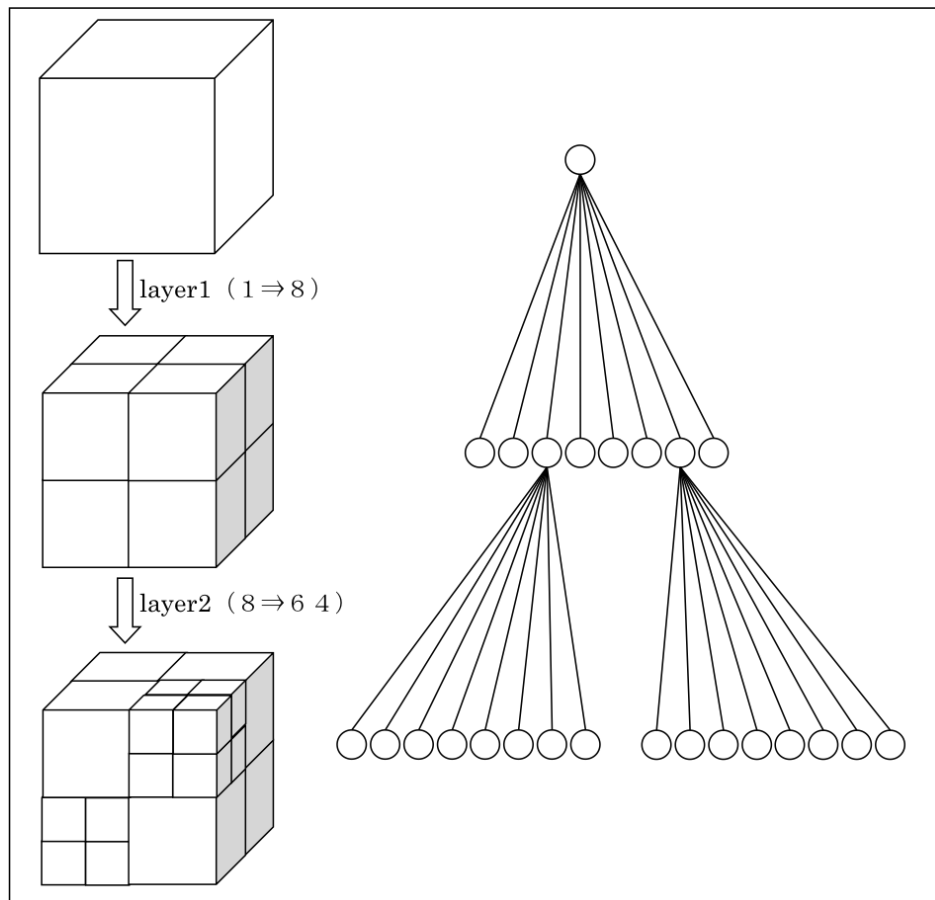


Figure 3 Space partitioning with the octree data structure

As shown in Figure 4, the boundaries of the child-cuboids are computed by dividing the sum of the minimum and maximum coordinate values by two. Given a point in the domain, the cuboid containing the point can be determined by comparing the coordinates of the vertex and the boundaries.

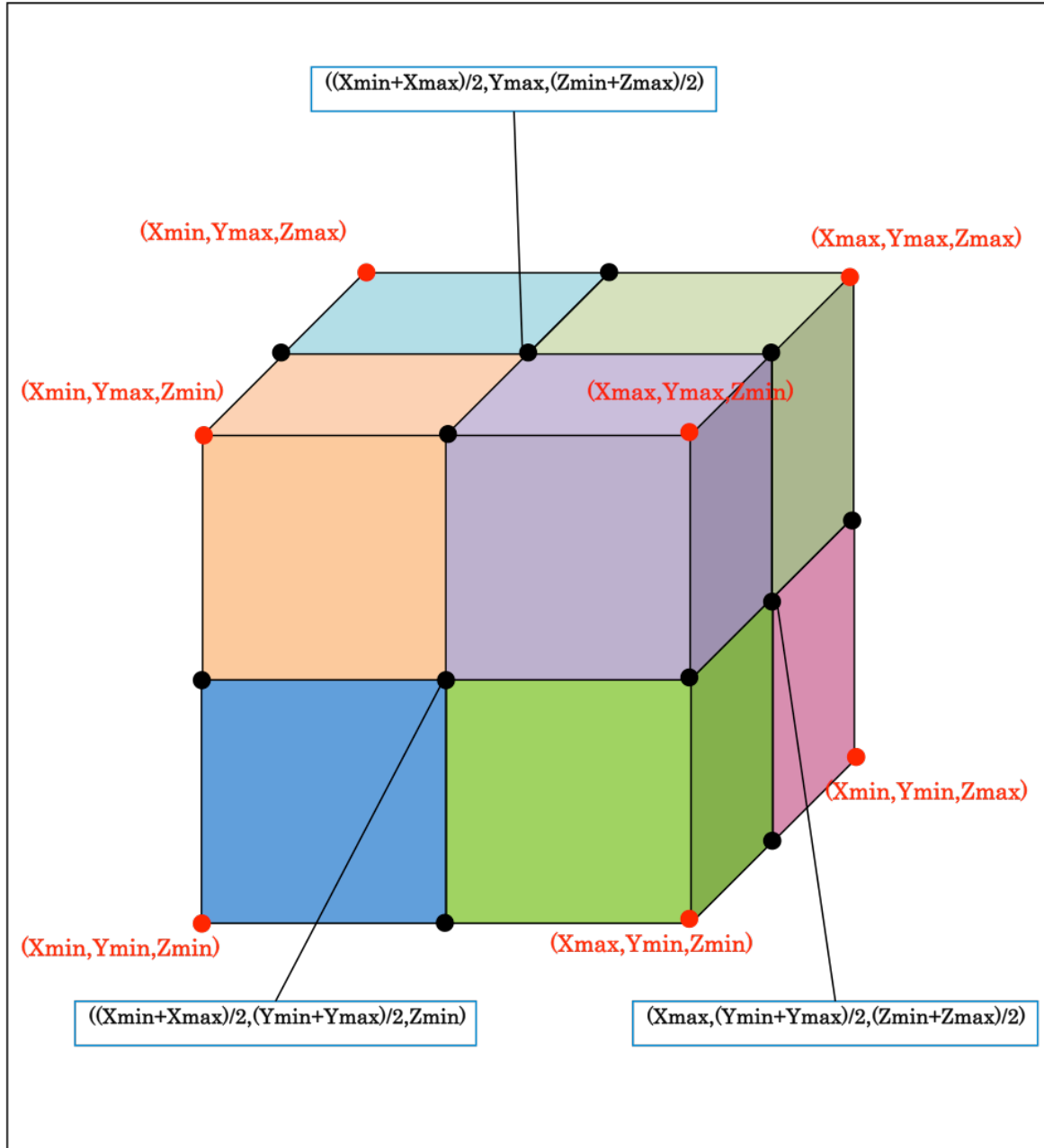


Figure 4 Coordinates of the boundaries in the octree data structure.

3.3 Launching PBVR Filter

The following examples show how to launch PBVR Filter. Note that PBVR Filter requires parameters that are specified in a parameter file. The name of the parameter file should be specified in the command line when launching PBVR Filter. When no parameter file name is given or a non-existent file name is provided, the execution of PBVR Filter fails.

Examples:

Launch the MPI+OpenMP version of PBVR Filter with N processes:

```
$ mpiexec -n N filter param.txt
```

Launch the OpenMP version:

```
$ filter param.txt
```

*1. In both cases, the number of OpenMP threads is set in the environment variable 'OMP_NUM_THREADS'.

3.3.1 Launching VTK supported PBVR Filter

Set environment variable depending on your environment in order to launch VTK supported PBVR Filter.

Installation in Linux

Set the following variable.

```
$ export LD_LIBRARY_PATH=${VTK_LIB_PATH}:$LD_LIBRARY_PATH
```

Installation in Mac

Set the following variable.

```
$ export DYLD_LIBRARY_PATH=${VTK_LIB_PATH}:$DYLD_LIBRARY_PATH
```

Here, $n.n$ denotes the version of the VTK library, and each path should be modified depending on the VTK installation directory.

Installation in Windows

Set the following environment variables with

Control panel -> System -> Property -> Environment.

<i>Variable</i>	<i>Value</i>
Path	d:\Program\%VTK6.3.0%bin

The Path should be specified to the bin directory under the VTK installation directory.

3.4 File Formats

This section describes the file formats that are read/written by PBVR Filter. All binary format data in input/output files are given in single precision, without a header/footer, and in little endian. Three file formats are available: the SPLIT format (that actually make use of kvsmf format), the sub-volume aggregate format, and the step aggregate format. (See Figure 5.) The SPLIT format generates independent files for each time step, for each sub-volume. However, in this format, the number of files grows explosively as the number of layers in octree increases. This problem can be avoided by using either of the other two file formats. The sub-volume aggregate format aggregates files at different time steps (but of the same sub-volume) to a single file. Conversely, the step aggregate format aggregates files of different sub-volumes (at the same time step) to a single file. The following sections explain these three file formats in detail.

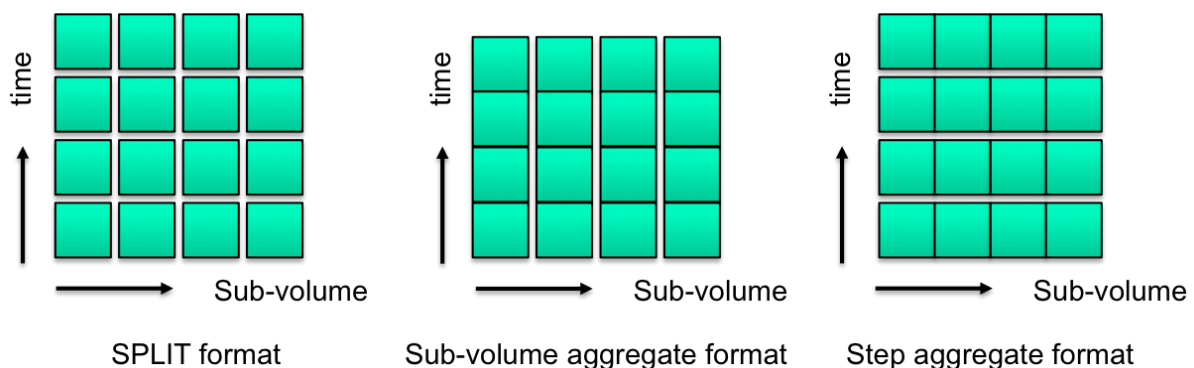


Figure 5 The output file formats available for PBVR Filter

3.4.1 Input Data Format

PBVR Filter can process the following data formats as input.

- 1) AVSFLD binary data*1
- 2) AVSUCD ascii and binary data*1
- 3) STL binary data*2
- 4) PLOT3D binary data*3
- 5) VTK Legacy binary data *4

*1. Refer the details of AVS data formats in the manual of AVS or at <http://www.cybernet.co.jp/avs/products/avsexpress/dataformat.html>. AVSUCD binary data with “data” format can be used. However, the geom and the data_geom formats are not supported. 2D/3D elements in Table 8 and their mixed elements are supported.

*2. Refer the details of STL data formats at [https://en.wikipedia.org/wiki/STL_\(file_format\)](https://en.wikipedia.org/wiki/STL_(file_format)).

*3. Refer the details of PLOT3D data formats at <http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19900013774.pdf>.

*4. Refer the details of VTK data formats at <http://www.vtk.org/>. PBVR Filter can

process VTK Structured Points, VTK Structured Grid, VTK Rectilinear Grid, VTK UnstructuredGrid, and VTKPolygonalData.

3.4.2 Endian

The binary files used in PBVR Filter are in little endian. On a big endian machine, if input data files do not use the little endian format, conversion is necessary.

3.4.3 Filter Output Information File (.pfi)

A .pfi file is a binary data file that summarizes the information of the input volume.

Total number of nodes (int)
Total number of elements (int)
Element type (int) *1
File type (int) *2
Number of files (int) *3
Number of components (int)
Beginning time step (int)
Ending time step (int)
Number of sub-volumes (int) *4
Minimum X-coordinate value of the entire 3D space (float)
Minimum Y-coordinate value of the entire 3D space (float)
Minimum Z-coordinate value of the entire 3D space (float)
Maximum X-coordinate value of the entire 3D space (float)
Maximum Y-coordinate value of the entire 3D space (float)
Maximum Z-coordinate value of the entire 3D space (float)
Number of nodes for sub-volume 1 (int)
Number of nodes for sub-volume 2 (int)
Number of nodes for sub-volume 3 (int)
:
Number of nodes for sub-volume n (int)
Number of elements for sub-volume 1 (int)
Number of elements for sub-volume 2 (int)
Number of elements for sub-volume 3 (int)
:
Number of elements for sub-volume n (int)
Minimum X-coordinate value of sub-volume 1 (float)
Minimum Y-coordinate value of sub-volume 1 (float)
Minimum Z-coordinate value of sub-volume 1 (float)
Maximum X-coordinate value of sub-volume 1 (float)
Maximum Y-coordinate value of sub-volume 1 (float)
Maximum Z-coordinate value of sub-volume 1 (float)
Minimum X-coordinate value of sub-volume 2 (float)
Minimum Y-coordinate value of sub-volume 2 (float)
Minimum Z-coordinate value of sub-volume 2 (float)
Maximum X-coordinate value of sub-volume 2 (float)
Maximum Y-coordinate value of sub-volume 2 (float)
Maximum Z-coordinate value of sub-volume 2 (float)
:
Minimum X-coordinate value of sub-volume n (float)
Minimum Y-coordinate value of sub-volume n (float)
Minimum Z-coordinate value of sub-volume n (float)
Maximum X-coordinate value of sub-volume n (float)
Maximum Y-coordinate value of sub-volume n (float)

Maximum Z-coordinate value of sub-volume n (float)
Minimum value of variable 1 for time step 1
Maximum value of variable 1 for time step 1
Minimum value of variable 2 for time step 1
Maximum value of variable 2 for time step 1
:
Minimum value of variable N for time step 1
Maximum value of variable N for time step 1
:
Minimum value of variable 1 for time step m
Maximum value of variable 1 for time step m
Minimum value of variable 2 for time step m
Maximum value of variable 2 for time step m
:
Minimum value of variable N for time step m
Maximum value of variable N for time step m

- *1. Element types are defined in Table 9.
- *2. Set the int value to 0-2 in order to specify one of the following file formats.
 - 0: SPLIT format
 - 1: sub-volume aggregate format
 - 2: step aggregate format
- *3. The number of files, when the input file format is sub-volume aggregate format.
- *4. The number of sub-volumes is $8^{n_{layer}}$. Examples follow.
 - $n_{layer} = 0 : 1$
 - $n_{layer} = 1 : 8$
 - $n_{layer} = 2 : 64$
 - $n_{layer} = 3 : 512$
 - $n_{layer} = 4 : 4,096$
 - $n_{layer} = 5 : 32,768$
 - $n_{layer} = 6 : 262,144$
 - $n_{layer} = 7 : 2,097,152$

3.4.4 SPLIT File Format

When the SPLIT file format is used, two files are produced for each sub-volume. The first is called an element configuration file. This file describes which of the nodes constitutes each cell. The second is called a node coordinate file, which specifies the coordinates of the nodes. In addition, each sub-volume gets another file for each time step. This file, which is called a variable file, assigns the values of variables (physical quantities) to each node. All these three types of files are formatted as a kvsml file. It is worth noting that the total number of files can be calculated as follows:

The number of sub-volume $\times 2$ + the number of sub-volume \times the number of time steps $\times 2$.

Example:

If n_{layer} is 7 and the number of time steps is 100, then the total number of files is 423,624,704.

3.4.4.1 File Name Convention

In PBVR, files in the SPLIT format have the following naming convention.

<i>prefix_XXXXX_YYYYYYY_ZZZZZZZ.kvsml</i>	: kvsml file (ASCII format)
<i>prefix_YYYYYYY_ZZZZZZZ_connect.dat</i>	: element configuration file (binary format)
<i>prefix_YYYYYYY_ZZZZZZZ_coord.dat</i>	: node coordinate file (binary format)
<i>prefix_XXXXX_YYYYYYY_ZZZZZZZ_value.dat</i>	: variable file (binary format)

'prefix', 'XXXXX', 'YYYYYYY', and 'ZZZZZZZ' should be replaced with the following strings.

'prefix'	: arbitrary string of characters that are allowed for a file name
'XXXXX'	: number of steps (in 5 digits)
'YYYYYYY'	: index for sub-volume (in 7 digits)
'ZZZZZZZ'	: total number of sub-volumes (in 7 digits)

3.4.4.2 kvsml File Format

```
<?xml version="1.0" ?>
<KVSML>
  <Object type="UnstructuredVolumeObject">
    <UnstructuredVolumeObject cell_type=" type of elements">
      <Node nnodes="number of nodes in the sub-volume">
        <Value veclen="number of variables">
          <DataArray type="float" file="prefix_XXXXX_YYYYYYY_ZZZZZZ_value.dat" format="binary" />
        </Value>
        <Coord>
          <DataArray type="float" file=" prefix_YYYYYYY_ZZZZZZ_coord.dat" format="binary" />
        </Coord>
      </Node>
      <Cell ncells="number of elements in the sub-volume">
        <Connection>
          <DataArray type="uint" file=" prefix_YYYYYYY_ZZZZZZ_connect.dat" format="binary" />
        </Connection>
      </Cell>
    </UnstructuredVolumeObject>
  </Object>
</KVSML>
```

3.4.4.3 Format of Element Configuration File

Node 1 of element 1
Node 2 of element 1
:
Node n of element 1
Node 1 of element 2
Node 2 of element 2
:
Node n of element 2
Node 1 of element 3
Node 2 of element 3
:
Node n of element 3
:
Node 1 of element N
Node 2 of element N
:
Node n of element N

3.4.4.4 Format of Node Coordinate File

X-coordinate value of node 1
Y-coordinate value of node 1
Z-coordinate value of node 1
X-coordinate value of node 2
Y-coordinate value of node 2
Z-coordinate value of node 2
X-coordinate value of node 3
Y-coordinate value of node 3
Z-coordinate value of node 3
:
:
X-coordinate value of node m
Y-coordinate value of node m
Z-coordinate value of node m

3.4.4.5 Variable File

Variable 1 of Node 1
Variable 1 of Node 2
Variable 1 of Node 3
:
Variable 1 of Node n
Variable 2 of Node 1
Variable 2 of Node 2
Variable 2 of Node 3
:
Variable 1 of Node n
Variable m of Node 1
Variable m of Node 2
Variable m of Node 3
:
Variable m of Node n

3.4.5 Sub-volume Aggregate Format

In sub-volume aggregate format, the information of element configuration, node coordinates, and variables of all time steps are gathered in a single file for each sub-volume. By specifying the 'Number of file' (which is explained in Section 3.5), one can aggregate the information of several sub-volumes into arbitrary number of files from one to the number of sub-volumes. (If n_{layer} is 7, then the number of files is 2,097,152.)

3.4.5.1 Naming Convention

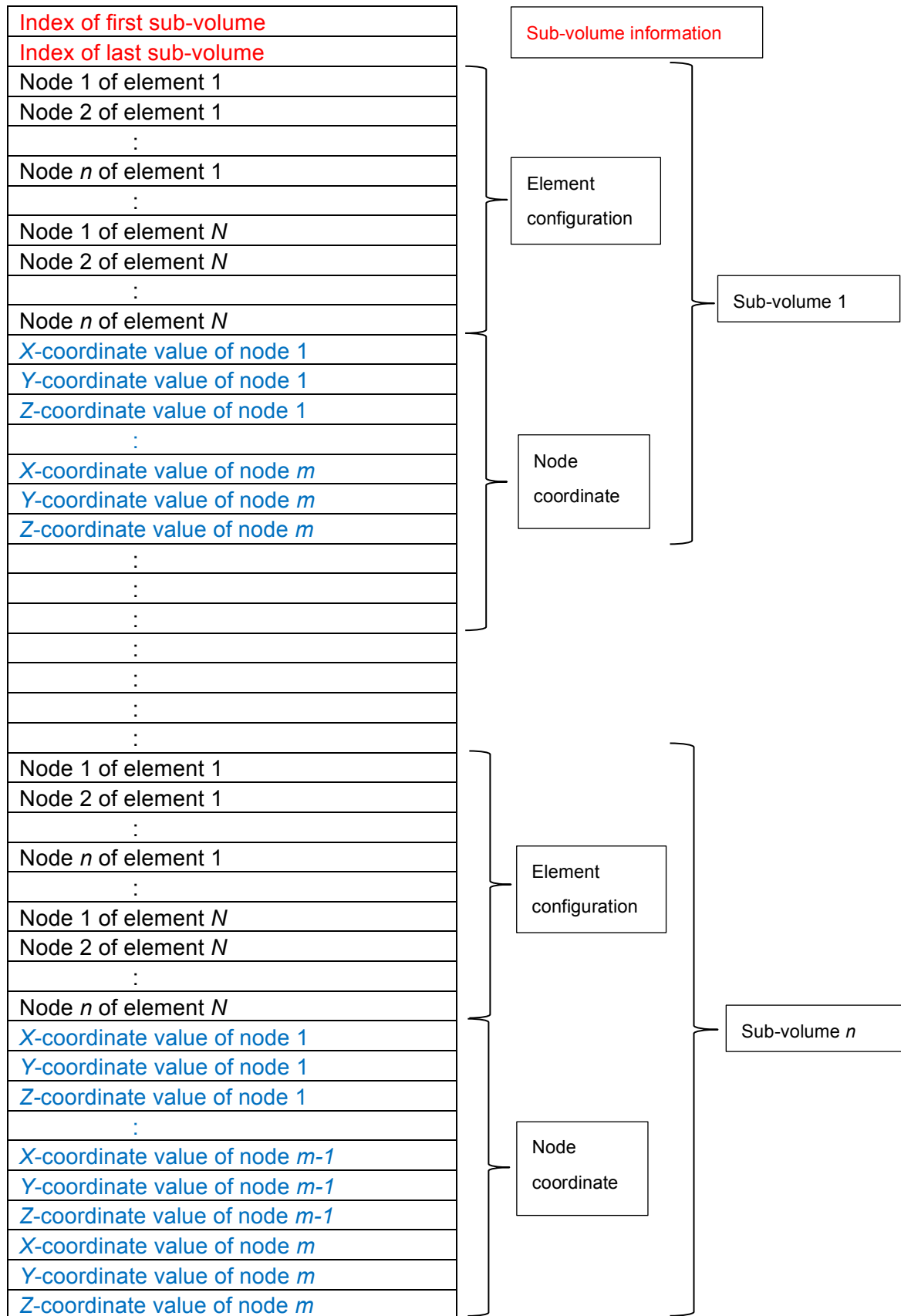
In PBVR, files in the sub-volume aggregate format have the following naming convention.

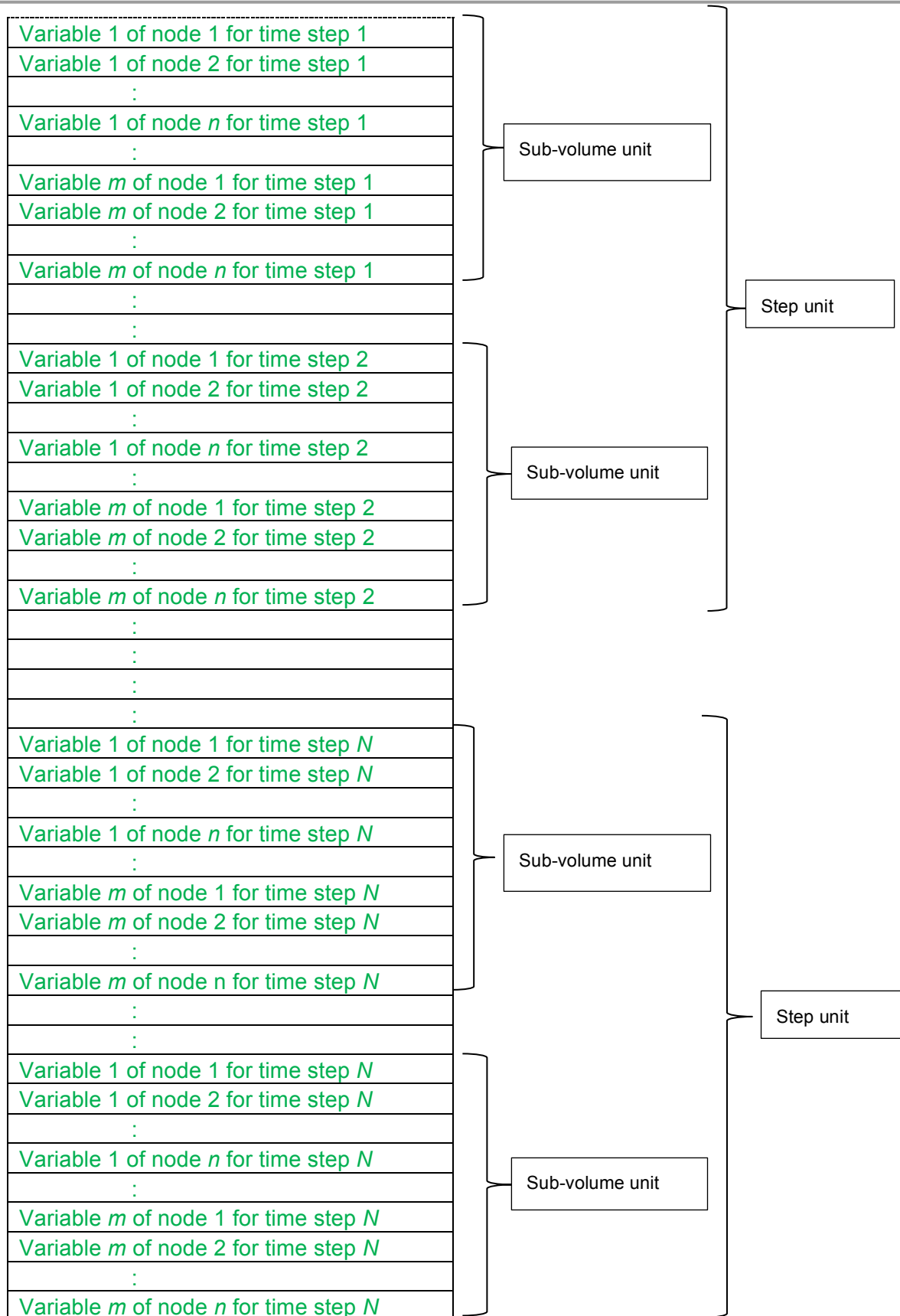
prefix_YYYYYYY_ZZZZZZZ.dat (A binary file)

'prefix', 'XXXXX', 'YYYYYYY', and 'ZZZZZZZ' should be replaced with the following strings.

prefix	: arbitrary string of characters that are allowed for a file name
YYYYYYY	: file number (in 7 digits)
ZZZZZZZ	: total number of files (in 7 digits)

3.4.5.2 File Format





3.4.6 Step Aggregate Format

The step aggregate format is made up of by an element configuration file and a node coordinate file. These two files contain the information of all the sub-volumes. A variable file is produced for each step. Therefore, the total number of files becomes the number of steps + 2.

3.4.6.1 File Name

In PBVR, files in the step aggregate format have the following name convention.

prefix_connect.dat : element configuration file (binary format)

prefix_coord.dat : node coordinate file (binary format)

prefix_XXXXX_value.dat: variable file (binary format)

'prefix' and 'XXXXX' should be replaced with the following strings.

prefix : arbitrary string of characters that are allowed for a file name

XXXXX: number of steps (in 5 digits)

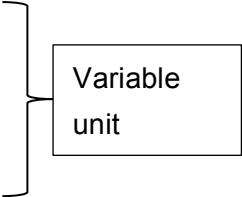
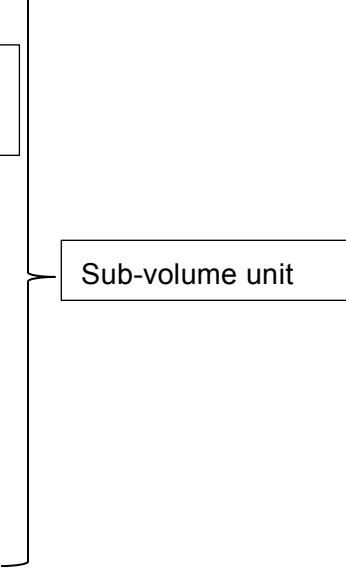
3.4.6.2 Element Configuration File Format

Node 1 of element 1 for sub-volume 1	}	Element unit	}	Sub-volume unit		
Node 2 of element 1 for sub-volume 1						
:						
Node n of element 1 for sub-volume 1						
Node 1 of element 2 for sub-volume 1						
Node 2 of element 2 for sub-volume 1						
:						
Node n of element 2 for sub-volume 1						
Node 1 of element 3 for sub-volume 1						
Node 2 of element 3 for sub-volume 1						
:						
Node n of element 3 for sub-volume 1						
:						
Node 1 of element N for sub-volume 1						
Node 2 of element N for sub-volume 1						
:						
Node n of element N for sub-volume 1						
:						
Node 1 of element 1 for sub-volume M						
Node 2 of element 1 for sub-volume M						
:						
Node n of element 1 for sub-volume M						
Node 1 of element 2 for sub-volume M						
Node 2 of element 2 for sub-volume M						
:						
Node n of element 2 for sub-volume M						
Node 1 of element 3 for sub-volume M						
Node 2 of element 3 for sub-volume M						
:						
Node n of element 3 for sub-volume M						
:						
Node 1 of element N for sub-volume M						
Node 2 of element N for sub-volume M						
:						
Node n of element N for sub-volume M						

3.4.6.1 Node Coordinate File Format

X-coordinate of node 1 for sub-volume 1	}	Node unit	}	Sub-volume unit		
Y-coordinate of node 1 for sub-volume 1						
Z-coordinate of node 1 for sub-volume 1						
X-coordinate of node 2 for sub-volume 1	}	Node unit				
Y-coordinate of node 2 for sub-volume 1						
Z-coordinate of node 2 for sub-volume 1						
X-coordinate of node 3 for sub-volume 1	}	Node unit				
Y-coordinate of node 3 for sub-volume 1						
Z-coordinate of node 3 for sub-volume 1						
:	}	Node unit				
:						
:						
X-coordinate of node m for sub-volume 1	}	Node unit				
Y-coordinate of node m for sub-volume 1						
Z-coordinate of node m for sub-volume 1						
:	}	Node unit				
:						
:						
X-coordinate of node 1 for sub-volume M	}	Node unit				
Y-coordinate of node 1 for sub-volume M						
Z-coordinate of node 1 for sub-volume M						
X-coordinate of node 2 for sub-volume M	}	Node unit				
Y-coordinate of node 2 for sub-volume M						
Z-coordinate of node 2 for sub-volume M						
X-coordinate of node 3 for sub-volume M	}	Node unit				
Y-coordinate of node 3 for sub-volume M						
Z-coordinate of node 3 for sub-volume M						
:	}	Node unit				
:						
:						
X-coordinate of node m for sub-volume M	}	Node unit				
Y-coordinate of node m for sub-volume M						
Z-coordinate of node m for sub-volume M						

3.4.6.2 Variable File Format

Variable 1 of node 1 for sub-volume 1		
Variable 1 of node 2 for sub-volume 1		
Variable 1 of node 3 for sub-volume 1		
:		
Variable 1 of node n for sub-volume 1		
Variable 2 of node 1 for sub-volume 1		
Variable 2 of node 2 for sub-volume 1		
Variable 2 of node 3 for sub-volume 1		
:		
Variable 2 of node n for sub-volume 1		
Variable m of node 1 for sub-volume 1		
Variable m of node 2 for sub-volume 1		
Variable m of node 3 for sub-volume 1		
:		
Variable m of node n for sub-volume 1		
:		
:		
:		
Variable 1 of node 1 for sub-volume M		
Variable 1 of node 2 for sub-volume M		
Variable 1 of node 3 for sub-volume M		
:		
Variable 1 of node n for sub-volume M		
Variable 2 of node 1 for sub-volume M		
Variable 2 of node 2 for sub-volume M		
Variable 2 of node 3 for sub-volume M		
:		
Variable 2 of node n for sub-volume M		
Variable m of node 1 for sub-volume M		
Variable m of node 2 for sub-volume M		
Variable m of node 3 for sub-volume M		
:		
Variable m of node n for sub-volume M		

3.5 Parameter File

The parameter file is in ASCII format, and is commonly used for both PBVR Filter (for AVSFLD/UCD, PLOT3D, and STL data) and PBVR Filter for VTK data. By specifying the file name in the command line when provoking PBVR Filter, the parameters inside are set as input to PBVR Filter. Table 6 lists the available parameters.

Table 7 List of PBVR Filter input parameters

Parameter name	Parameter detail	Default value	Notes
in_dir	Input file directory	‘.’	Directory path of input files *1
field_file	AVSFLD file name	-	*2, *3, *4
stl_binary_file	STL file name	-	*2
Plot3d_config_file	PLOT3D configuration file name	-	*2, *3
vtk_file	VTK file name	-	*2, *3, *5
vtk_in_prefix	Prefix of time series VTK data files	-	*2, *3, *5
vtk_in_suffix	Suffix of time series VTK data files	-	*2, *3, *5
ucd_inp	AVSUCD file name	-	Ascii format*2
in_prefix	Prefix of time series AVSUCD data files	-	Binary format*2
in_sufix	Suffix of time series AVSUCD data files	-	Binary format*2
format	Step number format for time series data	“%05d”	
out_dir	Output file directory	‘.’	Directory path of output files *1
out_prefix	Output file prefix	‘output.’	
start_step	Starting step number	‘1’	*6
end_step	Ending step number	‘1’	*6
n_layer	Number of octree layer	‘0’	An integer from ‘0’ to ‘7’
output_type	File format	‘0’	‘0’: SPLIT format ‘1’: sub-volume aggregate ‘2’: step aggregate

file_number	Number of output files	'0'	An integer greater than 0. When set to '0', the number of sub-volume is used. Valid only in Sub-volume aggregate file format.
mpi_volume_div	Number of MPI parallelism in sub-volume	'1'	The total number of MPI processes is given by $\text{mpi_volume_div} \times \text{mpi_step_div}$. *7
mpi_step_div	Number of MPI parallelism in time step	'1'	The total number of MPI processes is given by $\text{mpi_volume_div} \times \text{mpi_step_div}$. *7
mpi_div	Configuration of 2D MPI parallel processing	'2'	'0': defined by mpi_volume_div and mpi_step_div. '1': automatic with priority on sub-volume decomposition. '2': automatic with priority on step decomposition. Options 1 and 2 do not work when mpi_volume_div and mpi_step_div are set.
multi_elem_type	Flag on mixed element type unstructured grid	'0'	'0': data with a single element type '1': data with multiple element types
temp_delete	Flag on temporary files produced by processing mixed element data	'1'	'0': keep temporary files '1': delete temporary file

- *1. Directories can be specified either with an absolute path or a relative path, although tilde (~) cannot be used as an abbreviation for the HOME directory.
- *2. One of the following options, field_file, stl_binary_file, plot3d_config_file, vtk_file, vtk_in_prefix(suffix), ucd_inp, and in_prefix(suffix) should be given.
- *3. When input data is two dimensional or three dimensional structured grid data, the output data is converted to unstructured grid data with linear quadrilateral or hexahedral elements, respectively.
- *4. Only the parameters 'nstep', 'ndim', 'dim1', 'dim2', 'dim3', 'veclen', 'coord [123]', and 'variable' are referred.
- *5. Five VTK Legacy data formats (VTK Structured Points, VTK Structured Grid, VTK

Rectilinear Grid, VTK UnstructuredGrid, and VTKPolygonalData) are automatically recognized by PBVR Filter.

- *6. Specified only for time series data.
- *7. When 'mpi_volume_div' and 'mpi_step_div' are specified, an error occurs if the value of 'mpi_volume_div' \times 'mpi_step_div' is not identical to the number of processes.

3.5.1 PLOT3D configuration file

PLOT3D data formats are described by a PLOT3D configuration file. Here, usebytecount should be chosen to be 1 and 0 for Fortran and C binary data, respectively.

Parameter name	Parameter detail	Default value
coordinate_file_prefix	Prefix of coordinate file	-
coordinate_file_suffix	Suffix of coordinate file	-
coordinate_mode_precision	Precision (float double)	double
coordinate_mode_usebytecount	1 for true, 0 for false	true
coordinate_mode_endian	Endian (little big)	little
coordinate_mode_iblanks	1 for true, 0 for false	false
solution_file_prefix	Prefix of solution file	-
solution_file_suffix	Suffix of solution file	-
solution_mode_precision	Precision (float double)	double
solution_mode_usebytecount	1 for true, 0 for false	true
solution_mode_endian	Endian (little big)	little
function_file_prefix	Prefix of function file	-
function_file_suffix	Suffix of function file	-
function_mode_precision	Precision (float double)	double
function_mode_usebytecount	1 for true, 0 for false	true
function_mode_endian	Endian (little big)	little

3.6 MPI Parallel Processing

This section describes the ways of dividing the computation in MPI parallel processing. As an example, consider processing data with 50 steps \times 8 sub-volumes.

- 1) Partitioning the set of time steps first
 - If the number of processes is equal to or less than the number of the time steps, divide the time steps by the number of processes.
Example:
Since 8 processes exist, each process treats 6 steps \times 8 sub-volumes, or 7 steps \times 8 sub-volumes.
 - When the number of processes is larger than the number of time steps, each process handles a single time step. The number of sub-volumes for each process is specified

in the following manner. First, divide the number of processes by the number of time steps. Then, divide by the quotient the number of sub-volumes.

Example:

When 128 processes are used, PBVR Filter works with $50 \times 2 = 100$ processes (with the residue of 28 processes), and each process treats $1 \text{ step} \times 4$ sub-volumes.

2) Partitioning the set of sub-volumes first

- When the number of processes is equal to or less than the number sub-volumes, divide all the sub-volumes by the number of processes.

Example:

When 8 processes are used, each process treats $50 \text{ steps} \times 1$ sub-volume.

- When the number of processes is larger than the number of sub-volumes, each process handles a single sub-volume. The number of time steps for each process is specified in the following manner. First, divide the number of processes by the number of sub-volumes. Then, divide by the quotient the number of time-steps.

Example:

When 128 processes are used, PBVR Filter program works with $8 \times 16 = 128$ processes (with the residue of 0 process), and each process treats $3 \text{ steps} \times 1$ sub-volume or $2 \text{ steps} \times 1$ sub-volume

3) Employing a parallelization that is more complex

- When the parallel processing number 'mpi_volume_div' and 'mpi_step_div' are specified, an error occurs if 'mpi_volume_div \times mpi_step_div' does not agree with the number of processes..

3.7 Execution in Staging Environment of K computer

This section describes how to execute PBVR Filter in the staging environment on the K computer. When launching PBVR Filter, the parameter file and staging parameters must be consistent with each other. Depending on the output data format of PBVR Filter, multiple processes may write to a single file. In such a case, the output location should be specified in a shared domain on the local file system that is accessible from all the processes.

3.7.1 Execution Shell Script and Parameter File

```
#!/bin/bash -x
#
#PJM --rsc-list "elapse=01:00:00"
#PJM --rsc-list "node=64"
#PJM --rsc-list "rscgrp=small"
#PJM --stg-transfiles all
#PJM --mpi "proc=64"
#PJM --mpi "use-rankdir"                                #Use rank directory
#PJM --stgin "rank=* ./filter"                          %r:./"    #Stage in for load module
.....①
#PJM --stgin "rank=* ./param.txt"                        %r:./"    #Stage in for file.....
.....②
#PJM --stgin "rank=0 /data/ucd/ucd*.dat"                 0:./"    #Stage in for shared file
.....③
#PJM --stgout "rank=* %r:./output*.dat"                 ./"    #Stage out for resulting
file.....④
#PJM --stgout "rank=* %r:./pbvr_filter.*"                ./LOG/"    #Stage out for file.....
.....⑤
#PJM -S

. /work/system/Env_base

export PARALLEL=8
export OMP_NUM_THREADS=8

mpiexec -n 64 lpgparm -p 4MB -s 4MB -d 4MB -h 4MB -t 4MB filter param.txt ...
.....⑥
```

- ① Transfer the load module to the rank directory of each process.
- ② Transfer a parameter file to the rank directory of each process.
- ③ Transfer input data to the shared domain in the local file system.
- ④ Transfer output data from the shared domain to a directory in global file system.
- ⑤ Transfer log and error files from the rank directory to a directory in the global file system.
- ⑥ When launching the load module in the rank directory of each process, specify the parameter file (which lies in the rank directory of each process) in the command line argument.

```
#
in_dir=./ .....⑦
field_file=pd3d.fld
out_prefix=case0
out_dir=./ .....⑧
file_type=0 .....⑨
n_layer=3
start_step=0
end_step=511
```

- ⑦ Specify the path for input data files. (The path should be provided as a relative path. The above sample reads input data from a shared domain.)
- ⑧ Specify the path for output data file. (The path should be given as a relative path. The above sample writes output data to a rank directory for each process by using of SPLIT file format.)
- ⑨ Specify an output file format. (The above sample uses the SPLIT format.)

3.7.2 Input/Output Files and Directories

This section describes the relation between input/output files treated in PBVR Filter and directories in the staging environment. Output data in the SPLIT format can be written in a rank directory, while output data in the other formats requires a shared directory for data aggregation.

Table 8 Table of input-output files and directories on K computer

I/O	File type		Rank directory	Shared domain
Input	Parameter file		Yes *1	Yes
	Input data		Yes *2	Yes
Output	Output data	SPLIT format	Yes	Yes
		Step aggregate format	No	Yes
		Sub-volume aggregate format	No	Yes
	Log & error file		Yes *3	No

*1. The parameter file is read only from rank 0.

*2. The size and number of the input files should not exceed the resource limit of the staging environment (800 files/node, 14GB/node).

*3. The output directory is always a rank directory.

3.8 Unstructured Grid Data with Mixed Elements

When unstructured grid data contains several element types, PBVR Filter firstly generates UCD binary data for each element type, and then divides the UCD binary data with a single element type into sub-volumes, which are read by the PBVR Server.

By setting the parameter 'multi_element_type' to '1' in the parameter file, PBVR Filter produces a sub-volume for each element type.

```
#
in_dir=.
in_prefix=MULTI
in_suffix=.dat
out_dir=.
out_prefix=div
out_prefix=.dat
format=%03
start_step=1
end_step=20
multi_element_type=1
```

Output files are generated for each element type, and have file names with a 2 digit prefix that represents the element type. The following list shows the names of the elements and the corresponding prefix.

Table 9 List of element types

Element name	Element type code
Triangle Linear	2
Quadrilateral Linear	3
Tetrahedron Linear	4
Pyramid	5
Prism	6
Hexahedron Linear	7
Triangle Quadratic	9
Quadrilateral Quadratic	10
Tetrahedral Quadratic	11
Hexahedral Quadratic	14

When the input data with the above parameter file consists of linear tetrahedral elements and quadratic tetrahedral elements, the following output files are generated.

Table 10 File names for mixed elements

Original mixed elements data		Linear tetrahedral data	Quadratic tetrahedral data
MULTI001.dat	⇒ Decompose	04-div001_-	11-div001_-
MULTI002.dat		04-div002_-	11-div002_-
MULTI003.dat		04-div003_-	11-div003_-
MULTI004.dat		04-div004_-	11-div004_-
MULTI005.dat		04-div005_-	11-div005_-
:		:	:
MULTI020.dat		04-div020_-	11-div020_-

4 PBVR Server

4.1 Overview

PBVR Server reads sub-volume files, which are produced by PBVR Filter, and performs parallel visualization with the PBVR technique to generate particle data as visualization results.

4.2 Launching PBVR Server

PBVR can operate in supercomputers both in batch mode, which generates only particle data in batch processing, and in client-server mode, which generates particle data in interactive processing by connecting PBVR Client and PBVR Server via a socket communication. Stand-alone processing on PCs or workstations is also possible by launching PBVR Client and PBVR Server in the client-server mode on the same machine. The followings show how to launch PBVR Server.

Examples:

Launch the MPI+OpenMP version, and use N processes

```
$ mpiexec -n N pbvr_server
```

Launch the OpenMP version

```
$ pbvr_server
```

- *1. Since the MPI+OpenMP version of PBVR Server operates with master-slave MPI processing, the number of process N should be specified by the number of slave process + 1.
- *2. In both processing modes, the number of OpenMP threads is set with OMP_NUM_THREADS environment variable.
- *3. In Windows, these commands should be launched from Visual Studio 2013 x64 Native Tools command prompt.

Table 11 List of command line options for the PBVR Server program

Option	Launch mode	Possible parameters	Default parameters	Functionality
-h	CS,B	-	-	This shows the list of available options and parameters
-B	B	-	-	To launch in the batch mode
-pa	B	File name	-	Visualization parameter file
-pd	B	Real number	1.0	Particle density *2

-S	B	u, m	u	Method for sampling particles u: uniform sampling m: metropolis sampling
-plimit	B	1-99999999	1000000	Maximum number of particles *2
-vin	B	File name	-	Input volume data (a .pfi or .pfl file) *2
-pout	B	File name	./	Name of the output particle data file *3
-p	CS	Port number	60000	Port number for socket communication
-viewer	B	100-9999 ×100-9999	620×620	Viewer resolution
-Bd	B	-	-	Create particle files separately without aggregating the subvolumes
-Bs	B	Integer of 0 or more	First step of specified pfi file group	First time step for visualizing
-Be	B	Integer of 0 or more	Last step of specified pfi file group	Last time step for visualizing

- *1. In launch mode, CS and B denote client-server mode and batch mode, respectively.
- *2. If this option conflicts with the option in the parameter file specified with '-pa', the latter is ignored.
- *3. This generates a set of particle data files with names
 "[file name]_[time step]_[number of sub-volumes]_[sub-volume index].kvsml,"
 where [file name] is the prefix specified with this option. If the prefix is omitted, the prefix 'server' will be inserted automatically.

4.2.1 Launching PBVR Server in Batch Mode

When the command line option '-B' is given, PBVR Server is launched in batch mode. The following example shows how to launch PBVR Server in the batch mode (for the MPI+OpenMP version).

```
$ mpiexec -n 5 pbvr_server -B -vin ./data/case.pfi -pout ./output/case -pa ./param.in
```

In this example, the input data *./data/case.pfi* is processed with the visualization parameter file *./param.in* to output the following particle data.

```
./output/case_XXXXX_YYYYYYY_ZZZZZZ.kvsml
```

XXXXXX	: Number of steps (5 digit number)
YYYYYYY	: Index for the sub-volume (7 digit number)
ZZZZZZZ	: Total number of Sub-volumes (7 digit number)

Usually all of the subvolume for each time is integrated, so both YYYYYYY, ZZZZZZZ shall be 1. If you want to output particle data for each of the subvolume without the integration, command-line options '-Bd' must be specified the server startup of batch mode.

The visualization parameter file is specified with the command line option '-pa'. This file is generated in client-server mode interactively. Large-scale data processing in the batch mode is executed by using this file as it is, or with desirable modifications to the parameters.

4.2.2 Processing of Distributed Files

Multiple volume data files stored in distributed environments are integrated to visualize by this system. The multiple volume data files are filtered one by one, and generate pfi files for each volume data files. To specify two or more pfi files for an input volume data file, make the pfl file that lists the pfi files, and specify the pfl file with the command line option '-vin'.

It is necessary to write "#PBVR PFI FILES" to the head of the pfl file. The pfi file names are written from the second line of the pfl file, by absolute path or relative path of the pfl file. The following example shows content of pfl file.

```
#PBVR PFI FILES
hex_filter_out/hex.pfi
hex2_filter_out/hex2.pfi
```

4.2.3 Launching PBVR Server in Client-Server Mode

When the command line option '-B' is not specified, PBVR Server is launched in the client-server mode. See the following example.

```
$ mpiexec -n 5 pbvr_server
first reading time[ms]:0
Server initialize done
Server bind done
Server listen done
Waiting for connection ...
```

When "Waiting for connection" appears as in the above example and PBVR Server waits for a socket communications with PBVR Client, launch the PBVR Client in another terminal. In the client-server mode, input volume data name should be given to PBVR Client rather than to PBVR Server.

The default port number for the socket communication is 60000. To change the port number, use the command line option '-p':

```
$mpiexec -n 5 pbvr_server -p 55555
```

4.2.4 Connecting Client and Server via Socket Communication

4.2.4.1 Local Connection

The following example shows how to launch both PBVR Client and PBVR Server on a single machine 'machineA'. In this example, they cooperate using the default port number 60000 of 'machineA'.

Step 1 [Launch PBVR Server]

```
machineA> mpiexec -n 5 pbvr_server
```

Step 2 [Launch PBVR Client]

```
machineA> pbvr_client -vin filename
```

4.2.4.2 Remote Connection between Two Machines

The following example shows how to launch PBVR Client on a machine 'machineA' and PBVR Server program on another machine 'machineB' where the two machines are located at distant places. This example uses SSH port forwarding to connect the port 60000 of 'machineA' to the port 60000 of 'machineB'. In this way, PBVR Server and Client on the two machines cooperate through the default port number 60000. Once the SSH port forwarding is established, the launching procedure is basically the same as that in stand-alone mode. In Windows, SSH port forwarding can be setup by using a third-party application such as TeraTerm or Putty.

Step1 [SSH port forwarding from machineA to machineB]

```
machineA> ssh -L 60000:localhost:60000 username@machineB
```

(Forwarding the 60000 port of machineA to the 60000 port of machineB)

Step2 [Launch PBVR Server]

```
machineB> mpiexec -n 5 pbvr_server
```

Step3 [Launch PBVR Client]

```
machineA> pbvr_client -vin filename
```

4.2.4.3 Remote Connection with Several Machines

This section provides an example of connecting PBVR Server and PBVR Client on two remote machines 'machineA' and 'machineB' via 'machineC' for some reason, e.g. security. Once the SSH port forwarding is established, the launching method is basically the same as the stand-alone mode, as with the two point remote connection mentioned before.

Step1 [SSH port forwarding from machineA to machineC]

```
machineA> ssh -L 60000:localhost:60000 username@machineC
```

(Forwarding the 60000 port of machineA to the 60000 port of machineC)

Step2 [SSH port forwarding from machineC to machineB]

```
machineC> ssh -L 60000:localhost:60000 username@machineB
```

(Forwarding the 60000 port of machineC to the 60000 port of machineB)

Step3 [Launch PBVR Server]

```
machineB> mpiexec -n 5 pbvr_server
```

Step4 [Launch PBVR Client]

```
machineA> pbvr_client -vin filename
```

4.2.4.4 Testing SSH Port Forwarding Connection

To check if SSH port forwarding is available, use the following test program, which simply transfers characters input from PBVR Server to PBVR Client. This program is available from the link below.

“C for Linux 2” Mitsuyuki Komata, SYUWA System, Inc., September 2005 (Japanese).

<http://www.ncad.co.jp/~komata/c4linux2/>

Launch PBVR Server

server port_number

Launch PBVR Client

client server_hostname port_number

4.2.4.5 Connecting to Pre-post Server of K computer

This section shows an example of connecting a PC ('machineA') in s laboratory to the data processing server of the K computer (Pre-post server pps3) via the login node of the K computer (klogin).

Step1 [SSH port forward from machine to klogin]

```
machineA> ssh -L 60000:localhost:60000 username@k.aics.riken.jp
```

(Forwarding the 60000 port of machineA to the 60000 port of klogin)

Step2 [SSH port forward from K login node to pre-post server]

```
klogin> ssh -L 60000:localhost:60000 username@pps3
```

(Forwarding the 60000 port of klogin to the 60000 port of pps3)

Step3 [Launch PBVR Server]

```
pps3> mpiexec -n 5 pbvr_server
```

Step4 [Launch PBVR Client]

```
machineA> pbvr_client -vin filename
```

(Forwarding the 60000 port of klogin to the 60000 port of pps3)

4.2.4.6 Local Connection in Windows

This section shows how to launch both PBVR Sever and PBVR Client on a single Windows machine. The Visual Studio 2013 x64 Cross Tools command prompt in Visual Studio 2013 is used as the terminal for launching the programs.

Step1 [Launch PBVR Server]

```
Windows> pbvr_server.exe
```

Step2 [Set the client parameter for Windows]

```
Windows> set TIMER_EVENT_INTERVAL=1000
```

Step3 [Launch PBVR Client]

```
Windows> pbvr_client.exe -vin filename
```

Another way of launching PBVR Server and Client is to execute a batch file with the following lines.

```
set TIMER_EVENT_INTERVAL=1000
start PBVR_Server_win.exe
pbvr_client.exe -vin filename
```

4.2.4.7 Remote Connection from Windows Client

To connect PBVR Client in a Windows machine to PBVR Server in a remote machine, setup port forwarding with the help of an SSH client software such as TeraTerm or Putty. The following shows an example for TeraTerm.

- 1) Launch TeraTerm and hit cancel in the “New connection” dialog.

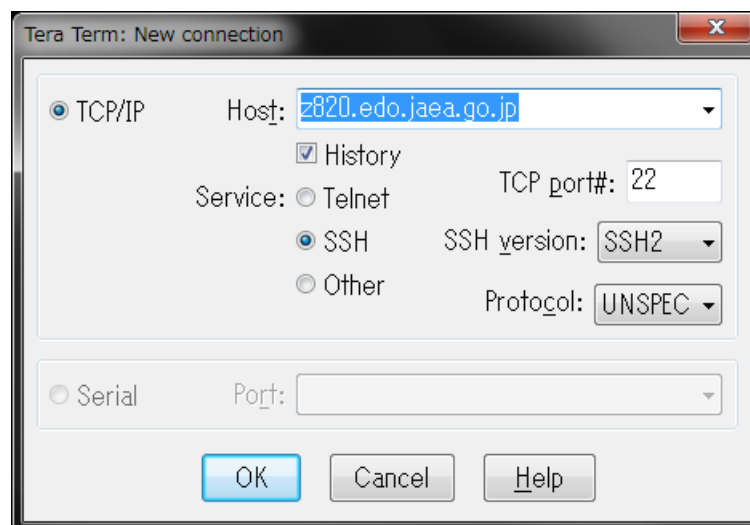


Figure 6 Tera Term dialog 1)

-
- 2) Select **Setup > SSH Transfer** from the menu bar. Click **Add...** in the **Forwarding Setup** dialog.

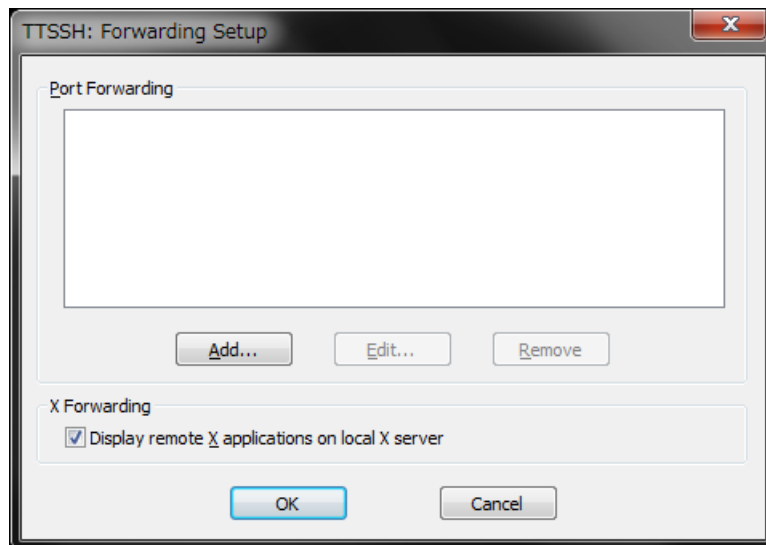


Figure 7 Tera Term dialog 2)

- 3) In the **Select Direction for Forwarded Port** dialog, select **Forward Local Port** and enter the port number to be used for PBVR Client. In the **to remote machine** text field, enter the domain name or the IP address of the server. In the **port** field, enter the port number to be used on PBVR Server. Click on **OK** to complete the setup of port forwarding.

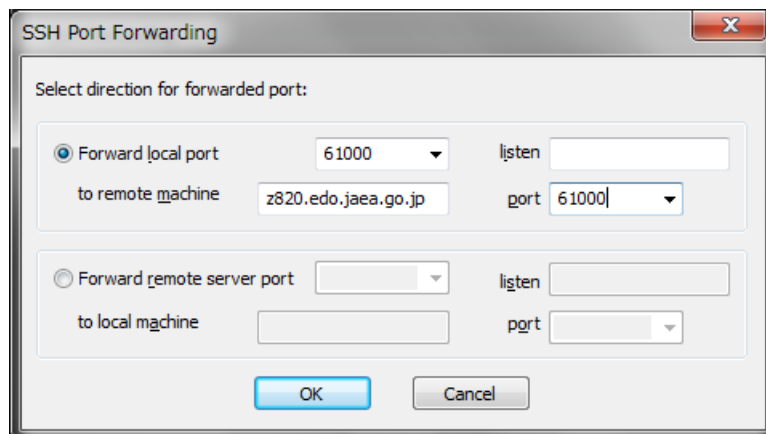


Figure 8 Tera Term dialog 3)

- 4) Connect to the server. Select **File > New Connection** from the menu bar. In the **New Connection** panel, enter the host name of the server and click on **OK**. In the **SSH Authentication** panel, enter the user name and passphrase, or specify the location of the private key file, and click on **OK**.

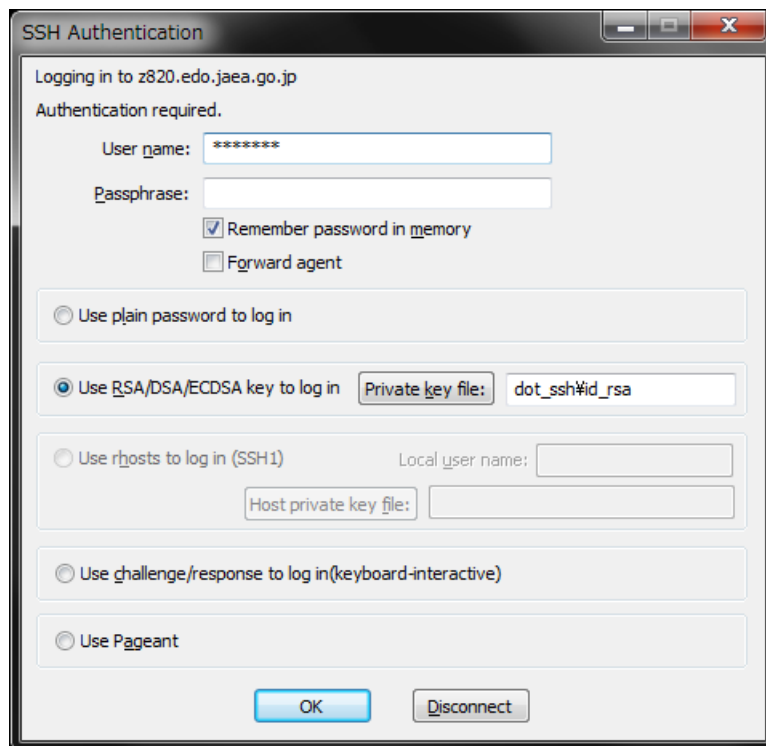


Figure 9 Tera Term dialog 4)

The following procedures show how to launch PBVR Server and Client after establishing port forwarding. This example uses the Visual Studio 2013 x64 Cross Tools command prompt in Visual Studio 2013 as the terminal for launching PBVR Client.

Step1 [Launch PBVR Server]

```
Server> mpiexec -n 4 pbvr_server -p port_number
```

Step2 [Set a client parameter for Windows]

```
Windows> set TIMER_EVENT_INTERVAL=1000
```

Step3 [Launch PBVR Client]

```
Windows> pbvr_client.exe -vin filename -p port_number
```

Note that PBVR Client on a Windows machine can be launched also by executing a batch file with the following lines.

```
set TIMER_EVENT_INTERVAL=1000
pbvr_client.exe -vin filename -p port_number
```

5 PBVR Client

5.1 Overview

PBVR Client can operate either in client-server mode or in stand-alone mode.

In client-server mode, PBVR Client receives particle data that is rendering primitives generated in PBVR Server. Further, PBVR Client renders the data using OpenGL. PBVR Client also gets visualization parameters (a transfer function etc.) via user interaction and sends the parameters to PBVR Server. In this way, PBVR Client controls the volume rendering process in PBVR Server. Data transfer between PBVR Client and PBVR Server uses a socket communication with a user-specified port number.

In contrast, when PBVR is in stand-alone mode, it reads and displays particle data generated by PBVR Server operating in batch mode.

5.2 Launching PBVR Client

The following examples show how to launch the client program in client-server mode and to do so in stand-alone mode. When PBVR Client starts, it opens three panels: **Viewer**, **Main panel**, and **Time Panel**.

Launch PBVR Client in client-server mode *1

```
$ pbvr_client -vin [sub-volume file name *2] [command line options]
```

Launch PBVR Client in stand-alone mode

```
$ pbvr_client [particle data file name] [command line options]
```

- *1. Client-server mode requires starting PBVR Server beforehand.
- *2. The file name for sub-volume can be specified with the absolute or the relative path to the .pfi file.

To specify two or more pfi files for an input volume data file, make the pfl file that lists the pfi files, and specify the pfl file with the command line option '-vin'.

It is necessary to write "#PBVR PFI FILES" to the head of the pfl file. The pfi file names are written from the second line of the pfl file, by absolute path or relative path of the pfl file. The following example shows content of pfl file.

```
#PBVR PFI FILES
hex_filter_out/hex.pfi
hex2_filter_out/hex2.pfi
```

Table 12 List of command line option for client

Option	Launch mode *1	Parameter value	Default parameters	Function
-h	CS,SA	-	-	Display the list of options and parameters
-pd	CS	Real number	1.0	Particle density
-S	CS	u, m	u	Particle sampling method u: uniform sampling m:metropolis sampling
-plimit	CS	1~99999999	1000000	Particle limit *2
-tdata	CS	all, div	all	Particle data transfer method all: step batch transmission, div: sub-volume divide forwarding)
-pa	CS,SA	File name	-	Visualization parameter file
-vin	CS	File name	-	Name of the pfi or pfl file of input volume data *2
-tf	CS	File name	-	Name of the transfer function file *3
-p	CS	Port number	60000	Port number of socket communication
-viewer	CS,SA	100-9999 ×100-9999	620×620	Viewer resolution
-shading	CS,SA	{L/P/B}, ka, kd, ks, n	-	Shading method *4
-pout	CS,SA	File name	-	Output file name for particle data *5
-pin1	SA	File name	-	Input file name for particle data
-iout	CS,SA	Directory name	./	Output directory name for image files

*1. CS and SA denote client-server mode and stand-alone mode, respectively.

-
- *2. If this option conflicts with the option in the parameter file specified with '-pa', the latter is ignored.
 - *3. Transfer function files are generated by hitting the **Export File** button in the **Transfer Function Editor**. In order to apply the transfer function specified in this option, hit the **Apply** button in **Transfer Function Editor**. Alternatively, the transfer function file can be loaded also with the **Import File** button.
 - *4. This argument specifies the shading parameters.

L: Lambert Shading

This method ignores specular reflection in the shading process.

Parameters 'ka' and 'kd' are the coefficient for ambient and diffusion, respectively.

They can have a value between 0-1.

P : Phong Shading

This method adds the specular reflection to Lambert shading. Phong shading imitates smooth metal and mirrors. (This is sometimes called highlight).

Parameter 'ka', 'kd', 'ks' (coefficients for specular reflection lying between 0-1) and 'n' (strength of highlight lying between 0-100) are used.

B : Blinn-Phong Shading

This is a shading model that simplifies Phong shading. Parameters 'ka', 'kd', 'ks', and 'n' exist.

- *5. This generates a series of particle data files that are named
"[file name]_[time index]_[number of sub-volumes]_[sub-volume index].kvsmi",
where the [file name] is the prefix specified this option.

5.3 Terminating PBVR

5.3.1 Standard Termination

PBVR Client's rendering process for the time-series data starts from the initial time step, and continues to the final time step. When the final time step is rendered, PBVR Client returns to the initial time step to loop over the steps. To terminate PBVR Client, press **Ctrl+C** in the console running PBVR.

In client-server mode, pressing **Ctrl+C** in the client console terminates both PBVR Client and PBVR Server. Just before the termination, PBVR Client and Server will synchronize their time step. However, PBVR Client ignores pressing **Ctrl+C** whenever the client-server communications are interrupted with the **Stop** button in **Time Panel**.

5.3.2 Forced Termination

When PBVR Server is terminated not by pressing **Ctrl+C** in PBVR Client's console, PBVR Client becomes stuck and cannot be terminated with **Ctrl+C**. Furthermore, even if **Ctrl+C** is pressed to terminate PBVR Client, both PBVR Client and Server might become stuck. This can happen if the time step is not updated due to heavy particle generation processes or some other reason. In such a case, obtain the process IDs of PBVR Client and PBVR Server using the `ps` command in the console, and then force them to quit with the `kill` command as follows.

[Force the termination of a PBVR Client process]

```
$ ps -C pbvr_client
```

PID	TTY	TIME	CMD
-----	-----	------	-----

19582	pts/6	00:00:00	pbvr_client
-------	-------	----------	-------------

```
$ kill -9 19582
```

[Force the termination of a PBVR Server process]

```
$ ps -C pbvr_server
```

PID	TTY	TIME	CMD
-----	-----	------	-----

19539	pts/5	00:00:00	pbvr_server
-------	-------	----------	-------------

```
$ kill -9 19539
```

5.4 Using PBVR Client GUI

5.4.1 Viewer

As shown in Figure 10, **Viewer** displays the rendering result of particle data.

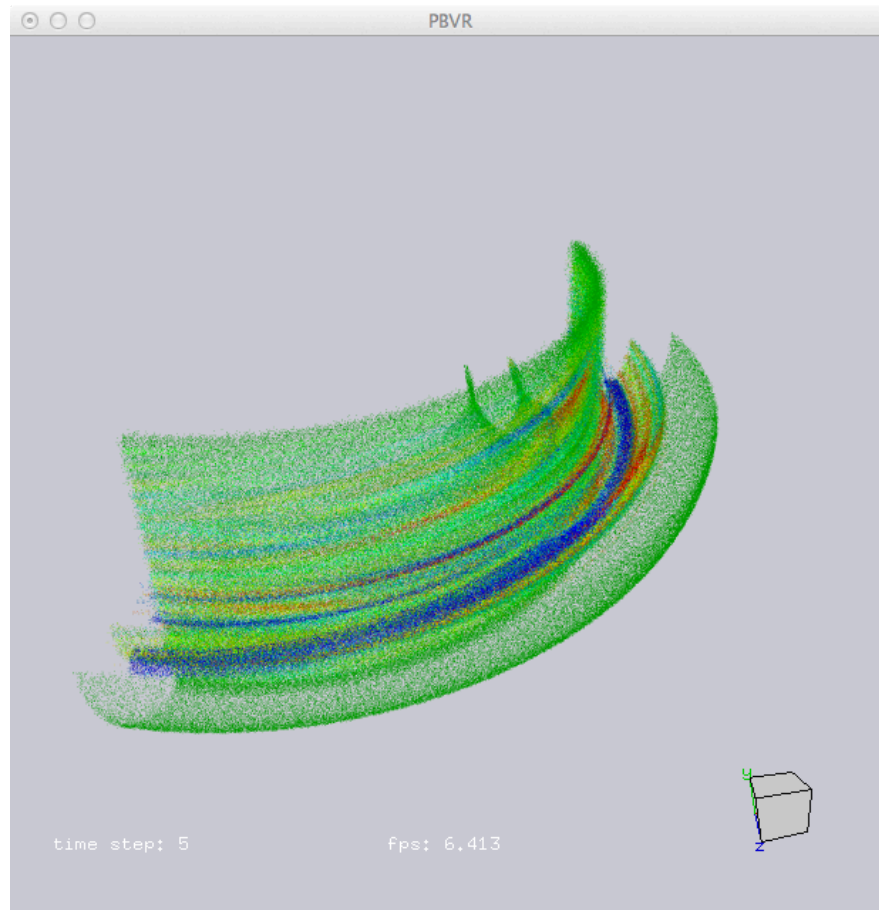


Figure 10 **Viewer**

[Operations]

Rotation: move the mouse while pressing the left-button

Translation: move the mouse while pressing the right-button

Zoom: scroll up/down the mouse wheel, or move the mouse up/down while pressing the **Ctrl** key

Reset: home button (fn + left arrow on Mac)

[Display]

time step: the time step of the displayed data

fps: the frame rate [frame/sec]

5.4.2 Main Panel

Figure 11 shows **Main panel** of PBVR Client. The items of the panel are described below.

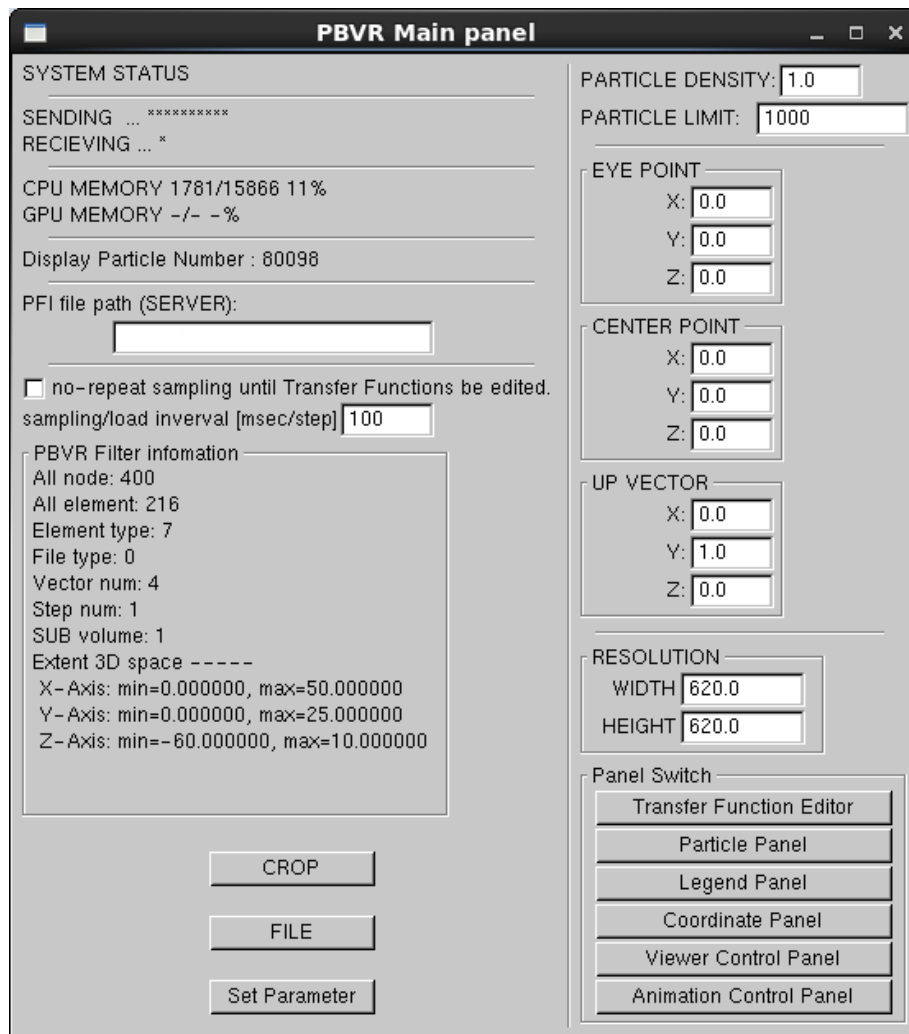


Figure 11 **Main panel**

- **PARTICLE DENSITY**

Specifies the particle density related to the depth of the image.

- **PARTICLE LIMIT**

Specifies the maximum number of particles that are generated in PBVR Server. Use this to avoid the explosive increase of the number of particles (e.g. due to the false settings of a transfer function). The number is multiplied by 10^6 .

- **EYE POINT**

Specifies the viewpoint.

- **CENTER POINT**

Specifies the location where the camera looks at.

- **UP VECTOR**

Specifies the up vector of the camera.

- **RESOLUTION**

Specifies the Viewer's resolution.

- **Transfer Function Editor**

Displays Transfer Function Editor, which is described in the next section.

- **Particle Panel**

Displays Particle Panel, which is described in the next section.

- **Legend Panel**

Displays Legend Panel, which is described in the next section.

- **Coordinate Panel**

Displays Coordinate Panel, which is described in the next section.

- **Viewer Control Panel**

Displays Viewer Control Panel, which is described in the next section.

- **Animation Control Panel**

Displays Animation Control Panel, which is described in the next section.

- **SENDING**

Shows the progress of data transfer to the server program.

- **RECEIVING**

Shows the progress of data transfer from the server program.

- **CPU MEMORY**

Displays the system memory usage in megabytes.

- **GPU MEMORY**

Displays the GPU memory usage in megabytes.

- **Display Particle Number**

Display the number of the particle shown to a viewer is indicated.

- **PFI file path (SERVER)**

Specifies .pfi or pfl file name of input volume data in PBVR Server.

- **no-repeat sampling until Transfer Functions be edited**

When the transfer function has not been changed in the client server mode, do repetition drawing of time series data by using particle data in client memory.

- **PBVR Filter information**

Displays information about the volume data in PBVR Server, which is the contents of the .pfi file.

- **FILE**

This button shows the **FILE Panel**, whose detail is described later.

- **CROP**

Displays **CROP Panel**, which is described in the next section.

- **Set parameter**

Sends parameters specified in "Main panel" to the server program.

5.4.2.1 FILE Panel

FILE Panel is a panel for reading and writing visualization parameter files. This panel is shown when the **FILE** button is hit.

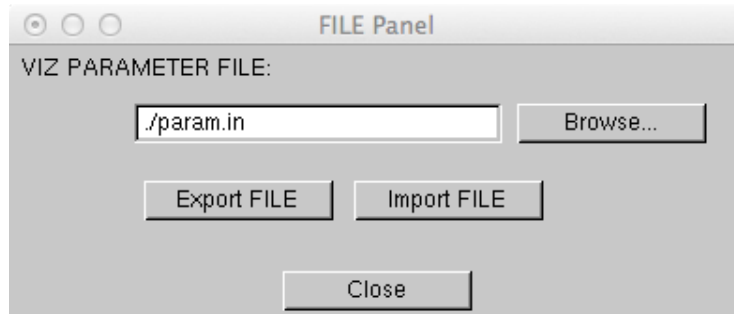


Figure 12 **FILE Panel**

- **VIZ PARAMETER FILE**
specifies the path to a visualization parameter file.
- **Browse ...**
Opens a file dialog for specifying the path to a visualization parameter file.
- **Export FILE**
Saves the current parameter settings to a visualization parameter file.
- **Import FILE**
Imports a visualization parameter file.
- **Close**
Closes **FILE Panel**.

5.4.2.2 CROP Panel

CROP Panel is activated by hitting the **CROP** button in **Main panel**. Use **CROP panel** for operations related to extracting and rendering elements involved within the Region Of Interest (ROI). ROI can be specified with a cuboid, a sphere, or a cylinder.

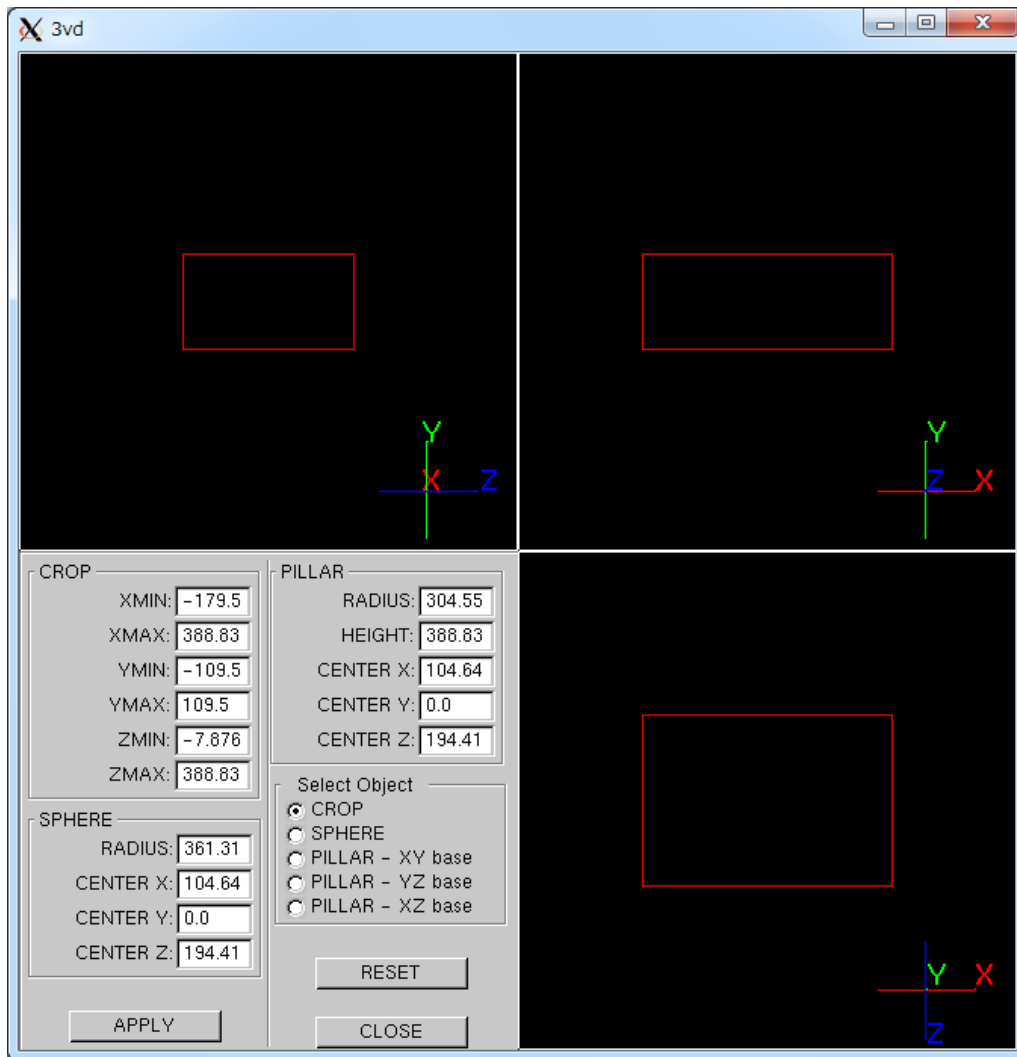


Figure 13 **CROP panel**

[Operations]

Move region: move the mouse on trihedral panel

Zoom region: move the mouse on trihedral panel while pressing Ctrl

Select Object: Specifies the shape of the ROI

CROP: A cuboid

SPHERE: A sphere

PILLAR-XY base: A cylinder with a X-Y base

PILLAR-YZ base: A cylinder with a Y-Z base

PILLAR-XZ base: A cylinder with a X-Z base

CROP: Specifies the range of the cuboid

SPHERE: Specifies the center and radius of the sphere

PILLER: Specifies the radius, the height, and the center coordinate values of the cylinder

RESET: Resets the **CROP** panel

APPLY: Extracts the ROI

CLOSE: Closes the panel

Displaying **CROP** panel overdraws the shape of the ROI in **Viewer** as in Figure 14.

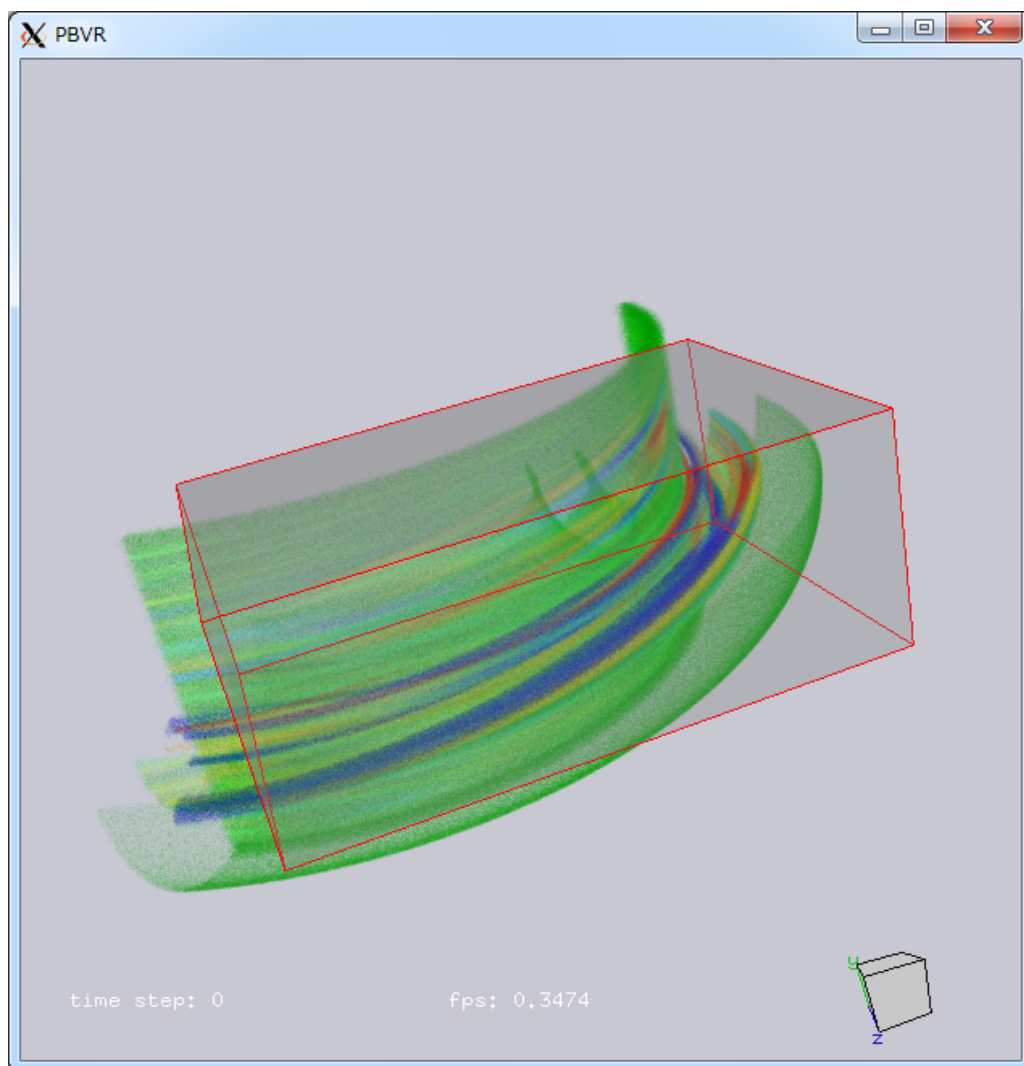


Figure 14 **Viewer** panel interacting with CROP

5.4.3 Transfer Function Editor

Transfer Function Editor edits the transfer functions, which assigns a color/opacity to each scalar value for volume rendering. **Transfer Function Editor** is activated by hitting the Transfer Function Editor button in Main panel. In a standard volume rendering, a transfer function is defined by only one physical quantity. In contrast, PBVR provides a new multi-dimensional transfer function design, which has the following three features:

- 1) Assign two independent variable quantities to color and opacity.
- 2) Define each variable quantity with an arbitrary function of the X - Y - Z coordinates and variables $q1, q2, q3...$
- 3) Synthesize a multidimensional transfer function from one-dimensional transfer functions $t1$ - $t5$ using equations.

This new transfer function design adds significant flexibility to visualization. **Transfer Function Editor** is shown in Figure 15. Each item in the panel is explained below.

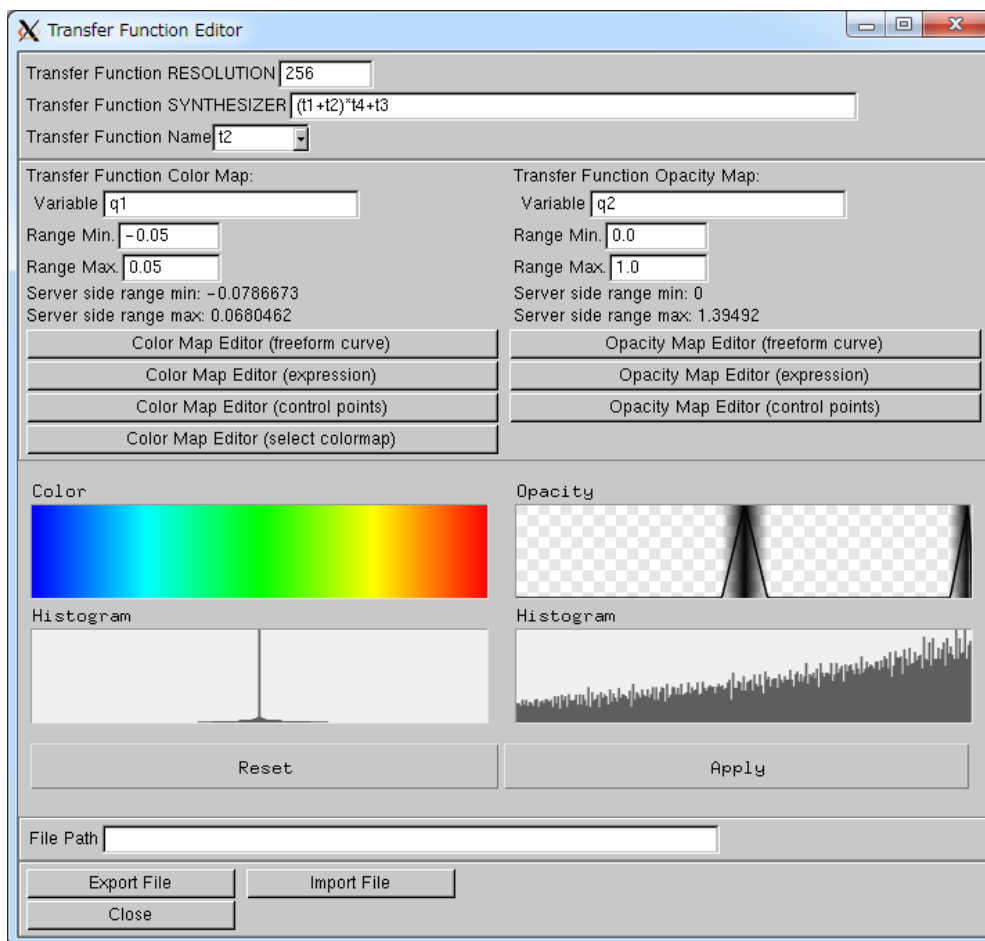


Figure 15 **Transfer Function Editor**

[Operations]

Scale change in histogram: Drag the mouse up/down on **Histogram**

- **Transfer Function RESOLUTION**

Species the resolution of the transfer function

- **Transfer Function SYNTHESIZER**

Specifies a function to synthesize one dimensional transfer functions $t1-t5$ *1

- **Transfer Function Name**

Selects a transfer function (t1-t5) to edit with a pull-down menu.

- **Reset**

Resets the panel.

- **Apply**

Sends a transfer function defined with this panel to the server.

- **File Path**

Specifies a file path for saving and loading a transfer function file.

- **Export File**

Saves a transfer function defined with this panel to a file in the same format as the parameter file specified with the command line option '-pa'.

- **Import File**

Loads a transfer function stored in a file to this panel

- **Close**

Close Transfer Function Editor.

5.4.3.1 Color Map Editor Panel

[**Transfer Function Color Map** category]

The GUI components in this category set a variable quantity and color for the transfer function specified with the **Transfer Function Name** field.

- **Color**

Displays the colors that were assigned to the values of variable quantity by the transfer function.

- **Variable**

Defines the (synthesized) variable quantity used for color of the selected transfer function. An equation can be entered, while the following variables are available.

Physical quantities : $q1, q2, q3, \dots, qn$.

Coordinate values : X, Y, Z .

- **Range Min**

Specifies the minimum value of the specified variable quantity.

- **Range Max**

Specifies the maximum value of the specified variable quantity.

- **Server side range min**

Displays the minimum value of the (synthesized) variable quantity obtained in the server program.

- **Server side range max**

Display the maximum value of the (synthesized) variable quantity obtained in the server program.

- **Color Map Editor (freeform curve)**

Displays a sub-panel, which specifies a transfer function with a freeform curve. Use the mouse to edit the freeform curve.

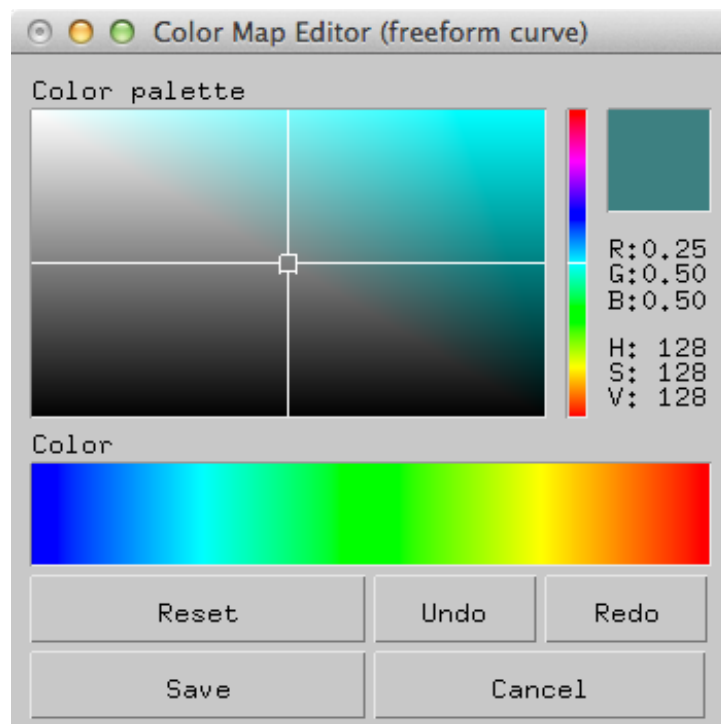


Figure 16 **Color Map Editor (freeform curve)** panel

- **Color palette**

Specifies the saturation, the brightness, and the hue of a color with mouse cursor. On the left, the horizontal and vertical axes correspond to the saturation and brightness, respectively. The neighboring bar shows the hue.

- **RGB**

Specifies the hue of the color by placing a mouse cursor. The upper-right box displays the color created by **Color palette** and **RGB bar**.

- **Color**

Blends the colors in **Color** area with a color specified with **Color palette** and **RGB bar**. To specify the locations in **Color** area, trace the locations by dragging the mouse cursor while pressing the left mouse button. The blending ratio of the original color and the overpainting color is determined by the mouse cursor's vertical position. For example, when the upper edge of the color bar is traced from left to

right, the **Color** bar is painted completely by the specified color rather than by blended colors; when the vertical center line of **Color** bar is traced, the colors are replaced with blended colors with 50% of the original color and 50% of the specified color.

- **Reset**

Resets the panel.

- **Undo**

Undoes the last mouse action.

- **Redo**

Redoes the last mouse action undone.

- **Save**

Saves the transfer function.

- **Cancel**

Closes the panel.

- **Color Map Editor (expression)**

Displays a panel to create a transfer function by taking equations as input.

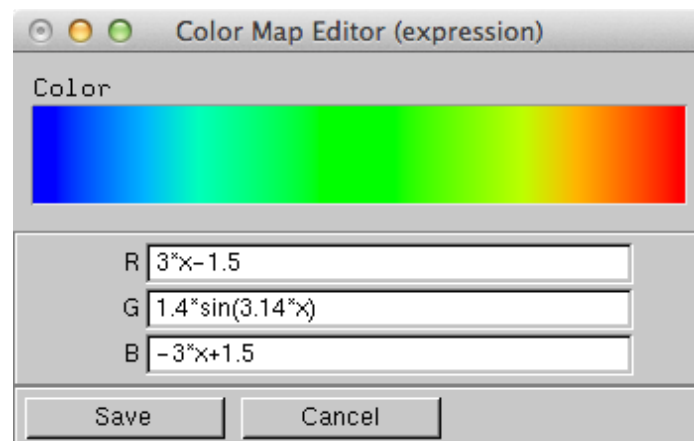


Figure 17 **Color Map Editor (expression) panel**

- **Color**

Displays a color bar of a transfer function created in this panel.

- **R**

Describes a transfer function of the R component of the color.

- **G**

Describes a transfer function of the G component of the color.

- **B**

Describes a transfer function of the B component of the color.

- **Save** button

Saves a transfer function created in this panel.

- **Cancel**

Closes the panel.

- **Color Map Editor (control points)**

Displays a panel for creating a transfer function. This editor takes control points as input.

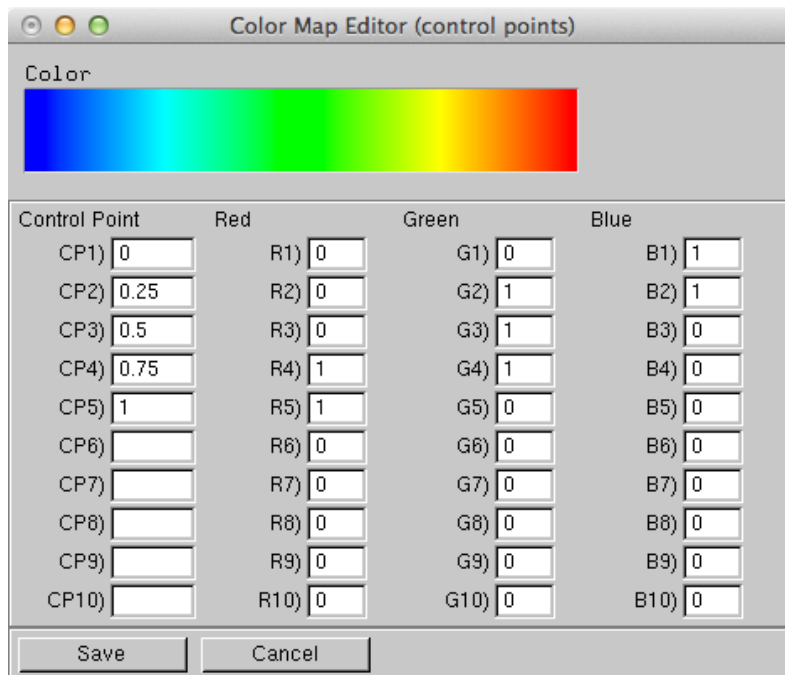


Figure 18 **Color Map Editor (control points) panel**

- **Color**

Displays a color bar for the transfer function that is being defined with this panel.

- **Control Point**

Specifies the values of (up to 10) control points with the fields **CP1)-10)** .

- **Red**

Specifies the R component of the color at the control points.

- **Green**

Specifies the G component of the color at the control points.

- **Blue**

Specifies the B component of the color at the control points.

- **Save**

Saves the transfer function.

- **Cancel**

Closes the panel.

- **Color Map Editor (select colormap)**

Displays a panel to create a transfer function from preset color bar templates.

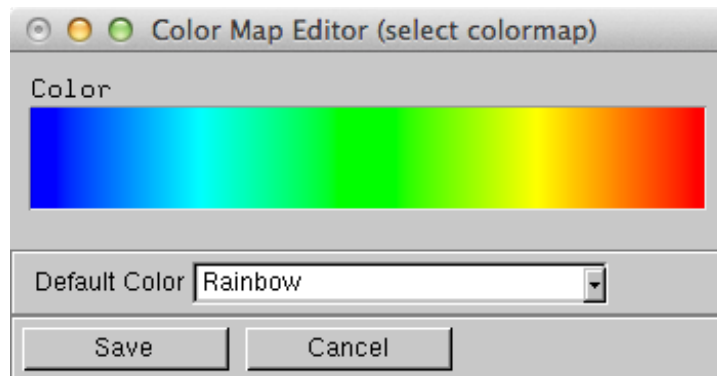


Figure 19 **Color Map Editor (select colormap) panel**

- **Color**

Displays the color bar of the transfer function that is being created with this panel.

- **Default Color**

Selects a color bar to be set as the transfer function. The following templates are available.

Rainbow

Blue-white-red

Black-red-yellow-white

Black-blue-violet--yellow-white

Black-yellow-white

Blue-green-red

Green-red-violet

Green- blue--white

HSV model

Gray-scale

Black

White

- **Save**

Saves the transfer function created with this panel.

- **Cancel**

Closes the panel.

5.4.3.2 Opacity Editor

[Transfer Function Opacity Map Category]

The GUI components in this category set a variable quantity and color for the transfer function specified with the **Transfer Function Name** field.

- **Opacity**

Displays the transfer function curve under edit.

- **Variable**

Defines the (synthesized) variable quantity used for the opacity of the selected transfer function. An equation can be entered, while the following variables are available.

Physical quantities: q_1 , q_2 , q_3 , ..., q_n .

Coordinate values: X, Y, Z.

- **Range Min**

Specifies the minimum value of the variable quantity.

- **Range Max**

Specifies the maximum value of the variable quantity.

- **Server side range min**

Displays the minimum value of the (synthesized) variable quantity obtained in the server program.

- **Server side range max**

Display the maximum value of the (synthesized) variable quantity obtained in the server program.

- **Color Map Editor (freeform curve)**

Displays a panel for creating a transfer function with a freeform curve. Use the mouse to edit the freeform curve.

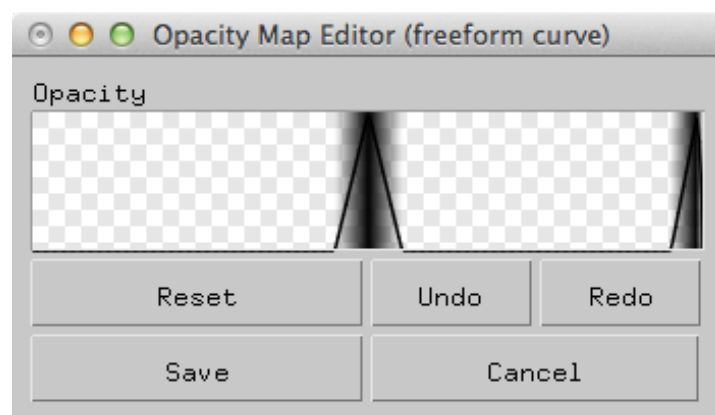


Figure 20 **Opacity Map Editor (freeform curve) panel**

-
- **Opacity**
Specifies a transfer function for the opacity. A freeform curve is drawn by dragging the mouse while holding the left mouse button. A piecewise linear curve is drawn by specifying control points with right clicks.
 - **Reset**
Resets the panel.
 - **Undo**
Undoes the last mouse action.
 - **Redo**
Redoes the last mouse action undone.
 - **Save**
Saves the transfer function created with this panel.
 - **Cancel**
Closes the panel.
 - **Color Map Editor (expression)**
Display a panel to create a transfer function using equations.

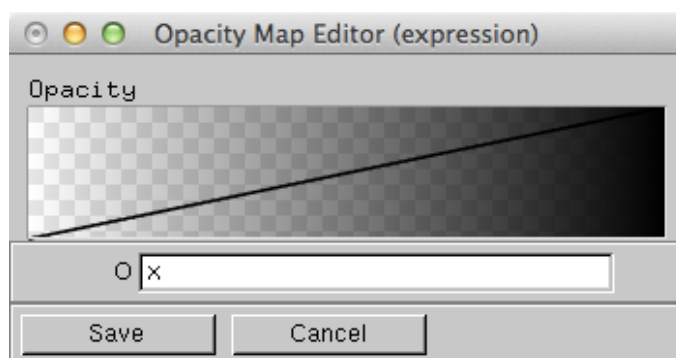


Figure 21 **Opacity Map Editor (expression) panel**

- **Opacity**
Displays the transfer function for opacity specified by the equation in the field **O**.
- **O**
Specifies the equation for the curve that specifies the transfer function of opacity.
- **Save**
Saves the transfer function created with this panel.
- **Cancel**
Closes the panel.

- **Color Map Editor (control point)**

Displays a panel to create a transfer function by taking equations as input.

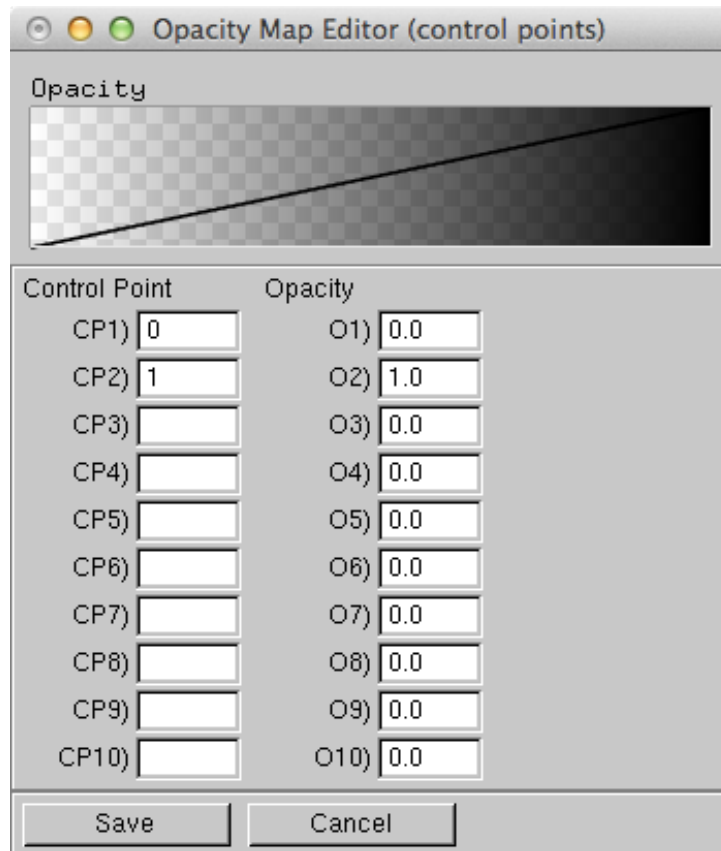


Figure 22 **Opacity Map Editor (control points) panel**

- **Opacity** (on the top)

Displays the transfer function for the opacities specified in this panel.

- **Control Point**

Specifies the values of (up to 10) control points in the fields **CP1)-10)** .

- **Opacity** (on the bottom right)

Specifies the opacities at the control points.

- **Save**

Saves the transfer function created with this panel.

- **Cancel**

Closes the panel.

5.4.3.3 Function Editor

Table 12 lists the built-in math operations available in the function editor. They can be used to synthesize transfer functions and variable quantities, and to define colormap/opacity curves.

Table 13 Math operations in function editors

Math operation	In function editors
+	+
-	-
×	*
/	/
sin	sin(x)
cos	cos(x)
tan	tan(x)
log	log(x)
exp	exp(x)
square root	sqrt(x)
power	x^y

When NaN appears by the arithmetic processing of the function editor, PBVR outputs the error message and stops the drawing process.

5.4.4 Time panel

Figure 23 shows **Time panel**, which specifies the time steps for visualization. Each widget works as described in the followings.

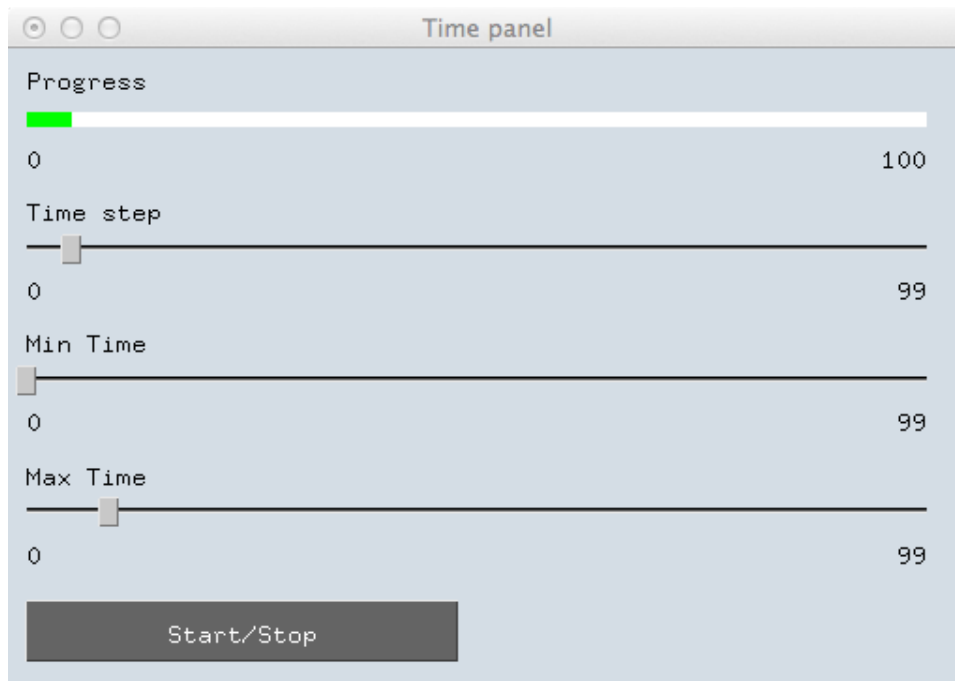


Figure 23 **Time panel**

- **Progress**
Expresses the current time step as percentage.
- **Time step**
Specifies the time step of the data to be rendered.
- **Min Time**
Specifies the minimum time step for ROI.
- **Max Time**
Specifies the maximum time step for ROI.
- **Start/Stop**
Starts/stops the communication between PBVR Client and PBVR Server.

5.4.5 Particle panel

Figure 24 shows **Particle panel**, which integrates multiple particle datasets. Particle panel is activated by hitting the Particle panel button in Main panel. Each widget works as described in the followings.

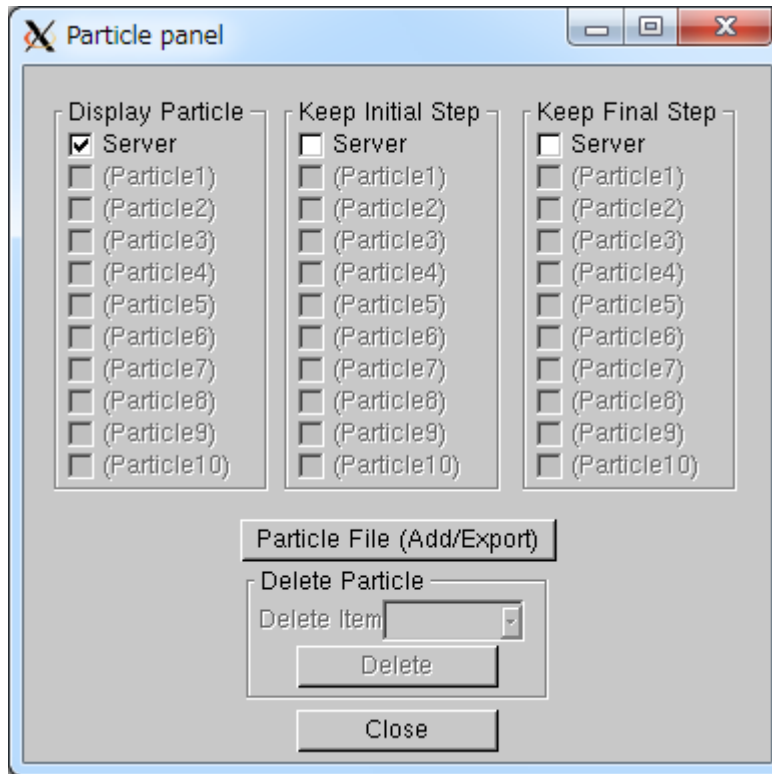


Figure 24 **Particle panel**

- **Display Particle**

Shows a list of particle datasets, which are sent from PBVR Server, or are loaded from local files (maximum 10 files).

- 1)Server check box

Activated when a particle dataset from PBVR Server is integrated with local particle data sets. This checkbox is not available in stand-alone mode.

- 2)(Particle1)-(Particle10) check box

Activated when particle datasets loaded from local files are integrated. The checkbox is not available before particle datasets are loaded via Particle file panel or command line options `-pin1`, `-pin2`, ..., `-pin10`.

- **Keep Initial Step**

Specifies particle datasets, in which the initial step data is displayed before the time series starts, when integrated particle datasets start from different time steps.

- **Keep Final Step**

- **Keep Final Step**

Specifies particle datasets, in which the final step data is displayed after the time series ends, when integrated particle datasets end at different time steps.

- **Particle File (Add/Export)**

Opens Particle File sub-panel.

- **Delete Particle**

Specifies a particle dataset to be deleted from a list in Display Particle.

- **Delete**

Delete a particle dataset.

- **Close**

Close Particle panel .

5.4.5.1 Particle File sub-panel

Particle File panel is a panel for reading and writing particle data files. This panel is shown when the **Particle File** button is hit.

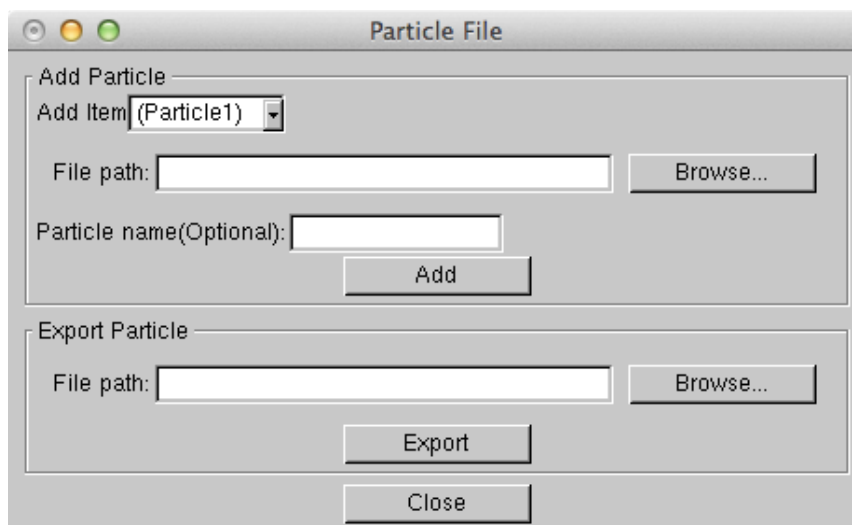


Figure 25 **Particle File panel**

- **Close**

Close Particle File panel.

【Add Particle category】

- **Add Item**

Specifies a particle data slot, in which a new particle dataset is loaded. When a old particle dataset exists for the particle data slot, the slot is overwritten by a new particle dataset.

- **File path**

Specify a particle data file.

- **Browse**

Opens a file dialog for specifying the path to a visualization parameter file.

- **Particle name (Optional)**

Specifies the name of a particle dataset shown in **Particle panel**.

- **Add**

Add a particle dataset to **Particle panel**.

【Export Particle Category】

- **File path**

Specify a particle data file.

- **Browse**

Opens a file dialog for specifying the path to a visualization parameter file.

- **Export**

Output integrated particle data.

5.4.6 Image file production

PBVR Client saves image data on Viewer in the following two modes, and plays it as a movie. Image file production is activated by hitting the Animation Control Panel button in Main panel.

- Time series data mode

Saves images of time series data as a series of image data files with the BMP format. The image data files are converted or compressed as a movie file via free softwares such as ImageMagic and ffmpeg

- Key frame animation mode

Keeps geometry information of viewer at an arbitrary point as a key frame, and plays a series of key frames as a key frame animation.

Figure 26 shows **Animation Control Panel**. Each widget works as described in the followings.

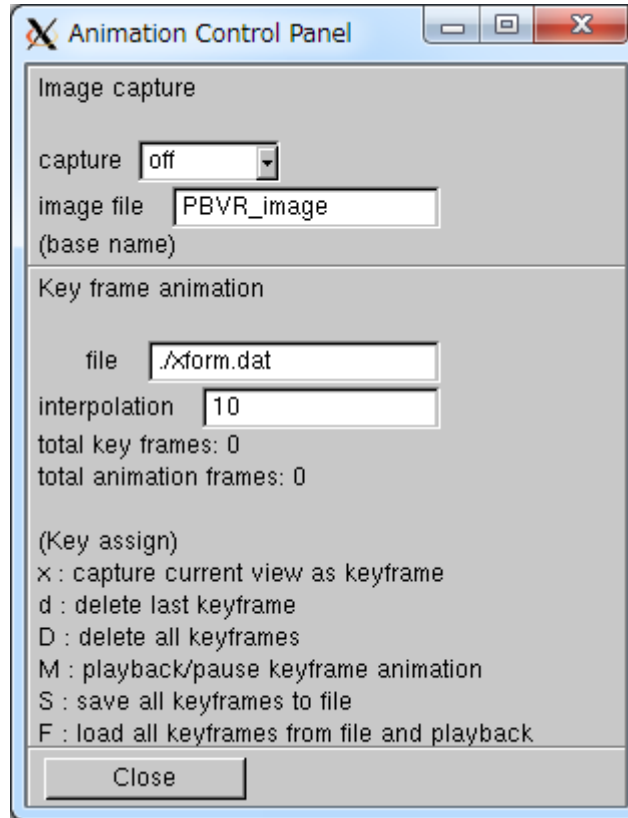


Figure 26 Animation Control Panel

- **capture**
Controls on/off of image production.
- **image file**
Specifies a prefix of image data files. The default name is PBVR_image.
- **file**
Specifies a key frame file, which contains a series of geometry data. The default name is ./xform.dat.
- **interpolation**
Specifies the number of frames used for linear interpolation of geometry data between two key frames in a key frame animation. The default value is 10.
- **total key frames**
Shows the number of key frames stored in the current key frame animation. The value is initialized to 0, and incremented (or decremented) by pressing “x” (or “d”). The value is initialized to 0 by pressing “D”.
- **total animation frames**
Shows the number of total frames stored in the current key frame animation, which is calculated as
$$(\text{total key frames} - 1) \times \text{interpolation}$$
- **Close**
Close Animation Control Panel .

5.4.6.1 Image production

Image files are produced as follows.

- ① Specify prefix of image files in **image file**.
- ② Select “on” in the **capture** drop down menu.
- ③ A series of image files are saved at each time step.
- ④ Image production is stopped by selecting “off” in the **capture** drop down menu.

The image files are saved in the directory specified by the command line option ‘-iout’. When ‘-iout’ option is not specified, they are saved in the current directory ‘./’. The following shows an example of image data produced with the default prefix “PBVR_image”.

```
PBVR_image.00001.bmp  
PBVR_image.00002.bmp  
:  
:
```

When the image files are produced from a key frame animation, which is explained later, the file names are modified by adding “_k” after the prefix.

```
PBVR_image_k.00001.bmp  
PBVR_image_k.00002.bmp  
:  
:
```

5.4.6.2 Key frame animation of a still image

A key frame animation of a still image, which is obtained by pressing **Stop** in **Time Panel**, is produced as follows.

【Capture key frames and save them in a file】

- ① Specify a key frame file in **file**.
- ② Activate Viewer by clicking it.
- ③ Adjust view and press ‘x’ to store the geometry information of view on a memory.
- ④ Repeat ③.
- ⑤ Press ‘M (Shift+m)’ to play the key frame animation.
- ⑥ If the contents of the key frame animation is OK, press ‘S (Shift+s)’ to save a series of geometry information in the key frame file.

【Play a key frame file】

- ① Specify a key frame file in **file**.

-
- ② Activate Viewer by clicking it.
 - ③ Press 'F (Shift+f)' to play a key frame animation stored in the key frame file.
 - ④ Press 'x' to add new key frames to the current key frame animation.

Table 14 Keys used for controlling key frame animation

Key	Function
x	Add geometry information of the current Viewer to key frame data on a memory
d	Delete the last key frame
D	Delete all key frames
M	Play and pause key frame data on a memory
S	Save key frame data on a memory to a key frame file
F	Load a key frame file and play its key frame data

5.4.6.3 Key frame animation of time series data

A key frame animation of time series data is produced as follows.

- ① By pressing 'x' while time series data is rendered, both geometry information and a time step number are stored in a memory.
- ② Press 'S' to save a series of geometry information and time step numbers in the key frame file.
- ③ Press 'F' to load a series of geometry information and time step numbers in the key frame file and play a key frame animation. Here, If one sets key frames at unequal intervals, interpolation frames, which are specified in **interpolation**, are assigned non-uniform in time.

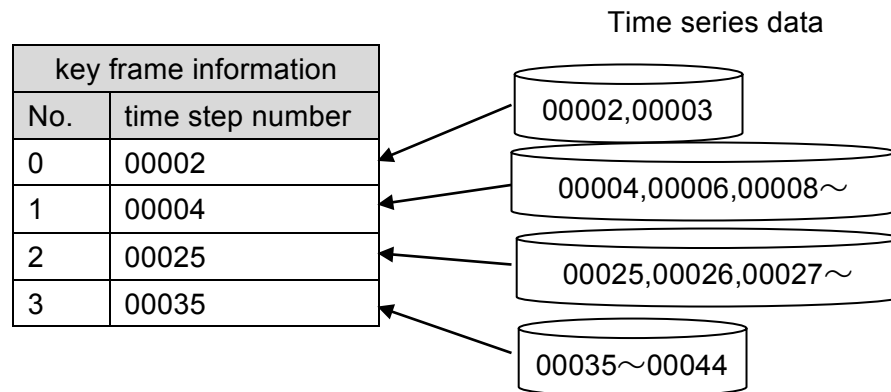


Figure 27 Key frame animation for time series data

In an example in Figure 27, if one uses 10 interpolation frames between key frames, 5 interpolation frames are assigned to the time steps 00002 and 00003 in between key frames No.0 and 1. On the other hand, in between No.1 and 2, 10 interpolation frames are assigned to the time steps from 00004 to 00024. As a results, the time steps, 00004, 00006, ...00024 are shown in the key frame animation.

5.4.6.4 Key frame file format

A key frame file contains binary data with the following format.

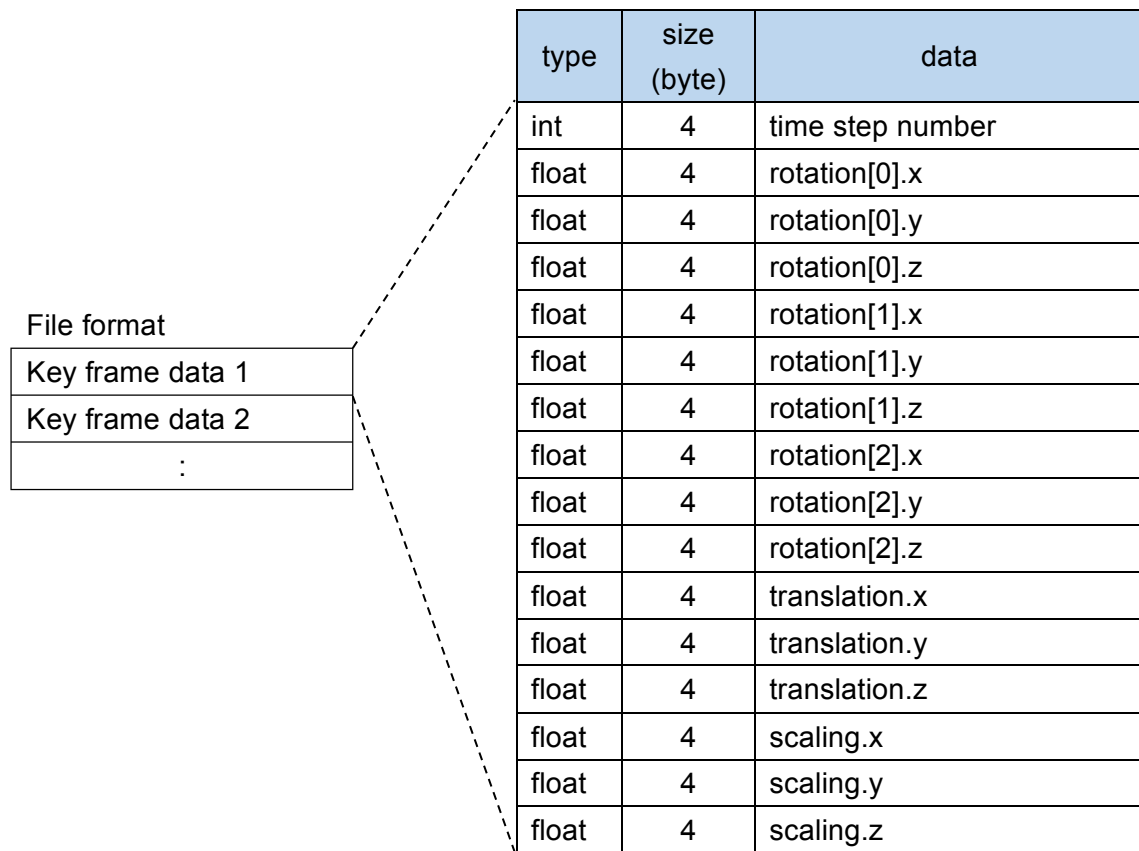


Figure 28 Key frame file format

5.4.7 Legend panel

Figure 29 shows Legend panel, which displays a bar relation between physical quantity and color is shown. Legend panel is activated by hitting the Legend Panel button in Main panel. Each widget works as described in the followings.

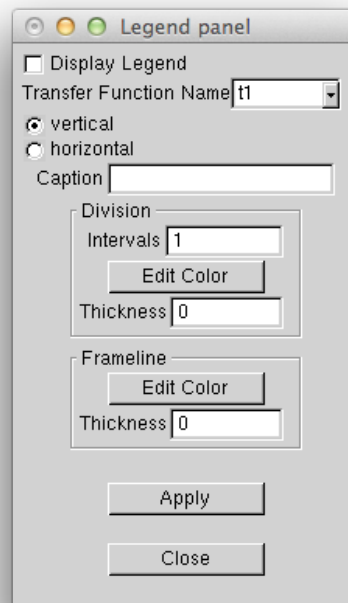


Figure 29 Legend panel

- **Display Legend**

By turning on the Display Legend check box, the legend is shown.

- **Transfer Function Name**

Selects a transfer function (t1-t5) to specify color map and range of legend with a pull-down menu.

- **vertical or horizontal**

Specifies a direction of legend.

- **Caption**

Specifies a caption of legend.

- **Division**

Specifies a properties of tickmark in legend.

Intervals : Number of tickmarks.

Edit Color : Color of tickmark.

Thickness : Thickness of tickmark.

- **Frameline**

Specifies a properties of frame border in legend .

Edit Color : Color of frame border.

Thickness : Thickness of frame border.

- **Apply**

Setting is reflected .

- **Close**

Close Legend panel.

Figure 30 shows an example of legend.

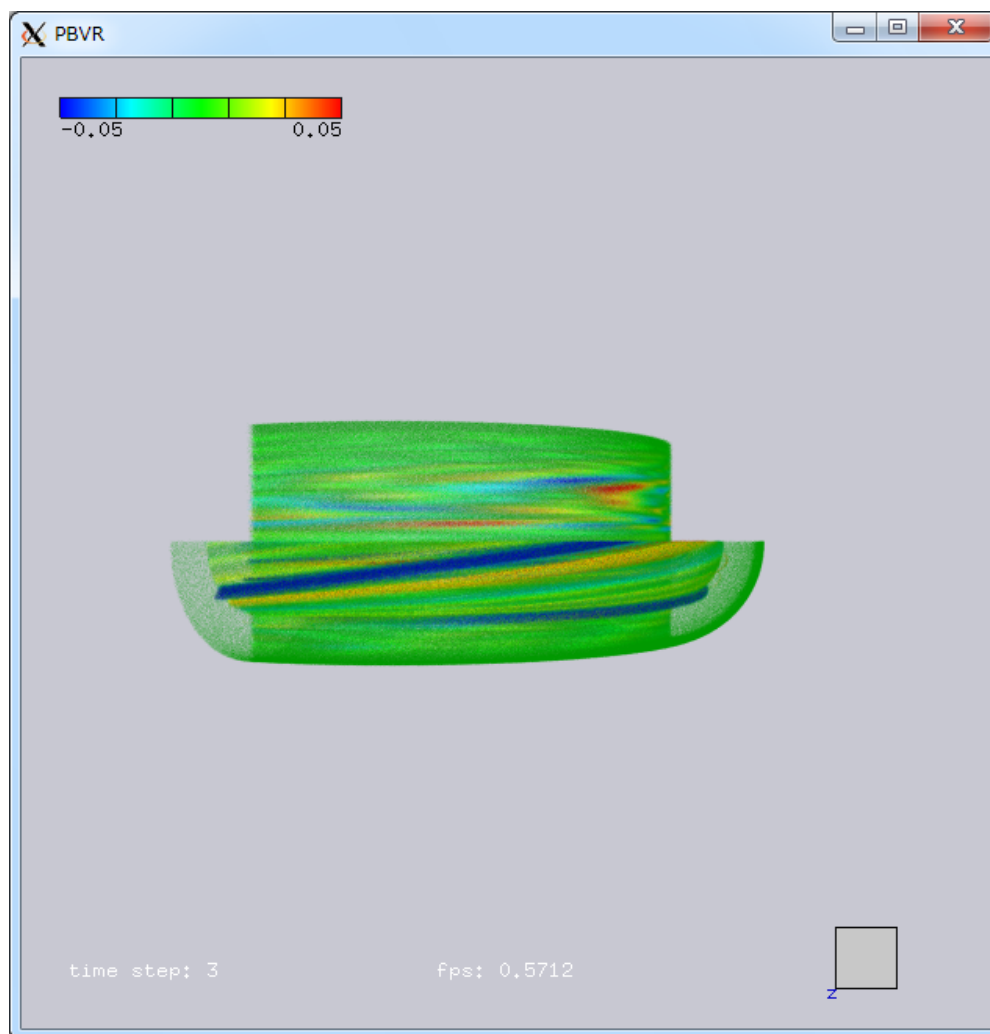


Figure 30 Exanple of legend

5.4.8 Coordinate panel

Figure 31 shows Coordinate panel, A coordinate change by designation of a numerical formula is performed to each coordinate axis. For example you can change from Cartesian coordinates system to cylindrical coordinates system.

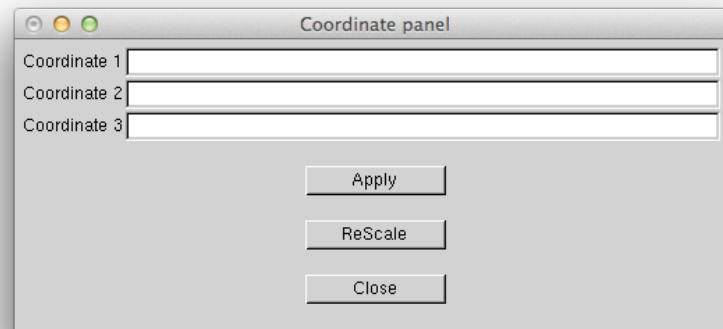


Figure 31 Coordinate panel

- Coordinate 1
Specifies the numerical formula to calculate the new X coordinate.
Empty or blank means just "X".
- Coordinate 2
Specifies the numerical formula to calculate the new Y coordinate.
Empty or blank means just "Y".
- Coordinate 3
Specifies the numerical formula to calculate the new Z coordinate.
Empty or blank means just "Z".
- ReScale
Changing the scale of the view with the new coordinates.
- Apply
Sends a formula defined with this panel to the server.
- Close
Close Coordinate panel.

The text box Coordinate 1 - 3, it can be set coordinate transformation formula. Variables that can be described in the formula, is the original coordinates (X, Y, Z), physical data (q1, q2, ... , q9) and time (T). X, Y, Z, and T does not distinguish between the upper / lower case. In addition, operations that can be described in the formula is the same as the transfer function editor (see 5.4.3.3). If specified physical data is not existed in the data, will be evaluated as 0.

After push apply button, a formula is reflected .

5.4.9 Viewer control panel

Figure 32 shows Viewer control panel, which specifies a properties of viewer. Viewer control panel is activated by hitting the Viewer Control Panel button in Main panel. Each widget works as described in the followings.

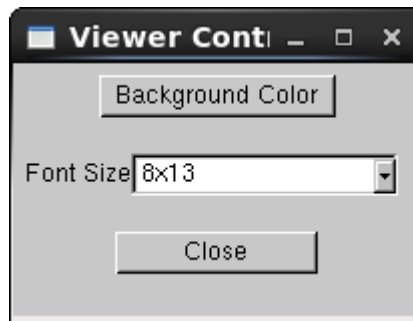


Figure 32 Viewer control panel

- **Background color**

Specifies a background color of viewer.

- **Font Size**

A font type of the character shown to a viewer is chosen. The available fonts are:

8x13 A fixed width font with every character fitting in an 8 by 13 pixel rectangle.

9x15 A fixed width font with every character fitting in an 9 by 15 pixel rectangle.

TIMES_ROMAN_10 A 10-point proportional spaced Times Roman font.

TIMES_ROMAN_24 A 24-point proportional spaced Times Roman font.

HELVETICA_10 A 10-point proportional spaced Helvetica font.

HELVETICA_12 A 12-point proportional spaced Helvetica font.

HELVETICA_18 A 18-point proportional spaced Helvetica font.

- **Close**

Close Viewer control panel.

6 An Example with the Sample Dataset

The following sections demonstrate the usage of PBVR for a sample dataset *gt5d.tgz*.

6.1 Filtering Process

Uncompress *gt5d.tgz* to extract the following files under the directory *./gt5d*.

<i>gt5d.fld</i> :	An AVS field file
<i>co3d.dat</i> :	A coordinate data file
<i>pd3d.dat</i> :	The variable 1
<i>psid.dat</i> :	The variable 2
<i>param.txt</i> :	Input parameters for PBVR Filter
<i>demo.tf</i> :	A transfer function file for demonstration

Execute PBVR Filter with the following command (which invokes the OpenMP version).

```
$ filter ./ param.txt
```

The contents of *param.txt* are the followings.

```
#
in_dir=./gt5d
field_file=gt5d.fld
out_dir=./gt5d
out_prefix=case
start_step=0
end_step=4
```

The above example specifies the SPLIT file format (which is the default format), a single sub-volume (without sub-volume decomposition), and the same directory both for input and output. This filtering process generates the following files in the specified output directory.

<i>case.pfi</i>	: a .pfi file
<i>case_YYYYYYY_ZZZZZZZ_connect.dat</i>	: an element configuration file
<i>case_YYYYYYY_ZZZZZZZ_coord.dat</i>	: a node coordinate file
<i>case_XXXXX_YYYYYYY_ZZZZZZZ.kvsmf</i>	: a kvsmf file
<i>case_XXXXX_YYYYYYY_ZZZZZZZ_value.dat</i>	: a variable file

6.2 Starting PBVR

[step 1] Launch PBVR Server (which is the OpenMP version)

```
$ pbvr_server
first reading time[ms]:0
Server initialize done
Server bind done
Server listen done
Waiting for connection ...
```

[step 2] Launch PBVR Client. This example uses the metropolis sampling and Phong Shading.

```
$ pbvr_client -S m -vin ./gt5d/case.pfi -shading P,0.6,0.6,0.6,30
```

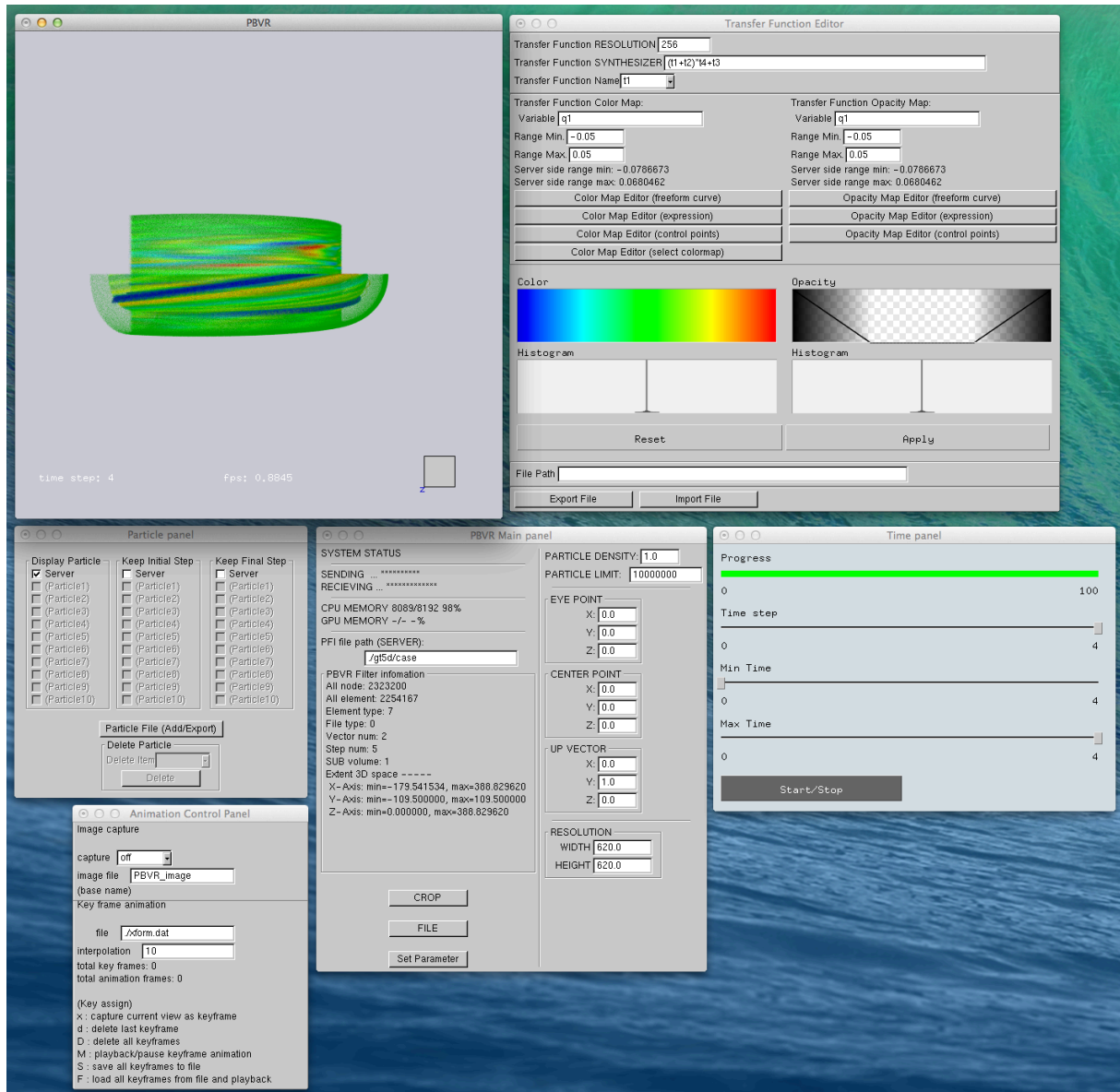


Figure 33 The GUIs of PBVR

6.3 Designing Transfer Functions

This section shows examples of visualizing *gt5d.fld*, using the multi-dimensional transfer function that is produced with the advanced transfer function design capability of PBVR. *gt5d.fld* contains structured grid volume data that consists of two variables.

6.3.1 Volume Rendering for a Single Variable

First of all, understand the variable $q1$ by setting the transfer function $t1$ as shown in Figure 34. In this example, the transfer function is designed with **Transfer Function Editor**. Shown in the left of **Transfer Function Editor** is the configuration of colors, while in the right is that of the opacities. Notice that this configuration is the conventional volume rendering for a single variable.

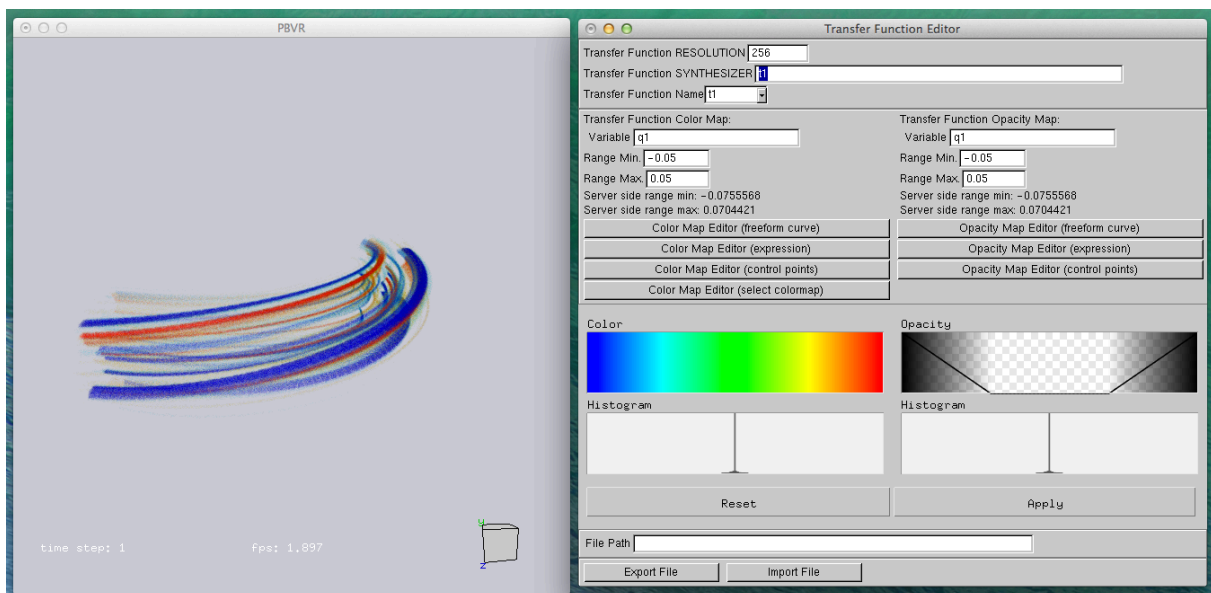


Figure 34 The volume rendering result for the variable $q1$.

6.3.2 Multivariate Volume Rendering

The next example shows the result of multivariate volume rendering, in which the variables $q1$ and $q2$ are synthesized as shown in Figure 35. In this example, the colors are assigned to the variable $q1$, while the opacities are assigned to the variable $q2$. The opacity map extracts two torus surfaces, which are given by the iso-surfaces of the variable $q2$. The colors encode the distribution of the $q1$ values in these iso-surfaces.

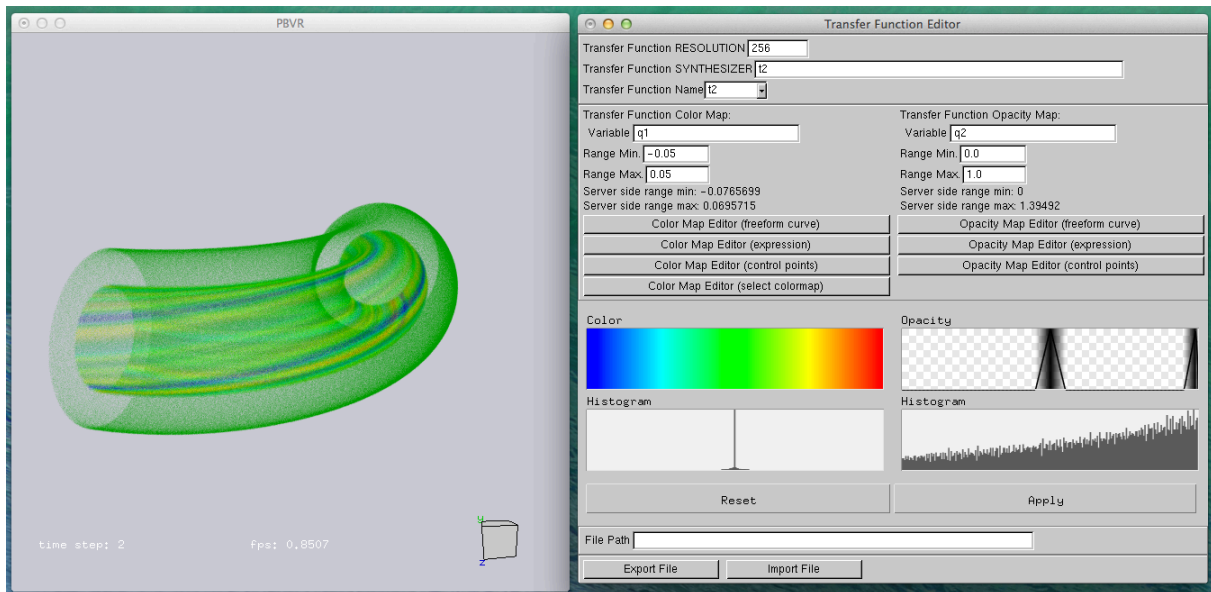


Figure 35 Rendering a multivariate volume. The $q1$ values are color-mapped onto the iso-surfaces of $q2$.

6.3.3 Slicing Volumes

Figure 36 shows an application of PBVR's multivariate volume rendering for extracting a slice. With PBVR, an arbitrary function can be used to design a transfer function. In this example, the cylindrical surface ($X^2+Z^2=const.$) is extracted and the color of the variable $q1$ is mapped onto it.

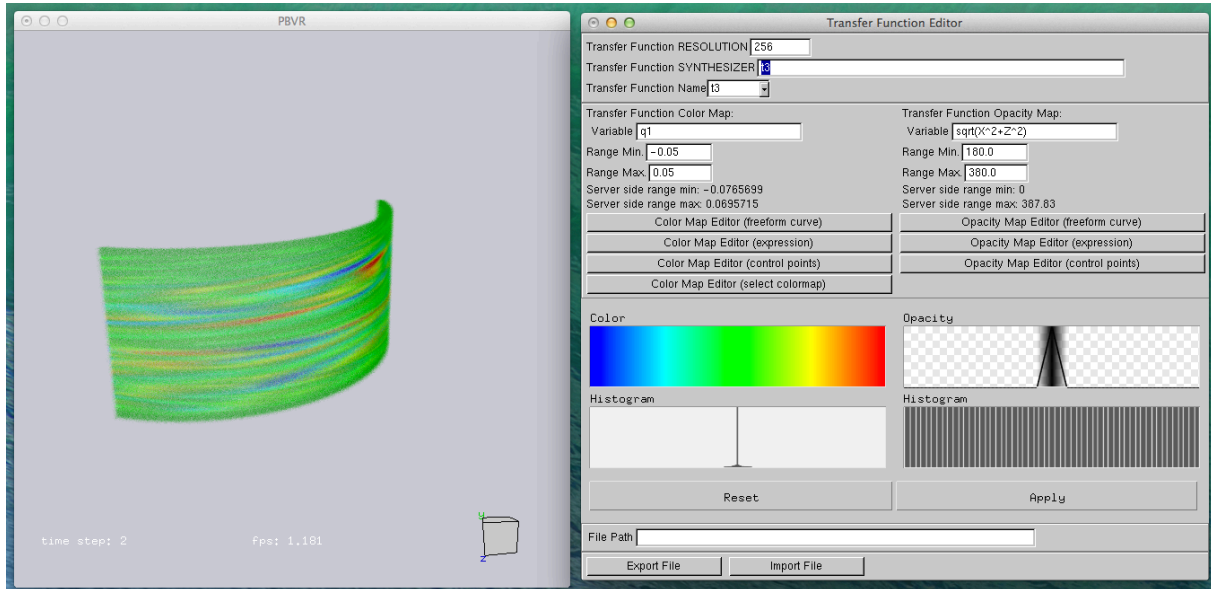


Figure 36 A rendering result for Slicing the volume with PBVR's multivariate volume rendering capability.

6.3.4 Synthesis of Transfer Functions

This section explains how to synthesize transfer functions in PBVR. Figure 37 shows a transfer function $t4$, whose opacity function makes the region $Y > 0$ transparent. By synthesizing the previously described transfer functions $t1$, $t2$, and $t3$ together with a new transfer function $t4$ as $(t1 + t2) * t4 + t3$, the individually extracted sub-regions can undergo flexible composition through arithmetic operations. In this example, the colors of $t2$ and $t3$ are set to $(R, G, B) = (0, 0, 0)$, while the color of $t4$ is set to $(R, G, B) = (1, 1, 1)$. In the above synthesis equation, the final colors obey the rainbow colormap defined for $t1$. On the other hand, the opacity of $t4$ is multiplied to the sum of $t1$ and $t2$ in order to extract the lower half region ($Y < 0$) of $t1$ and $t2$. Then, the resulting region is synthesized with the cylindrical surface given by $t3$. As revealed in these examples, PBVR's ability to synthesize transfer functions is powerful considering the capability to extract arbitrary region for each variable and to carry out a preferred series of operations.

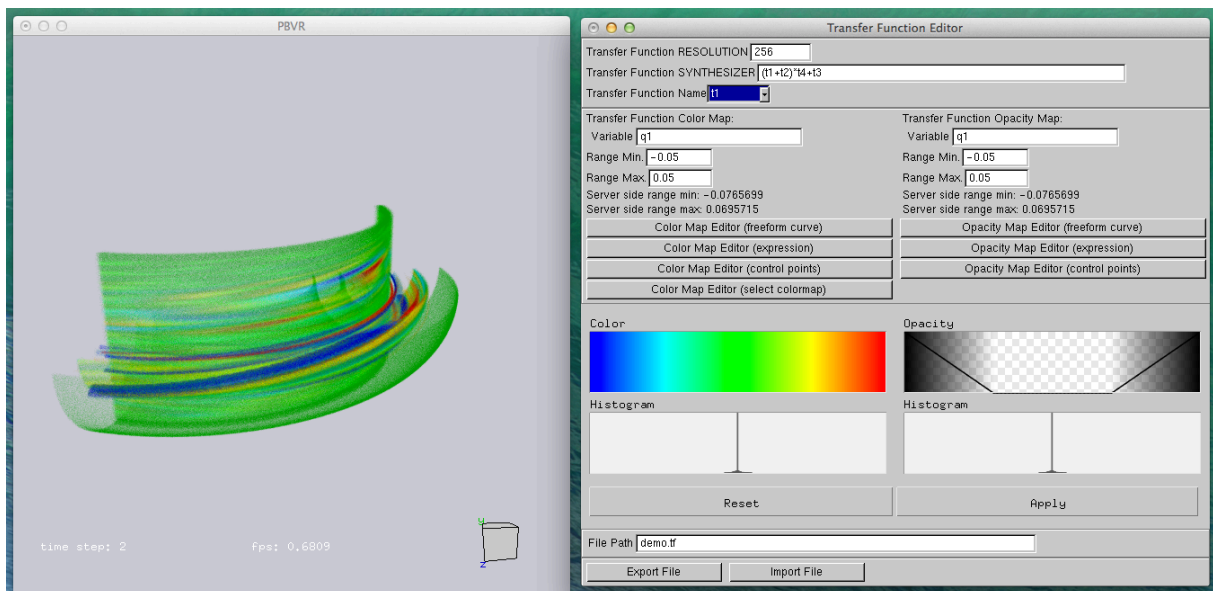


Figure 37 Synthesizing transfer functions

6.4 Integration of particle datasets

While the previous section shows a composition of volume rendering, iso-surfaces, and surface rendering via multi-dimensional transfer functions, the similar image composition is possible also by integrating multiple particle datasets. This section explains an example of particle integration.

6.4.1 Save particle datasets

Particle datasets are stored via **Particle File sub-panel** in **Particle panel**. Figure 38 shows an example of “Export Particle”. In this case, the following files are generated with the prefix “p1”.

```
./particle/p1_XXXXX_YYYYYYY_ZZZZZZZ.kvsmI  
./particle/p1_XXXXX_YYYYYYY_ZZZZZZZ_colors.dat  
./particle/p1_XXXXX_YYYYYYY_ZZZZZZZ_coords.dat  
./particle/p1_XXXXX_YYYYYYY_ZZZZZZZ_normals.dat
```

Here, XXXXX is the time step, YYYYYYY is the sub-volume number, and ZZZZZZZ is the total sub-volume number. “colors”, “coords”, and “normal” contain color, coordinates, and normal vector of each particle, respectively. By hitting the **Export** button, integrated particle data is stored in the above files, and during the saving process, the **Export** button is de-activated, and after whole time series data is stored, the **Export** button becomes active again.

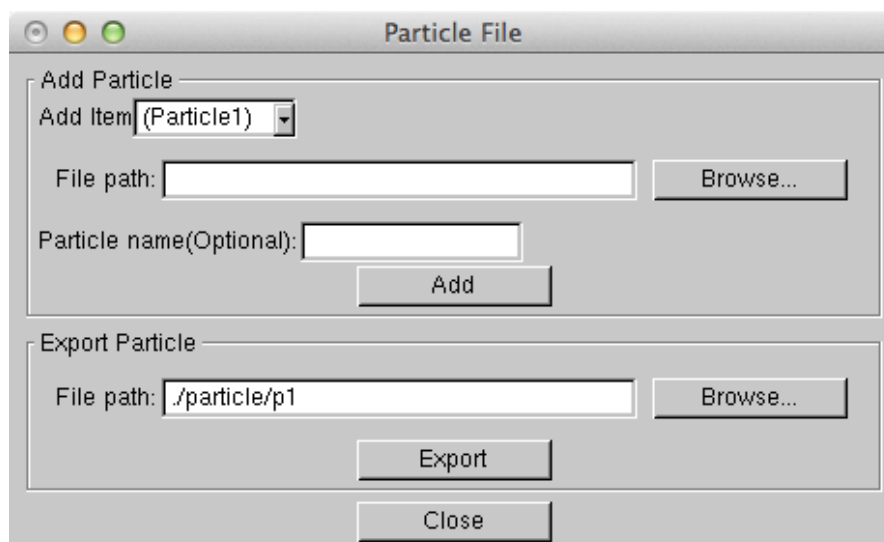


Figure 38 Particle File panel (**Export** is active)

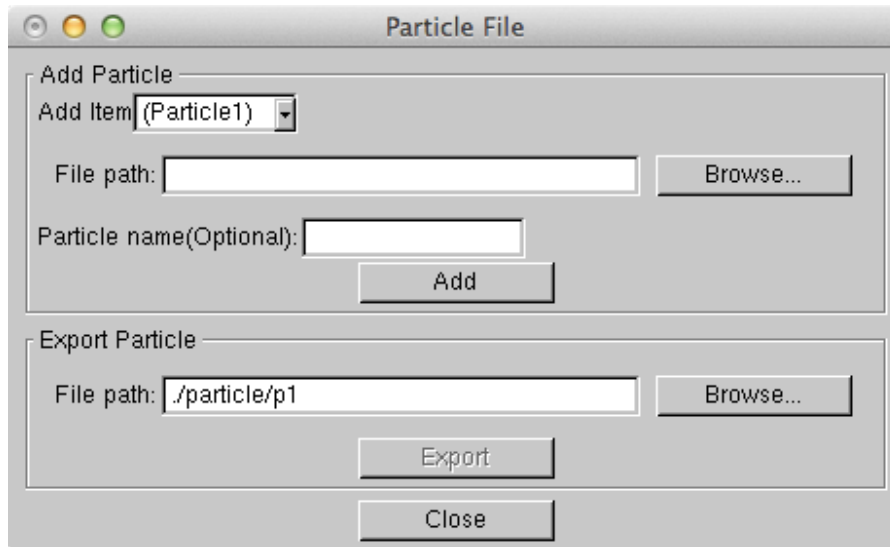


Figure 39 Particle File panel (**Export** is non-active)

6.4.2 Load particle datasets

In the following example, three particle datasets p1, p2, and p3, which corresponds to the images in Figures 30~32, are loaded and integrated. Here, PBVR Client in stand-alone mode is launched with the following command, and the particle datasets are specified in the command line options. (In client-server mode, particle datasets are specified in **Particle panel**.)

```
$ pbvr_client -shading P,0.6,0.6,0.6,30 -pin1 ./particle/p1 -pin2 ./particle/p2 -pin3 ./particle/p3
```

After launching, p1~p3 are loaded in **Particle panel**. By turning on the **Display particle** check box for p1, the volume rendering is shown as in Figure 40. In addition, by turning on the **Display particle** check boxes for p2 and p3, all three particle datasets are integrated as in Figure 41. The integrated particle data can be stored as a single particle dataset via **Particle File panel**. It is noted that in order to obtain correct integrated images, all particle datasets have to be generated by using the same “particle density” and “particle limit” parameters, which are specified by the command line options, “-pd” and “-plimit”, or by the **Main panel**.

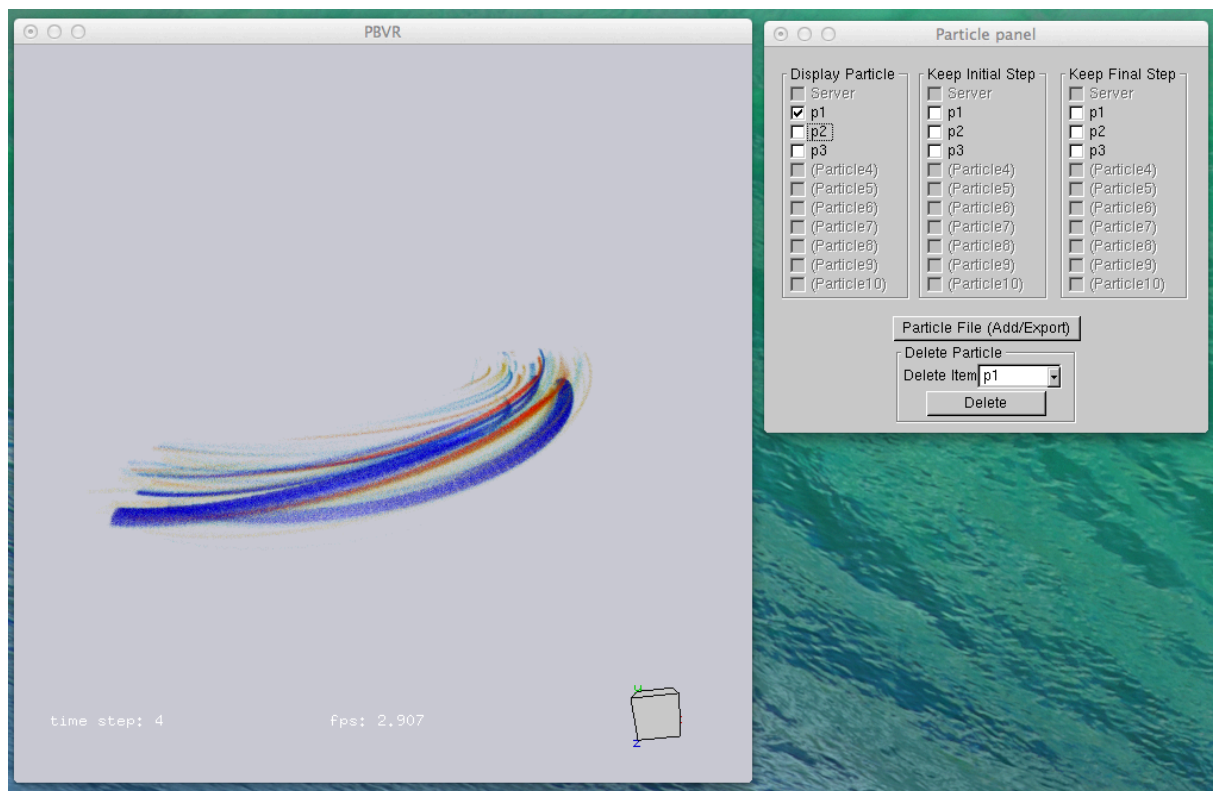


Figure 40 Particle dataset p1

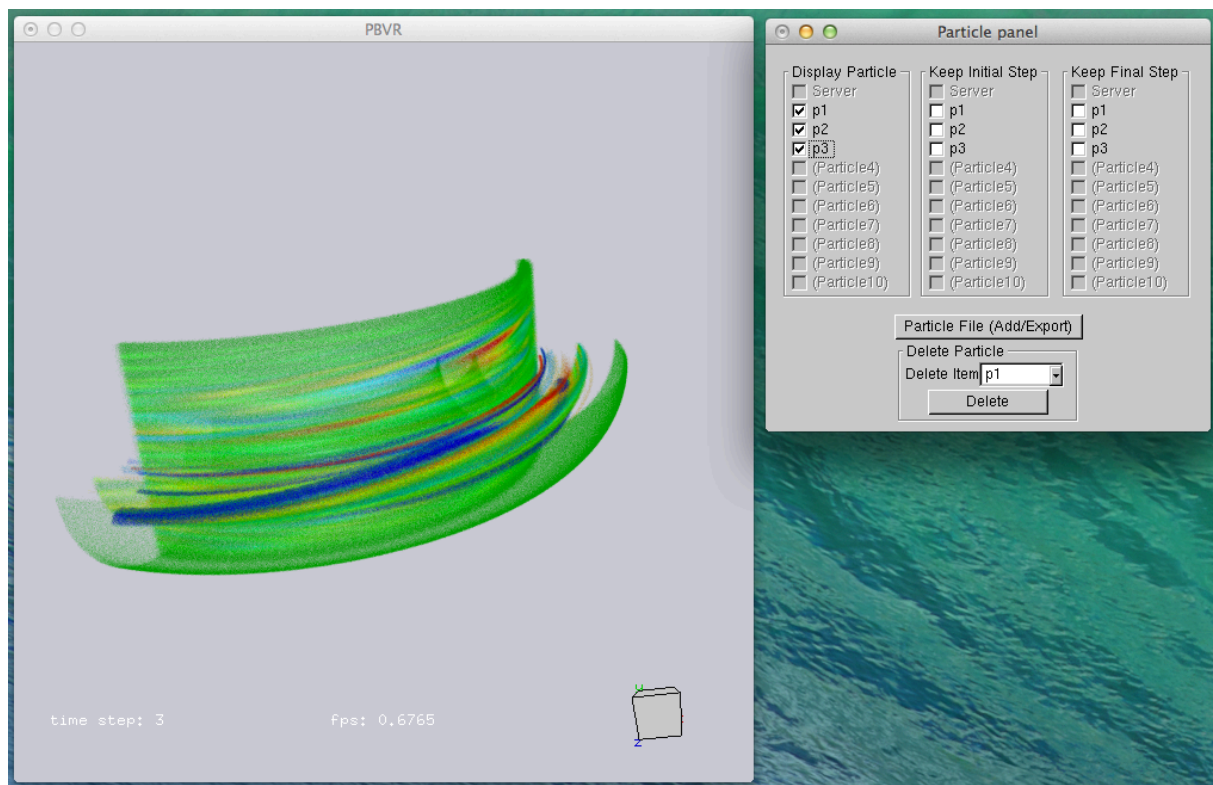


Figure 41 Integration of p1, p2, and p3

6.5 Saving Results

After designing the transfer function, PBVR can save the resulting image and parameters in following three ways.

1) Image output (5.4.5)

In order to save the results as images, select **on** from the **capture** drop down menu in **Animation panel**. The bitmap image files (PBVR_image.xxxx.bmp) are generated.

2) Transfer function file (5.4.3)

In order to generate the transfer function file, write file name of the transfer function in **File Path** field of **Transfer Function Editor** and press **Export File**. Later, this file can be loaded by hitting **Import File**.

3) Visualization parameter file (5.4.2)

In order to run PBVR Server in batch mode, all the visualization parameters including the transfer function can be exported. Open **File panel** from **Main panel**, specify the parameter filename, and press **Export File**.

6.6 Example of Batch Mode

This section explains how to run PBVR Server in batch mode using the visualization parameter file exported in the previous section. This mode is developed for carrying out massively parallel processing with supercomputers. In addition, this mode is useful also for high speed rendering of time series data with PBVR Client in stand-alone mode, since the latency due to particle generation and particle data transfer can be eliminated.

[Step 1] Launch PBVR Server (of OpenMP version) in batch mode

```
$ pbvr_server -B -vin ./gt5d/case.pfi -pout ./output/case -S m -pa ./param.in
```

[Step 2] Launch PBVR in stand-alone mode

```
$ pbvr_client -pin1 ./output/case -shading P,0.6,0.6,0.6,30
```