Data Visualization Study at Earth Simulator Center

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Research and development for visualization technologies carried out by Advanced Perception Research Group of the Earth Simulator Center in the fiscal year 2007 is reported. A GUI tool to realize fly-through visualization in YYView, a semi-interactive visualization program system, is developed. The fly-through visualization technique under research collaboration with Computational Visualization Center, the University of Texas at Austin in last fiscal year is applied to this GUI tool. Several types of parallel rendering programs derived from MovieMaker are newly developed, aiming to use on massively parallel computer systems. Our virtual reality visualization program for CAVE-type virtual reality system, VFIVE, has been continuously developed, achieving the stage of practical use. The source code of VFIVE is now open to public. A novel technique, point-sprite method to render massive numbers of spherical particles is developed. This method is applied to the data visualization of crack tip dislocations and cloud formation simulations. Another novel technique to render a cloud, physically-based rendering, is also developed and tested. This method is achieved by a couple of programs based on the light scattering by particle and light transport in the participating media. Examinations show that the photo-realistic appearance of a cumulus is captured.

Keywords: large-scale data visualization, Parallel rendering, Virtual Reality, Physically-based rendering

1. Introduction

Advanced Perception Research Group (APRG) of the Earth Simulator Center (ESC) focuses on two kinds of problems for scientific visualization of large-scale and three-dimensional simulation results with time evolution.

One is the difficulty which comes from the fact that computational cost of data handling is much expensive, because the data size reaches several gigabytes per step. Interactive visualization, which is a typical style of data analysis on a researcher's PC, is no longer possible without reduction of the data sufficiently small. For solving this problem, we have been developing a high-quality rendering and movie-making program, MovieMaker and a semi-interactive visualization program, YYView. The progress on the developments of them for this fiscal year is reported in Section 2.

Another is the fact that it is difficult to comprehend complicated structures like inter-twisted streamlines in the three-dimensional flow field. On the flat PC monitor, most of the depth information of visualized three- dimensional objects is lost, because of overwrapping each other. Virtual reality (VR), especially innovative visual display technology of VR, is a key to solve this problem. We have been developing three-dimensional VR visualization program named VFIVE, for several kinds of VR systems. Section 3 describes the overview of VFIVE and the current state of the development.

In addition, research and development of novel visualization methods are also included in the mission of APRG. In this fiscal year, we have developed two different types of novel representation methods. These are reported in Section 4.

2. Development of large-scale data visualization programs

2.1 Overview of MovieMaker and YYView

MovieMaker is a parallel rendering program based on the master/slave model. It is designed for the symmetric multi-processor computer architecture. A master process and slave processes share simulation data stored in a single shared main memory area. The master process performs the following tasks; (i) to read a configuration file, (ii) to read simulation data into the shared memory area; and (iii) to control the slave processes keeping a good load balance. Each slave process performs rendering tasks and then returns partial images back to the master via the shared memory. Inter-process communications are performed with Message Passing Interface (MPI). The dynamic load balancing in MovieMaker is achieved by an active monitoring and dynamic control of the slave processes.

Before running MovieMaker, its user should prepare a configuration file that includes information for data profiles and several kinds of visualization parameters such as lighting, viewport, color map and others for visualization functions. However, it is difficult to determine all of the parameters except data profiles in advance. Those should be tuned interactively, watching results frequently displayed on user's PC monitor.

This difficulty has motivated us to develop a semi-interactive visualization program system, YYView. YYView is composed of MovieMaker, a console program and several support program tools, such as a previewer (PlayWright), a data reduction tool (Filter) and a resulting movie browser (MoviePlayer). Each of the tools is also available as an independent program. However, when one uses each of them individually, whole of visualization procedures become cumbersome and complicated. YYView provides a simple and systematic work environment for user by linkage between those tools. We show data flow by their linkages in Fig. 1. In the YYView environment, a reduced data instead of the original (non-downsized) data is used for quick visualization. User can specify the appearance of visualization

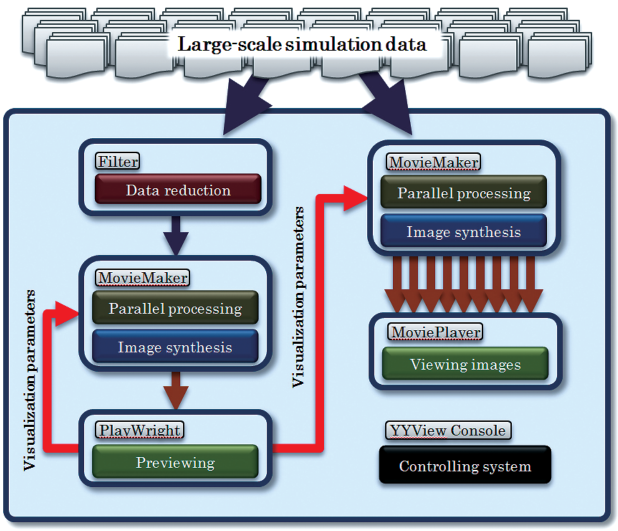

Fig. 1 Data flow of YYView.

interactively through PlayWright and the console program as shown in Fig. 2. After that, YYView throws the visualization parameters determined here to MovieMaker to generate high-quality images from the original large-scale data.

2.2 Development of additional user interface

In last fiscal year, we developed and tested the fly-through visualization by MovieMaker under research collaboration with Computational Visualization Center (CVC), the University of Texas at Austin [1]. Fly-through is a method that visualizes the simulation data from a bird-like viewpoint flying through the three-dimensional simulation space. In order to perform the fly-through visualization with MovieMaker, one has to specify a smooth camera path and view parameters such as gaze and upper directions and a viewport. These parameters should be stamped at each point on the path. When those parameters apply to MovieMaker, it can generate a sequence of images. However, it was not easy to set up the series of those parameters along the camera path. It needs a dedicated program. In the fiscal year 2006, we experimented with the fly-through visualization by MovieMaker, assisted by a tool developed by CVC.

In this fiscal year, we applied know-how of the fly-through method to develop a GUI program tool, CameraPathEditor, to edit camera path parameters in the YYView system. Figure 3 shows a screen capture of this program. The use of this becomes easy to set camera parameters with movement of viewpoint, though it was difficult to set these parameters in our previously software.

See also the reference [2] for more information.

2.3 Derivative developments of MovieMaker

We are developing several visualization programs, generically named as "Armada", based on MovieMaker. The aim of Armada is to visualize time-varying simulation data on a massively parallel and distributed memory computer system

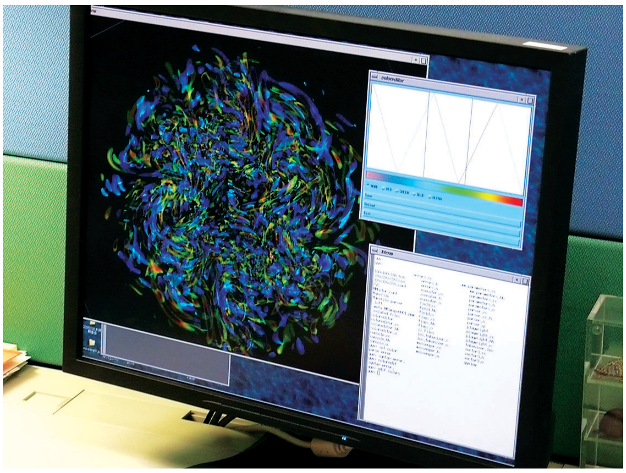

Fig. 2 A snapshot of user interfaces of YYView.

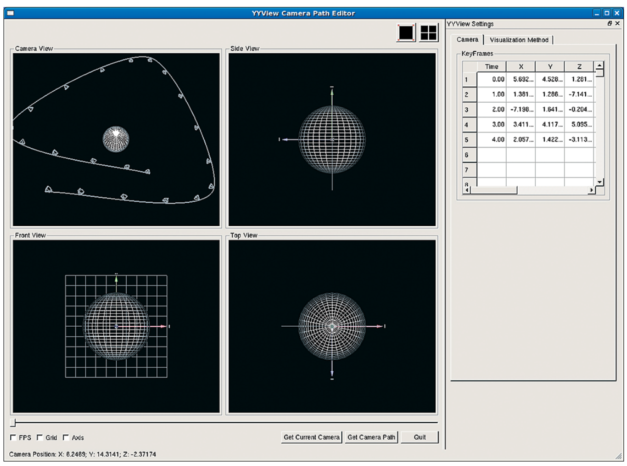

Fig. 3 Graphical user interface of CameraPathEditor.

like supercomputers or Earth Simulator. Points of the development are as following; (i) combination use of MPI and OpenMP for parallelization, (ii) software-rendering, (iii) support for several kinds of geometries, and (iv) additional visualization functions.

For the first item, MovieMaker was designed for single computer system of a symmetric multiprocessing architecture which is used in most common multiprocessor systems today. In this system, two or more identical processors are connected to a single shared main memory, so that the data size stored in the memory is limited by its capacity. To process much more data effectively, combination use of MPI and OpenMP libraries for parallelization has been adopted in Armada. MPI parallelizes a visualization process to respective time steps. At each visualization process, computations of rendering such as ray casting are parallelized by OpenMP. For the second item, usual supercomputers do not have any graphics hardware, so that Armada has been designed to be unaided by it. Both of the scalar visualization functions, isosurfacing and volume rendering, are performed by the ray casting algorithm. For the third item, three types of Armada programs are provided for rectangular, spherical and Yin-Yang coordinate systems, respectively. For the last item, a new visualization functions, color slicing and depth cueing, have been also implemented. The color slicing indicates value distribution by colors on the section of a volume. The depth cueing is one of visual effects to give depth feel as more distant objects look darker. Armada is possible to be executed by a configuration file of the same format as MovieMaker's. The newly implemented functions here are also available by adding the corresponding commands into that file.

Currently, we are testing these Armada programs on several supercomputers at JAMSTEC, such as SGI Altix 4700, NEC SX-8R and also Earth Simulator. These approaches are expected to be more effective for the time-varying data visualization than the past achievements by MovieMaker.

3. VFIVE

We have been developing an interactive visualization program called VFIVE for CAVE system as shown in Fig. 4. VFIVE is designed to make the best use of the immersive, stereoscopic and interactive VR environment. VFIVE is written in C++ with OpenGL and CAVELib, so that it is also available on any other VR systems powered by the CAVELib. VFIVE has a graphical user interface that helps the viewer to select visualization functions and control parameters in the three-dimensional virtual space. Various visualization functions are provided for analyzing three-dimensional simulation data interactively and aiding viewer's intuitive comprehension. Figure 5 shows several of those functions. In this picture, viewer analyzes the data of a geodynamo simulation. The viewer operates a controller and probes vector fields with the "local arrows" function. The vorticity of the fields is also visualized by "isosurface" function. The boundaries of the simulation data are also indicated by white spherical meshes.

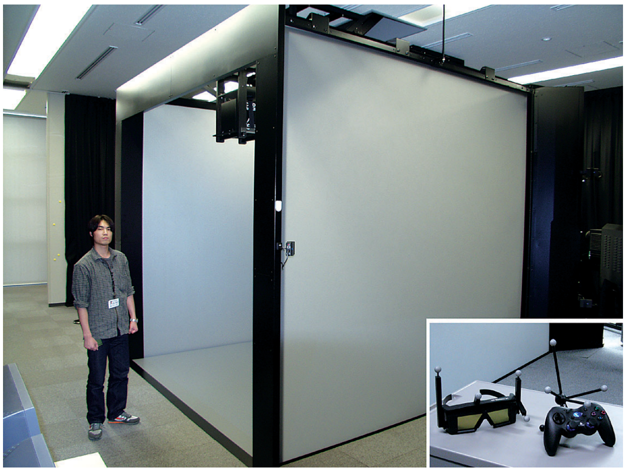

Fig. 4 A CAVE system "BRAVE" installed in ESC.

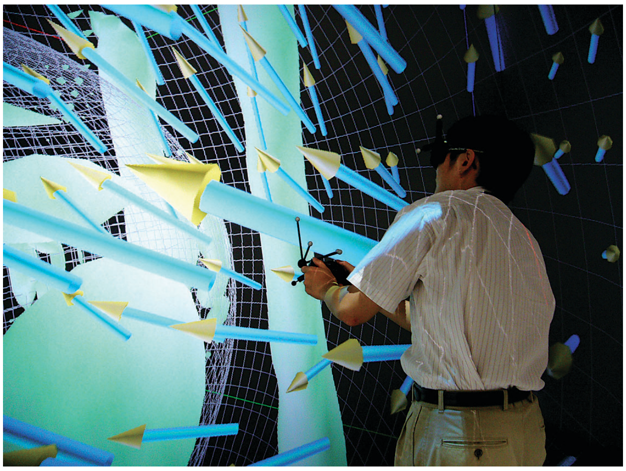

Fig. 5 The interactive data analysis of geodynamo simulation in the CAVE's virtual space. VFIVE's visualization functions, "local arrows" and "isosurface", are used.

On the basis of our past development of VFIVE, we think that VFIVE is achieving in the stage of practical use. In this fiscal year, we then opened the source of VFIVE on the Earth Simulator Center's Web site [3].

4. Novel visualization methods

4.1 Point-sprite method

We have worked on the visualization of particle data as a new attempt in this fiscal year. When particle data are visualized, visualizing these data as polygonal sphere object is simple method if the shapes of each particle are a perfect sphere. However, computational cost for drawing becomes very huge, because large amount of polygons were needed for drawing all particles. As more reasonable method than polygon-based drawing, there is the visualization method that is called billboard. Billboard is a visualization method using texture mapped polygons always faces the camera. By using sphere image as texture map to square polygon, same effect was achieved with drawing polygonal sphere objects. In this method, four vertexes to make a square polygon and normal vector for each vertex is needed as information for drawing, and direction of all square polygons must also need to face front if view point was changed. In this work, we employed new function of OpenGL 2.0 that is called point sprite to visualize particle data as more low-cost visualization method. Though this function also uses the texture image like as billboard, necessary information for drawing is only a diameter of each particle and a vertex that is the central coordination for texture mapping. It expected that drawing cost is lower than polygon-based drawing and billboard.

As an application of this function, we developed software to visualize particle data and visualized some data sets. As a result, it succeeded to visualize large amounts of particle data faster than the past software (Fig. 6).

We also developed original software with same visualization method to visualize the results of the cloud and rainfall simulation with the new concept called super-droplet [4], and visualized it. In this program, particles that mean each super-droplet are expressed with the texture image of a sphere, and RGBA color of each texture image are set based on the particle radius of super-droplet. When large amounts of objects with the transparency are drawn, the computational cost to decide the drawing order of these becomes very huge. However, it was significantly reduced by the original data management algorithm based on the grid that was set in the simulation area. We also reduce the computational cost for drawing by the data reduction based on particle radius of super-droplet. As result of visualization that used the developed program, we could observe the cloud formation and the rainfall process by minuscule droplet of water at the particle level (Fig. 7).

4.2 Physically-based rendering of cloud

When we concentrate on the fact that each of super-droplets discussed in the previous subsection has own radius as the attribution, another aspect is also possible to be found. That is, appearance of the cumulus cloud may be visualized photo-realistically, when we consider light transport and multiple Mie scattering which depends strongly on particle radii.

In order to visualize a cumulus cloud by the super-droplets photo-realistically, we developed then a couple of program codes, photon tracing and ray marching code, for calculating the light transport in the participating media of the super-droplets. These programs are parallelized by OpenMP and designed as each process shares memory area for the data of super-droplets and their optical properties.

The photon tracing is one of the methods which simulate traveling and scattering of photons in the participating media based on the Monte-Carlo method. The "photon" here means not an elementary particle in physics but a kind of calculation concept, and carries some attributions such as flux, wavelength and incident direction into the scattering point. At each scattering point of the photon tracing simulation, the photon is stored into a storage area called volume photon map.

After the simulation, the ray marching code is applied to synthesize the image from the photons stored into the volume photon map. The ray marching is one of the numerical integration methods for the volume rendering equation, and integrates the contribution of radiance to the camera direction. The radiance at each sampling point of ray marching is estimated by photons searched from the volume photon map in the neighborhood at that point.

Visualization experiment by those programs was done with 128 processer cores of the supercomputer SGI Altix 4700 at JAMSTEC. One of the resulting images is shown in Fig. 8. We successfully captured the process of cumulus grows and decay photo-realistically.

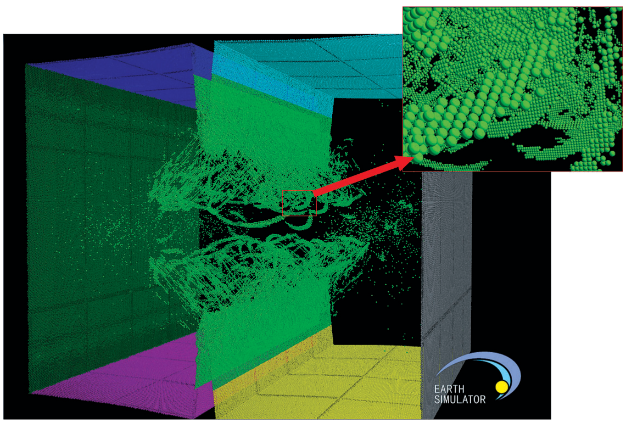

Fig. 6 Visualization results of crack tip dislocations, using the point-sprite method. This simulation was performed by Applied Simulation Research Group of ESC.

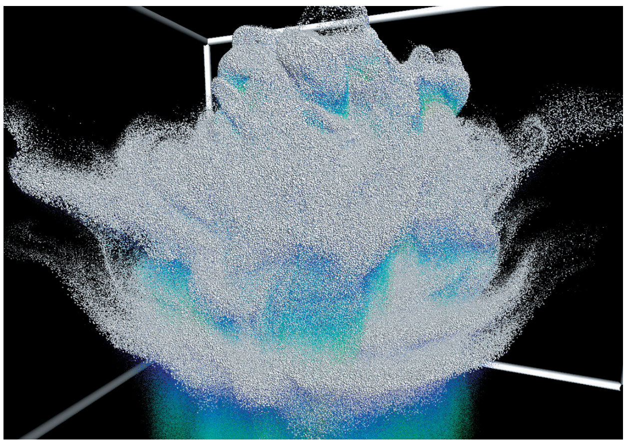

Fig. 7 Visualization result of cloud simulation with Super-Droplet Method, using the point-sprite method. This simulation was performed by Holistic Algorithm Research Group of ESC.

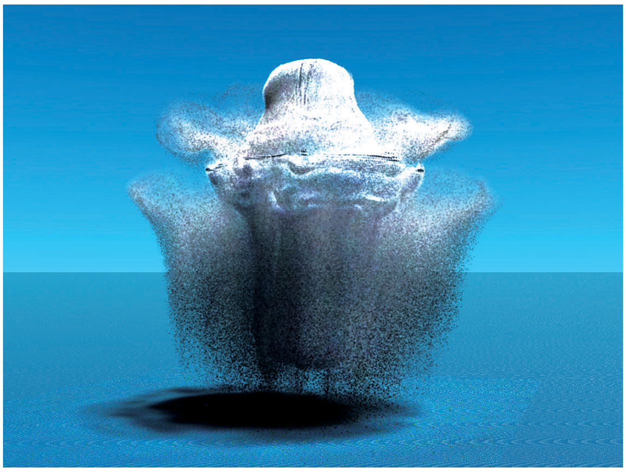

Fig. 8 Photo-realistic visualization result of cloud simulation with Super-Droplet Method. Appearance of a cumulus with vertical growth, soft texture, rainfall and shadow on the cumulus are represented in this figure. This simulation was also performed by Holistic Algorithm Research Group of ESC.

Summary

We have been continuously developed and improved the large-scale data visualization programs, MovieMaker and YYView, and the virtual reality visualization program VFIVE. On the YYView's framework, a GUI tool to realize fly-through visualization, CameraPathEditor, is newly developed. This tool provides a sequence of view parameters along a camera path which is needed for smooth moving of scene. A parallel rendering program, Armada, is newly developed aiming to use on massively parallel computer systems. Currently, we are testing Armada on several supercomputers at JAMSTEC. It is expected to be more effective for the time-varying data visualization than the past achievements by MovieMaker. On the development of VFIVE, we think that VFIVE has arrived to the phase of practical use. The source code is downloadable at our web site [3].

In the fiscal year 2007, we also developed several kinds of innovative visualization programs focusing on inherent characteristics in each of the simulations. For the particle-based simulation, we developed visualization program with the point-sprite method. The point-sprite method enables to reduce the number of polygons drastically, so that massive numbers of spherical particles can be rendered efficiently on user's PC monitor. For a cloud simulation with the super-droplet method, we developed also novel programs with physically-based rendering and the volume photon map technique. We successfully captured the process of cumulus grows and decay photo-realistically.

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地球シミュレータセンターにおけるデータ可視化の研究

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地球シミュレータセンター高度計算表現法研究グループで本年度実施した可視化技術に関する研究開発を報告する。本グループでは、並列レンダリング型可視化プログラムMovieMaker、MovieMakerを核とした準対話型可視化プログラムシステムYYViewおよびバーチャルリアリティ可視化プログラムVFIVEの開発を継続的に進めている。MovieMakerおよびYYViewに関して、昨年度はMovieMakerを用いて、米国テキサス大学計算可視化センターが開発したフライスルー可視化ツールと連携させた大規模データのフライスルー可視化実験を実施した。本年度はこの手法をYYViewシステム内で実現できるようにするため、昨年度の経験を踏まえてYYView用GUIツールを新たに開発した。また、地球シミュレータを含む超並列計算機システムでの大規模並列型可視化をターゲットとして、MovieMakerをベースにしたいくつかの並列レンダリングプログラムを新たに試作した。VFIVEに関しては、これまでの継続的な研究開発によって充分実用段階に達していると判断した。それゆえ本年度はVFIVEのソースコードを公開した。

本グループでは、上記の可視化プログラム以外にも、可視化における表現アルゴリズムの研究、新しい可視化プログラムの開発、および実験も進めている。本年度は、ポイントスプライト法を用いた効率的な粒子可視化プログラムの開発を実施し、亀裂先端に発生する転位のシミュレーションおよび超水滴法を用いた雲形成シミュレーションの可視化に応用した。また関与媒質中での光散乱、光輸送を考慮した物理ベースCG技術に基づく可視化プログラムの開発を実施し、超水滴法を用いた雲形成シミュレーションの可視化において積雲を写実的に可視化する実験を行った。

キーワード: 大規模データ可視化, 並列レンダリング, バーチャルリアリティ, 物理ベースレンダリング