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ARTICLE

Spatio-Temporal Mapping -A Technique for Overview Visualization of Time-Series Datasets-

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Numerical simulations have recently increased in scale and have often output high dimensional (three-dimensional and time-evolving) datasets. This makes it difficult for users to quickly grasp physical phenomena involved in such datasets. To overcome this difficulty, we propose a spatio-temporal information mapping technique with a map-design capability (spatio-temporal map) by using an information visualization technique. The spatio-temporal map is generated by mapping the values of a three-dimensional and time-evolving physical quantity into a two-dimensional space with spatial and temporal axes. Here, three-dimensional spatial information is condensed into one dimension by subdividing a target model with an octree. By using the map, users can quickly find regions of interest involved in high dimensional datasets. In addition, users can interactively change several aspects of the map such as its resolution and color coding method. Furthermore, users can design the map by changing the tree structure. By applying the spatio-temporal map to a full-scale three-dimensional vibration simulator for an entire nuclear power plant, we confirmed that the map is a useful technique to quickly identify appropriate regions of interest.

KEYWORDS: scientific visualization, information visualization, interactive visualization, user interface, time-series dataset, large-scale datasets, numerical simulation data

I. Introduction

Numerical simulations have become a common scientific approach in a wide variety of fields, including the nuclear field. As the performance of supercomputers has increased, such simulations have increased in scale and complexity, and have involved higher numbers of dimensions. In some cases, the results of such simulations can be terabytes or petabytes in size, which makes it extremely difficult for users to evaluate such results, even if they spend a large amount of time on this evaluation.

One effective solution to this problem is to specify a region of interest (ROI) that should be observed in detail. However, in order to select an appropriate ROI, it is necessary to observe the target data from various directions. This often means observing a large number of visualization images, depending on the size or complexity of the target data, and the number of time steps involved.

In order to effectively select the ROI, we propose a novel spatio-temporal information mapping technique (spatio-temporal map) by which changes in the data over time can be visualized. Using the spatio-temporal map, the ROI can be quickly identified and subjected to traditional visualization techniques, leading to a large reduction in the overall time involved.

Moreover, it is often impossible to transfer the entire set of simulation results from a server computer to a client computer due to the large amount of data involved. There is no definite way to observe such a large-scale and high dimensional datasets on client-server environment. Therefore we propose a way to make the entire large-scale and higher dimension datasets observable with relatively few data transfers form server to client. By using the proposed technique, users can select the ROI on the client computer with relatively few data transfers, and it enables them to transfer only the data corresponding to this limited region to a client computer. To achieve this, we developed a spatio-temporal map design function in a client-server environment, allowing users to interactively change many aspects of the map, including its resolution and color-coding method.

As a practical test of the newly developed technique, we applied it to a full-scale three-dimensional vibration simulator for an entire nuclear power plant, and attempted to identify ROIs with spatio-temporal features, for example, regions that have the same or different stress cycles and regions that are subject to high stress.

II. Previous Work

To date, several different visualization techniques have been developed to allow users to flexibly define and search for ROIs. One such technique is to present them with a spreadsheet which shows a large amount of image data enumerated in a manner they have chosen. Using this, users can select the desired regions.[1)] Here, an information visualization technique is used for the selection process, and a scientific visualization technique is used to generate individual images corresponding to the results.

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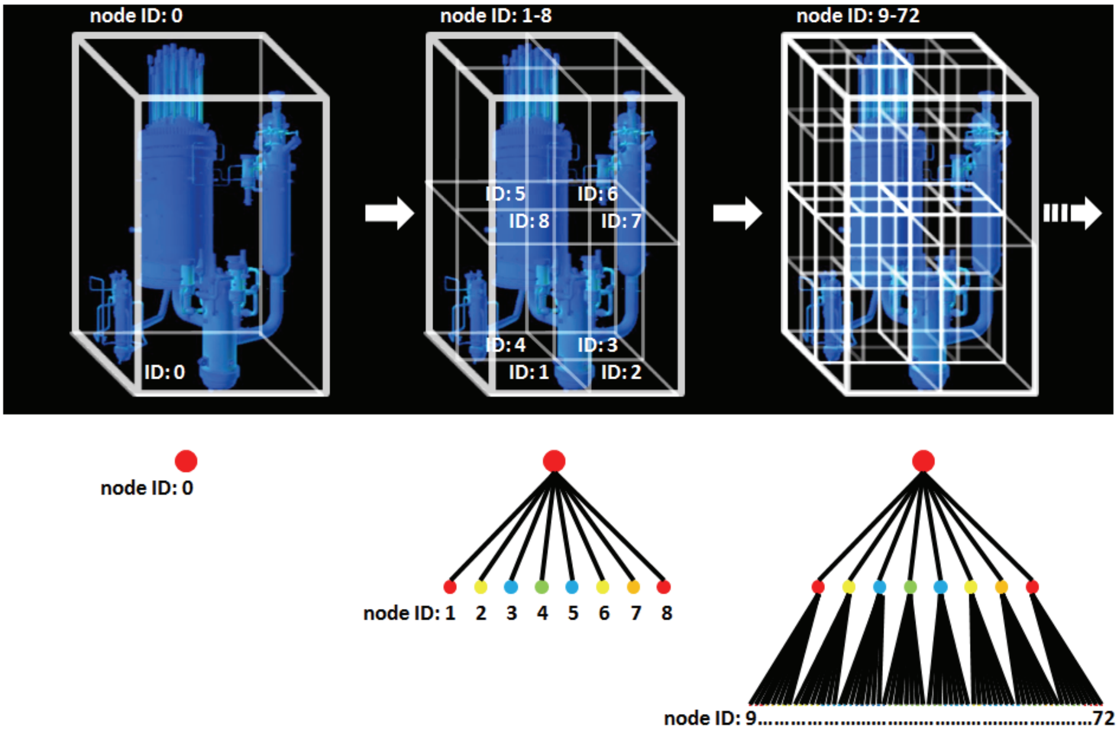


Fig. 1 Voxel subdivision and tree graph

Another technique involves multi-dimensional data visualization and the use of “parallel coordinates”.[2] This method displays multivariate datasets of the simulation results. The “parallel coordinates” technique is a method to show several physical values at the same time. The axes are arranged parallel to each other, physical values are plotted on each axis, and the plotted points are then connected. This allows users to visualize changes in the physical results as a function of the simulation parameters.

A technique using parallel coordinates to search for ROIs in multivariate time series data was also proposed.[3] This method combines the use of parallel coordinates and a time histogram, and generates simulation results as three-dimensional volume datasets. By changing the projection plane, these datasets can be visualized as histograms of parallel coordinates and time. Cross sectioning can be used to provide users with global information.

On the other hand, some techniques of the original data reduction have been proposed,[4,5] the effective technique that can be applied to a variety of element form datasets hasn't been found yet.

In the present study, to allow ROIs to be specified without an oversight, we adopt a method involving the projection of the spatio-temporal information onto a two-dimensional plane. Our technique has no limitation on the data form of input datasets, because it adopts data reduction using space sub-division.

III. Spatio-Temporal Map Visualization

The spatio-temporal map is a two-dimensional diagram with spatial and temporal information along each axis. The

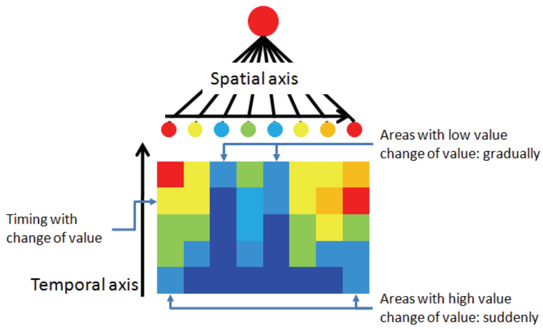


Fig. 2 Two-dimensional color table (spatio-temporal map)

map is created as follows:

Step 1. An octree is created using voxel subdivision.

Step 2. A two-dimensional color table (spatio-temporal map) is created using octree datasets.

1. Octree Creation

In step 1, to project three-dimensional information onto one dimension, we create a hierarchical structure of a three-dimensional target model by using voxel subdivision (**Fig. 1**). In terms of data storage and transfer, making a perfect octree by subdividing the empty area doesn't seem to be very efficient. However, the perfect octree can refer to a sub-space of orginal datasets by dividing node ID by eight, which is a notable feature. The subdivided voxel is then represented by a hierarchical structure expressed as an octree graph (Fig. 1). In this way, the vertices of the three-dimensional model can be represented in one dimension.

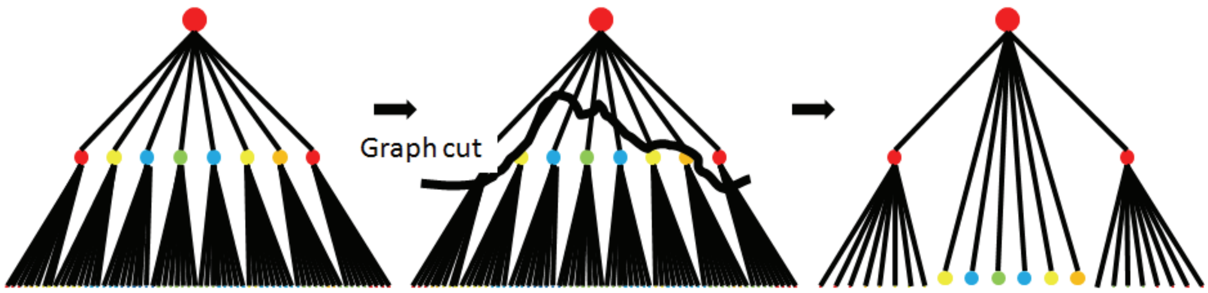


Fig. 3 Adaptive tree graph

Octree is made in the initial state and tree node ID is allocated in the each vertex. The tree node ID in each vertex is not changed in all time steps. Mesh connectivity information and topological information are not used. Therefore, allocated tree node ID doesn't change even if topology is changed.

2. Two-Dimensional Color Table

In step 2, a two-dimensional color table is created. In this table, the horizontal axis represents the one-dimensionally represented spatial information, the vertical axis denotes time, and the color indicates the characteristic in each voxel, such as maximum or minimum magnitude of physical value in each voxel (**Fig. 2**). In this way, both spatial and temporal changes in the data can be represented by a single diagram.

An advantage of this technique is that it assists to find the ROI which has feature value, such as high or low. At the same time, much information about distribution of physical value can be obtained. For instance the change of value is suddenly or gradually, or periodically, and so on.

3. Map Design Interface

We also developed a user interface function allowing interactive design of the spatio-temporal map. To achieve this, the octree nodes are color-coded based on the values which show the characteristic of the sub-region, which are specified by the user. The procedure is as follows. First, a hierarchical structure and a tree graph are created (Fig. 1). As described above, the nodes of the tree graph have a parameter representing some characteristic of the sub-region. Graph links are then cut based on the values of this parameter, and the details of the hierarchical structure are decided (**Fig. 3**). If the user changes the value of the parameter, the tree graph is reconstructed at a different resolution. In addition, if the user changes the nature of the parameter chosen, a new tree graph is constructed. We call this type of tree graph an "adaptive tree graph".

IV. Visualization Method in a Client-Server Environment

In a client-server environment, the amount of transferred data needs to be considered, because it is sometimes impossible to transfer all of the simulation results from a server computer to a client computer.

In our method, the tree graph is created from the large-scale time-series numerical simulation results on the server computer, and its size is considerably smaller than that of the entire dataset. This tree graph is transferred quickly from the server to a client. Next, on the client computer, the spatio-temporal map is created. This map can be used for overview visualization, displaying the spatial and temporal characteristics of the entire dataset. A spatio-temporal ROI can then be identified and a request sent for data in this region to the server; the server responds by sending this data and this data only. This is then interactively visualized and observed on the client computer. In addition, information visualization techniques can be combined, allowing evaluation of changes in the simulation results and the errors involved.

The main merit of this technique is that users can change the spatio-temporal map on the client computer according to the type of information they want displayed. For example, in the case of a mechanical stress simulation, users can observe the map while changing certain threshold stress values. Also, users can observe changes in the features of a particular area in real time while changing the physical values being displayed.

V. Results

The proposed visualization technique was applied to the results of "a full-scale three-dimensional vibration simulator for an entire nuclear power plant"[6] which has been developed based on the finite element method at our research center (CCSE/JAEA). A model was constructed with tetrahedral elements, and the nodes of the model were subjected to Von Mises stresses. The model contained 26,047,774 nodes and 127,077,003 elements. The number of time steps was 70. The size of entire datasets was about 300 Gbyte.

Experiments were performed on a Microsoft Windows XP(CPU: PentiumM 1.6 GHz, RAM: 1 GB). In these experiments, the window size of the rendering system is 400 *300 pixels.

A rectangular area was constructed to enclose the entire dataset, and a four-level octree was generated, and its size is about 13 Mbyte. The spatio-temporal map was color-coded based on the maximum values of the Von Mises stress. The spatio-temporal map in **Fig. 4** (a) shows perfect octree for a part of the nuclear power plant. Gray region denotes empty sub-region. While the large-scale nature of the tree graph makes it difficult to form a clear understanding, it is apparent that there are some regions with high stress. To increase the level of detail, the threshold is set interactively.

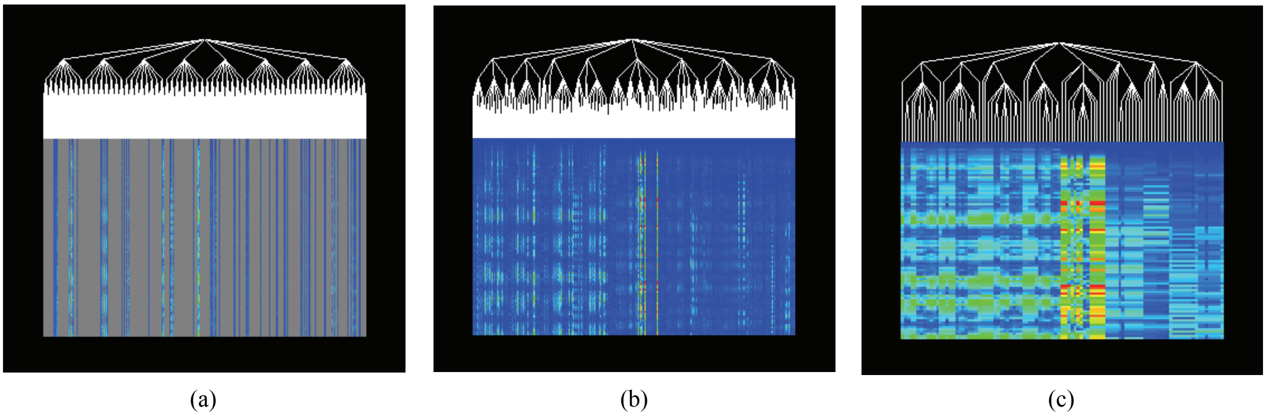


Fig. 4 Spatio-temporal map; (a) result when graph is not cut, (b) result when leaf nodes are not overlapped, and (c) result when region of maximum stress can be found

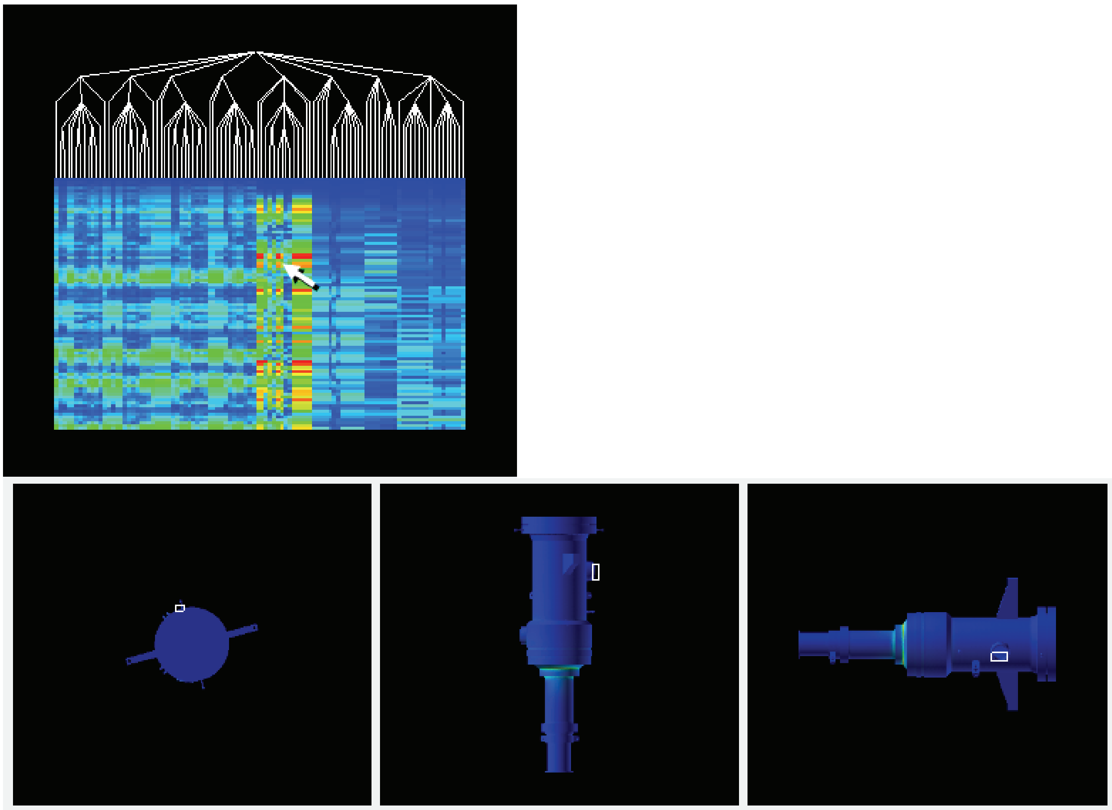


Fig. 5 Location of a selected ROI on the original model

Figures 4(b) and (c) show the results for a threshold of 1,000 and 5,000, respectively. Figure 4(b) is result when leaf nodes are not overlapped. From Fig. 4(c), a ROI which has a high Von Mises stress can be specified, and its location can be determined. **Figure 5** shows the location of the selected ROI on the original model. This example shows that it is easy to specify the ROI by changing the threshold.

In addition, more detail can be observed in Fig. 4(c). Namely, it can be clearly seen that the color variation pattern is different between the left and right sides of the figure. On the left side, the Von Mises stress values of the lower half of the model are mapped on the spatio-temporal map. On the other hand, on the right side, the Von Mises stress values of the upper half of model are mapped on the spatio-temporal map. Thus, it is clear that the cycle of the change of the Von Mises stress is different between the upper and lower areas.

Finally, the ROI is specified, and the original data of the specified ROI is observed (**Fig. 6**). By observing the spatio-temporal map, the user can specify an area with a high Von Mises stress value, because there is a possibility that some phenomena are caused in such area. The location of the area is determined using the spatio-temporal map, and the user observes this local area carefully. In this case, we know that the area is a part of the piping. This section of piping

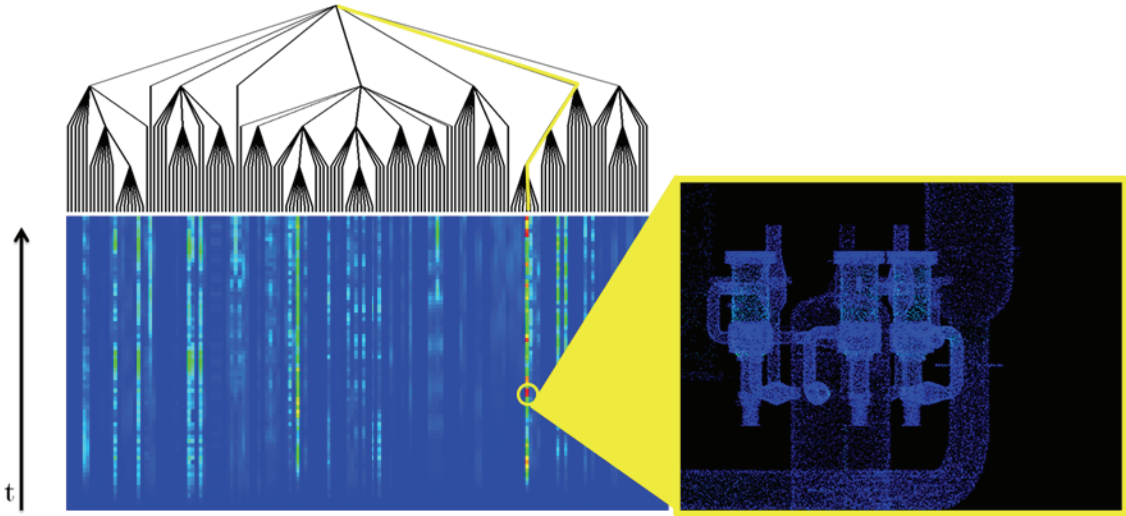
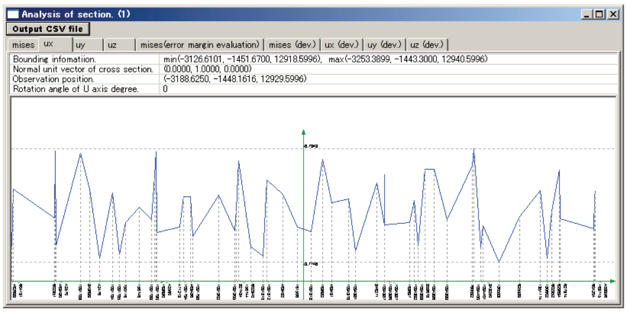
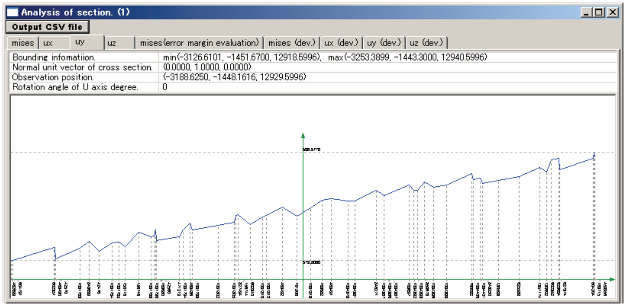


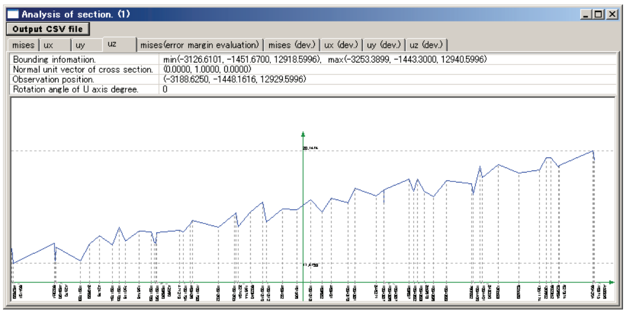
Fig. 6 Specification of ROI and corresponding detailed image using traditional visualization technique



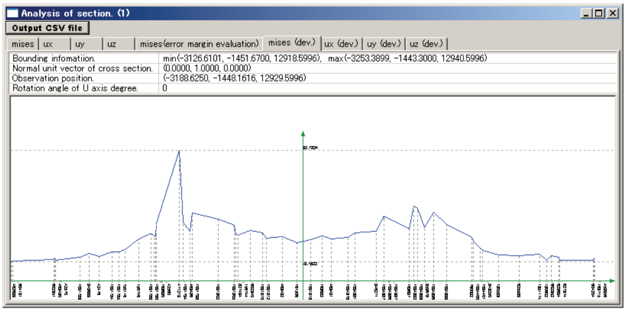
(a)



(b)



(c)



(d)

Fig. 7 Graphs of physical values on the selected ROI: (a) graph of movement in the direction of x, (b) graph of movement in the direction of y, (c) graph of movement in the direction of z, (d) graph of Von Mises stress

and its surroundings can be observed from various directions. Subsequently, the physical characteristics of the piping section are examined in detail using traditional visualization techniques such as volume rendering, iso-surfacing, and cross sectioning. In Fig. 6, we use a point base rendering technique to observe the specified ROI. In this visualization technique, Von Mises stress value on vertices of three dimension model is allocated to the color.

In addition, the physical values around the part of piping are observed in detail. **Figure 7** shows the physical value graphs. The distribution of movement in the direction of x is large, and the movement in the direction of y and z are comparatively monotonic increase. It is understood to cause the change from this in the direction of yz. Next, the graph of the Von Misses stress is observed. The value in the area where the value is high is no problem as structure.

In our experiment, the number of tree graph elements does not exceed 10,000, and the rendering time is less than 0.1 seconds. The results of Figs. 4(a), (b), and (c) are rendered interactively. The proposed method is necessary to cut the tree graph. It is possible to cutting the graph less than 0.0001 seconds. Therefore, interactive operations are accepted in the proposed method.

VI. Conclusion

In this study, we proposed the use of spatio-temporal information mapping technique to observe datasets of large-scale time-series simulation. An advantage of our technique is that it assists to find the ROI. At the same time, much information about distribution of physical value can be obtained. For instance the change of value is suddenly or gradually, or periodically, and so on. The particular case of finding the maximum value, existing methods could be efficient. However, our method shows more information to meet the interests of users. This technique was implemented in a client-server environment, where users can decide the amount of data transferred based not on the size of the original simulation dataset but on the voxel subdivision number.

In our technique, topological information of the simulated model is not considered. In the future, we discuss to create a tree graph based on structural hierarchy.

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