”Shadow Clustering”: Surface Extraction from Non-equidistantly Sampled Multi-field 3D Scalar Data Using Multi-dimensional Cluster Visualization

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1 INTRODUCTION

Data sets resulting from physical simulations typically contain a multitude of physical variables. In most cases they are highly dependent on each other and most phenomena can only be explained with a view in most of the attributes. Nevertheless we have only at most four dimensions as domain for visualizations. Hence scientific approaches are necessary to convert the high-dimensional data to human understandable pictures and animations.

The provided time-varying data set shows the simulation of the propagation of an ionization front instability. It includes a variety of different attributes, including density, temperature, mass abundances of eight chemical species and velocity. The size of each data set of the 200 time steps is $37 \cdot 10^6$ points resulting in 1.7 GB of data per time step.

Our goal was to present a visualization method that takes into account the entire multi-field volume data rather than concentrating on one variable. We propose a combined approach based on non-equidistant resampling, multi-dimensional clustering and surface extraction.

It is well known that equidistant resampling of regular grids often introduces resampling artifacts. Since visualization of unstructured point-based data made a rapid development in recent years, it seems to get more and more reasonable to use this type of data. Thus we decided to resample the huge amount of data at uniformly distributed random positions. Due to limitations of the clustering algorithm, we are restricted to one million unstructured sample points. We first resample the entire data set for each time step. Afterwards, the region of interest is extracted and again resampled from the original data set to obtain a higher resolution. In this phase we also include an additional attribute to the sample points, the magnitude of the curl of the velocity field, giving an estimation of the turbulence.

The multi-dimensional feature space of the resulting data set is analyzed by applying an automatic multi-dimensional clustering based on density computations, accepted for publication at VIS 2008 [1]. The multi-dimensional domain of the data set is subdivided into equal sized hypercubes. Regions of connected hypercubes are detected with respect to the point density and result in a density cluster tree. The clusters can be analyzed in a star coordinate view, optimized to separate projected clusters while maintaining the structure of the individual clusters. From this view it is easy to determine cluster properties and select clusters of interest.

With selected clusters, corresponding to subsets of the data set in object space, we have a variety of possibilities to continue the analysis of the data set. One is the rendering of the cluster points in object space, with different colors to distinguish between the clusters. To achieve a better overview and insight into the data, one can also leave away clusters or merge them.

A contrary approach arises from the segmentation property induced by the cluster membership. Based on this property, we can extract a surface from the volume data using direct surface extraction [3]. More precisely, we extract the isosurface with isovalue 0.5 to the characteristic function of the cluster. We directly extract our surfaces without prior resampling or grid generation. The surface extraction computes individual points on the surface, which is supported by a neighborhood computation using *k*d-trees and an efficient indexing scheme.

The extracted surface points are rendered using point-based rendering operations. One interactive approach used in `picture3.png` is image-space point cloud rendering [4]. The lit surface points are directly rendered to the screen. Possible holes are filled with image-based filters. This results in a surface rendering exhibiting no more holes.

A second approach for rendering the surface points is splat-based raytracing [2], which gives renderings with higher quality but with no interactivity. For each surface point a circular splat is fit to the surface using a least-squares approach providing also a normal map of the splat. The resulting splats are raytraced using the normal map.

2 SCIENTIFIC QUESTIONS

2.1 Symmetry of the Shadow Instability

First we want to clarify the three-dimensional shape of the observed shadow instability. For this purpose, we randomly resampled the data set of time step 90. Afterwards it was clustered in feature space according to all attributes. We extracted the surface segmenting the cluster of the ambient gas with a temperature around 72 K from the shocked and ionized gas. This surface represents the front of the ionization process. A raytraced picture of the surface is shown in `picture1.png`.

It is clearly visible that the shadow instability is not symmetric around the x-axis. Instead it is symmetric with respect to the $y = 124$ and the $z = 124$ plane. Furthermore it is symmetric with respect to the two planes, that are perpendicular to the x-axis and lying diagonal in the y-z-plane. The symmetry around the x-axis is mainly broken by the eight ”fingers” leading the instability front.

2.2 Prevalence of H_2

We chose time step 99 to show the regions, where $\mathbf{H_2}$ is most prevalent. The randomly resampled data set was again clustered in feature space. In `picture2.png` we show a point rendering of two important clusters. The points of the cluster with most $\mathbf{H_2}$ are rendered in green. To have a context for this cluster, we additionally render the points of the cluster with highest turbulence in red. These points indicate the zone of the shocked gas in the ionization process.

The picture shows, that most of the $\mathbf{H_2}$ is generated at the very beginning of the ionization process. It is most prevalent directly at the beginning of the zone with shocked gas and high turbulence. The properties of the extracted clusters, more precisely the average attribute values, also show that in this regions, where $\mathbf{H_2}$ is most prevalent, most of $\mathbf{He}$ is already ionized to $\mathbf{He}_+$ but only some $\mathbf{H}_+$ was ionized from $\mathbf{H}$.

2.3 Radiation Fingers

To see how thick the first fingers of radiation are, that break through the front, we have to study data sets very early in time. We took time step 10, where this phenomenon first clearly appears. The generation

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of `picture3.png` was done in a similar way to Section 2.1. Again a non-equidistant sampling followed by a multi-dimensional clustering was applied. Thereafter two segmenting surfaces were extracted and rendered using image-space point cloud rendering.

The bluish surface segments the ambient gas from the rest and gives the context for a better understanding of the picture. The red surface segments the first finger of radiation breaking through. The picture was rendered with a viewport parallel to the x-y-plane to allow a better judgment of the size. We clearly see, that the diameter of the finger of radiation is approximately 0.017 parsecs.

2.4 Cause of Turbulence

To answer the question if turbulence is stired up in the front of the shadow instability, we again refer to `picture2.png`. As mentioned in Section 2.2, time step 99 was resampled and clustered in feature space. To have an indication for turbulence, we introduced the magnitude of the curl for the provided velocity field as an additional data dimension. The points of the cluster with high turbulence are rendered in red.

It is clearly visible, that most turbulence is present in the region of shocked gas, i. e. directly after the ionization front. So we have a real strong indication, that the shadow instability stirs up the turbulence in the gas.

2.5 $\mathbf{H_2}$ Formation and Turbulence

To answer the last two key questions we refer to the attached video `video.avi` and still images `picture4.png` and `picture5.png`. The video shows an interactive rendering of a scene similar to `picture2.png`. The data set for time step 99 was resampled non-equidistantly and clustered in feature space. Afterwards, three clusters were extracted. The points of these clusters were rendered with different colors to provide a three-dimensional view of the cluster distribution.

The points of the cluster with most $\mathbf{H_2}$ are colored green. All red and blue points represent points of high turbulence, cf. `picture2.png`. These points were split into two clusters representing points with low $\mathbf{H}_+$ density, colored red, and points with high $\mathbf{H}_+$ density, colored blue.

From the animation one sees, that most of the $\mathbf{H_2}$ is generated at the very beginning of the turbulence cluster, where $\mathbf{H}_+$ density is low, i. e. where it is lower than 0.2. This indicates, that turbulence is essential for the formation of $\mathbf{H_2}$, but the needed electrons do not mostly come from $\mathbf{H}_+$. Instead a relatively very high density of $\mathbf{He}_+$, which is greater than 0.15, is observable in the regions of $\mathbf{H_2}$ formation. This also heavily correlates with the presence of $\mathbf{H}_-$ and $\mathbf{H_{2+}}$.

More precisely one gets the following impression from the procedures causing the turbulence. If the ionization front reaches the ambient gas with $\rho_{\mathbf{H}} \approx 0.76$ and $\rho_{\mathbf{He}} \approx 0.24$ both chemical species are ionized at approximately the same speed. But a high amount of the $\mathbf{H}_+$ is converted into $\mathbf{H_2}$ with the help of the free electrons from $\mathbf{He}_+$. This process and probably also the breakup of $\mathbf{H_2}$ afterwards lead to the observable turbulences behind the $\mathbf{H_2}$ front. This behavior can be observed at the front of the instability as well as at the front of the ”normal” ionization front.

REFERENCES

[1] L. Linsen, T. V. Long, P. Rosenthal, and S. Rosswog. Surface extraction from multi-field particle volume data using multi-dimensional cluster visualization. To appear in Proceedings of IEEE Visualization 2008.

[2] L. Linsen, K. Müller, and P. Rosenthal. Splat-based ray tracing of point clouds. *Journal of WSCG*, 15(1–3), 2007.

[3] P. Rosenthal and L. Linsen. Direct isosurface extraction from scattered volume data. In *Proceedings of Eurographics/IEEE-VGTC Symposium on Visualization*, pages 99–106, 2006.

[4] P. Rosenthal and L. Linsen. Image-space point cloud rendering. In *Proceedings of Computer Graphics International*, 2008.