In Situ Visualization with Explorable Images

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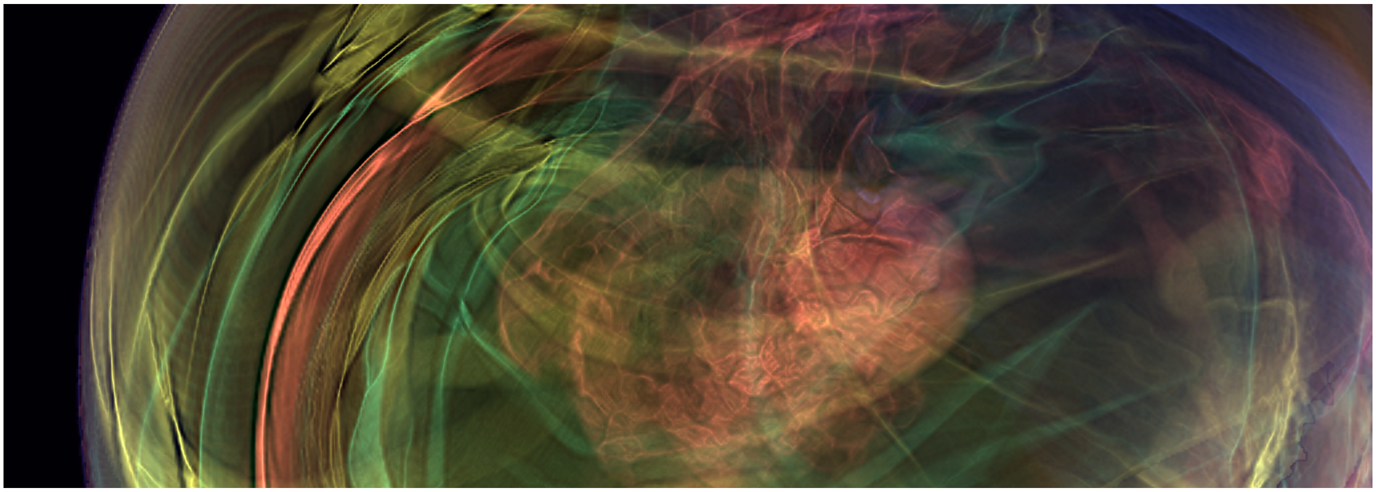

Fig. 1. Explorable Images enable similar data reduction to static images, while enabling many types of data analysis previously feasible only with access to raw simulation output. Above, we show an explorable image generated in situ on a supercomputer, then transferred to a local workstation where we can explore the data with operations such as transfer function editing and relighting.

Researchers have long been aware that the computational power of modern supercomputers far outstrip their associated I/O and storage capabilities[1]. Because visualization techniques often require a small computational overhead and even smaller I/O, it is often practical to perform the visualization on the supercomputer in tandem with the simulation. Despite development of such 'in situ' visualization techniques, it nonetheless remains common practice for simulations to simply store raw simulation time steps to disk, then transfer the data to local workstations for visualization as a postprocess.

As simulations enter the exascale, visualization as a postprocess is becoming impractically burdensome and exacerbates existing I/O and storage bottlenecks[2]. The solution thus far has been to reduce the number of timesteps stored to disk, but this approach is reaching its limits: this reduction in the temporal resolution of the output means that behavior between saved timesteps is becoming steadily more difficult to determine. Additionally, the increasing size of the stored timesteps is pushing the limits of practical visualization on local workstations, thus requiring the use of visualization clusters.

Part of the problem with standard in situ visualization is that it can be difficult to choose good visualization parameters before the simulation has been run. Because the corresponding raw data for an in situ static image will be unavailable after completion of the simulation, it is critical to choose these parameters wisely. This can set up a chicken-and-egg problem because it may be unknown *a priori* what camera positions will capture features of interest. Similarly, determining a good transfer function to make relevant features stand out from irrelevant background information can be impractical before the output data is available. Given that the cost of poor parameter choice could be a costly simulation re-run simply to obtain better visualization, it is perhaps unsurprising that many researchers have chosen instead to accept the high cost of storage of raw output for later visualization.

We present Explorable Images as a solution for the preceding concerns. Explorable images, like static images, may be generated in situ on a supercomputer, thus reducing the need for separate visualization clusters. The storage requirements of each explorable image is only slightly larger than a static image of the same resolution, but retains enough information about the simulation output to allow specific types of data exploration that would otherwise only be possible with access to the raw simulation output. Specifically, Explorable Images provide a solution for each of the following topics:

- Previewing simulation results by providing exploration along multiple dimensions
- Reduction of the total data necessarily stored to disk
- Creation of visualizations that would otherwise be impossible or impractical to generate as a postprocess

Past experiments have demonstrated the viability of Explorable Images for various types of data, ranging from the output of medical imaging devices[6] to the results of large-scale scientific simulations such as the supernova dataset[5] used as a representative example in this paper. Figure 1 and 2 are examples of volume renderings of scalar field data using explorable images. In addition to volume renderings of scalar field data, we have also demonstrated the use of Explorable Images for vector field data[7] as shown in Figure 3. For each of these types of data, Explorable Images can support exploration in multiple dimensions, including transfer function editing, view-angle modification, adjustment of lighting parameters, and the addition of cut planes[4][7].

When Explorable Images are generated in situ, it is possible to use them to preview the simulation results generated thus far. Like other forms of simulation monitoring, this can allow researchers to pause and reconfigure their simulation if necessary to prevent expensive resimulation, but using Explorable Images in this manner also provides a

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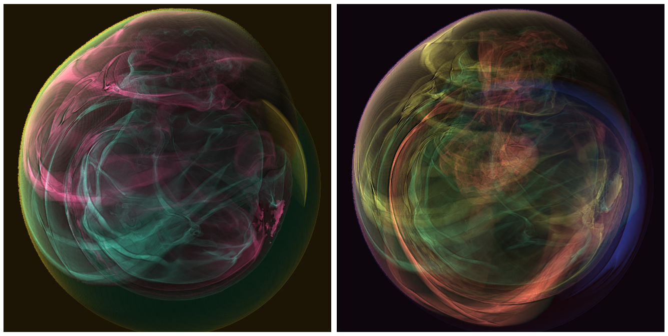

Fig. 2. Scalar field data can be rendered with explorable image. The two images are rendered using the same explorable image. The supernova core isn't shown on the left image. Because of explorable image, we are able to change the transfer function without access to the raw simulation output, thus we are able to adjust the transfer function to reveal the supernova core, which is shown in red in the center of the right image.

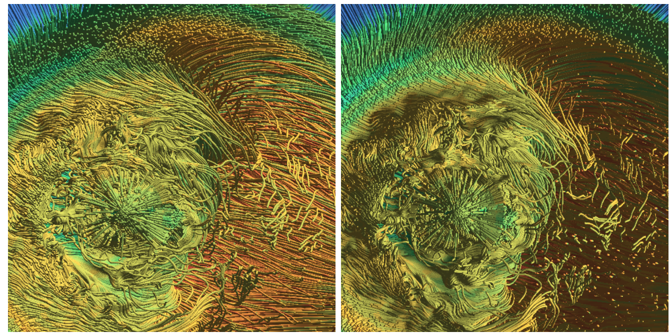

Fig. 3. Explorable Images can be used for with vector field data as well as scalar field data. Here we demonstrate the use of explorable images for pathtube visualization. By modifying the transfer function, adding cut planes and lighting, we may find features of interest that would be difficult to obtain by outputting only static images, but without the storage overhead of raw data. These two images show the effect of changing the lighting parameters.

simple method for determination of good visualization parameters to ensure that later timesteps capture more features of interest, and fewer irrelevant results. Depending on how much of a priority data reduction is for a given simulation, Explorable Images can be configured so that the output is more explorable, but has a slightly higher storage cost, or so that the output is less explorable but smaller.

The reduction in temporal resolution caused by storing simulation output for only some timesteps can prevent smooth animation in visualization of the results. In-situ static images, due to their low storage cost, can be used to generate smooth continuous animations. Explorable Images can expand on this advantage by capturing the high temporal resolution of the simulation like static images, but providing much of the rich explorability of raw data. Good visualization parameters can be chosen for every frame as a postprocess, which would be impractical with static images because it would require constant monitoring and adjustment during simulation. On the other hand, the high temporal resolution provided allows for much smoother animation than would be possible via postprocessing of raw data. Explorable Images can thus provide visualizations that would be infeasible otherwise.

Each explorable image is an approximation to the original direct volume rendering. Each image is a discretization of the direct volume rendering integral into a finite number of bins, usually a small number. As a result, an explorable image is unable to reconstruct a completely accurate direct volume rendering image, but the result is usually close enough for user analysis [6].

A major stumbling block for researchers when presented with any new visualization technology is that there is often a difficult process required to make use of the technology in their own simulations. For this reason, we have designed the API for explorable image generation to be as simple as possible to learn. All that is necessary for a simulation to support explorable images is to specify a configuration file and to pass in the data to visualize at each desired timestep. An additional advantage of generating Explorable Images in this way is that it provides a packaged 'thumbnail' of simulation results that can be easily distributed to others for further exploration. Because the exploration is not computationally intensive, it can also be used to generate dynamic presentations or show features interactively in response to audience queries.

In conclusion, the combined advantages of low storage costs with high explorability and support for a variety of data types will make Explorable Images a valuable tool for researchers as simulations grow into the exascale and beyond.

Acknowledgments

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