Interactive Visual Analysis of Hurricane Isabel with SimVis
http://www.VRVis.at/SimVis/Isabel/

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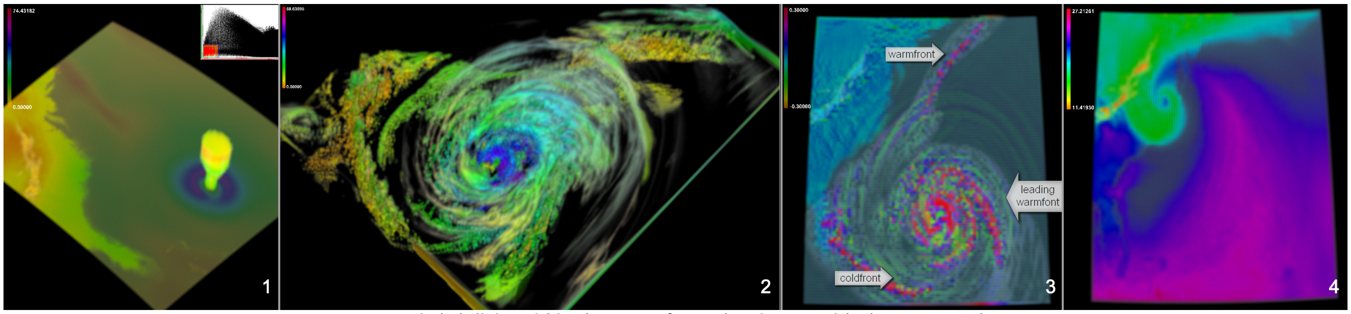


Note: encircled digits within the text refer to the pictures with the same number.

ABSTRACT

In this document we describe our solution to the IEEE Visualization 2004 Contest, i.e., the interactive visual exploration and analysis of the simulated hurricane Isabel by the means of SimVis. SimVis is an interactive visual analysis technology which was developed at the VRVis Research Center in Vienna, Austria, in the past few years. It was originally developed to support the analysis of CFD datasets from the automotive industry, but proved to do a great job also on the hurricane data. Its approach of combining InfoVis and SciVis technology to concurrently access both the space-time aspect of the data as well as the (more abstract) multi-dimensional attribute space, enables users to develop a fairly comprehensive (mental) image of simulation data. In this document we comment on SimVis methodology as well as on our actual visual analysis and exploration of the hurricane data. URL http://www.VRVis.at/SimVis/Isabel/ leads to a web page with more information, a lot of graphical material (images, video sequences), as well as a short and a long version of a video which has been compiled from captured sequences of on-line exploration and analysis.

SIMVIS TECHNOLOGY

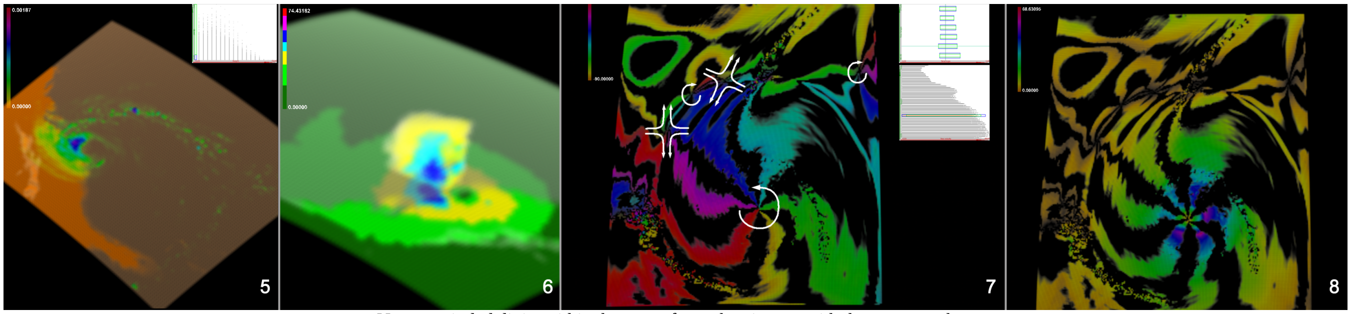
SimVis is an interactive visualization technology which has been developed at the VRVis Research Center in Vienna, Austria, in the past few years [1, 2, etc.]. Time-dependent simulation data, which usually is given on an unstructured grid, is shown in views of various kind (InfoVis and SciVis, e.g., in scatterplots, histograms, and by the means of 3D rendering). This enables the user to intuitively explore the data (and its intra-relations) with respect to all provided data dimensions.

An important part of the SimVis technology is that the user has the opportunity to interactively focus on especially interesting subsets of the data, so-called features. By interactively brushing InfoVis views of the data, the user formulates his or her current interest in an intuitive way (very much like domain experts do when talking about their data). A so-called feature definition language allows to combine simple brushes and to thereby formulate complex feature specifications. An important characteristic of the SimVis feature specification is that a non-sharp discrimination between the data subsets of interest (the current focus) and all the rest (the context) is utilized. Similar to the field of fuzzy logic, continuous degree-of-interest values (from the unit interval) are assigned to every grid cell under investigation. This allows to reflect the usually smooth characteristic of a flow simulation dataset and avoid artificially sharp boundaries of flow features, which in reality rarely occur (a vortex, for example, usually has no sharp boundary).

A typical SimVis-scenario for interactive exploration of a CFD dataset is that the user, at first, uses a scatterplot to visualize the distribution of all data items according to two (or three) selected data attributes, such as pressure and velocity, for example. The user then interactively brushes parts of the scatterplot to indicate a special interest in a certain subset of the data items, e.g., all cells which exhibit relatively low pressure values at relatively high velocities. This information (which cells are of current interest) is then used to cause a visual focus–context discrimination in the 3D SciVis view – cells which are of interest are drawn in color and at a relatively high opacity whereas all the other cells (context) are drawn in grayscale and at very low opacity. Thereby it is possible to visually relate flow properties across multiple dimensions including space, time, and other data attributes.

SimVis provides additional functionality to deal with the special dimension of time. In every view it is possible to navigate in time and to show the data of selected time steps. Also, temporal derivatives (as well as other derived quantities with respect to time) can be interactively computed from all available data attributs and reinserted within the database. In general, this ability to interactively derive new, synthetic data attributes from already given ones, and then considering these derived quantities for brushing also, proved to be very useful (this is one way to specifying fairly complex flow features). More details about SimVis can be found, for example, at web page http://www.VRVis.at/SimVis/.

SimVis is designed to work on regular PCs. Apart from certain size limitations which restrict the amount of data to less than 2 GB which can be held in memory, interactive visual analysis and exploration is very well possible even without very expensive hardware. Especially in the context of this contest we want to emphasize that all the below presented analysis has been carried out on an Intel P4 3 GHz PC with 2 GB of memory and a GeforceFX 5950 graphics card (with 256 MB of RAM).



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Exploring and Analyzing the Hurricane

Before we started with our analysis, we sub-sampled the hurricane data to a 100 (longitude) $\times$ 100 (latitude) $\times$ 20 (height) $\times$ 24 (time) grid with 23 data attributes at every grid cell. This was necessary to allow an interactive visual exploration and analysis of all the data with SimVis on a regular PC. Among the 23 data attributes we also included several new and synthetic data attributes such as flow velocity vectors in polar coordinates (ϕ, θ) and flow veloctity ($|\mathbf{v}|$), values of pressure and temperature normalized to $[0,1]$ per height-layer, as well as spatial derivatives of the cloud measure and velocities ($|\nabla cloud|$, $|\nabla \mathbf{v}|$). To also achieve HQ-results with respect to 3D rendering, we allow to (on demand) port the current visual analysis to another version of the dataset at resolution 250 $\times$ 250 $\times$ 50 $\times$ 1 (higher resolution, but only one time step).

To get a first overview of the hurricane dataset, we investigated the eye of the hurricane (characterized by comparably low pressure and relatively low wind speeds and interactively specified with a brush on a scatterplot of pressure and velocity values ①) as well as the cloud structures (brushing relatively high values of *cloud* ②, later differentiating between fast and slow clouds). The eye of the hurricane proves to be a very stable flow feature which can be easily identified in every time step. Visualizing clouds helps to get a very intuitive picture of the hurricane as we are reminded of photos which are taken from real storms like the actual Isabel in 2003. Fast clouds around the eye of the hurricane as well as comparably slow clouds (thunderstorms at three fronts) give a good overview of the data. To improve the spatial reference for our analysis, we used a separate feature representing land almost all the time throughout the here described process.

Apart from the eye of the hurricane and cloud structures, we investigated a number of other properties of this dataset as described in more detail on the related web page (this two-pages document does not give enough space for an elaborate description). Through the linking-and-brushing methodology of the SimVis approach, hurricane structures such as fronts ③, the temperature distribution ④, amounts of precipitation ⑤, classified wind velocities ⑥, etc., can be examined, revealing interesting information about the simulated two days of this storm.

Another interesting part of the flow analysis was the one of flow directions. To do so, we emphasized six bands of horizontal flow directions ($-60° \pm 10°$, $0° \pm 10°$ (North), $60° \pm 10°$, $120° \pm 10°$, $180° \pm 10°$ (South), $240° \pm 10°$) through brushing ϕ of the polar coordinates representation of flow directions. This results in images of the hurricane where regions of almost parallel flow direction are interleaved with dark bands which represent the complementary set as compared to the used brushes ($-30° \pm 10°$, $30° \pm 10°$, etc.). When coloring the emphasized bands according to the wind directions (we use a color map with an order of colors as in the HSV color system), then a pseudo-topological analysis of the flow data is possible. Where all the bands join we see either a swirling node (center or spiral) or a saddle within the data. Concentrating on the dominating flow structures such as the center of the hurricane, for example, it is possible to sketch the most important parts of the apparent flow topology ⑦ and to find regions of relatively high turbulence (at the fronts, for example).

Once the directional bands are interpreted with respect to their predominant flow direction, these bands also can be colored according to another flow attribute, for example, flow velocity. Thereby it is possible to not only show where the flow goes, but also how fast the wind is ⑧. This example of a pseudo-topological analysis of the hurricane also allows to briefly outline a general pattern of SimVis analysis: First the visualization is restricted to a certain subset of the data of special interest, e.g., one time step and one height-layer. In this subspace a visual analysis is set up (such as the pseudo-topological analysis). Afterwards, the dimensions, in which the visualization originally has been restricted (time, height), are revisited by stepping through these dimensions with the prepared analysis. With such an approach it is possible to get a useful overview of three spatial, one temporal, and three attribute dimensions with one visual setup.

Conclusions

SimVis provides a flexible fusion of InfoVis and SciVis to enable the interactive visual access to spatiotemporal data properties as well as to all the other data attributes. Interactive feature specification is intelligently linked to focus+context visualization in 3D – color and opacity are made dependent on multiple data attributes in an intuitive way. Immediate visual feedback allows to efficiently explore and analyze the data. Smooth feature boundaries match the smooth nature of simulation data and the feature definition language matches the way domain experts formulate flow features and thus provides a useful notion of addressing features. Although not everything was possible throughout this analysis (we had to subsample the data, sophisticated feature extraction methods were not applied), we conclude that SimVis seems to be close to optimal for the tasks as set in this contest.

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References

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