Interactive Visual Analysis – an Opportunity for Industrial Simulation

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Computational simulation has become an important factor in industrial development as well as in scientific work. Significant amounts of time and money are spent on the simulation of real-world phenomena such as combustion processes, fluid flow, wheather phenomena, etc. Along with the rapid development of computer hardware as well as simulation software, also the results of simulation develop quickly in terms of size and complexity. It is common practice these days that simulation datasets are computed for grids with millions of grid cells. Often, simulation datasets are computed for a large set of timesteps and usually many data attributes are simulated for all the grid cells (or vertices) and for all the time steps. This often results in large and complex data files (sized in the orders of Gigabytes). In selected application fields, however, these numbers can be still a lot larger – super computing, for example, commonly results in data files which are Terabytes of size.

Making sense out of large and complex data files is by far not easy and straight forward. This is especially true when the data integrates spatial information, time-varying information, and multi-variate information. In practice, data analysis often is made on the basis of computational measures. Various statistical measures are computed for the simulation result, graphs are drawn (measures vs. time), stacks of slices are investigated, etc. Thereby, interesting information is extracted from the simulation data which is valuable for analysis.

Visualization is an alternative approach to the investigation of simulation data. Visualization solutions range from the one-to-one visual representation of flow data (direct visualization), e.g., in the form of hedgehog plots or color maps, via texture-based flow visualization and integration-based flow visualization to feature-based visualization [PVH+02]. The fact that quite many useful flow visualization techniques coexist next to each other, stems from the fact that it heavily depends on the user task whether the one or the other visualization technique is better. User questions arise in the context of the application at hand and include questions about the flow behavior (considered locally or globally), about physical or chemical processes which are related to the flow (e.g., a cooling or combustion process), as well as many others.

The fact that it is usually not possible (anymore) to fully comprehend all the contents of a simulation dataset of these days just by looking at one visualization (either a single image

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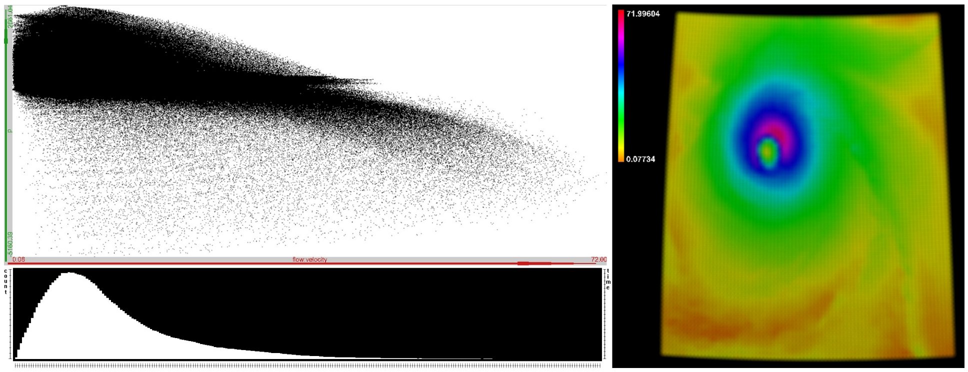

Figure 1: Different views on one simulation dataset (simulated hurricane Isabel). In the lower left, a histogram reports about the distribution of velocities in the data (very fast winds are comparably rare). In the upper left, the relation between velocity values (on x) and pressure values (on y) is depicted (very high velocities coincide with low pressure). On the right, velocities are color-coded for one selected height-slice – we see ring-shaped hurricane in shades of blue and red.

or a video or the like) makes more advanced analysis technology necessary so that the full potential of computational simulation indeed is exploited (without proper analysis a lot of the valuable potential of modern simulation technology is wasted).

There are different options of how to approach the challenge of how to visually analyze large and complex datasets. In one class of visualization approaches, feature extraction methods are utilized to automatically extract features from the flow data (such as vortices, shock waves, etc.) and to base the visualization on the extracted flow features [PVH$^+$03]. Here we focus on the alternative approach of *interactive visual analysis* which utilizes human-computer interaction to reveal interesting features in the data, based on the interests of the visualization user. This approach integrates the following key aspects:

1. Interactive Visualization –

   Flexible means of interactive visualization are provided so that the visualization user can easily investigate all the different aspects of the simulation data. On demand, the visualization user can investigate all the attribute distributions in the simulation data, either isolated, i.e., as data distribution with respect to one attribute dimension only (e.g. in a histogram), in relation to any other attribute dimension, i.e., in the form of a distribution of 2D, 3D, or nD relations between selected data attributes (e.g. in a scatterplot), or in relation to the data's spatial and temporal context (e.g. in a time-varying 3D rendering).

   In figure 1 we see the distribution of flow velocities in a simulation of hurricane Isabel in a histogram (lower left). We also see the relation between velocities and pressure values in a scatterplot (upper left) as well as the distribution of flow velocities in one horizontal slice through color coding (on the right).

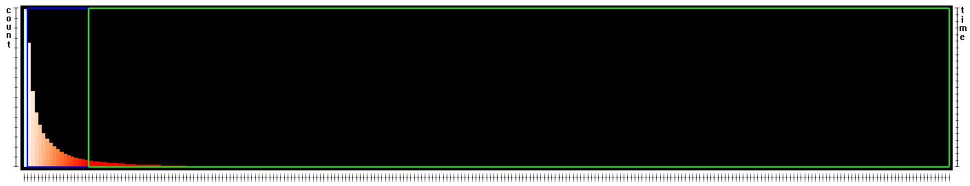

Figure 2: Through interactive brushing in a histogram (a measure for how cloudy a cell is along x), the user has focussed on the clouds in the data.

2. Interactive Feature Specification –

   In conjunction with the interactive visualization, the user has the opportunity to interactively specify selected features in the data according to his or her interests. This is enabled through the mechanism of interactive brushing, i.e., the user is enabled to interactively mark up interesting data subsets directly in the views. Through this mechanism it is possible that the user can focus on data subsets of special interest, e.g., fast flow or flow regions of low pressure. In figure 2 a brushed histogram is shown. The histogram was configured to show the distribution of `cloud` values in the data (how cloudy a cell is). Through the operation of brushing the middle to right parts of the histogram, the user indicated an interest in cloudy cells.

   In this example, a *smooth brush* has been used [DH02] which allows for a gradual selection of data subsets so that data entries in a transitional region (between fully selected and unselected data subsets) are partially selected. Thereby a smooth transition between selected and not selected data subsets is possible. With smooth brushing a degree of interest (from the unit interval) is assigned to all the data items.

   Often, it is not enough to enable focussing with respect to one selected attribute dimension only, e.g., just on flow velocities. In many cases, users formulate their interest in terms of more than just one attribute. In views which depict the relations between two or more data attributes, e.g., a scatterplot or the like, also interactive brushing leads to subsetting in relation to the visualized dimensions. In a 2D scatterplot with flow velocities on x and `cloud` values on y, for example, a rectangular brush can lead to a selection which is characterized by high velocities *and* high `cloud` values, i.e., the selection of the fast clouds in the data (figure 3, right).

   In many cases, however, this still is not enough. For advanced analysis, often combinations of several brushes in different views are necessary to capture a specific phenomenon in the flow. To enable the user to formulate such queries to the simulation data, a so-called feature definition language is very useful [DGH03]. In a tree of logical combinations different brushes can be combined, even from different views and through different logical operations (`AND`, `OR`, `SUB` = `AND NOT`). Thereby, also structures which require complex specifications can be captured by the visualization. To capture the oxidation front in a combustion process, for example, temperatures, oxidation products, and spatial locations are considered during feature specification [DMG$^+$04].

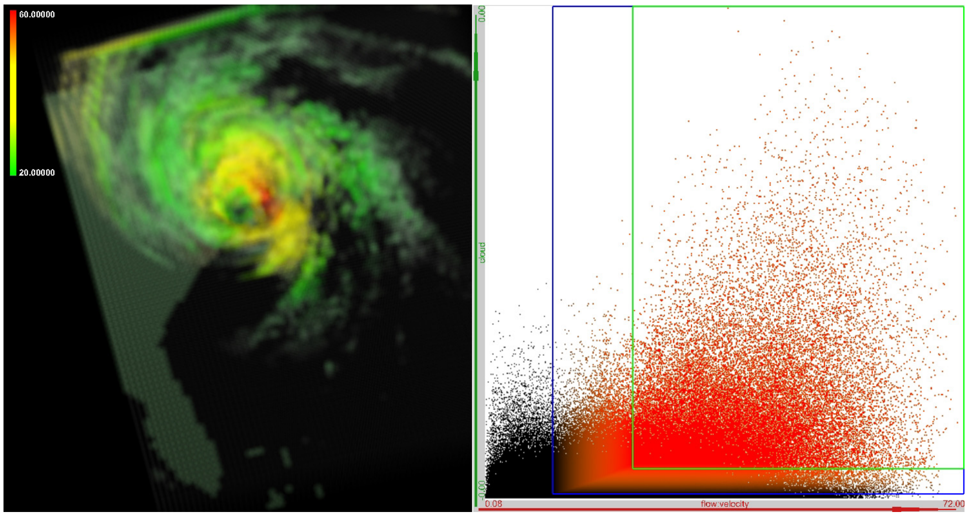

Figure 3: In the scatterplot on the right (flow velocities on x, `cloud` values on y) the fast clouds in this data set have been markes with a rectangular brush. The 3D view on the left shows this selection enhanced (more opacity and color coded according to flow velocities).

3. Focus+Context Visualization and View Linking –

   Interactive brushing is very useful to intuitively select interesting subsets in a large and complex dataset. Once a specific data subset is selected, different options with respect to visualization exist. One straight-forward approach is to confine the visualization (after brushing) to the selected data subset only (and to do not show the rest of the data). While this approach usually has the advantageous side effect that visualization becomes more effective if less data is to be shown (and thereby visualization becomes faster), it also has the drawback that if too much data is excluded from visualization an additional mental load is generated on the user side – it becomes more difficult for the user to stay oriented and to keep the visualized data subset in mental relation with the rest of the data.

   A very interesting approach is to use focus+context visualization instead [Hau05]. Instead of omitting the unselected data subsets from visualization, they are included in a reduced visual form, e.g., without being colored and rather transparent. Thereby, it becomes easy to visually relate the selected data subsets to their context. In figure 3, on the right, red points represent selected data items whereas black points represent their context. On the left, the selected data subset (fast clouds) are shown rather opaque and colored whereas the context is rather transparent and not colored.

   View linking is of great importance, when brushing is used in conjunction with multiple views. Once a specific data subset is marked with a brush in one view, all other views of the same data (which also reflect subset selection, e.g., in a focus+context style) need to be updated instantly. Thereby, visual consistency is maintained be-

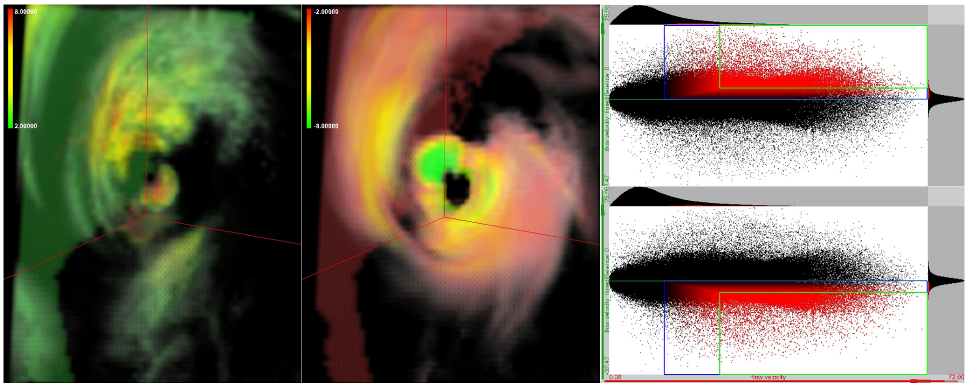

Figure 4: Change visualization after data derivation. An approximation of the temporal derivation of the velocity attribute has been derived interactively and then used for visualization. Fast winds which still accelerate are selected in the top right and spatially located in the left (red means strong acceleration). Fast winds which decelerate are selected in the lower right and located in the middle (green means strong deceleration).

tween the views. The great potential of this approach is that through the use of multiple linked views, interactive brushing, and focus+context visualization an explorative analysis of multi-variate features within simulation data is enabled.

4. Interactive Attribute Derivation and Iterative Analysis –

   An interactive brushing framework as described above is very powerful and enables an efficient and rewarding interactive visual analysis of large and complex datasets in many cases. To furthermore advance the analytic procedures in this context, it is useful to also enable interactive attribute derivation. The visualization user can instantiate additional, synthetic data attributes which contain the results of computations which are carried out on the given data. Thereby, some of the advantages which computational methods provide (such as vortex extraction methods or the like) can be integrated within this approach.

   It proved to be very useful, for example, to enable the user to compute local derivates (either with respect to spatial dimensions or especially also with respect to time) of selected data attributes. Treating derived data attributes just as original ones and enabling iterative analysis in the sense that brushes can be moved, changed, and extended in a continued loop of interactive focussing and visual feedback, allows for advanced analysis of simulation data.

   In figure 4 a sample result is shown. First, interactive data derivation has been used to compute the changes of flow velocities with respect to time. Then, this new data attribute is used to visualize all those locations in the data which are exposed to strong winds which will still accelerate (top right & left) or already decelerate (bottom right & middle).

The above described approach of interactive visual analysis has been implemented in a system called SimVis at the VRVis Research Center in Vienna, Austria [Dol04, HD04, www.SimVis.at]. It has been successfully applied to a number of application cases, including the interactive visual analysis of a Diesel exhaust system [DMG+04], combustion processes [DMG+05], a cooling jacket [LGD+05], or meteorological datasets such as the hurricane data [DMH04].

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References

[DGH03] H. Doleisch, M. Gasser, and H. Hauser. Interactive feature specification for focus+context visualization of complex simulation data. In *Proc. 5th Joint IEEE TCVG – EG Symp. on Visualization (VisSym)*, pages 239–248, May 2003.

[DH02] H. Doleisch and H. Hauser. Smooth brushing for focus and context visualization of simulation data in 3D. In *Proc. WSCG 2002*, pages 147–151, February 2002.

[DMG+04] H. Doleisch, M. Mayer, M. Gasser, R. Wanker, and H. Hauser. Case study: Visual analysis of complex, time-dependent simulation results of a diesel exhaust system. In *Proc. 6th Joint IEEE TCVG – EG Symp. on Visualization (VisSym)*, pages 91–96, 2004.

[DMG+05] H. Doleisch, M. Mayer, M. Gasser, P. Priesching, and H. Hauser. Interactive feature specification for simulation data on time-varying grids. In *Conf. on Simulation and Visualization 2005 (SimVis 2005)*, pages 291–304, 2005.

[DMH04] H. Doleisch, P. Muigg, and H. Hauser. Interactive visual analysis of hurricane isabel with simvis. Technical Report TR-VRVis-2004-058, VRVis Research Center, 2004. www.SimVis.at/Isabel.

[Dol04] H. Doleisch. *Visual Analysis of Complex Simulation Data using Multiple Heterogenous Views*. PhD thesis, Vienna Univ. of Techn., 2004. www.VRVis.at/vis/resources/diss-HD.

[Hau05] H. Hauser. Generalizing focus+context visualization. In G.-P. Bonneau, Th. Ertl, and Gr. Nielson, editors, *Scientific Visualization: The Visual Extraction of Knowledge from Data*, pages 305–327. Springer, 2005.

[HD04] H. Hauser and H. Doleisch. About SimVis and the related state of the art. Technical Report TR-VRVis-2004-028, VRVis Research Center, 2004.

[LGD+05] R. Laramee, C. Garth, H. Doleisch, J. Schneider, H. Hauser, and H. Hagen. Visual analysis and exploration of fluid flow in a cooling jacket. In *Proceedings IEEE Visualization '05*, pages 623–630, 2005.

[PVH+02] F. Post, B. Vrolijk, H. Hauser, R. Laramee, and H. Doleisch. Feature extraction and visualization of flow fields. In *EG State-of-the-Art Reports*, pages 69–100, Sept. 2002.

[PVH+03] F. Post, B. Vrolijk, H. Hauser, R. Laramee, and H. Doleisch. The state of the art in flow visualization: Feature extraction and tracking. *Computer Graphics Forum*, 22(4):775–792, Dec. 2003.