Advanced Visualization of Tensors

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Summary

To aid in visualizing complex simulation data, we modernize a well-known, century-old method of looking at tensors.

As they push the limits of simulation research, computer scientists work with larger, more complex data. Understanding the resulting data is an area of important visualization research.

A simulation can produce many types of data. Some of the data are easy to understand on graphs. More complex quantities, such as points and vectors, can be represented in three dimensions - a point is often visualized as a dot, and a vector as an arrow pointing in a particular direction. A simulation can also produce complex quantities consisting of nine values called tensors. A tensor encapsulates information about rotation and stress at a particular point in space. Looking at the nine values, it's hard to get a good understanding of all of the information it contains. This is part of the challenge in visualizing tensors.

Visualization researchers develop techniques to visualize data like tensors. They'd like to create pictures that give scientists an intuitive feel for the data from their simulations. However, sometimes it's hard to understand the picture that results. Sometimes, a useful research technique cannot be put into production because scientists cannot easily understand it. If a

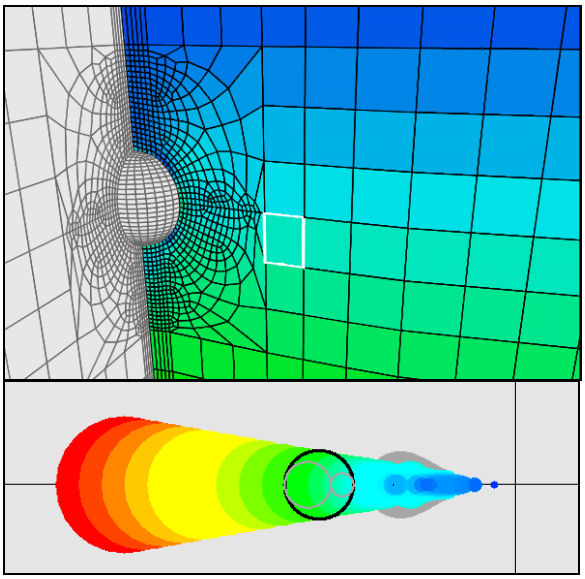

Figure 1. Multiple views of simulation data. Top view is a conventional view of finite element simulation. Bottom view is the interactive Mohr diagram.

visualization technique relates to the knowledge of the person using it, it's easier for them to understand, and can be more easily adopted.

To create a visualization technique for tensors, visualization researchers met with mechanical engineering researchers and experts in tensors. They discovered that there are graphical techniques that are already used to understand tensors. Mechanical engineers learn these techniques

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during their undergraduate education, so these techniques provide a common information visualization language that the customer already understands. The visualization researchers took advantage of this language to try to solve new problems.

The technique that was explored and expanded was developed around 1900 by Otto Mohr. Mohr developed a graphical technique to help people intuitively understand tensors. Called a Mohr diagram, it helps people understand the information contained within the tensor. This information is extremely difficult to extract by just looking at the numbers.

In a Mohr diagram, a triplet of circles, known as a Mohr's circle, represents a single tensor. The position, size, and internal composition of the Mohr's circle all show information about the tensor. A Mohr's circle to the left of the vertical axis represents an area in the data that is in compression. A Mohr's circle to the right of the vertical axis represents an area that is in tension. A big Mohr's circle shows a tensor with stresses that are very different, while a small Mohr's circle shows a tensor that has stresses that are very similar. (See Figure 2)

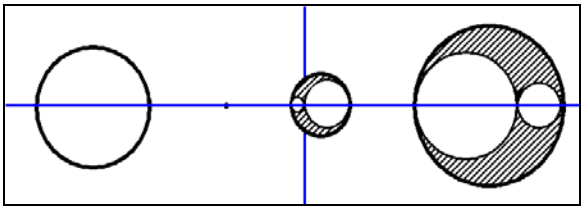

Figure 2. Mohr diagram, showing four Mohr's circles and internal details

A conventional Mohr diagram contains all this information in a form that engineers already understand. The visualization researchers' contribution lies in extending this technique. First, they provide a context for a Mohr's circle, which lets the scientist see how a single tensor relates to other tensors. In addition, the new Mohr diagram is interactive. As the scientist moves the mouse over the data view, the interactive Mohr's view is updated so that the 'focus' diagram shows information about the area under the pointer.

This visualization technique has been well received by researchers working with tensors, and by those who use tensors in drilling applications. The data set shown in Figure 1 is a preliminary simulation of a salt body surrounded by earth. Engineers use the simulation to understand the geomechanics around oil drilling sites. Tensor visualization is extremely important to these engineers, as they are primarily concerned with understanding the stress (compression or tension) and the rotation at every point in their simulations. Using a combination of the interactive Mohr diagram and conventional vector visualization techniques, engineers have been able to understand their data, and are working to improve it.

We plan to integrate this technique into ParaView, an open source application built on the open source visualization toolkit (VTK). ParaView will serve as a platform to quickly deliver visualization research code into a production tool that scientists can use.

By delivering our dynamic Mohr diagram visualization technique to engineers, we hope to help them understand their data by modernizing useful techniques developed almost 100 years ago.

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