Tensor Field Visualization in Geomechanics Applications

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Introduction

Scalar and vector fields, and especially tensor fields like stress and strain tensor fields, play an important role in the study of geophysics, including studies of mantle dynamics and crustal deformation. For example, time-varying tensor data result from finite element modeling of mantle dynamics, in which the stress and rate of strain tensors are calculated. We focus on visualizing tensor data to improve understanding of models of subducting slabs and bending phenomena in the Earth's lithosphere. The associated mathematical models and numerical simulations generate stress and strain data that are tensors.

The graphical representation of data and models is typically restricted to either scalar fields, such as a damage parameter, vector fields, such as velocity, or to representation of tensors at isolated points, such as earthquake focal mechanism. But there is much more information contained in the tensor fields. For continuous three-dimensional complex data sets it may not be obvious which locations to choose and thus the exploration of the entire data set is very cumbersome. A visualization method giving an intuitive overview of the tensor field allows an effective detection of interesting regions, which than can be investigated with classical

Geomchanics Applications

We apply new techniques developed for visualizing tensor fields to tensor data from two simulation examples. The first is a time-dependet two-dimesnsional data set resulting from a simulation of a model of the inelastic behavior of solid materials. Continuum damage mechanics is applied to the flexure of a plate under its own weight. Where the von Mises stress exceeds the yield stress within the plate, damage will occur, changing the material rheology. Damage formation relaxes the stress within the damaged material, and causes stress changes in the surrounding region.

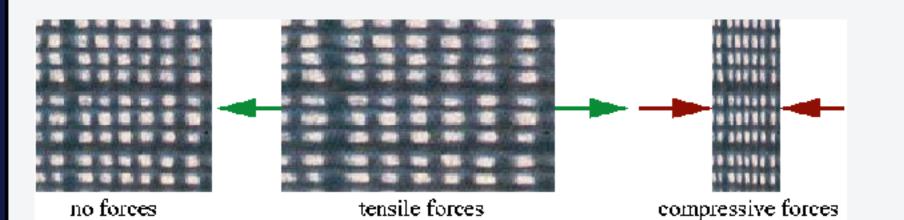
The second example we apply these techniques to a three-dimensional model of the subduction of a slab [Billen and Gurnis, 2003a and b, 2005, and Billen and Hirth, 2005]. The instantaneous stress and strain tensors in and around the slab were generated using the finite element method. The structure in the visco-plastic deformation simulation is modeled after the 3-D geometry of the subducting Pacific Plate beneath Southern Alaska. The structure in the visco-plastic deformation simulation is modeled after the 3-D geometry of the subducting Pacific Plate beneath Southern Alaska. The subducting plate resides in a plate boundary corner formed by an east-west trending subduction zone (convergent motion) that meets a north-south trending strike-slip boundary that extends south from the subduction zone. This model for the Southern Alaska subduction zone is the first 3-D model to explore the deformation of a slab in a plate boundary corner and the flow of the mantle around a slab edge. Understanding the pattern of deformation can help to understand the localization of strain and the evolution of the rheology in variable-viscosity models. Because seismic anisotropy can develop in the mantle as a consequence of flow patterns, developing a better method for visualizing the stress and strain-rate tensors can improve our understanding of the origins of anisotropy.

The usual method for conveying the results of these models is to plot graphs of displacement and single tensor components. These graphics, while extremely useful, do not make full use of all the information provided by the numerical models, including changes in the stress and strain orientation. The effective visualization of temporal and spatial evolution of the stress and strain tensors, together with the other connected scalar fields as material damage, temperature or pressure allows for quick identification of patterns and behavioral trends. These data exploration techniques can also facilitate comparison of models with observational data.

Visualization Method - 2D

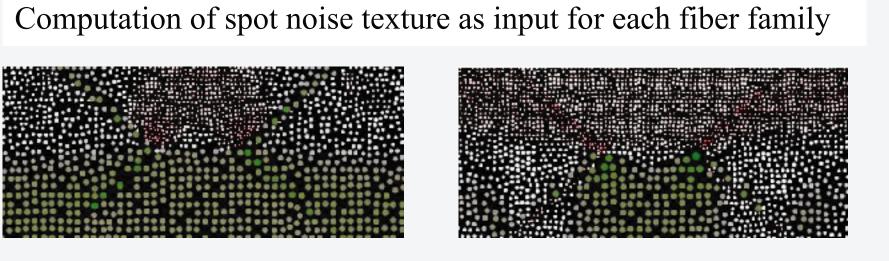
Texture Based Continuous Representation

Tensor field is mapped to a ``texture-deforming operator." Results in stretched or compressed and bent piece of fabric



Piece of fabric consisting of two fiber families with characteristic

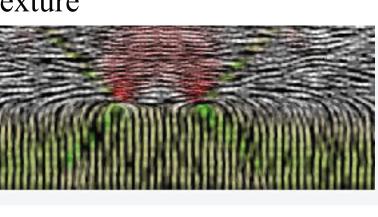
Method:

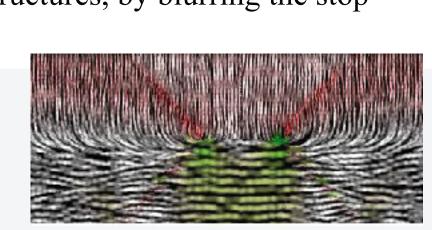


Line Integral Convolution (LIC)



Blurring of a noise texture in the principal stress direction





Step 3:

Combining both fiber families to generate the final texture

2D Example - Bending Plate under its own Weight

Color according to Eigenvalues

parameters: direction, density and color.

Texture Density Principal Stresses

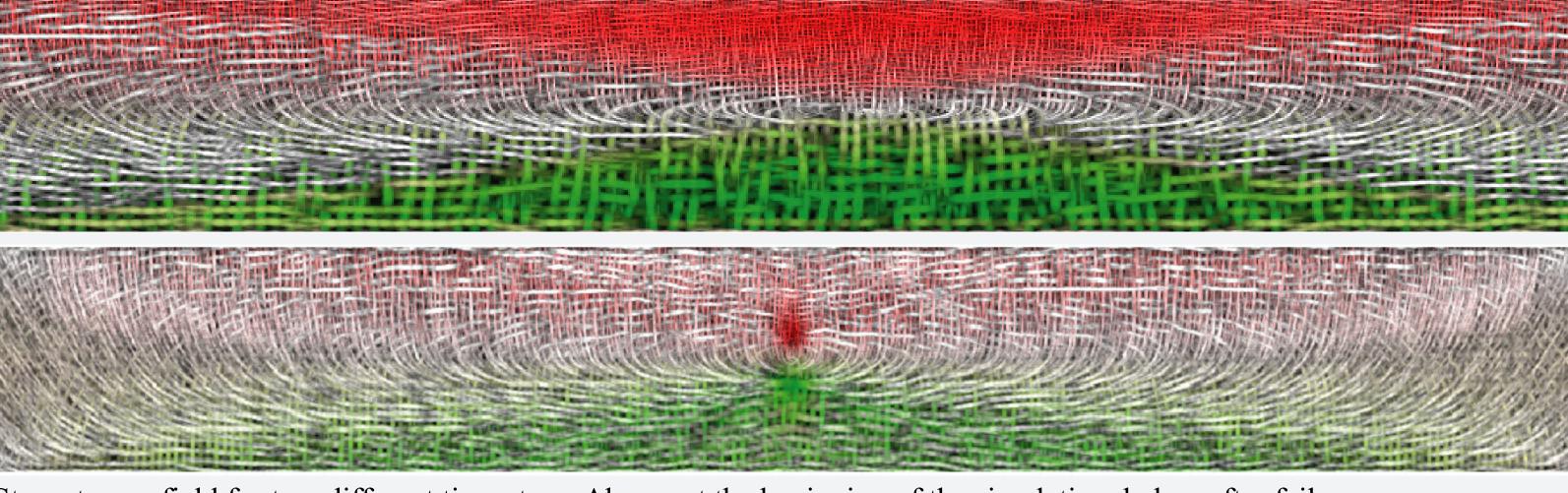
□Tensile Stresses □□ → Stretched piece of fabric

Compressive Stresses \square -> Compressed piece of fabric

-> Principal Stress Direction

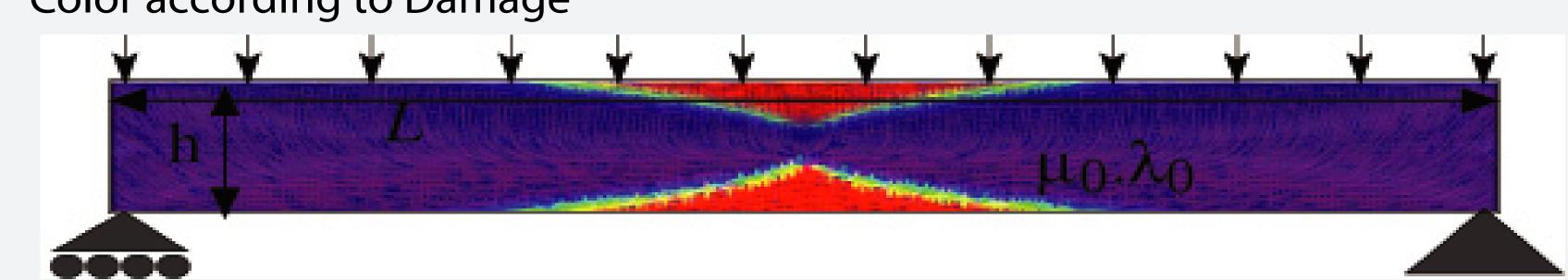
Texture definition:

Parameter specification:



Stress tensor field for two different time steps. Above: at the beginning of the simulation, below after failure.

Color according to Damage



Extension to 3D

Exploring 3D using moving surfaces

Texture-based methods are basically limited to 2D due to occlusion problems.

Solution:

Define one-parameter family of surfaces to explore

Final Visualization:

Display surfaces with fabric-texture representing the projected tensor filed moving through the

Surface Definition

Explicitly defined:

Based on a geometric property or symmetry inherent to the structure of the data. Examples: moving planes, cylinders, or parts of spheres or more complex surfaces as

Implicitly defined:

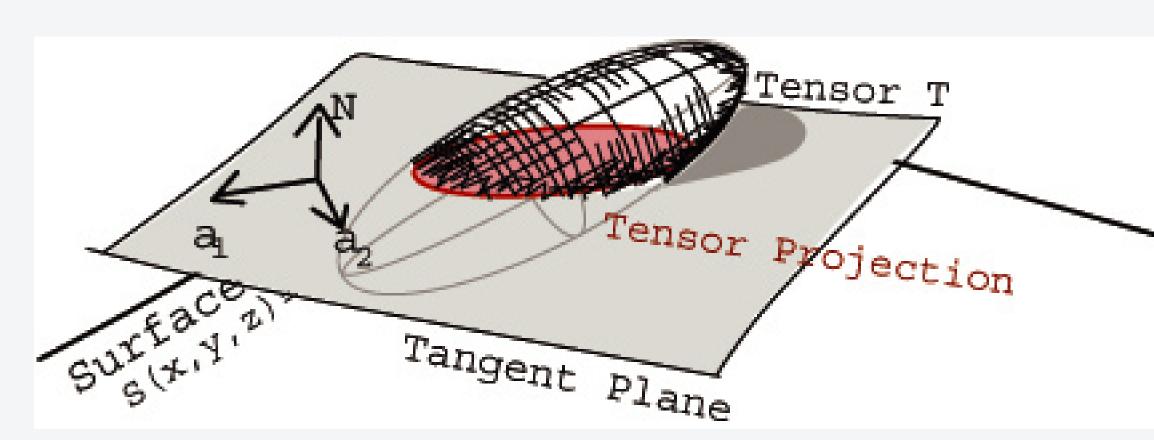
Isosurfaces based on a scalar field as isosurfaces e.g., pressure, temperature, or damage. This method supports supports the additional visualization of a connected scalar field.

Surface Representation: Volume rendering

Explicit extraction and visualization of the surfaces.

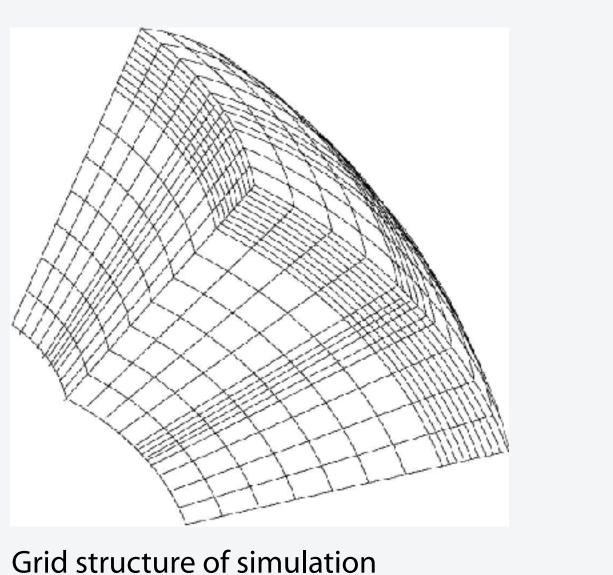
Tensor Projection

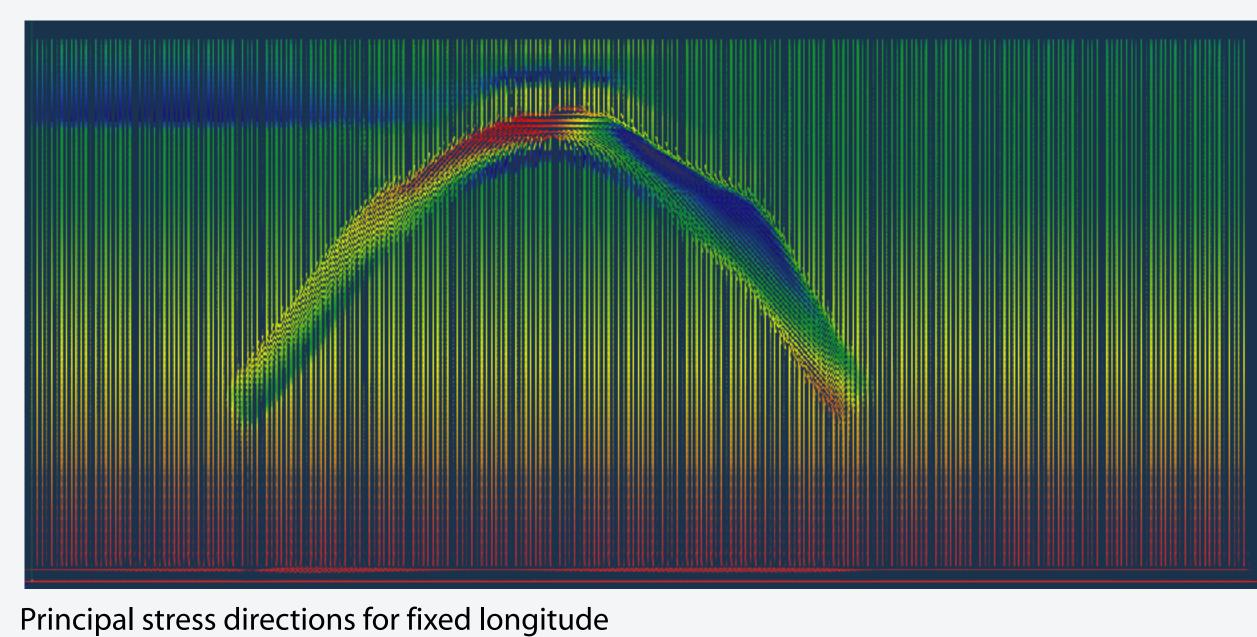
To compute the textures on the surfaces we project the tensor field onto the surfaces.

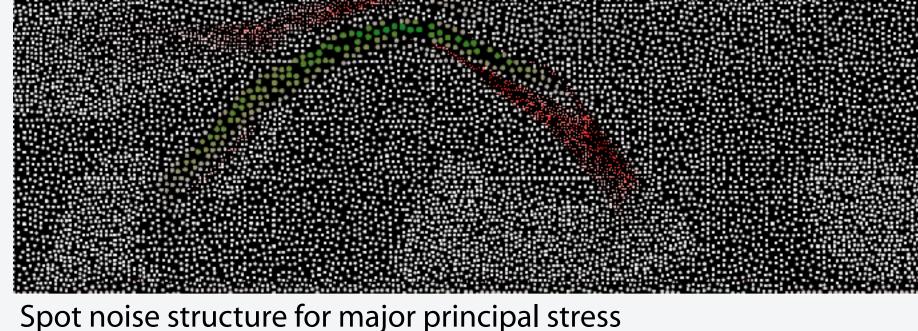


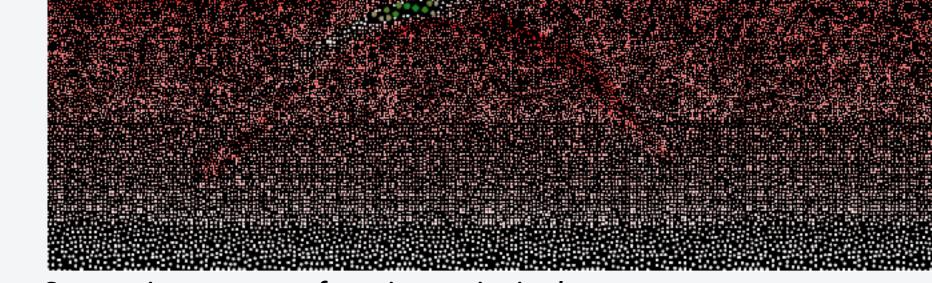
Examples

Subducting Pacific Plate beneath Southern Alaska

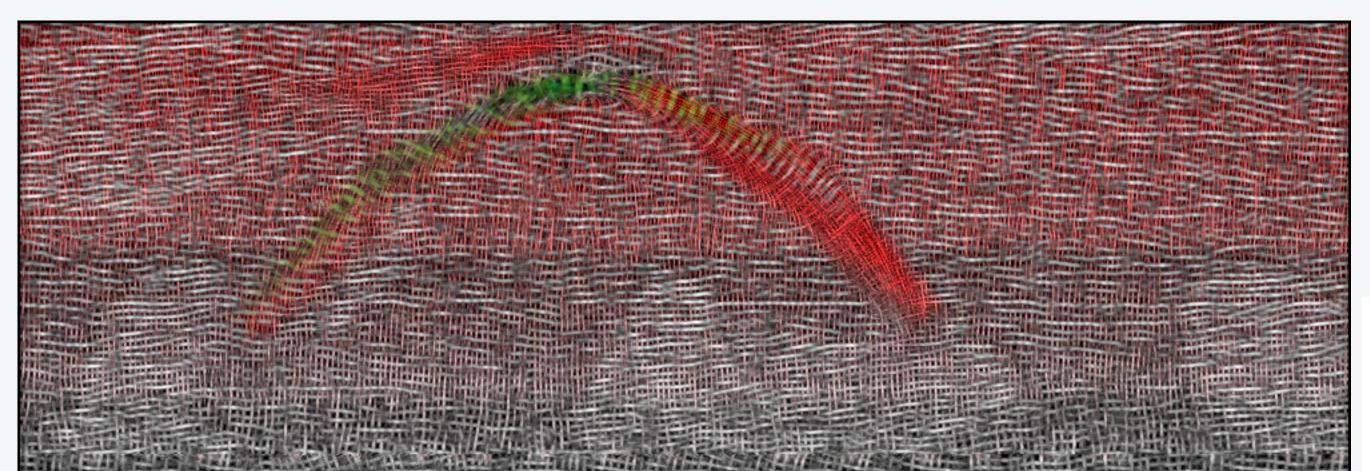




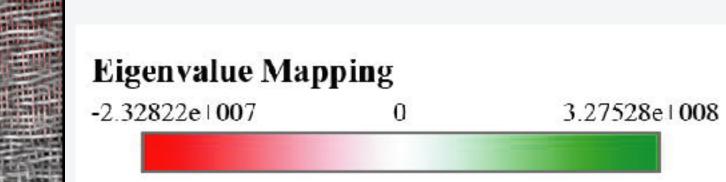


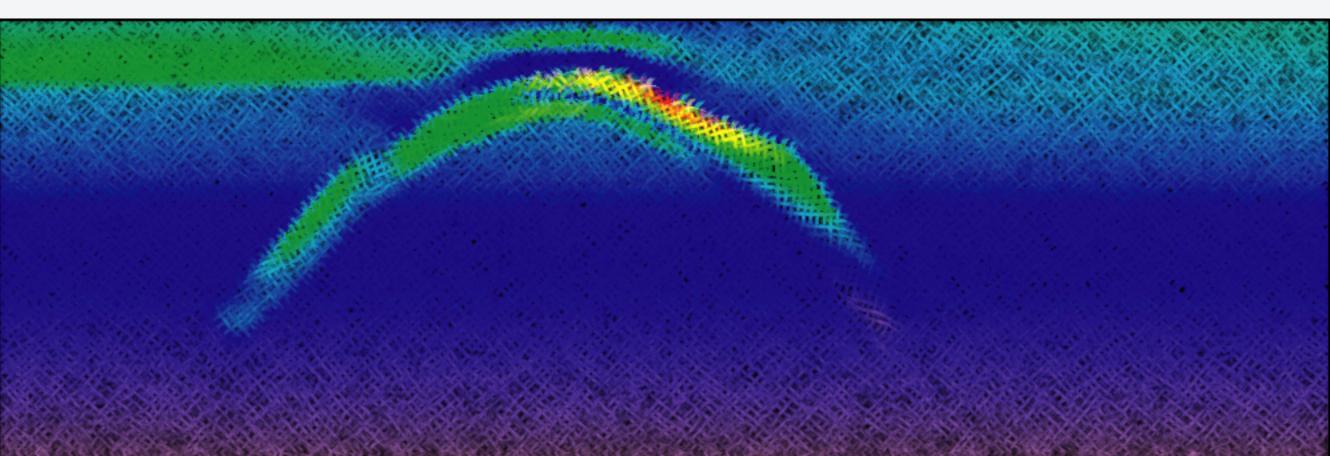


Spot noise structure for minor principal stress



Fabric texture showing the principal directions and principal values for a fixed Red color means compression, and green means tension.





Fabric texture showing the directions of maximum shear stress. The colors illustrate the maximum shear value.

Maximum Shear Stress 4.56803e1008

