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 earthquakes. For example, time-varying tensor data result from modeling the behavior of bending plates. Application areas we focus on are concerned with a better understanding of bending phenomena in rocks, in the Earth's lithosphere, and in subducting slabs. The associated mathematical models and numerical simulations generate stress and strain data that are tensors.

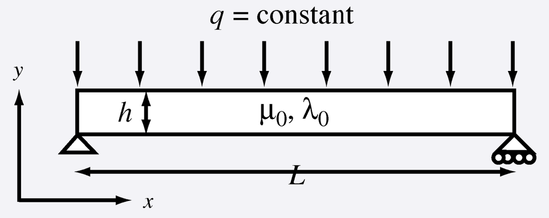
Tensors contain so much information and related components in each point that it is not easy to capture and visualize all information. Even though several visualization techniques exist for tensor fields, they only cover a few specific applications. Many of these methods are extensions of vector field visualization methods, which focus on a technical generalization without providing an intuitive physical interpretation of the resulting images. They often concentrate on the representation of Eigendirections and neglect the importance of the Eigenvalues. Additionally, showing the relationship between these tensor values and scalar quantities presents a unique challenge in visualization.

Geomchanics Applications

In the example below, we apply new techniques developed for visualizing tensors to a model of the inelastic behavior of solid materials. Since the 1980s, the engineering community has used continuum damage mechanics to describe such behavior [Kachanov, 1986; Krajcinovic, 1996]. More recently, the geophysical community used to continuum damage mechanics to describe inelastic behavior of the lithosphere [Lyakhovsky et al., 1997; Ben-Zion and Lyakhovsky, 2002; Shcherbakov and Turcotte, 2003, 2004; Turcotte et al., 2003; Turcotte and Glasscoe, 2004].

We apply continuum damage mechanics 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. Description of the methodology and results of the flexure calculations is presented at the poster session NG31A-0858 (Flexure with damage).

The usual method for conveying the results of these models is to plot graphs of displacement of the plate and to show the growth of the damage zone by displaying the damage parameter. 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 material damage and rheological properties, allows for quick identification of patterns and behavioral trends. These data exploration techniques can also facilitate comparison of models with observational data.



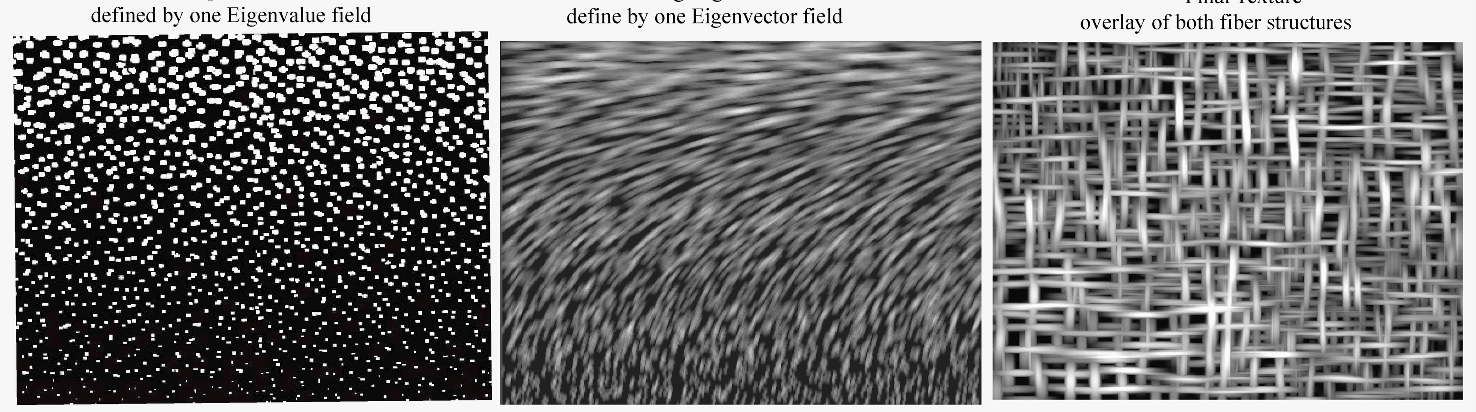
Visualization Methods

Texture Based Continuous Representation

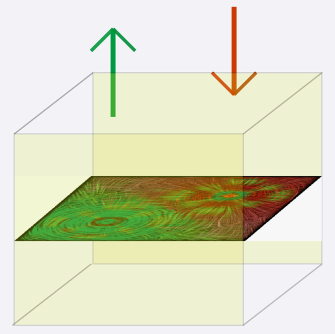
Idea:
Tensor field is mapped to a ``texture-deforming operator."
Results in stretched or compressed and bended piece of fabric

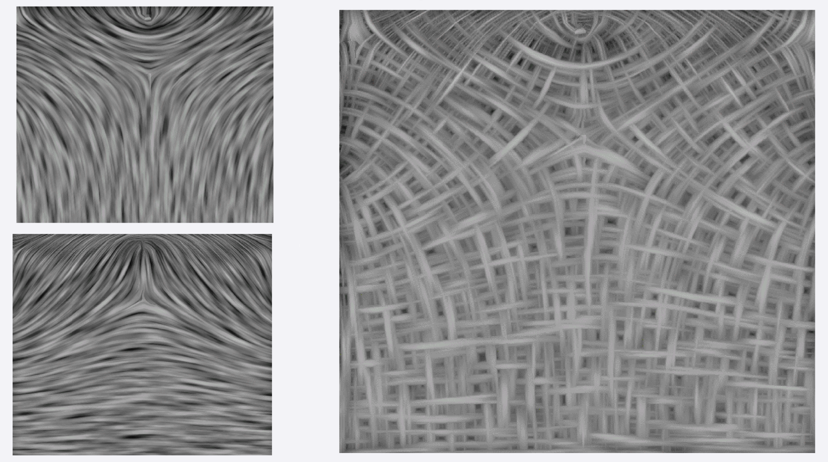
Method:
Line Integral Convolution (LIC)
Blurring of a noise texture in direction of the tensor

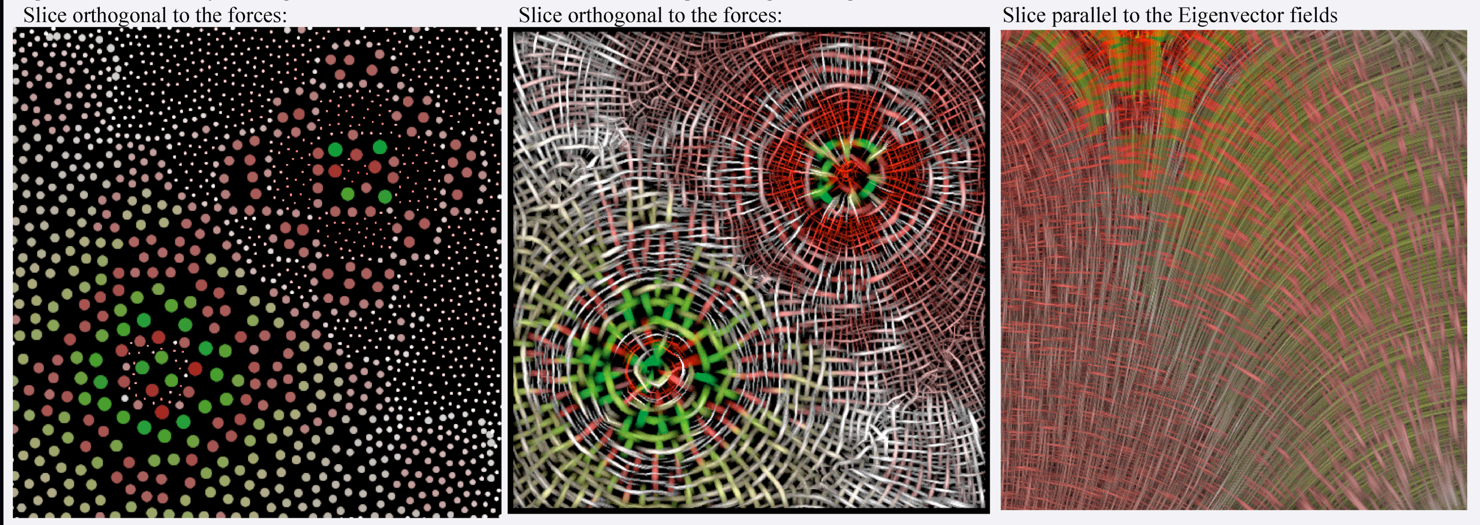
Eigenvalues -> Density of the Texture
Positive Eigenvalues -> Stretched piece of fabric
Negative Eigenvalues -> Compressed piece of fabric
Eigenvector fields -> Fiber Direction



One and Two-Point Load Data set:
3d-stress-tensor data set

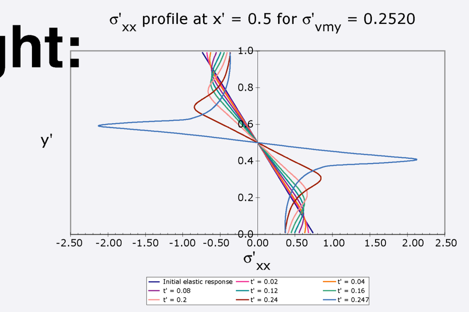


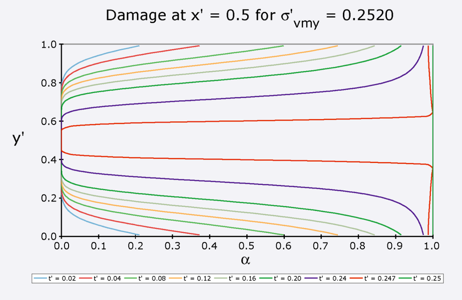


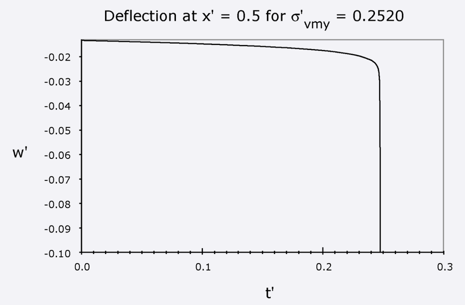


Results - Examples

Bending Plate under its own Weight:

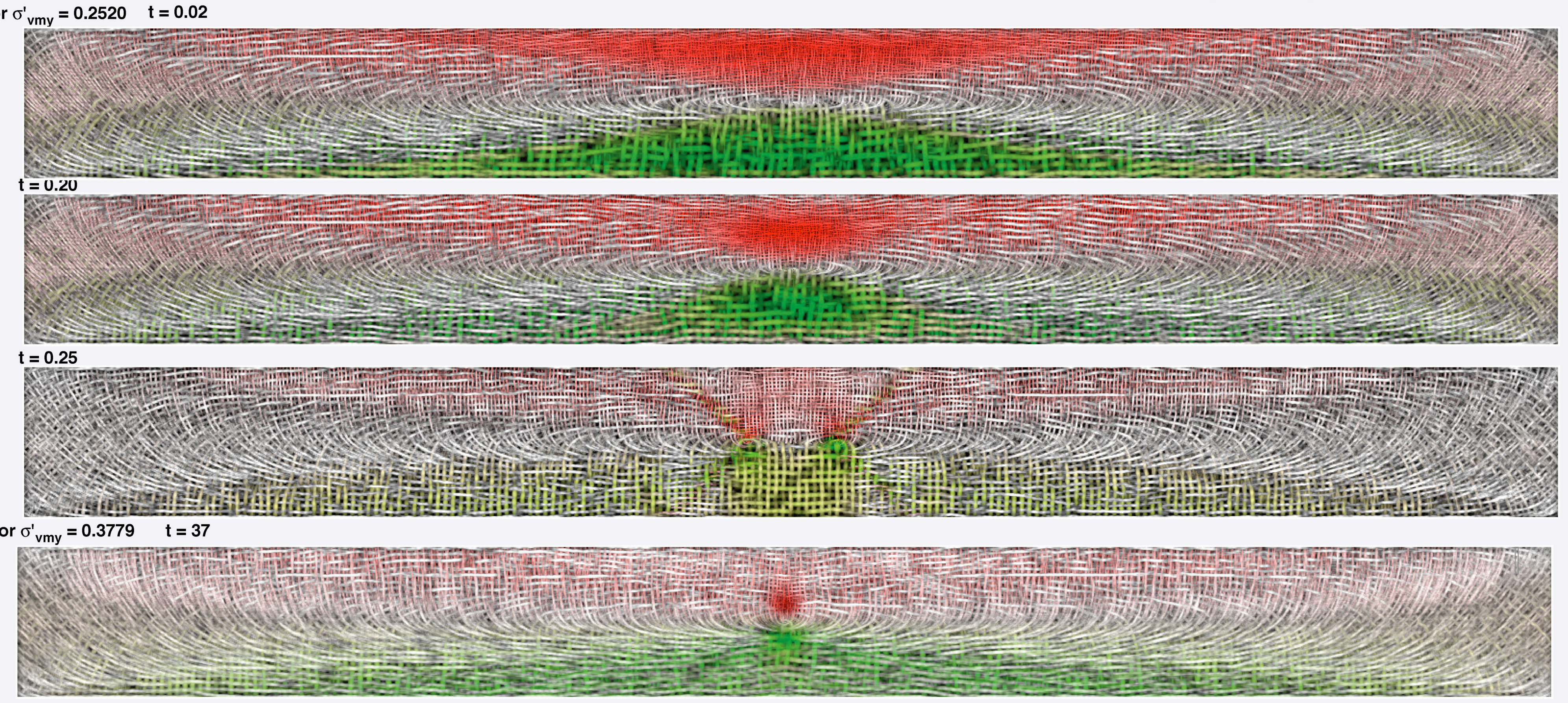




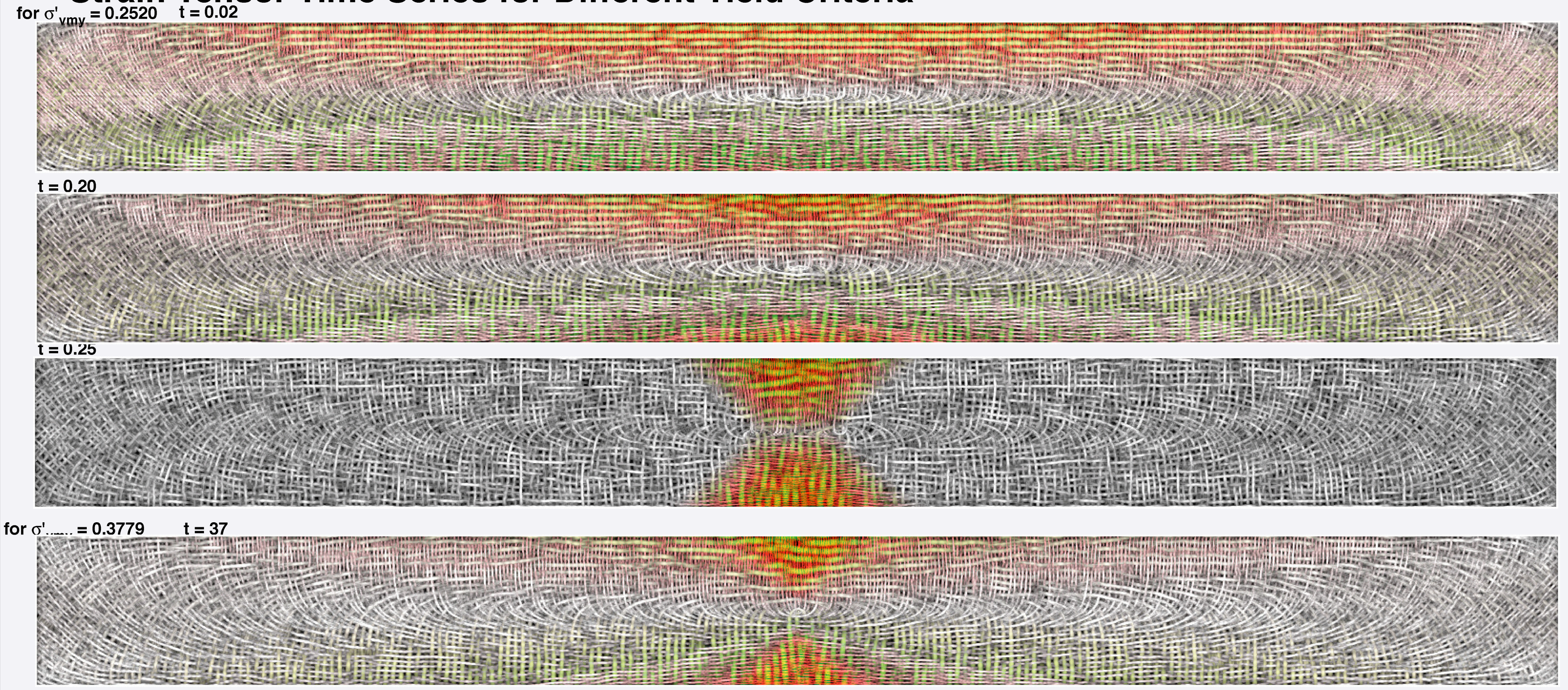


Stress Tensor Time Series for Different Yield Criteria

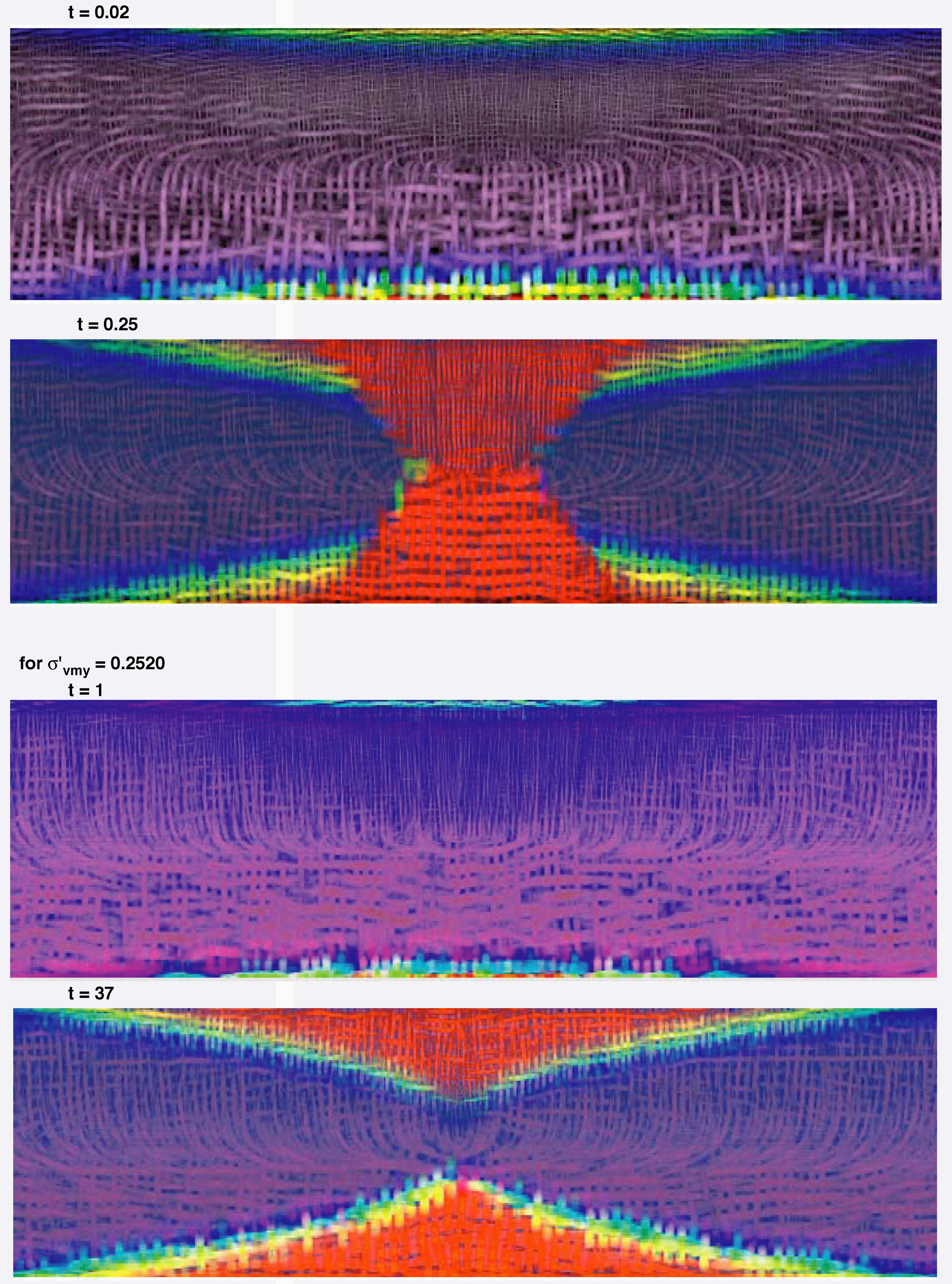
Color according to Eigenvalues



Strain Tensor Time Series for Different Yield Criteria



Color according to Damage



References

Ben-Zion, Y. and V. Lyakhovsky, Accelerated seismic release and related aspects of seismicity patterns on earthquake faults, *Pure Appl. Geophys., 159*, 2385-2412, 2002.

Delmarcelle, T., Hesselink, L., Visualization of second order tensor fields and matrix data. Proceedings of the Visualization '92 Conference, 1992, pages 316-323.

Hotz, I., Feng, L., Hagen, H., Hamann, B., Jeremic B., Joy, K., Physically Based Methods for Tensor Field Visualization. Proceedings of the IEEE Visualization '04 Conference, 2004, pages 123-130.

Kachanov, L. M., Introduction to continuum damage mechanics, Martinus Nijhoff, Netherlands, 1986.

Krajcinovic, D., Damage mechanics, Elsevier, Amsterdam, 1996.

Kriz, R.D., Glaessgen, E.H., MacRae, J.D., Visualization Blackboard: Visualizing gradients in composite design and fabrication. IEEE Computer Graphics and Applications, vol 15, 1995, pages 10-13.

Lyakhovsky, V., Y. Ben-Zion, and A. Agnon, Distributed damage, faulting and friction, *J. Geophys. Res., 102,* 27635-27649, 1997.

Shcherbakov, R., and D. L. Turcotte, A Damage mechanics model for aftershocks, *Pure Appl. Geophys., 161*, 2379-2391, 2004.

Shcherbakov, R., D. L. Turcotte, and J. B. Rundle, Aftershock statistics, *Pure Appl. Geophys.,* in press 2004.

Turcotte, D. L., W. I. Newman, and R. Shcherbakov, Micro- and macroscopic models of rock fracture, *Geophys. J. Int., 152*, 718-728, 2003.

Turcotte, D. L, and G. Schubert, Geodynamics, Cambridge Univ. Press, New York, 2002.

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