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Crease Surfaces for Seismic Wave Data Analysis and Visualization

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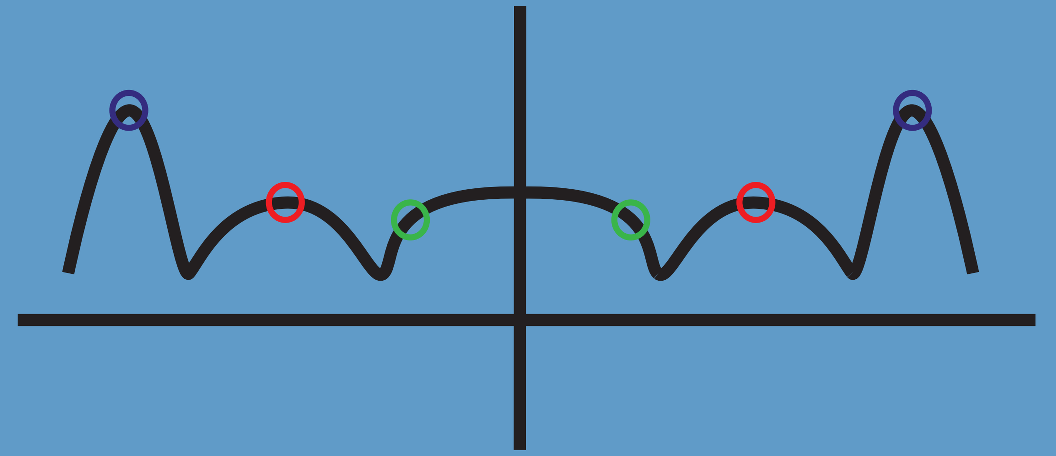
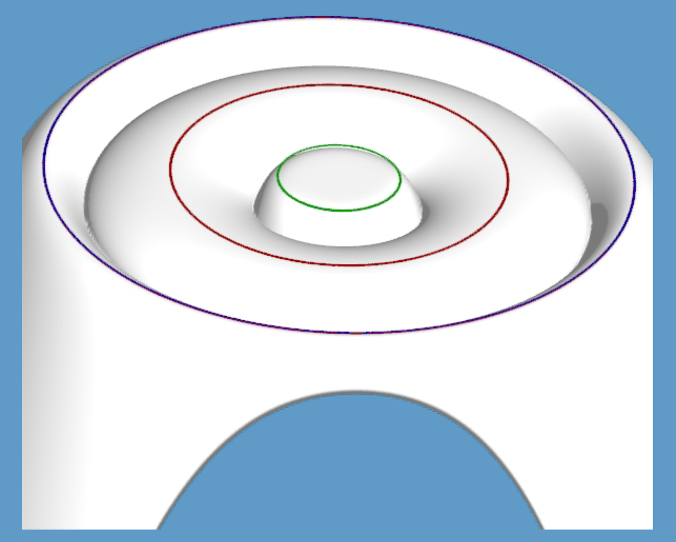
Crease surfaces are curvature-based surfaces corresponding to sharp changes in the spatial gradient of a volumetric scalar field. We are using these surfaces to visualize the most salient features in simulated seismic wave data, namely its crest and valley surfaces. The crests and valleys effectively represent the entire wave's motion, while requiring only a small fraction of the data set to be shown. Thus, we effectively address one of the most difficult problems in wave visualization, namely occlusion. By representing the wave data set by a set of surfaces, we are able to better differentiate changes in a wave's motion as it propagates through the control structure. This approach allows a scientist to better understand how the underlying model affects seismic wave propagation. Furthermore, this simplified representation is a valuable teaching tool for explaining complex behavior of wave propagation. We present our results on several data sets: two synthetic data set of an acoustic wave propagating from a point source, and a synthetic data set from the TeraShake 2.1 simulation of a 7.7 earthquake on the San Andreas Fault.

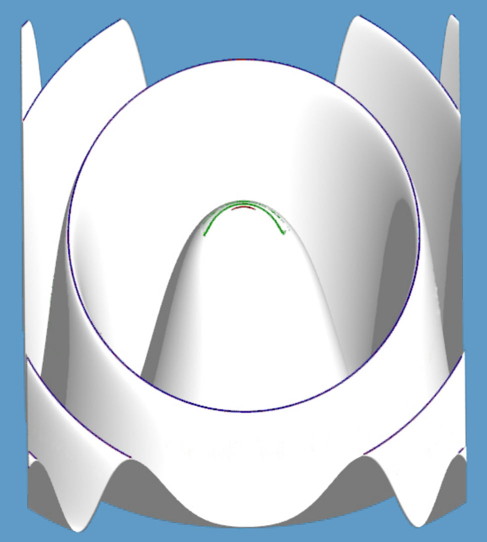
BACKGROUND

Our visualization method was motivated by finding points on a scalar valued function f where f depends on between one and three independent spacial variables (x,y and z), and also on an independent time variable (t).



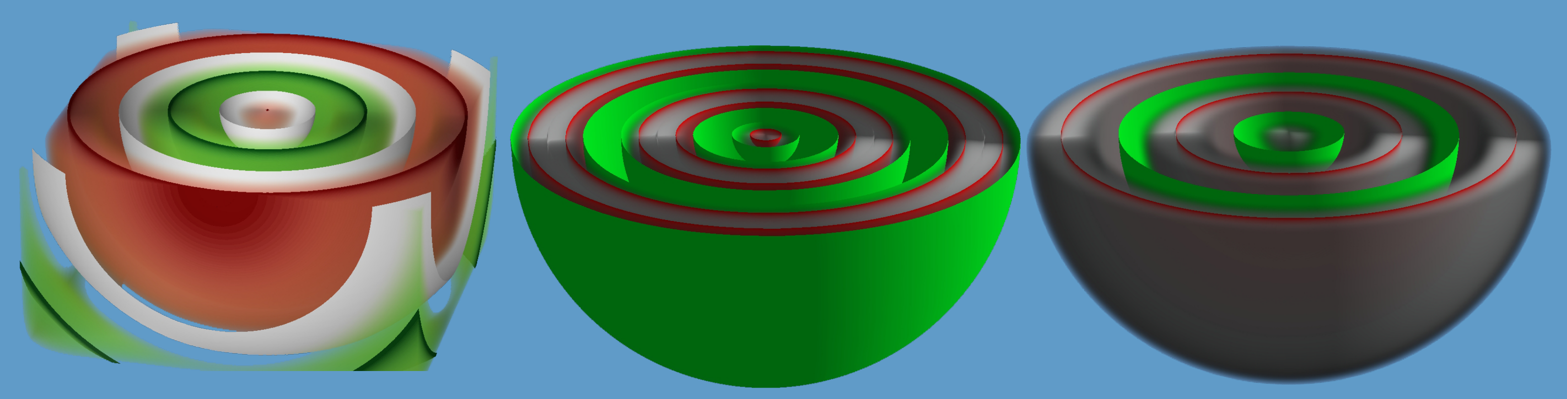
In the simplest case where f depends only on one spatial variable, i.e. f=f(x), we are interested in determining those points where either the function-value of f is locally extremal (red and blue) or where the curve defined by the tuple (x,f(x)) has locally extremal curvature (green and blue).



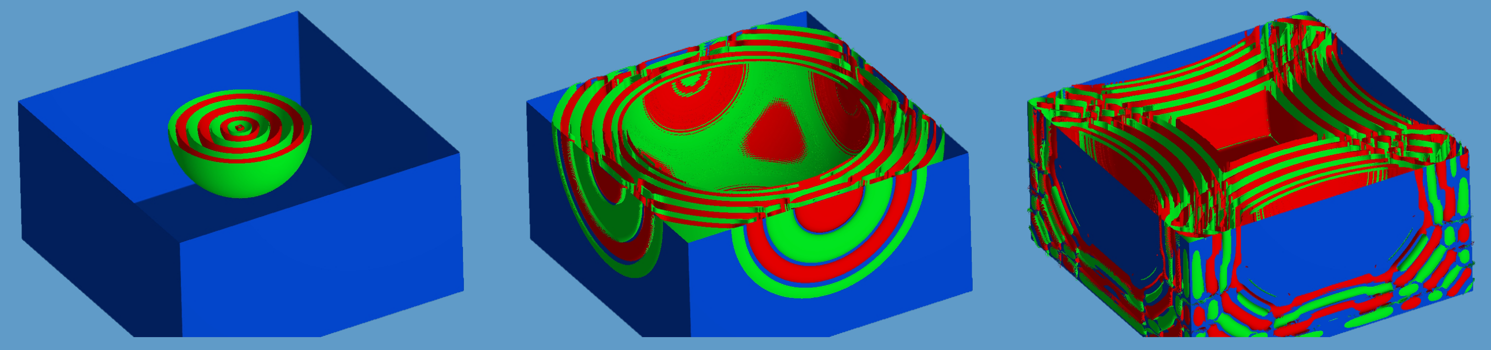


Considering now the case where f depends on two spatial variables. We are interested in those points which are locally extremal in function-value (height creases, red and blue) or principle surface curvature (curvature creases, green and blue) in at least one direction. We find this direction by using the principle directions of curvature on the surface defined by the tuple (x,y,f(x,y)).

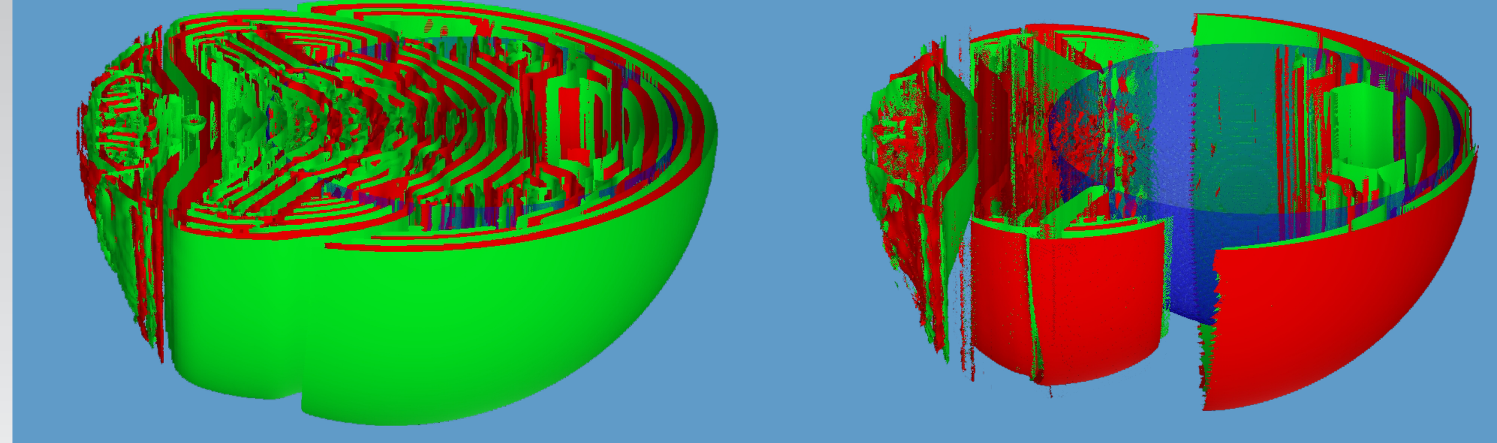
METHOD



In our application we are ultimately interested in visualizing functions of the form f(x,y,z,t). We extend the definition from the bivariate case to find points which are locally extremal in the direction of principal curvature for the hyper-surface defined by (x,y,z,f(x,y,z)). The direction of maximum curvature defines crest surfaces (red) and the direction of minimum curvature defines valley surfaces (green). We also distinguish between curvature extrema (upper middle) and function-value extrema (upper left).

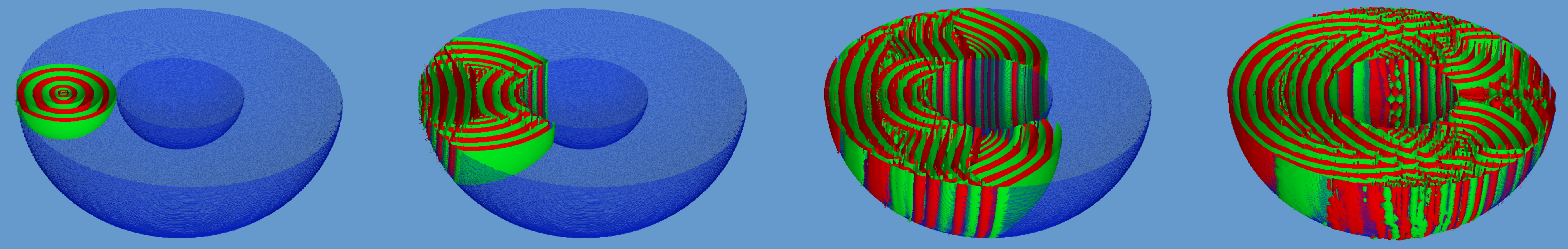


We want to visualize the evolution of these surfaces over time, to get a better understanding of how the underlying model affects wave propagation. In the above example we show three time steps from an acoustic wave simulation generated from a single point source. The control structure is homogeneous with a reflecting boundary. As the wave evolves we can clearly see the reflection off the walls and the resulting interference patterns.

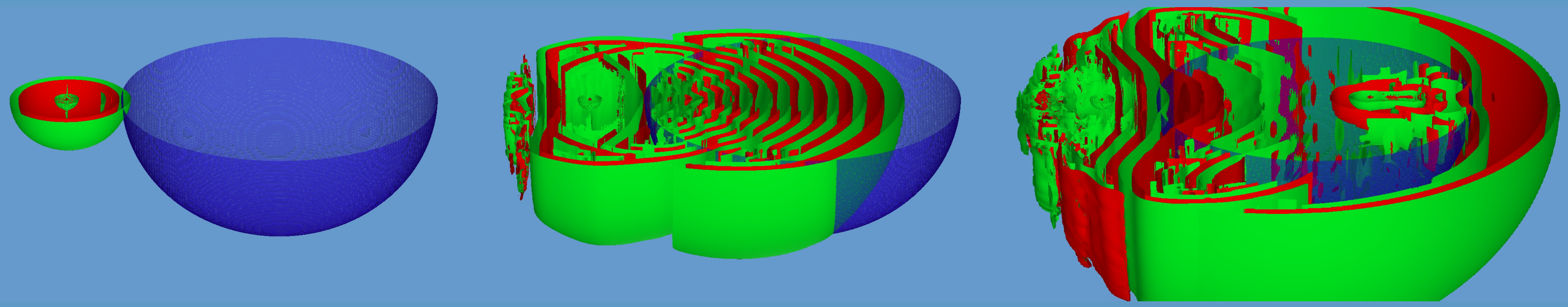


For many data sets visualizing curvature creases (left) or height creases (right) gives the user a different perspective. By manipulating a few intuitive parameters, the viewer can fine tune the final image to produce the most meaningful results.

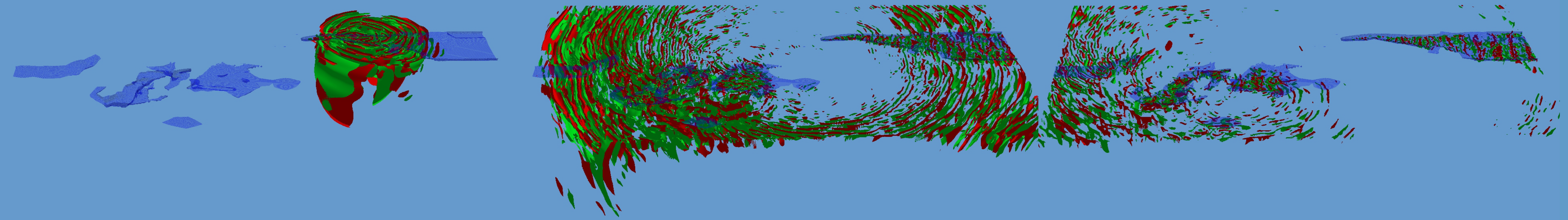
RESULTS



Above is the result of our method applied to a synthetic, acoustic-wave propagation data set. We use a homogeneous model with inner and outer spherical boundaries (blue). The wave emanates from a point source and reflects off the inner and outer boundaries. A clipping plane is used to view the interior.



Similarly we applied our method to a synthetic, acoustic-wave propagation data set, in this case using the PREM model of the earth as the control structure. The wave emanates from a point source in the mantle and both reflects and refracts off of the denser 'outer core (blue) as well as the outer boundary (not shown).



Finally we apply our method to the complex, synthetic data set taken from the TeraShake 2.1 simulation of a 7.7 earthquake on the San Andreas Fault. Several basins are represented in the control structure (blue). As the wave propagates down the fault line it resonates within the basins. These areas are of great interest as they are associated with the highest amount of damage. Our method clearly shows the resonation occurring long after the wave front has moved passed the area.

In conclusion we have found this method very effective for visualizing the wave propagation and better understanding how changes in the medium affect such propagation. We see this as an excellent tool for experts trying to understand the complex behaviors of seismic phenomena, as well as students learning about waves and there properties. In future work we will not only visualize these surfaces but extract them. Once extracted we can follow the motion of a single wave front and get a much clearer idea of the changes it undergoes while traveling through the control structure.