Uncertainty Visualization Prototypes for Materials Modeling

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INTRODUCTION

Material models describe the behavior of a specific material or class of materials and are used as inputs to multiphysics numerical simulations. Because the models are based on theory, they often require empirical information to calibrate or specify free parameters and results from the models may define ranges of possible values or a collection of valid scenarios. Sources of uncertainty within simulations are abundant; this work focuses on the uncertainty arising from variability in the material models and aims at understanding how users comprehend, incorporate, and utilize this qualitative information and how to enhance understanding through visual representations.

Our approach begins with understanding who the users of the material models are and how they are working with uncertainty information. To this end, we have conducted focus groups to engage modelers, analysts and code developers from the Sandia material modeling community in discussions on how visualization can help them understand the impact of material uncertainties in their workflow. The focus groups provided us with detailed insights into the challenge of developing usable and useful representations of material models and associated uncertainties for a user community with a wide range of interests and applications for such visualizations.

To facilitate discussion, we developed four visualization prototypes, each of which present uncertainty within a material model in a unique way. Participants evaluated specific features of each prototype and described scenarios in which different elements could prove helpful. We present each of the prototypes used in the focus group here, using results from a simplified equation of state simulation which produced seven realizations of a material surface.

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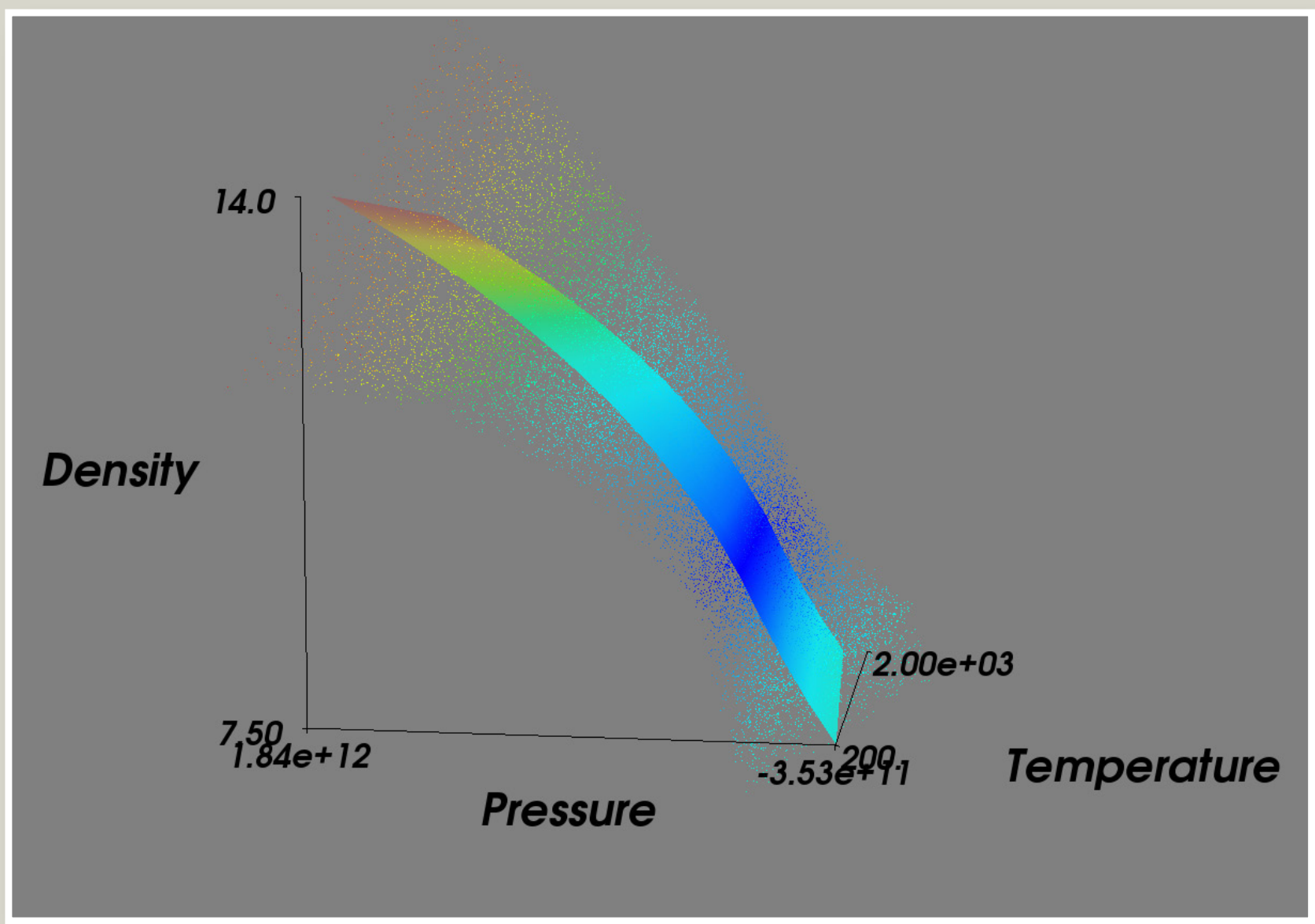
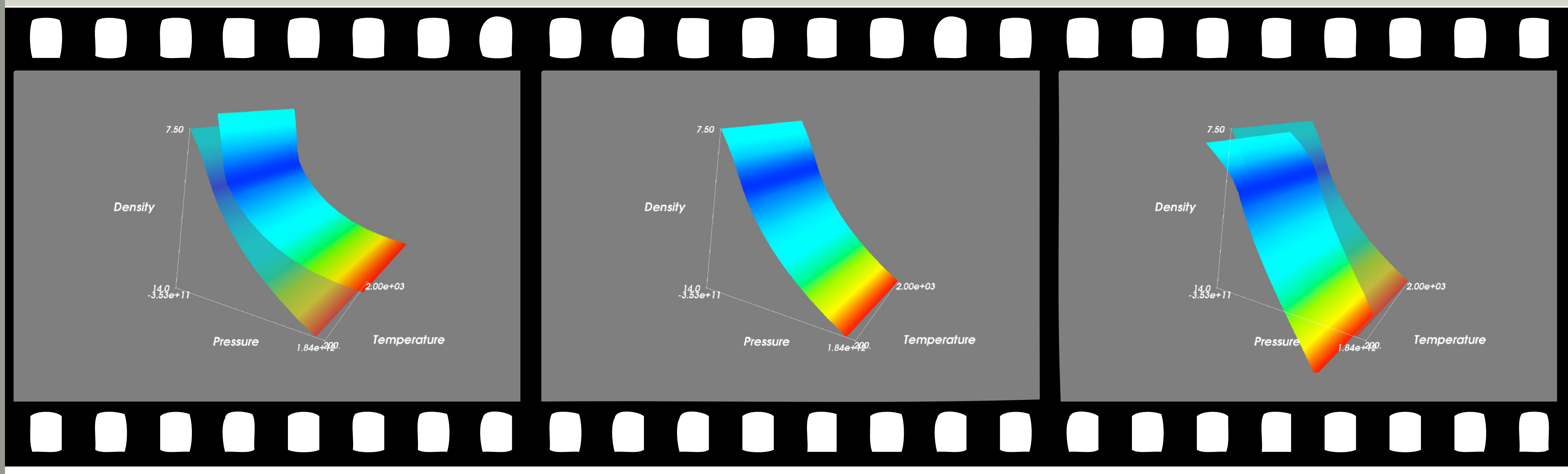
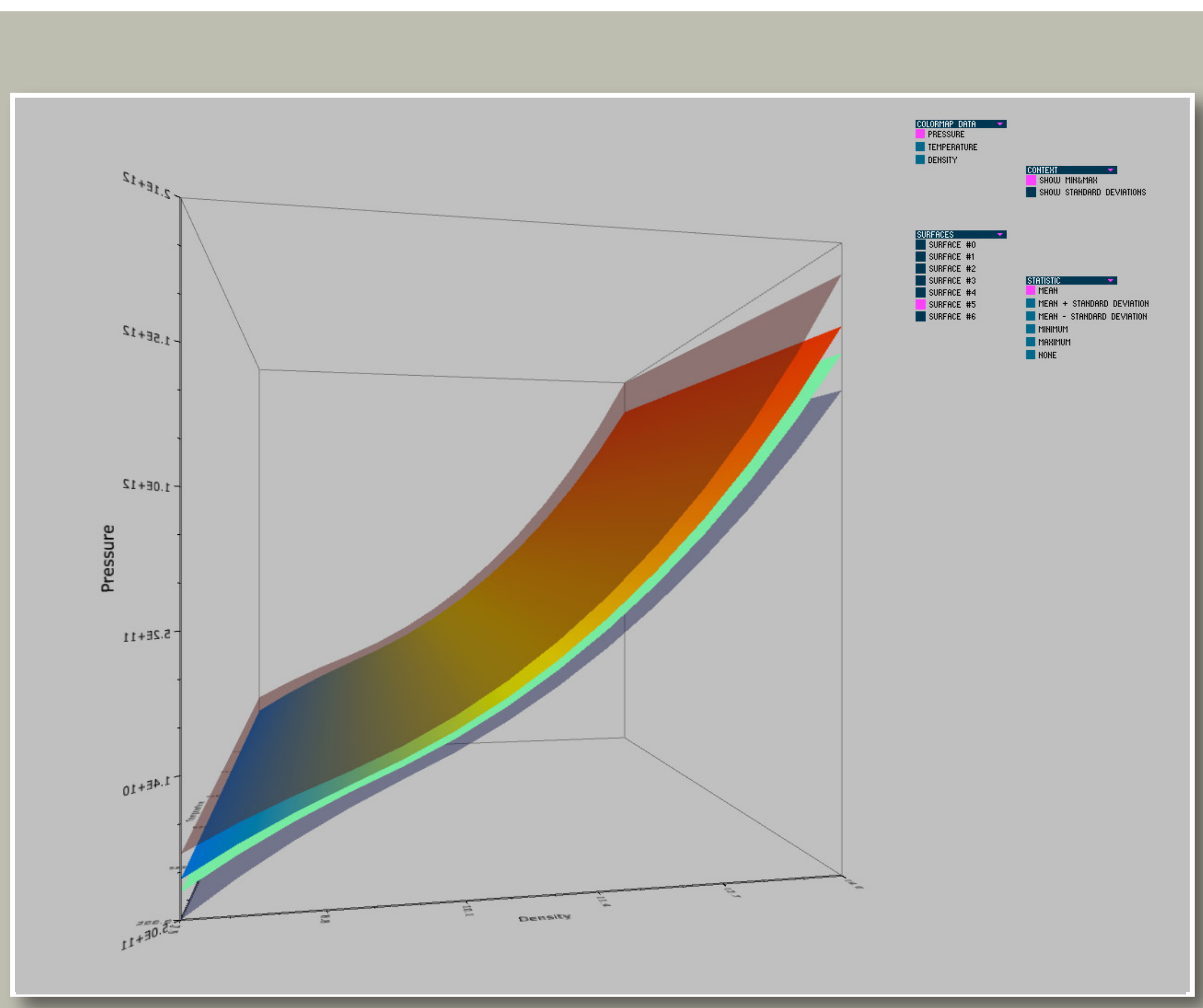


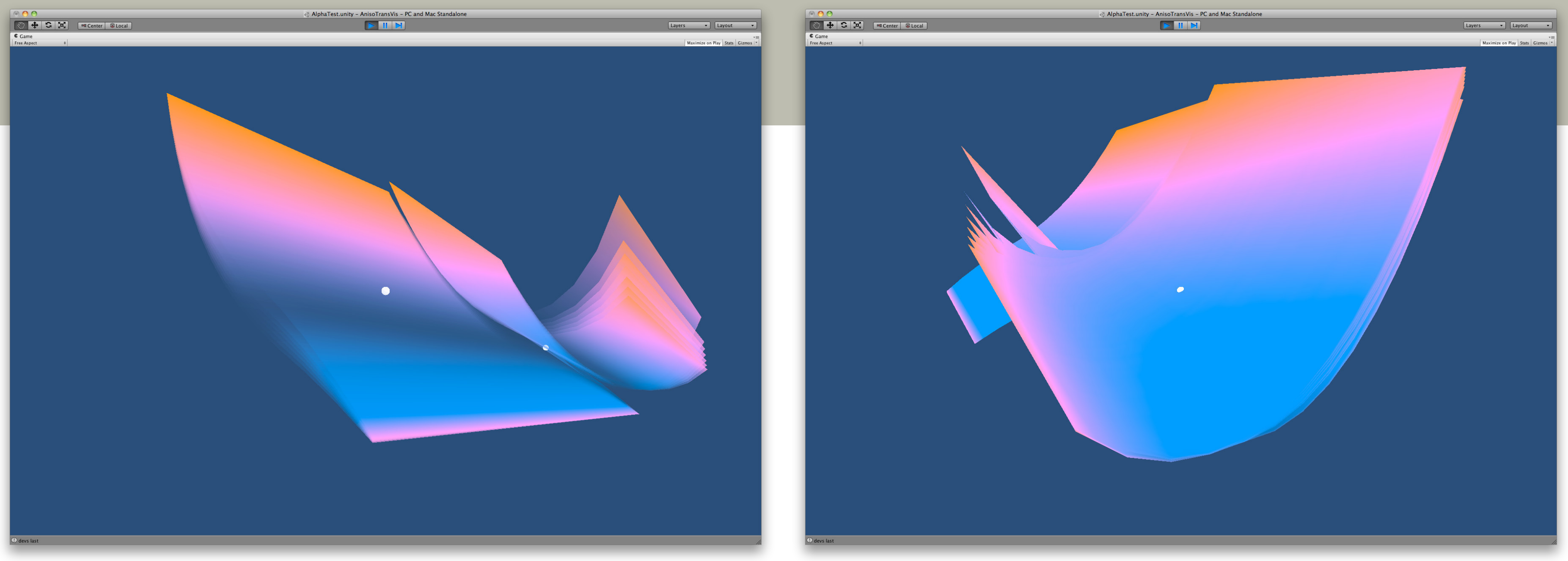
Point Cloud. The point cloud prototype implements a technique presented in [3] that renders a cloud of three dimensional points at a variable distance normal to a surface. The mean surface of the dataset is displayed centrally, indicating a likely position of the data. The distance each point in the cloud is away from the surface is random within a range defined by the amount of uncertainty about the surface location at a particular point. The algorithm creates a cloud of points that are further away from the surface in regions of high uncertainty, and closer to the surface in regions of lower uncertainty. Data colormapped onto the mean surface is reflected in the points, and transparency is used to redundantly encode uncertainty, making highly uncertain points more transparent. This creates a visual effect that feeds the expectation of the human visual system; regions of low uncertainty appear crisp and solid (blue areas), and regions of higher uncertainty appear hazy and indistinct (red areas).



Surface Animation. The surface animation prototype is based on a technique described by [2] that uses animated visual vibrations of the points defining a surface to show uncertainty in the surface location. The animation draws a fixed semi-transparent surface at the mean and sweeps another solid surface through one standard deviation above and below the mean surface. The animation transition is defined by a sinusoidal equation which creates a smooth evolution between the minimal and maximal positions over time for each vertex in the surface mesh. If the floor and amplitude for each vertex corresponds to the uncertainty at that point on the surface, then the viewers eye will naturally be drawn to areas of high uncertainty as the surface animates. Other oscillation functions could be used that cause more rapid transitions between states, such as step and sawtooth functions.

Bounding Statistics. The bounding statistics prototype uses statistics similar to the traditional boxplot [4] to bound the valid regions of the simulation. The minimum, maximum, and mean surfaces are calculated point-wise, as well as the standard deviation between all surfaces in the simulation. The user is given control over the display of the statistical surfaces through a graphical interface which also provides options to show each of the simulation surfaces and contextual surfaces such as the mean +/- standard deviation. Data values can be colormapped onto the mean surface and the user may choose which data values are displayed. The mean surface is central and flanked by the minimum and maximum surfaces which have reduced transparency to reduce visual clutter. The main goal of this prototype is to show the range of possible outcomes, as well as indicate where the data is most likely to reside.





View Dependent Opacity. The final prototype uses a model similar to the Blinn lighting model [1], in that the view angle is compared with the normal of the surface at each individual point. Instead of using this to modulate the lighting, it is instead used to modulate the opacity of the surface at each point. At a high level this technique is used to represent a collection of surfaces, each rendered individually with a transparency associated to confidence in the surface. Thus, when the viewer is directly above the surface, the opacity is determined entirely by the surface's transparency. When the viewer is at an oblique angle, the surface becomes solid, regardless of the underlying surface's transparency. In the case of this prototype, the transparency is established by the standard deviation of the surfaces as a whole at each position and is divided evenly between all surfaces.