Near-Solar Surface Magneto-Convection
Simulation data from Bob Stein, et al of Michigan State University

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The AVL worked with astrophysics data scientists to create a narrative journey through the dynamic processes of the sun in a digital fulldome production titled “Solar Superstorms”, narrated by Benedict Cumberbatch, as part of the CADENS NSF ACI-1445176 grant. This visualization represents a part of the story of the dynamic processes of our sun, and how they affect life on Earth.

Stein used results of global solar dynamo simulations to determine spatially and temporally evolving bottom boundary conditions for a magneto-convection simulation of the top of the solar convection zone (a slab of the sun’s surface 48000 km wide and 20000 km deep). Magnetic flux emergence in forming solar active regions is the driver of flares and coronal mass ejections that produce the dangerous storms in Earth's space weather. The simulation ran on Pleiades at NASA’s Advanced Supercomputing Division. Pat Moran, a visualization expert at NASA Ames, processed the output of these simulations through an advanced algorithm to produce spatially consistent visually meaningful field lines by selecting for lines that ultimately end up connecting with a particular active region on the sun’s surface.

From the simulation’s magnetic field, AVL constructed a current field (|curl B|), and visualized it volumetrically; the highest-current regions are concentrated into thin sheets, shown in yellow/orange. Embedded within this volume are Pat Moran’s bundles of magnetic field lines, in blue/cyan, colored by magnetic field strength.

The AVL team used a commercial visual effects tool called Houdini as its primary data processing environment to create derivative data assets which could demonstrate the particularly interesting features of the simulation. To allow the commercial tool to read and process scientific data, AVL programmer Kalina Borkiewicz wrote a C++ plugin using the Houdini Development Kit, that was able to read numerous file types and grid topologies, and produce Houdini-native assets that could be updated in the interactive graphic user interface. Attributes that could be updated include different varieties of volume domain edge falloff, asset volume resolution, and asset volume type. Using this, the AVL could adjust the asset volume to low resolution while experimenting with techniques. The volume type allowed the team to read the data into a rectangular grid, or into a sparse volume grid format called OpenVDB for render and processing optimization.

To create interactive previews of scientific datasets, the AVL uses an original open-source software tool called Partiview, which was primarily authored by AVL programmer Stuart Levy. Partiview is able to render particles, lines, triangle meshes, and star-like data and interactively update their visual attributes based on data attributes. To flexibly navigate through these Partiview environments, explore 3D data topology, and develop complex camera choreography in an immersive stereoscopic 4K environment, the team links Partiview with another original software tool called Virtual Director, authored by past AVL programmer Matt Hall and Marcus Thiebaux. Virtual Director is a remotely collaborative camera control and design tool capable of performing or keyframing path splines and editing them during interactive data playback.

To create an interactive time-evolving representation of this high resolution volume for camera choreography, the team seeded a uniform grid of points in the volume and colored them by the values of the nearest voxels. Additionally, Pat Moran's field lines were rendered as geometric objects in a different color range.

In Houdini, Pat Moran's field lines were splatted into sparse VDB volumes to create an integrated volumetric appearance. Volumetric rendering of the current field was also customized in Houdini. During the simulation's course, the grid resolution doubles, and the distribution of current changes significantly with time - it didn't work well to use any fixed mapping of current magnitude to visual color and opacity. AVL tied the current's transfer function to its histogram at each time, such that quantiles defined by e.g. the top 1%, 0.5%, 0.1%, etc. of the current distribution were colored consistently.

So that the shot could go above the surface of the sun, a sun surface asset was created using Matthias Rempel's solar surface convection supercomputer simulation. Matthias's data was interpolated in image compositing software, tiled to cover a larger percentage of the sun's surface, and displaced based on intensity. Matthias's data also included magnetic vectors, which were brought into Houdini as RGB values and then translated into small volumetric pointers on the surface of the sun. A halo was also put around the sun, mapped with imagery observed through NASA's Solar Dynamics Observatory telescope.

These many different datasets were rendered in several image layers from a unified camera path, and composited together using a commercial software tool called Nuke. Transitions past the solar surface utilized camera depth data and custom-drawn mattes to create an organic feeling between datasets.