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VTK Visualization for Field-driven Slicing & Toolpath Planning in Additive Manufacturing

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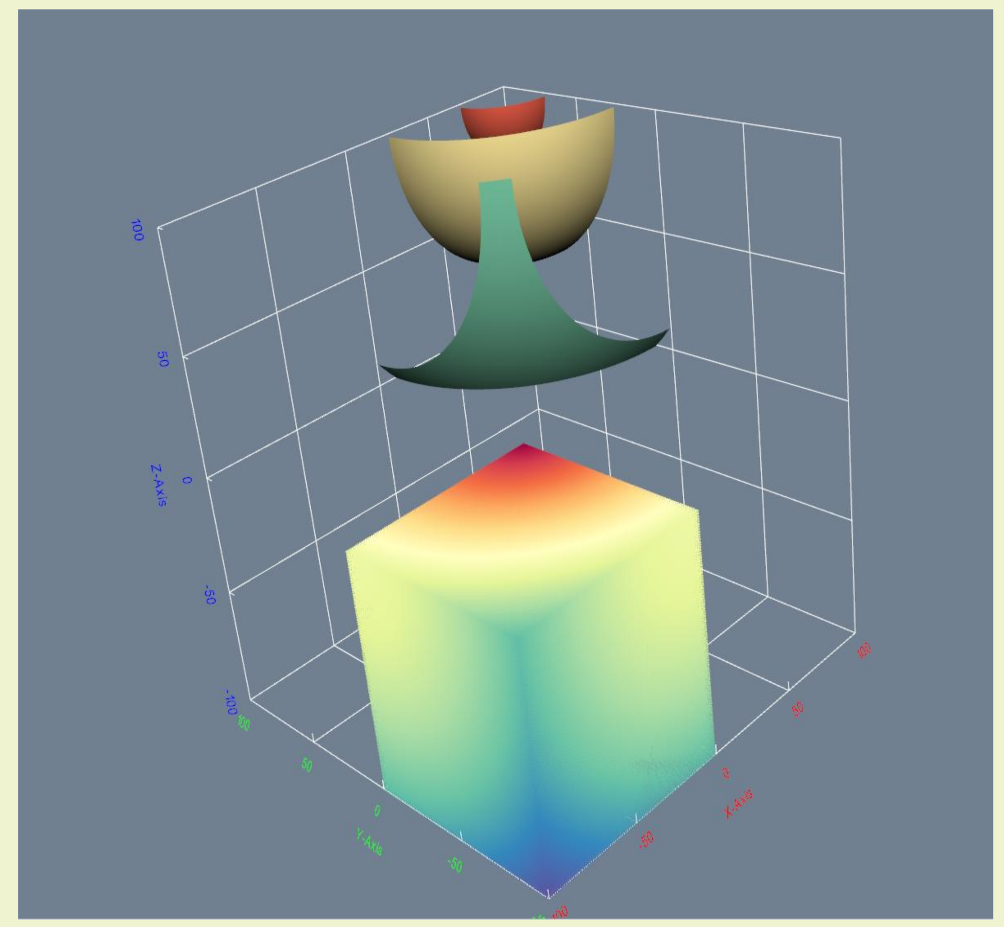
Abstract

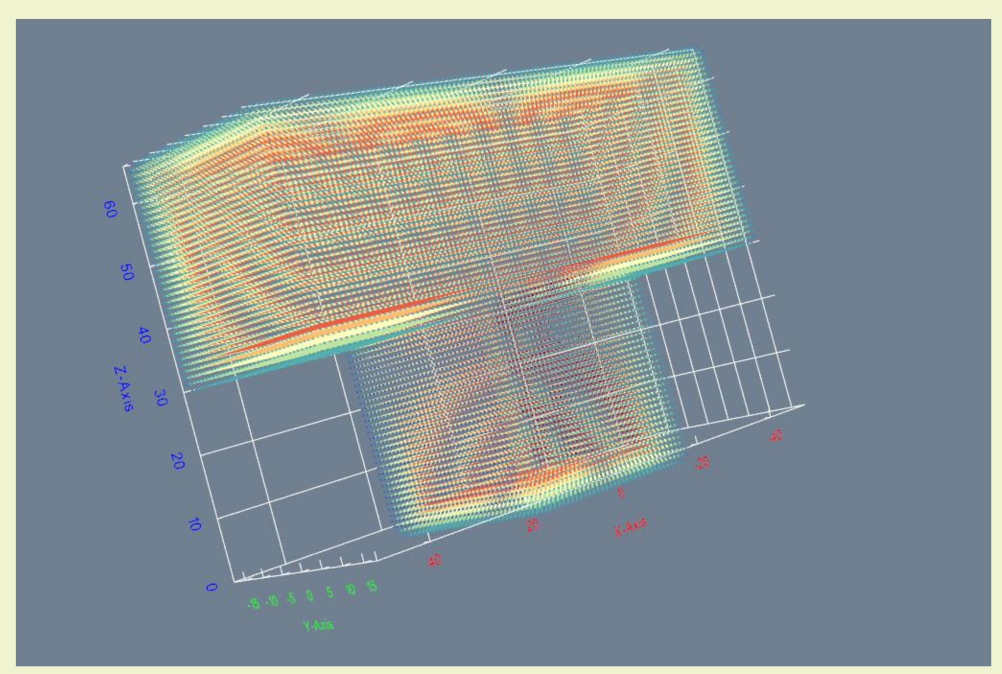
Additive manufacturing relies on precise toolpath planning to optimize material usage, print speed, and part accuracy. In this project, we develop a **VTK-based visualization tool** to support the **Field-driven Slicing & Toolpath Planning** algorithm within the **PathCompiler** software. This novel slicing approach leverages scalar fields to generate adaptive slice layers and toolpaths, improving manufacturability for complex geometries. The visualization tool enables real-time inspection of scalar field distributions, isosurface extractions, and resulting toolpath structures, providing engineers with critical feedback for algorithm validation and refinement. By integrating volumetric data representation and interactive visualization, this work enhances the debugging and optimization of advanced slicing techniques, paving the way for more efficient and adaptable additive manufacturing workflows.

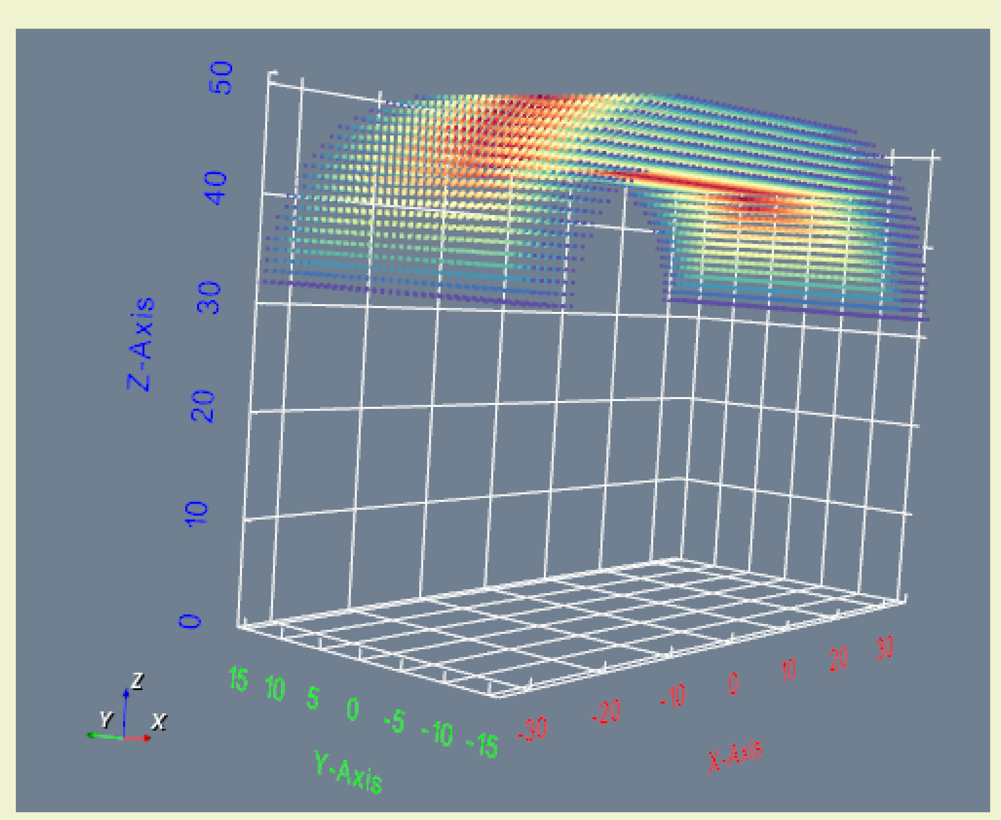
Methods / Methodology

To support the development and validation of the **Field-driven Slicing & Toolpath Planning** algorithm within the **PathCompiler** software, a **VTK-based visualization tool** was implemented. This tool enables real-time inspection of scalar fields, isosurfaces, and generated toolpaths, providing engineers with critical insights into the slicing process. The methodology consists of the following key steps:

- **Scalar Field Representation & Isosurface Extraction**
  - The **Field-driven Slicing & Toolpath Planning** algorithm generates scalar fields that dictate slice placement and toolpath generation.
  - The VTK-based visualization tool extracts and renders **isosurfaces** at user-defined field values to represent slice layers, allowing for direct inspection of the slicing behavior.
- **Visualization of Volumetric Data & Toolpaths**
  - Using **VTK's rendering pipeline**, the tool overlays **isosurfaces, contour lines, and generated toolpaths** onto the original model, providing a clear view of how the algorithm adapts slicing based on the scalar field.
  - Multiple visualization modes are supported, including **wireframe, solid, and semi-transparent overlays**, enabling engineers to analyze slicing decisions effectively.
- Interactive Exploration & Debugging
  - Users can interactively adjust **scalar field parameters** and immediately visualize changes in slice layers, aiding in debugging and optimizing toolpath generation.
  - The visualization highlights **regions of excessive material deposition, discontinuities in slice transitions, and toolpath inefficiencies**, helping refine the algorithm.
- **Performance Optimization & Integration**
  - The visualization tool was implemented in **C++ using VTK** to ensure efficient rendering of large-scale 3D datasets.
  - The tool was integrated directly into **PathCompiler**, allowing for seamless visualization alongside toolpath generation







Results

The VTK-based visualization tool developed for the **Field-driven Slicing & Toolpath Planning** algorithm significantly enhances the analysis and debugging of adaptive slicing techniques. The tool provides real-time visualization of **scalar field distributions, isosurface extractions, and generated toolpaths**, allowing engineers to inspect and refine slicing behavior with greater precision.

- **Improved Insight into Scalar Field-Based Slicing**
  - The visualization tool successfully **renders isosurfaces representing adaptive slice layers**, demonstrating how the scalar field influences the slicing process.
  - Engineers can identify **regions of high gradient change**, ensuring smooth transitions between slice layers and preventing abrupt toolpath discontinuities.
- **Enhanced Toolpath Analysis**
  - By overlaying toolpaths onto the isosurfaces, the visualization highlights **regions where toolpaths may be inefficient or where material deposition is suboptimal**.
  - Adjustments to the slicing algorithm were informed by these visualizations, leading to **smoother toolpaths, improved print stability, and better material utilization**.
- **Real-Time Interaction for Debugging and Optimization**
  - The interactive interface allows users to **modify scalar field parameters and immediately visualize the effect on slicing**, accelerating the debugging process.
  - This capability has **reduced iteration time** in algorithm development by enabling **on-the-fly** validation of slicing modifications.
- **Computational Performance and Scalability**
  - The tool effectively handles **complex geometries and high-resolution scalar fields**, demonstrating its scalability for diverse additive manufacturing applications.

By integrating this **VTK-based visualization into PathCompiler**, the Field-driven Slicing & Toolpath Planning algorithm can be analyzed and refined with unprecedented clarity, leading to more efficient, adaptive, and manufacturable toolpaths. Future improvements include expanding support for **multi-material visualization** and integrating additional **data-driven slicing optimizations**.

Conclusions

The development of a **VTK-based visualization tool** for the **Field-driven Slicing & Toolpath Planning** algorithm has provided an essential framework for analyzing and refining adaptive slicing techniques in additive manufacturing. By enabling real-time visualization of **scalar fields, isosurfaces, and toolpaths**, the tool offers engineers a deeper understanding of how the slicing algorithm adjusts layer placement based on field-driven parameters.

In addition to its impact on algorithm refinement, the VTK-based visualization demonstrated **high computational efficiency and scalability**, rendering complex scalar fields and large-scale models while maintaining interactive performance. The integration into **PathCompiler** ensures that slicing algorithm improvements can be directly visualized, tested, and iterated upon, streamlining the path from algorithm development to practical application.

Resources

Roschli, Alex, Borish, Michael, Barnes, Abigail, Wade, Charles, Crockett, Breanne, White, Liam, and Adkins, Cameron. "ORNL Slicer 2 - Open Source Copyright." Computer software. May 06, 2024. https://github.com/ORNLSlicer/Slicer-2. https://doi.org/10.11578/dc.20240520.1.