Immersive Visualization and Analysis of Ground Penetrating Radar Data

By
Matthew Sgambati

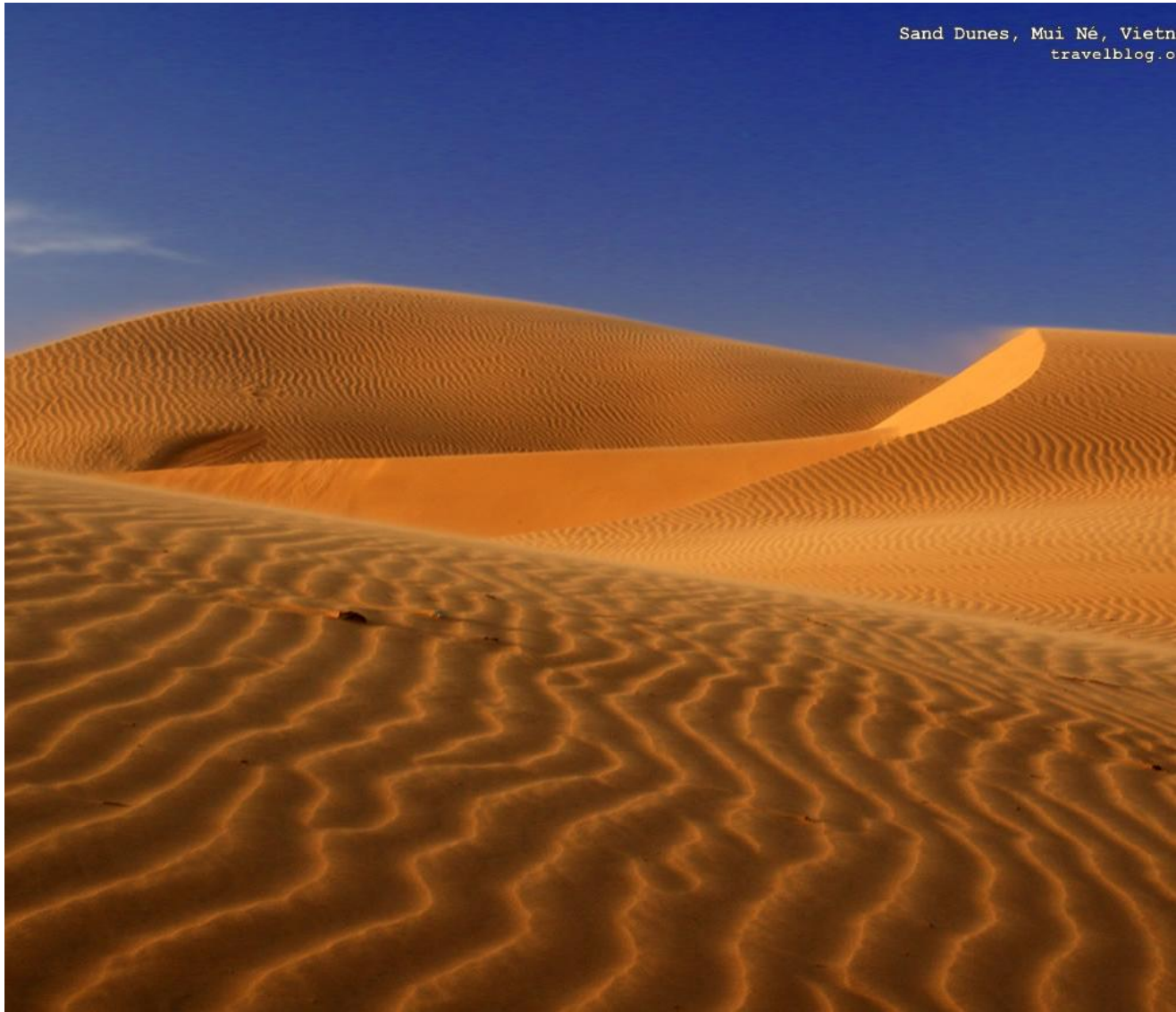
Committee

Dr. Daniel Coming
Dr. Frederick C. Harris, Jr.
Dr. Nicholas Lancaster

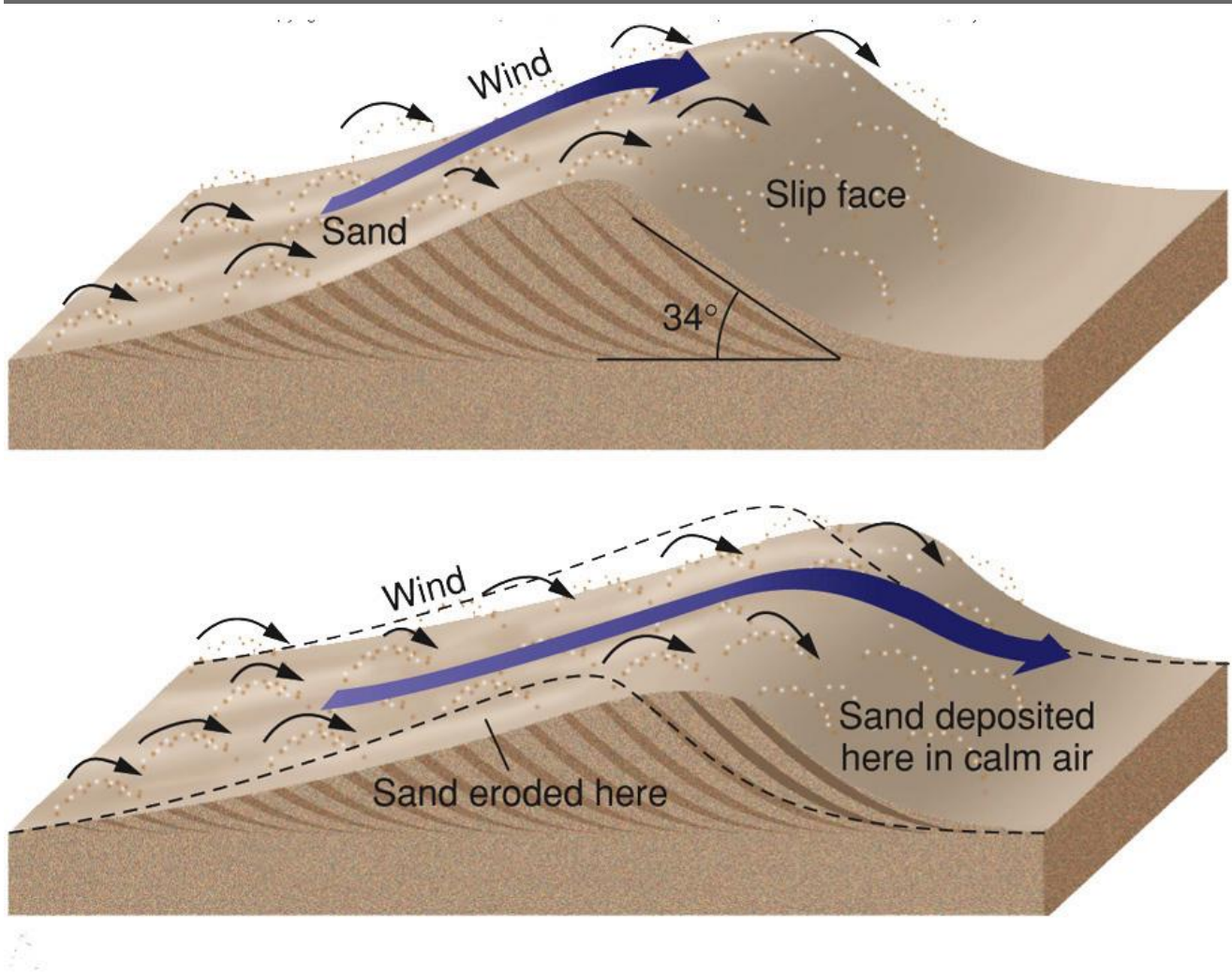
Overview

- Background
- The Project
- Software Specification and Design Process
- Implementation
- Results
- Conclusion
- Future Work

Sand Dunes



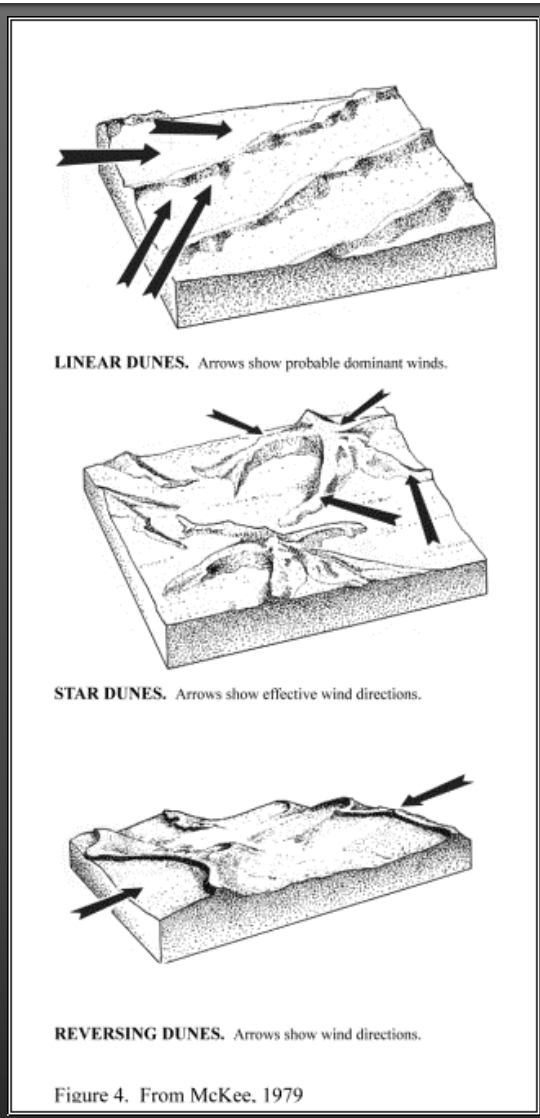
Sand Dunes



Sand Dunes

Sand Dunes

- Shapes
  - Crescentic
  - Linear
  - Star
  - Dome
  - Parabolic
  - Transverse
  - Reversing



LINEAR DUNES. Arrows show probable dominant winds.

STAR DUNES. Arrows show effective wind directions.

REVERSING DUNES. Arrows show wind directions.

Figure 4. From McKee, 1979

Sand Dunes

- Types
  - Sub-aqueous
  - Lithified
  - Coastal
  - Desert

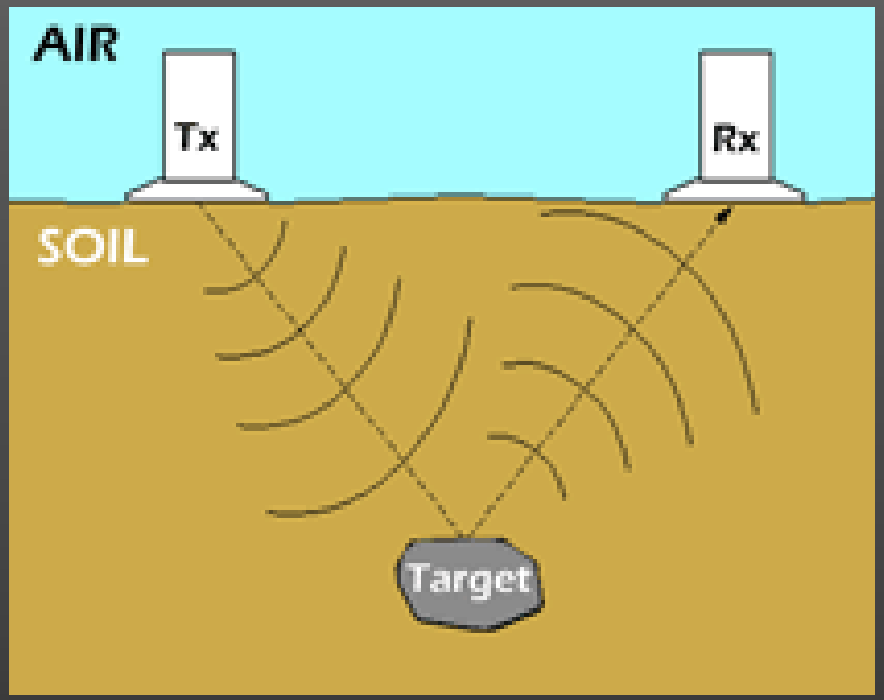
Sand Dunes

- Forms
  - Simple
  - Compound
  - Complex

Sand Dunes

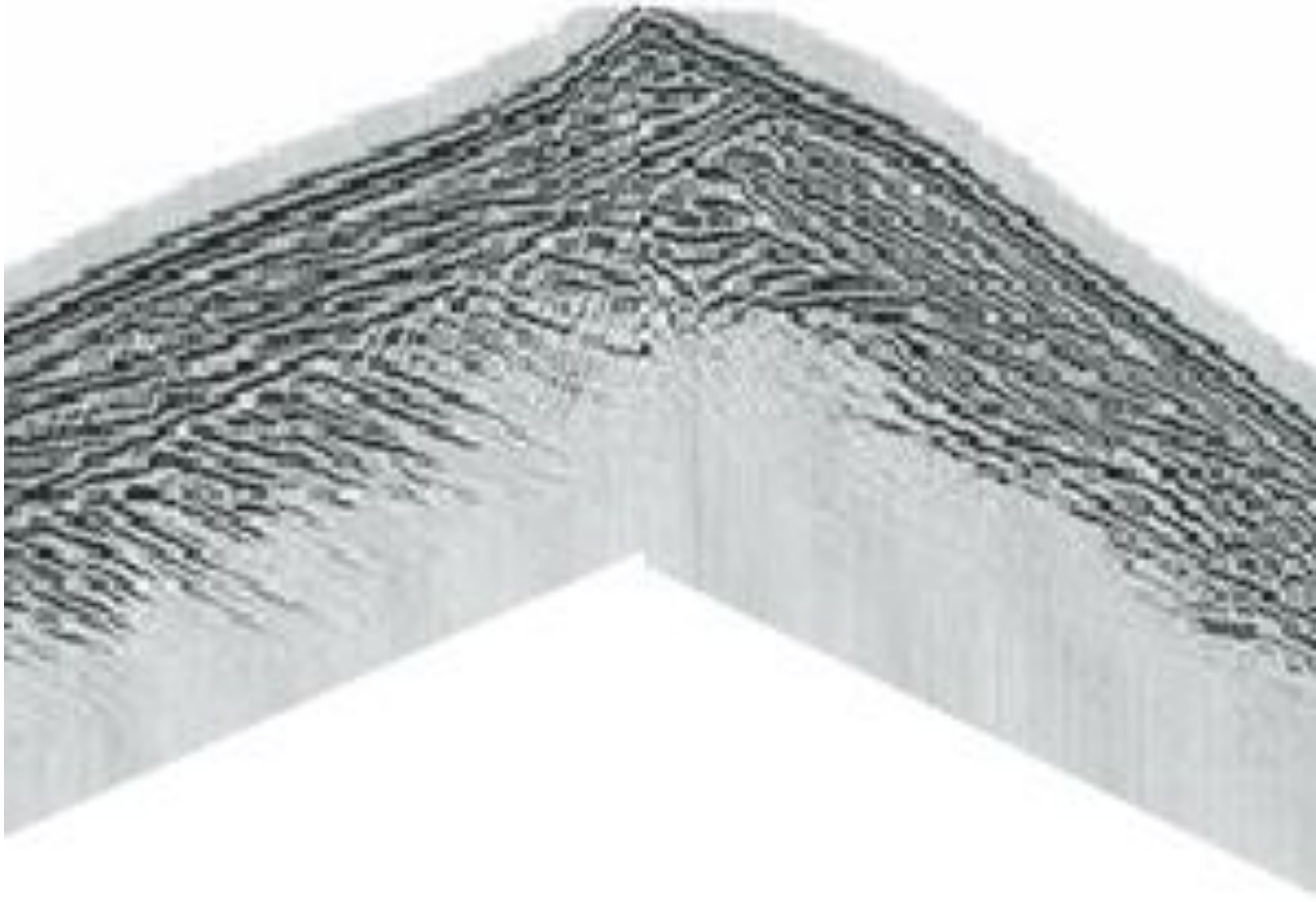
Dune 7 in the Namib desert

Ground Penetrating Radar



Ground Penetrating Radar

Ground Penetrating Radar

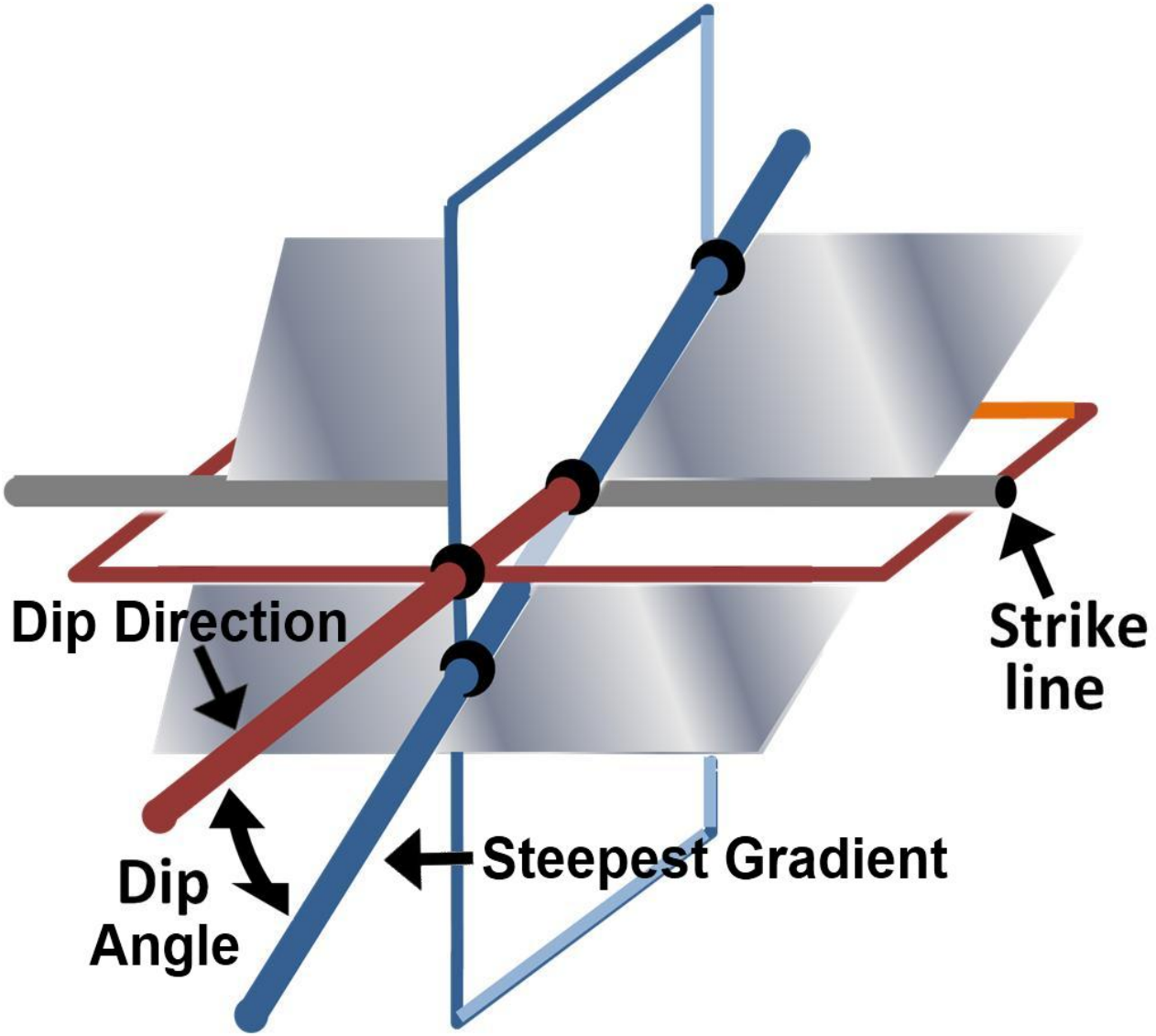


Brunton Compass

Background

Brunton Compass

Brunton Compass

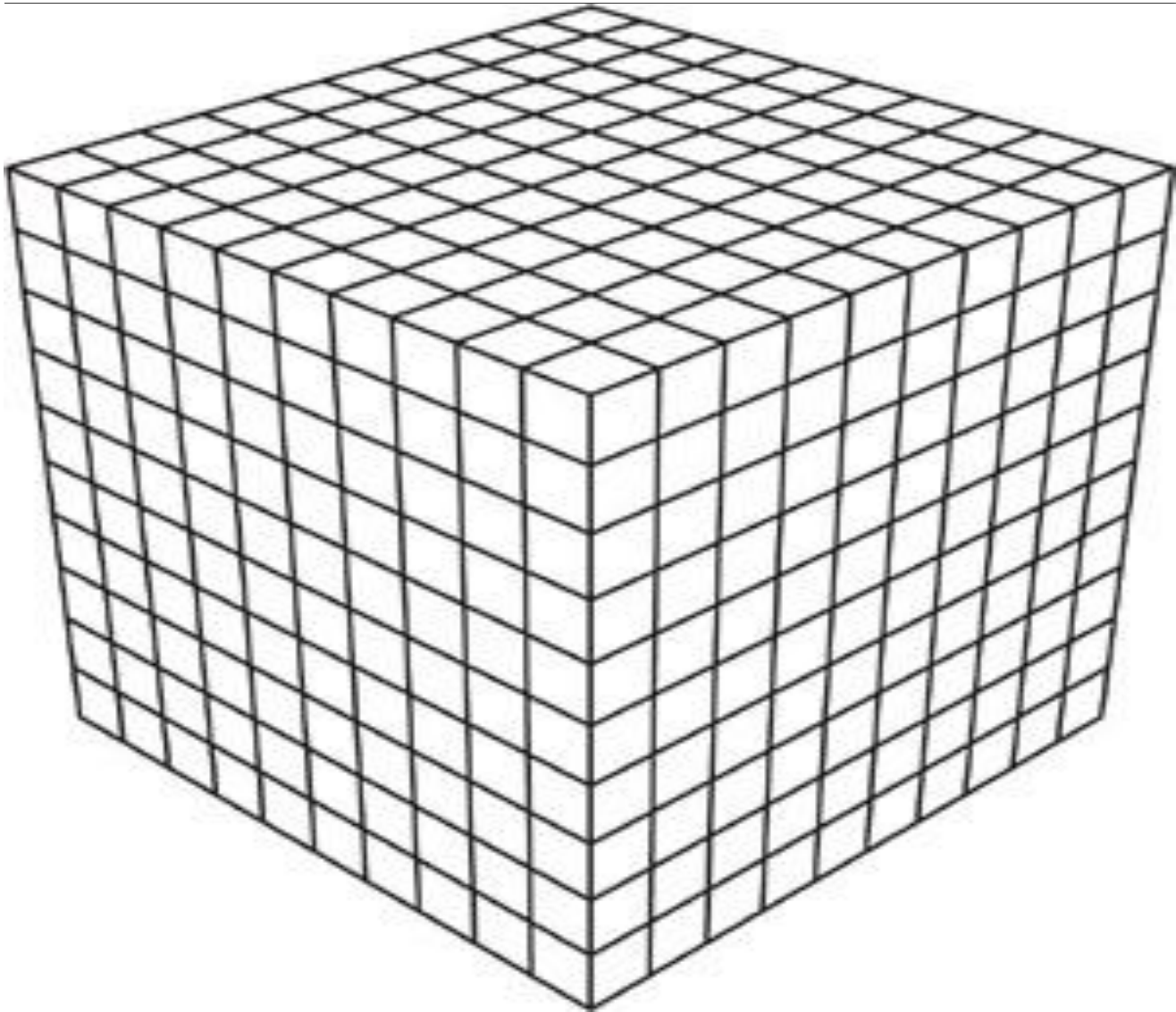


Volume Rendering

- Display of data sampled in three dimensions

Volume Rendering

Volume Rendering

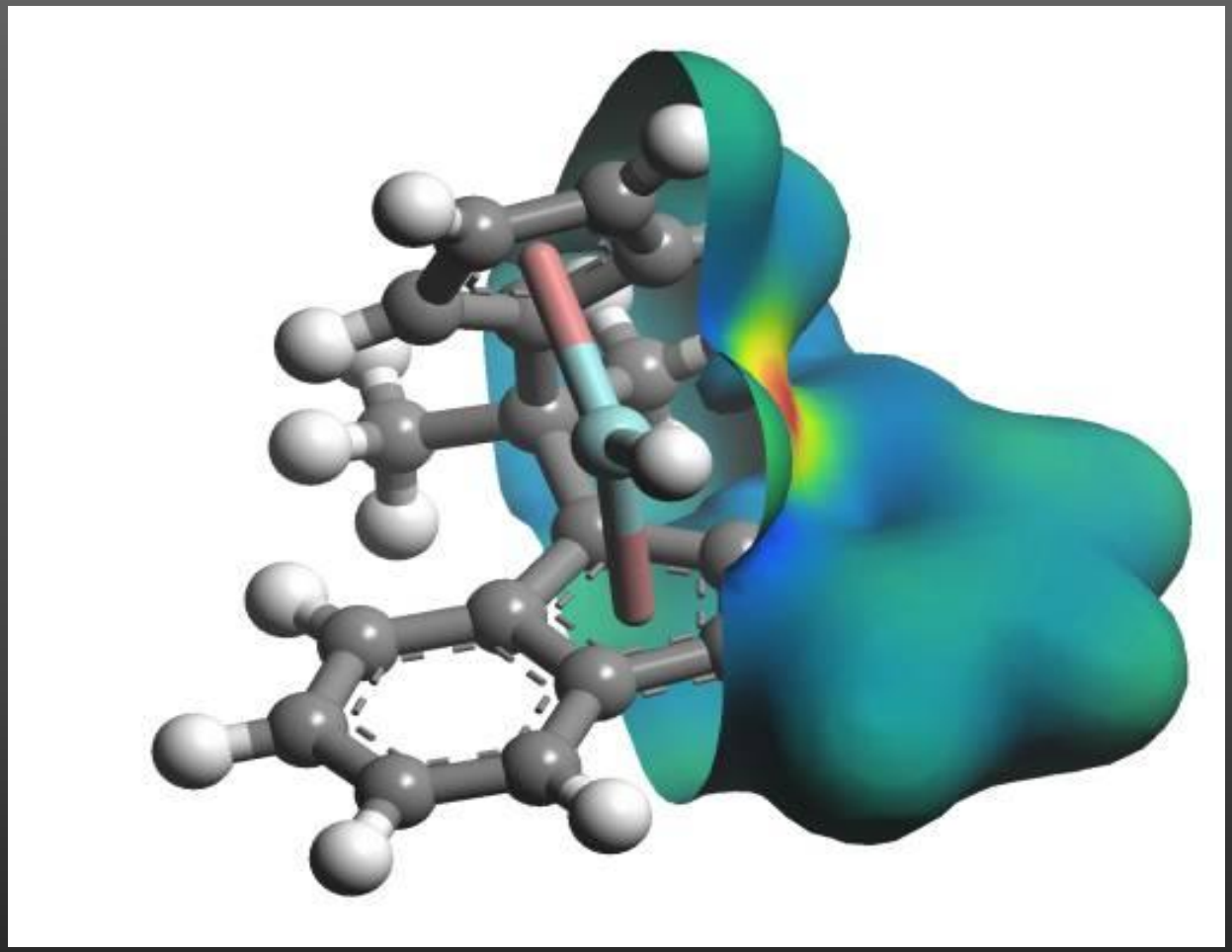


Volume Rendering

- Methodologies
  - Indirect
  - Direct
- Algorithm categories
  - Object-order
  - Image-order
  - Hybrid

Indirect

- Iso-surfaces



Indirect

- Assumptions
  - Iso-surfaces exist
  - Rendered within a reasonable degree of accuracy
- Complexity is an issue

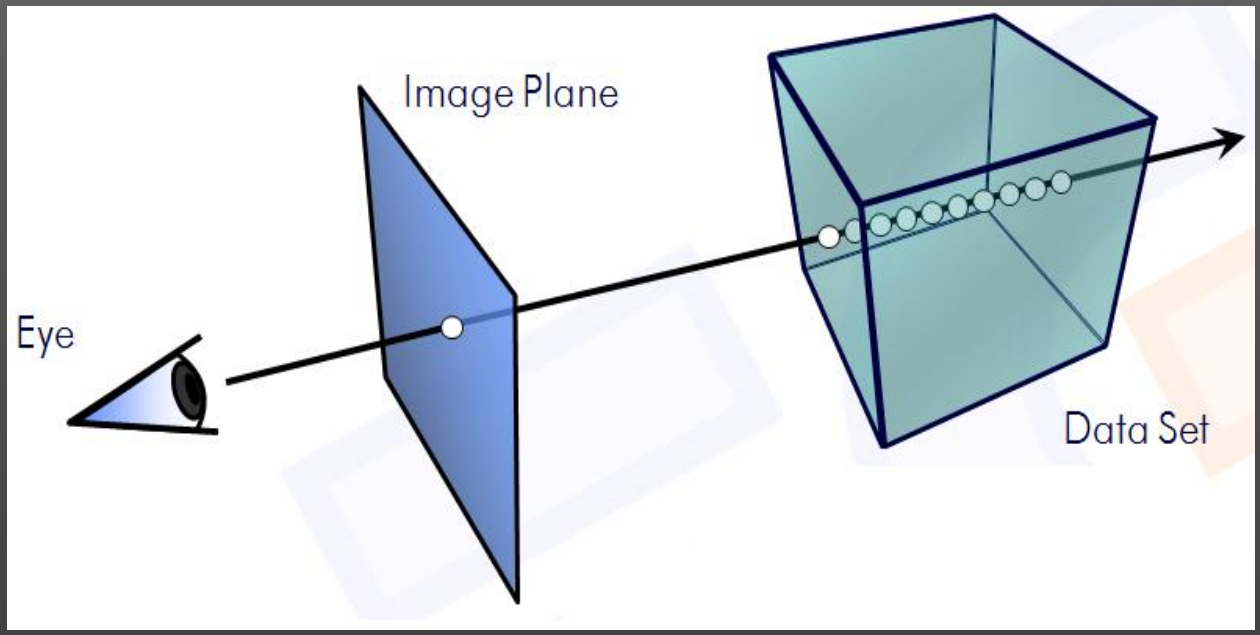
Direct

- Requirement
  - Every sample point is mapped to an opacity and color
- Techniques
  - Ray Casting
  - Splatting
  - Shear-Warp
  - Texture Mapping
  - Hardware Accelerated

Ray Casting

- Image-order algorithm
- Produces some of the highest quality images
- Very computationally expensive

Ray Casting



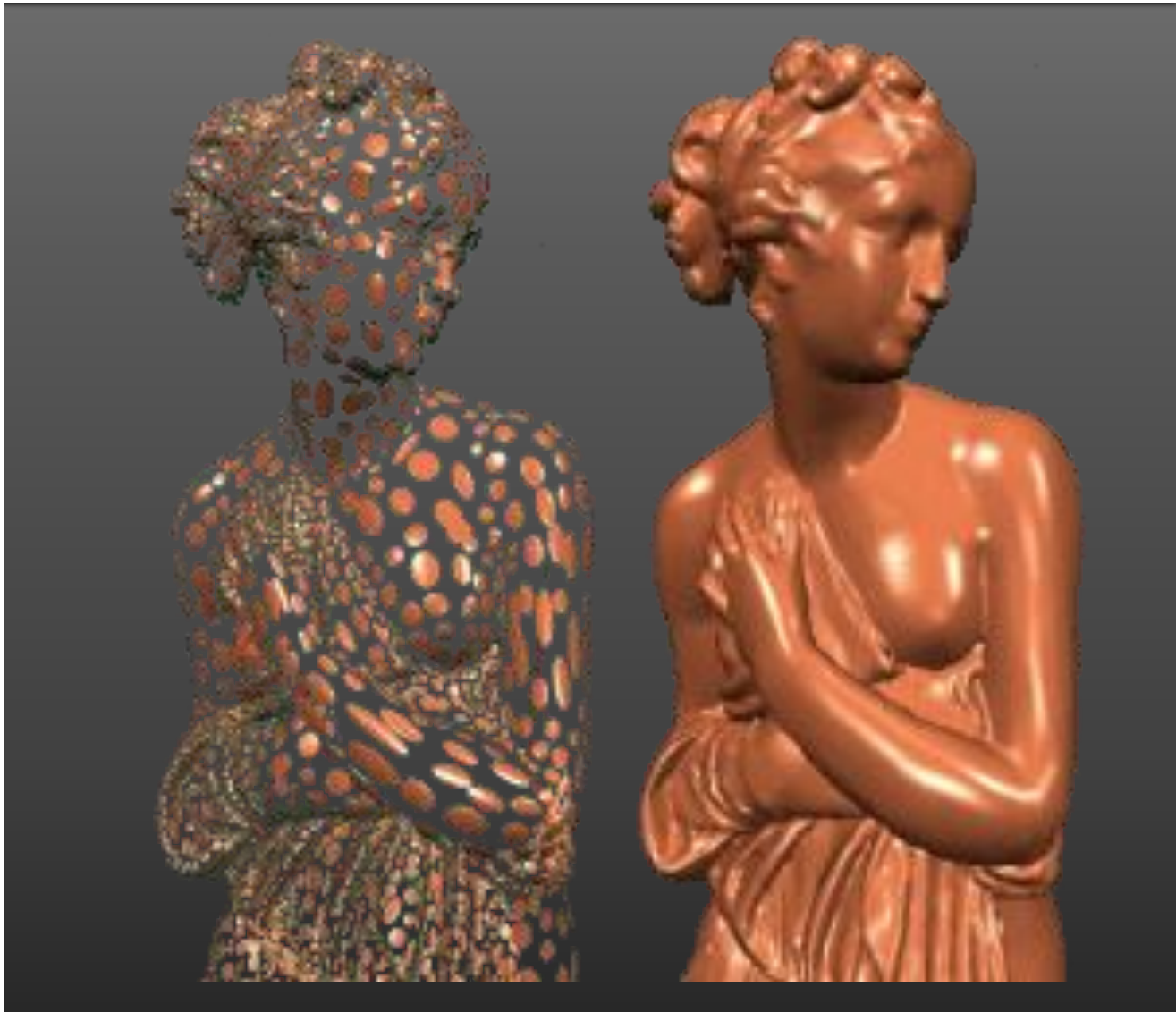
Splatting

- Object-order algorithm
- Less computationally expensive than Ray Casting
- Throw paint balls onto a surface to obtain an image

Splatting

- Maps every voxel to the viewing plane
- Footprint
  - Reconstruction Kernel
- Speed
  - Precompute footprints
- Issue
  - Reconstruction Kernel selection
    - Too larger results in a blurry image
    - Too small results in gaps in the image

Splatting

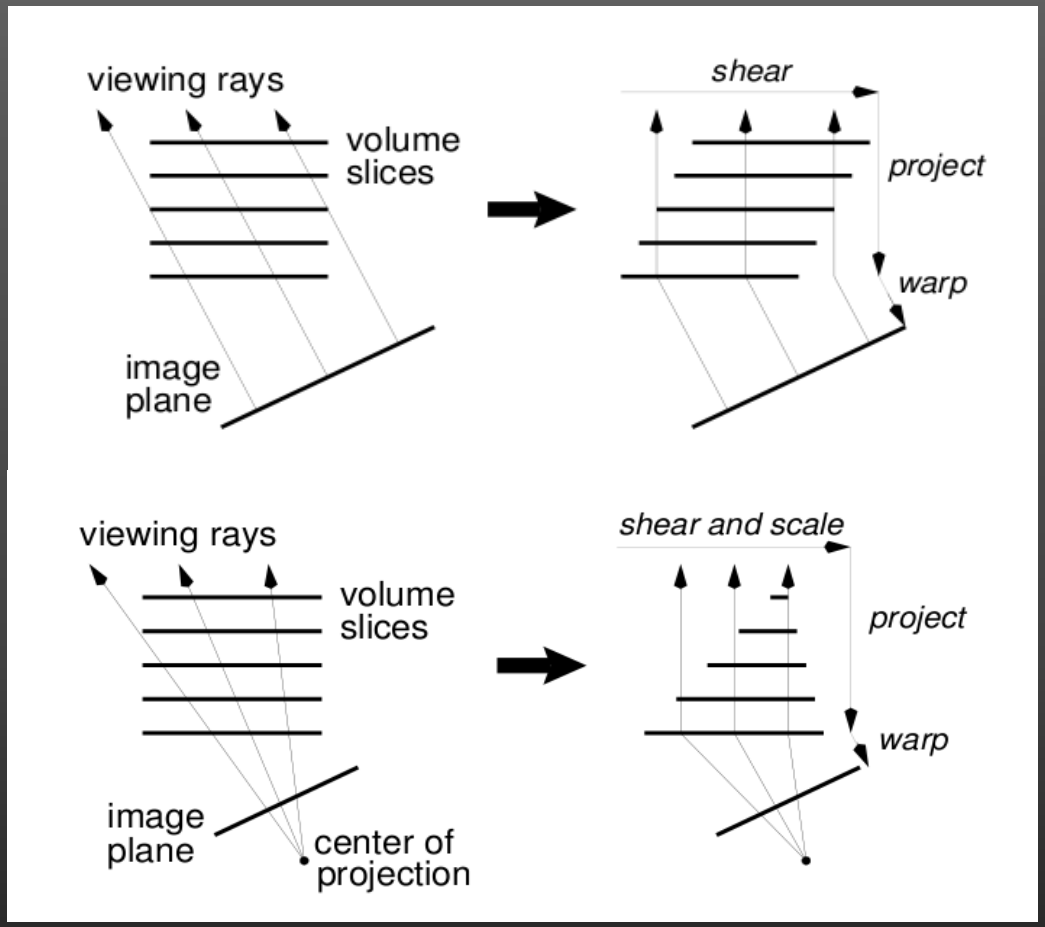


Shear-Warp

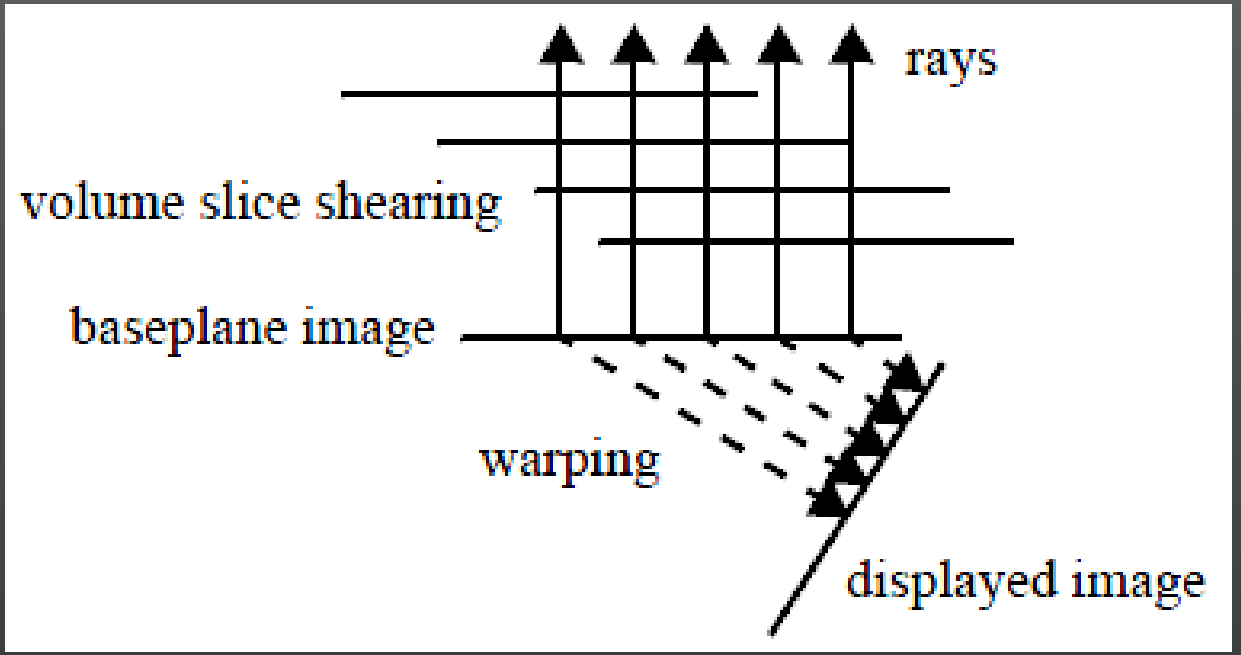
- Hybrid algorithm
- Fastest purely software-based algorithm

Shear-Warp

- Sheared object space



Shear-Warp



Shear-Warp

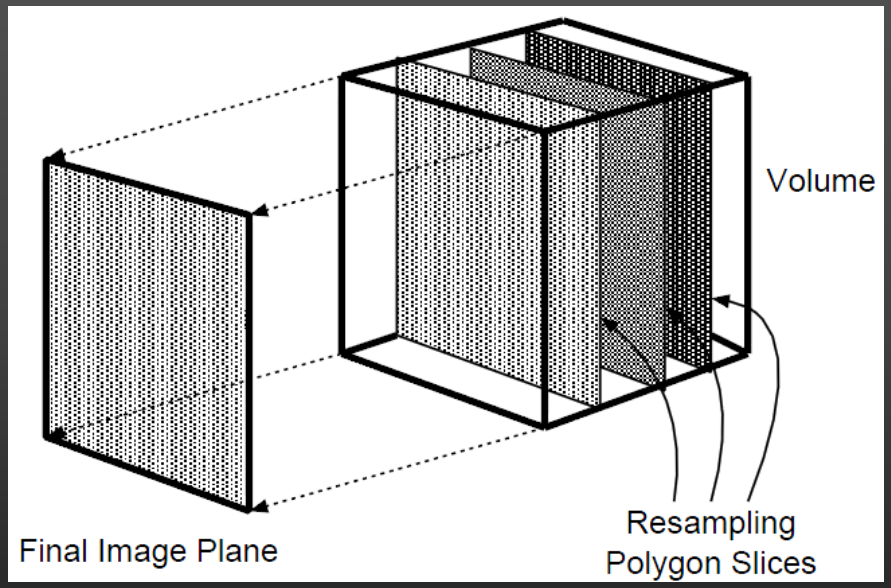
- Speed
  - Run-length encoding
- Issues
  - Run-length encoding
    - One for each axis, 3 x memory consumption
  - Interpolation is per slice
    - Aliasing
    - Staircasing

Texture Mapping

- Uses Graphics Hardware
  - Texture Mapping
  - Interpolation
- Types
  - 2D-texture mapping
  - 3D-texture mapping

2D-Texture Mapping

- Splits data into axis-aligned slices
- Composited in back-to-front order



2D-Texture Mapping

- Advantages
  - Simplicity
  - Takes advantage of graphics hardware (Bilinear interpolation)
- Disadvantages
  - Slices created for each axis, 3 x memory consumption
  - Flickering
  - Aliasing occurs when magnified

3D-Texture Mapping

- Stores data as a 3D-texture
- Creates viewport aligned slices

3D-Texture Mapping

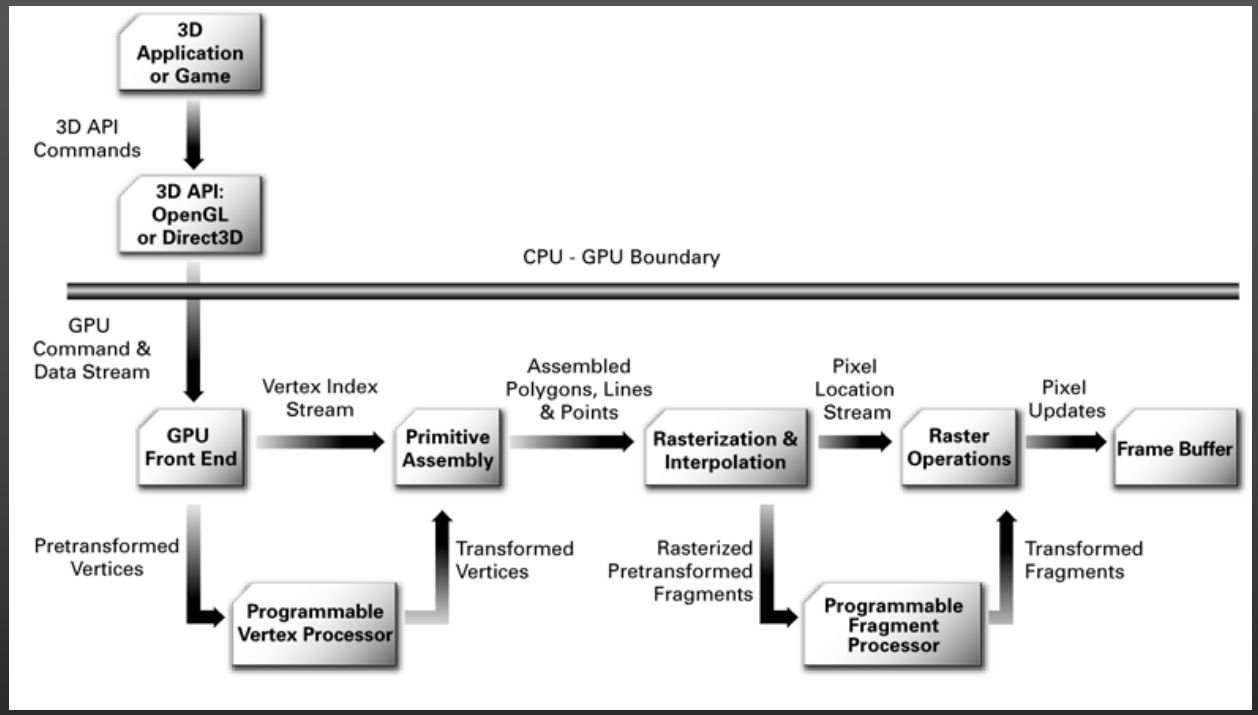
- Advantages
  - Overcomes disadvantages of 2D-texture mapping
  - Takes advantage of graphics hardware (Trilinear interpolation)

3D-Texture Mapping

- Disadvantages
  - Bricking mechanism required for large data sets
    - Limited by bandwidth between system memory and graphics hardware
    - Brick size
      - Too large wont fit into graphics hardware's memory cache
      - Too small increases memory footprint and number of intersection tests

Hardware Accelerated

- Uses Programmable Pipeline instead of the Fixed Functionality Pipeline



Virtual Reality

- Notion of mental immersion through feedback
  - Visual
  - Haptic
  - Olfactory
  - Auditory
- Depth Cues
  - Monoscopic
  - Stereoscopic
  - Motion

Virtual Reality

- Stereo Vision
  - Active
  - Passive
- Stereoscopic Displays
  - Fishtank
  - Head Mounted Display
  - Projection-based
- Input Devices
- Toolkits

Depth Cues

- Monoscopic
  - Provide information from only one eye
  - Information
    - Interposition
    - Size
    - Linear perspective
    - Motion parallax

Depth Cues

- Stereoscopic
  - Provide information from two eyes
  - Images are different perspectives of the same location
    - Provides spatial information
      - Obtained from the parallax between objects in the image
- Motion
  - Same as motion parallax
  - Not always present

Stereo Vision

- Active
  - 1 Projector with 120Hz refresh rate (60Hz each eye)
  - Synchronized signals between projector and glasses

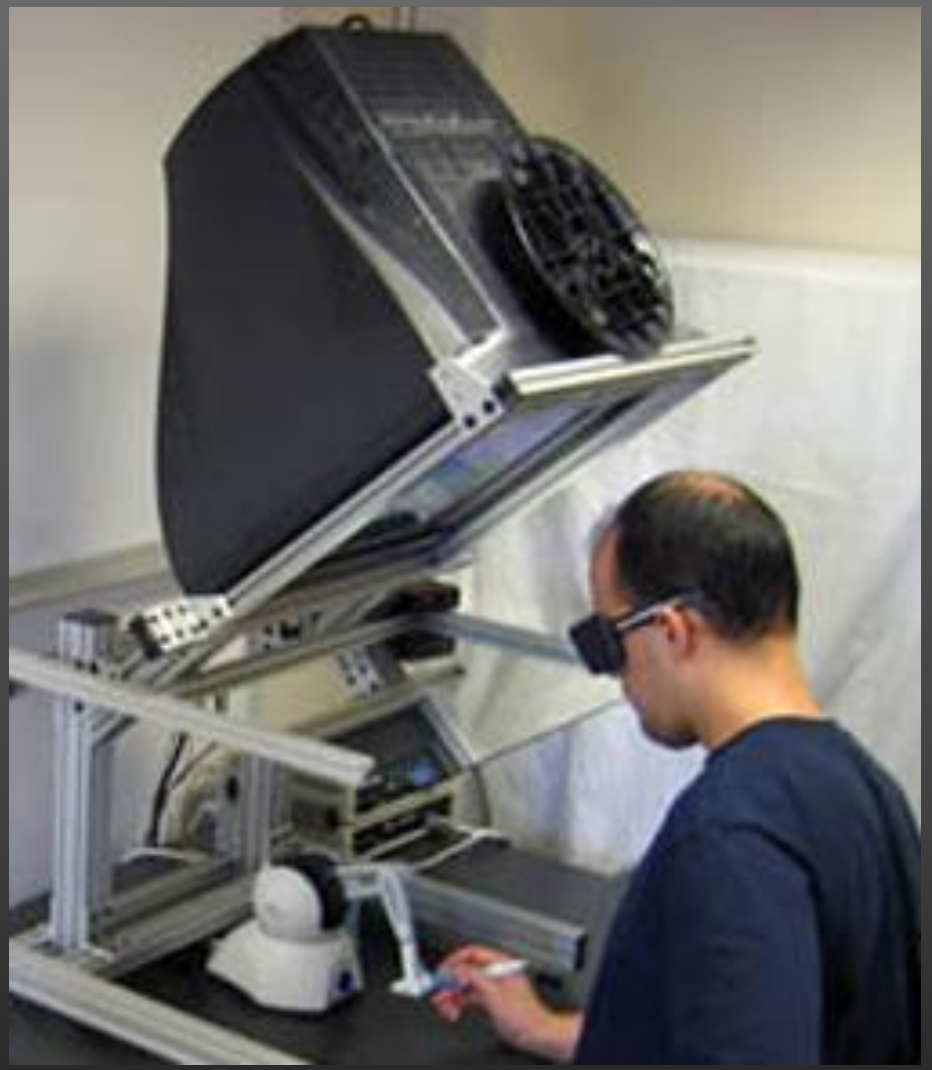
Stereo Vision

- Passive
  - 2 Projectors (60Hz refresh rate)
  - Polarized filters

Stereoscopic Displays

- Types
  - Fishtank
  - Head Mounted Display
  - Projection-based

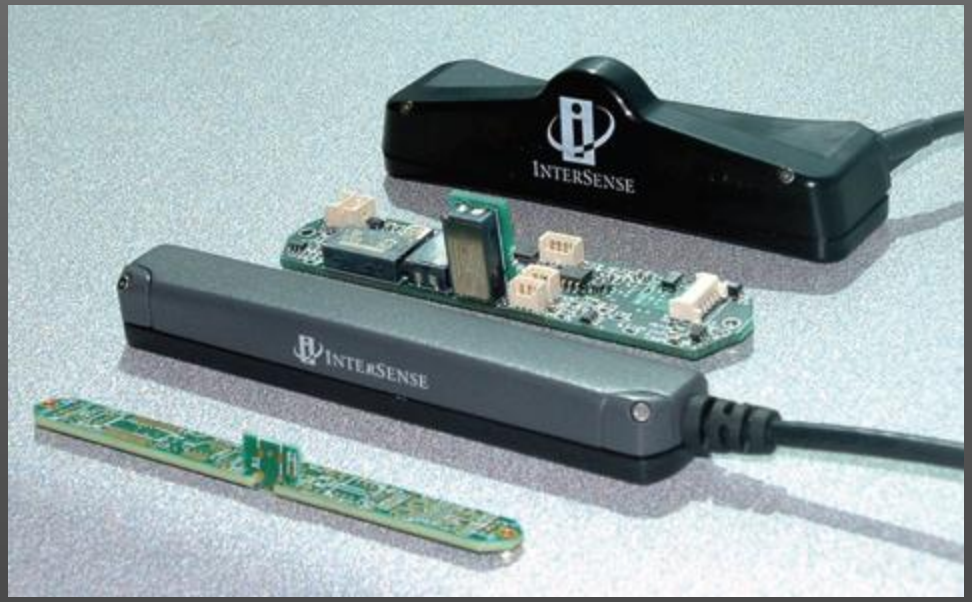
Stereoscopic Displays



Stereoscopic Displays

Stereoscopic Displays

Input Devices



Toolkits

- Designed to help users deal with VR systems
  - Specialized hardware
  - Specialized devices
  - Unique environments
- Examples
  - FreeVR
  - VR Juggler
  - Virtual reality user interface (Vrui)
  - Hydra

Vrui

- VR development toolkit written by Oliver Kreylos
- Goal is to shield developer from a particular configuration of a VR environment
  - Display abstraction
  - Distribution abstraction
  - Input abstraction

Toirt-Samhlaigh

- Volume rendering library
  - Patrick O'Leary
- 3D-texture mapping, hardware accelerated DVR type of algorithm
  - Slice-based rendering
- Heavily integrated with Vrui

Toirt-Samhlaigh

- Provides many features
  - Transfer functions
  - Directional lighting
  - Volume manipulation
  - Color maps
  - Tools, such as clipping plane tool
  - Modifiable slice factor
  - Load several data types

The Project

Create a program capable of visualizing GPR data in an IVE and create tools to assist in the analysis of the GPR data

This was done by taking Toirt-Samhlaigh and performing enhancements and expansions to the library

Software Specification

- Requirements
  - Functional
  - Nonfunctional

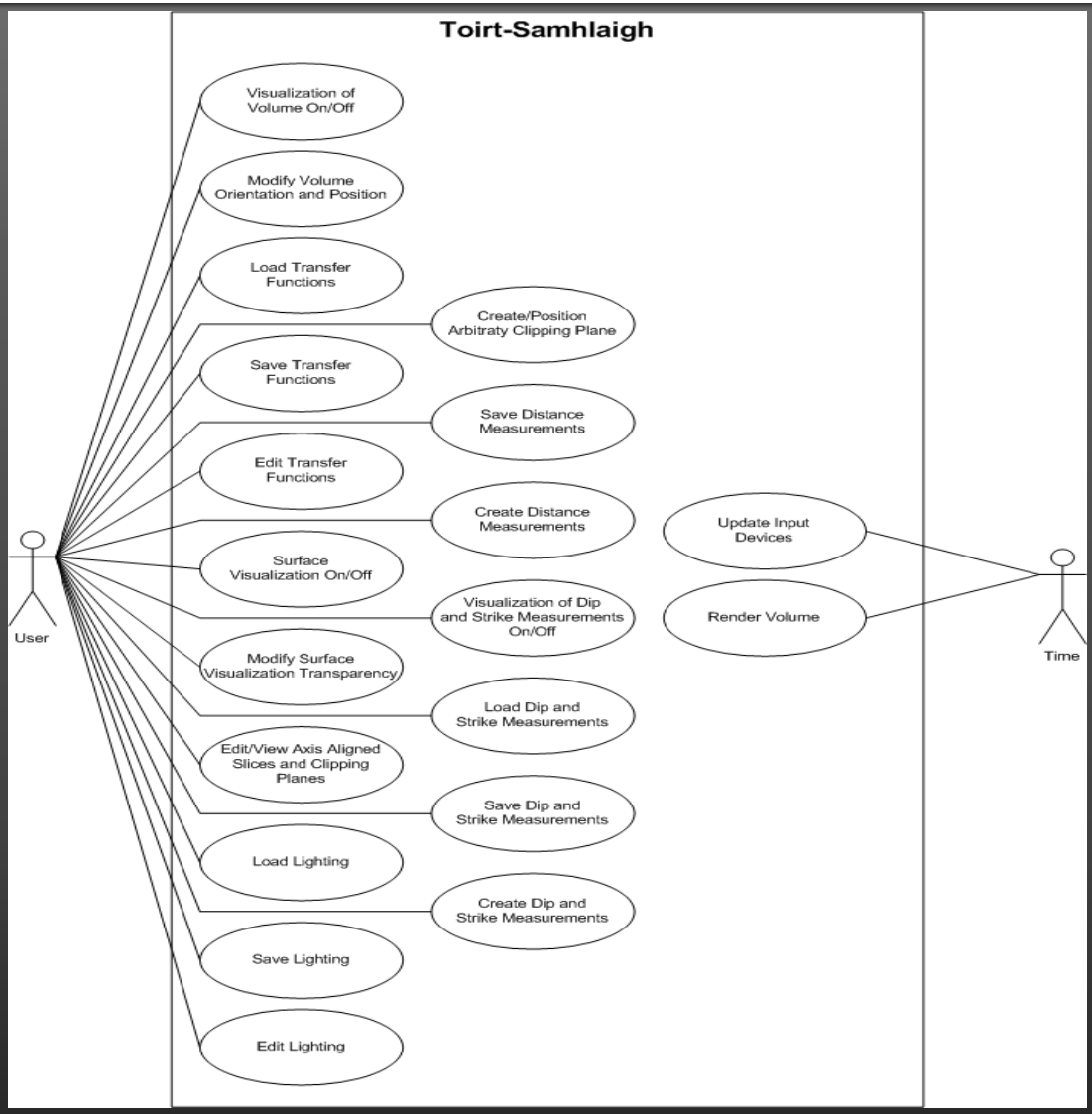
Requirements

- Functional
  - The program shall be able to load GPR data in SEGY revision 1 format.
  - The program shall allow the user to turn the data visualization on and off.
  - The program shall allow the user to change the orientation and position of the data.
  - The program shall allow the user to take dip and strike measurements.
  - The program shall allow the user to take distance and angle measurements.

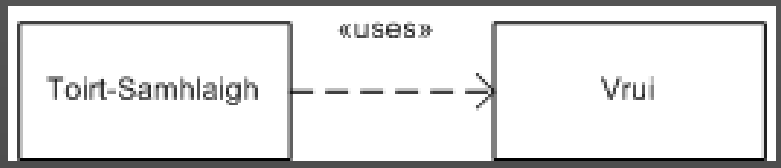
Requirements

- Nonfunctional
  - The program shall maintain interactive frame rates.
  - The program shall written in C/C++.
  - The program shall use a hardware accelerated, texture mapping DVR algorithm for its rendering.
  - The program shall use VRUI and Toirt-Samhlaigh for its prototype application.
  - The program's rendering algorithm shall use OpenGL.
  - The program shall be implemented on the Linux platform.

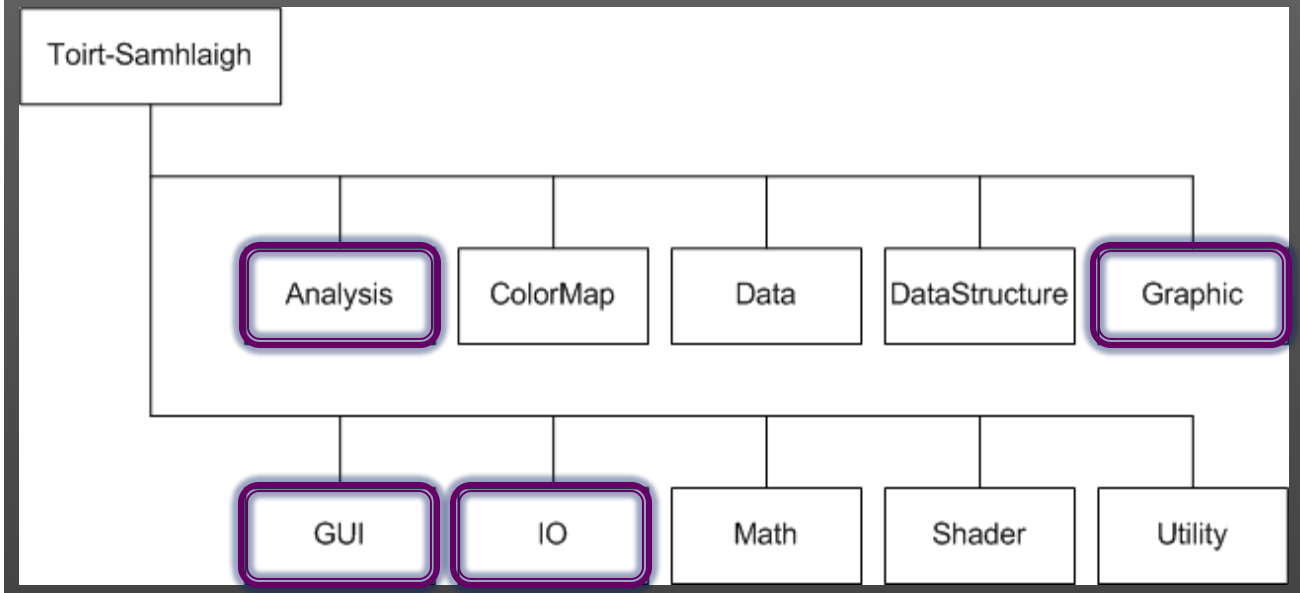
Use Cases



System Overview



Toirt-Samhlaigh



Iterative Design Process

- Conducted with a researcher at DRI
  - Valuable feedback
  - Valuable learning experience

Implementation

- SEGY file loader
- Toirt-Samhlaigh tools tested
- Modified Slicing Tool
  - Handle scaling of GPR data
  - Double as a clipping tool
- Added Topographic correction to SEGY file loader
- Surface Visualization
  - Transparency modifiable

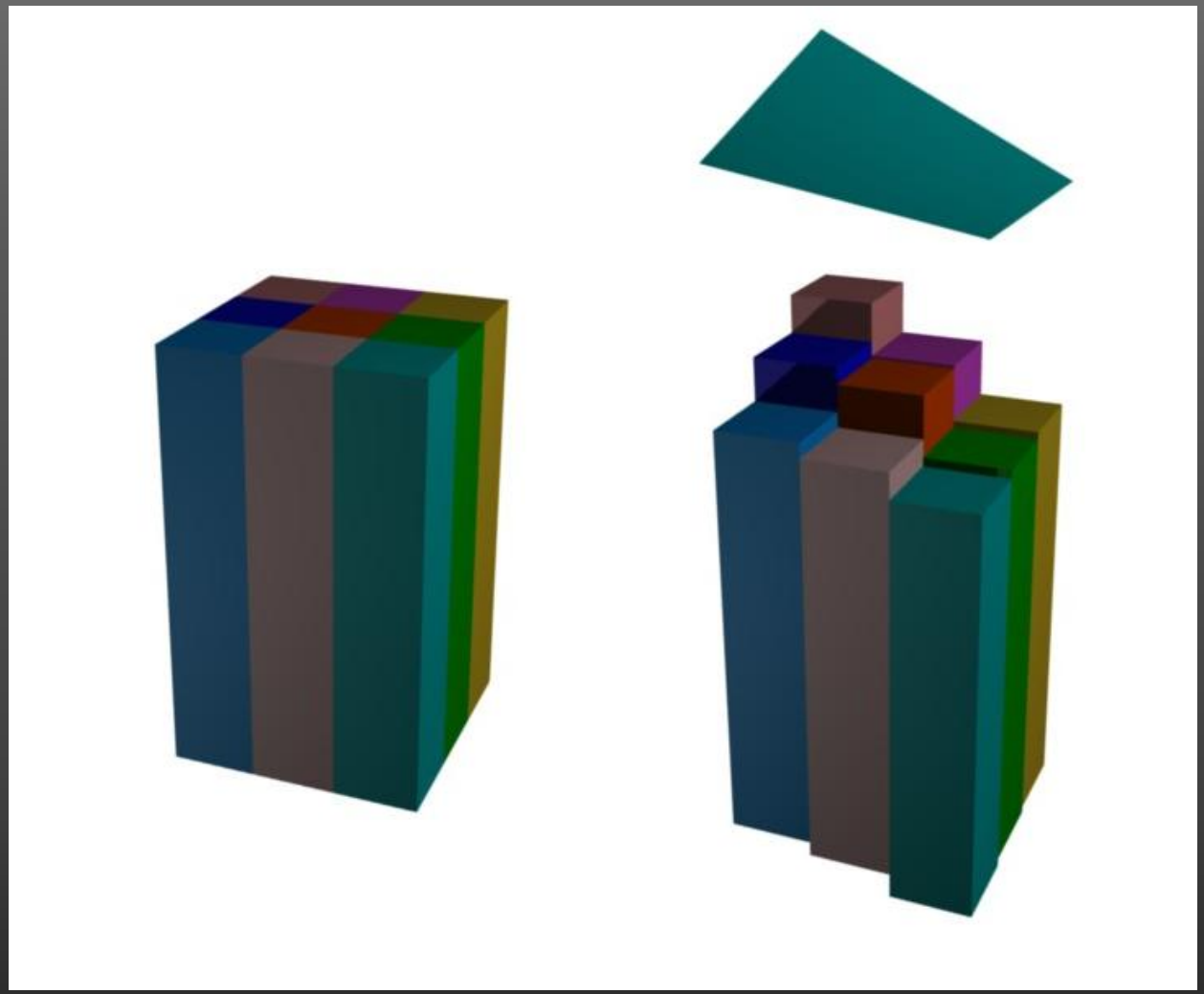
Implementation

- Two tools created
  - Distance Measurement Tool
  - Brunton Compass Tool
- GUIs were created as needed
- Save/Load Functionality

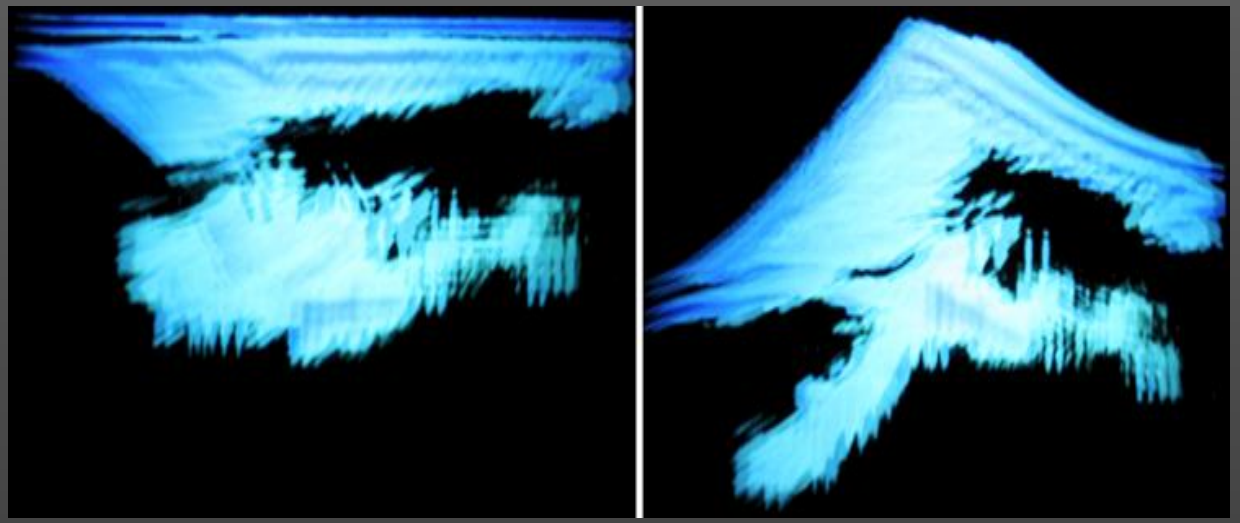
Topographic Correction

- Store values read in from a file into a 2D grid structure
  - x-coordinate, y-coordinate, elevation
  - Samples taken at regular intervals, plus at the peaks
- Performed linear interpolation

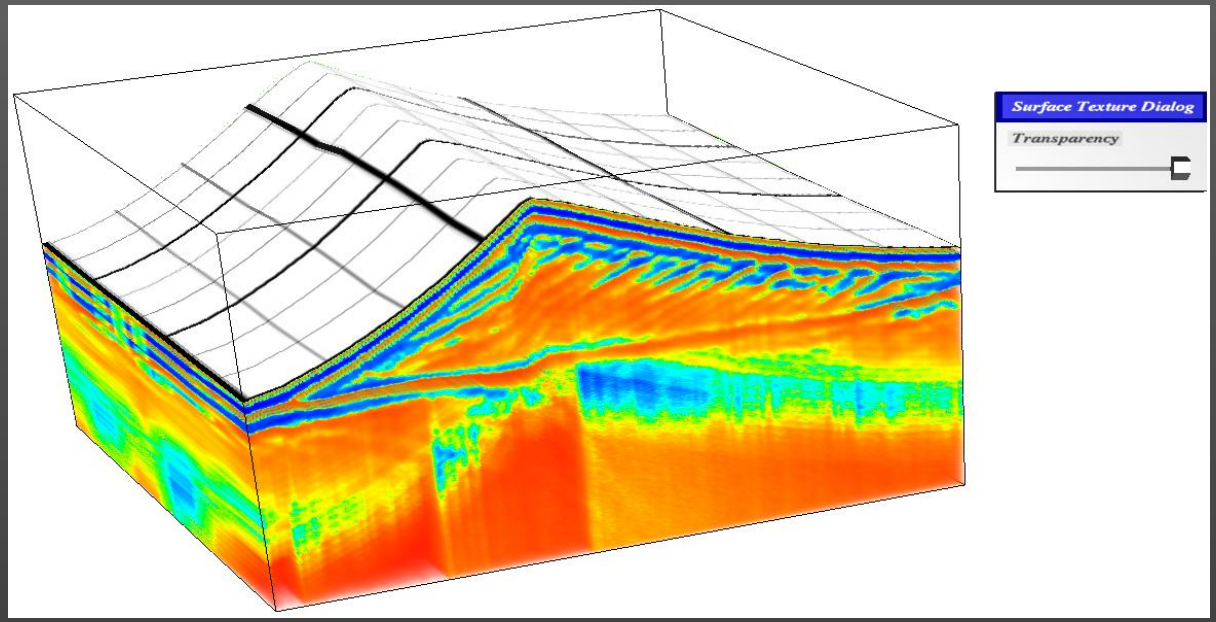
Topographic Correction



Topographic Correction



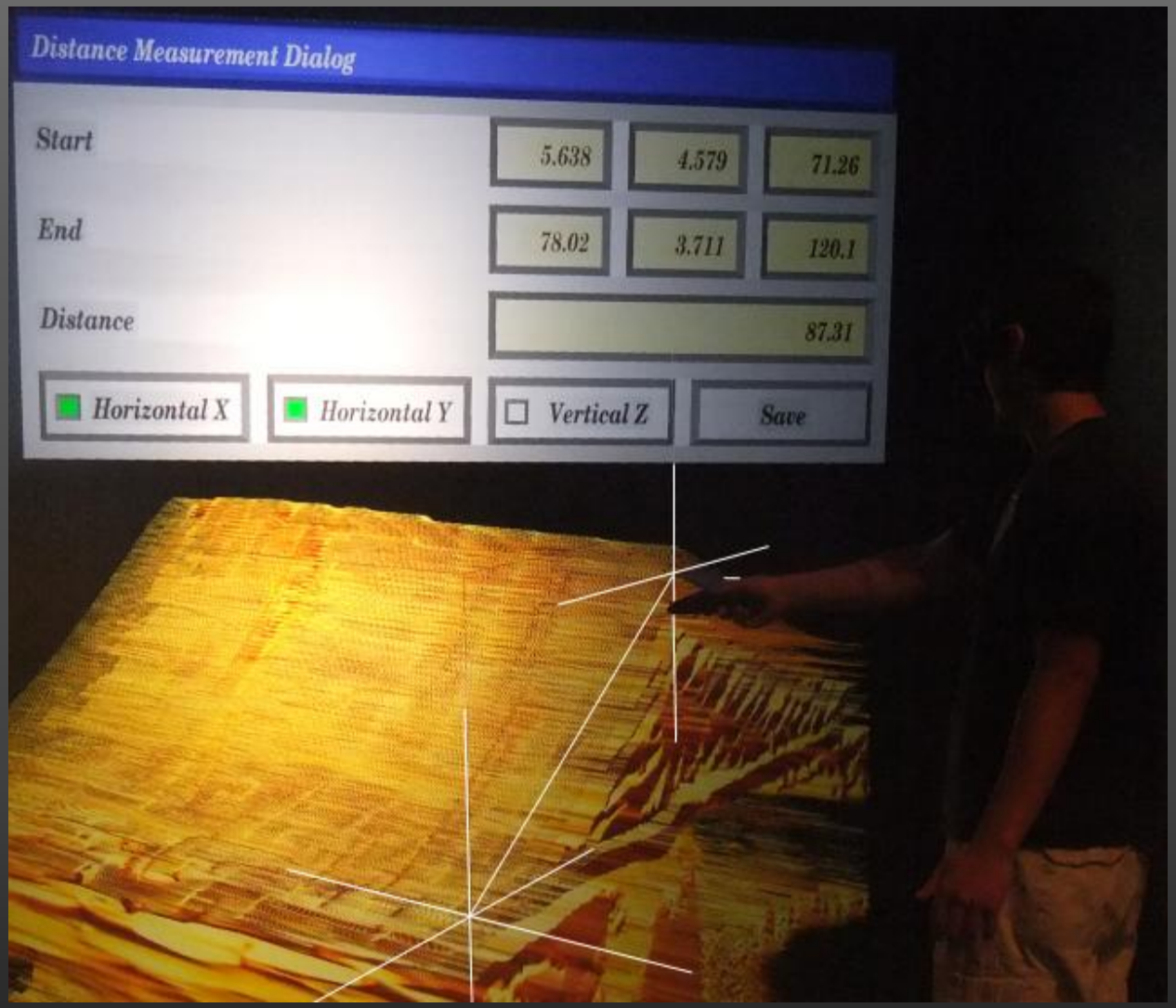
Surface Visualization



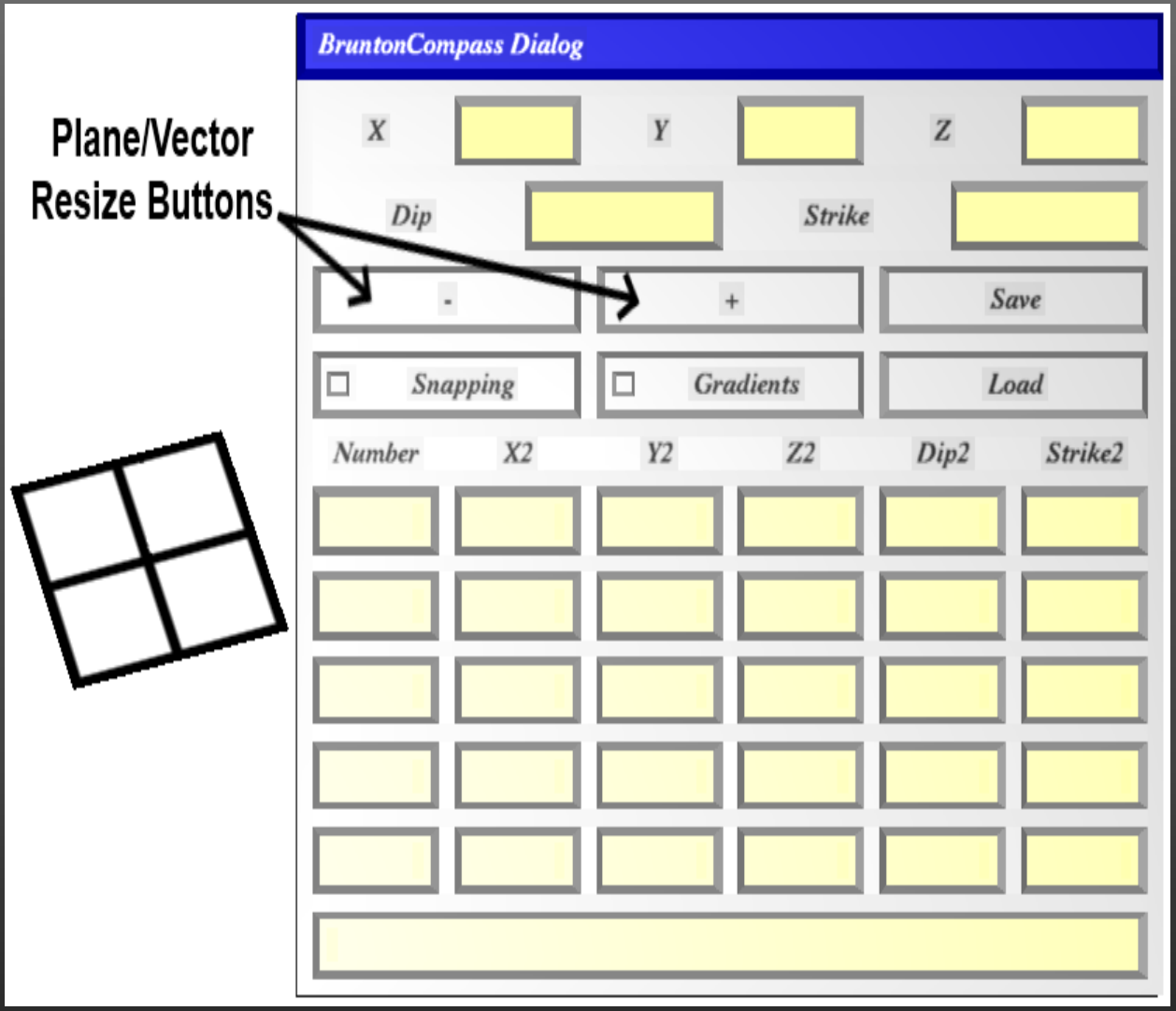
Implementation

Distance Measurement Tool

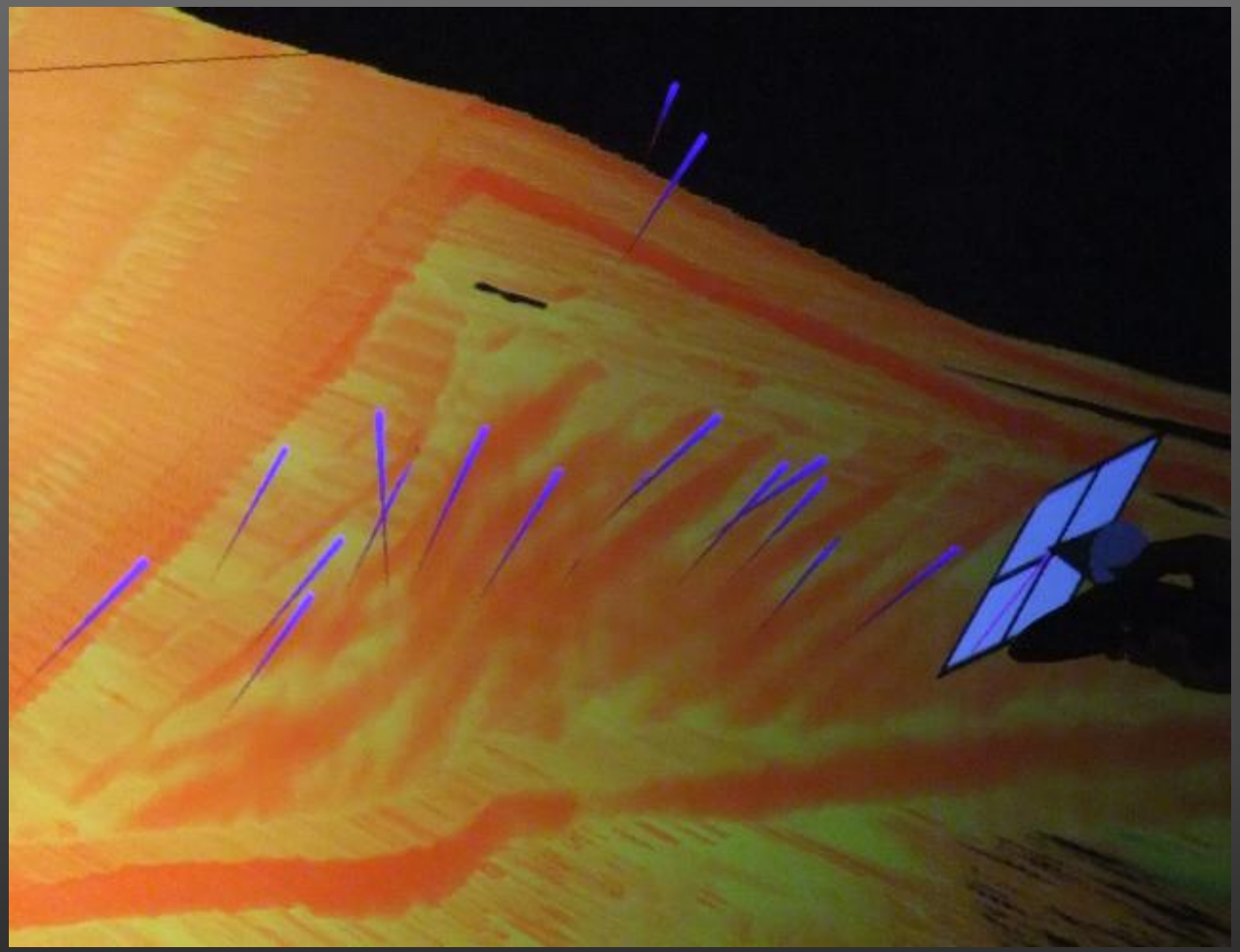
- Background
- The Project
- Software Specification and Design Process
- Implementation
- Results
- Conclusion
- Future Work



Brunton Compass Tool



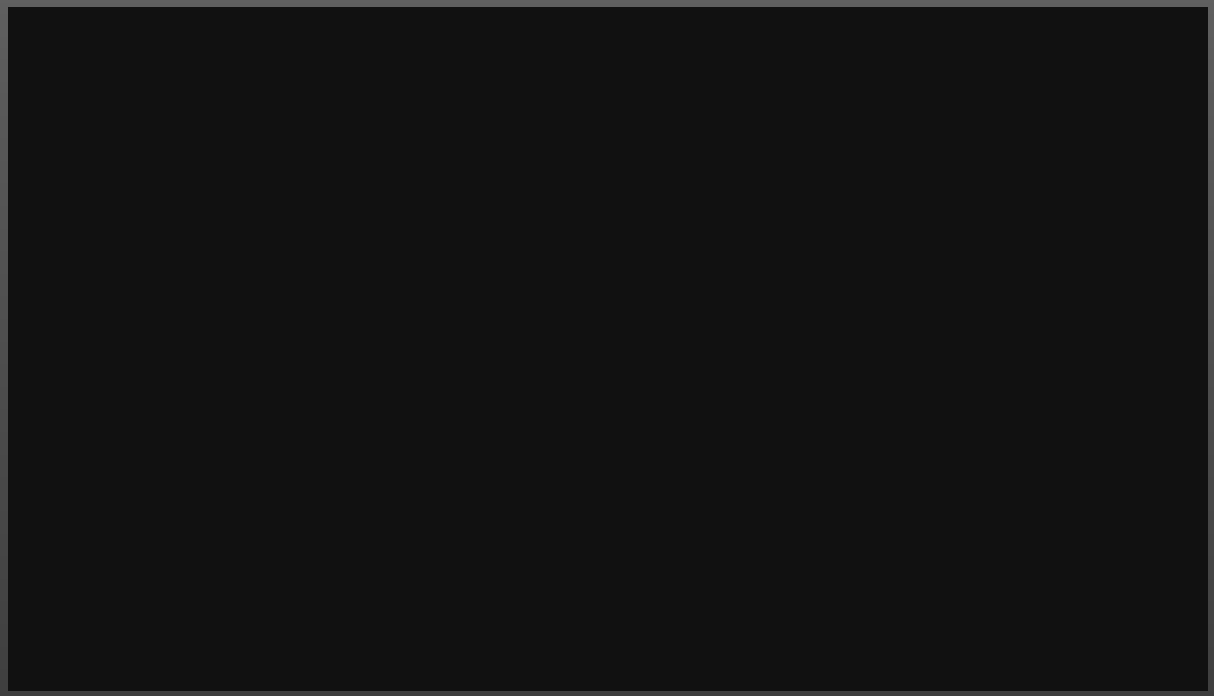
Brunton Compass Tool



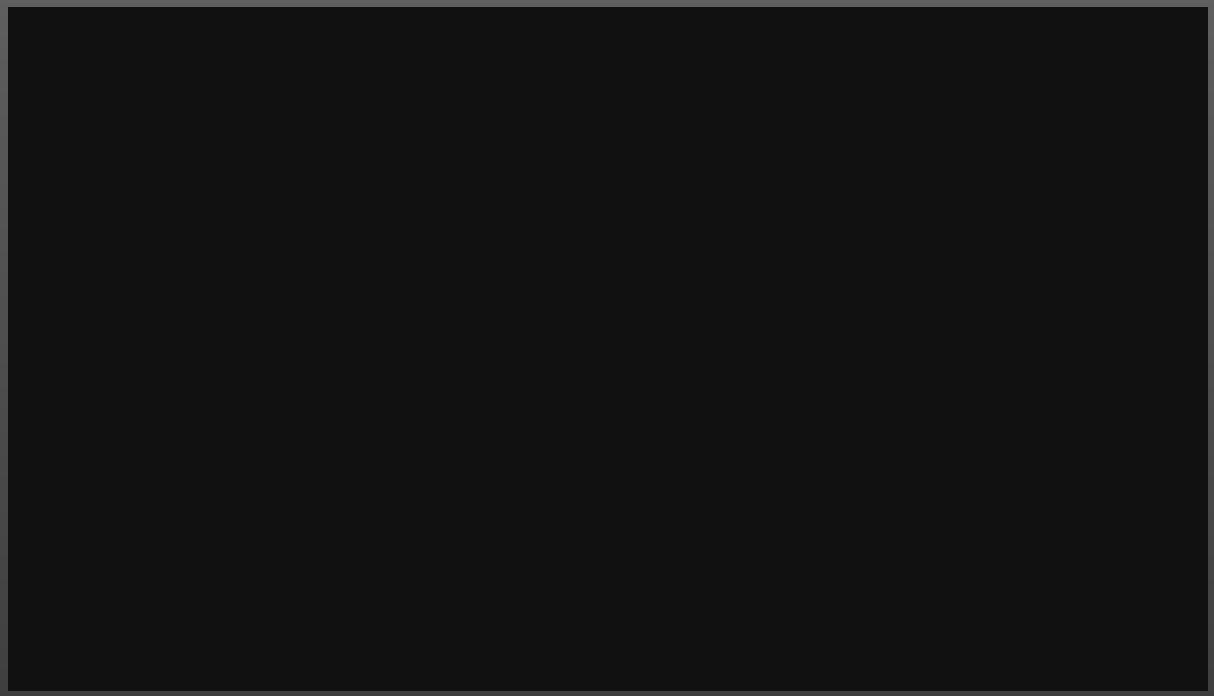
Results

- Videos
  - Volume orientation and position
  - Directional lighting
  - Color Maps
  - Slice Tool
  - 1D Transfer Function
  - Surface Visualization
  - Distance Measurement Tool
  - Brunton Compass Tool

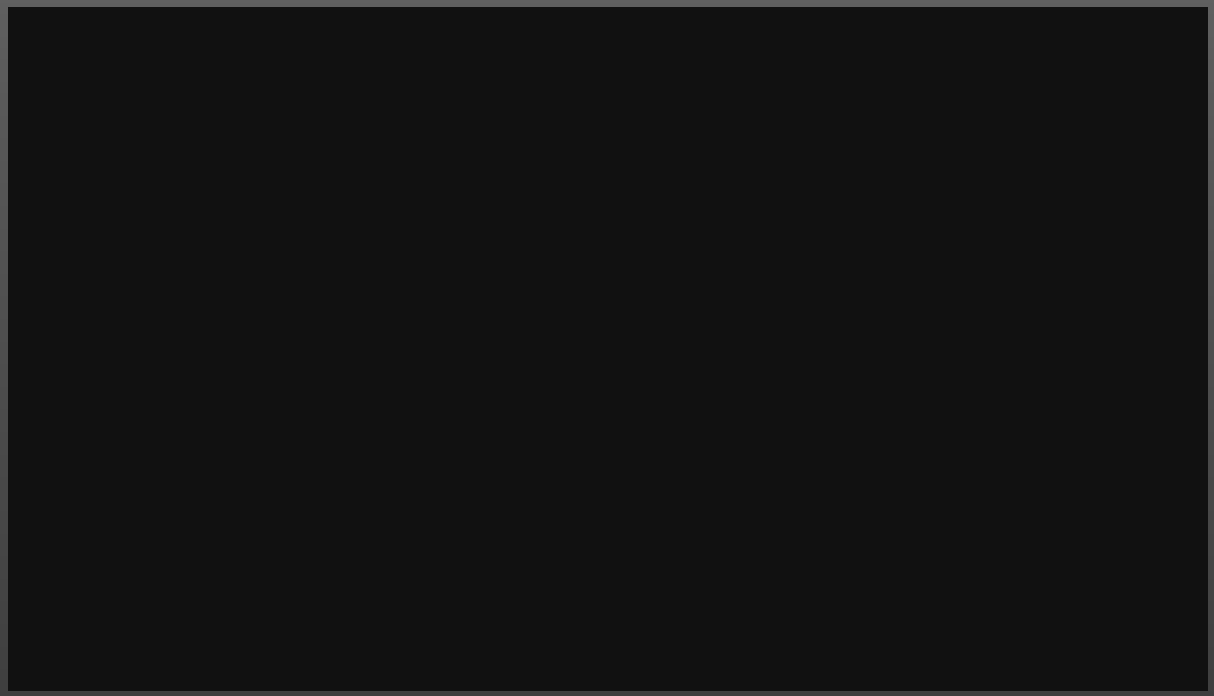
Volume Orientation and Position



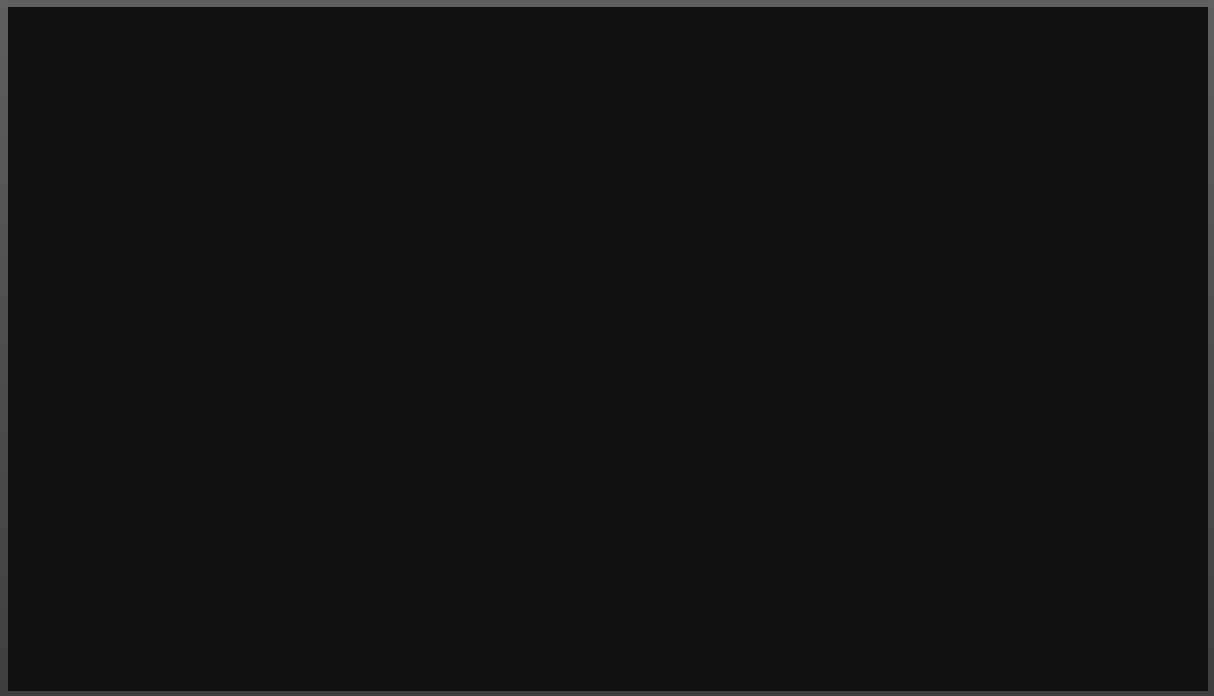
Directional Lighting



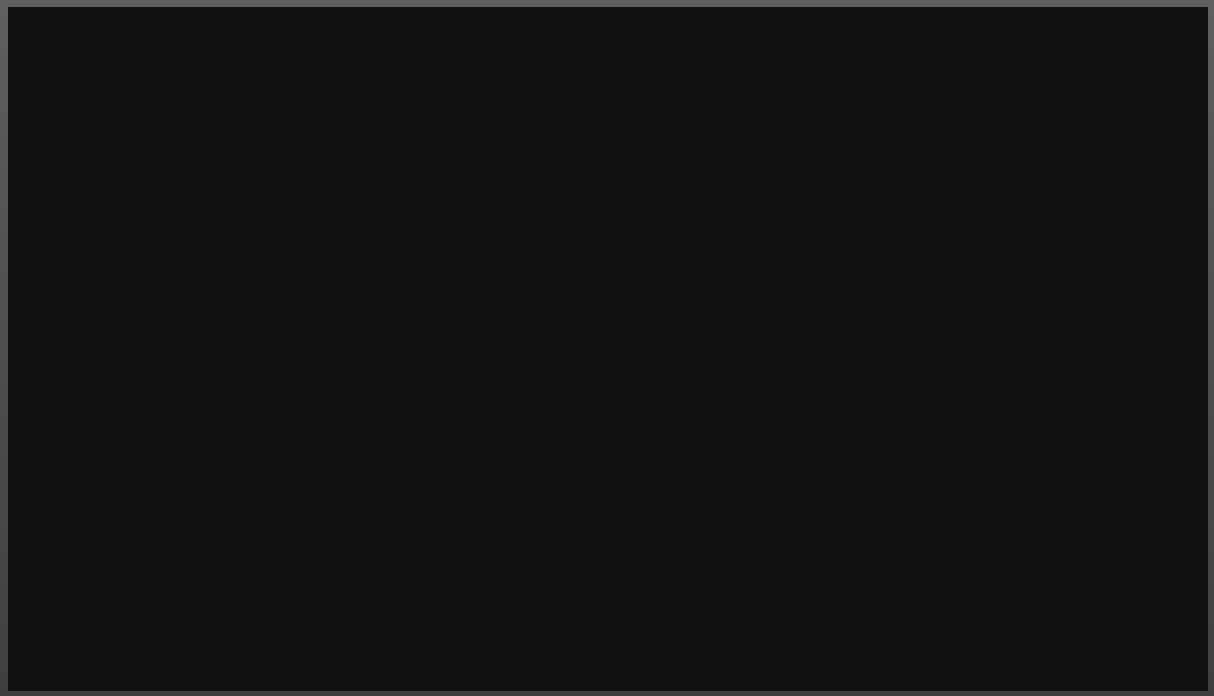
Color Maps



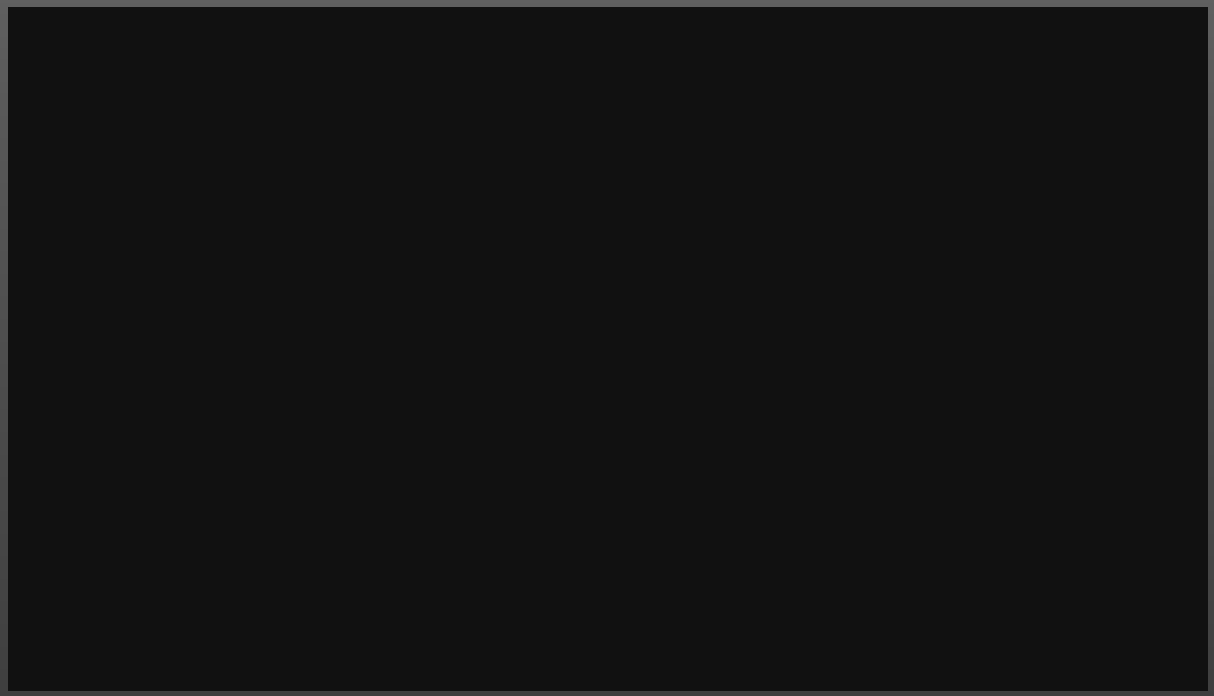
Slice Tool



1D Transfer Function

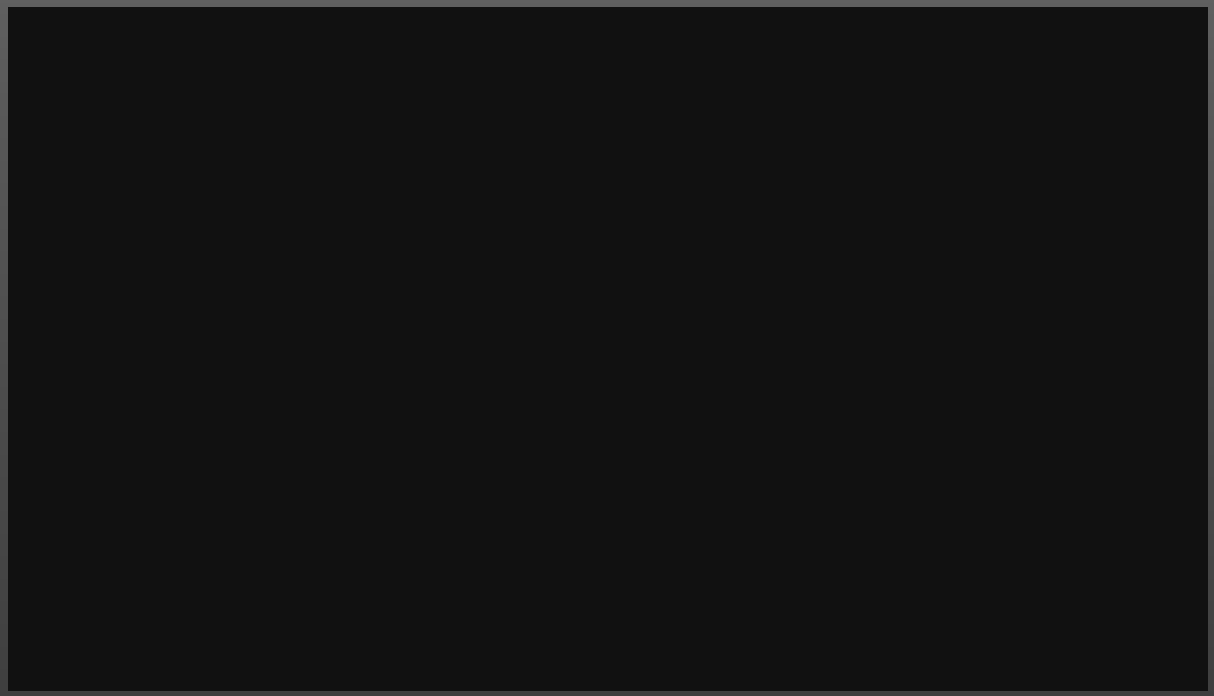


Surface Visualization

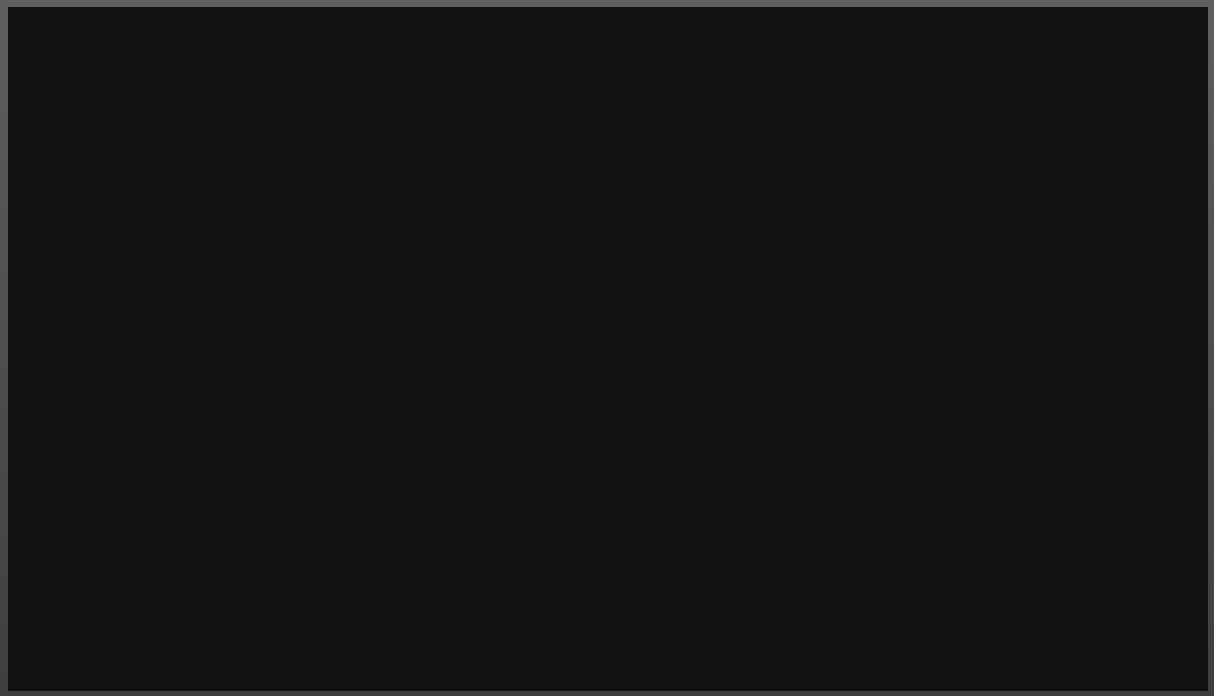


Distance Measurement Tool

- Background
- The Project
- Software Specification and Design Process
- Implementation
- Results
- Conclusion
- Future Work



Brunton Compass Tool



Conclusion

- Background
- The Project
- Software Specification and Design Process
- Implementation
- Results
- Conclusion
- Future Work

Future Work

- Improve User Friendliness
  - File selection menu
- Change the scale of the data
- Change the loaded data set
- Tools
  - Custom shaped viewing tool
  - Layer peeling tool
  - Auto subsurface generating tool
- Load more GPR file formats and different types of data

Future Work

- Have more than one volume loaded at a time
- Perform automatic or semi-automatic segmentation of the data into layers
- Clipping Plane issue
- Replace Toirt-Samhlaigh
  - Implements newer DVR algorithms
  - Takes better advantage of graphics hardware
  - Not integrated with a VR toolkit

Questions

Thank you for coming

Demo at 2:00 p.m.