2019 ZJU
International Summer School on Visual Analytics

Scientific Visualization

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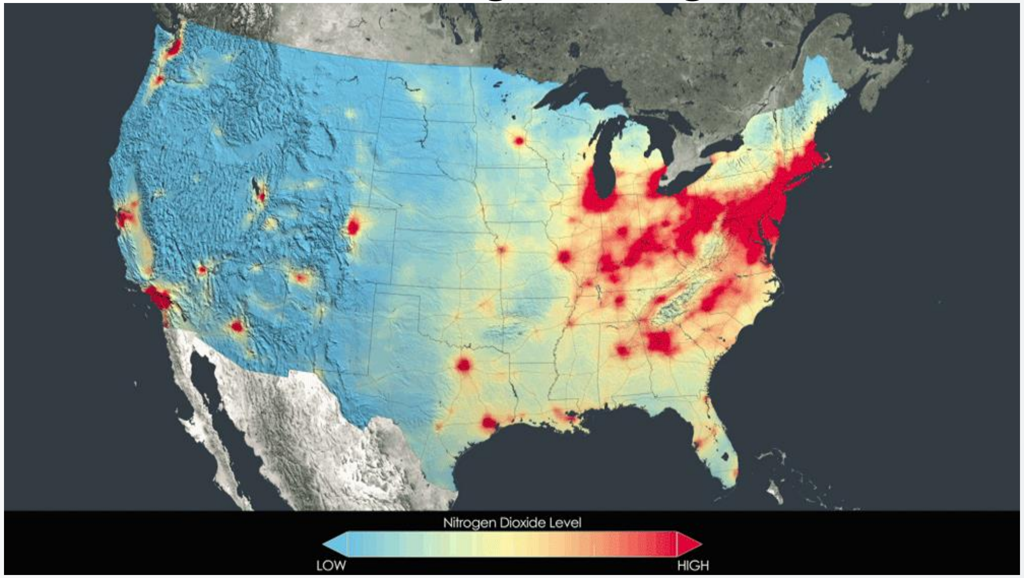
Scientific Visualization

- The visualization of three-dimensional phenomena (architectural, meteorological, medical, biological, etc.), where the emphasis is on realistic renderings of volumes, surfaces, illumination sources, and so forth, perhaps with a dynamic (time) component
- The purpose of scientific visualization is to graphically illustrate scientific data to enable scientists to understand, illustrate, and glean insight from their data



Scientific Visualization

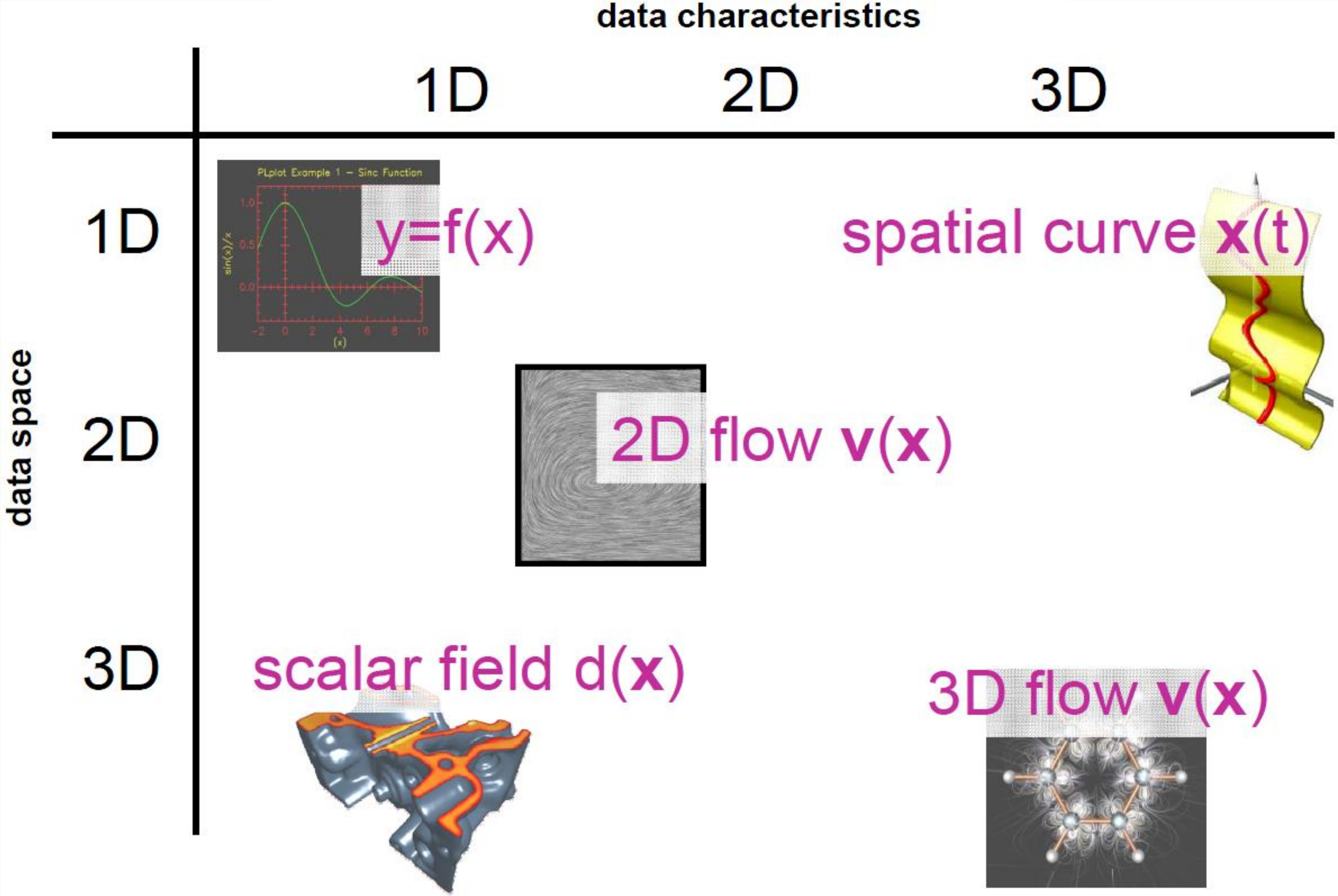
- Distributed and Collaborative Visualization
- Flow Visualization
- Information Visualization
- Isosurfaces and Surface extraction
- Large Data Visualization
- Multi-Resolution Techniques
- Multimodal Visualization
- Novel Mathematics for Visualization
- Parallel Visualization and Graphics Clusters
- Point-Based Visualization
- Security and Network Intrusion visualization
- Software Visualization
- Terrain Visualization
- Time Critical Visualization
- Time-Varying Data
- Uncertainty Visualization
- Unstructured Grids
- Usability and Human Factors in Visualization
- Vector/Tensor Visualization
- Virtual Environments
- Visual Knowledge Discovery
- Visualization Systems
- Visualization in Earth, Space, and Environmental Sciences
- Visualization in Physical Sciences, Life Sciences and Engineering
- Visualization in Social and Information Sciences
- Visualization over Networks, Grids, and the Internet
- Volume Visualization

Spatial Data

- What is spatial data?
  - Spatial data is usually stored as coordinates and topology

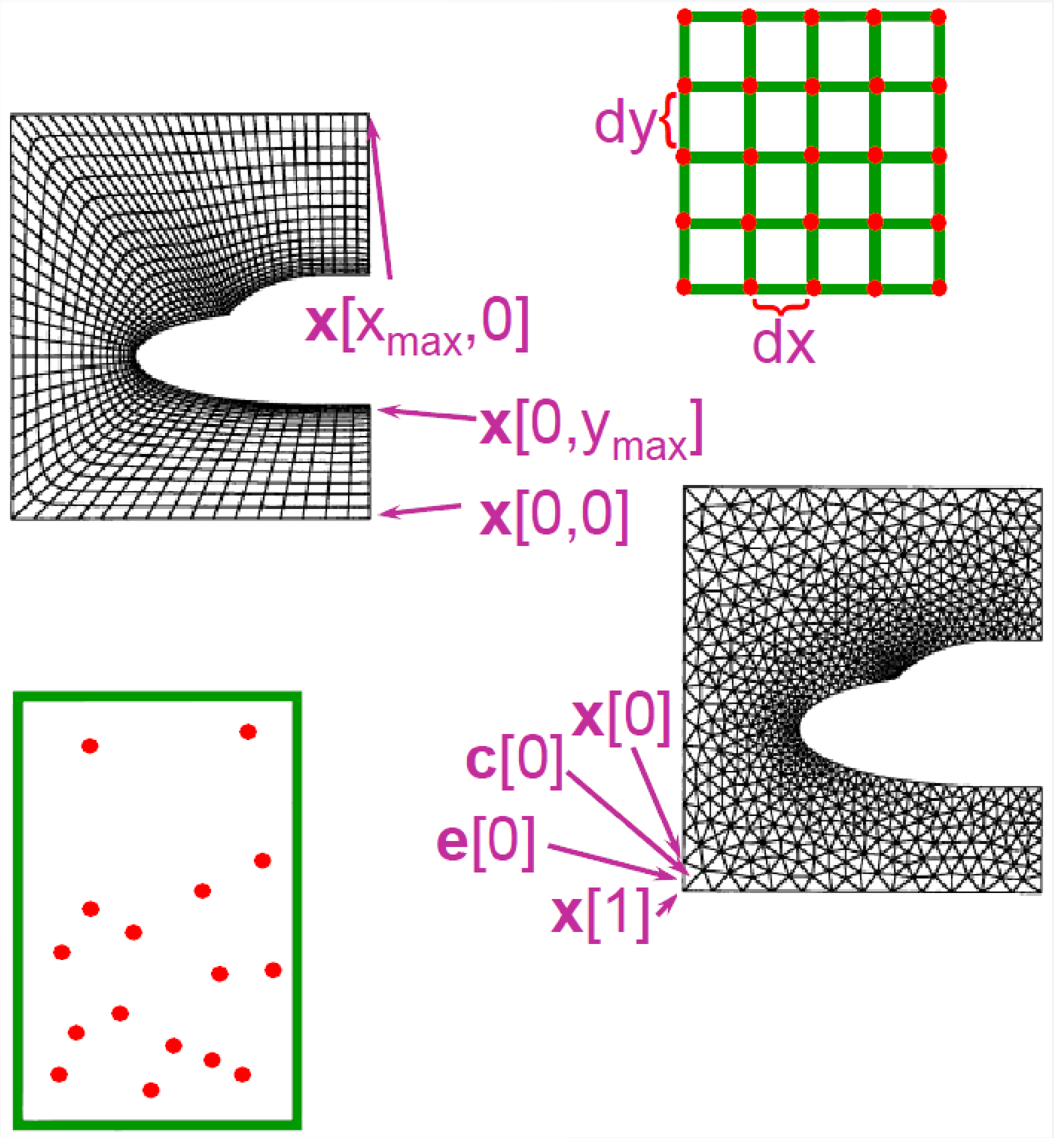
- Spatial data can be
  - 1D data, 2D data, 3D data and high dimensional data
  - scalar data, vector field data and tensor field data
  - medical data, atmosphere data, geographical data and volume data

Scientific Visualization

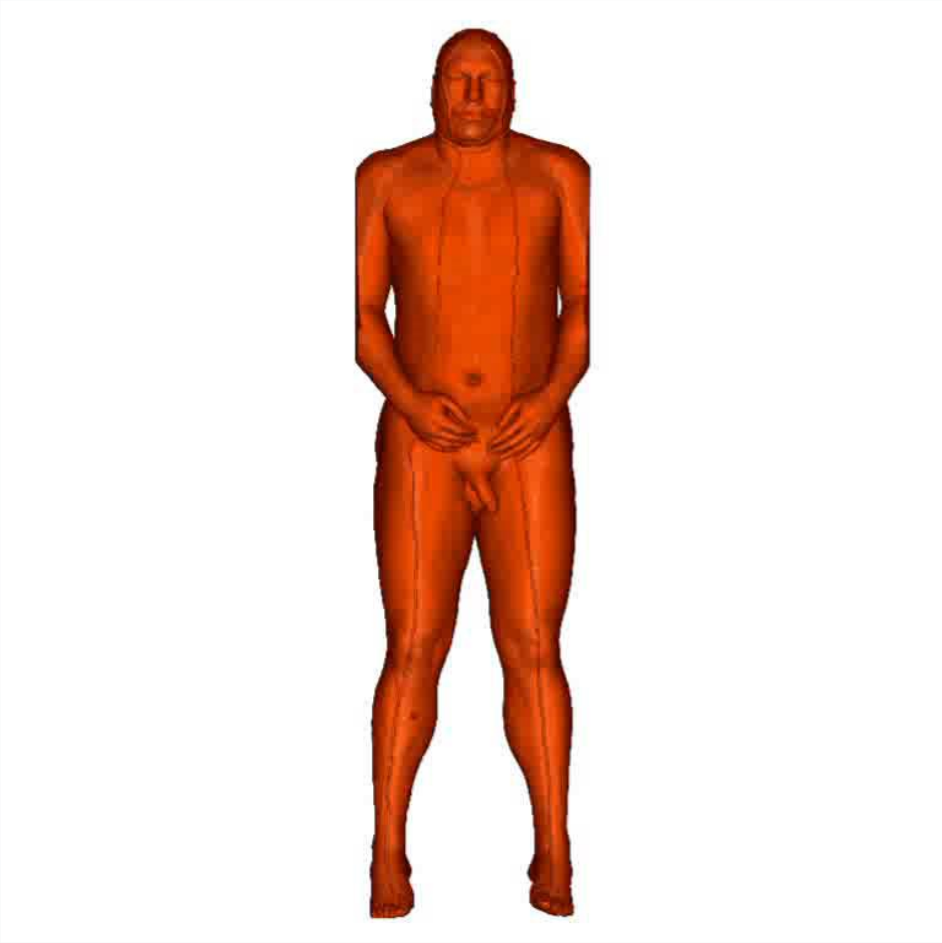


Scientific Visualization

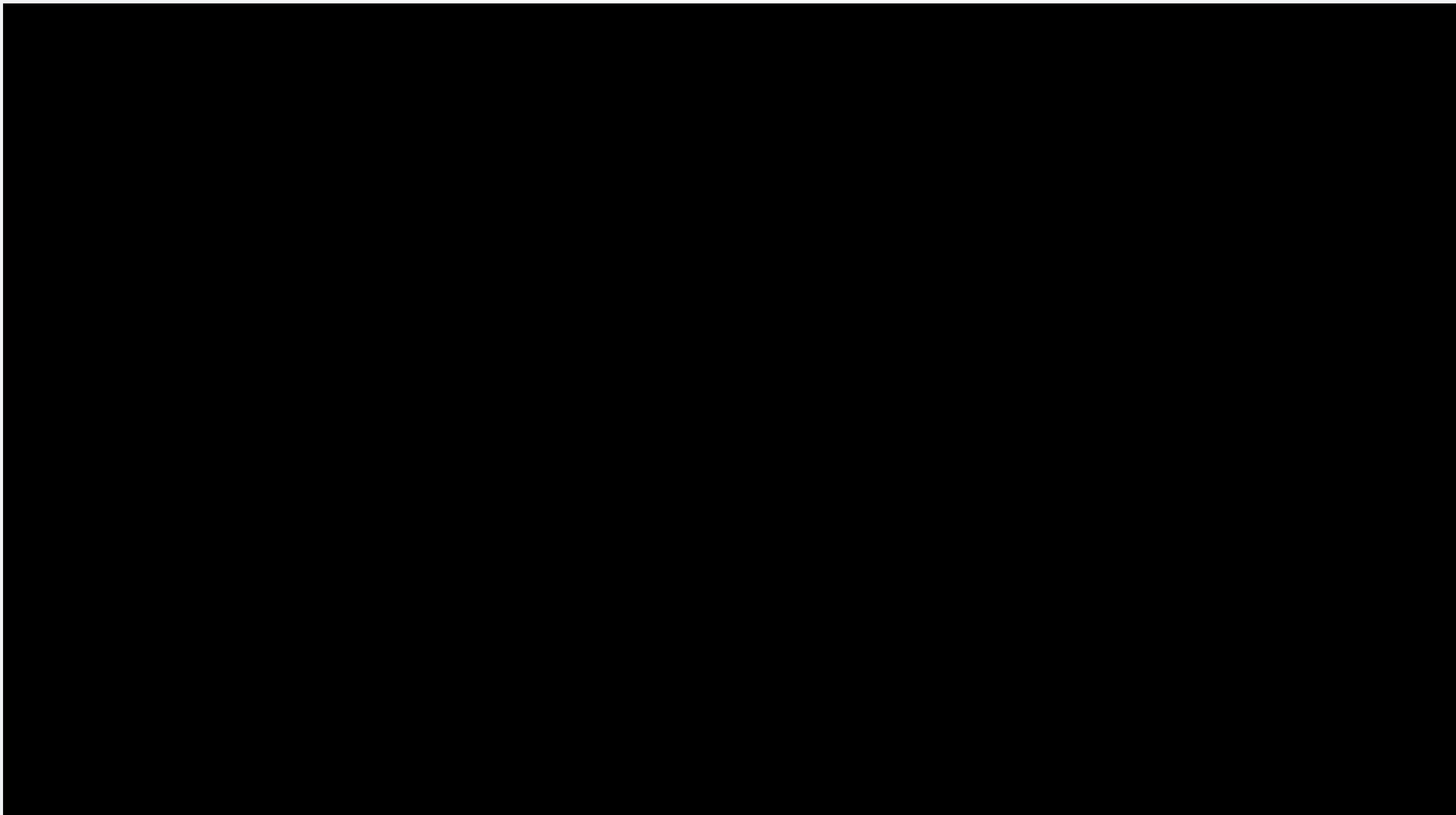
- Cartesian grid
- Cuivilinear grid
- Unstructured grid
- Scattered data



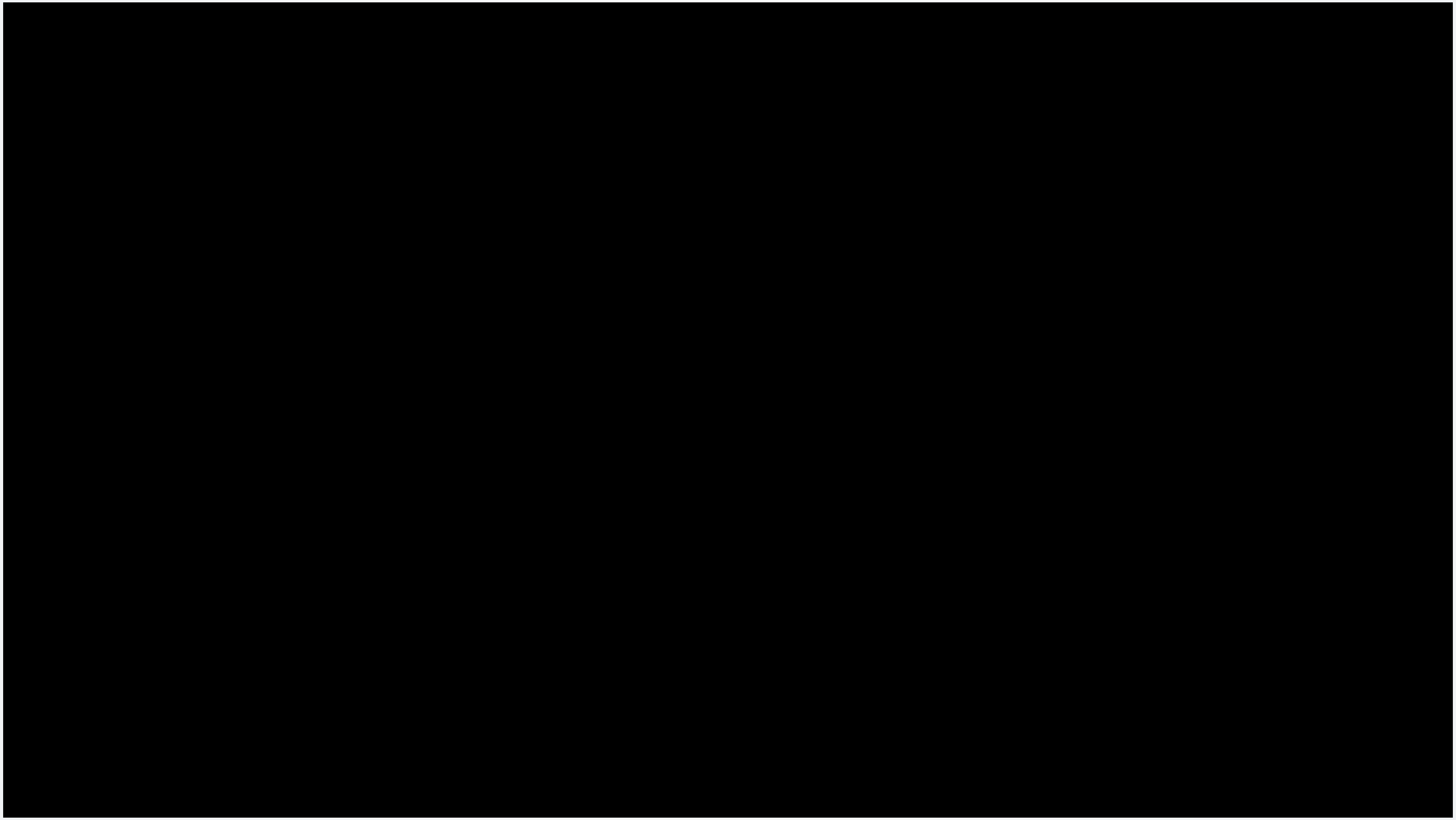
SciVis — Revealing Structures and Features



SciVis — Revealing Structures and Features

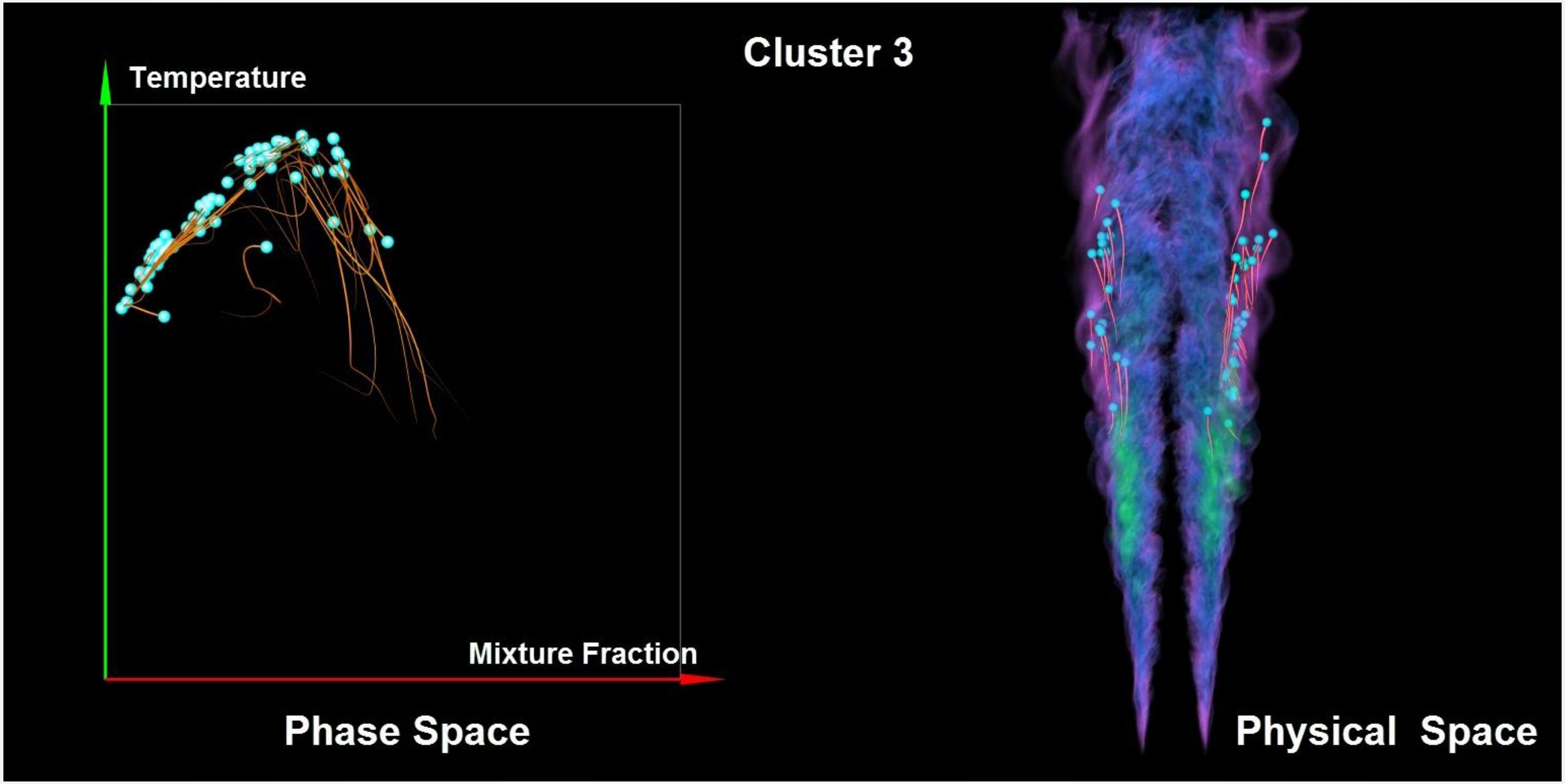


SciVis — Presenting Evolution Laws

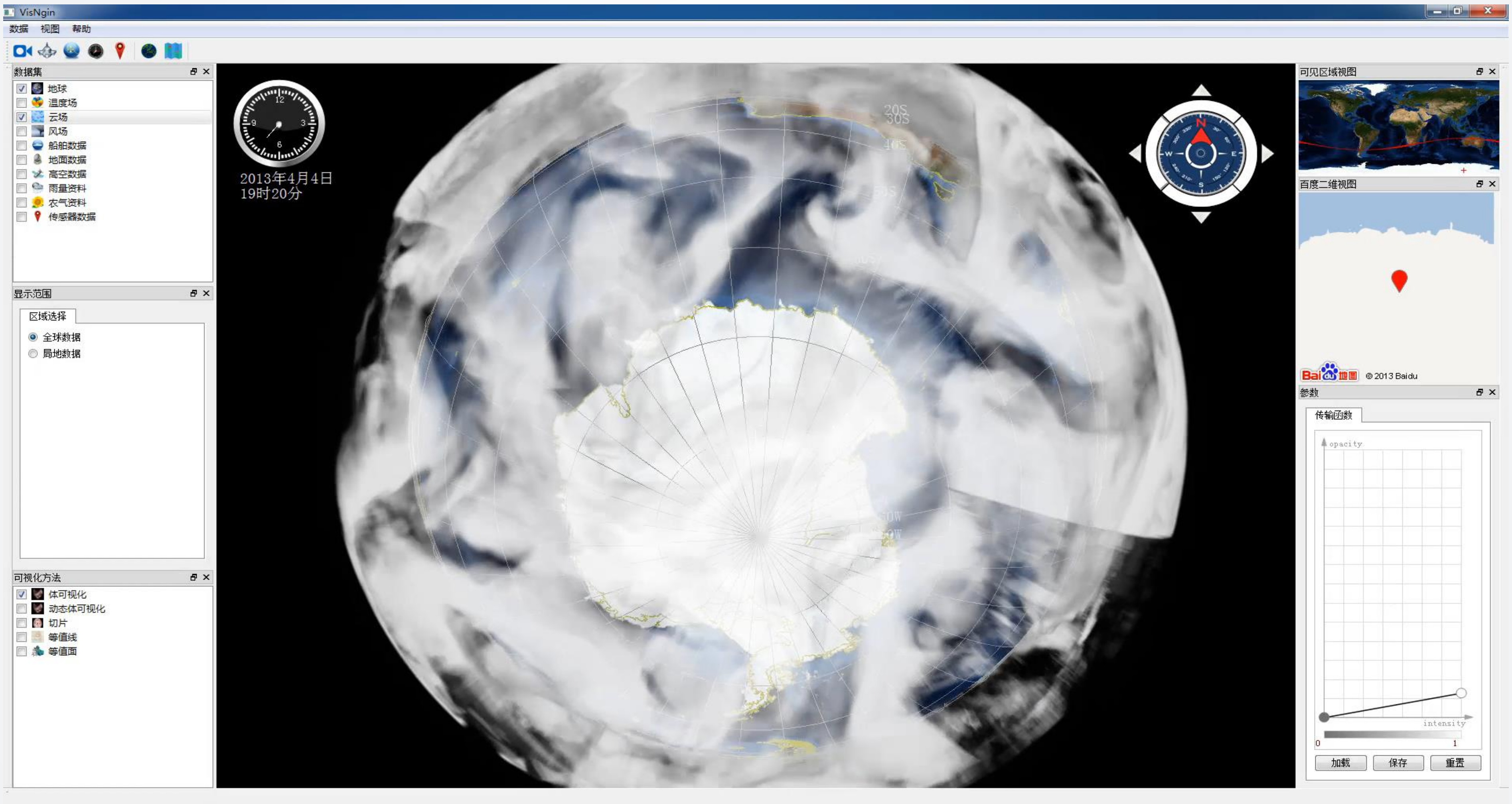


SciVis — Presenting Evolution Laws

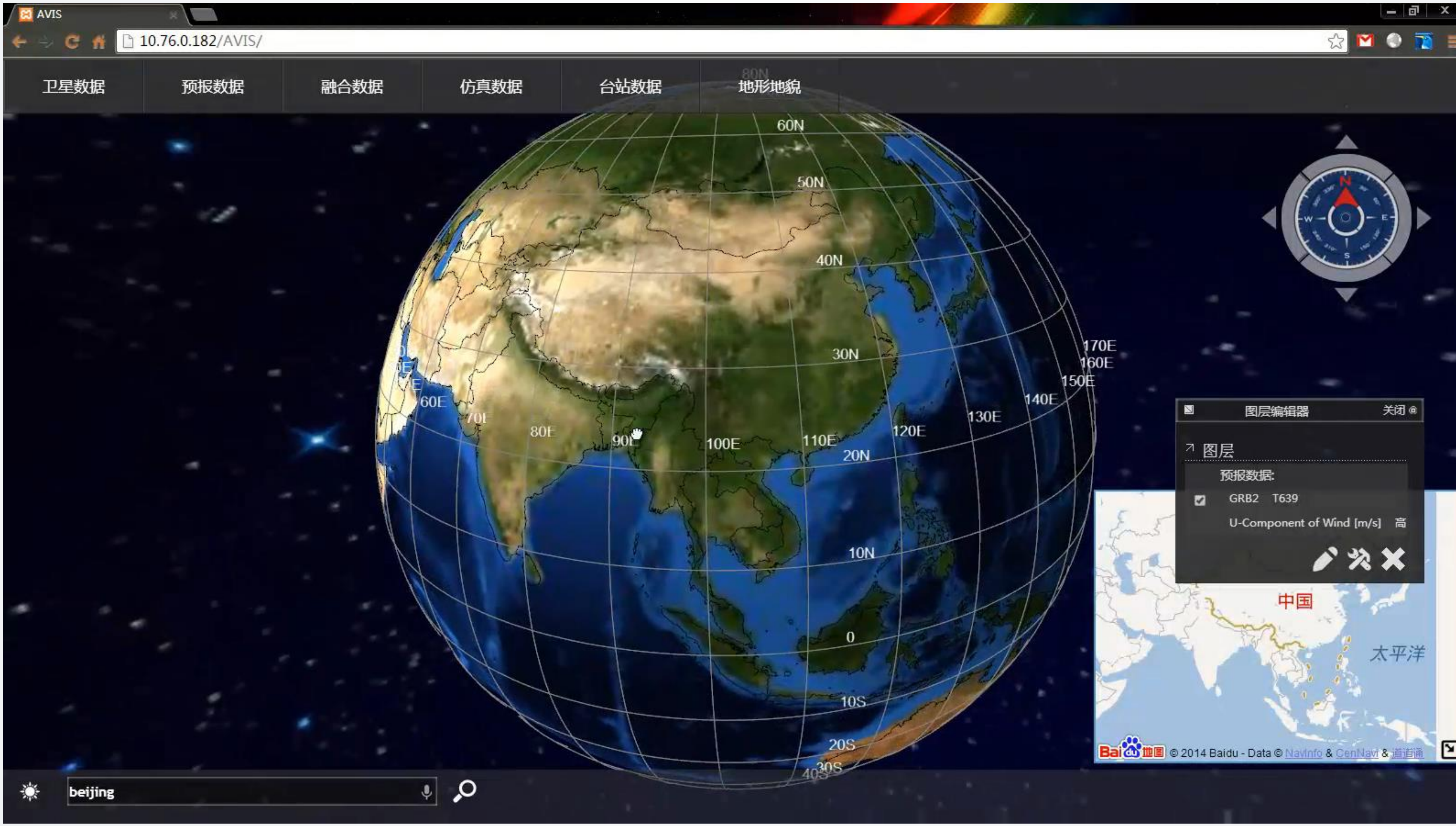
SciVis — Simulation and Visualization



3D Atmosphere Visualization



3D Atmosphere Visualization



OUTLINE

1. 1D Data Visualization
2. 2D Data Visualization
3. 3D Volume Visualization
4. Vector Field and Tensor Field
5. Medical Data Visualization

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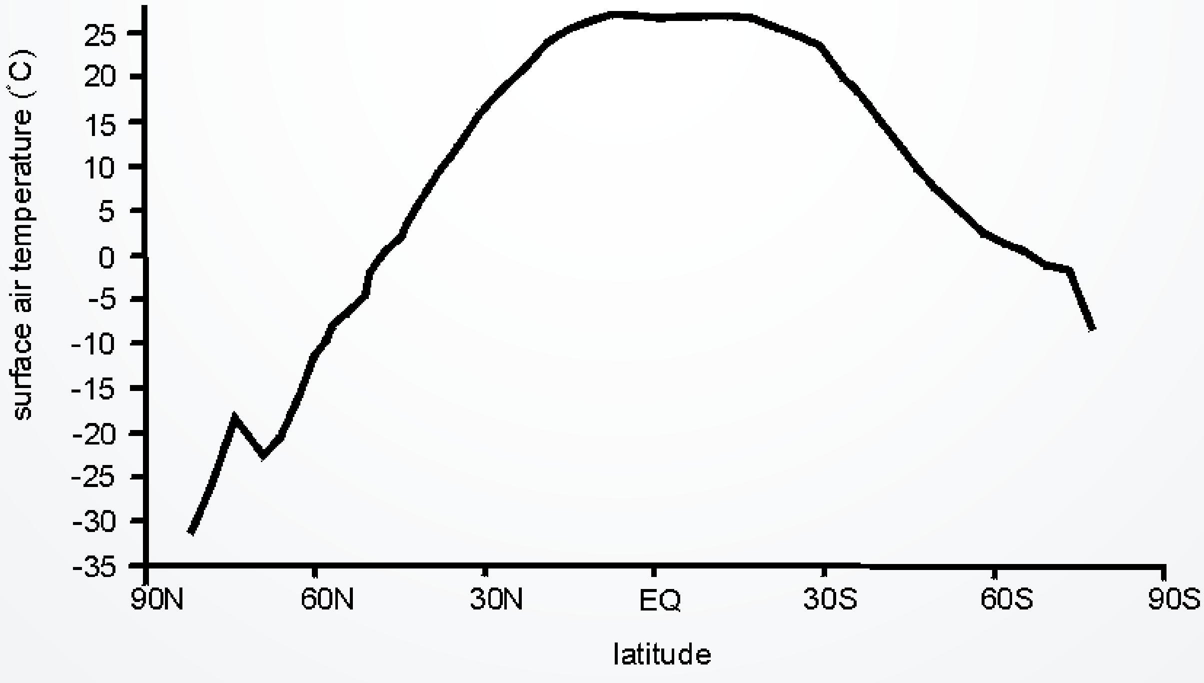
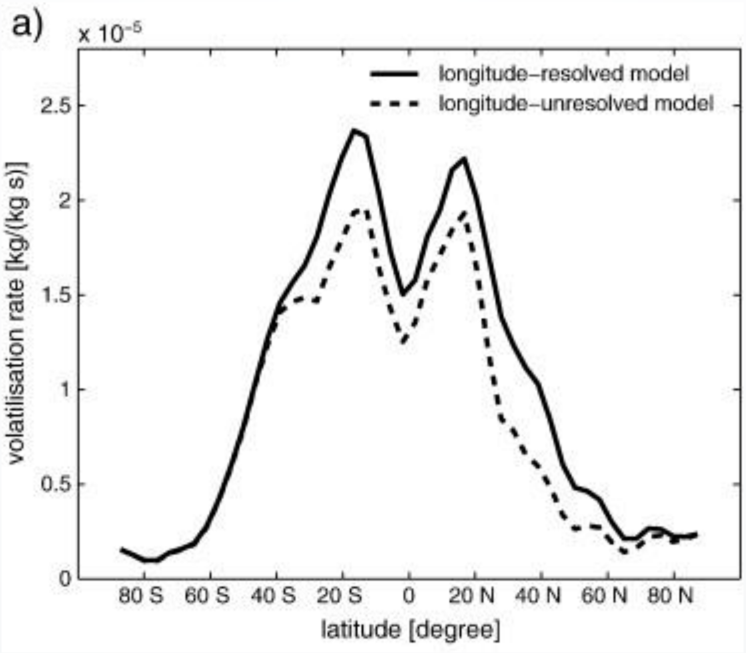
1D Data

- Sampling data obtained along a certain path in the space
- Examples
  - Soil depth obtained in soil drilling
  - Air pressure along a certain longitude



Visualization

- Statistical charts are widely used for 1D spatial data visualization.
- Usually the spatial information is encoded as variable, and codomain is the measured values.



Air–sea exchange
latitude VS. water volatilisation rate

OUTLINE

1 1D Data Visualization

2 2D Data Visualization

3 3D Volume Visualization

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5 Medical Data Visualization

2D Data

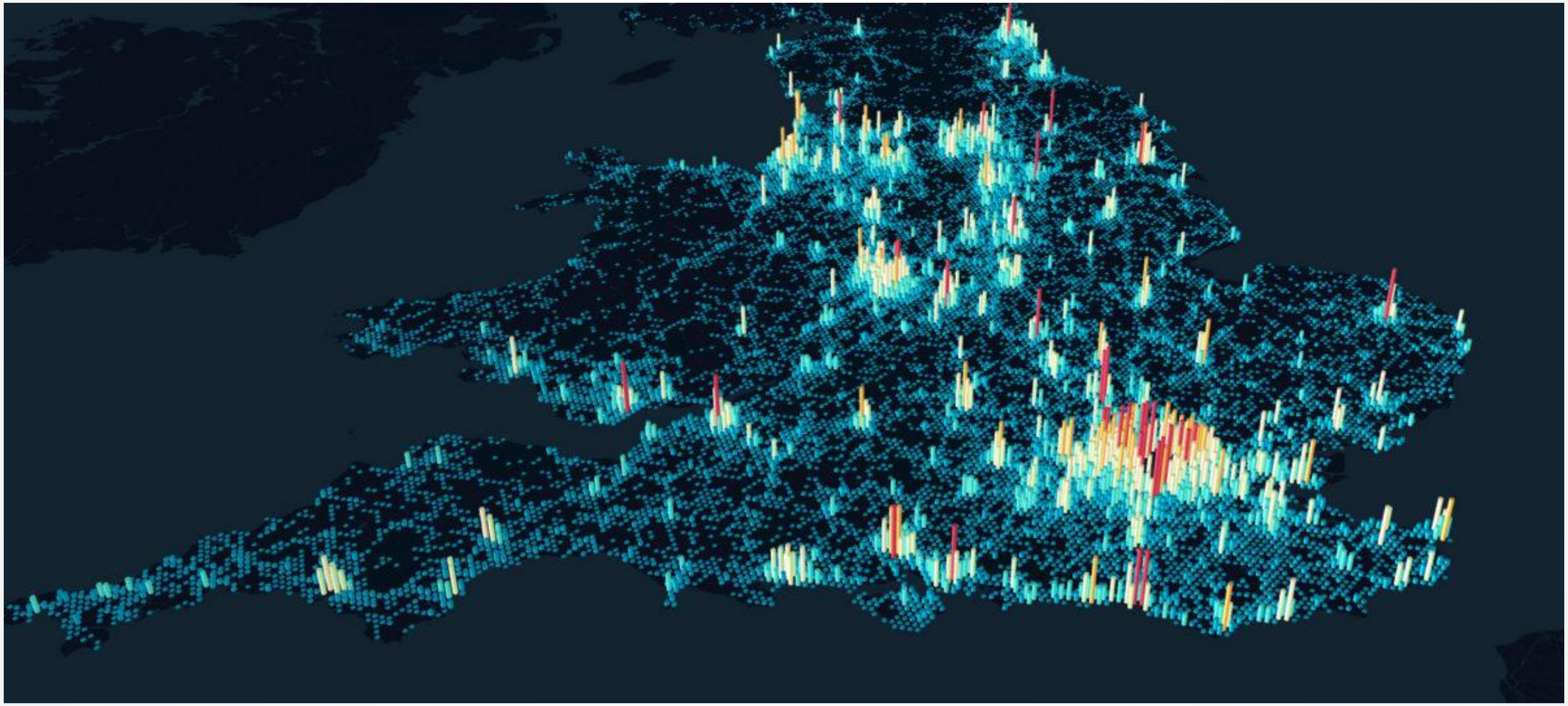
- Medical data
- Geographical data

American population map

The first x-ray image

Heightmap

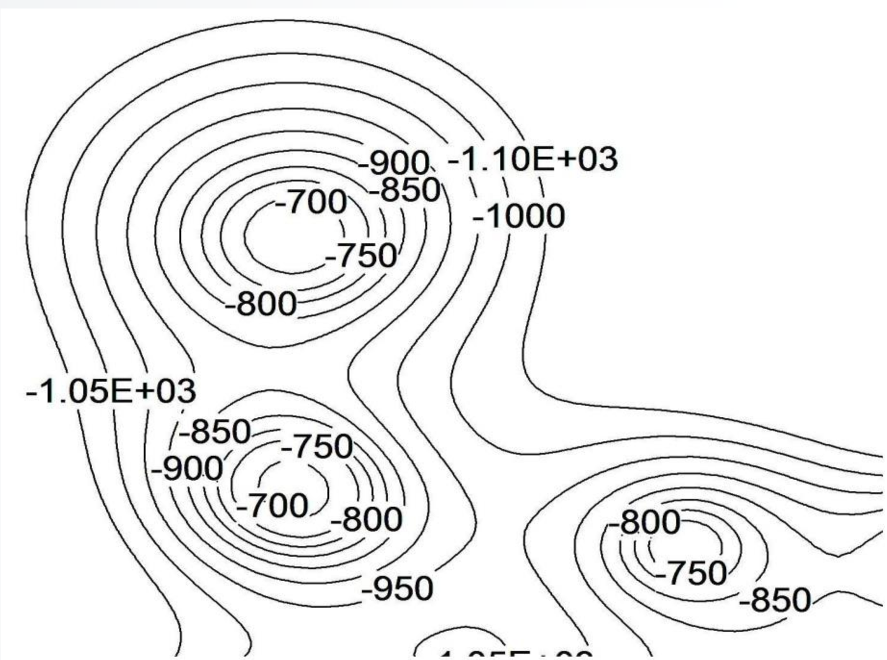
- Height is used to encode measured values

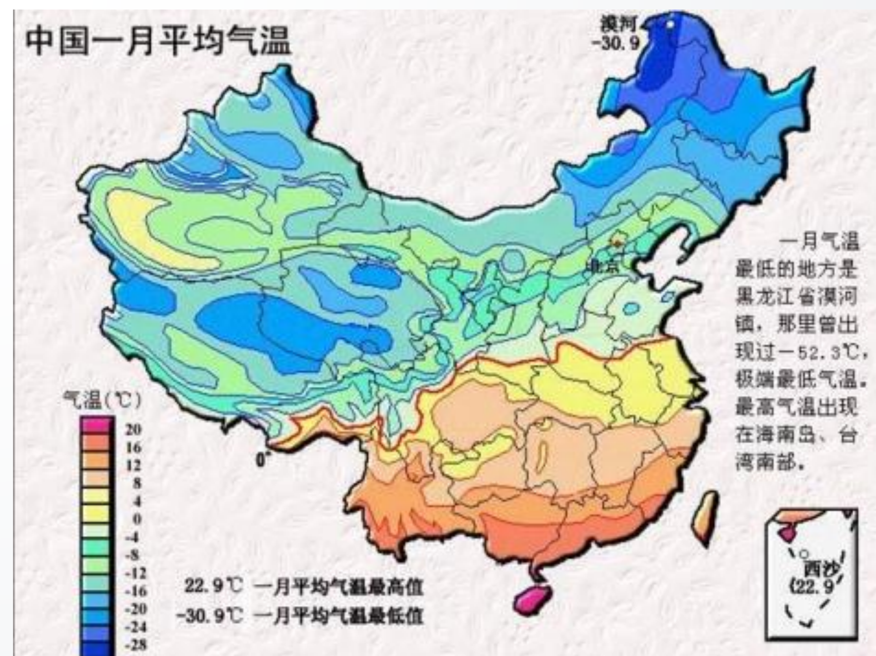


Personal injury road accidents in GB from 1979

Isocontours

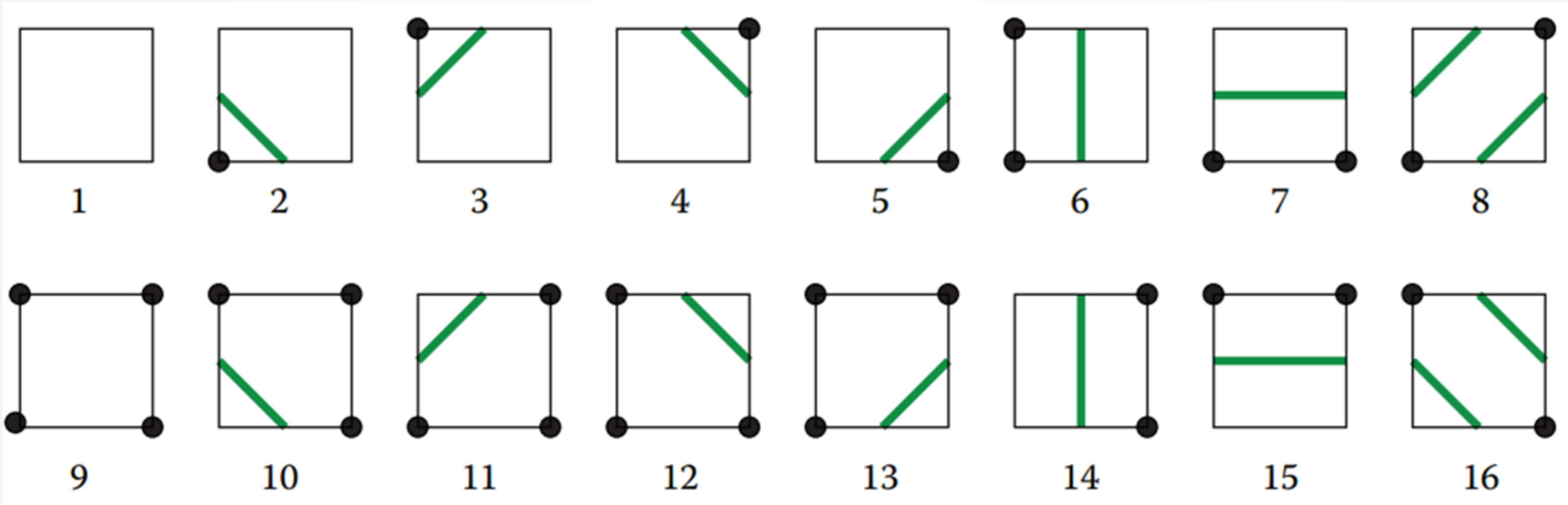
- A level set of curve where the function takes on a given constant value
  - The line formed by a same function value
  - Iso: equal
  - Contour: line



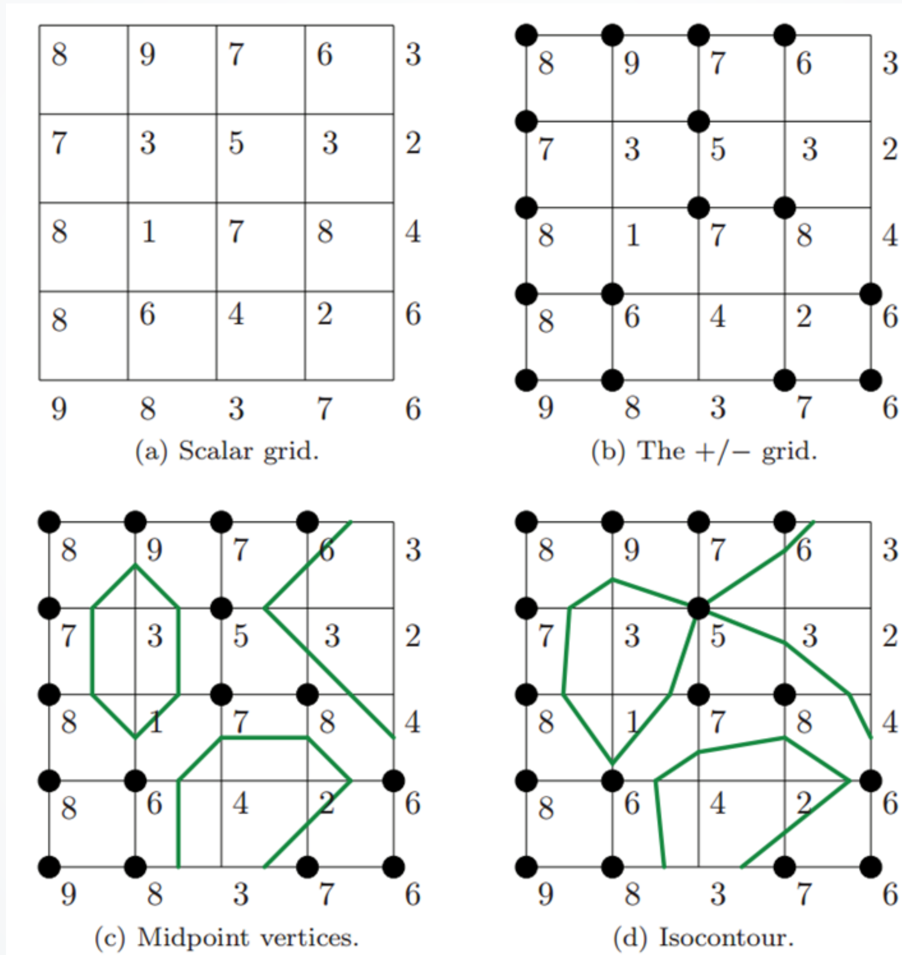


Isocontours

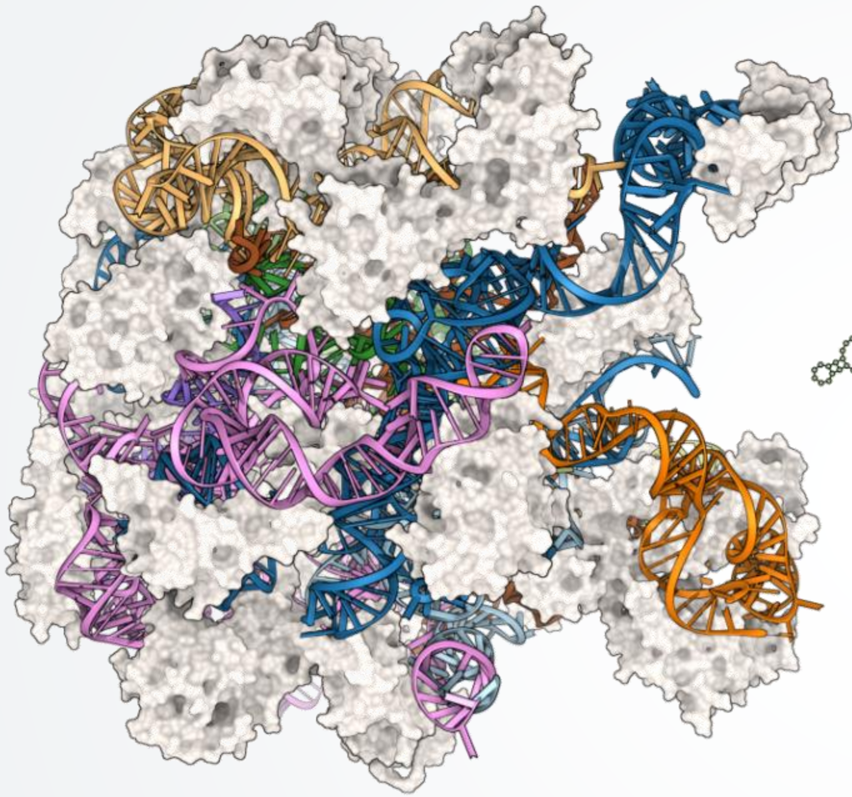
- Iscontours



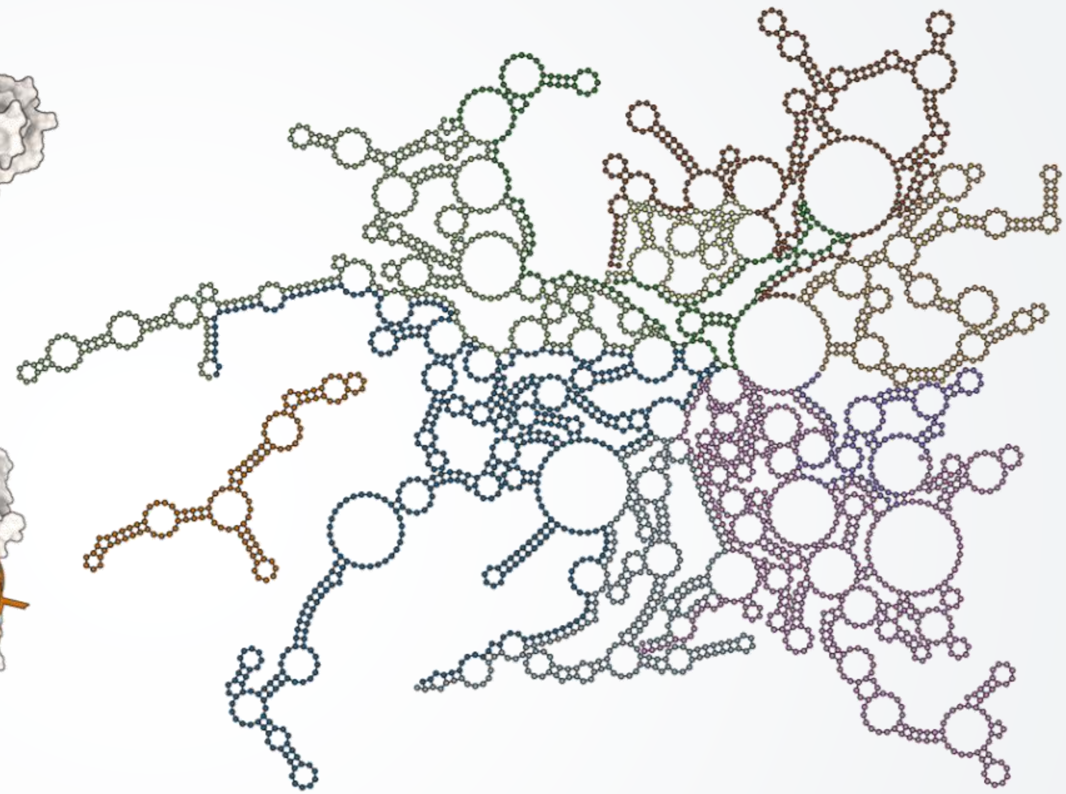
Isocontours



(a) Scalar grid. (b) The +/− grid. (c) Midpoint vertices. (d) Isocontour.

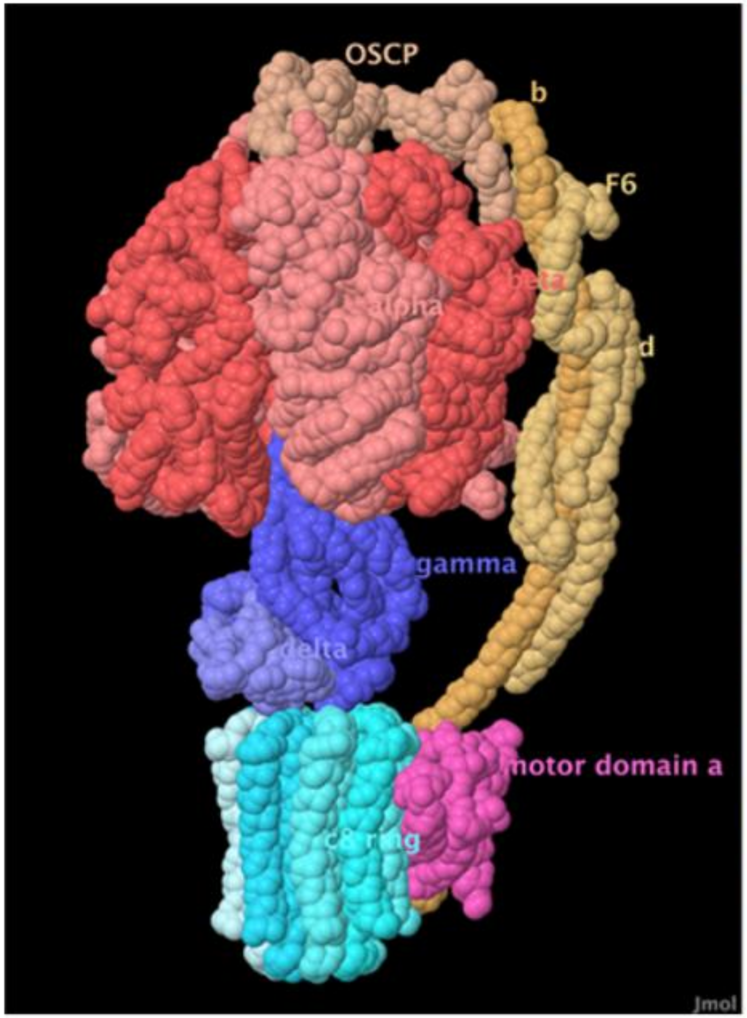


ribosomal RNA-3D model



ribosomal RNA-2D model

Lindow, Norbert, et al. "Interactive Visualization of RNA and DNA Structures." IEEE transactions on visualization and computer graphics (2018).

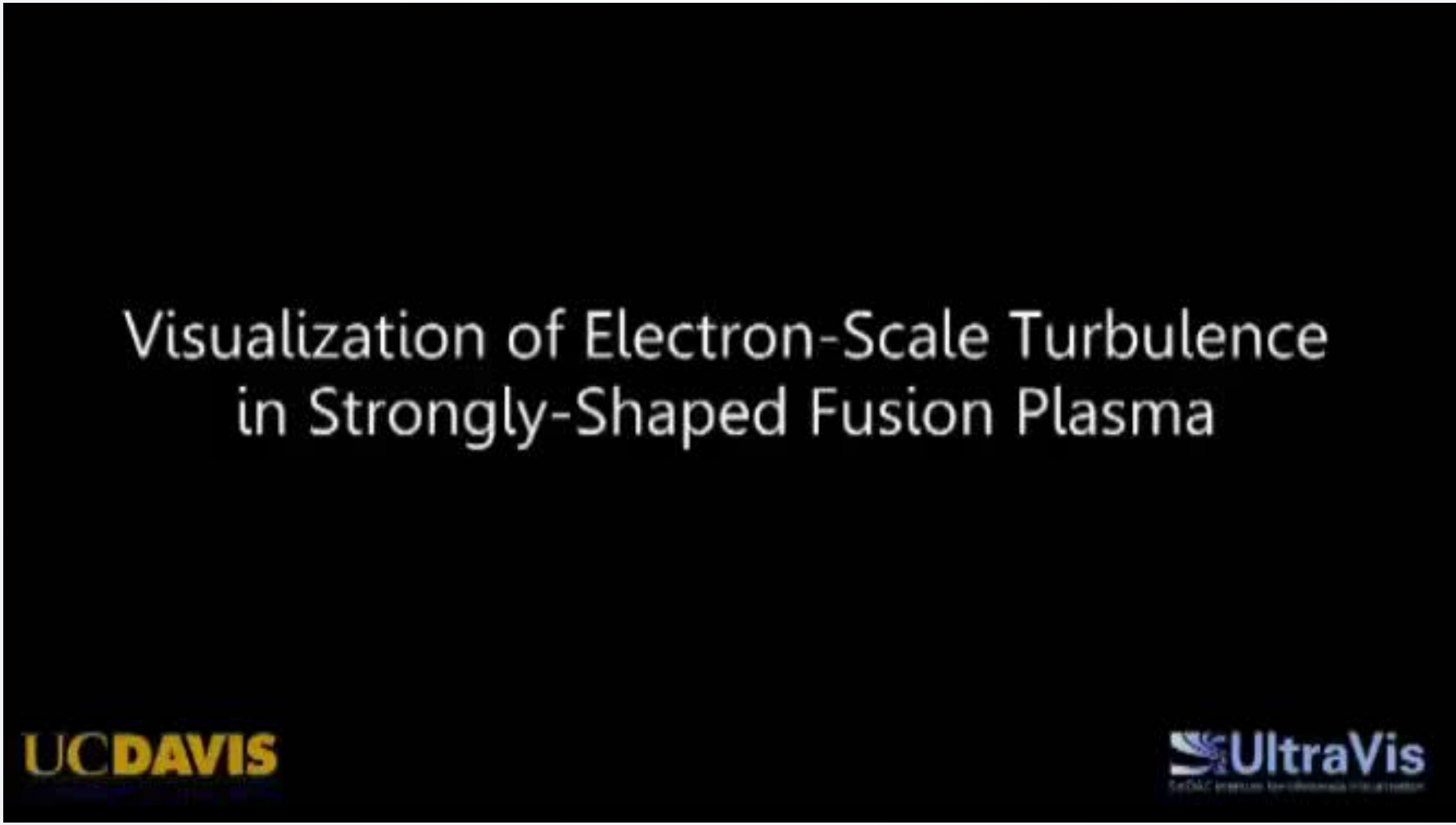


ATP synthase

molecular processes in insulin signaling

Kouřil, David, et al. "Labels on Levels: Labeling of Multi-Scale Multi-Instance and Crowded 3D Biological Environments." IEEE transactions on visualization and computer graphics(2018).

Iso-contours



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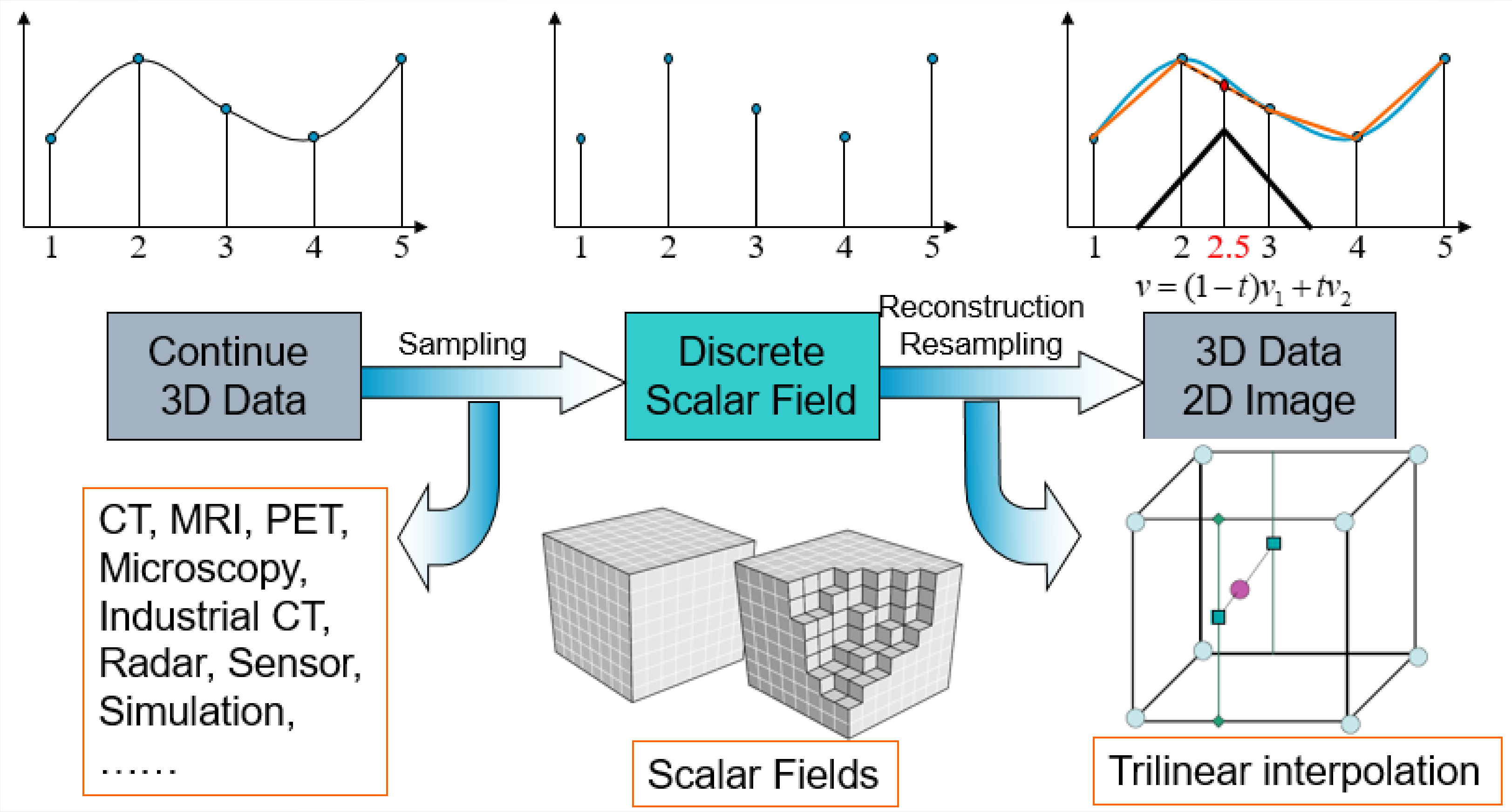
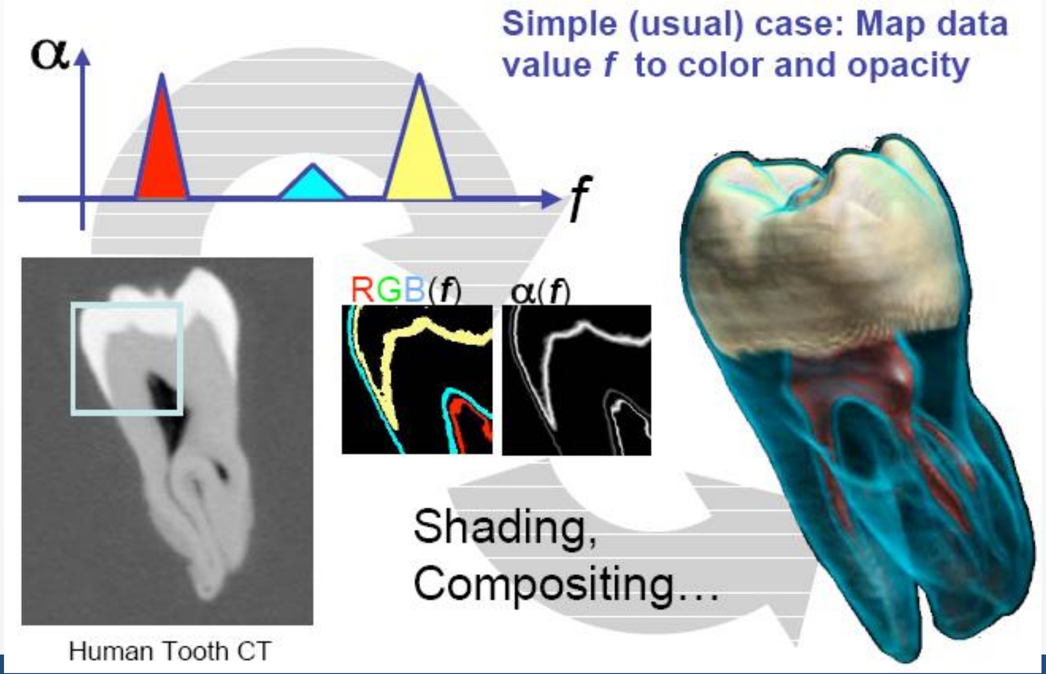
Scalar Field

- A volume is a 3D array of cubic elements (voxels)
- A voxel is not a little cube

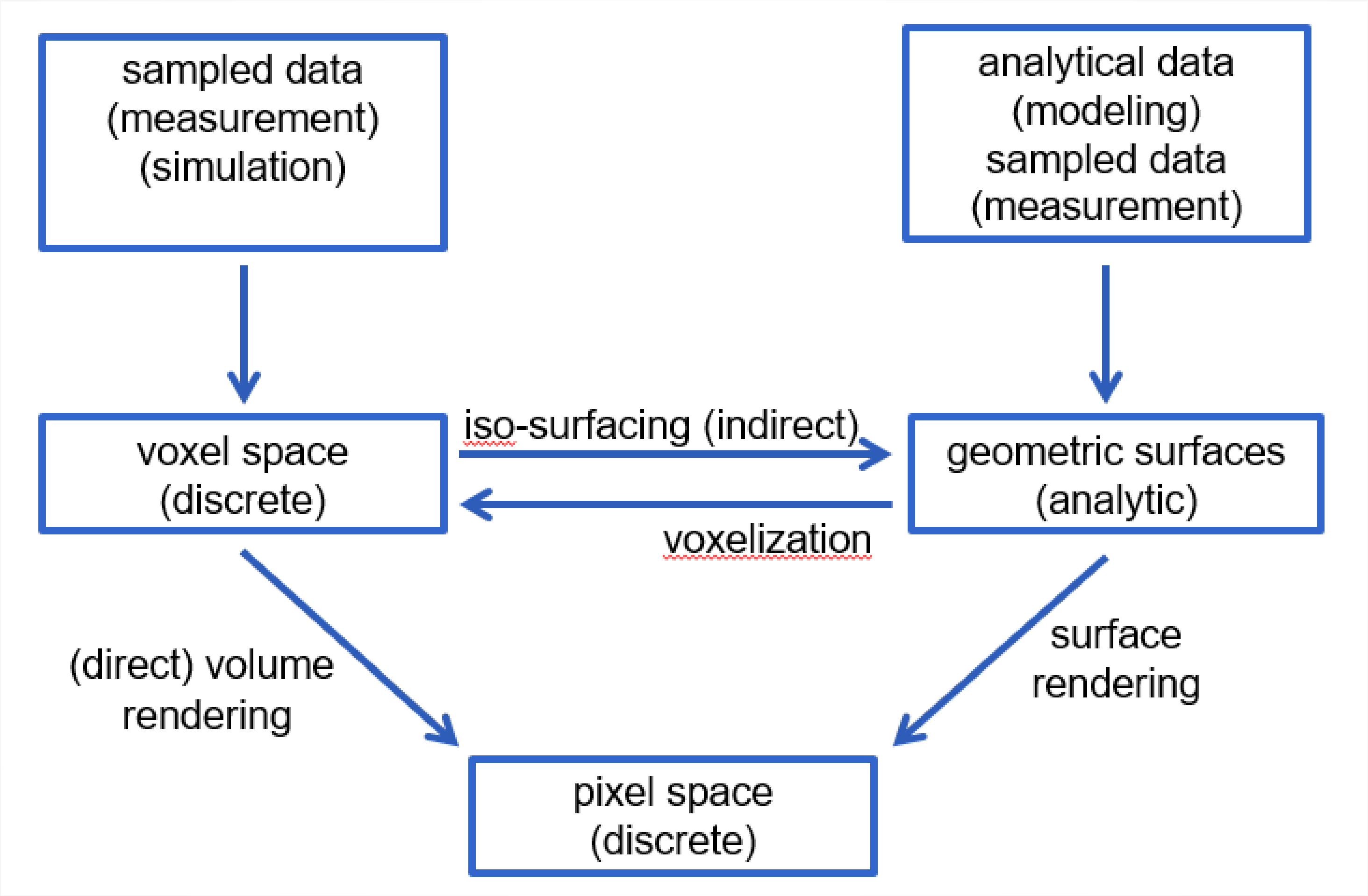


Scalar Field Visualization

- Volume visualization
  - Mapping 3D → 2D
- Goals
  - Gain insights in 3D
  - Structures of special interest + context (data classification)

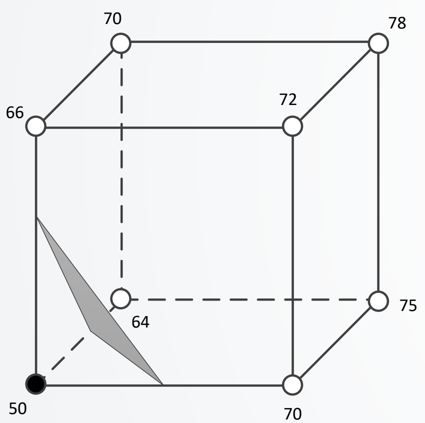


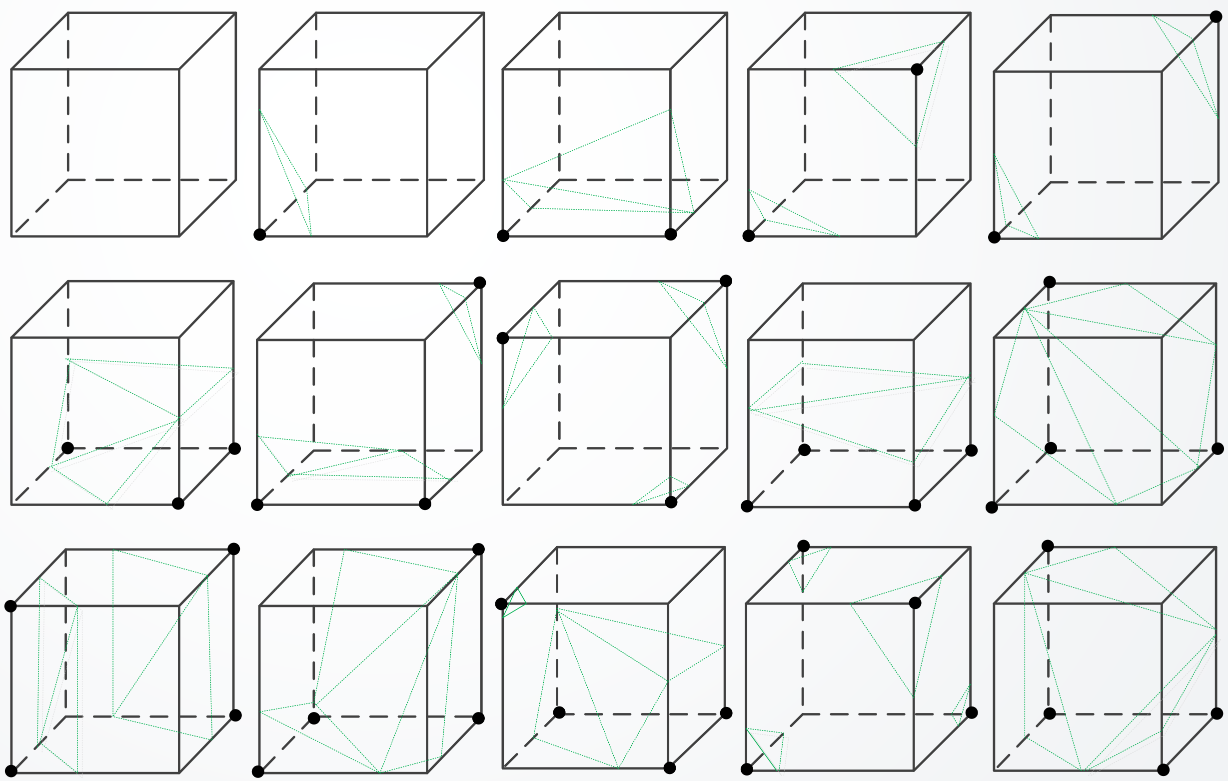
Scalar Field Visualization



Isosurfaces

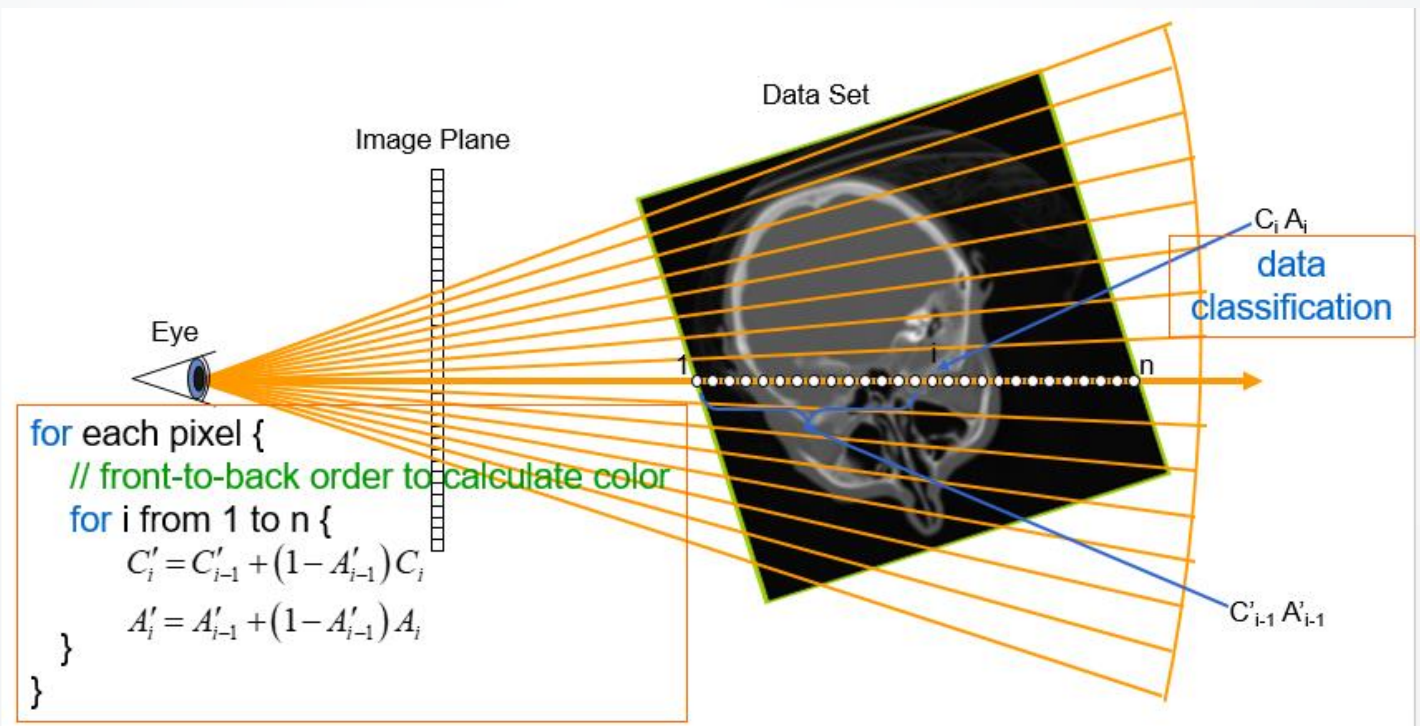
- Indirect volume rendering
  - Marching cubes





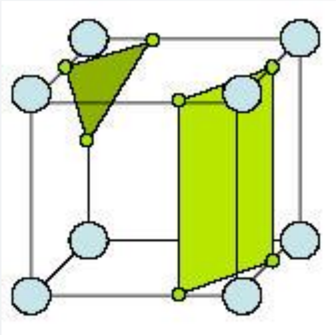
Ray Casting

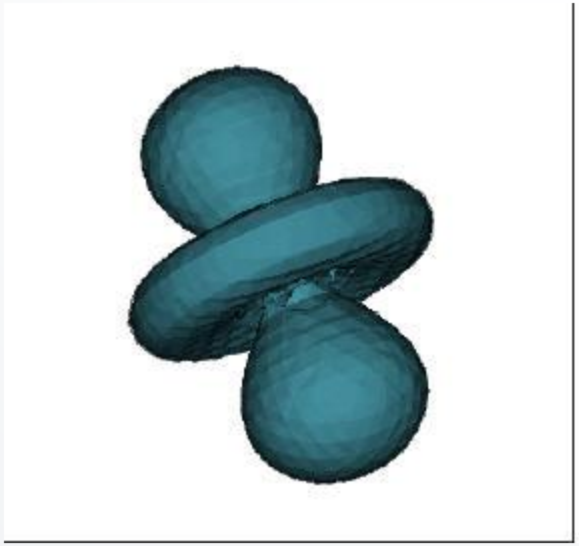
- Optical models
  - Absorption plus emission
- Volume rendering integral
- Numerical solutions

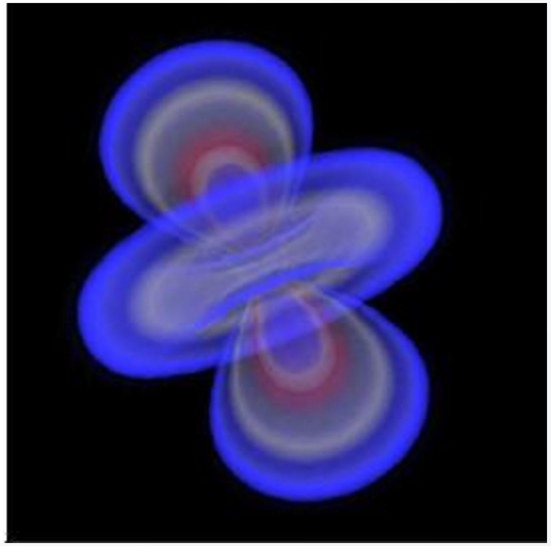


Scalar Field Visualization

- Volume rendering
  - Visual representation of scalar fields
- Indirect volume rendering
  - Marching cubes [Lorensen1987]
- Direct volume rendering
  - Ray casting [Levoy1988]

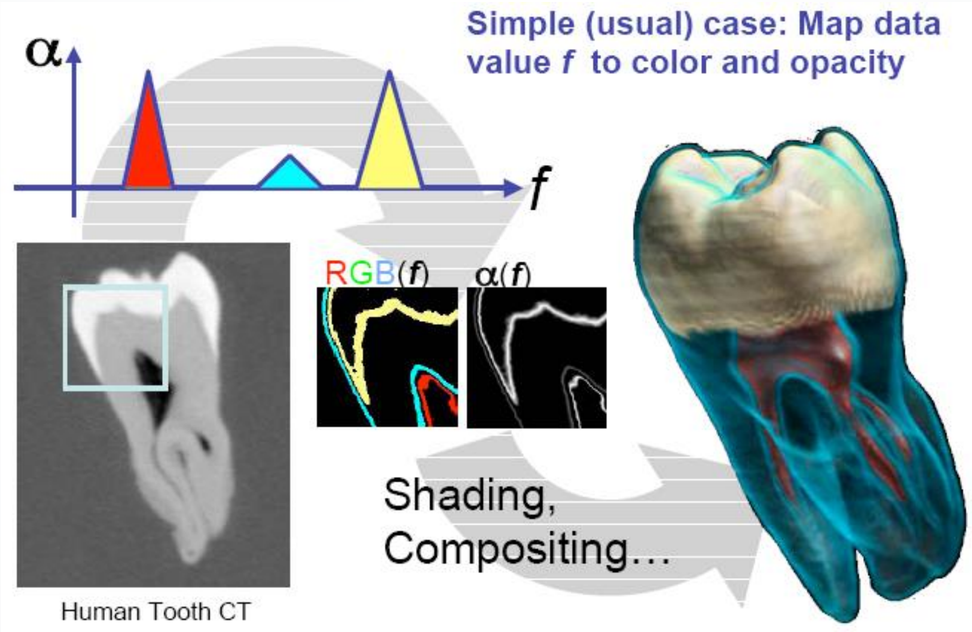






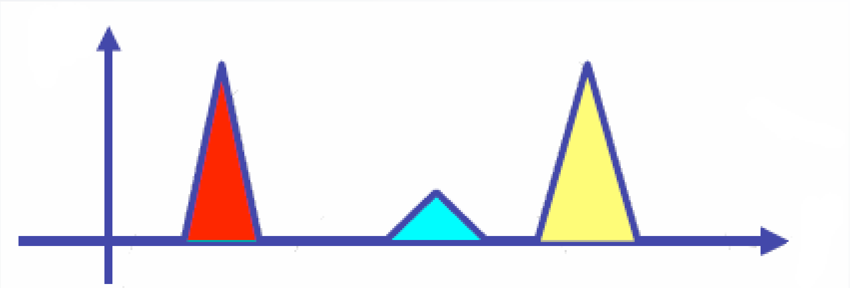
Transfer Functions

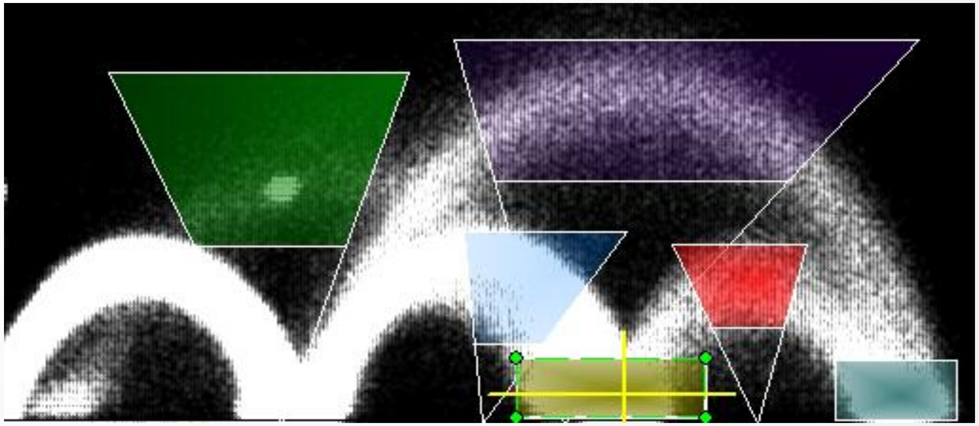
- Map properties of the sample (e.g. the scalar value) to optical properties (e.g. color and opacity) to classify different materials in the volume
  - Opacity transfer function – what to be visible
  - Color transfer function – how to label feature and context



Transfer Function Design

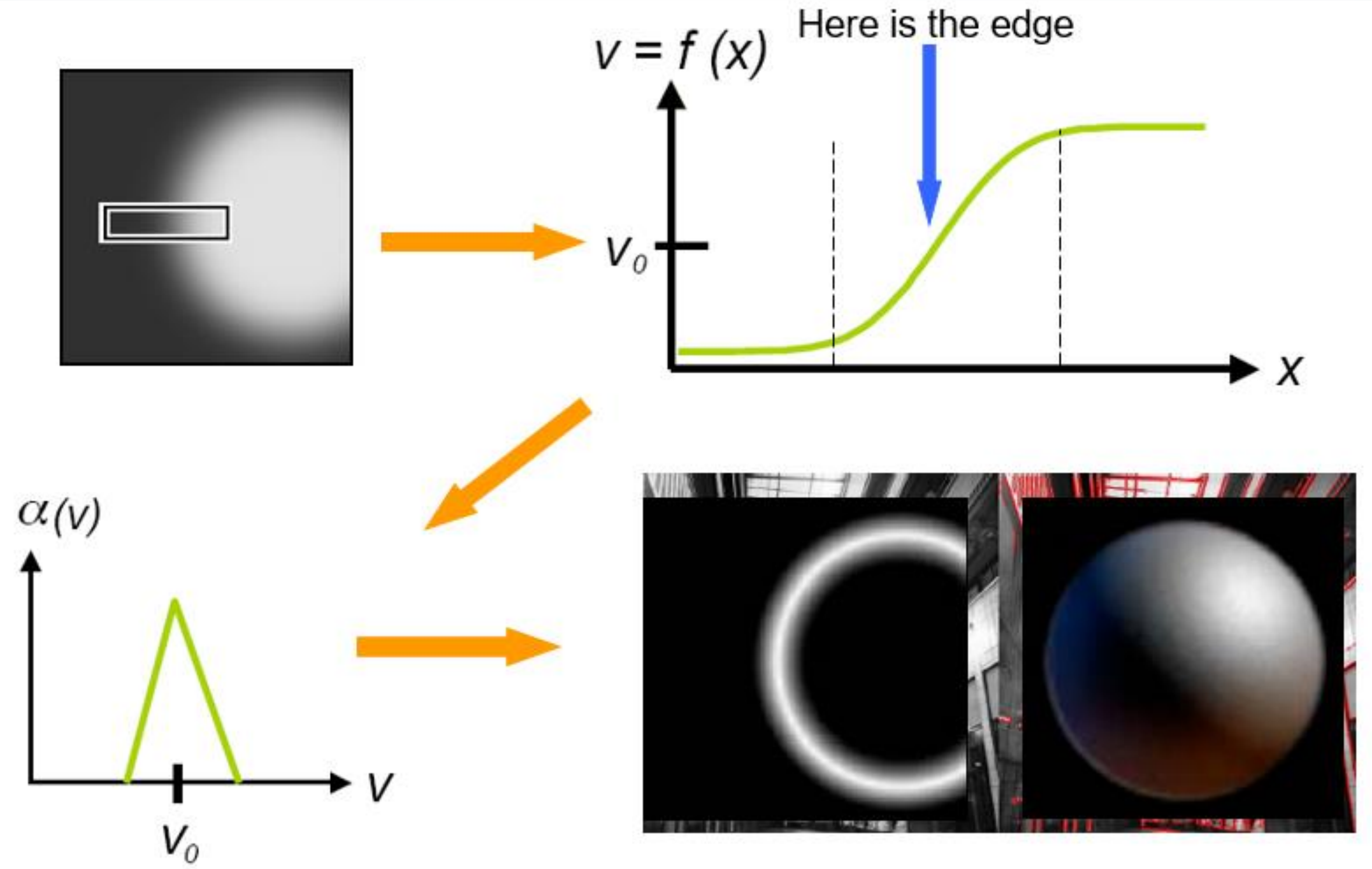
- Data classification
  - Interactively select features of interest in feature space
- Optical property specification
  - Assign different optical properties to different features
  - Highlight features of interest and suppress context
  - Visual labeling





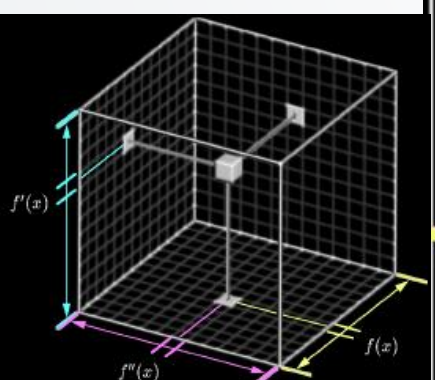
2D Transfer Functions

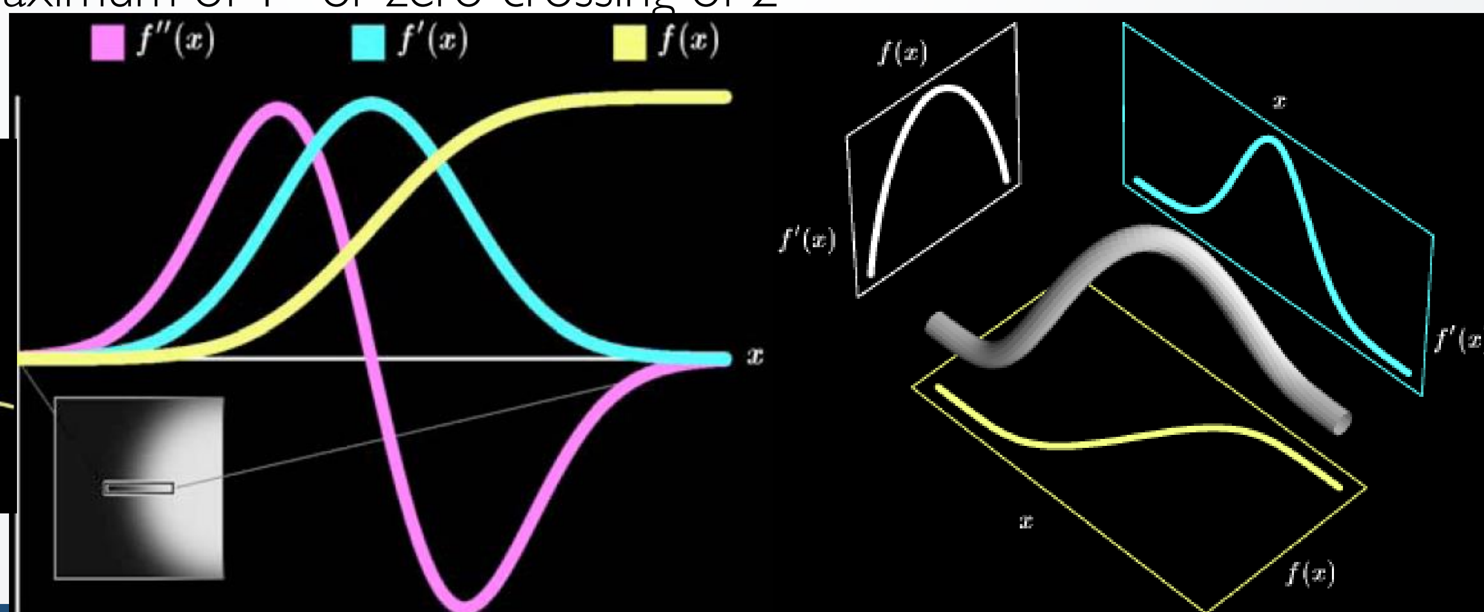
- Where is the edge?



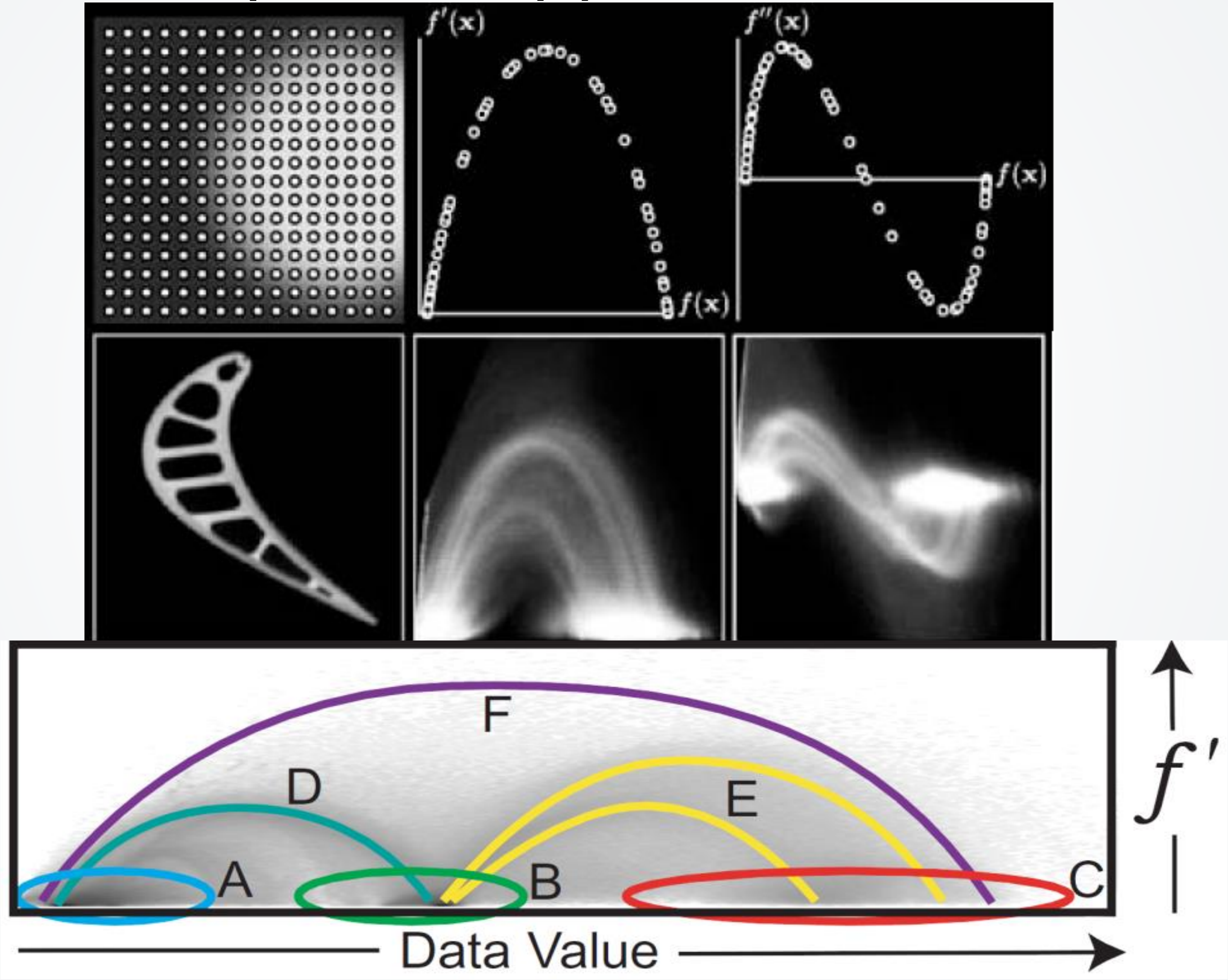
2D Transfer Functions

- Reasoning
  - TFs are volume-position invariant
  - Histograms "project out" position
  - Interested in boundaries between materials
  - Boundaries characterized by derivatives
- Edges at maximum of 1st or zero-crossing of 2ed



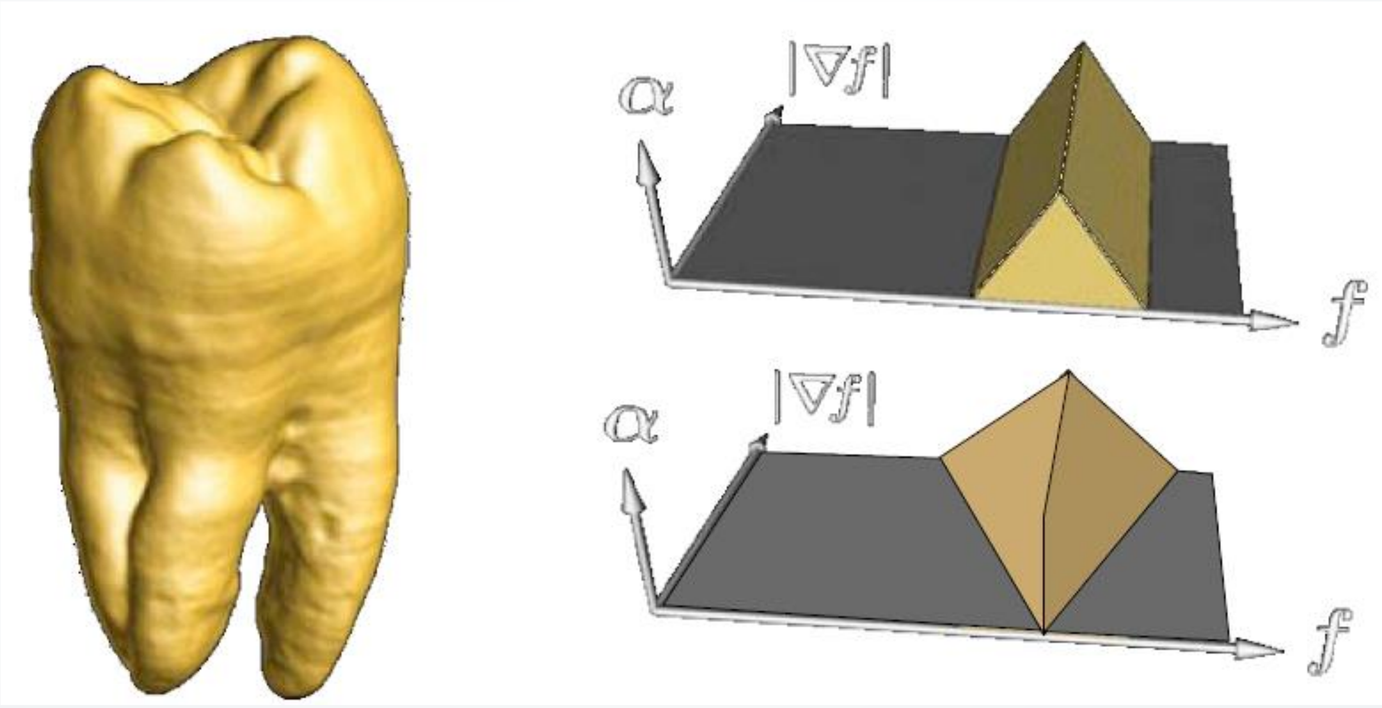


Scatterplots of *f*(*x*) versus *f'* and *f''*



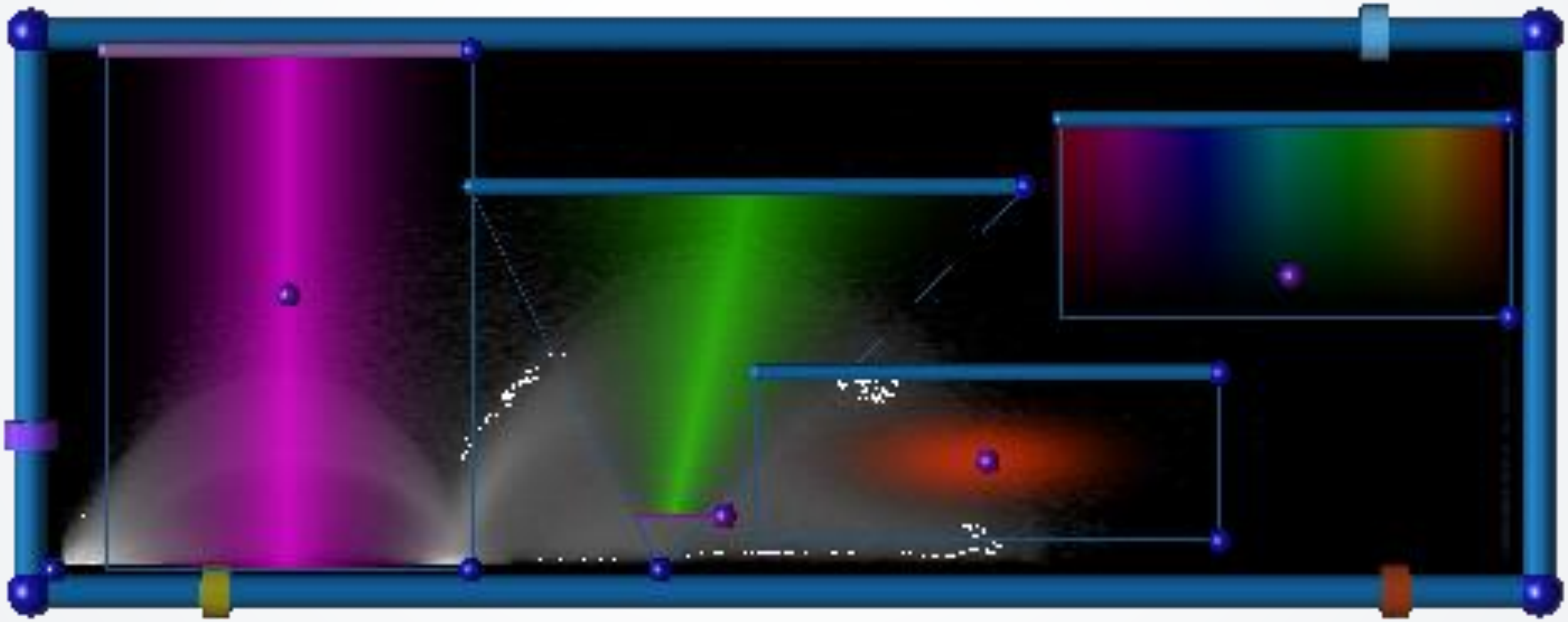
2D Transfer Functions

- Mapping two scalar values to color and opacity
- Each value is an axis of transfer function
- Editing interface becomes more complex as the function becomes higher dimensional



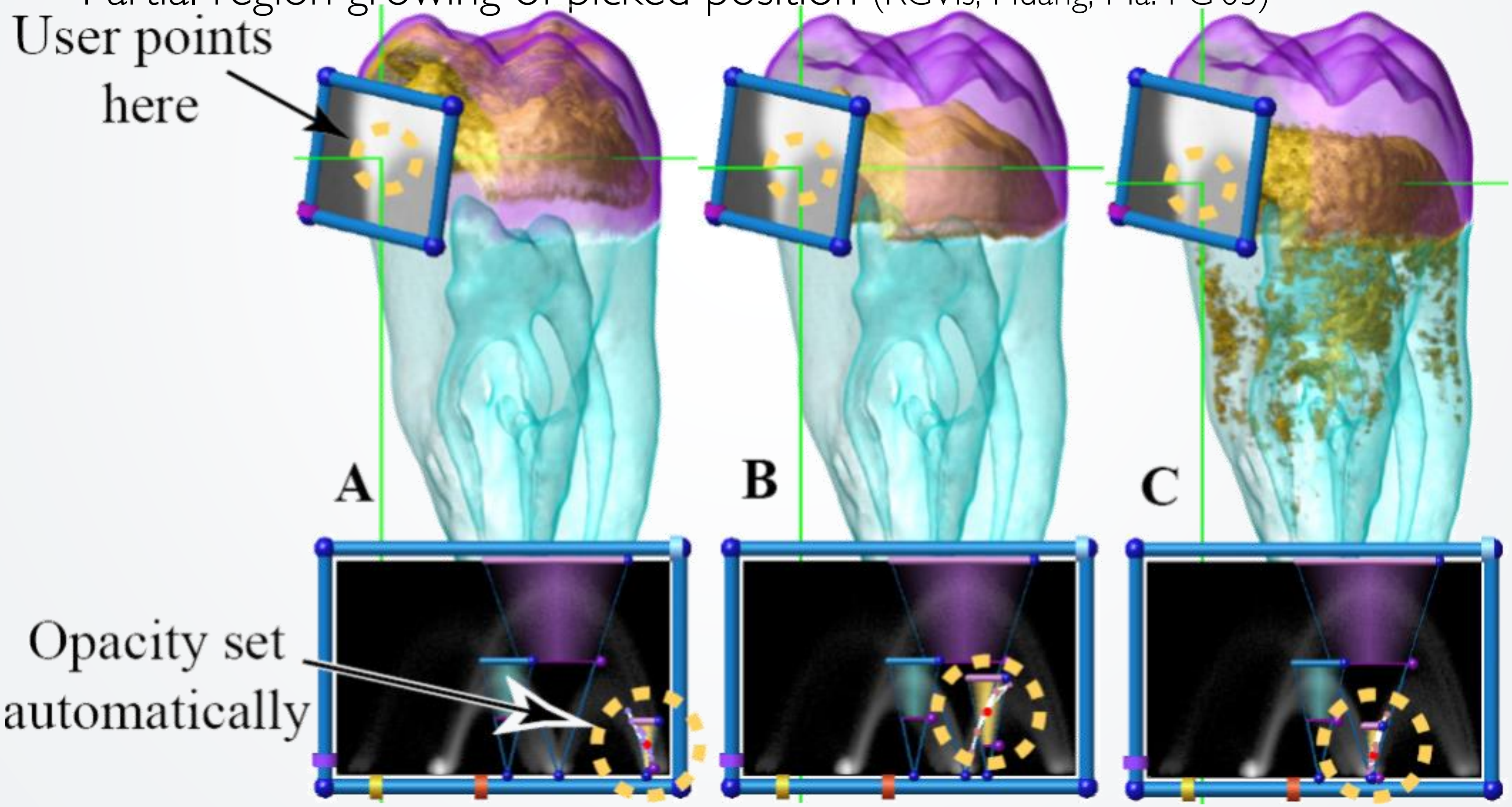
2D Transfer Functions

- Editors for 2D Transfer Function Design:
  - Editor based on geometric primitives: reduce the number of DOFs

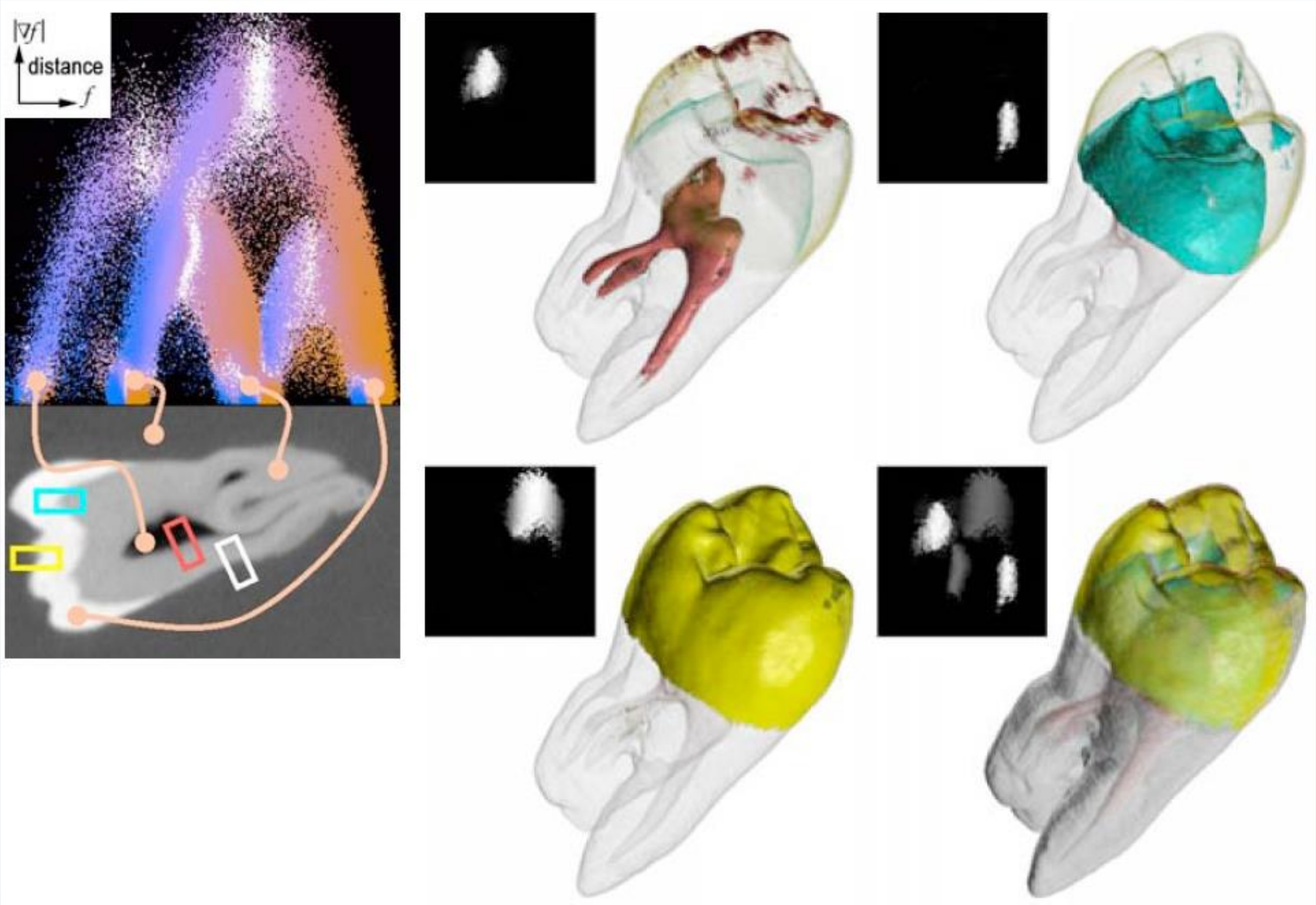


2D Transfer Functions

- Neighbor voxels of picked position (Kniss et al.:Vis'01)
- Partial region growing of picked position (RGVis, Huang, Ma: PG'03)



2D Transfer Functions



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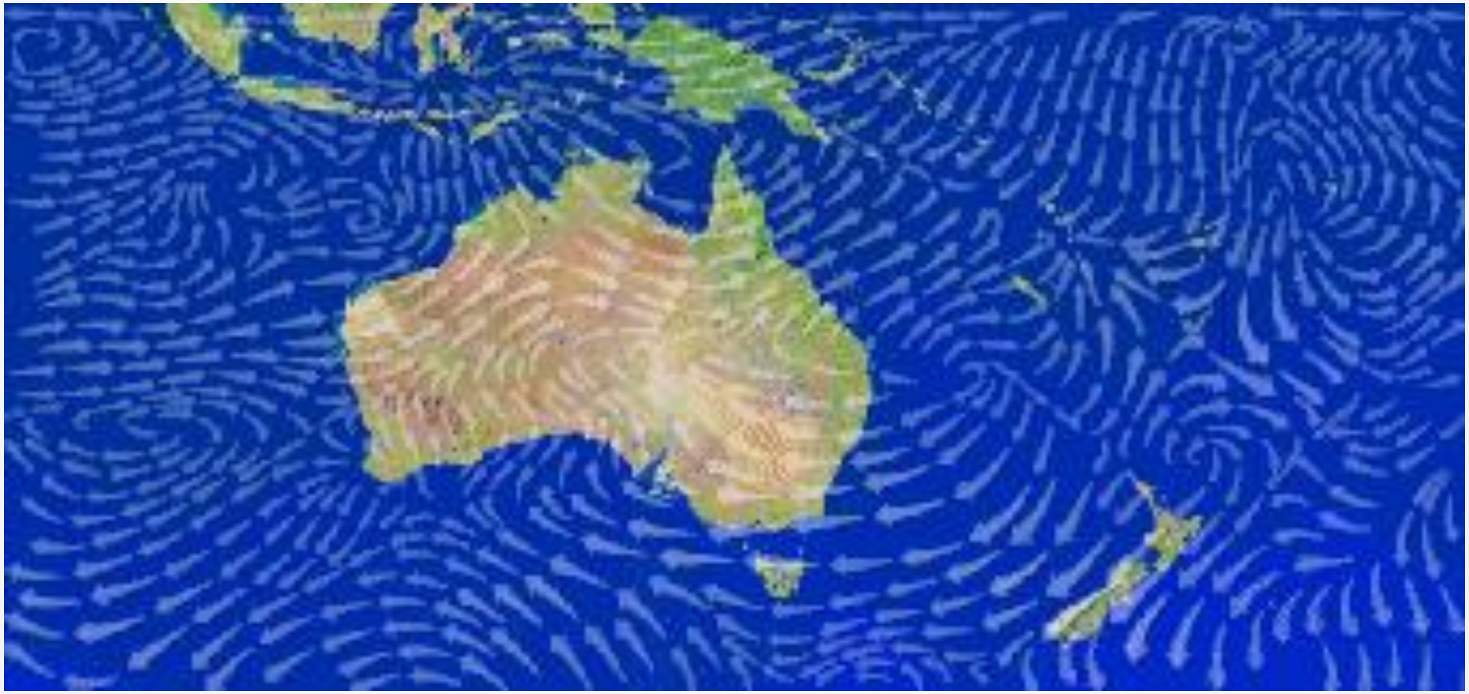
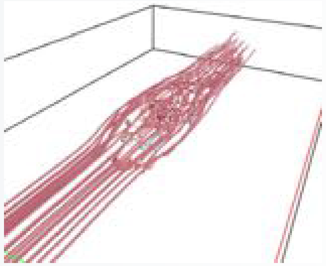
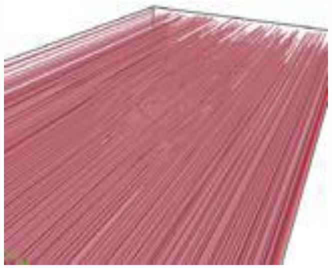
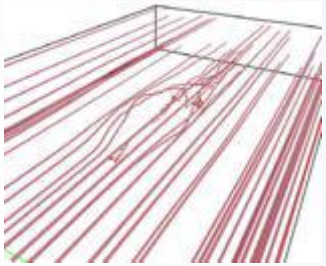
Vector Visualization

- Data set is given by a vector component and its magnitude
- General Goal:
  - Display the field's directional information
  - Convey patterns

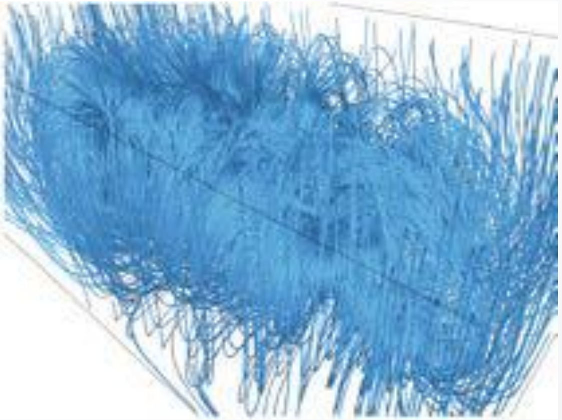


Vector Visualization

- Density

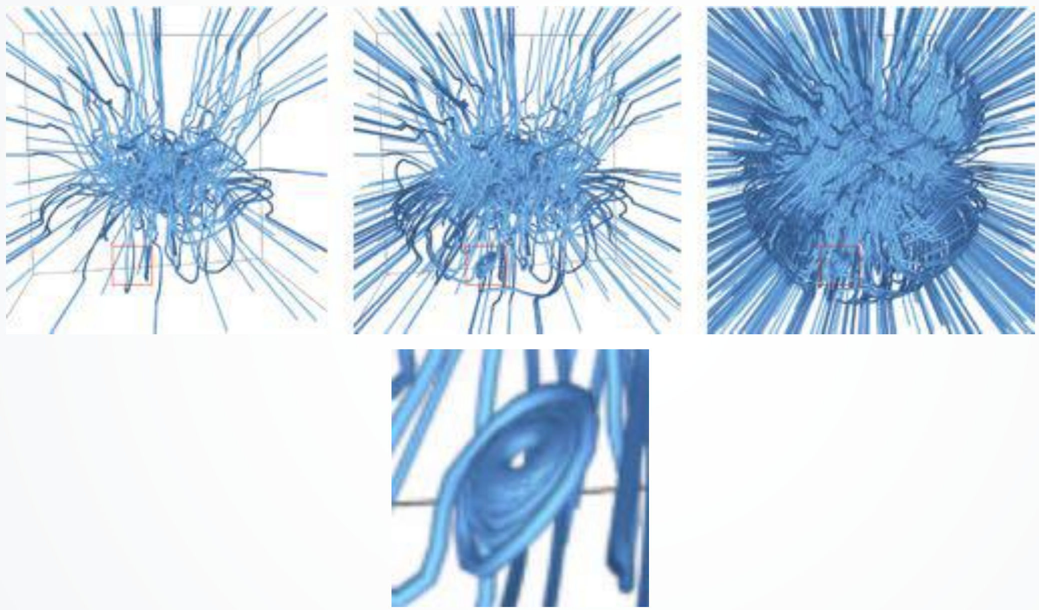




- Avoid overlapping

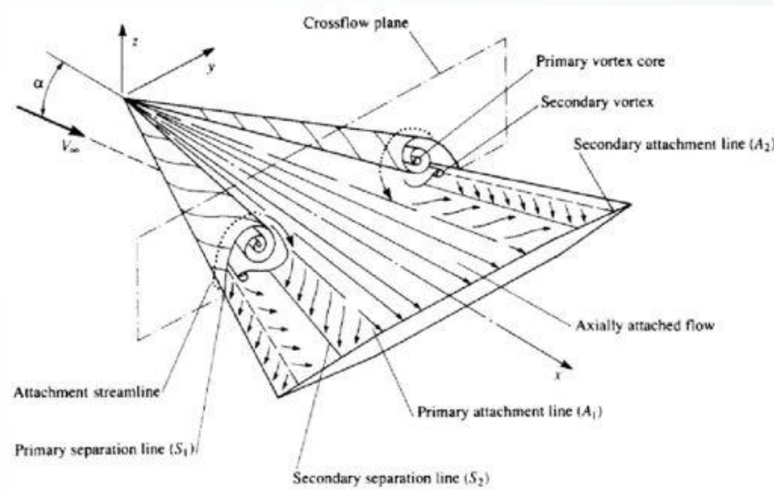
Vector Visualization

- Small features



Vector Visualization

- Features
  - Related to physical phenomenon

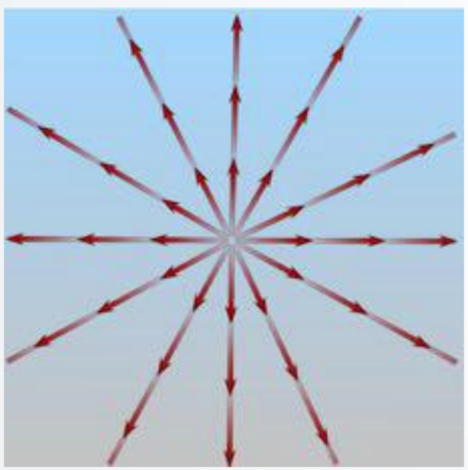


vortex

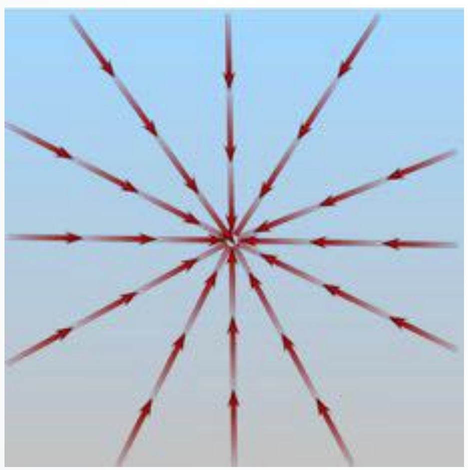
Separation line
Attachment line

Vector Visualization

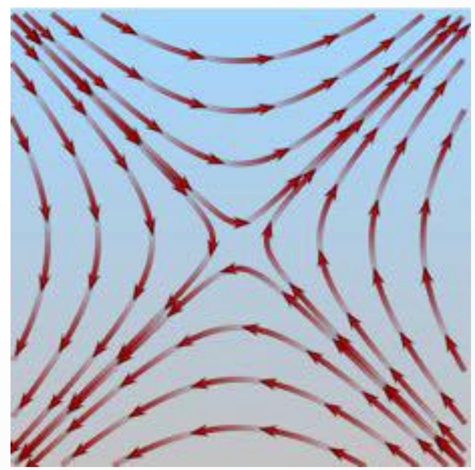
- Features
  - Based on mathematical definition
  - Critical point – points with the zero velocity



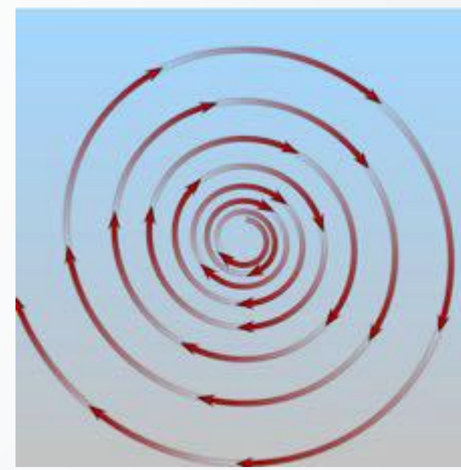
source



sink



saddle



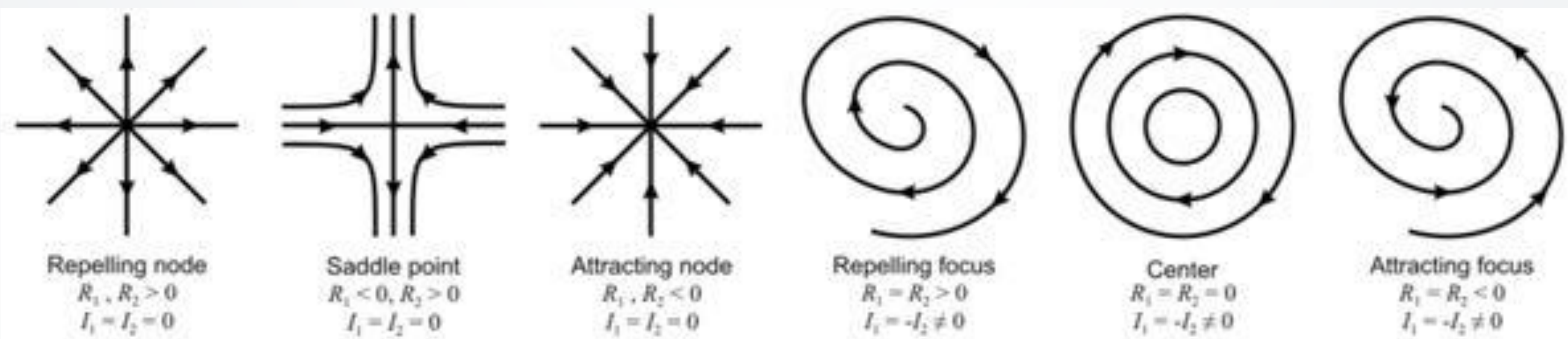
sprial

Vector Visualization

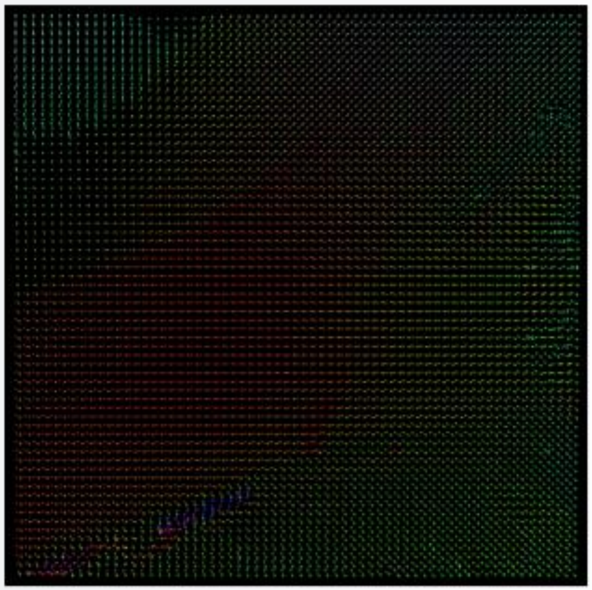
- Jacobian Matrix
  - Eigenvalue describes the pattern of critical points

$$\mathbf{v}(x,y,z) = \begin{pmatrix} u(x,y,z) \\ v(x,y,z) \\ w(x,y,z) \end{pmatrix}$$

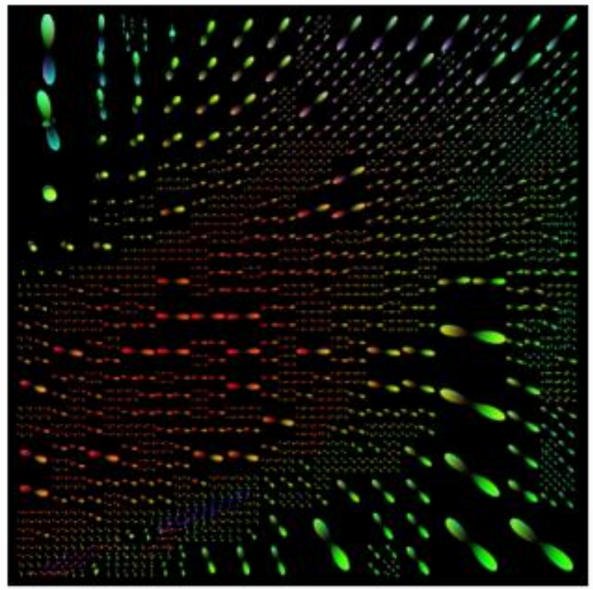
$$\mathbf{J}_{\mathbf{v}}(x,y,z) = \begin{pmatrix} \frac{\partial u(x,y,z)}{\partial x} & \frac{\partial u(x,y,z)}{\partial y} & \frac{\partial u(x,y,z)}{\partial z} \\ \frac{\partial v(x,y,z)}{\partial x} & \frac{\partial v(x,y,z)}{\partial y} & \frac{\partial v(x,y,z)}{\partial z} \\ \frac{\partial w(x,y,z)}{\partial x} & \frac{\partial w(x,y,z)}{\partial y} & \frac{\partial w(x,y,z)}{\partial z} \end{pmatrix}$$



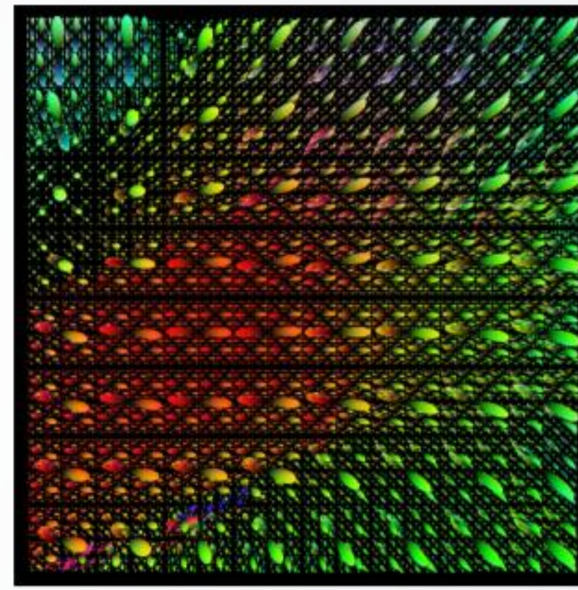
Vector Visualization



(a) Spherical harmonics



(b) Automatic clustering



(c) Comparing view

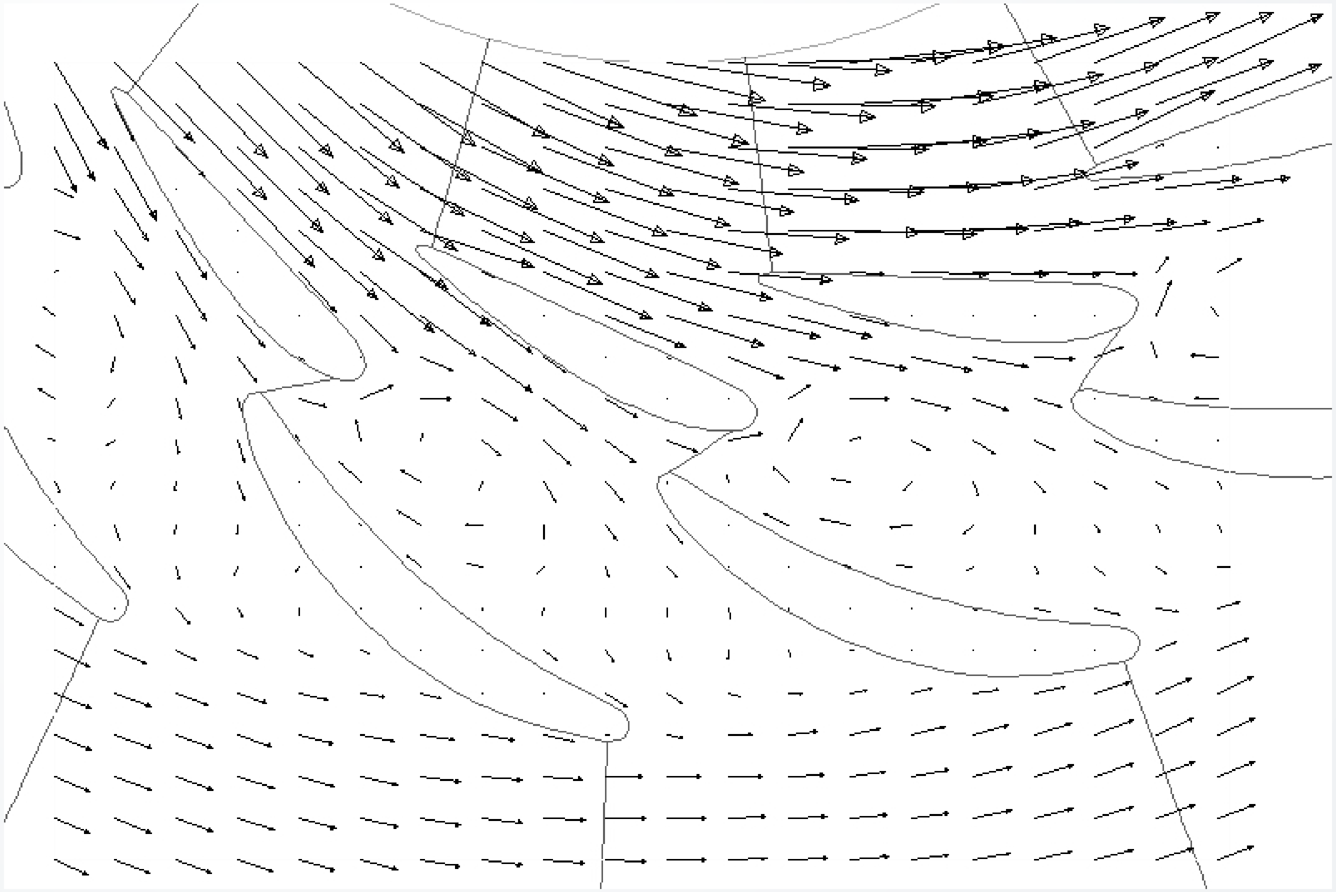
Hänel, Claudia, et al. "Interactive level-of-detail visualization of 3D-polarized light imaging data using spherical harmonics." Eurographics Conference on Visualization. 2017.

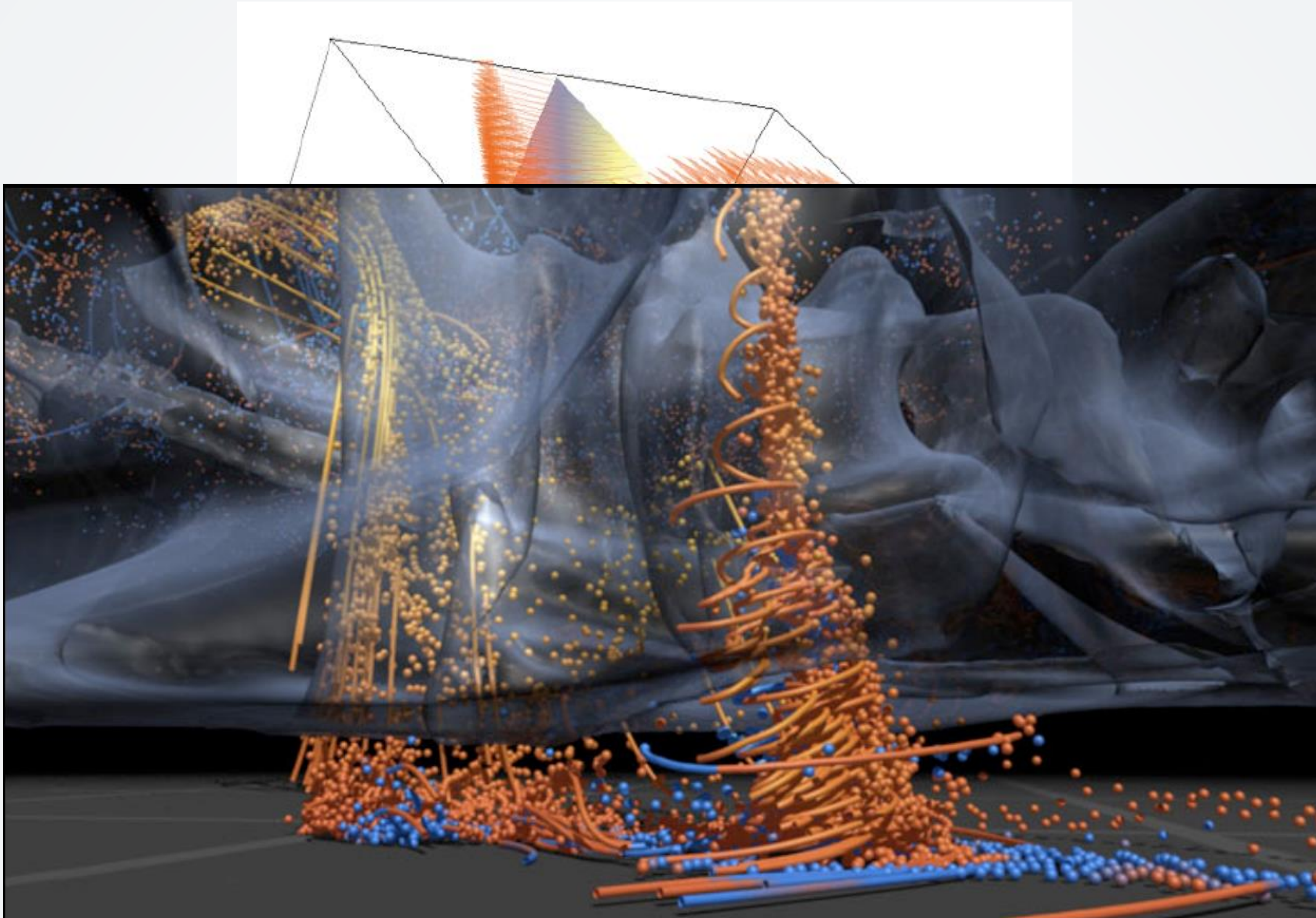
Vector Visualization Methods

- Direct visualization
- Streamline-based methods
- Texture-based and dense methods
- Topology*
- Feature extraction*
- Coherent structures*

Direct Visualization

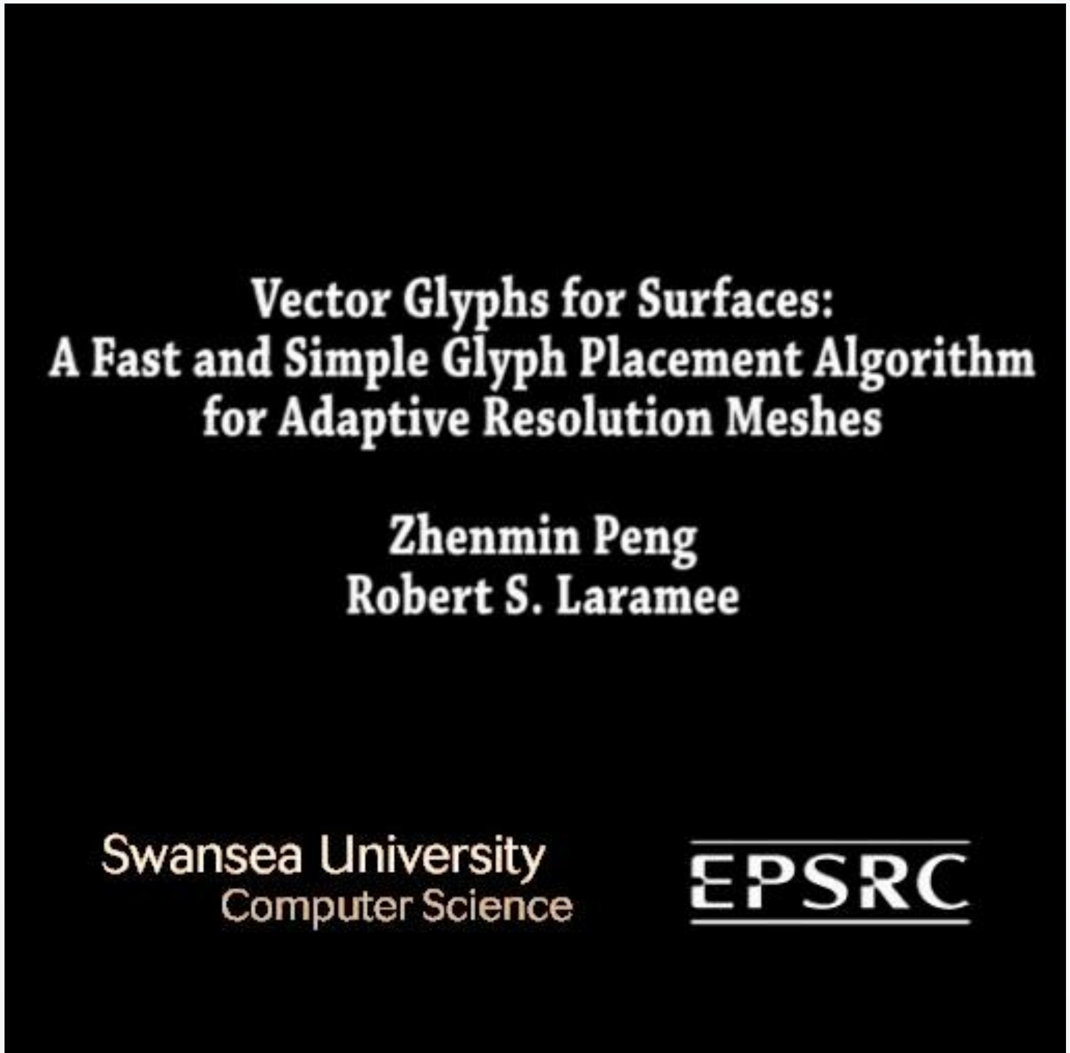
- Glyph
  - Hedge hogs
  - Arrows
  - Oriented glyphs





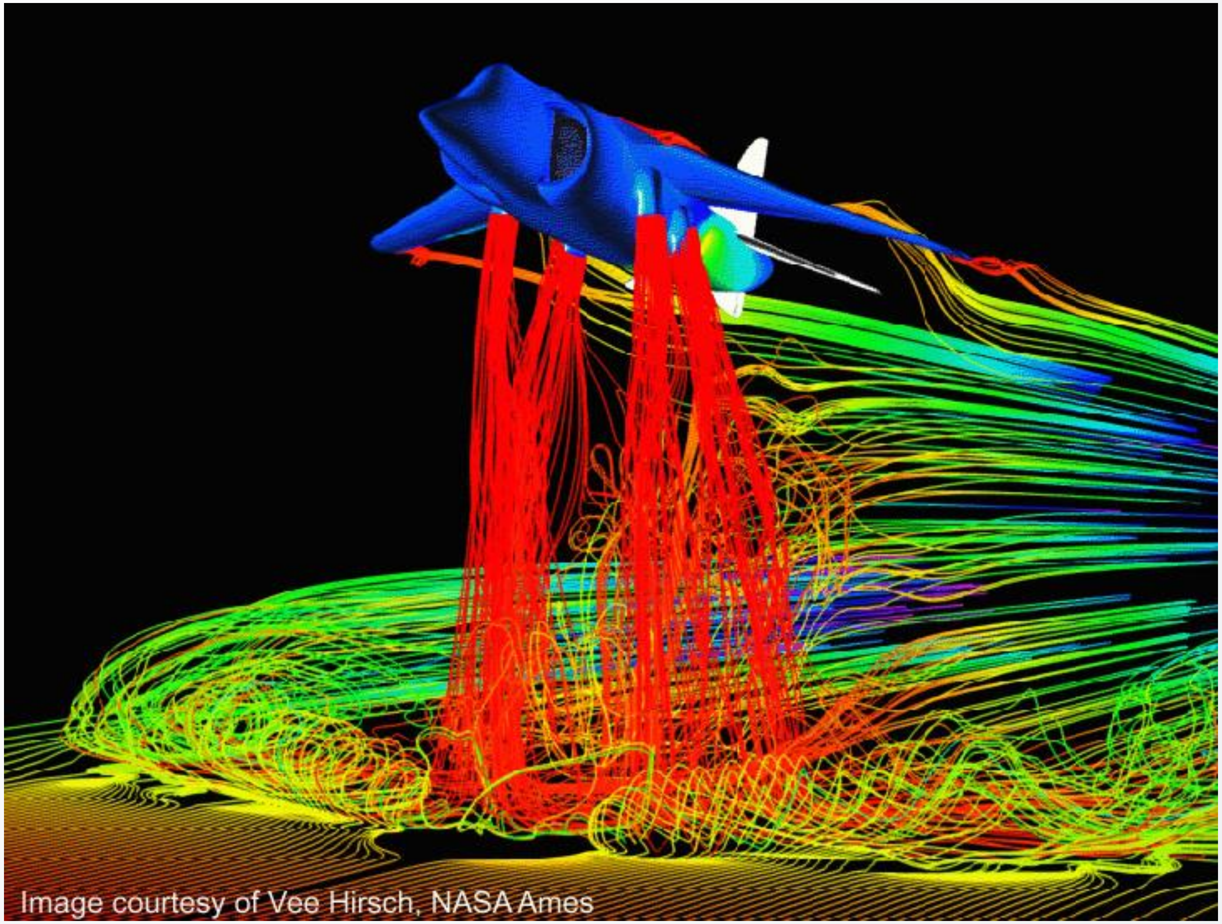
Dan Alcantara

Hedge Hogs


Vector Glyphs for Surfaces:
A Fast and Simple Glyph Placement Algorithm
for Adaptive Resolution Meshes
Zhenmin Peng
Robert S. Laramee
Swansea University
Computer Science
EPSRC

Streamline-based Methods

- Streamline, pathline, timeline and streakline
- Ribbons
- Tubes and bubbles
- Stream surfaces
- Stream volumes

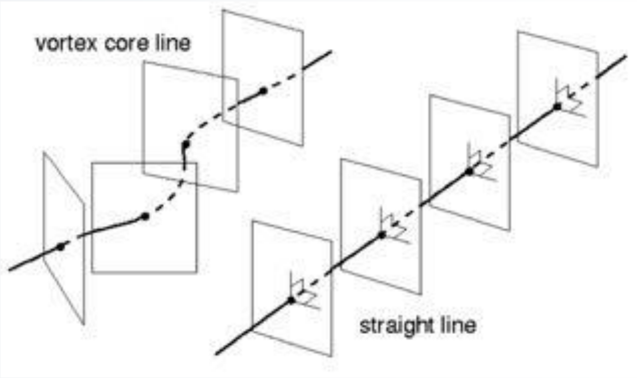


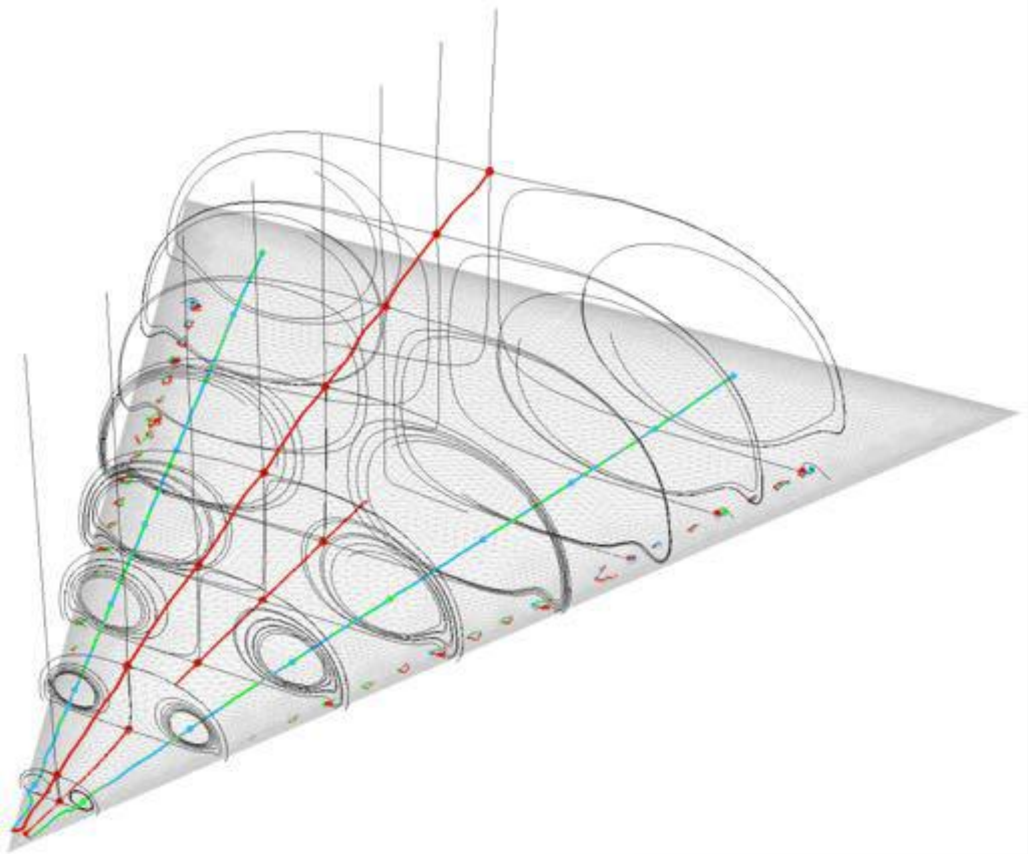
Definitions*

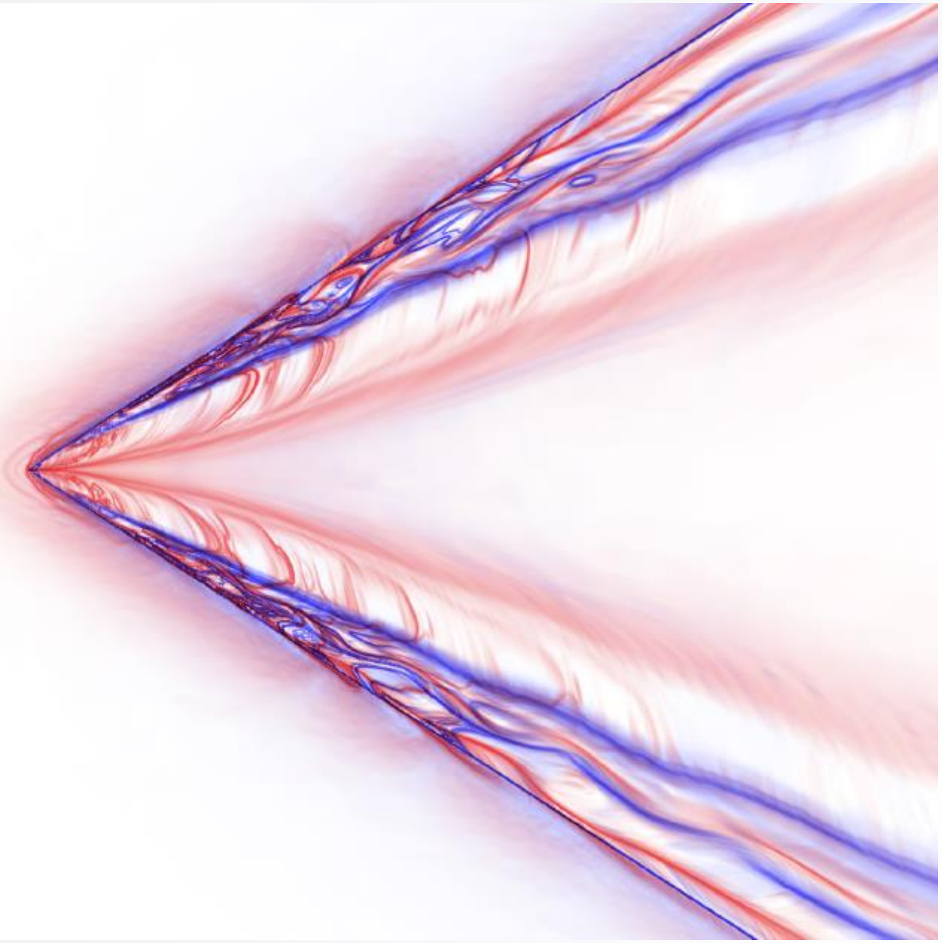
- Streamline
  - Trajectory of massless particle in a steady flow or path of a particle in a frozen unsteady field (non-physical)
- Pathline
  - Trajectory of massless particle in an unsteady flow
- Timeline
  - Connect particles released simultaneously at discrete time-steps
- Streakline
  - Continuously inject particles at a point in the flow and connect the particles

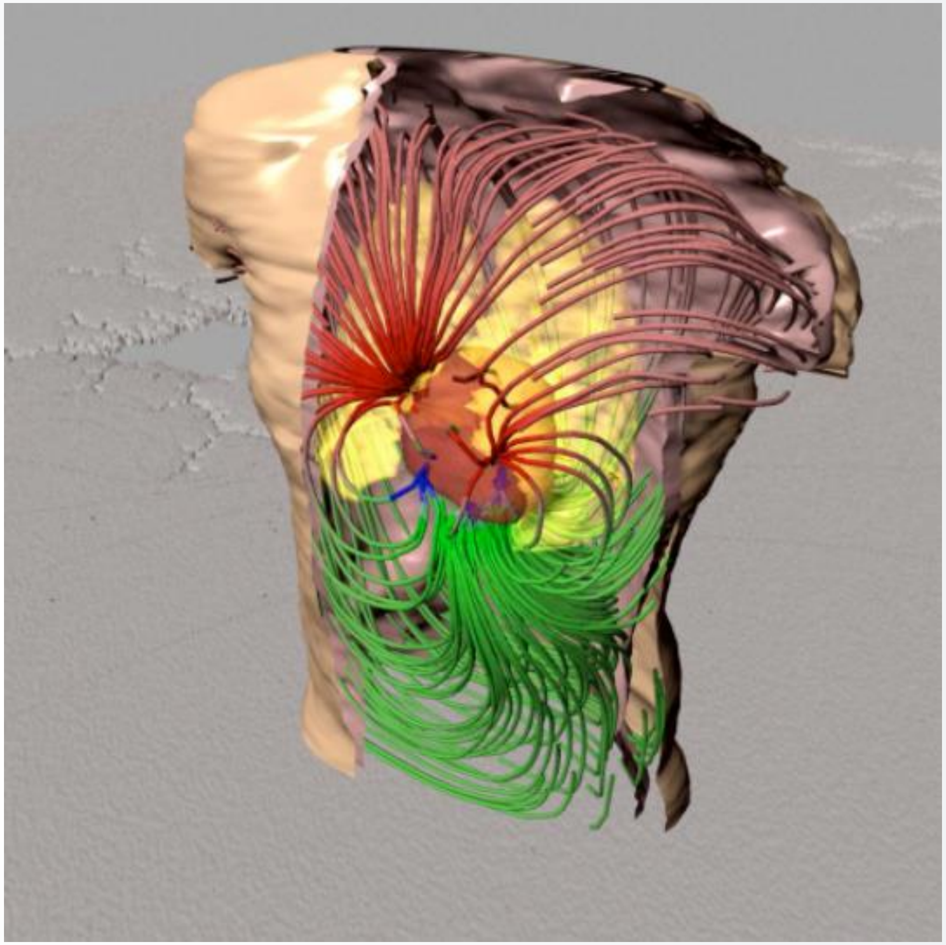
Streamline-based Methods

- Cutting plane topology





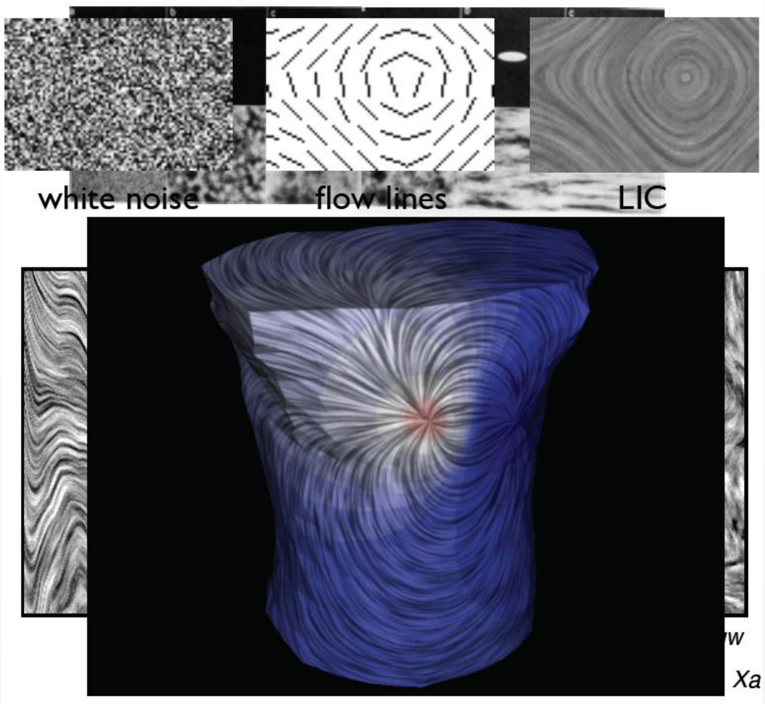


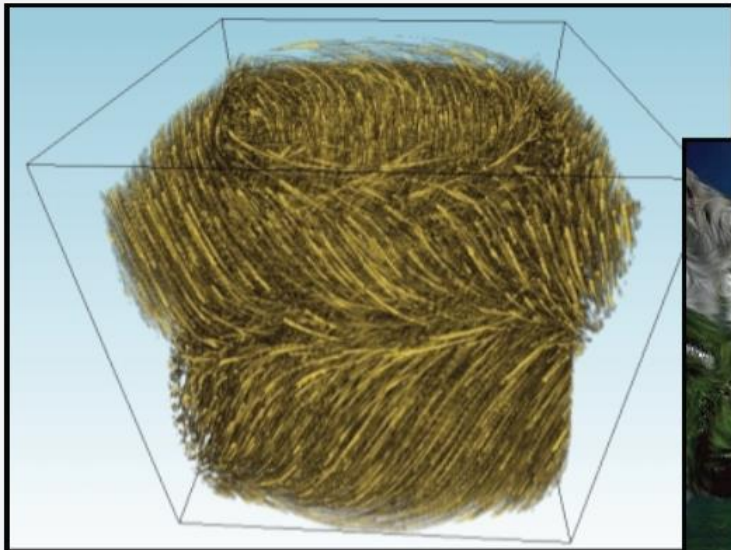


红线：迹线pathline
绿线：纹线streakline
黑线：流线streamline

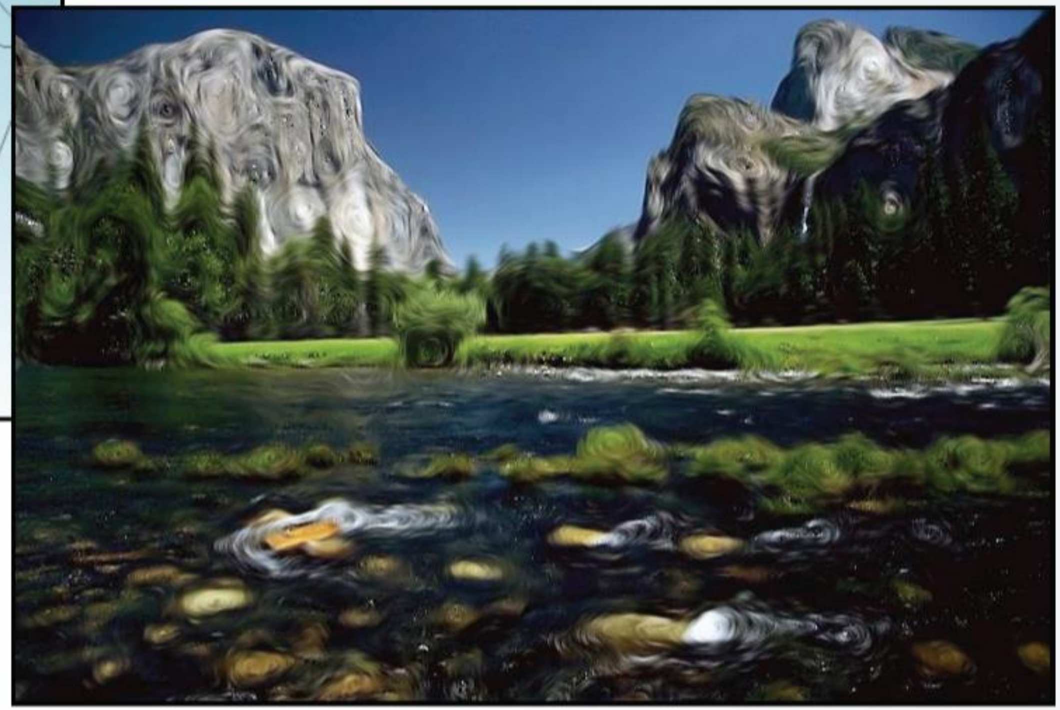
Texture-based and Dense Methods

- Spot noise
  - Convolve blurred spot with random noise
- Line integral convolution (LIC)
  - Integrate white noise with flow field





Anders Helgeland



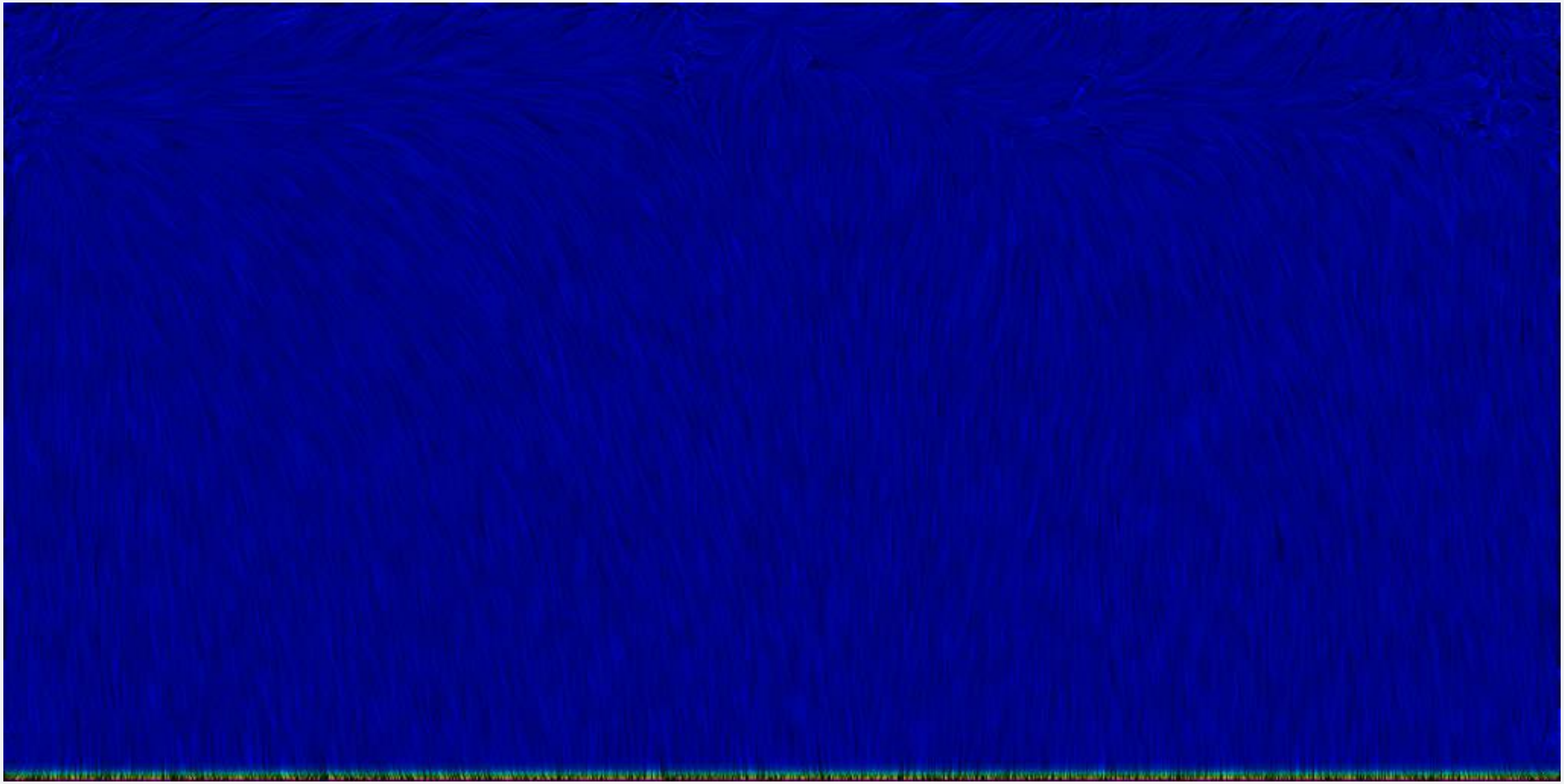
Gui-Shi Li

Noise Texture

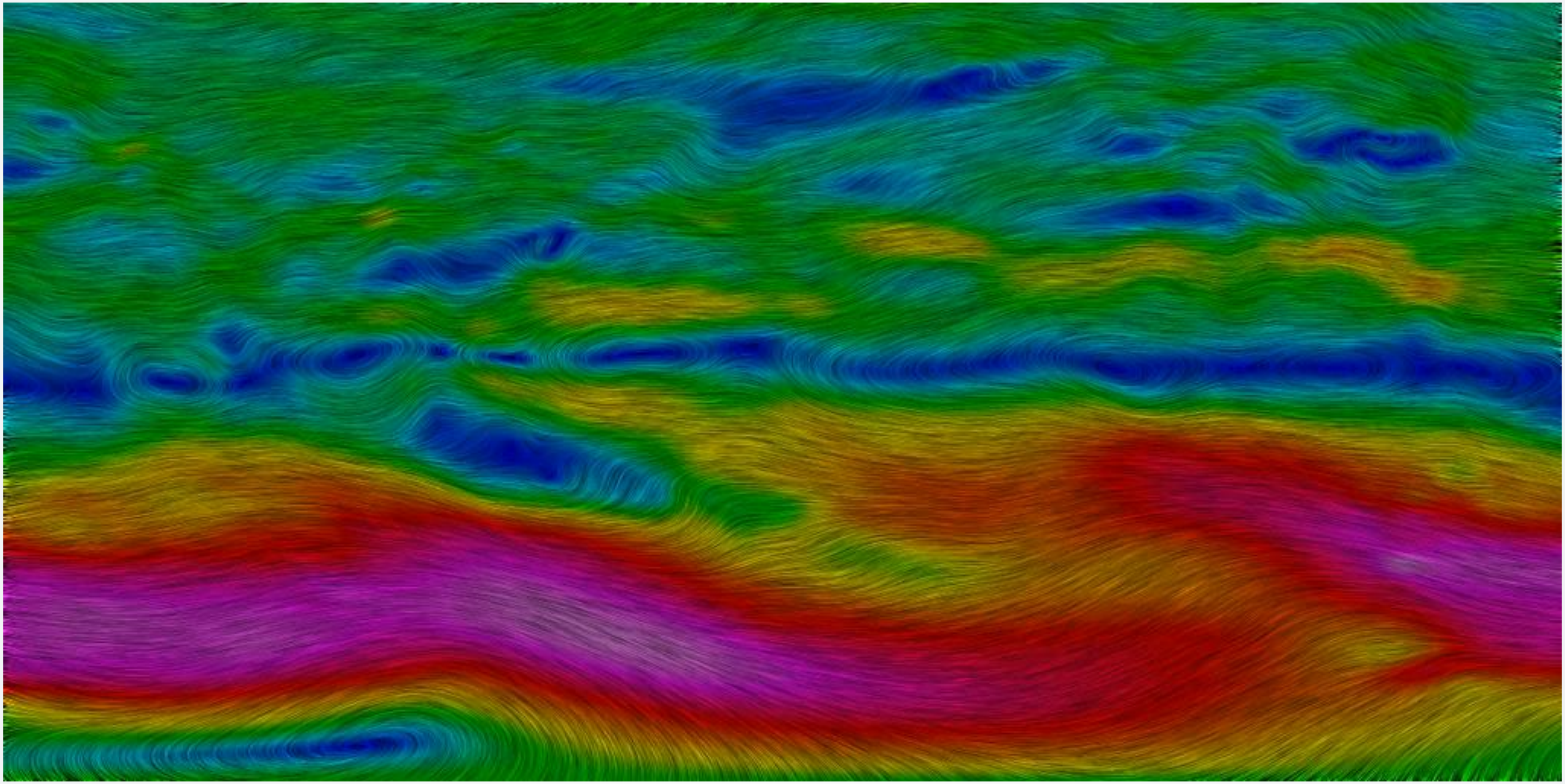
Texture Advection on Stream Surfaces: A Novel Hybrid Visualization Applied to CFD Simulation Results

Robert S. Laramee
Christoph Garth
Juergen Schneider
Helwig Hauser

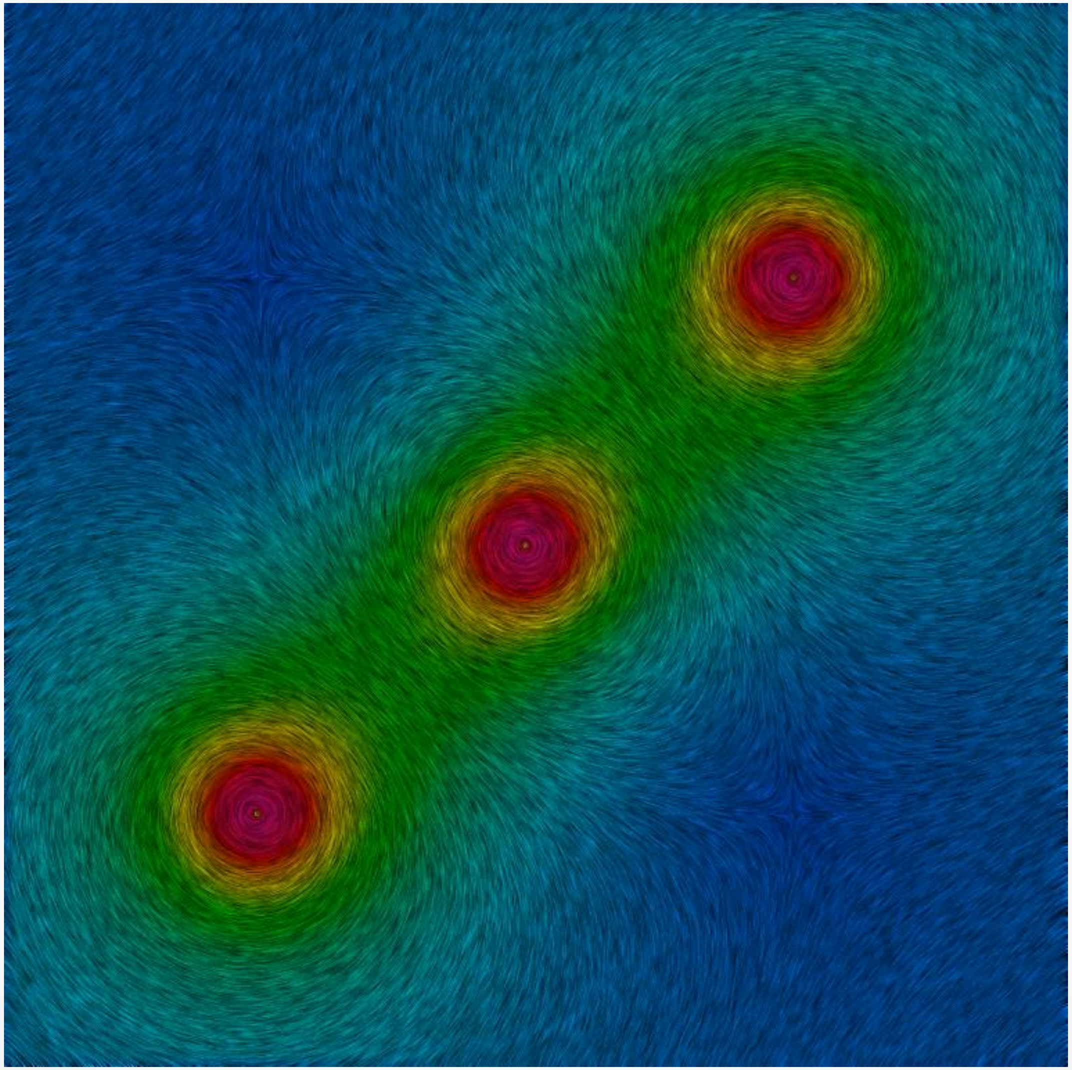
LIC



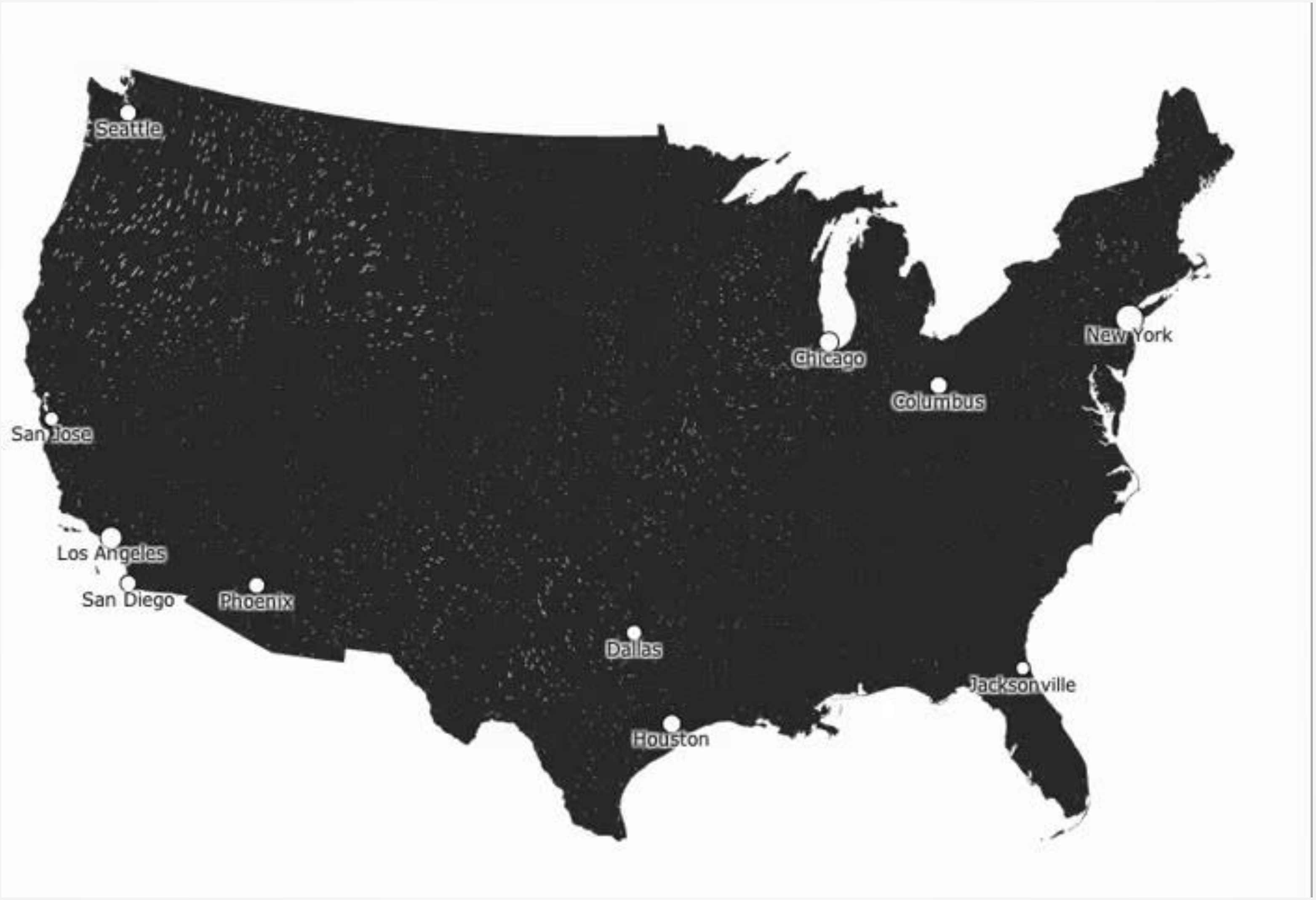
LIC



LIC



Wind map


Seattle
San Jose
Los Angeles
San Diego
Phoenix
Dallas
Houston
Chicago
Columbus
New York
Jacksonville

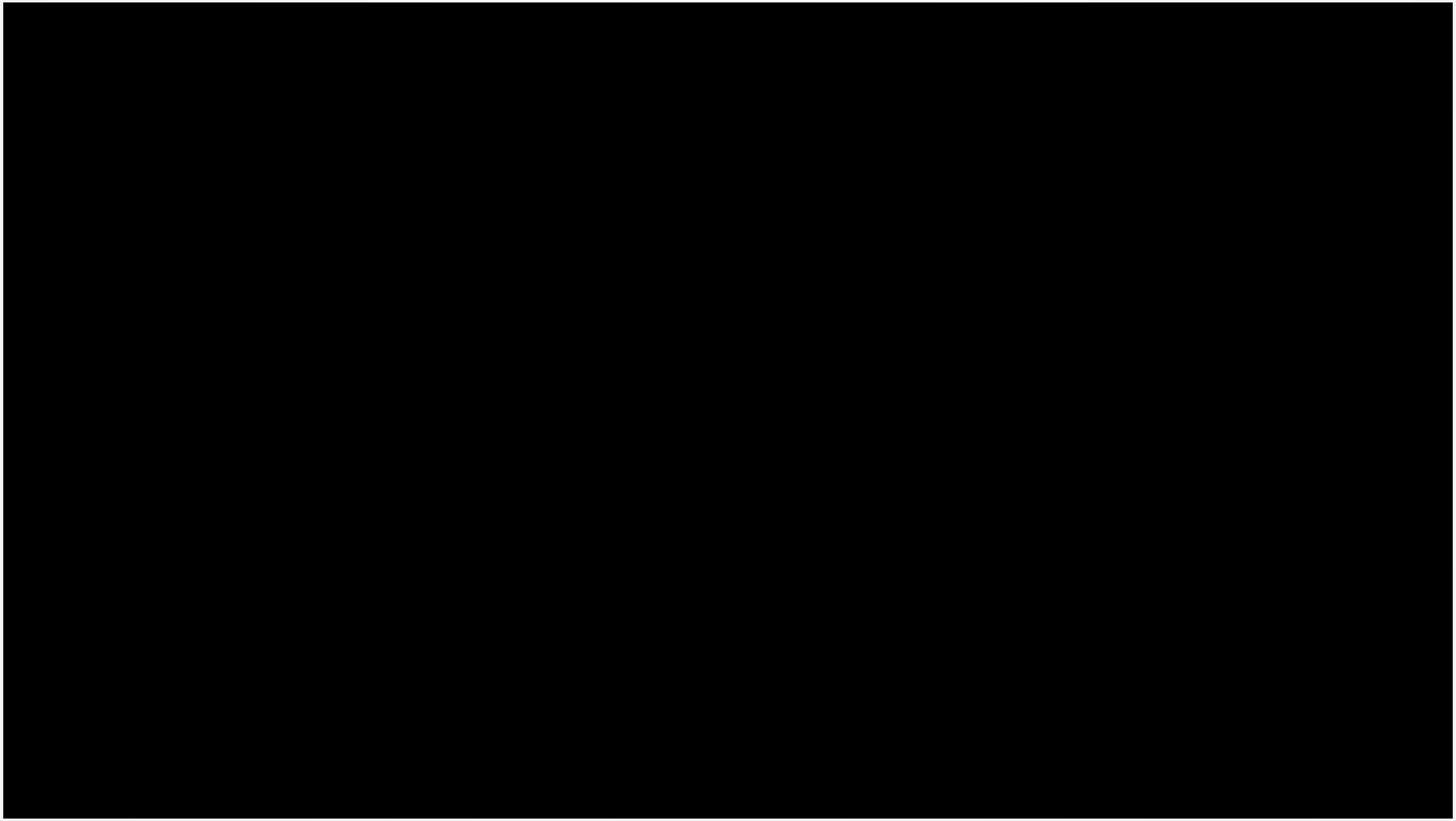
Wind Map

- $p_{i+1} = p_i + speed \; * v(p_i)$

```
MotionDisplay.prototype.moveThings = function(animator) {
    var speed = .01 * this.speedScale / animator.scale;
    for (var i = 0; i < this.particles.length; i++) {
        var p = this.particles[i];
        if (p.age > 0 && this.field.inBounds(p.x, p.y)) {
          var a = this.field.getValue(p.x, p.y);
            p.x += speed * a.x;
            p.y += speed * a.y;
            p.age--;
        } else {
            this.particles[i] = this.makeParticle(animator);
        }
    }
};
```

http://hint.fm/wind/

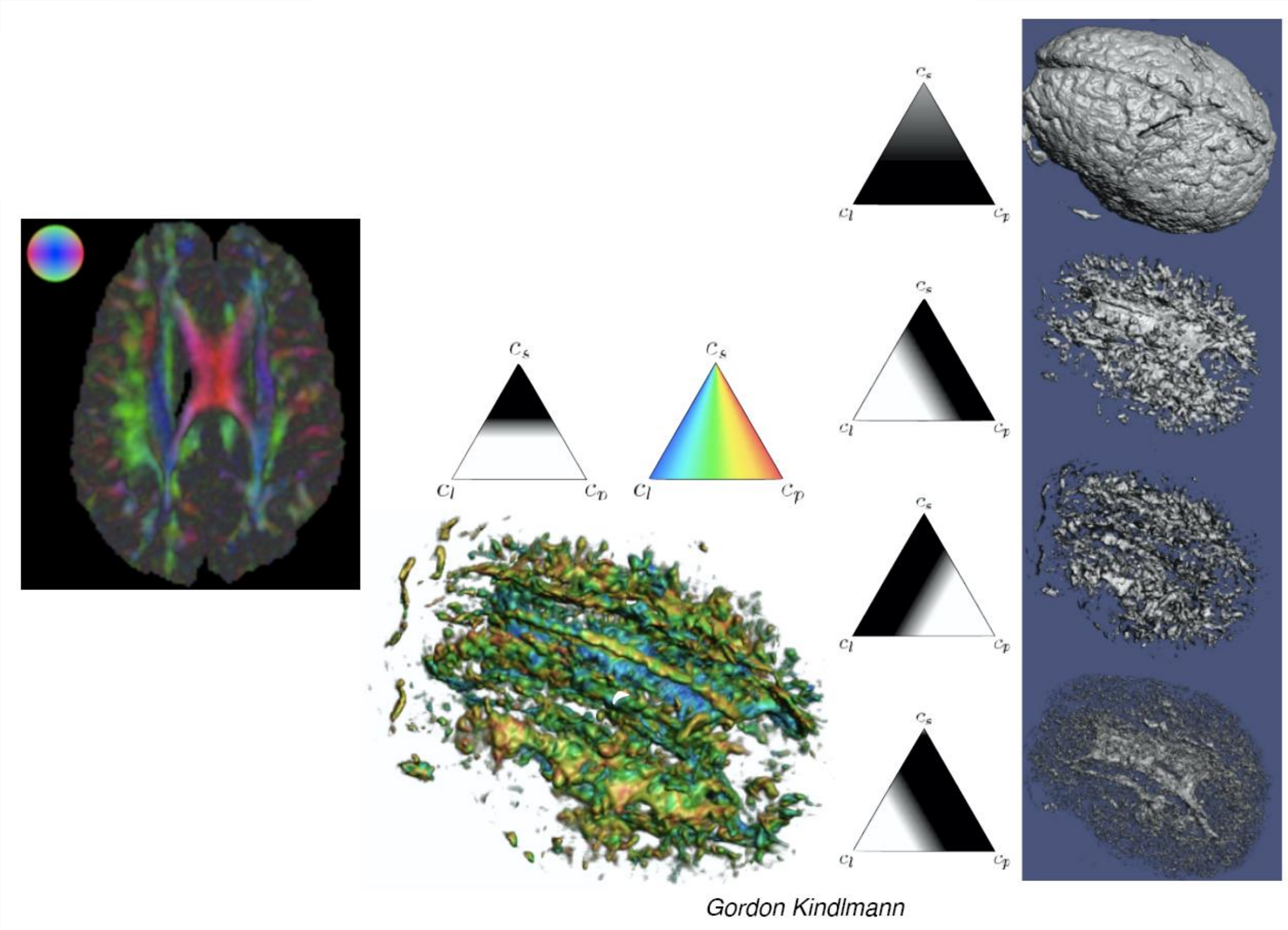
Starry Night



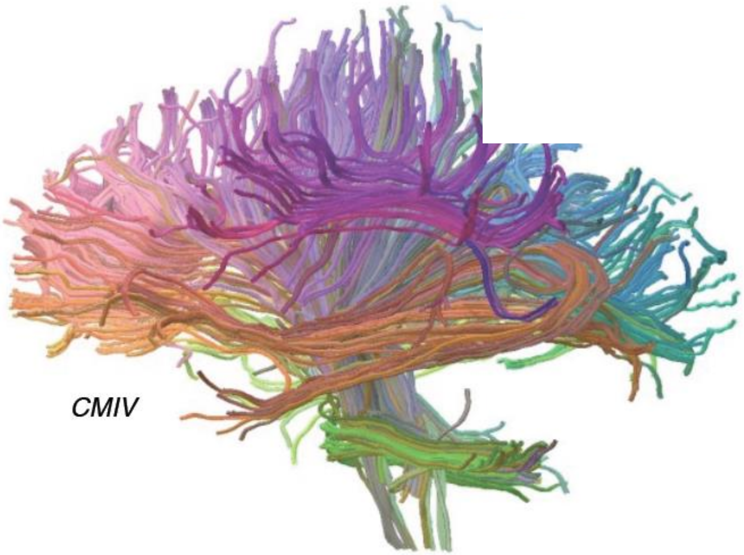
Tensor Field Visualization

- *n*D array of values at each data point
  - For 3D data, usually a 3x3x3 tensor
- Describes how data changes in a small sphere around the data point
  - From scanning devices: diffusion of water in brain
  - From simulations: stress, strain

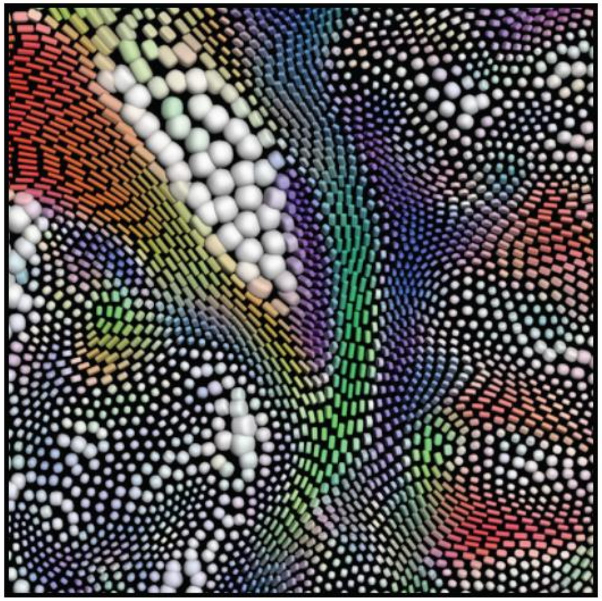
Color Encoding



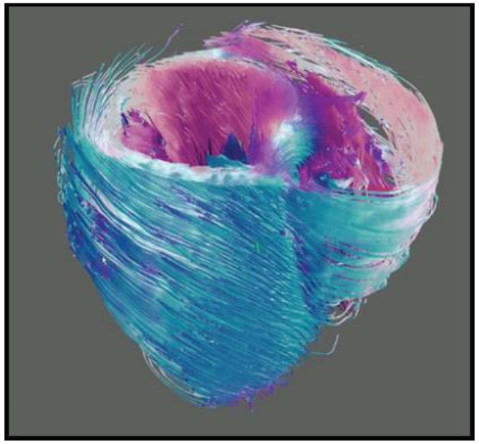
Steams and Glyphs



CMIV

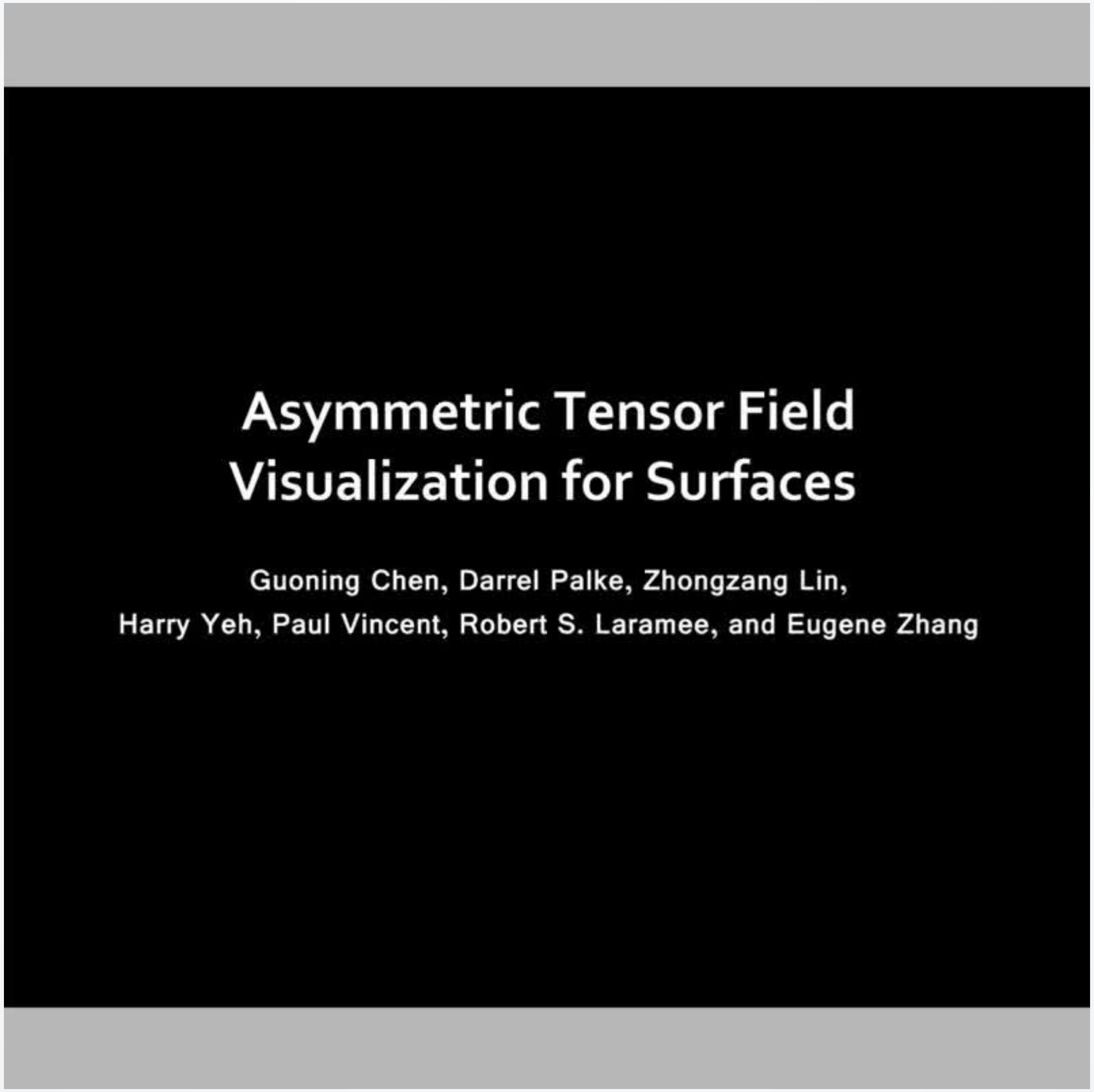


Gordon Kindlmann



Leonid Zhukov

Glyphs


Asymmetric Tensor Field
Visualization for Surfaces
Guoning Chen, Darrel Palke, Zhongzang Lin,
Harry Yeh, Paul Vincent, Robert S. Laramee, and Eugene Zhang

OUTLINE

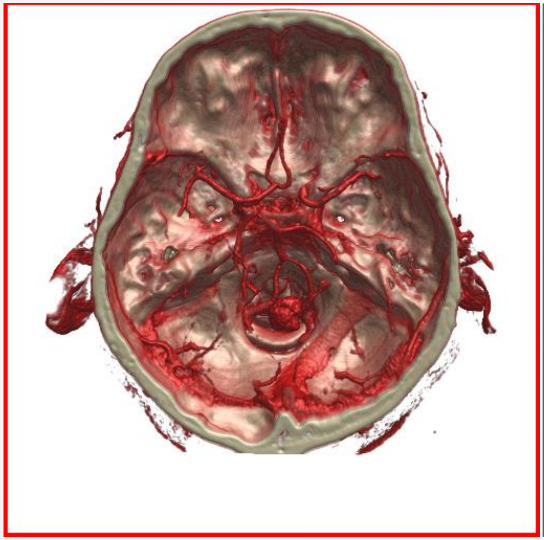
1. 1D Data Visualization
2. 2D Data Visualization
3. 3D Volume Visualization
4. Vector Field and Tensor Field
5. Medical Data Visualization

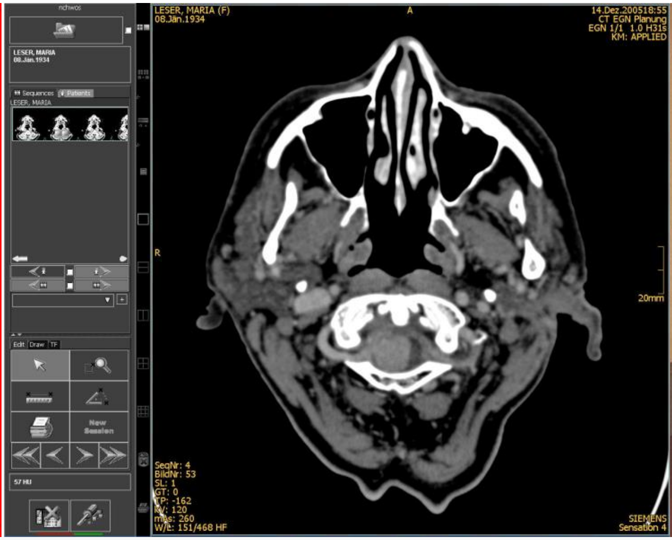
Data Sources

- Scanning devices:
  - MRI
  - CT
  - Ultrasound
  - X-ray

CT

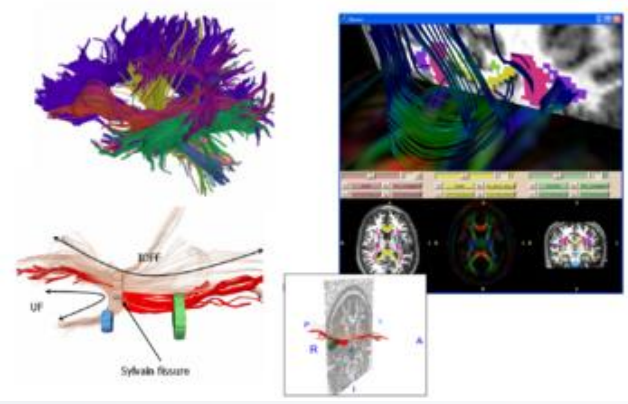
- Computed Tomography
- 3D X-rays
- Rebuild from image slices

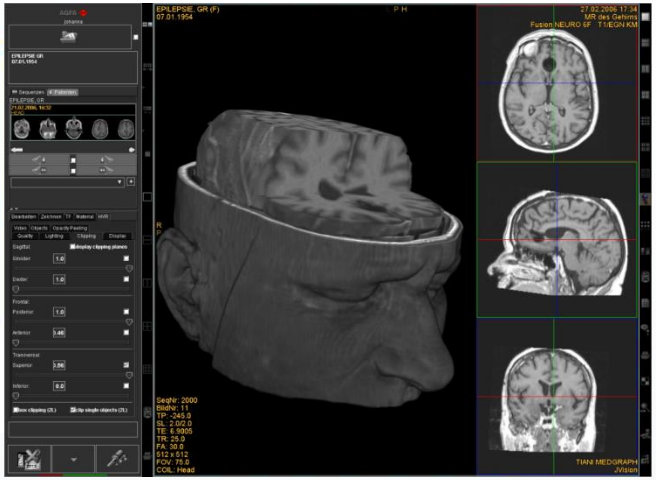




MR I

- Magnetic Resonance Imaging
- FMRI and DTI

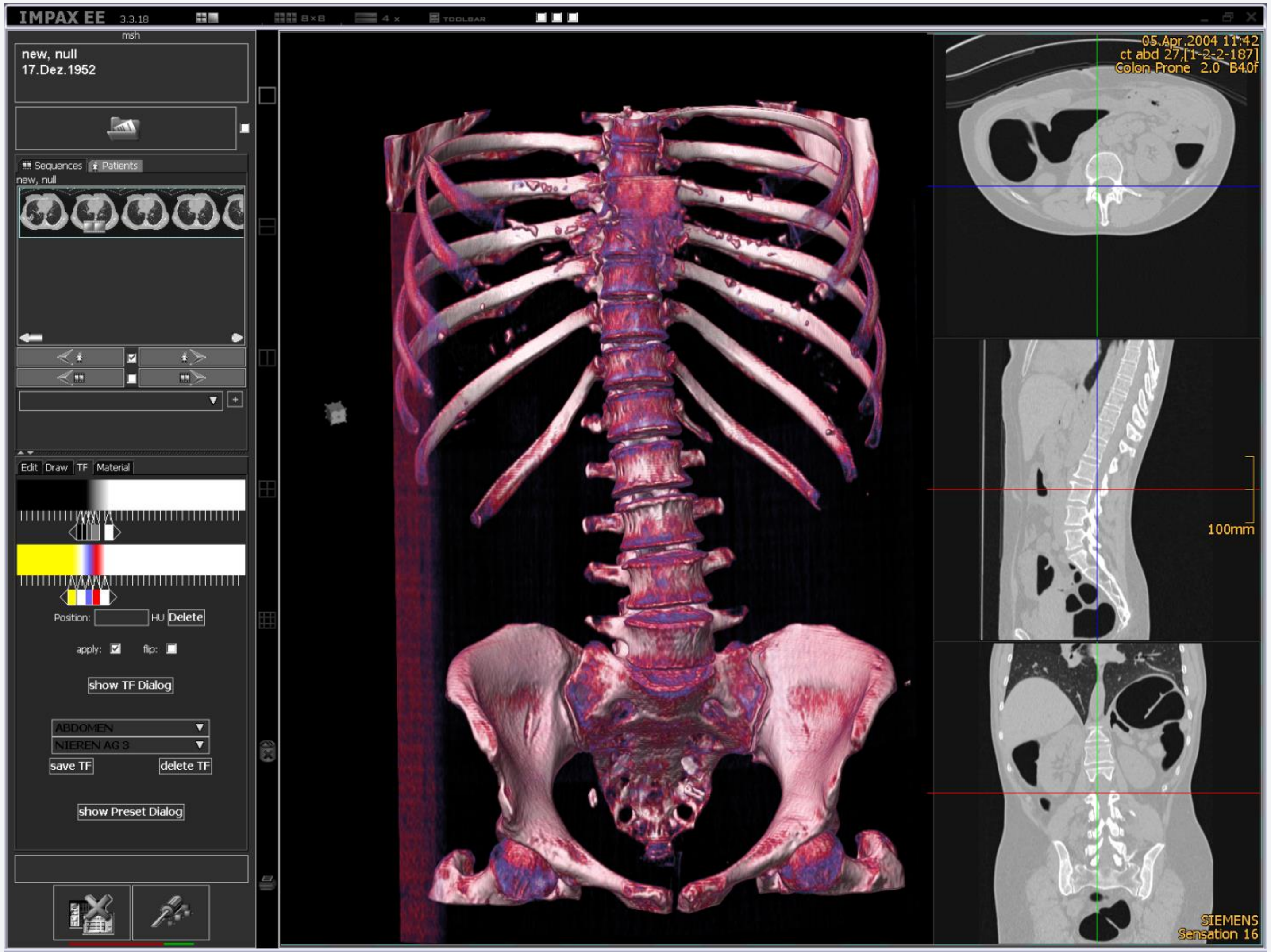




Ultrasound

- 2-18MHz
- Time and echo length
- Contour and texture

Medical Workstation Plugin

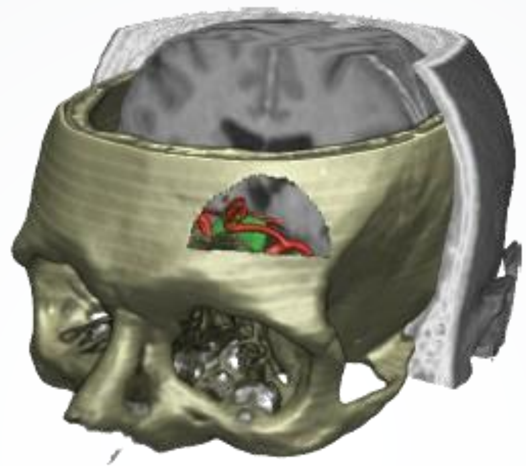


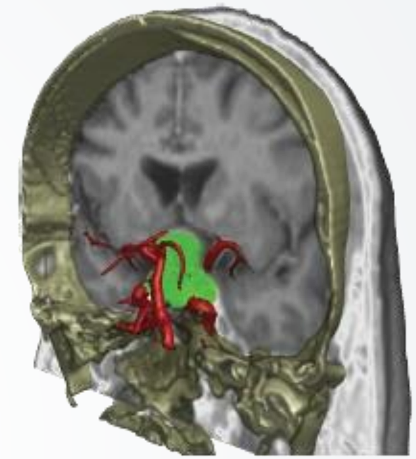
Medical Visualization

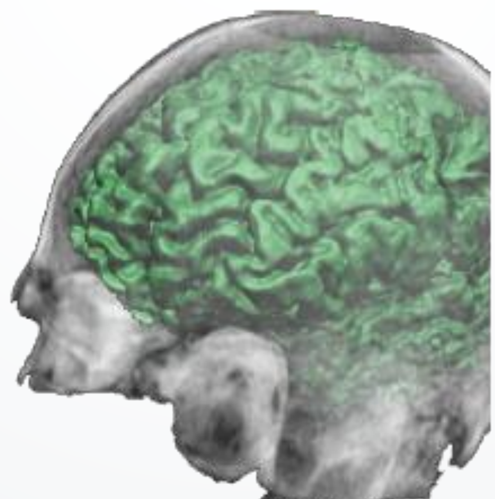
- Diagnostics
- Pre-operative planning
- Training and education
- Intra-operative support and navigation

Medical Visualization

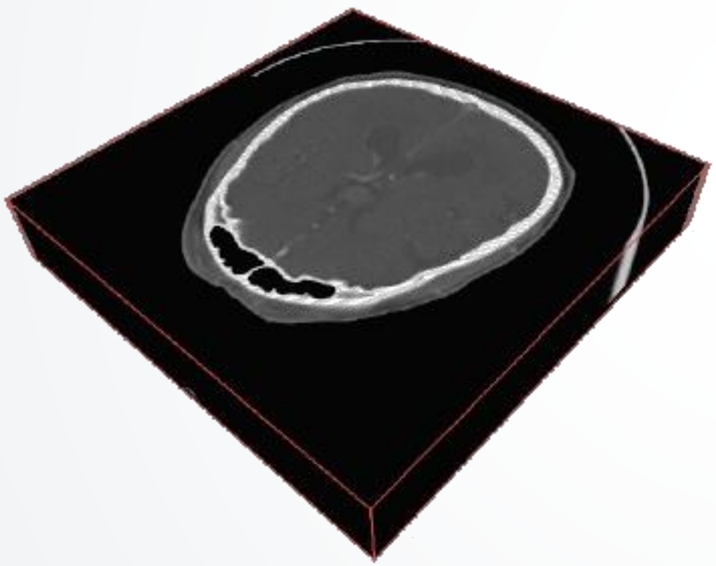
- Volume visualization
- Segmentation
- Analysis
- Measurements







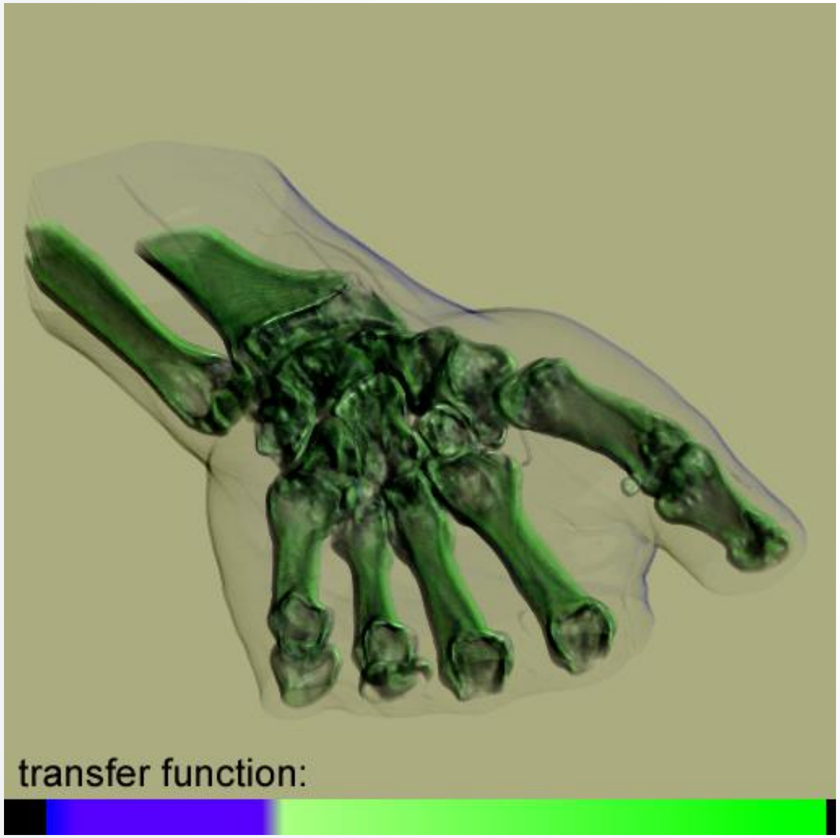
Direct Volume Visualization



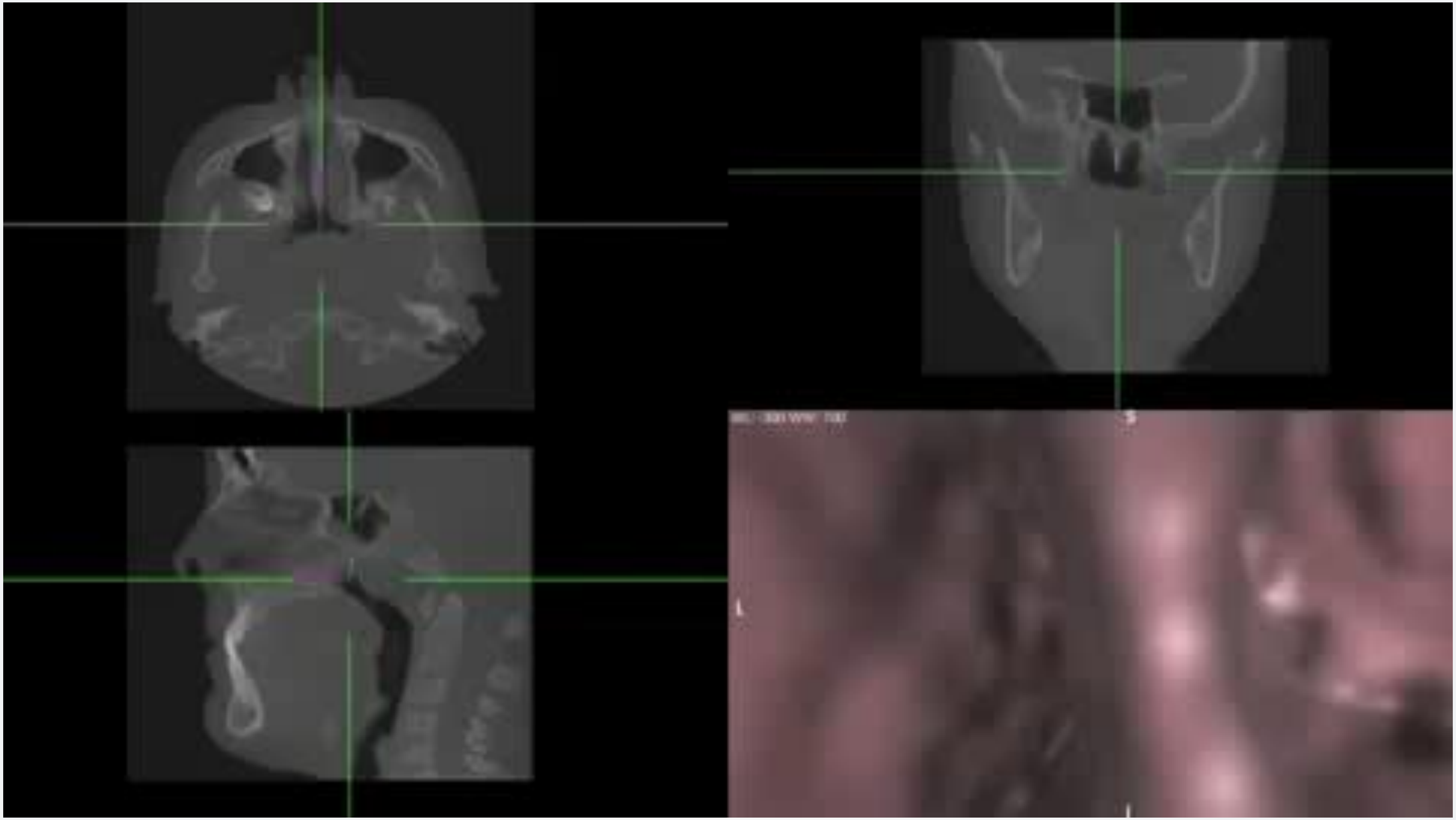
Rebuild from slices

Transfer Function (TF)

- Mapping of density, … to optical properties
- Simplest: color table with opacity over density

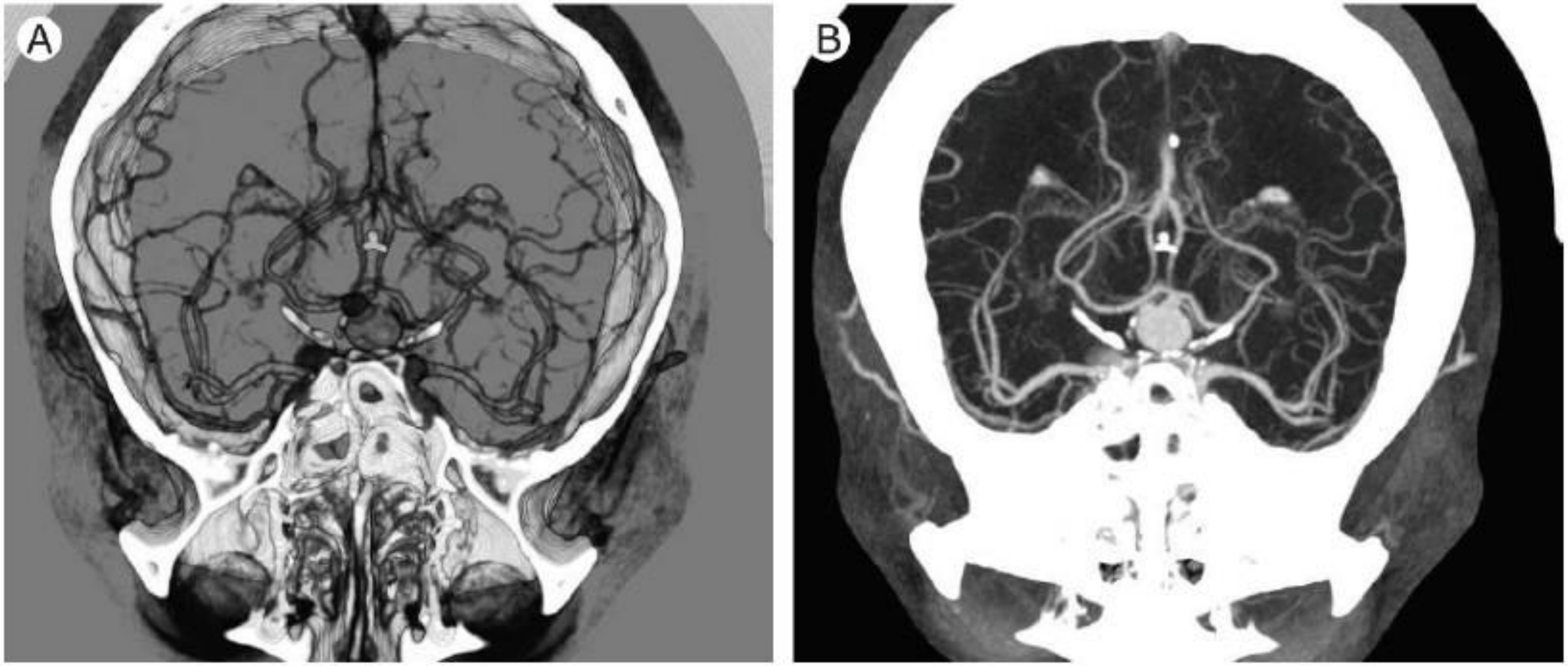


Virtual Endoscopy



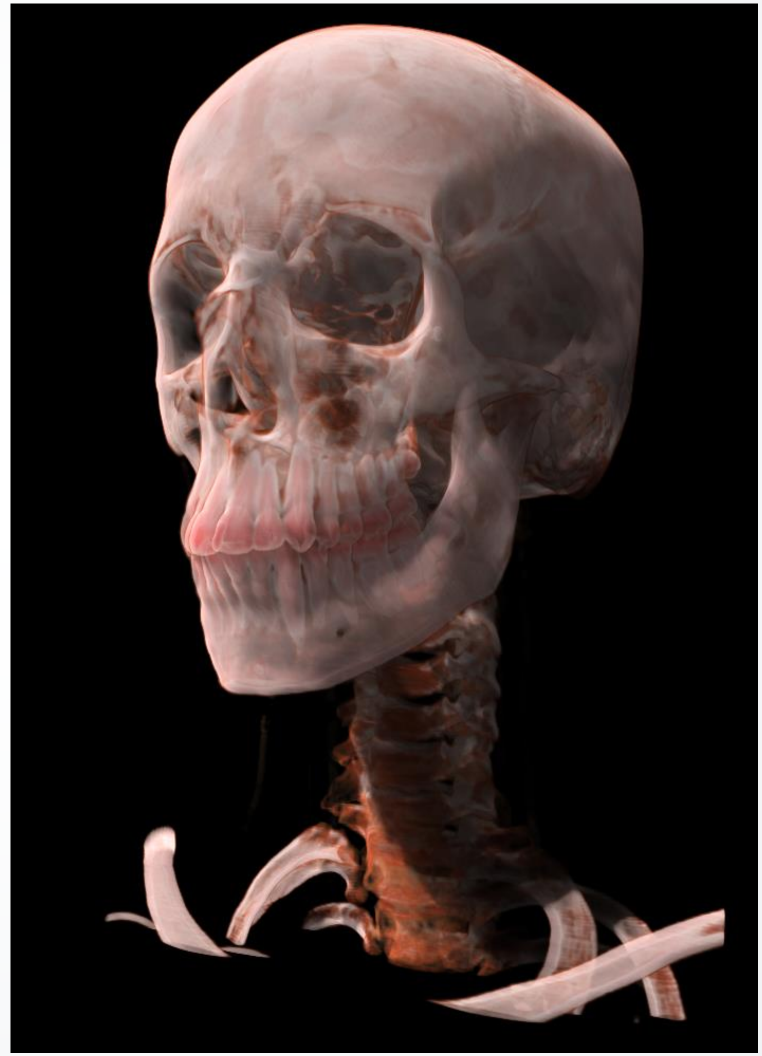
Maximum Intensity Projection

- Keeps structure of maximum intensity visible

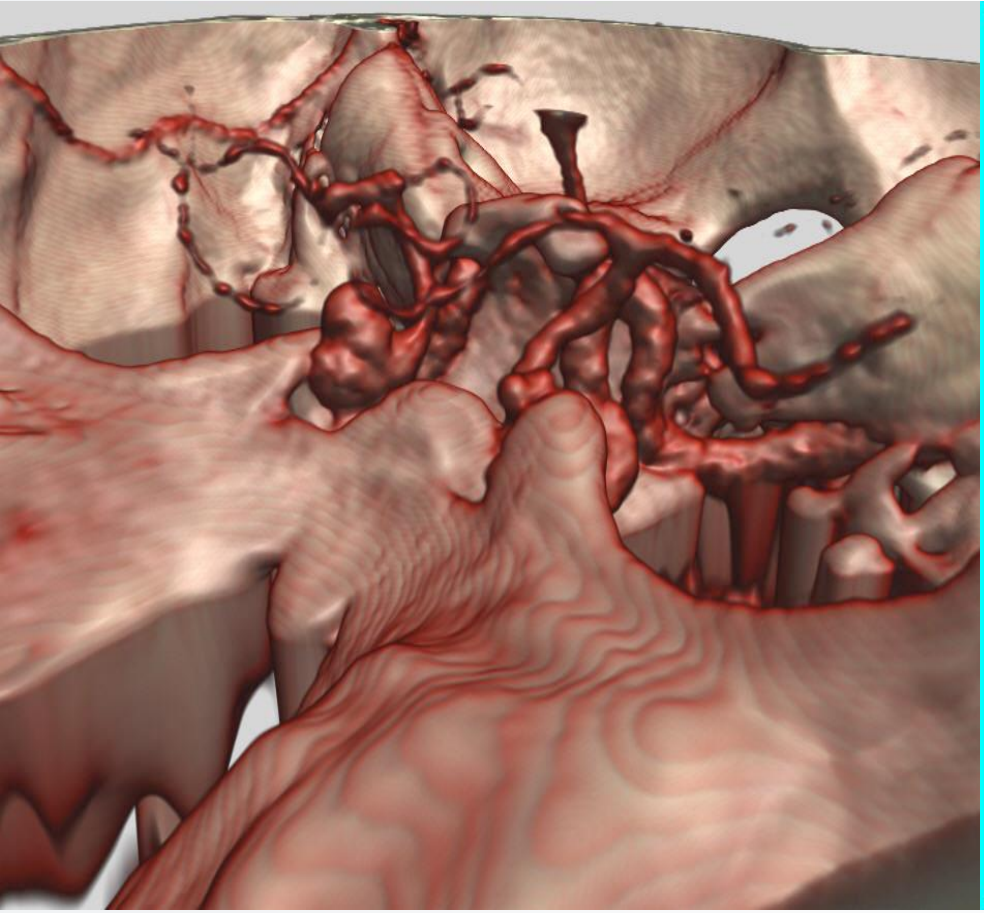


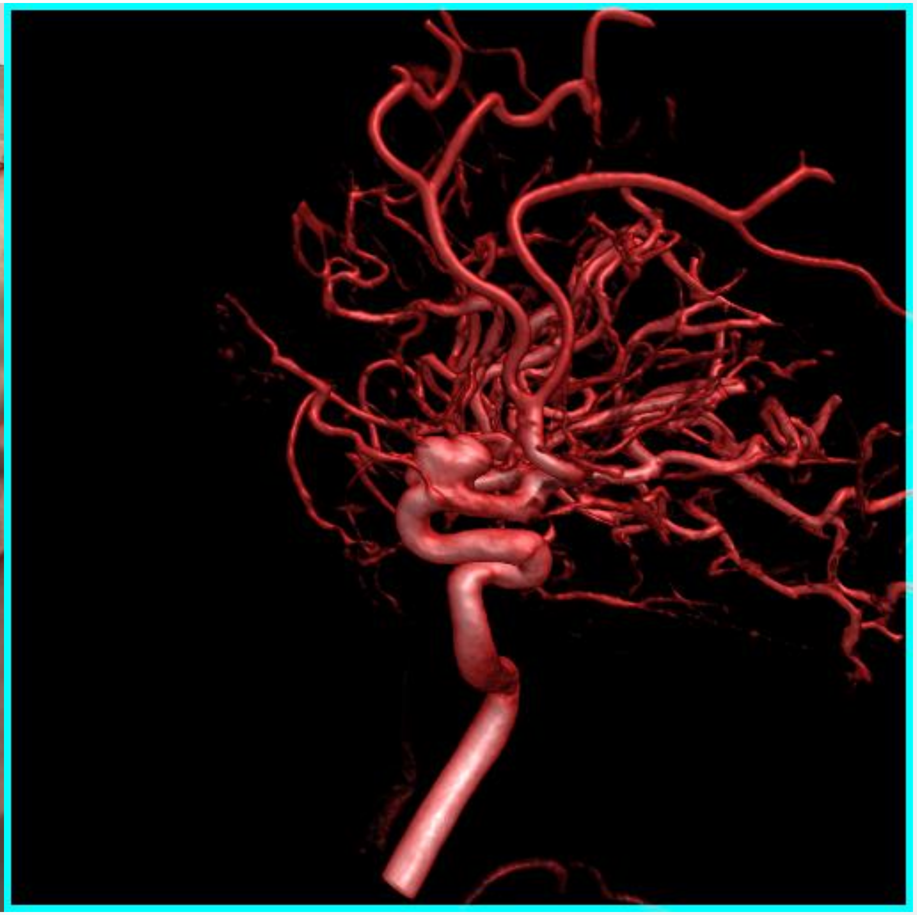
Christof Rezk-Salama

Advanced Lighting

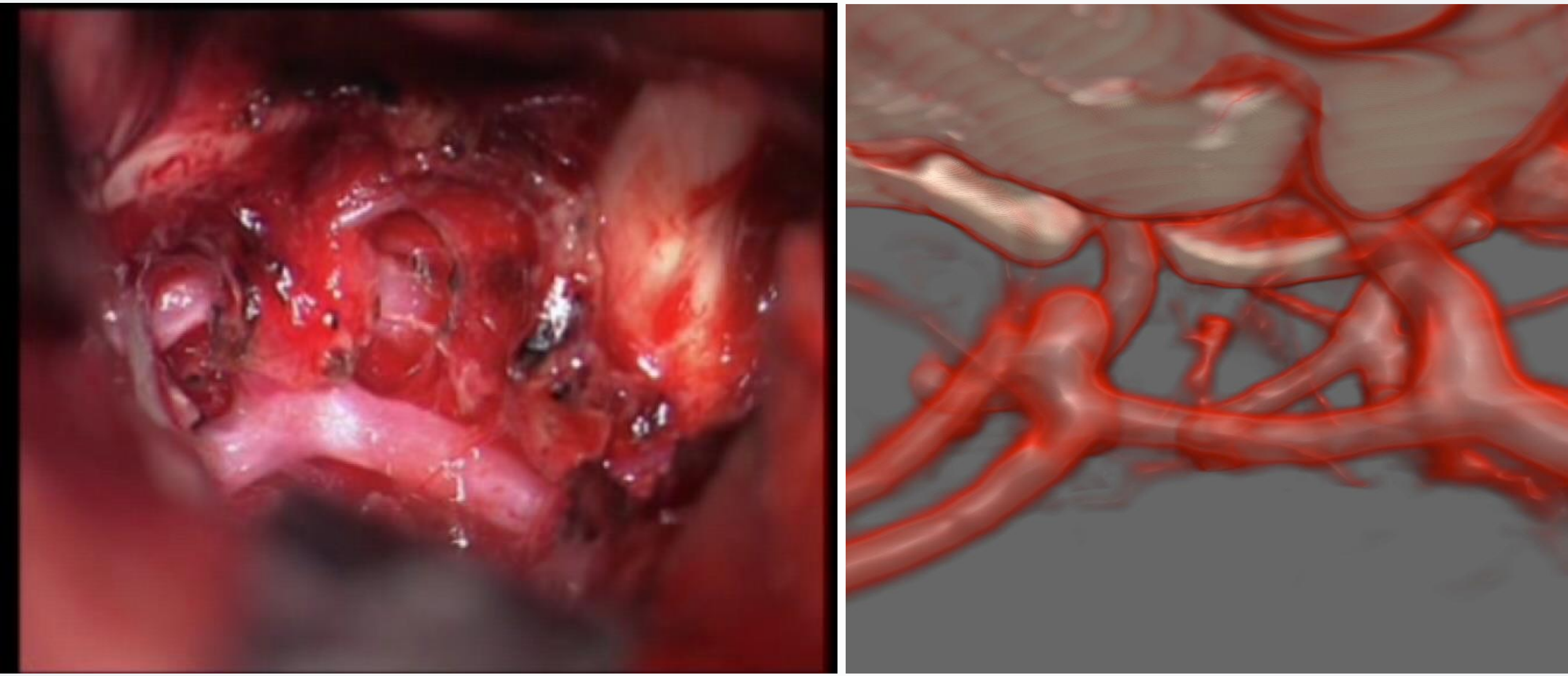


CTA, DSA





Aneurysm



Intra-operative vs. CTA

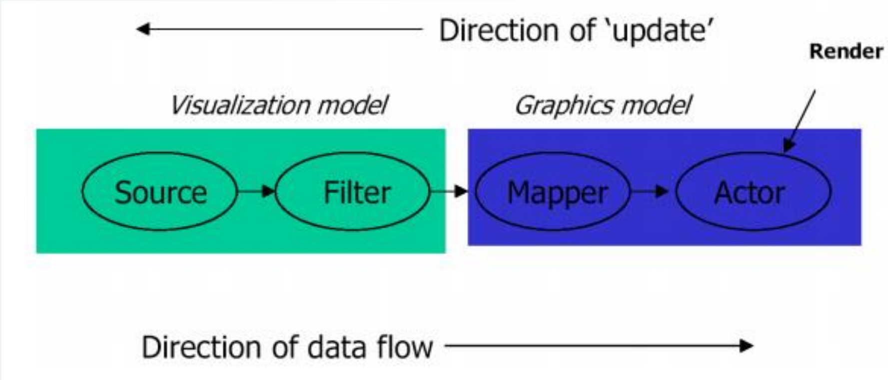
Medical Image Management and Visualization Platform

- DICOM image management and analysis
- 3D segmentation, registration and fusion
- 3D/4D/5D visual analytics
- Plugin based development

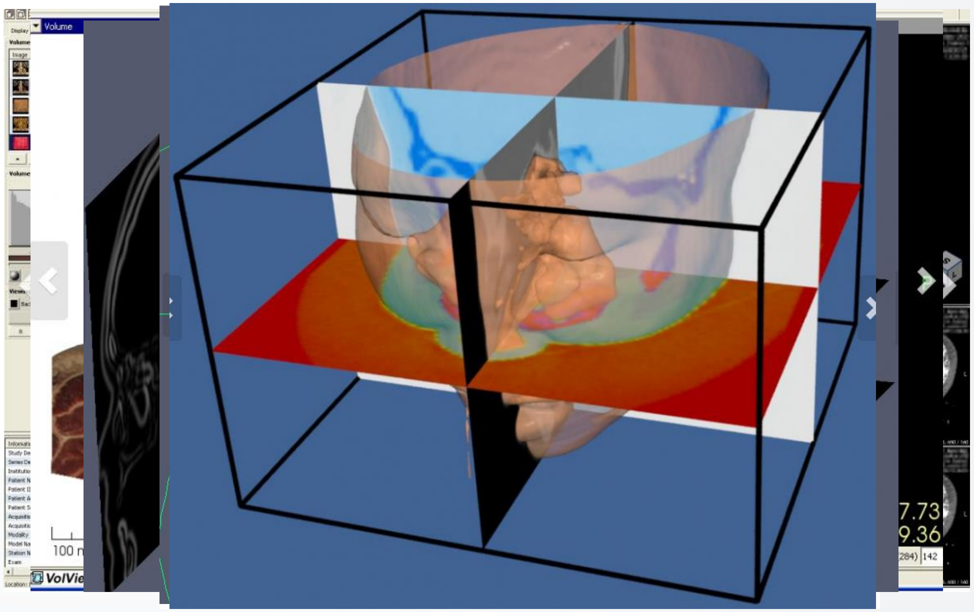
Medical Image Management and Visualization Platform

Scientific Visualization Toolkit

- VTK (Visualization Toolkit)
  - open source software for manipulating and displaying scientific data. It comes with state-of-the-art tools for 3D rendering, a suite of widgets for 3D interaction, and extensive 2D plotting capability

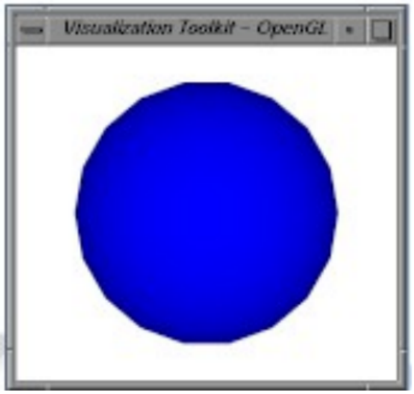


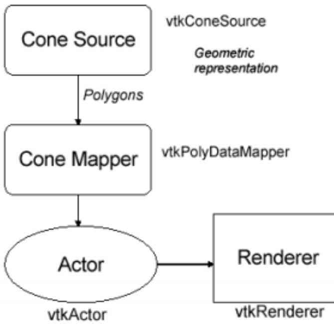
http://www.vtk.org/



Scientific Visualization Toolkit

```
// geometry for sphere created
vtkSphereSource *sphere = vtkSphereSource::New();
sphere->SetRadius(1.0);    sphere->SetThetaResolution(18); sphere->SetPhi…(18);

// map to graphics library
vtkPolyDataMapper *map = vtkPolyDataMapper::New();
map->SetInput(sphere->GetOutput());

// actor coordinates geometry, properties, transformation
vtkActor *aSphere = vtkActor::New();
aSphere->SetMapper(map);                aSphere->GetProperty()->SetColor(0,0,1); //
      sphere color blue

// renderer and render window
vtkRenderer *ren1 = vtkRenderer::New();

// render window
vtkRenderWindow *renWin = vtkRenderWindow::New(); renWin->AddRenderer(ren1);

// interactor
vtkRenderWindowInteractor *iren = vtkRenderWindowInteractor::New();
iren->SetRenderWindow(renWin);

ren1->AddActor(aSphere);                // add the actor to the scene
renWin->Render();                       // render an image
iren->Start(); }                        // begin mouse interaction
```

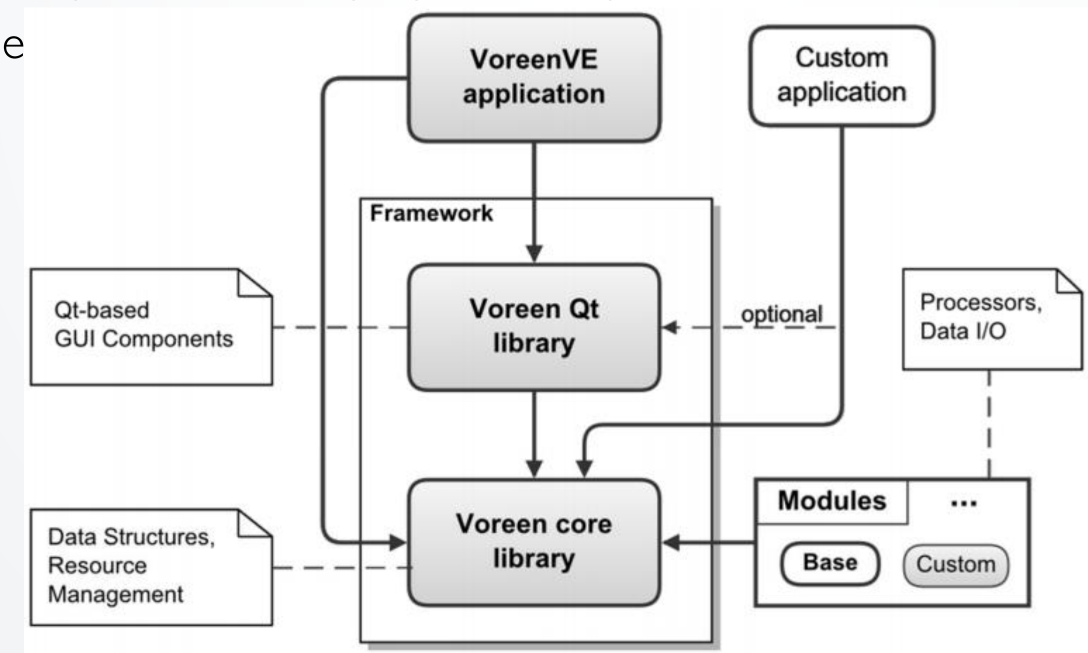


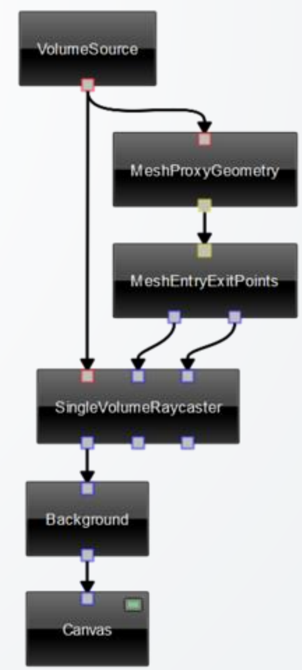


The 'Visualisation pipeline' for this application

Scientific Visualization Toolkit

- Voreen (volume rendering engine)
  - an open source rapid application development framework for the interactive visualization and analysis of multi-modal volumetric data sets
  - provides GPU-based volume rendering and data analysis techniques and offers high flexibility when developing new analysis workflows in collaboration with domain expe





http://www.uni-muenster.de/Voreen/

Thanks