Scientific Visualization

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Introduction to Scientific Visualization

What is Scientific Visualization?

In 1987,

- the National Science Foundation (of the U.S.) started "Visualization in scientific computing" as a new discipline,
- and a panel of the ACM coined the term "scientific visualization"

Scientific visualization, briefly defined:

- The use of computer graphics for the analysis and presentation of computed or measured scientific data.

Conferences and Journals

Conferences

- IEEE Visualization: http://vis.computer.org
- EuroVis: http://www.eurovis.org

Journals:

- Transactions on Visualization and Computer Graphics
  digital library access from ETH: http://ieeexplore.ieee.org

SciVis is interdisciplinary

Fields of application include engineering, natural + medical sciences.

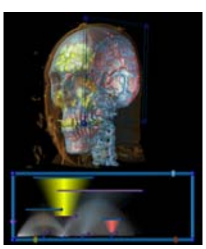


Image credit: J. Kniss, University of Utah

Video credit: K. Ono, Nissan Research Center

Video credit: B. Jobard, CSCS Manno

Types of data

Common to all application fields: numerical datasets, providing an abstraction from the particular application.

Characteristics of datasets:

- dimension of domain: number of coordinates or parameters
- dimension of values: scalar, vector, tensor
- discrete vs. discretized data
- type of discretization: (un-)structured grid, scattered data, …
- static vs. time-dependent

SciVis and InfoVis

Scientific visualization is mostly concerned with:

- 2, 3, 4 dimensional, spatial or spatio-temporal data
- discretized data

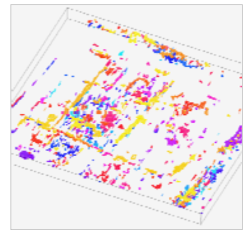
Information visualization focuses on:

- high-dimensional, abstract data
- discrete data
- financial, statistical, etc.
- visualization of large trees, networks, graphs
- data mining: finding patterns, clusters, voids, outliers

Preview of topics

2 – Contouring and Isosurfaces

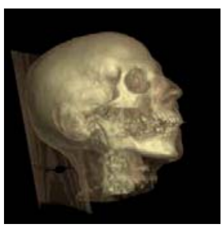
- 2D contours
- Marching cubes algorithm
- Asymptotic decider algorithm
- Faster methods



Preview of topics

3 – Raycasting

- Principle
- Transfer functions
- Pre-integration
- Optimizations
- Shear-warp factorization

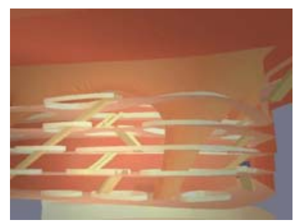


Video credit: P. Lacroute, Stanford

Preview of topics

4 – Volume Rendering

- Object space methods
- Texture-based methods
- Splatting
- Cell projection

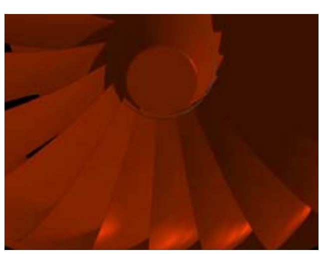


Video credit: O. Staubli, ETH Zurich

Preview of topics

5 – Vector Field Visualization

- Vector fields and ODEs
- Streamlines, streaklines, pathlines
- Point location methods
- Streamsurfaces



Preview of topics

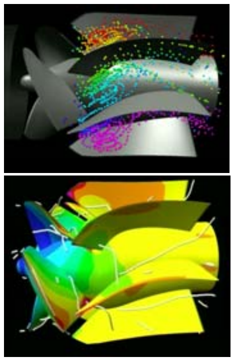
6 – Texture Advection

- Line integral convolution
- Lagrangian-Eulerian advection
- Image-Based Flow Vis

Video credit: R. Laramee, TU Wien

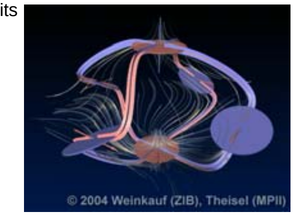
7 – Feature Extraction

- Feature classification
- Height ridges/valleys
- Vortex core lines
- Flow separation lines
- Feature tracking



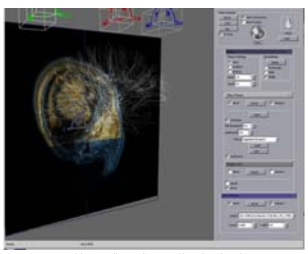
8 – Vector Field Topology

- Critical points and periodic orbits
- Visualization algorithms
- Topological skeletons in 2D
- Topology of 3D vector fields
- Chaotic attractors



9 – Tensor Field Visualization

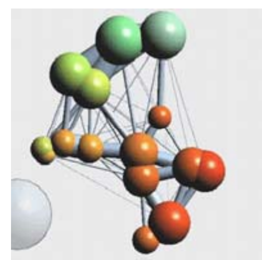
- Tensors
- Tensor glyphs
- Tensor line tracking
- Topology of tensor fields



Video credit: J. Blaas, Delft Univ. of Tech.

10 – Information Visualization

- Parallel coordinates
- Clustering methods
- Focus+context techniques
- Linked views



Video credit: F. van Ham, TU Eindhoven

11 – Visualization Systems

- Application Visualization System
- VTK/Paraview
- Covise

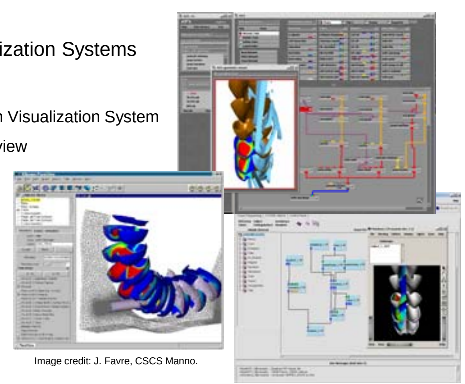
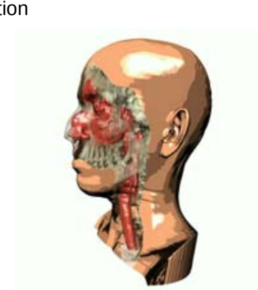


Image credit: J. Favre, CSCS Manno.

12 – Hot Topics in Visualization

- Illustrative visualization
- Multiscale, multiresolution methods
- Uncertainty visualization
- Out-of-core algorithms



Video credit: S. Bruckner, TU Wien

Data discretizations

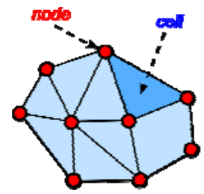
Types of data sources have typical types of discretizations:

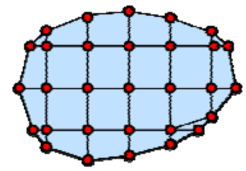
- Measurement data:
  - typically scattered (no grid)
- Numerical simulation data:
  - structured, block-structured, unstructured grids
  - adaptively refined meshes
  - multi-zone grids with relative motion
  - etc.
- Imaging methods:
  - uniform grids
- Mathematical functions:
  - uniform/adaptive sampling on demand

Unstructured grids

2D unstructured grids:

- cells are triangles and/or quadrangles
- domain can be a surface embedded in 3-space (distinguish n-dimensional from n-space)

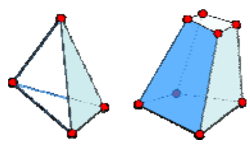




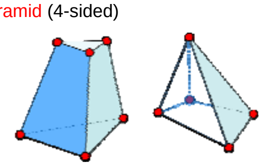
Unstructured grids

3D unstructured grids:

- cells are tetrahedra or hexahedra



- mixed grids (“zoo meshes”) require additional types: wedge (3-sided prism), and pyramid (4-sided)



Structured grids

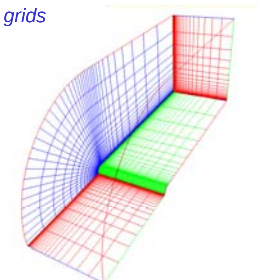
General case: curvilinear grid

- nodes given in array $N_i \times N_j \times N_k$
- cells are implicite

Special case: rectilinear grid

- simpler coordinate functions:

  $x = x(i), y = y(j), z = z(k)$



More special: uniform grid

- coordinates defined by axis-aligned bounding box (2 points)

Scattered data

Scattered data means: only nodes, no cells

Typical data sources: measurement data, e.g. meteorological

Options for visualization:

- point-based methods (relatively few algorithms)
- triangulation, e.g. constrained Delaunay, difficult in 3D
- resampling on uniform grid

Elementary visualization methods

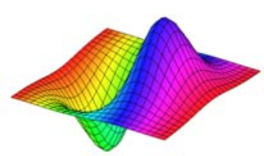
Scalar fields can be visualized by plotting its function graphs:

- 1D field: graph is a curve $y = f(x)$
- 2D field: graph is a height field $z = f(x, y)$

  Easy for rectilinear grids:

  Painter's algorithm (hidden surface removal in software):

  - Draw cells row by row, from back to front



Visualization by color coding:

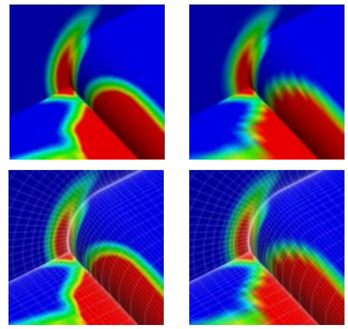
Use: 1D texture mapping!

```
glTexEnvi(GL_TEXTURE_ENV, GL_TEXTURE_ENV_MODE, GL_MODULATE);
glTexParameteri(GL_TEXTURE_1D, GL_TEXTURE_WRAP_S, GL_CLAMP);
```

Don't use: vertex colors + Gouraud shading!

- Problem of RGB mode:
  - interpolation in wrong space (RGB vs. color bar)
- Problem of color index mode:
  - lighting not possible

1D textures vertex colors



stagnation energy

5 6 7 8 9 10

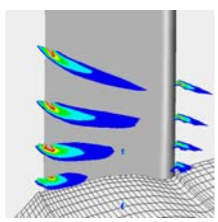
0.0 0.5 1.0

texture map

Transparent border color

```
glTexParameterf(GL_TEXTURE_1D, GL_TEXTURE_BORDER_COLOR, transp);
```

Example:
vorticity magnitude
on horizontal slices,
high values only



Example: von Kármán vortex street, colored by entropy