Scientific Visualization

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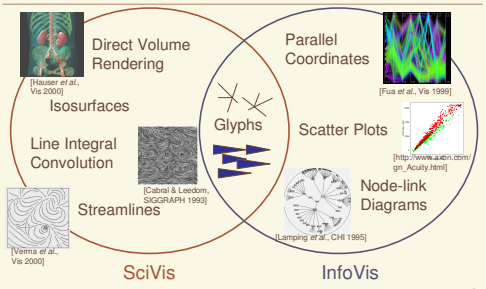
Acknowledgments:
Torsten Möller (Simon Fraser University)
Raghu Machiraju (Ohio State University)
Klaus Mueller (SUNY Stony Brook)

Overview

- **What is SciVis?**
- Data & Applications
- Iso-surfaces
- Direct Volume Rendering
- Vector Visualization
- Challenges

Difference between SciVis and InfoVis



Difference between SciVis and InfoVis

- **Card, Mackinlay, & Shneiderman:**
  - SciVis: Scientific, physically based
  - InfoVis: Abstract
- **Munzner:**
  - SciVis: Spatial layout given
  - InfoVis: Spatial layout chosen
- **Tory & Möller:**
  - SciVis: Spatial layout given + Continuous
  - InfoVis: Spatial layout chosen + Discrete
  - Everything else -- ?

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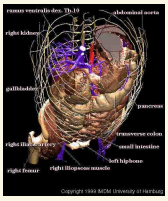
Medical Scanning

- MRI, CT, SPECT, PET, ultrasound

Medical Scanning - Applications

- Medical education for anatomy, surgery, etc.
- Illustration of medical procedures to the patient



7

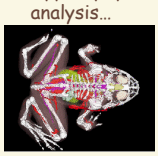
Medical Scanning - Applications

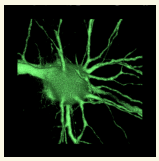
- Surgical simulation for treatment planning
- Tele-medicine
- Inter-operative visualization in brain surgery, biopsies, etc.

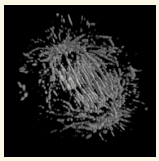
8

Biological Scanning

- Scanners: Biological scanners, electronic microscopes, confocal microscopes
- Apps – physiology, paleontology, microscopic analysis…



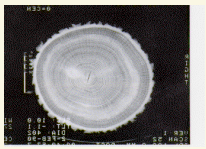




9

Industrial Scanning

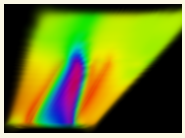
- Planning (e.g., log scanning)
- Quality control
- Security (e.g. airport scanners)



10

Scientific Computation - Domain

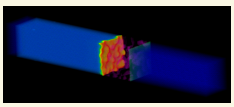
- Mathematical analysis
- ODE/PDE (ordinary and partial differential equations)
- Finite element analysis (FE)
- Supercomputer simulations

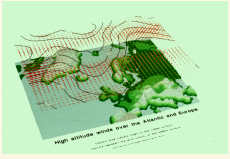


11

Scientific Computation - Apps

- Flow Visualization





12

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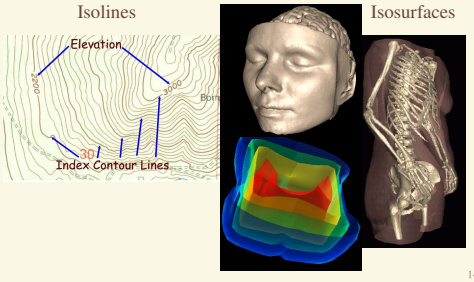
13

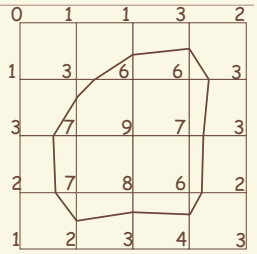
Isosurfaces - Examples



14

Isosurface Extraction

- by contouring
  - closed contours
  - continuous
  - determined by iso-value
- several methods
  - marching cubes is most common

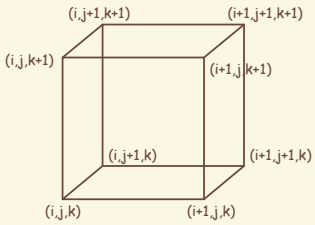


Iso-value = 5

15

MC 1: Create a Cube

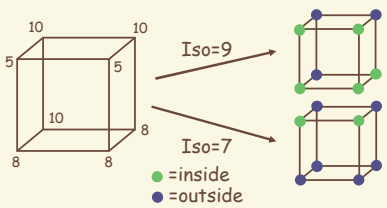
- Consider a Cube defined by eight data values:



16

MC 2: Classify Each Voxel

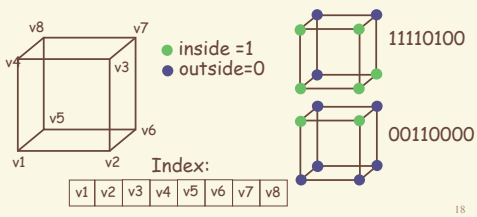
- Classify each voxel according to whether it lies outside the surface (value > iso-surface value) inside the surface (value <= iso-surface value)



17

MC 3: Build An Index

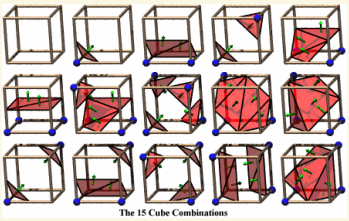
- Use the binary labeling of each voxel to create an index



18

MC 4: Lookup Edge List

- For a given index, access an array storing a list of edges

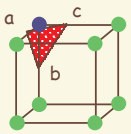


- all 256 cases can be derived from 15 base cases

19

MC 4: Example

- Index = 00000001
- triangle 1 = a, b, c



20

MC 5: Interp. Triangle Vertex

- For each triangle edge, find the vertex location along the edge using linear interpolation of the voxel values

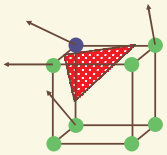
$$x = i + \left(\frac{T - v[i]}{v[i+1] - v[i]} \right)$$

21

MC 6: Compute Normals

- Calculate the normal at each cube vertex

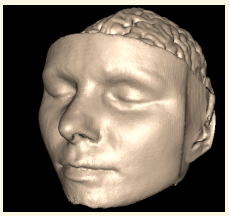
$$G_x = v_{i+1,j,k} - v_{i-1,j,k}$$
$$G_y = v_{i,j+1,k} - v_{i,j-1,k}$$
$$G_z = v_{i,j,k+1} - v_{i,j,k-1}$$



- Use linear interpolation to compute the polygon vertex normal

22

MC 7: Render!



23

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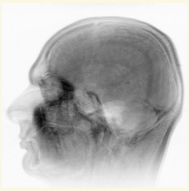
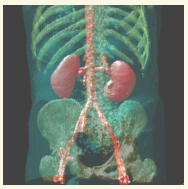
- **Direct Volume Rendering**
- Vector Visualization
- Challenges

24

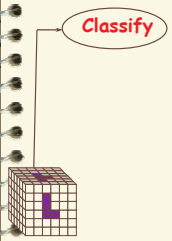
Direct Volume Rendering Examples





25

Rendering Pipeline (RP)



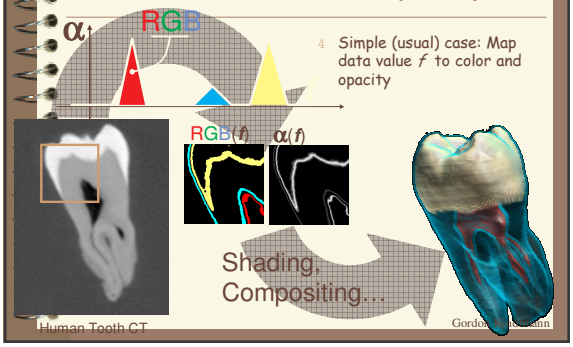
26

Classification

- original data set has application specific values (temperature, velocity, proton density, etc.)
- assign these to color/opacity values to make sense of data
- achieved through transfer functions

27

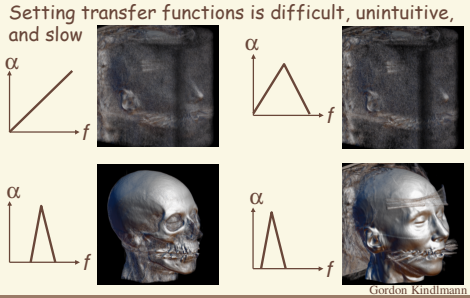
Transfer Functions (TF's)



- Simple (usual) case: Map data value f to color and opacity

TF's

- Setting transfer functions is difficult, unintuitive, and slow



Gordon Kindlmann

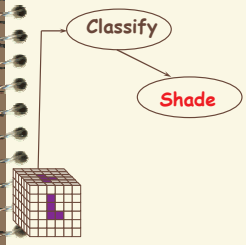
Transfer Function Challenges

- Better interfaces:
  - Make space of TFs less confusing
  - Remove excess "flexibility"
  - Provide guidance
- Automatic / semi-automatic transfer function generation
  - Typically highlight boundaries

30

Gordon Kindlmann

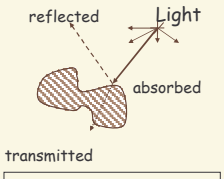
Rendering Pipeline (RP)

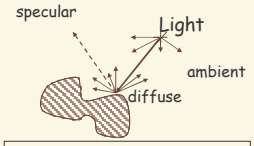


31

Light Effects

- Usually only considering reflected part





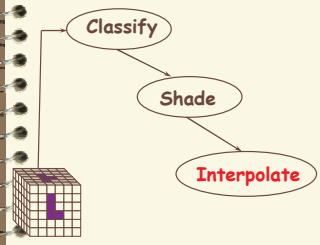
Light=refl.+absorbed+trans.

Light=ambient+diffuse+specular

$$I = k_a I_a + k_d I_d + k_s I_s$$

32

Rendering Pipeline (RP)

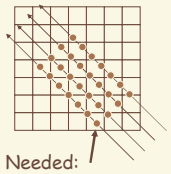


33

Interpolation

2D

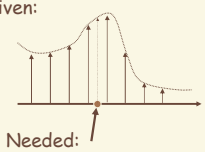
- Given:



- Needed:

1D

- Given:



- Needed:

34

Interpolation

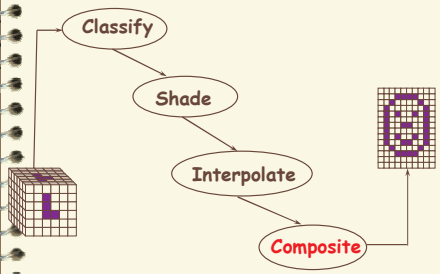
- Very important; regardless of algorithm
- Expensive => done very often for one image
- Requirements for good reconstruction
  - performance
  - stability of the numerical algorithm
  - accuracy

Nearest neighbor

Linear

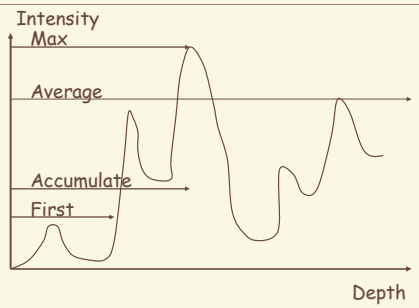
35

Rendering Pipeline (RP)



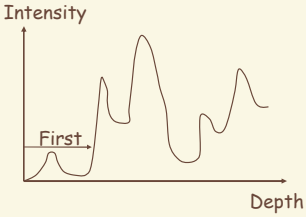
36

Ray Traversal Schemes



37

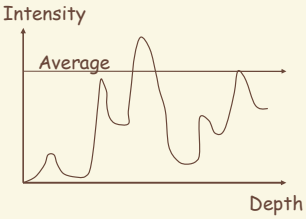
Ray Traversal - First

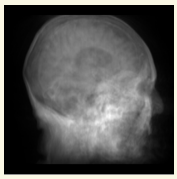


- **First**: extracts iso-surfaces (again!) done by Tuy&Tuy '84

38

Ray Traversal - Average

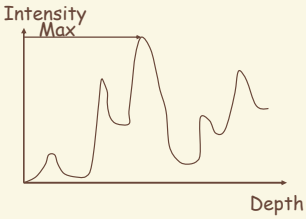




- **Average**: produces basically an X-ray picture

39

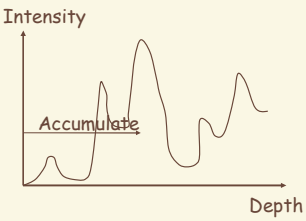
Ray Traversal - MIP

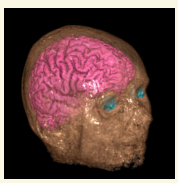


- **Max**: Maximum Intensity Projection used for Magnetic Resonance Angiogram

40

Ray Traversal - Accumulate

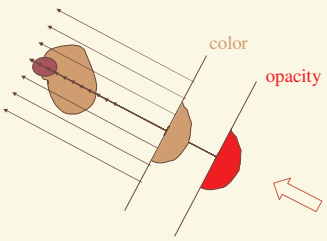




- **Accumulate**: make transparent layers visible! Levoy '88

41

Volumetric Ray Integration



42

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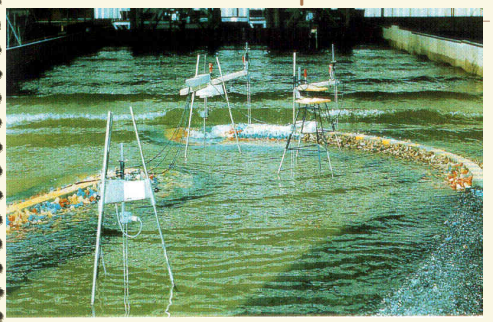
43

Flow Visualization

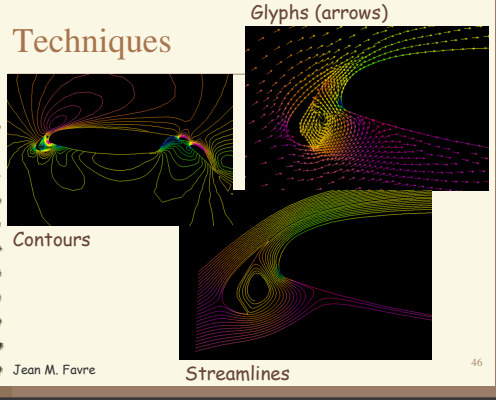
- Traditionally – Experimental Flow Vis
- Now – Computational Simulation
- Typical Applications:
  - Study physics of fluid flow
  - Design aerodynamic objects

44

Traditional Flow Experiments



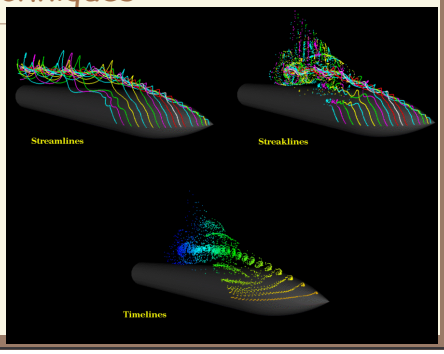
Techniques



Jean M. Favre

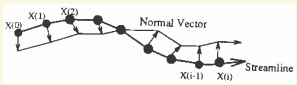
46

Techniques



Techniques - Stream-ribbon

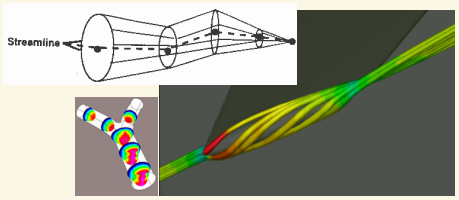
- Trace one streamline and a constant size vector with it
- Allows you to see places where flow twists



48

Techniques - Stream-tube

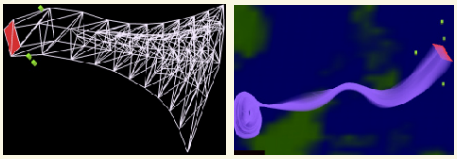
- Generate a stream-line and widen it to a tube
- Width can encode another variable



49

Mappings - Flow Volumes

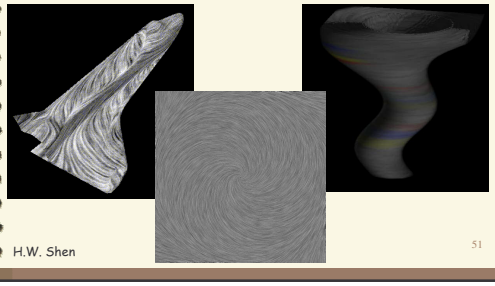
- Instead of tracing a line - trace a small polyhedron



50

LIC (Line Integral Convolution)

- Integrate noise texture along a streamline



H.W. Shen

51

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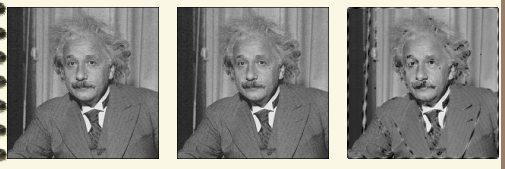
- **Challenges**

52

Challenges - Accuracy

- Need metrics -> perceptual metric



(a) Original (b) Bias-Added (c) Edge-Distorted

53

Challenges - Accuracy

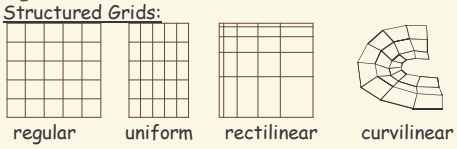
- Deal with unreliable data (noise, Ultrasound)

54

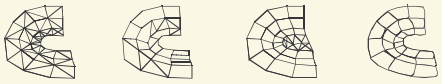
Challenges - Accuracy

- Irregular data sets

Structured Grids:



Unstructured Grids:



55

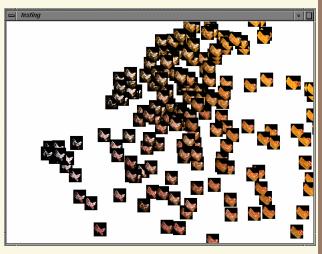
Challenges - Speed/Size

- Efficient algorithms
- Hardware developments (VolumePro)
- Utilize current hardware (nVidia, ATI)
- Compression schemes
- Tera-byte data sets

56

Challenges - HCI

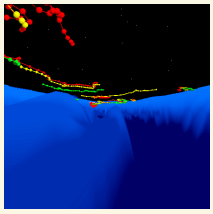
- Need better interfaces
- Which method is best?



57

Challenges - HCI

- "Augmented" reality
- Explore novel I/O devices



58