



Scientific Visualization

Melanie Tory

Acknowledgments:

Torsten Möller (Simon Fraser University)

Raghu Machiraju (Ohio State University)

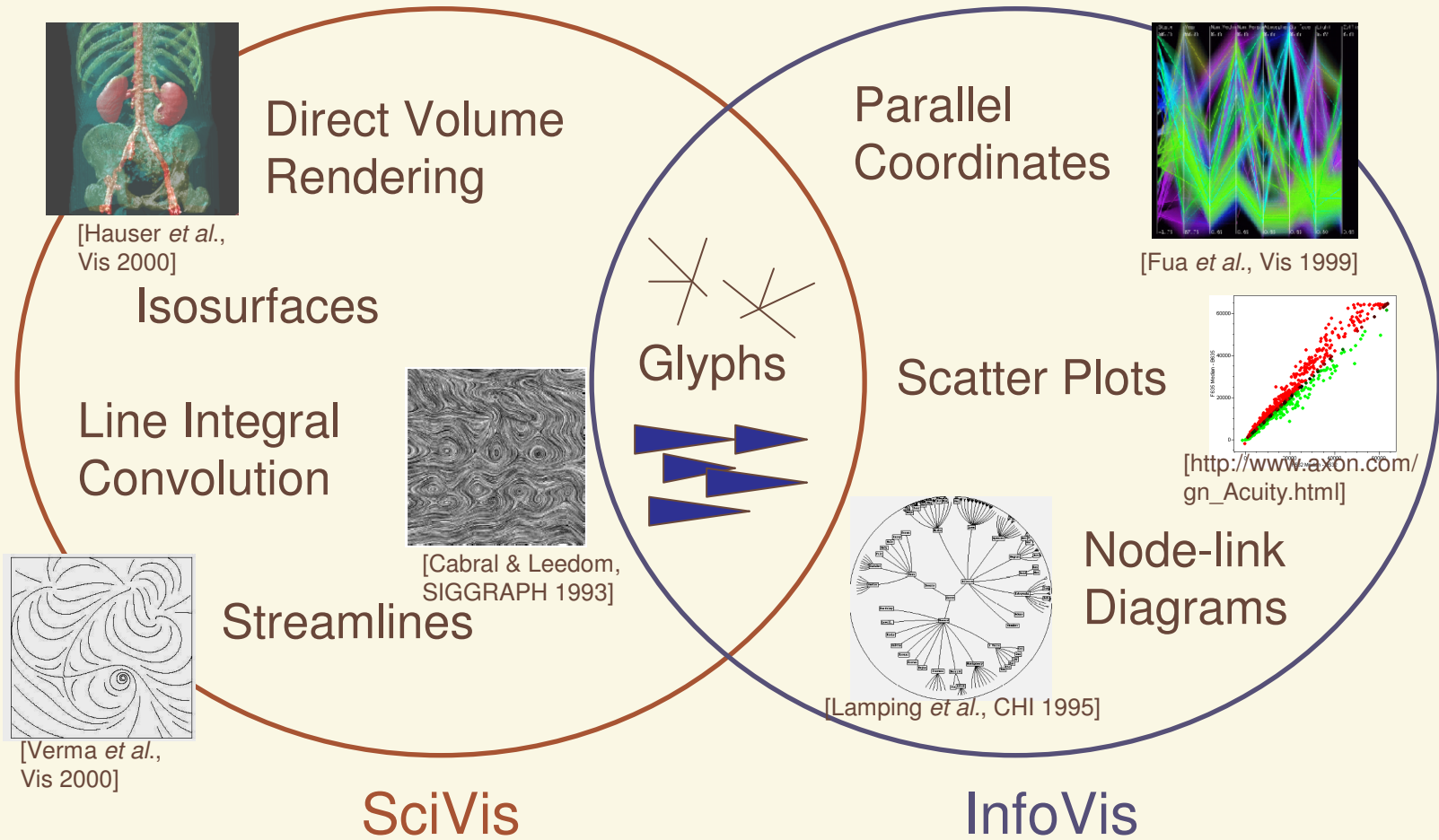
Klaus Mueller (SUNY Stony Brook)



Overview

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

Difference between SciVis and InfoVis



Difference between SciVis and InfoVis

4 **Card, Mackinlay, & Shneiderman:**

- SciVis: Scientific, physically based
- InfoVis: Abstract

4 **Munzner:**

- SciVis: Spatial layout given
- InfoVis: Spatial layout chosen

4 **Tory & Möller:**

- SciVis: Spatial layout given + Continuous
- InfoVis: Spatial layout chosen + Discrete
- Everything else -- ?

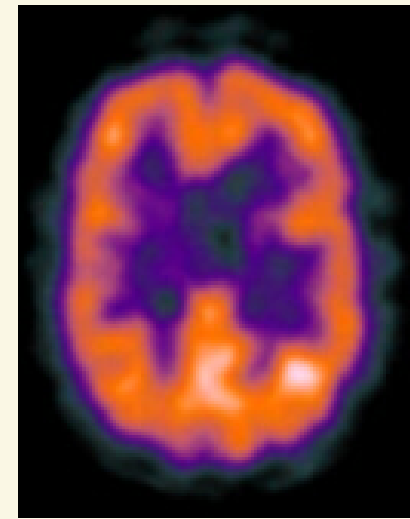
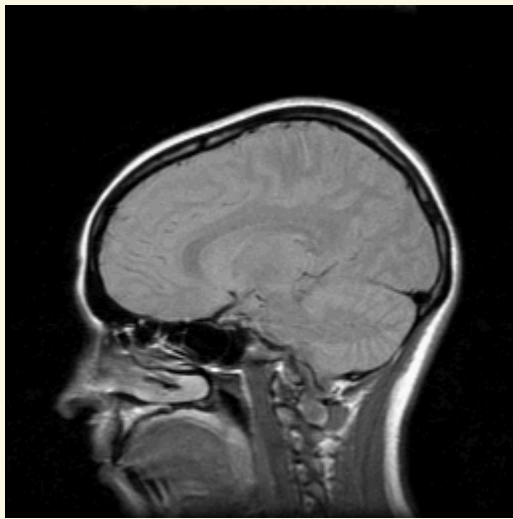


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- 4 **Data & Applications**
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- 4 Direct Volume Rendering
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- 4 Challenges

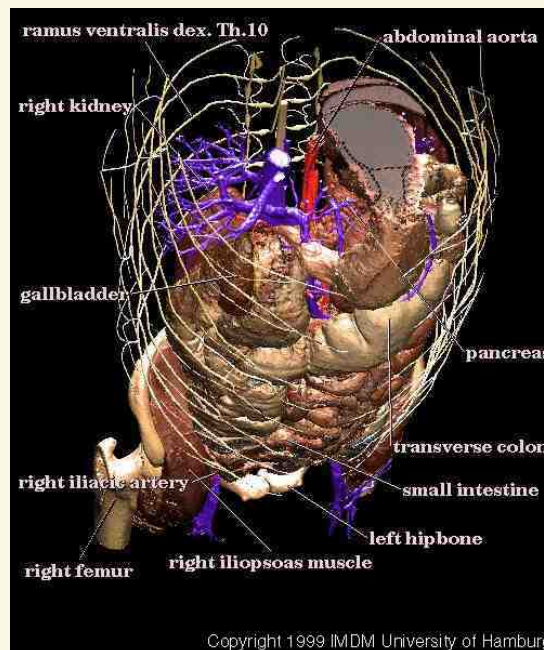
Medical Scanning

4 MRI, CT, SPECT, PET, ultrasound



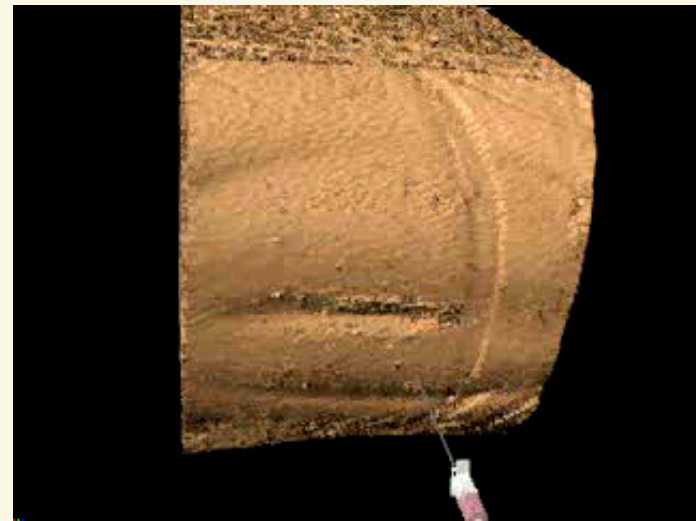
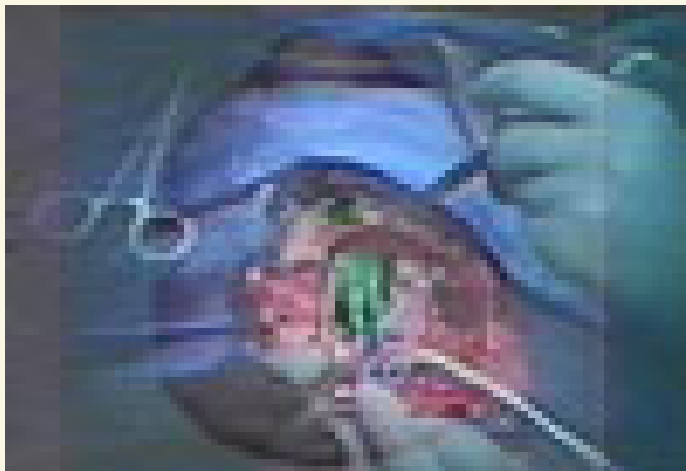
Medical Scanning - Applications

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



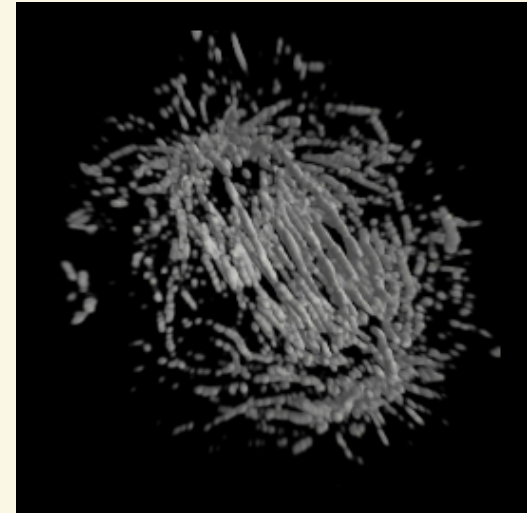
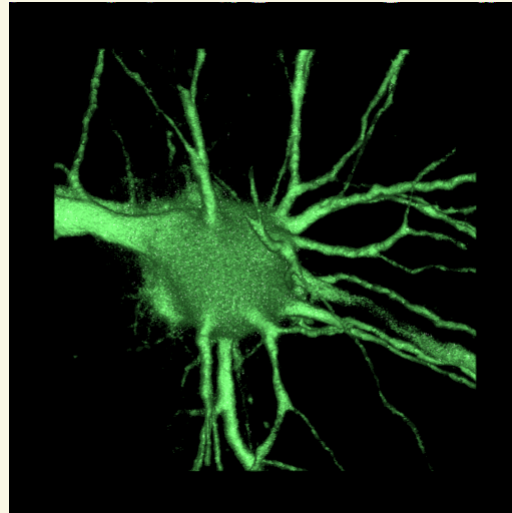
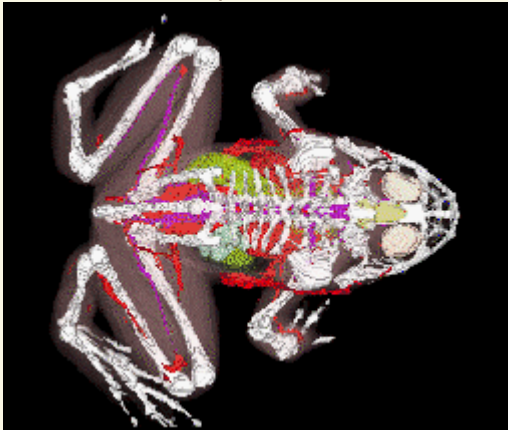
Medical Scanning - Applications

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



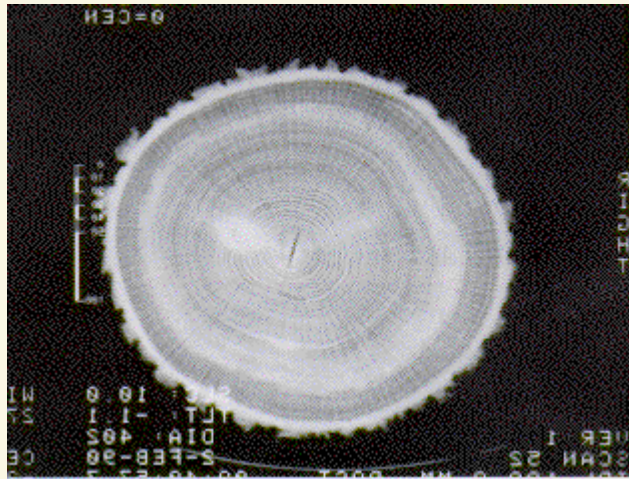
Biological Scanning

- 4 Scanners: Biological scanners, electronic microscopes, confocal microscopes
- 4 Apps - physiology, paleontology, microscopic analysis...



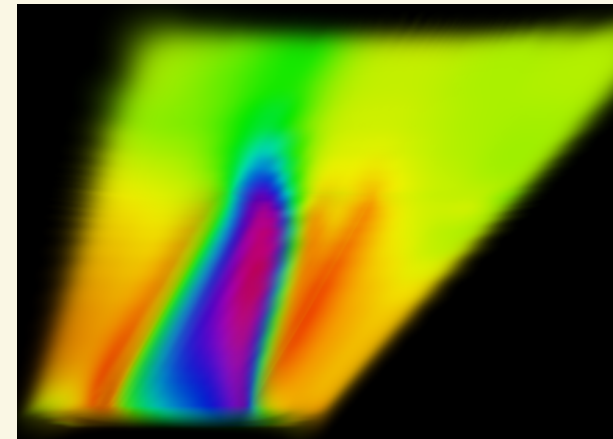
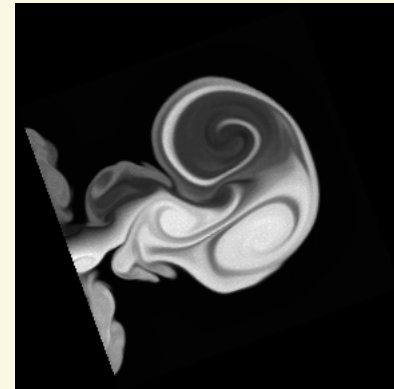
Industrial Scanning

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



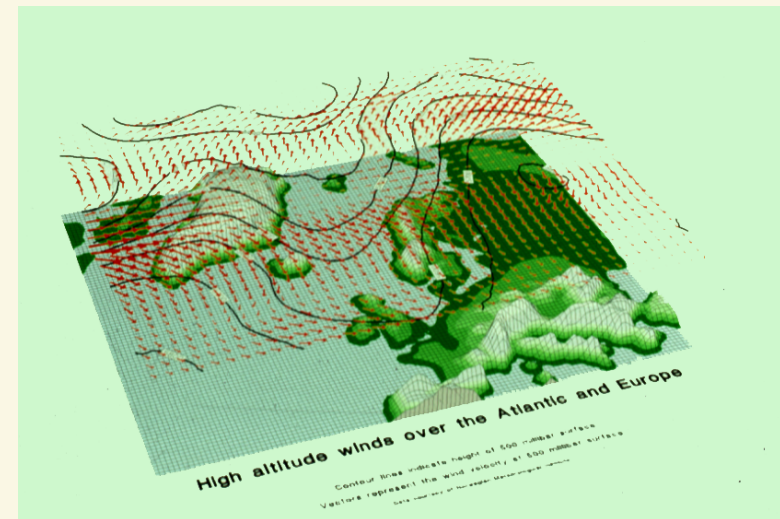
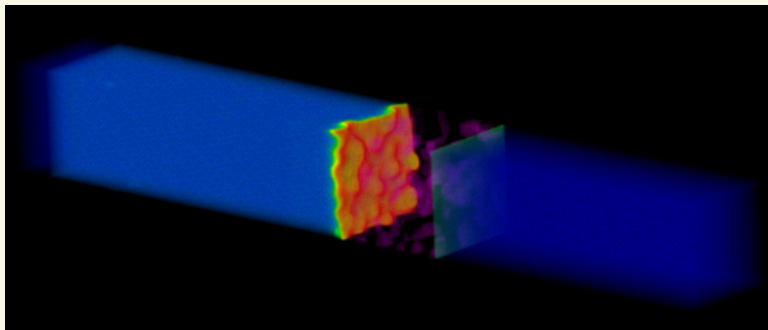
Scientific Computation - Domain

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



Scientific Computation - Apps

4 Flow Visualization



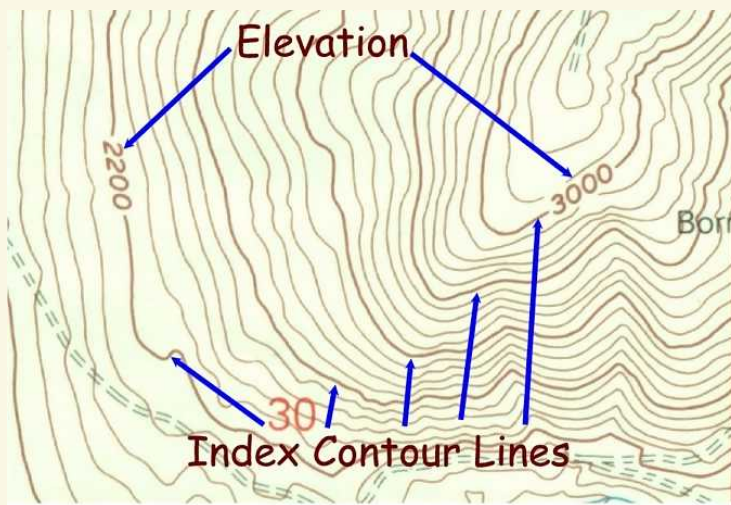


Overview

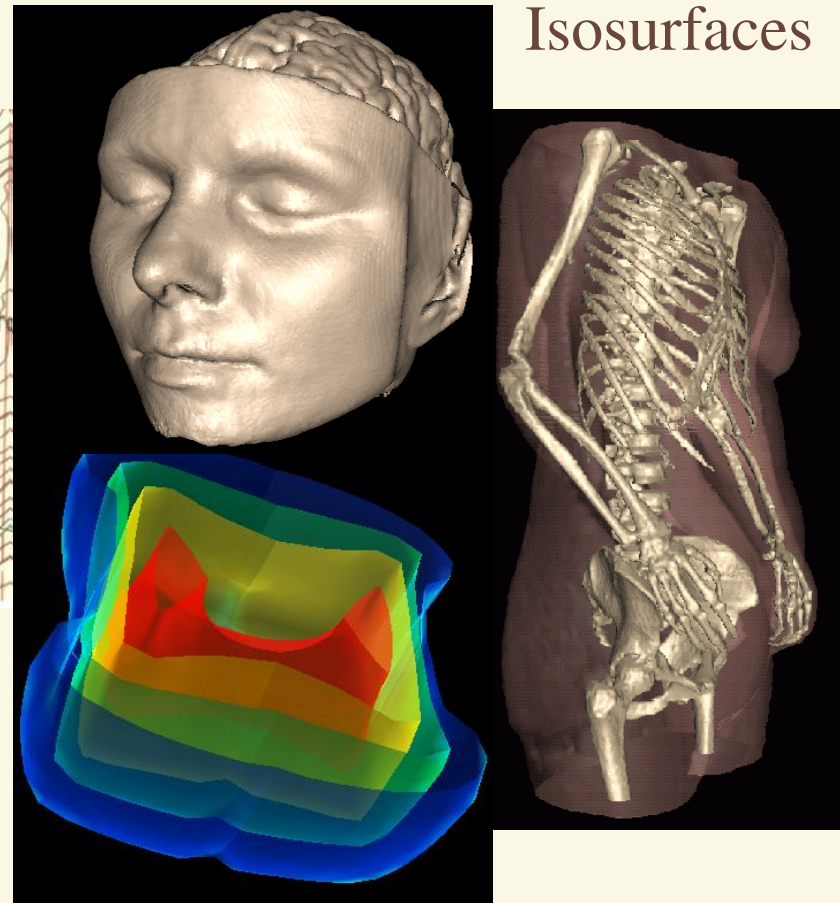
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Isosurfaces - Examples

Isolines

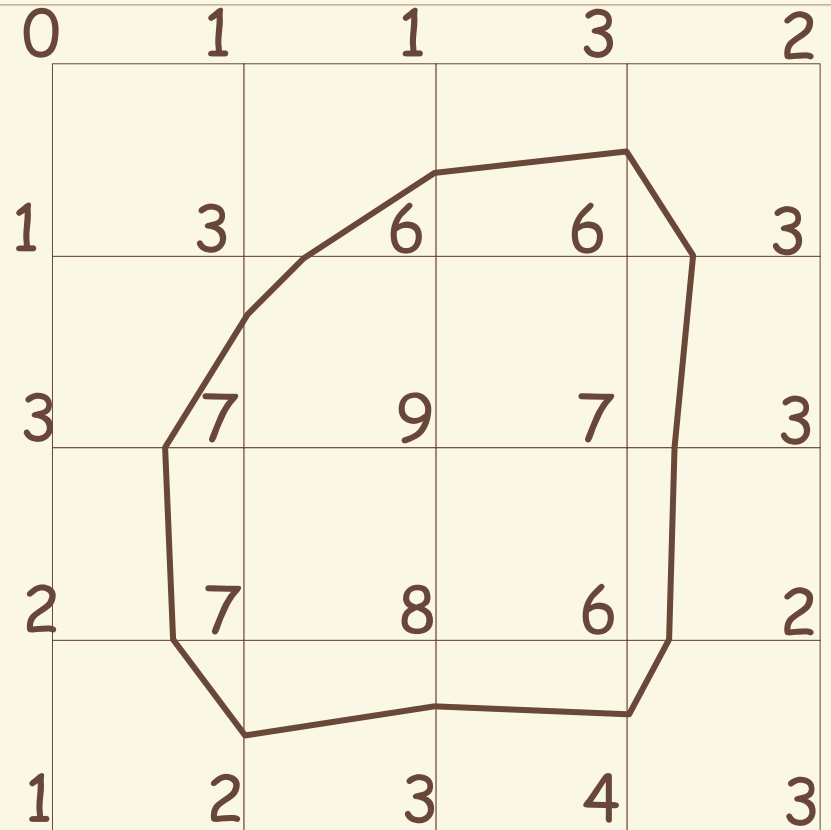


Isosurfaces



Isosurface Extraction

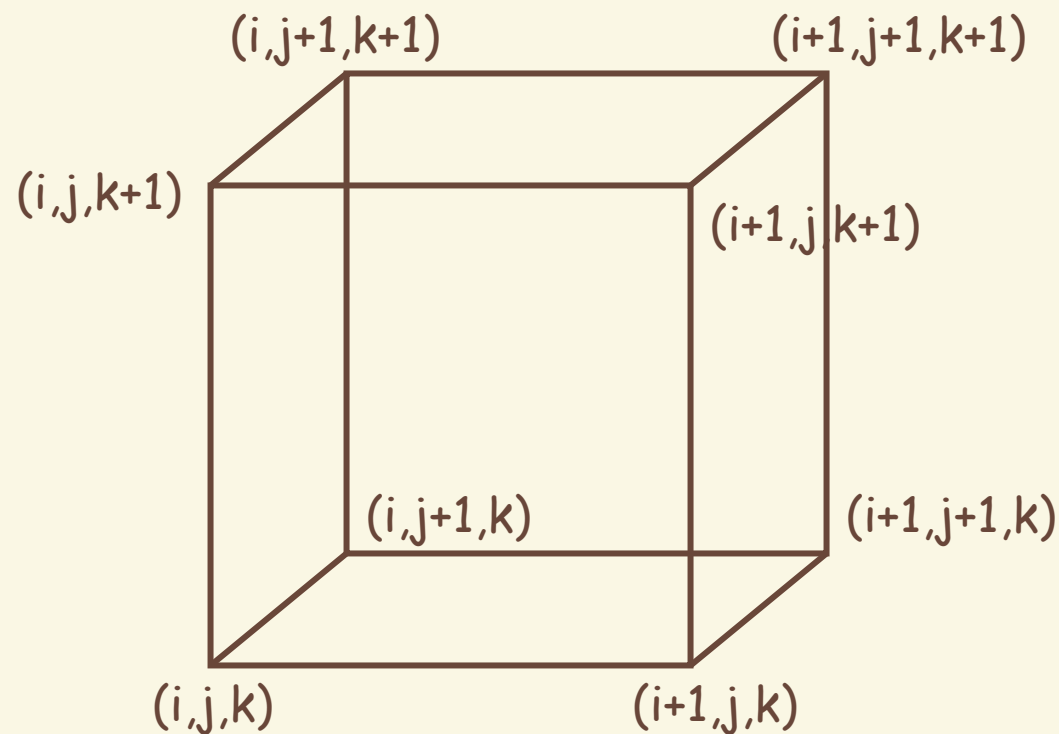
- 4 by contouring
 - closed contours
 - continuous
 - determined by iso-value
- 4 several methods
 - marching cubes is most common



Iso-value = 5

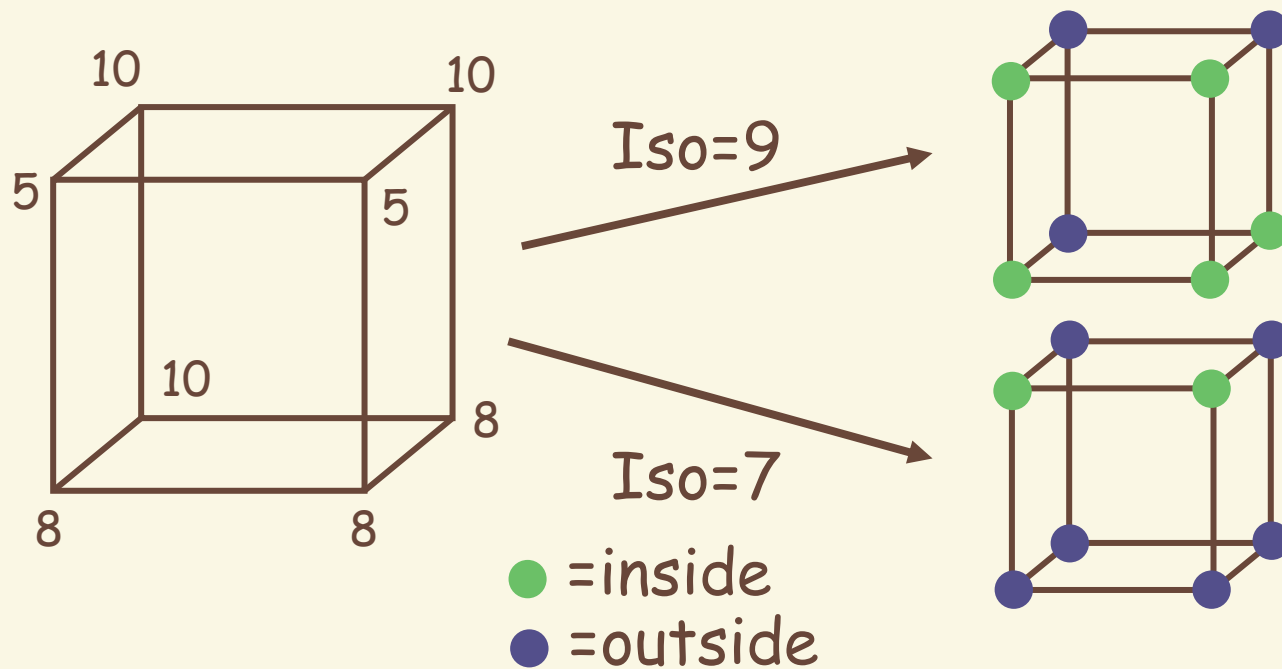
MC 1: Create a Cube

4 Consider a Cube defined by eight data values:



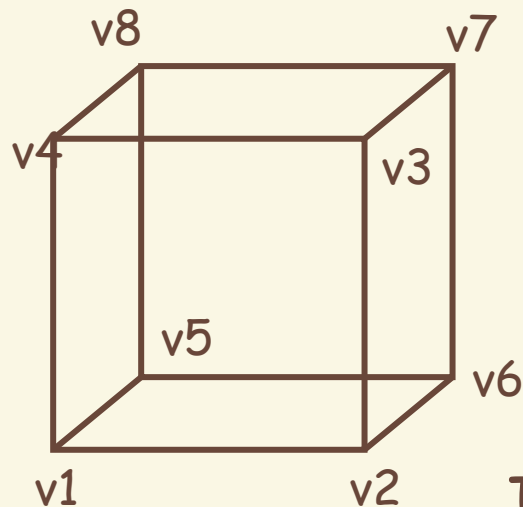
MC 2: Classify Each Voxel

- 4 Classify each voxel according to whether it lies outside the surface (value $>$ iso-surface value) inside the surface (value \leq iso-surface value)

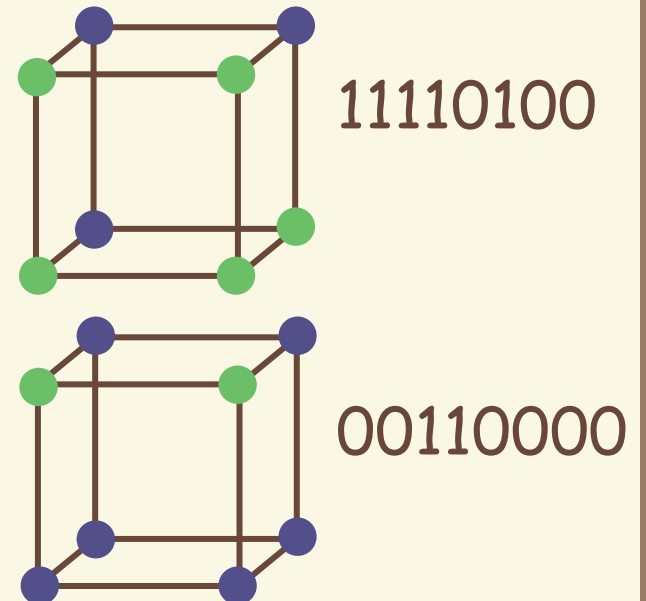


MC 3: Build An Index

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



● inside = 1
● outside = 0

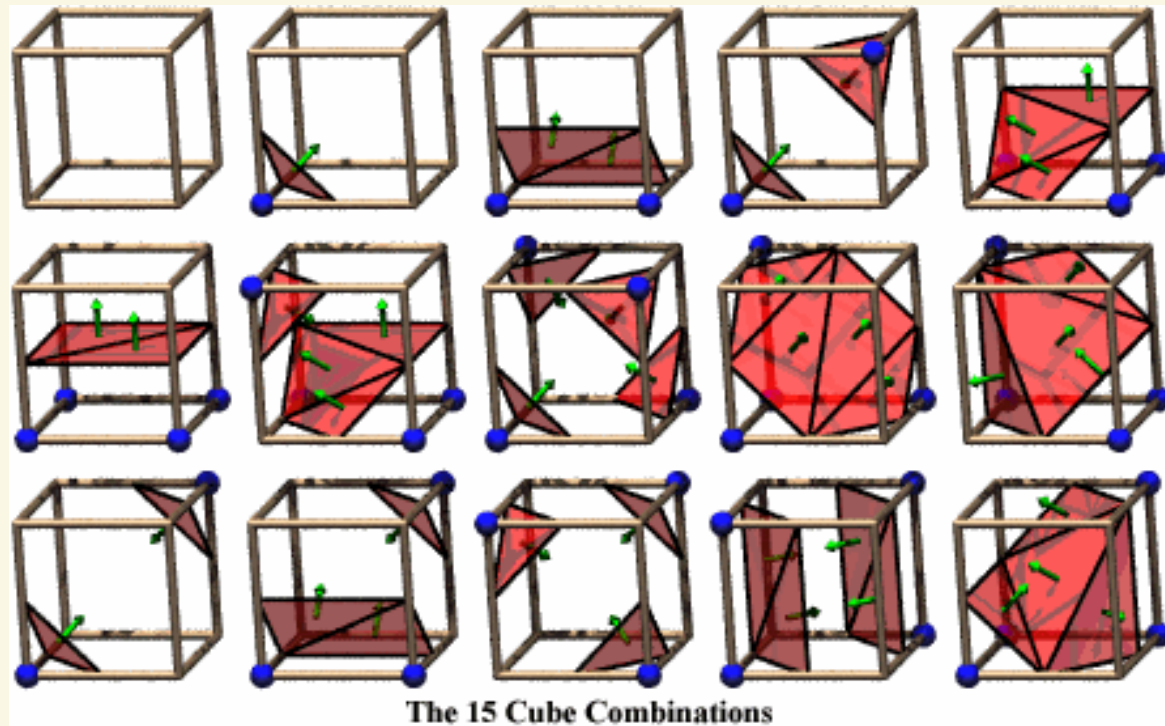


Index:

v1	v2	v3	v4	v5	v6	v7	v8
----	----	----	----	----	----	----	----

MC 4: Lookup Edge List

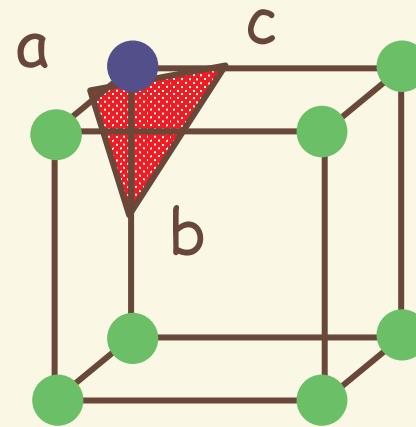
- 4 For a given index, access an array storing a list of edges



- 4 all 256 cases can be derived from 15 base cases

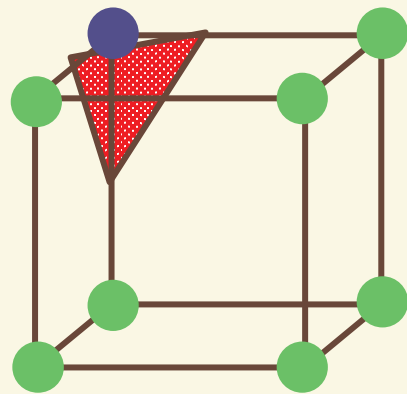
MC 4: Example

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



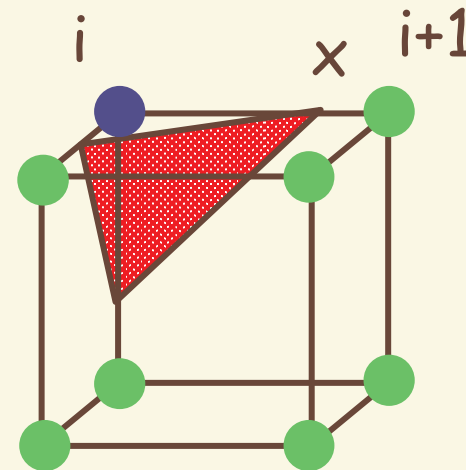
MC 5: Interp. Triangle Vertex

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



$T=5$

● = 10
● = 0



$T=8$

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

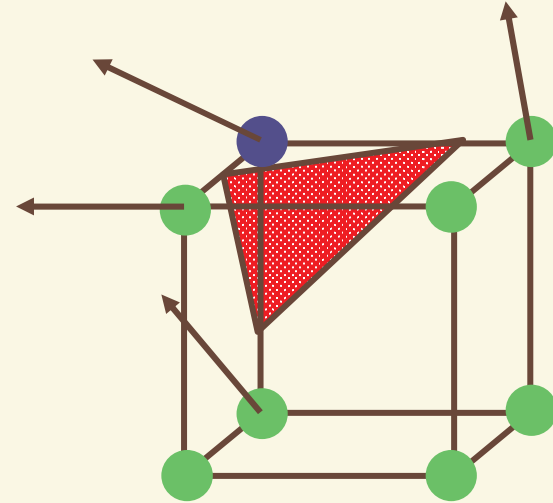
MC 6: Compute Normals

- 4 Calculate the normal at each cube vertex

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

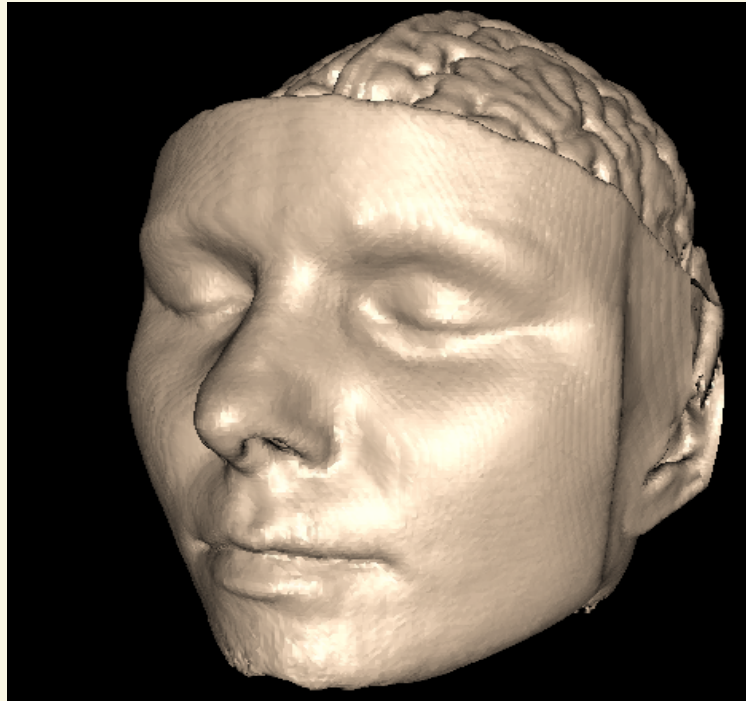
$$G_y = v_{i,j+1,k} - v_{i,j-1,k}$$

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



- 4 Use linear interpolation to compute the polygon vertex normal

MC 7: Render!

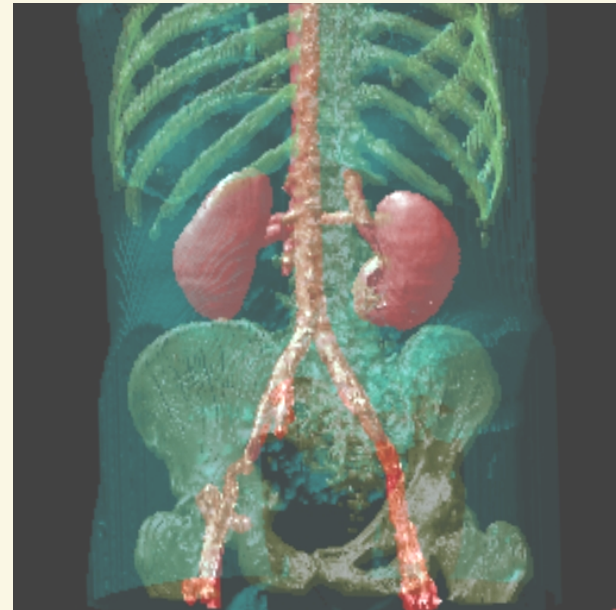
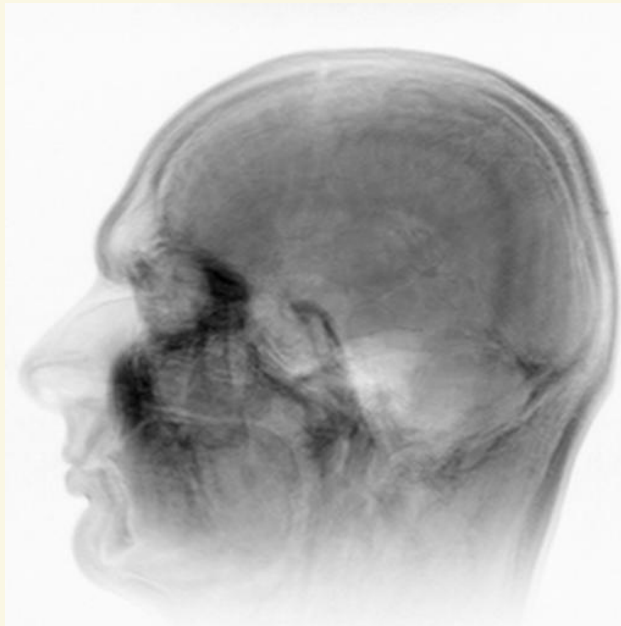




Overview

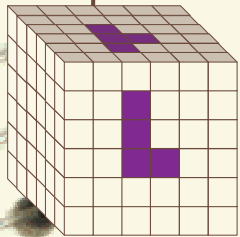
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Direct Volume Rendering Examples



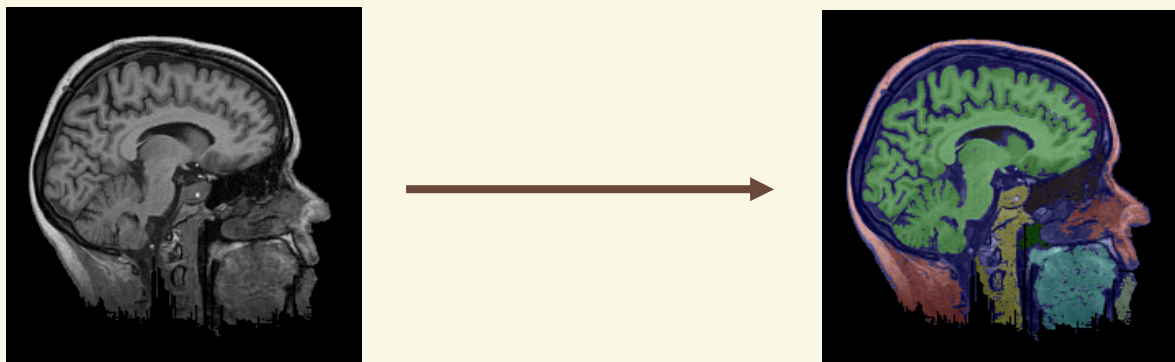
Rendering Pipeline (RP)

Classify

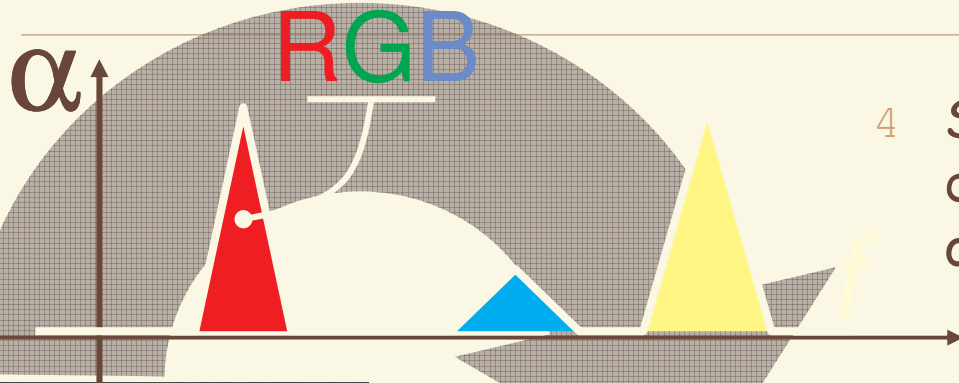


Classification

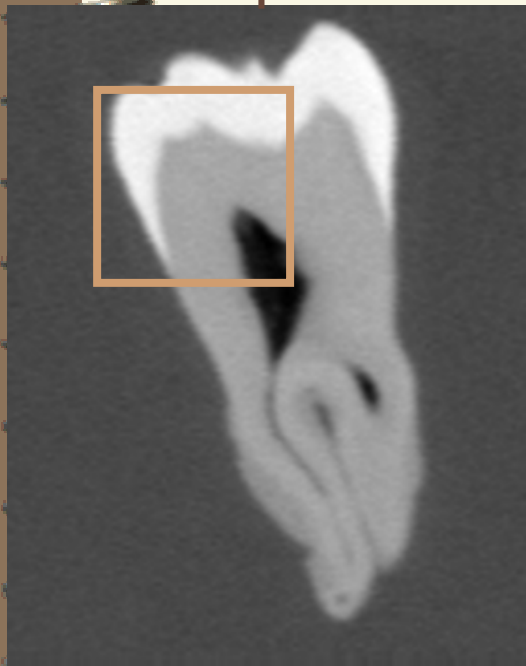
- 4 original data set has application specific values (temperature, velocity, proton density, etc.)
- 4 assign these to color/opacity values to make sense of data
- 4 achieved through transfer functions



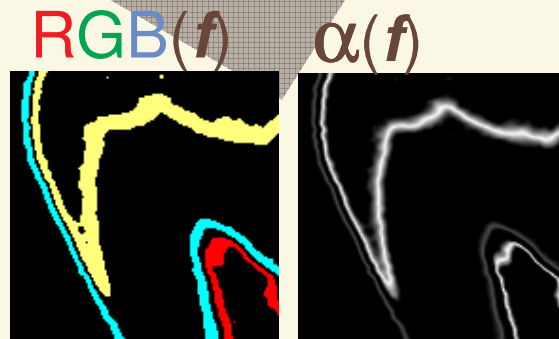
Transfer Functions (TF's)



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



Human Tooth CT

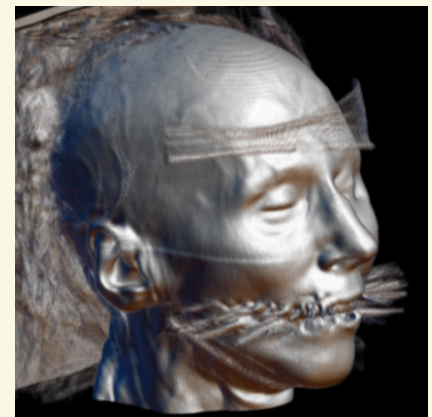
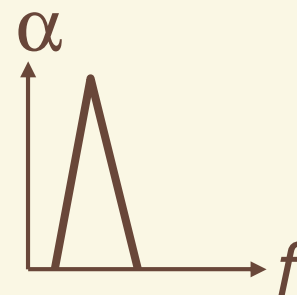
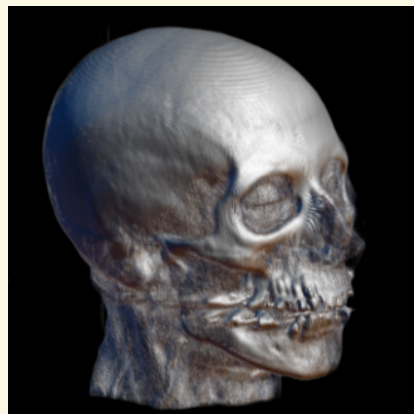
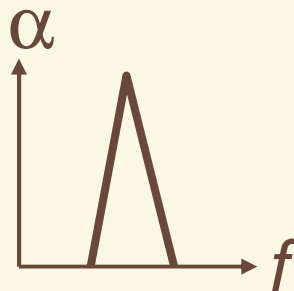
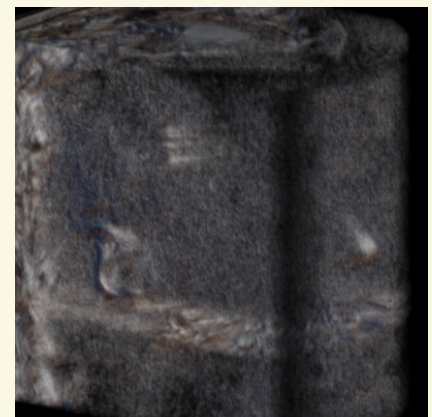
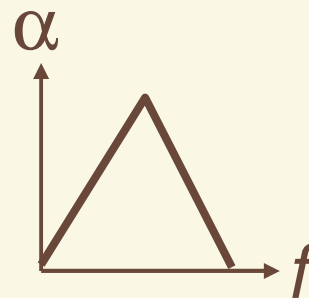
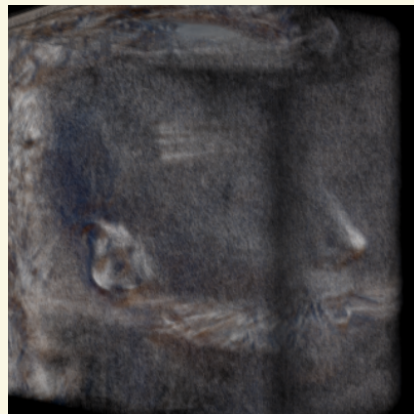
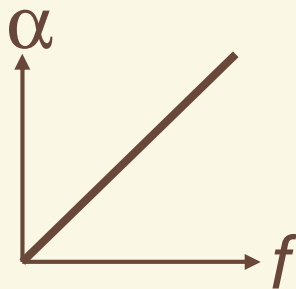


Shading,
Compositing...



TF's

4 Setting transfer functions is difficult, unintuitive, and slow



Gordon Kindlmann

Transfer Function Challenges

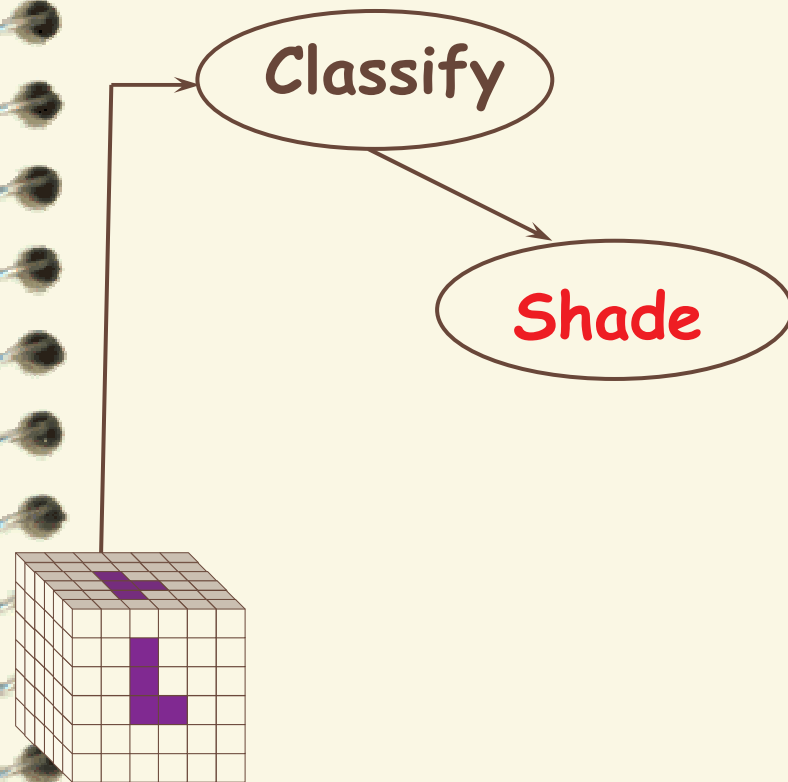
4 Better interfaces:

- Make space of TFs less confusing
- Remove excess "flexibility"
- Provide guidance

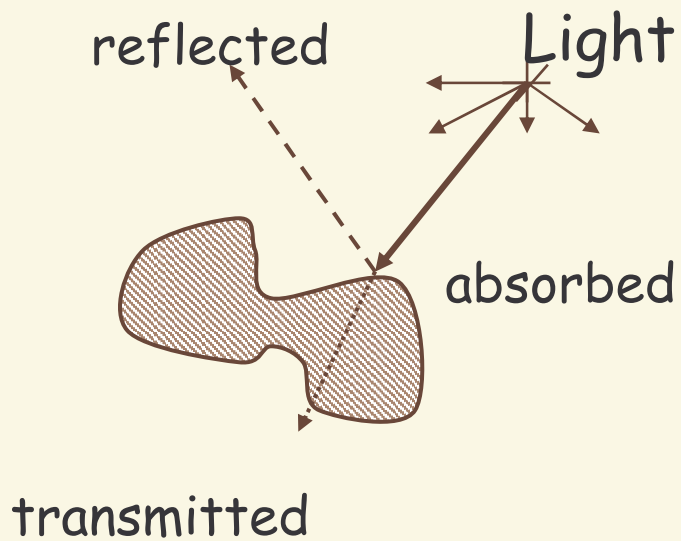
4 Automatic / semi-automatic transfer function generation

- Typically highlight boundaries

Rendering Pipeline (RP)

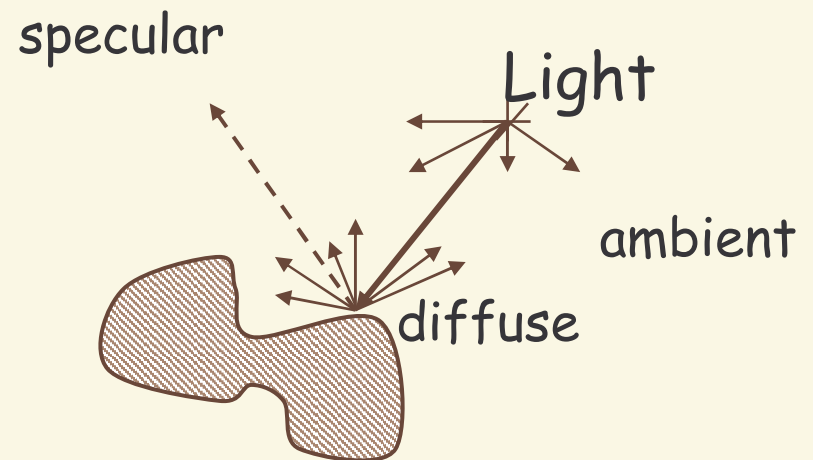


Light Effects



$$\text{Light} = \text{refl.} + \text{absorbed} + \text{trans.}$$

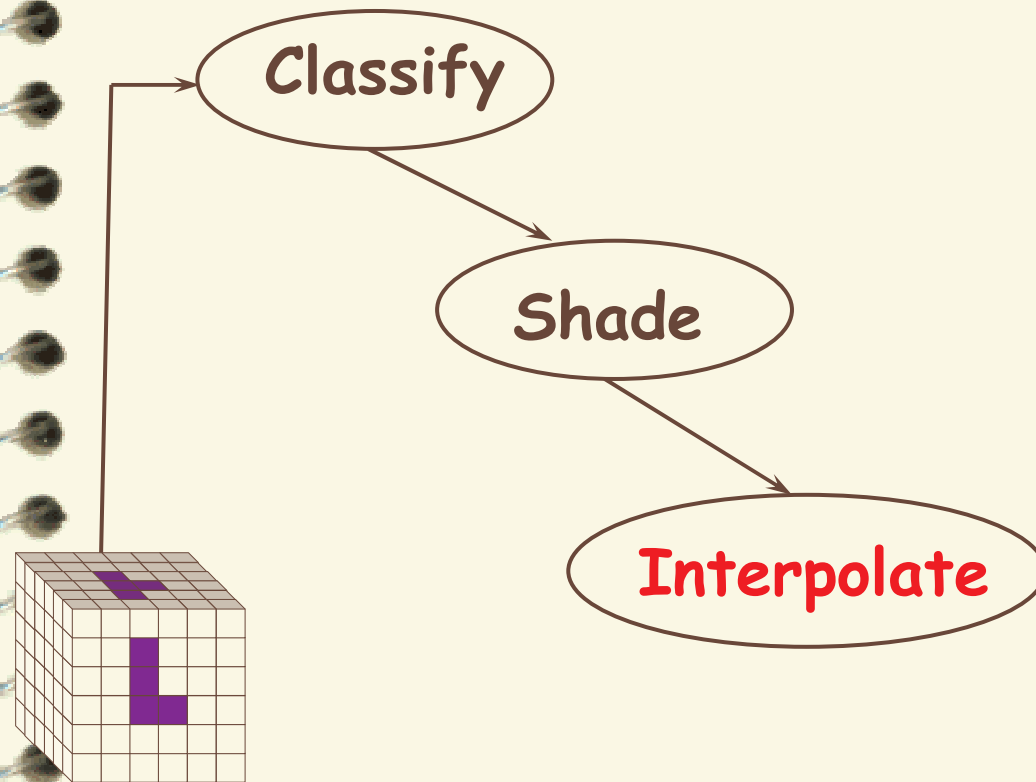
4 Usually only considering reflected part



$$\text{Light} = \text{ambient} + \text{diffuse} + \text{specular}$$

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

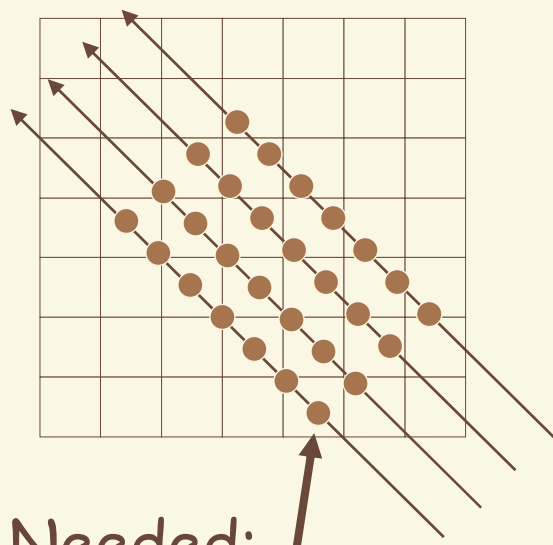
Rendering Pipeline (RP)



Interpolation

2D

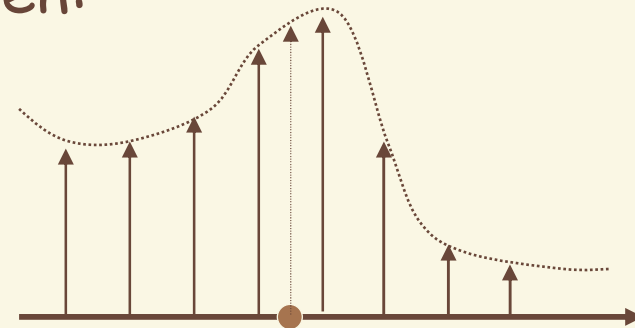
4 Given:



4 Needed:

1D

4 Given:

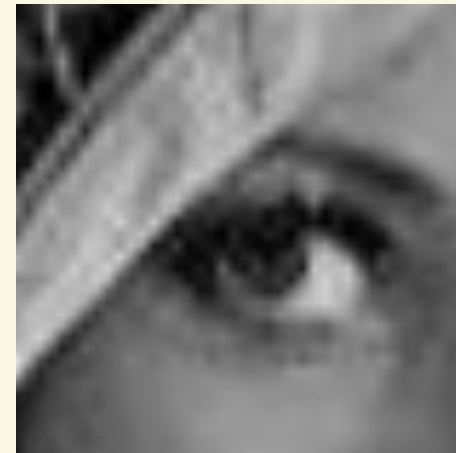


4 Needed:

Interpolation

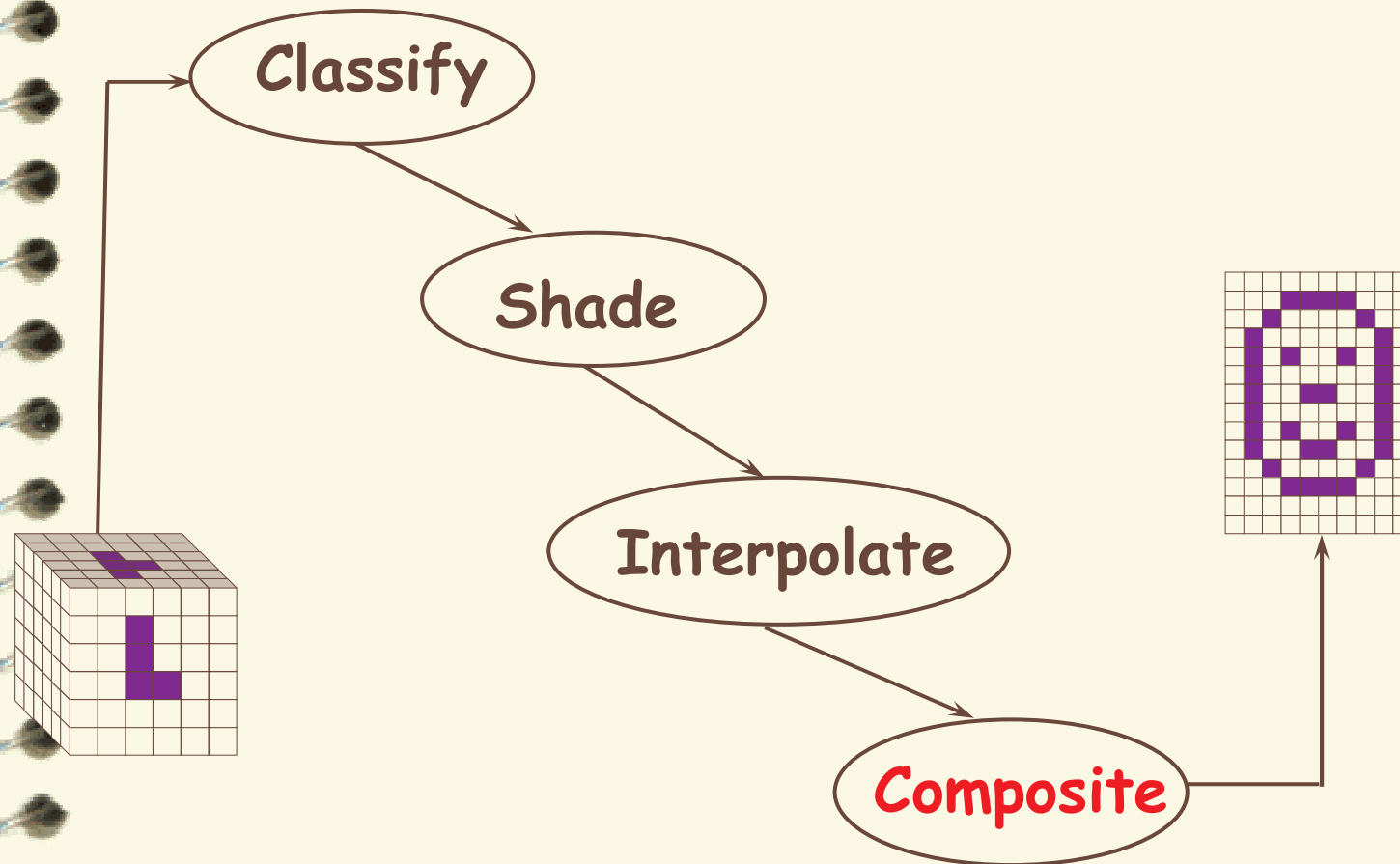
- 4 Very important; regardless of algorithm
- 4 Expensive => done very often for one image
- 4 Requirements for good reconstruction
 - performance
 - stability of the numerical algorithm
 - accuracy

Nearest
neighbor

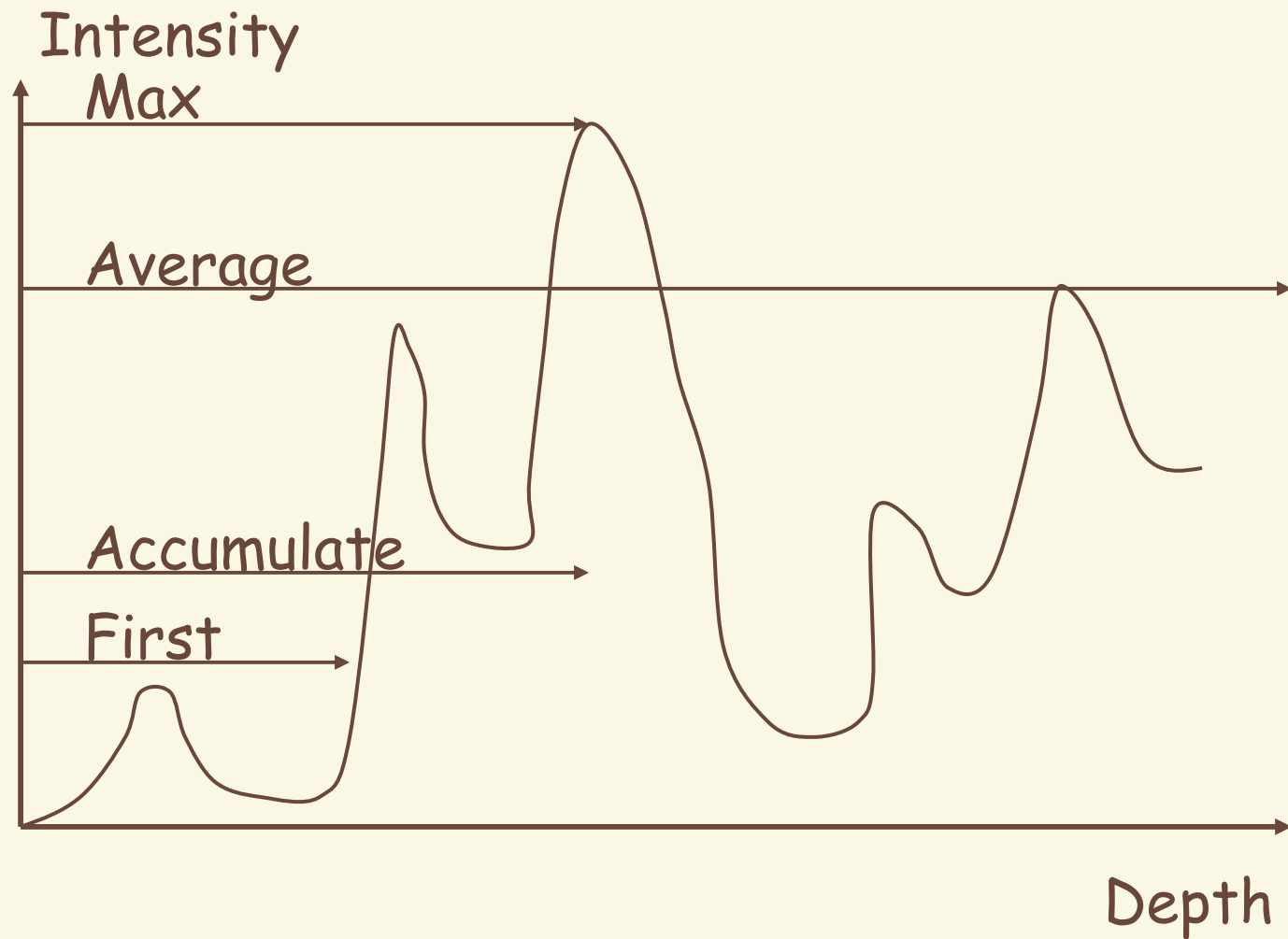


Linear

Rendering Pipeline (RP)

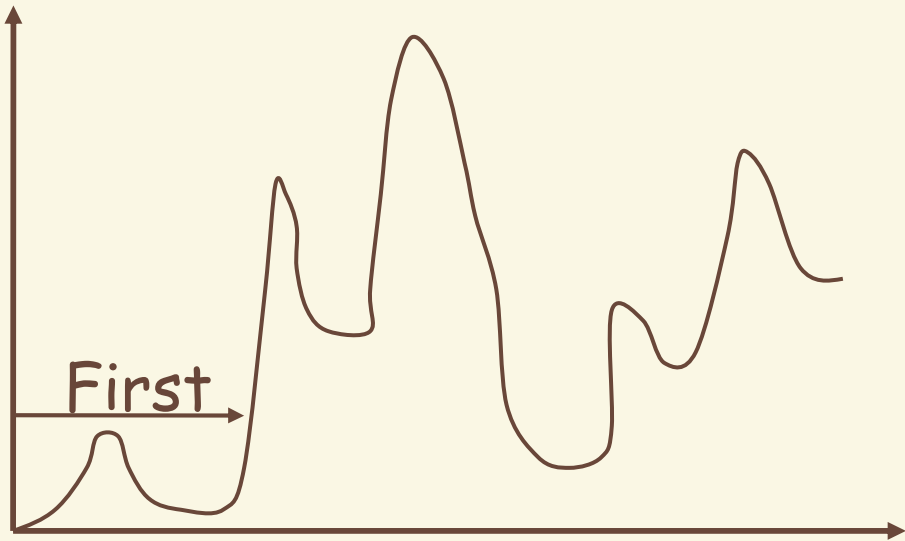


Ray Traversal Schemes



Ray Traversal - First

Intensity

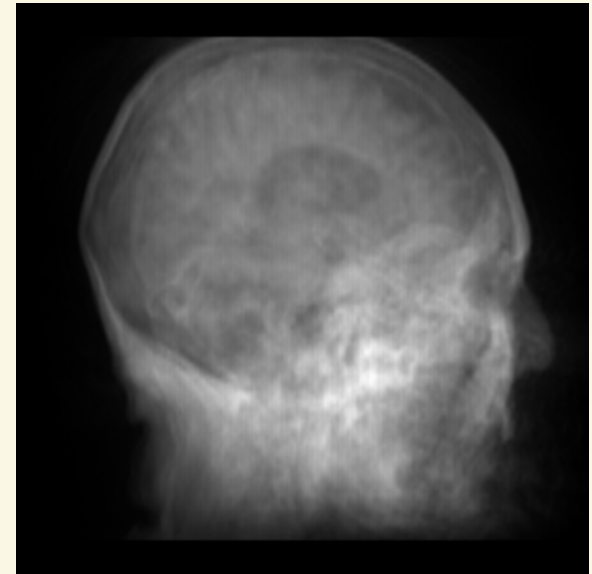
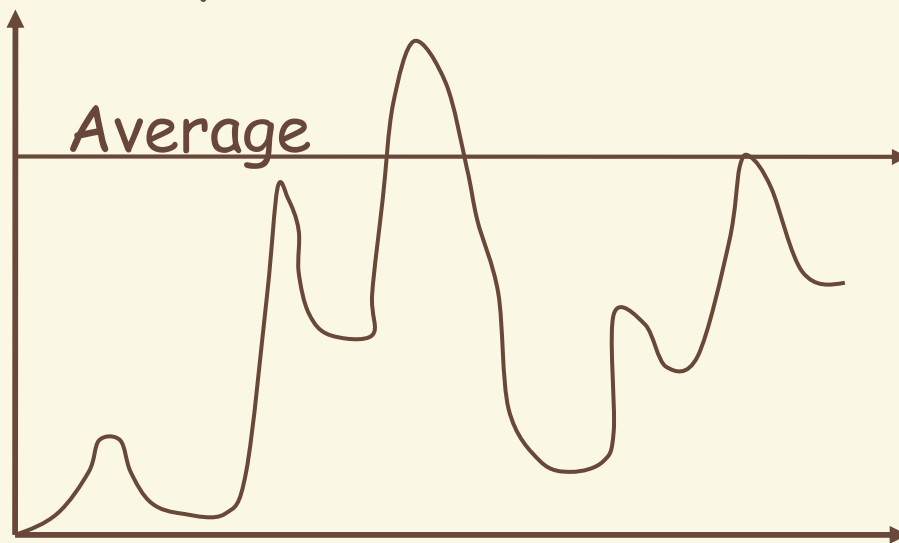


Depth

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

Ray Traversal - Average

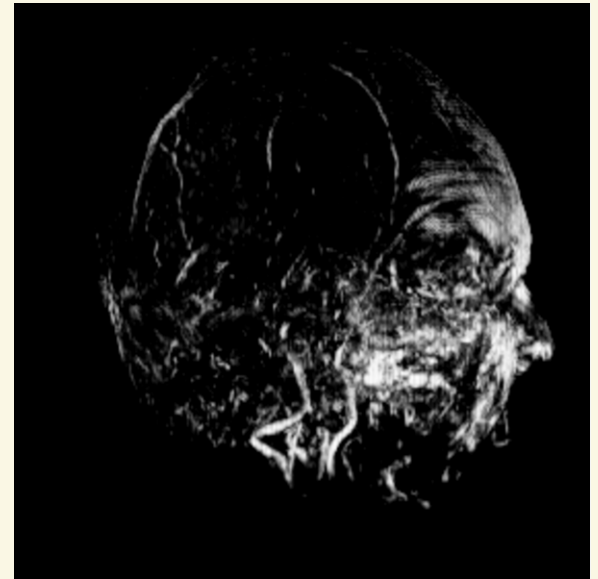
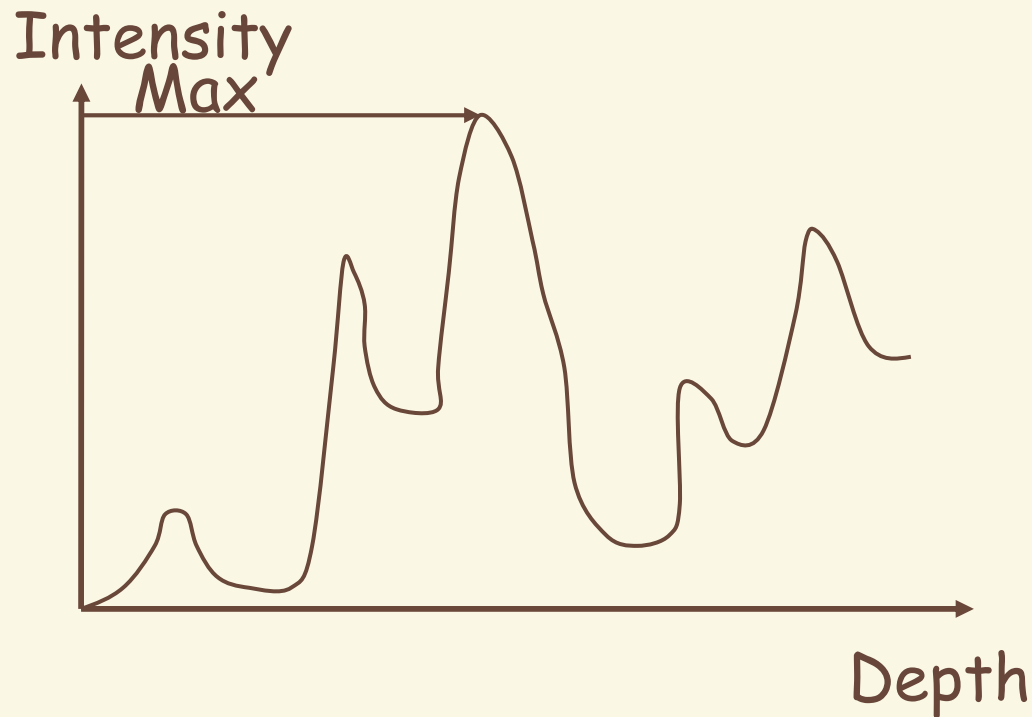
Intensity



Depth

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

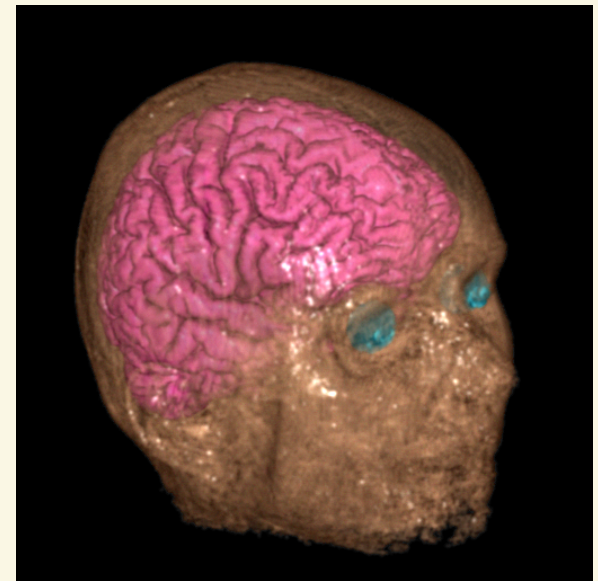
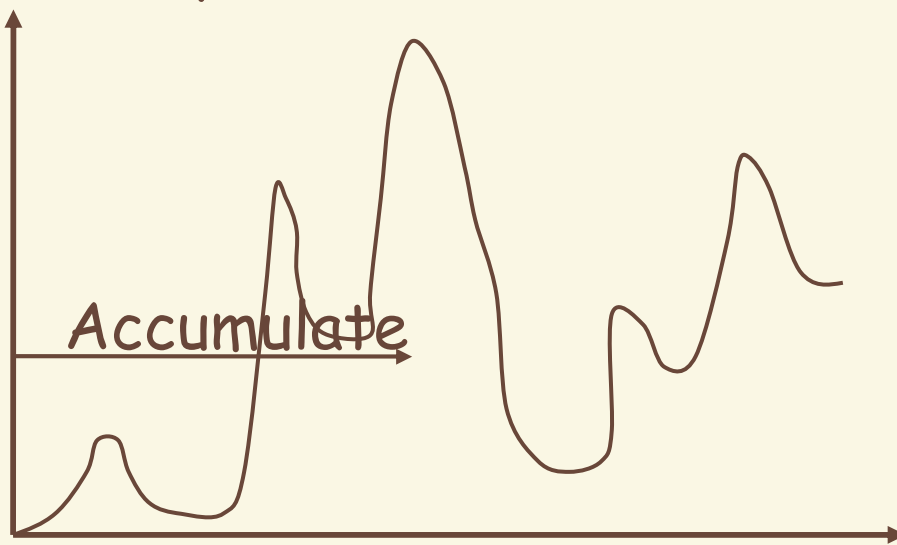
Ray Traversal - MIP



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

Ray Traversal - Accumulate

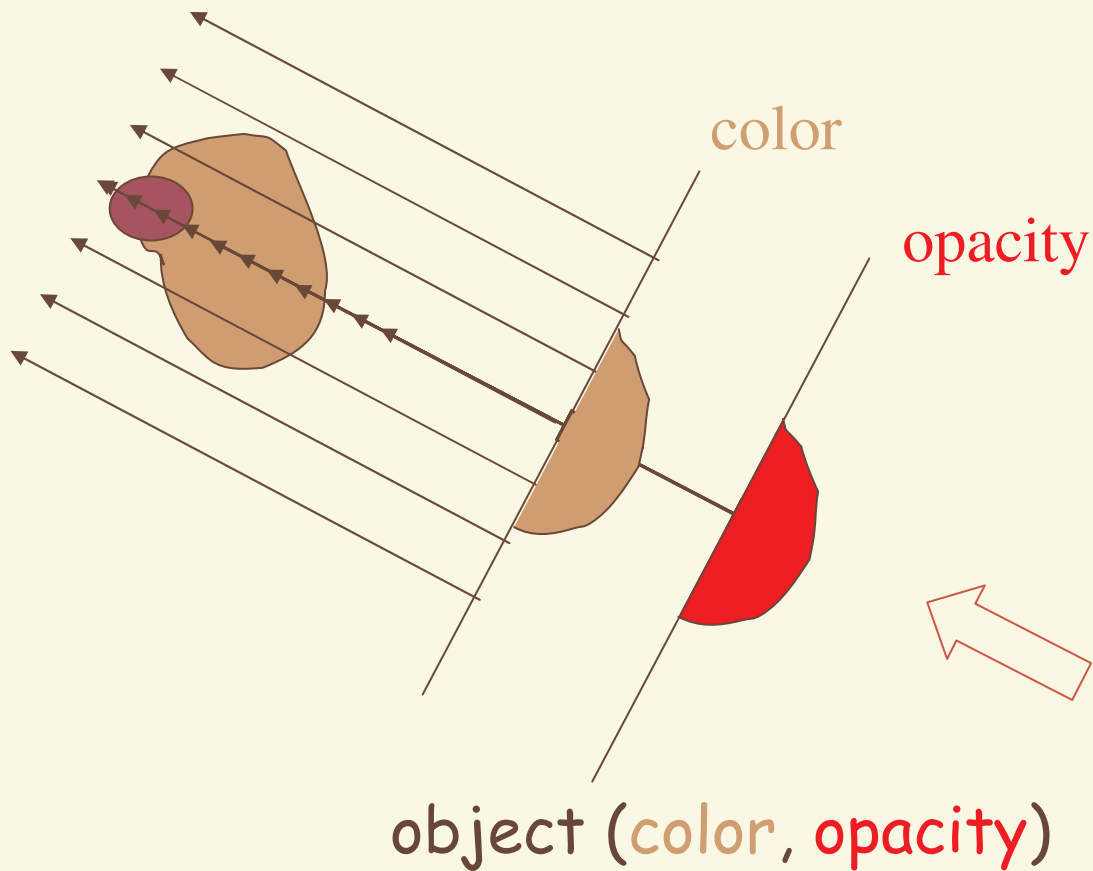
Intensity



Depth

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

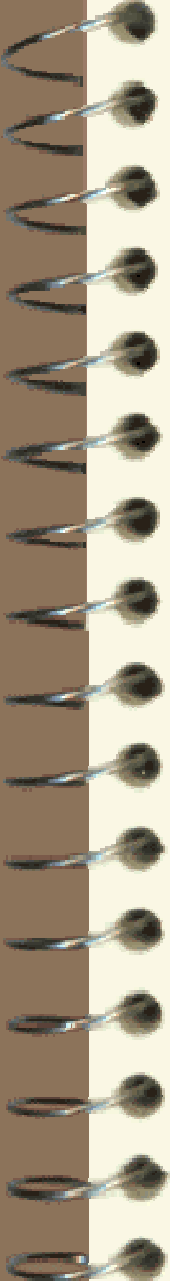
Volumetric Ray Integration





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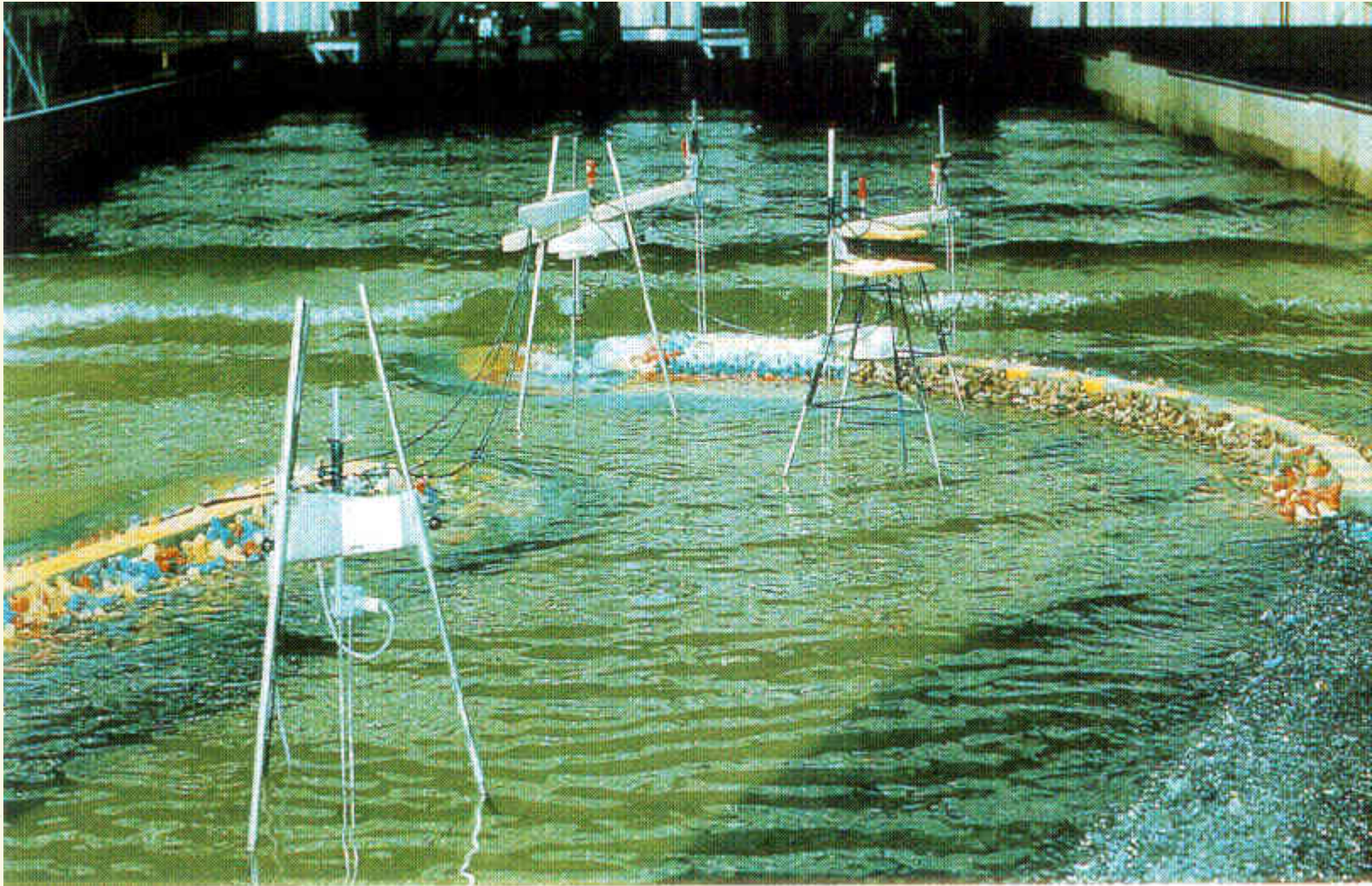


Flow Visualization

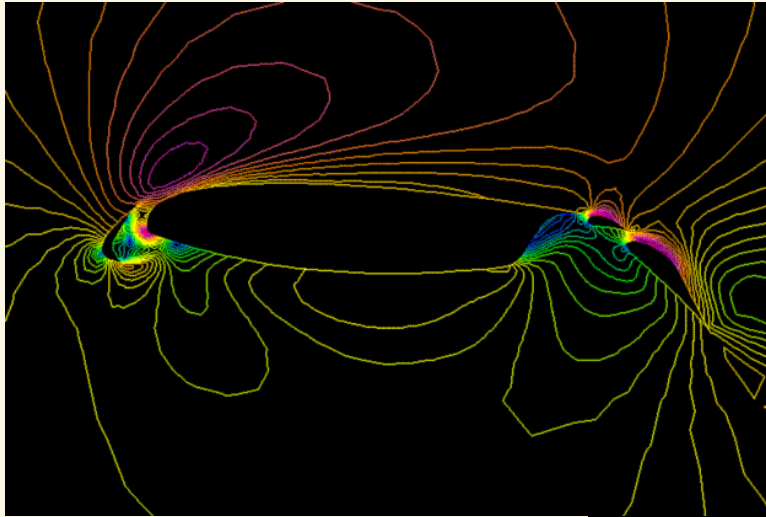
- 4 Traditionally - Experimental Flow Vis
- 4 Now - Computational Simulation

- 4 Typical Applications:
 - Study physics of fluid flow
 - Design aerodynamic objects

Traditional Flow Experiments

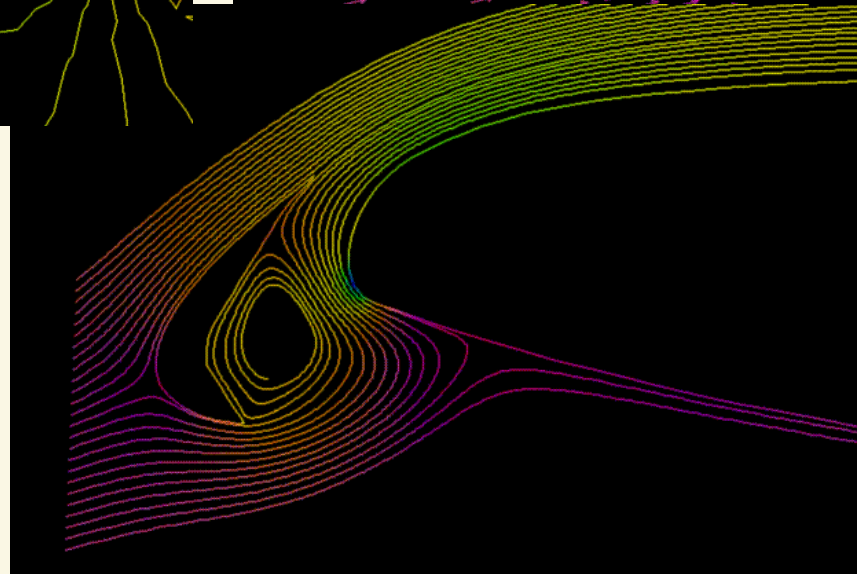
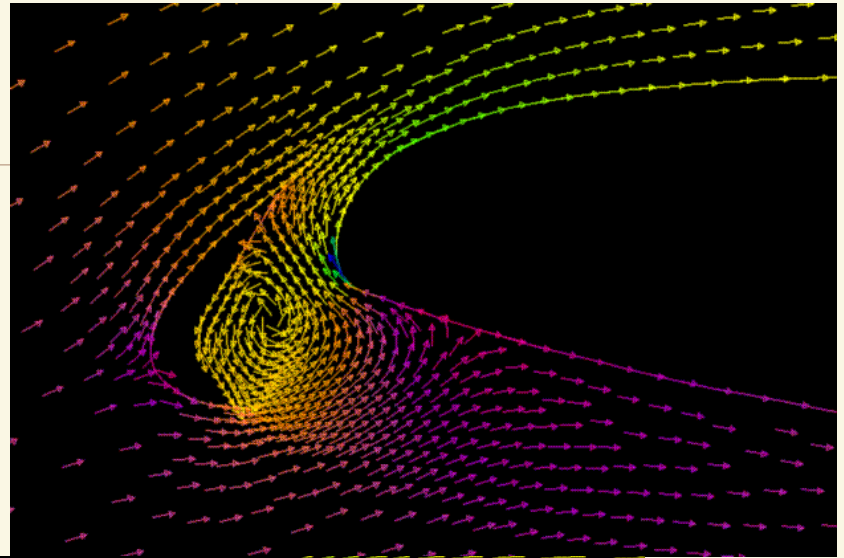


Techniques



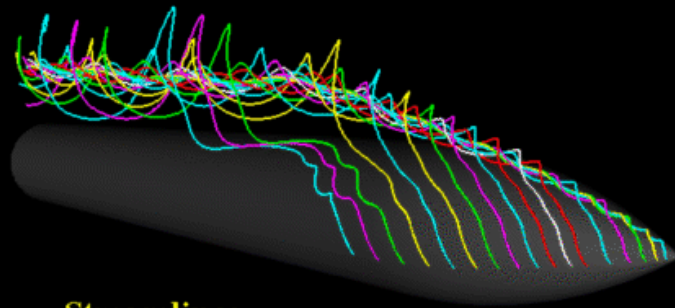
Contours

Glyphs (arrows)

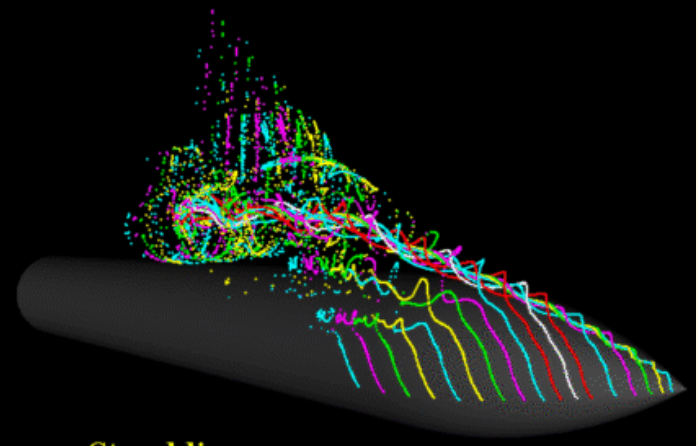


Streamlines

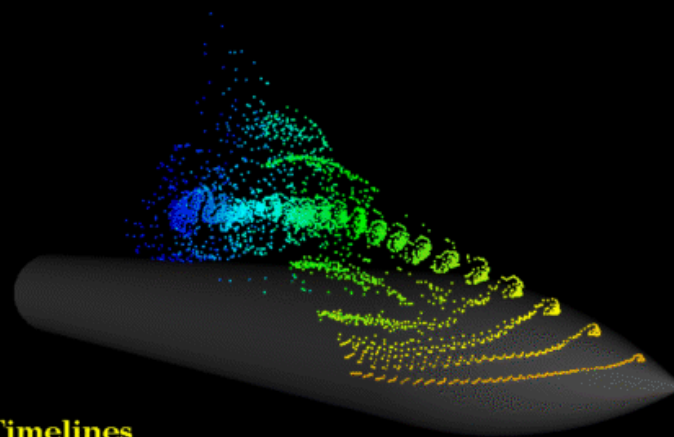
Techniques



Streamlines



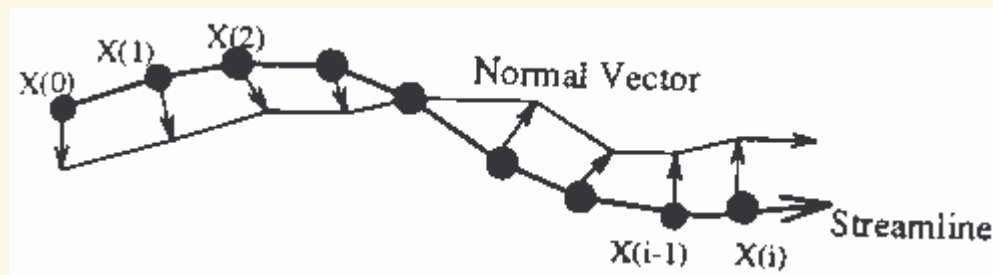
Streaklines



Timelines

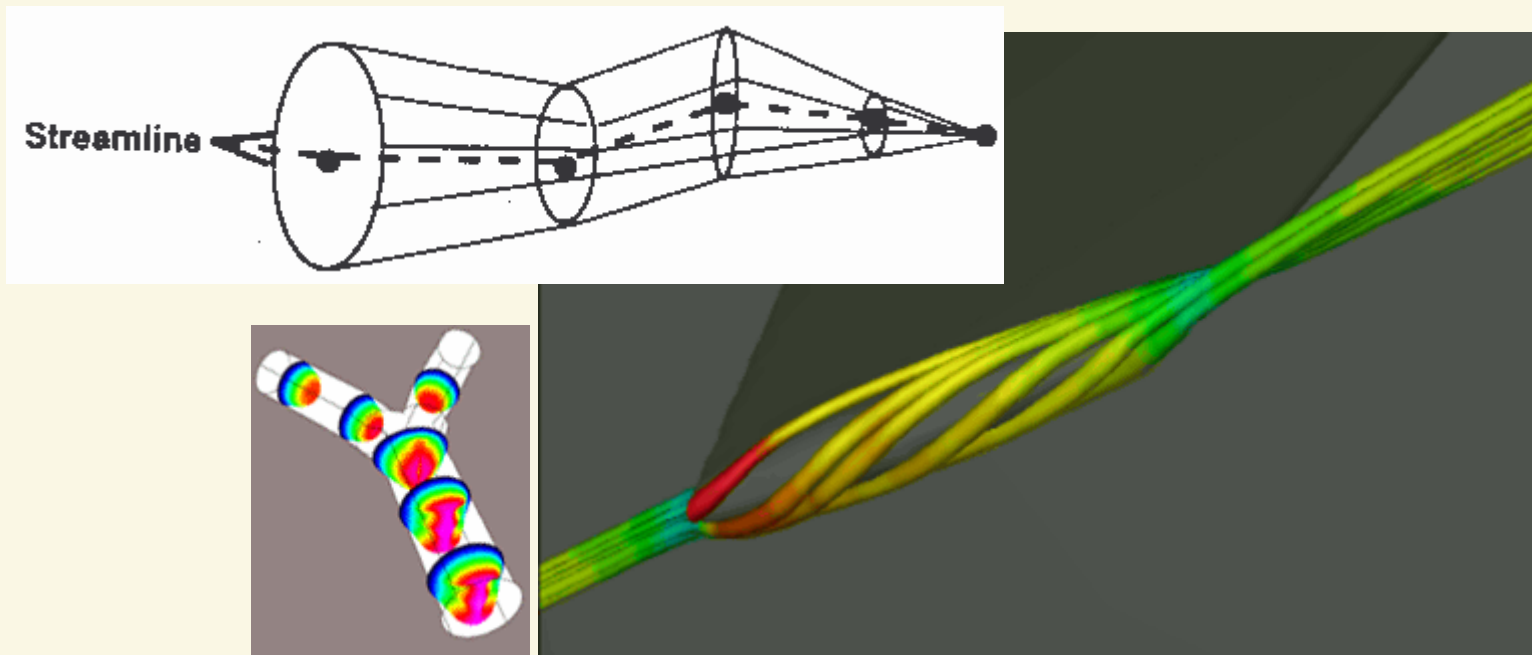
Techniques - Stream-ribbon

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



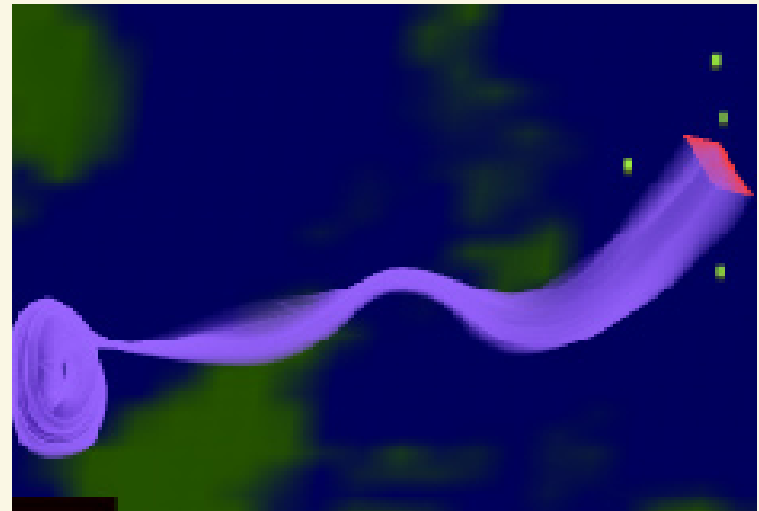
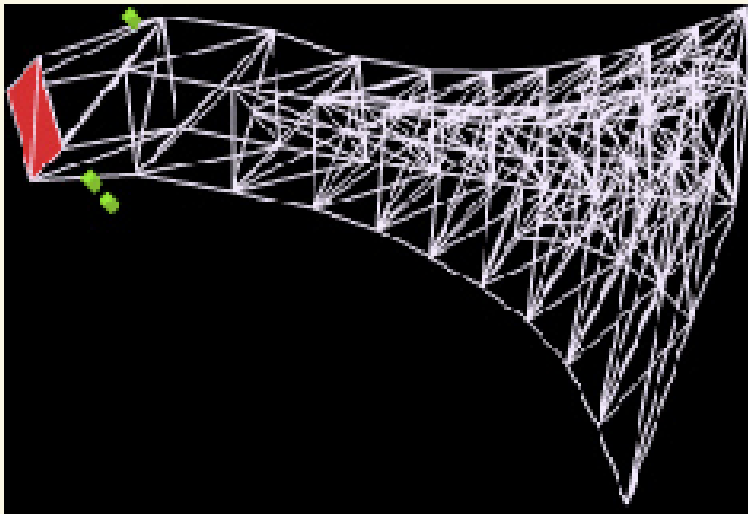
Techniques - Stream-tube

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



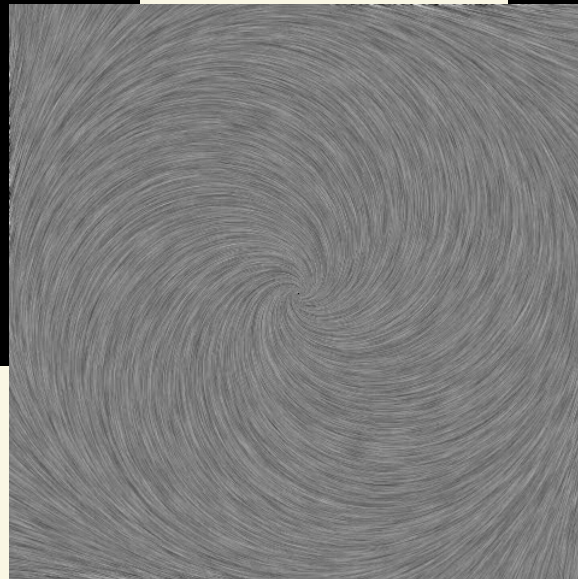
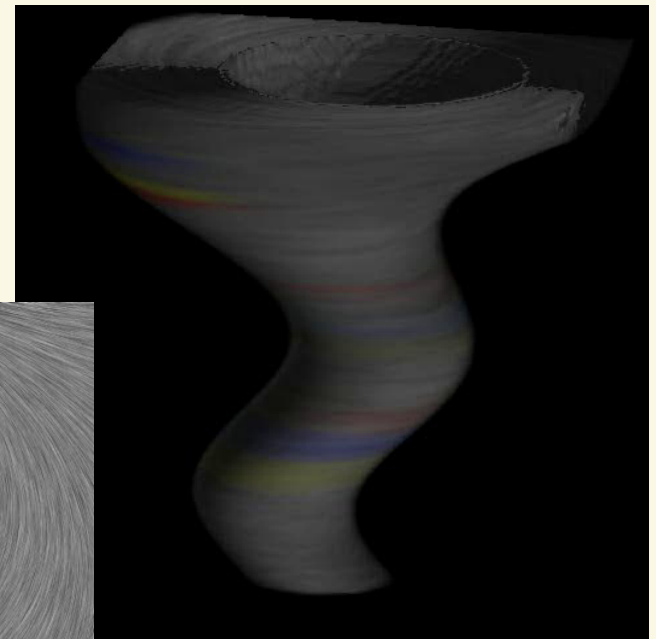
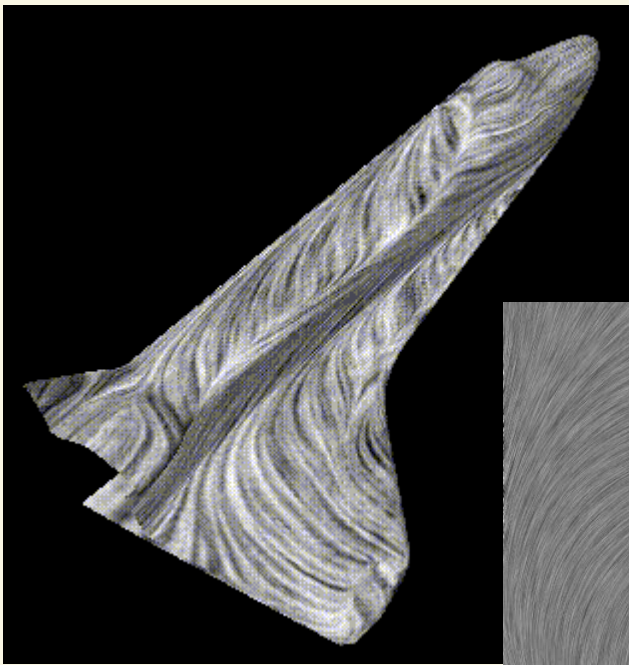
Mappings - Flow Volumes

- 4 Instead of tracing a line - trace a small polyhedron



LIC (Line Integral Convolution)

4 Integrate noise texture along a streamline



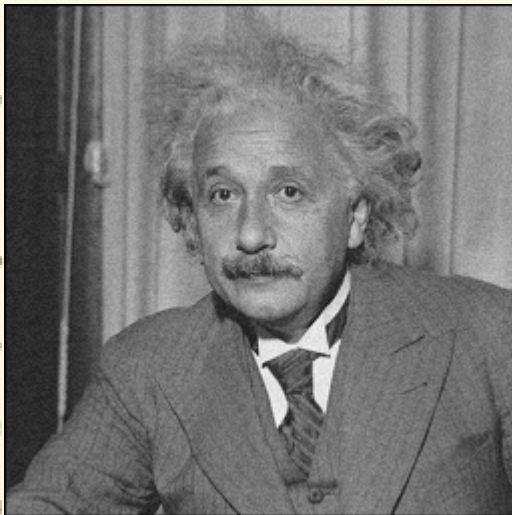


Overview

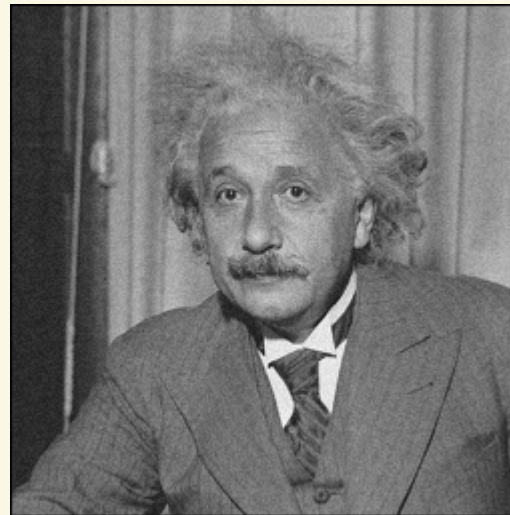
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- 4 Direct Volume Rendering
- 4 Vector Visualization
- 4 **Challenges**

Challenges - Accuracy

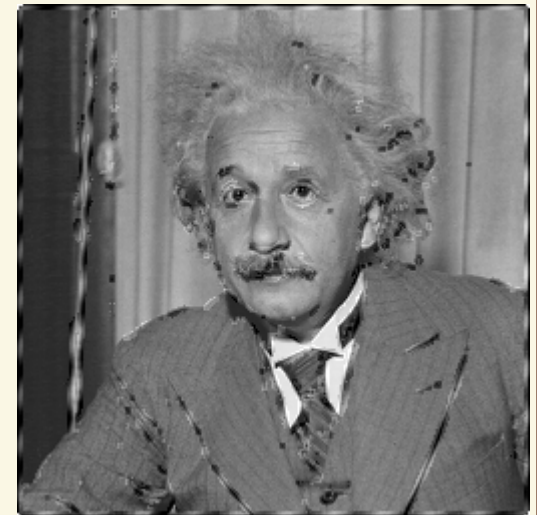
4 Need metrics -> perceptual metric



(a) Original



(b) Bias-Added



(c) Edge-Distorted

Challenges - Accuracy

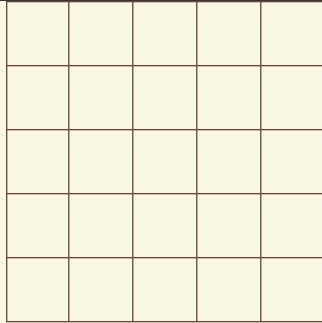
4 Deal with unreliable data (noise, Ultrasound)



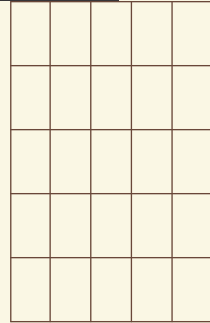
Challenges - Accuracy

4 Irregular data sets

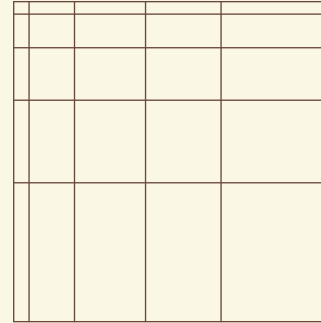
Structured Grids:



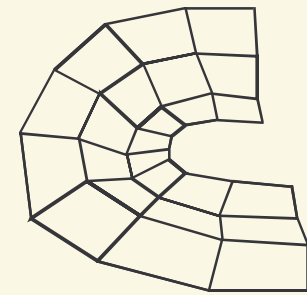
regular



uniform

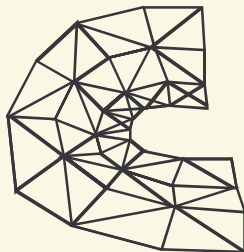


rectilinear

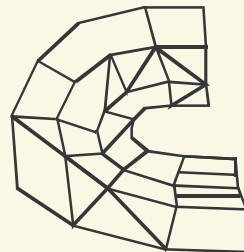


curvilinear

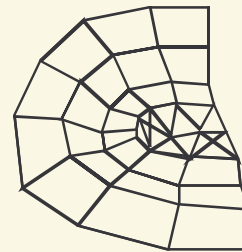
Unstructured Grids:



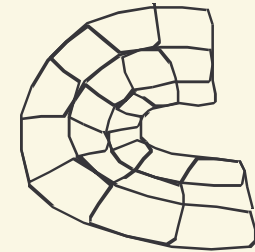
regular



irregular



hybrid



curved

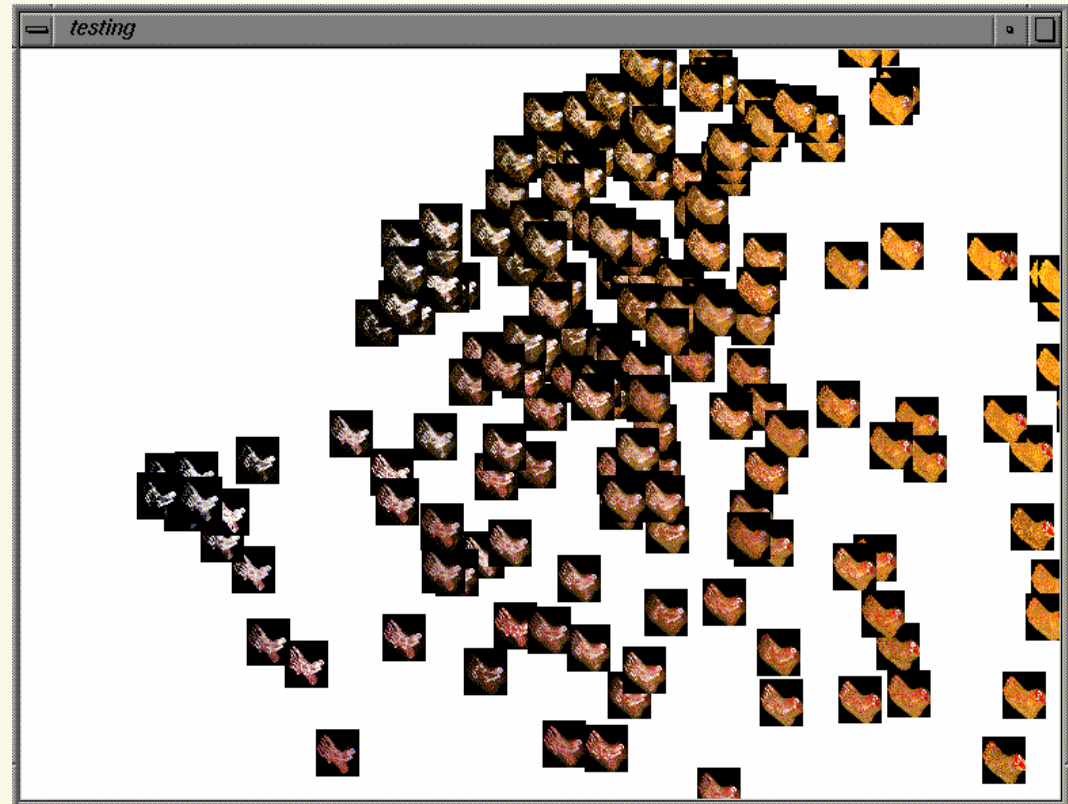
Challenges - Speed/Size

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



Challenges - HCI

- 4 Need better interfaces
- 4 Which method is best?



Challenges - HCI

- 4 “Augmented” reality
- 4 Explore novel I/O devices

