Scientific Visualization

Visualizing Spatial Data: Volumes and Flow

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What is Scientific Visualization?

- Visualization of 'scientific data'
- Datasets from simulation and physical measurements (quantitative)
- Inherent spatial reference
- Limited in how to use position channel in visual design

Visualization – Major Areas

- Four major areas

Inherent spatial reference

  - Volume Visualization
  - Flow Visualization

Scientific Visualization

2D/3D

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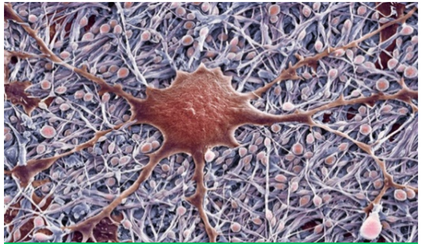
nD

  - Information Visualization
  - Visual Analytics

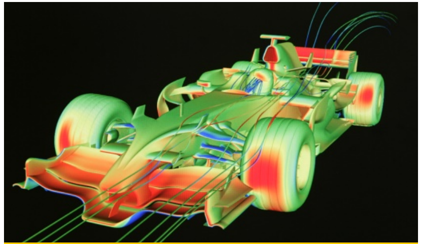
Usually no spatial reference

Applications

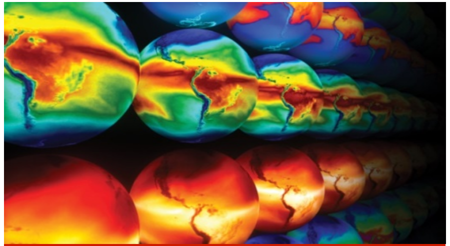
MEDICINE
Digital Health Records



BIOLOGY
Connectomics

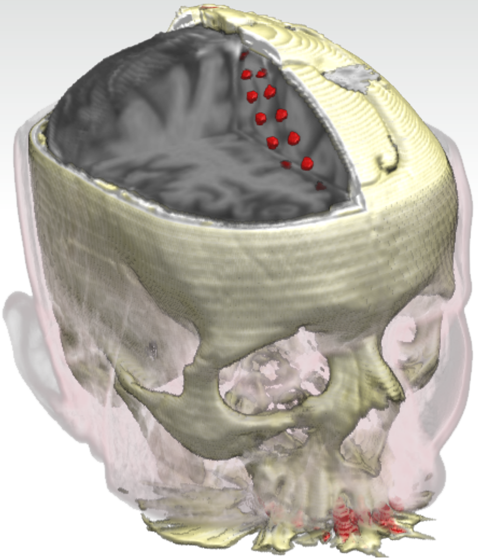


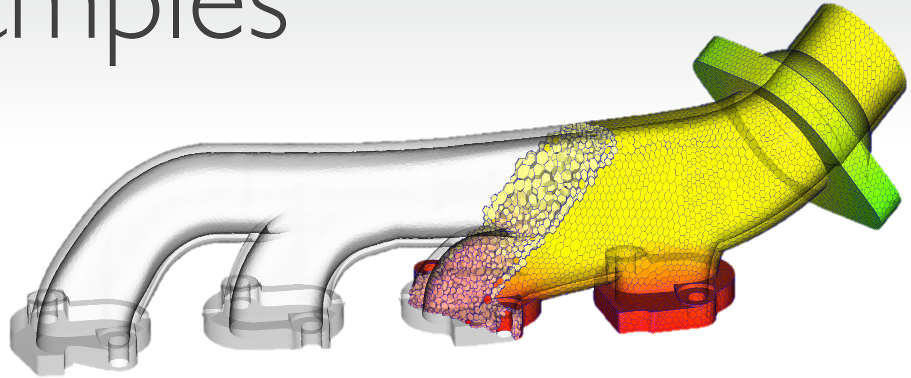
ENGINEERING
Large CFD Simulations

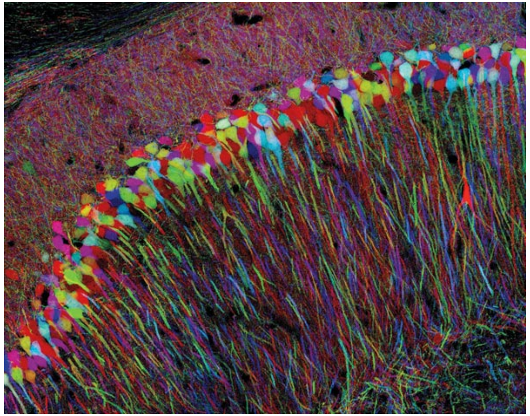


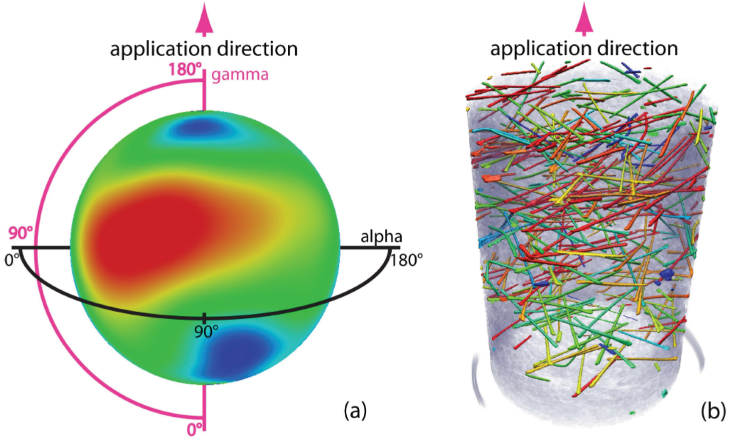
EARTH SCIENCES
Global Climate Models

Examples








application direction
180°
gamma
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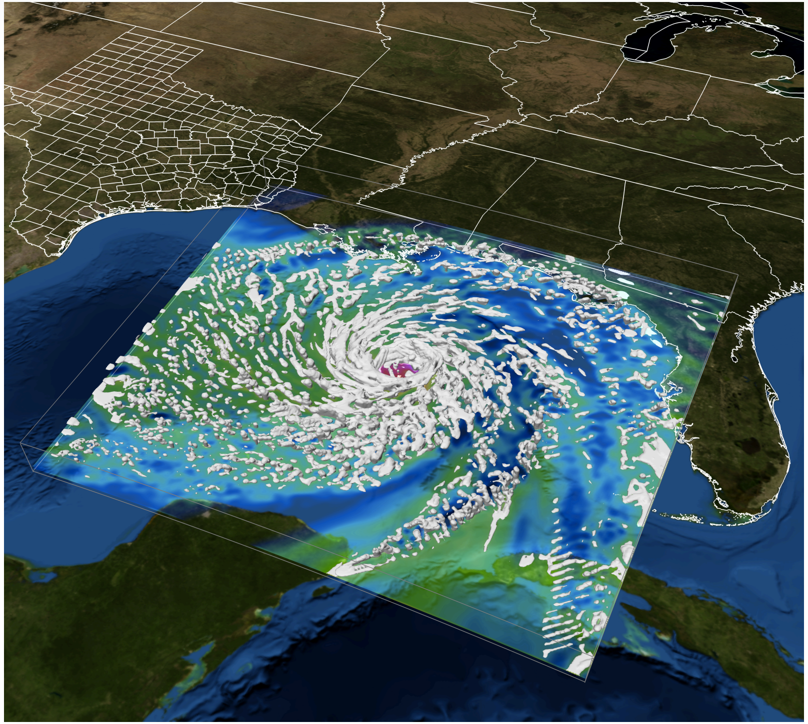
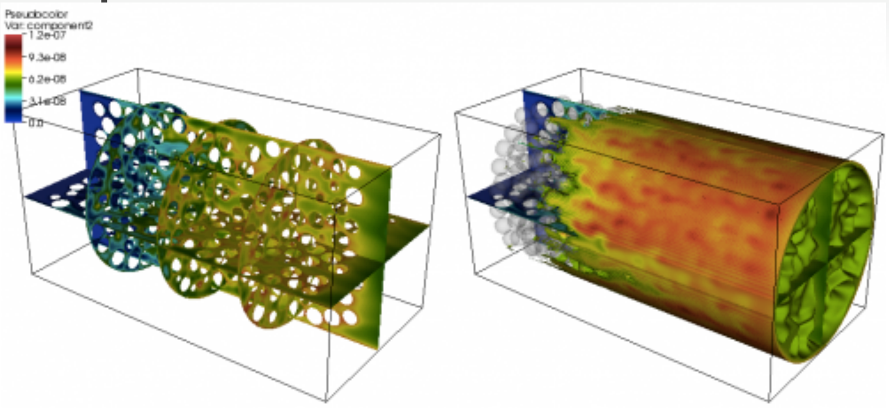
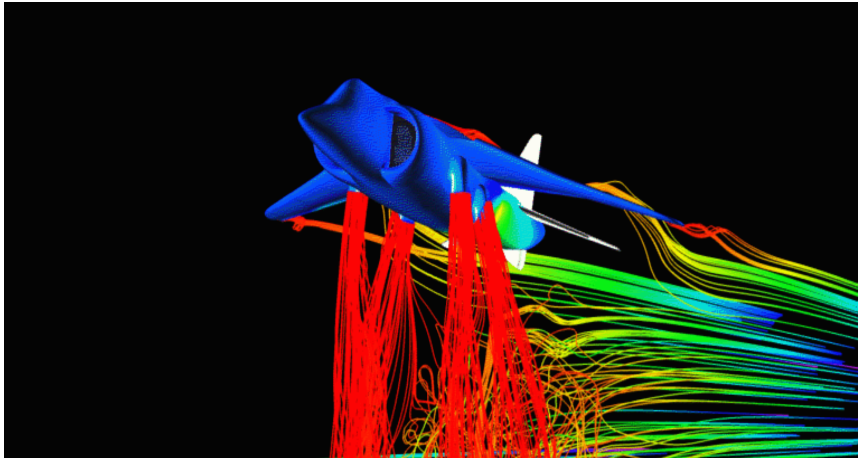
0°
alpha
180°
90°
0°
(a)
application direction
(b)

Examples

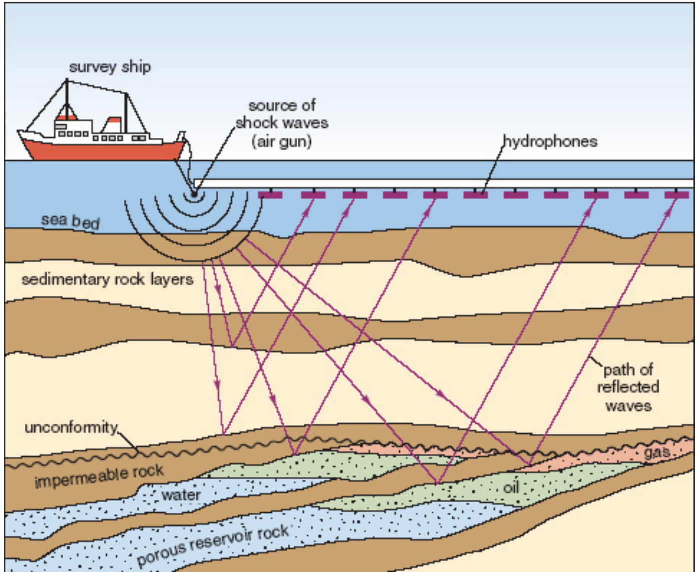


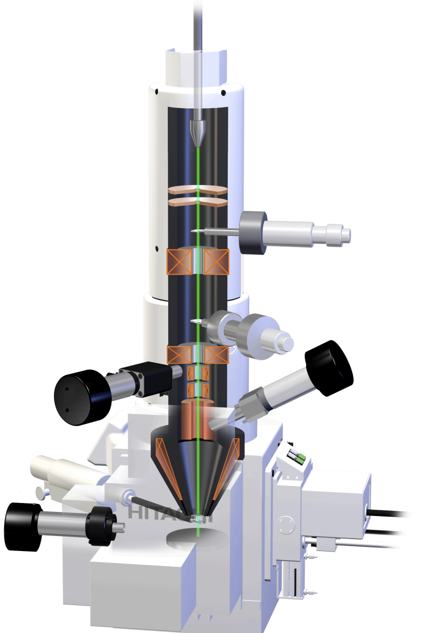




Data Sources

- Simulation
- Physical Measurements, Scientific Instruments





Data Types

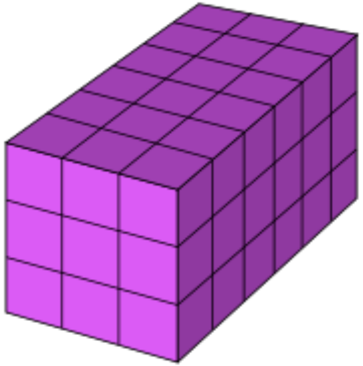
- 2D / 3D
- Points / grids
- Scalar / vector / tensor

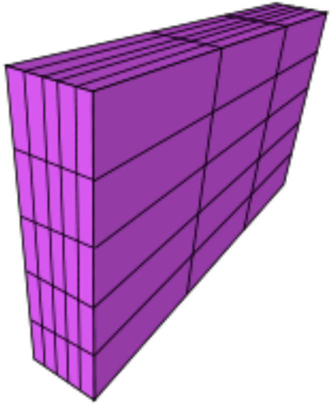
Volume:

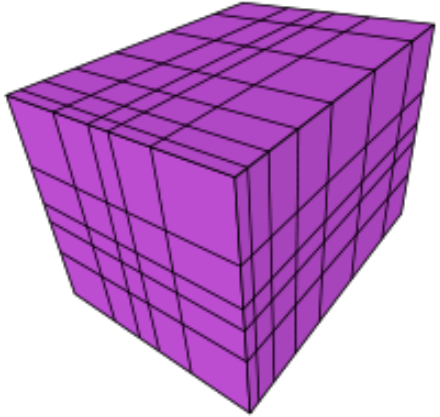
- 3D array of point samples
- Stack of images
- Single sample: voxel (3D pixel)

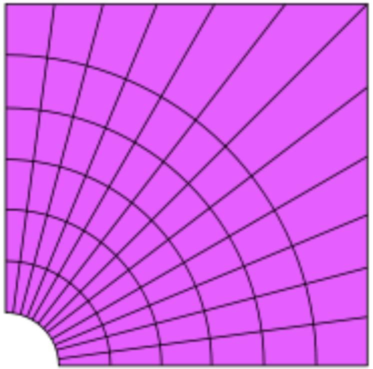
Grid Types

- Cartesian, regular, rectilinear, curvilinear



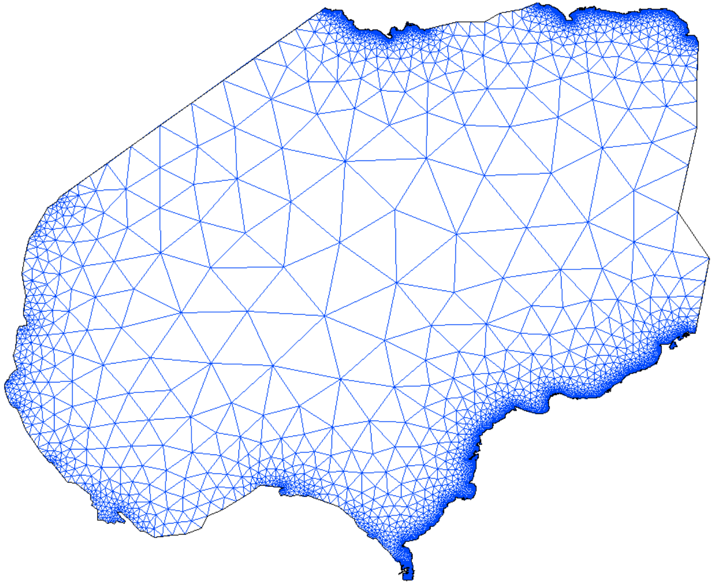


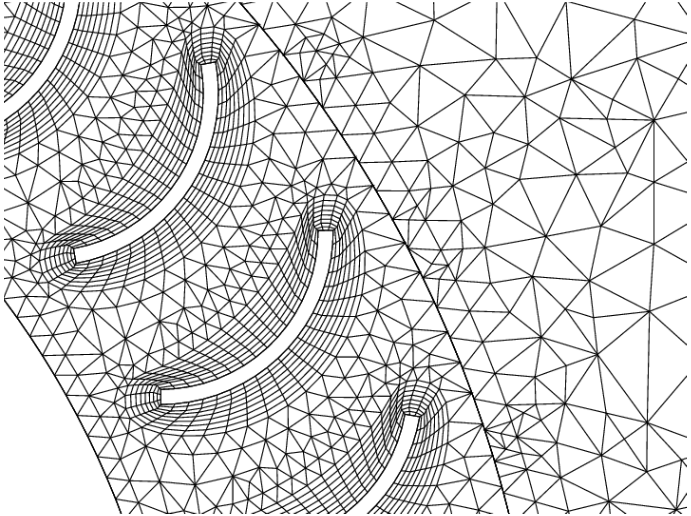




Grid Types

- Unstructured, hybrid

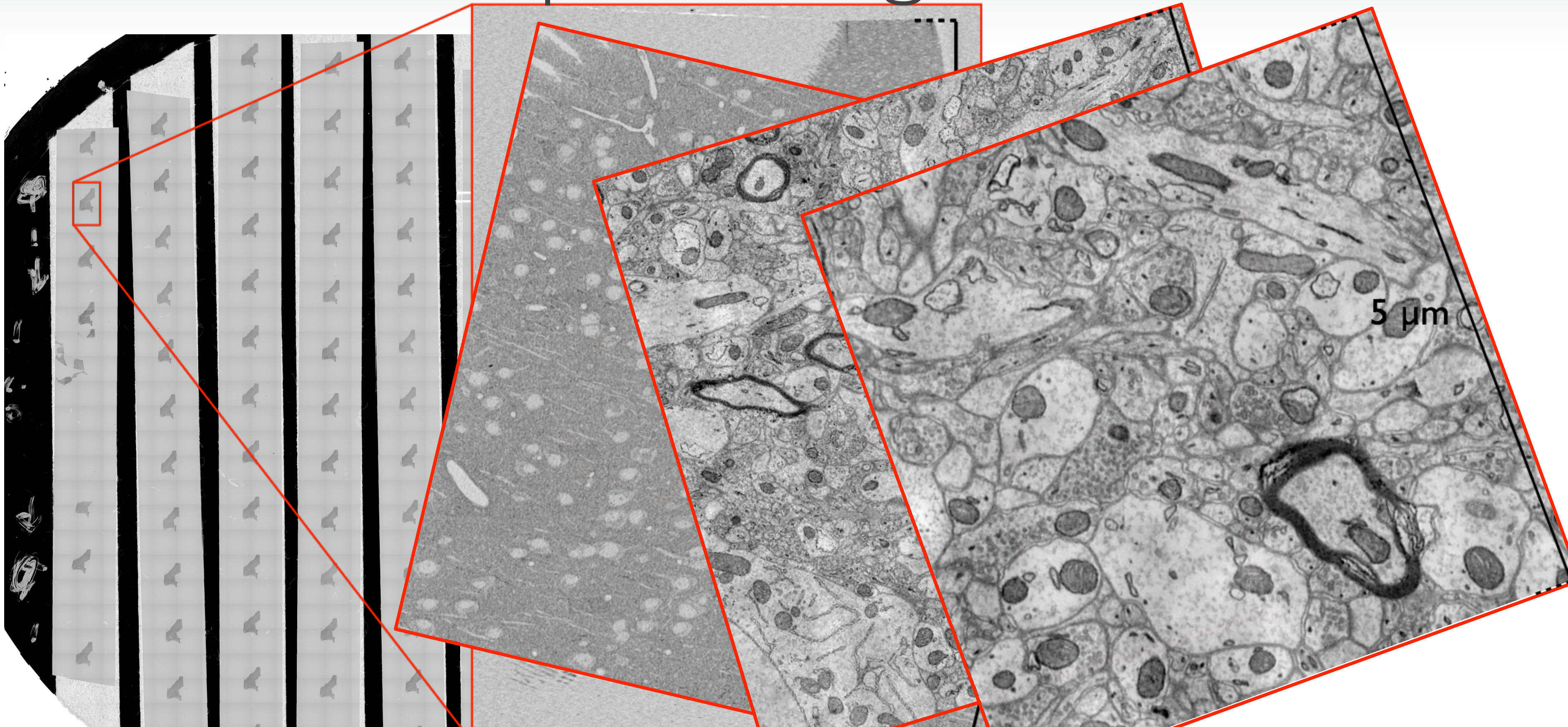




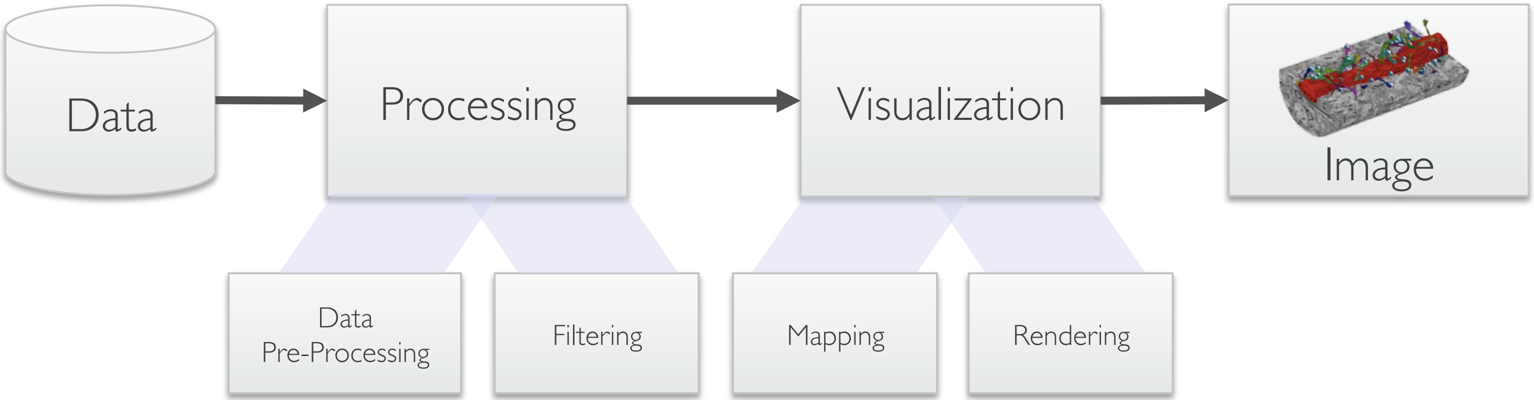
Challenges in Scientific Visualization

- Large data (storage, i/o, processing, rendering)
- Algorithms computationally expensive
  - Often require GPU processing for interactivity
- 3D
- Visualization methods depend heavily on dimensionality of domain

Complex, Large Data



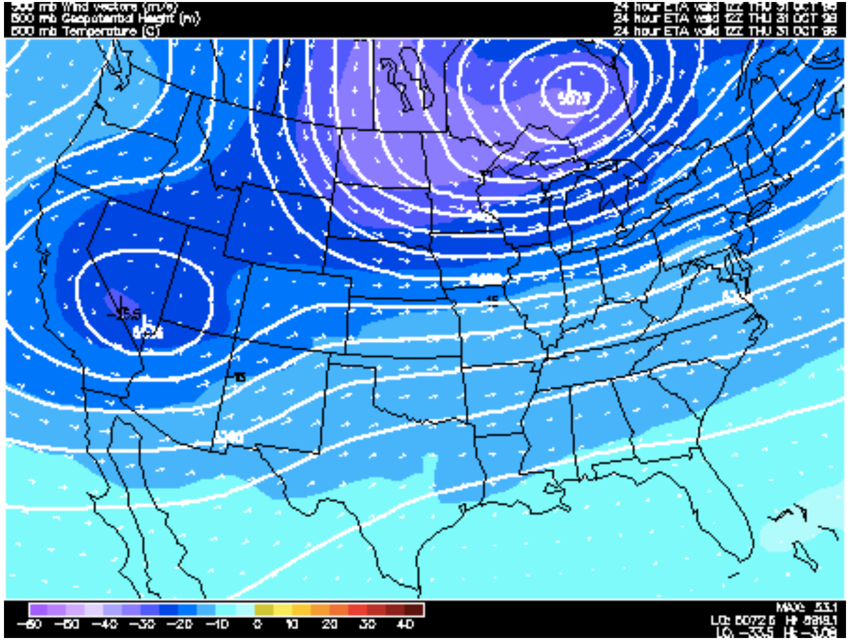
The Visualization Pipeline

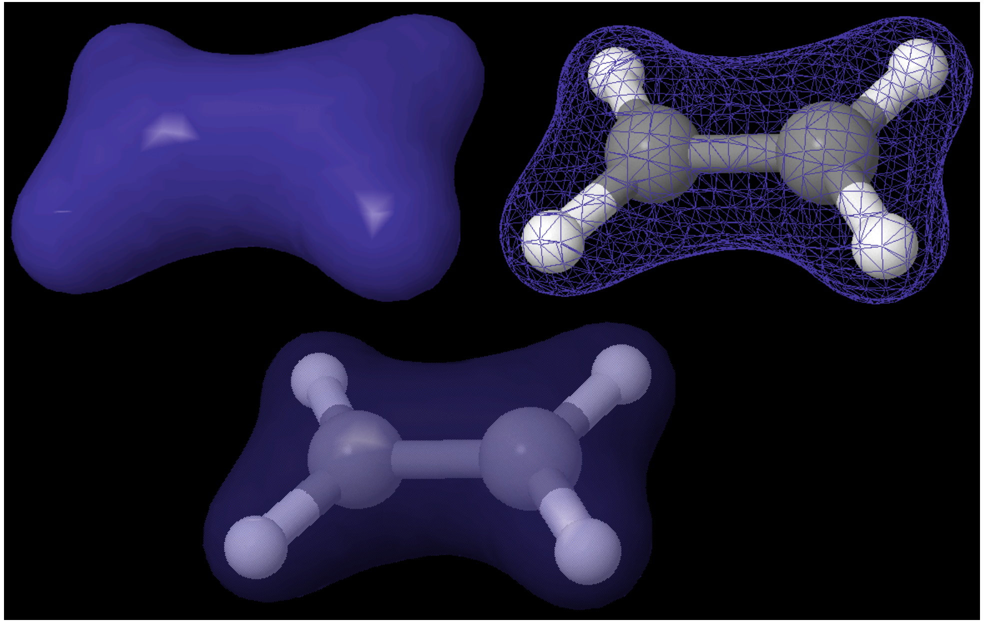


Basic Visualization Strategies

- Mapping to geometry
  - Height fields
  - Isocontours/isolines, isosurfaces
- Color mapping
- Specific techniques for 3D data
  - Indirect vs. direct volume visualization Direct volume visualization
  - Slicing
- Specific techniques for 3D data
  - Indirect vs. direct flow visualization
  - Dense flow visualization

Mapping to Geometry



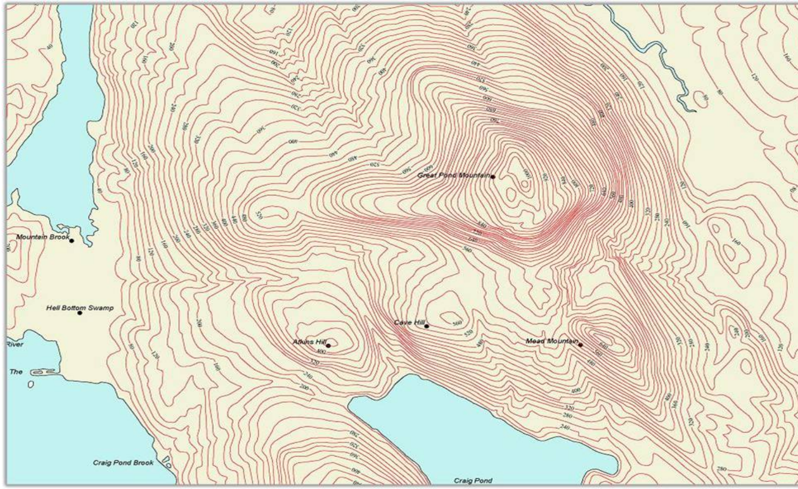


Contours

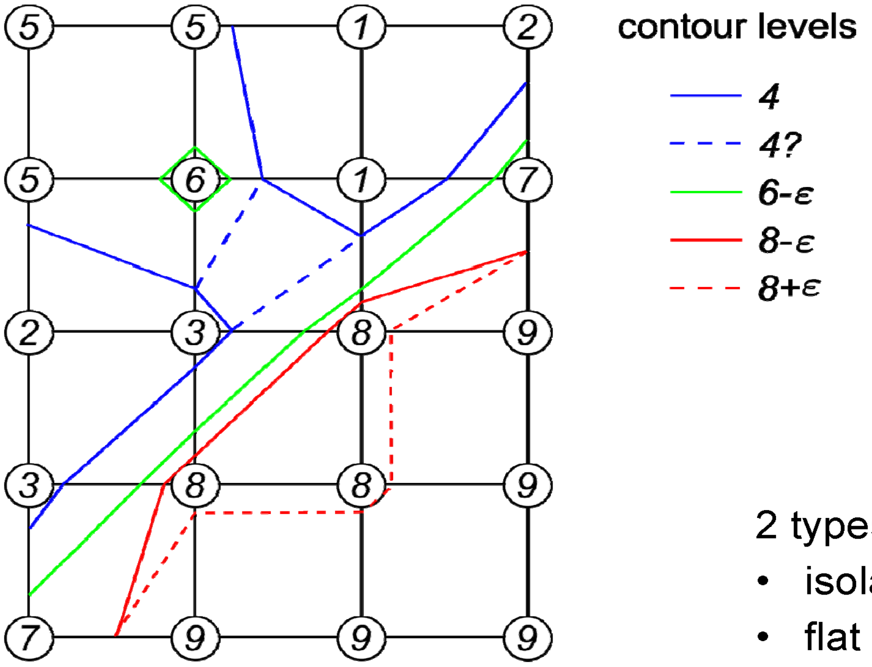
- Set of points where the scalar field *s* has a given value *c*:

$$\left\{ \mathbf{x} \in \mathbb{R}^n : s(\mathbf{x}) = c \right\}$$

- Common contouring algorithms
  - 2D: marching squares
  - 3D: marching cubes



Contours - Example

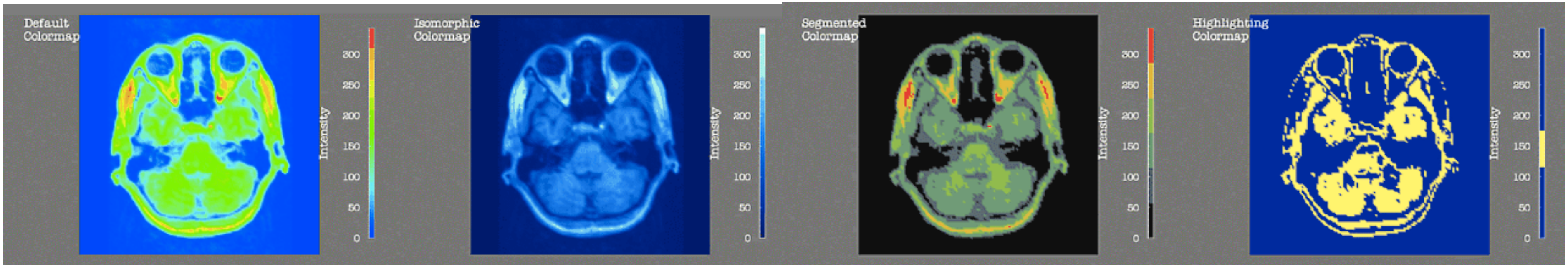


2 types of degeneracies:

- isolated points (c=6)
- flat regions (c=8)

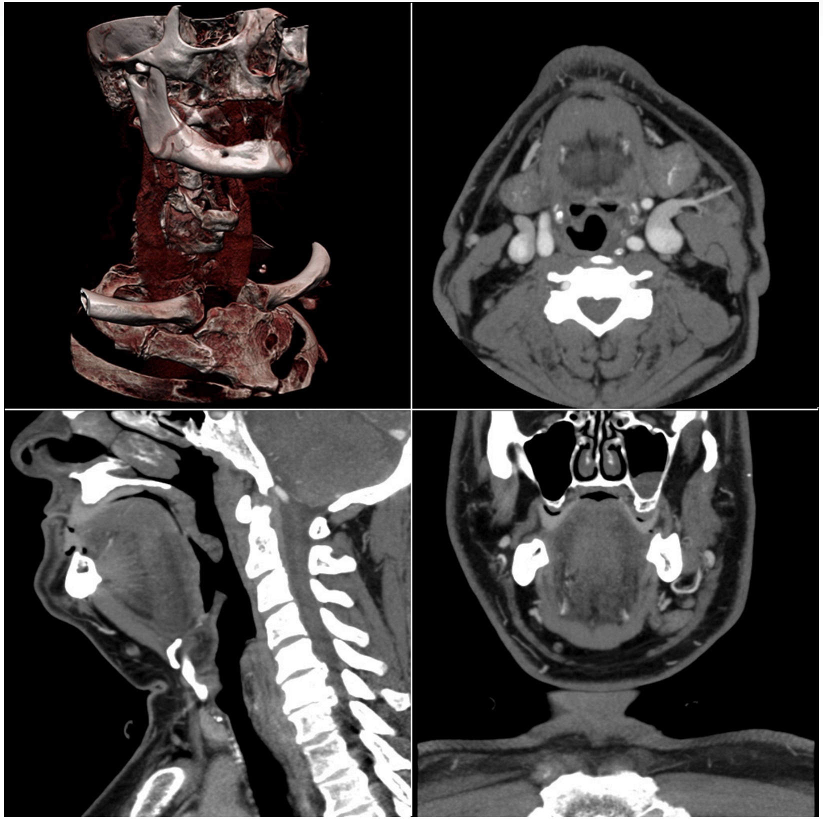
Color Mapping

- Map scalar value to color
  - Color table (e.g., array with RGB entries)
  - Procedural computation
- With opacity: 1D *transfer function*

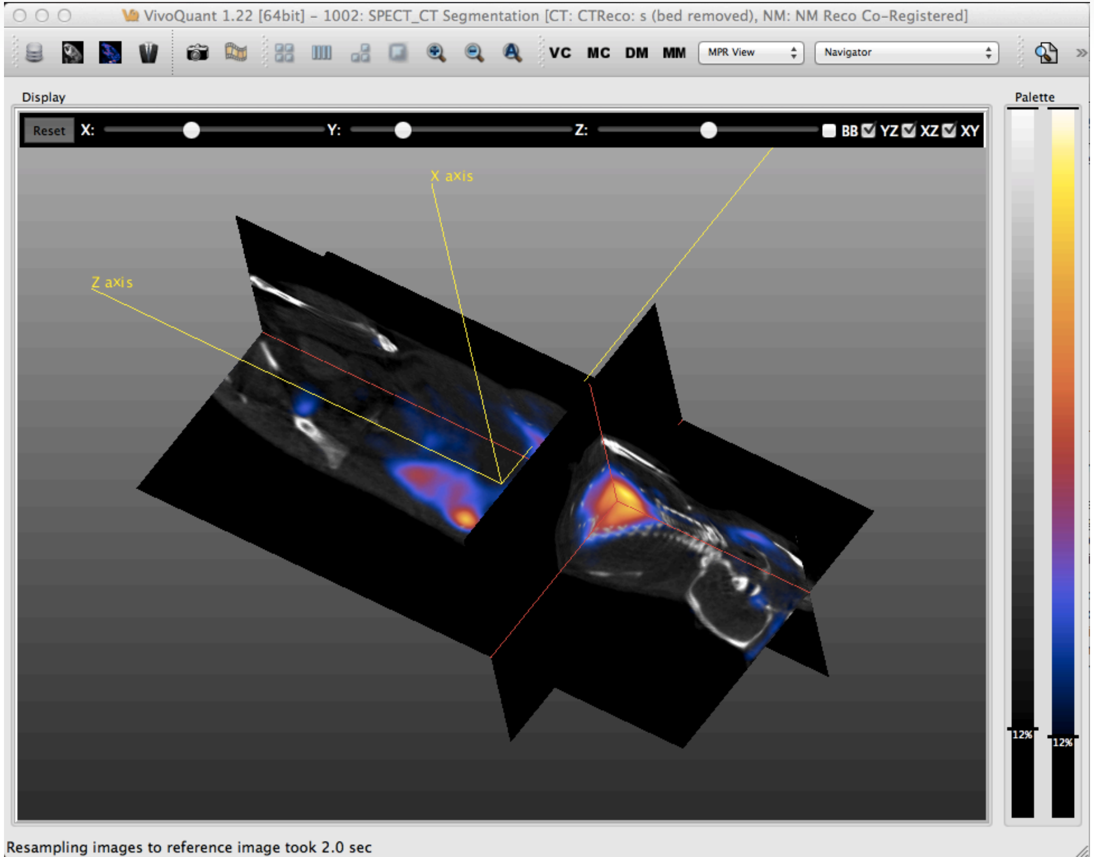


https://www.cs.ubc.ca/~tmm/courses/533-07/readings/pravda/truevis.htm

Slicing



Slicing


VivoQuant 1.22 [64bit] – 1002: SPECT_CT Segmentation [CT: CTReco: s (bed removed), NM: NM Reco Co-Registered]
VC
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DM
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MPR View
Navigator
Display
Palette
Reset
X:
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X axis
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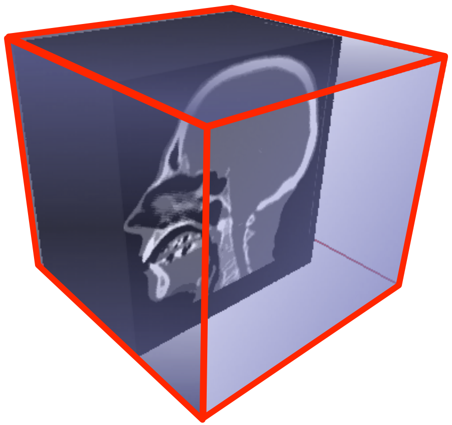
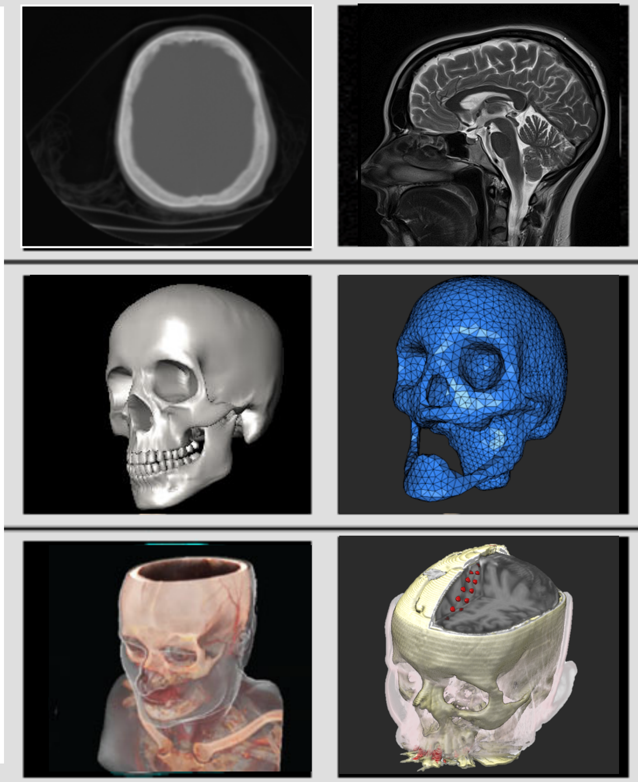
Resampling images to reference image took 2.0 sec

Volume Visualization

Volume Visualization

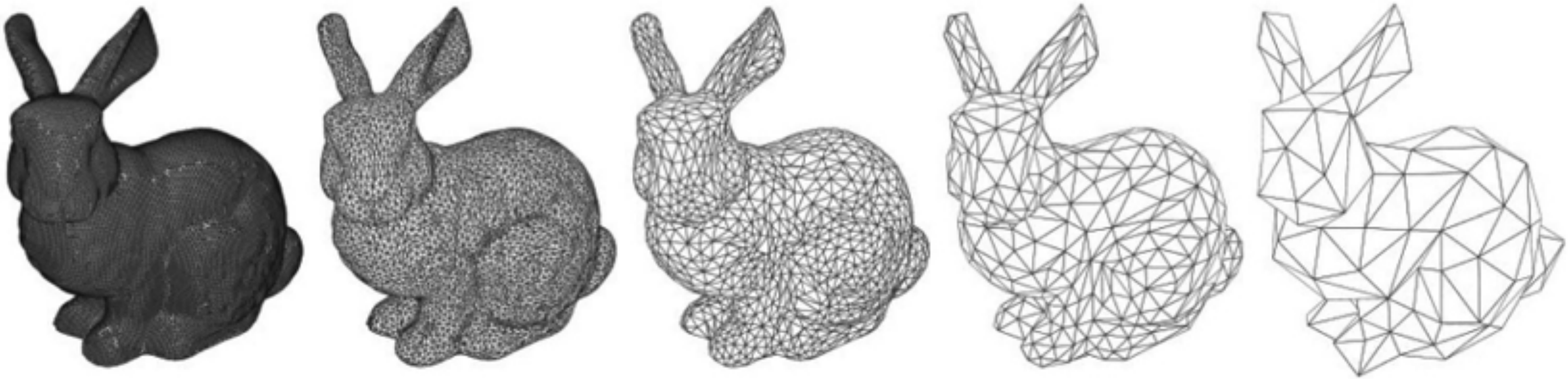


- 2D visualization
  slice images
  (or multi-planar
  reformatting MPR)
- *Indirect*
  3D visualization
  isosurfaces
- *Direct*
  3D visualization
  (direct volume
  rendering: DVR)



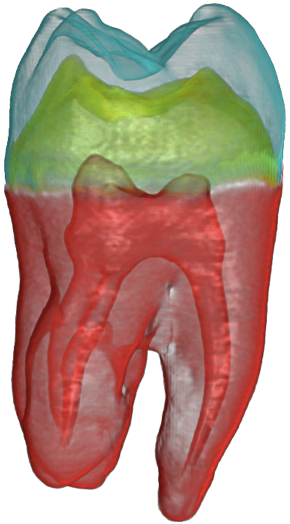
Surface Graphics

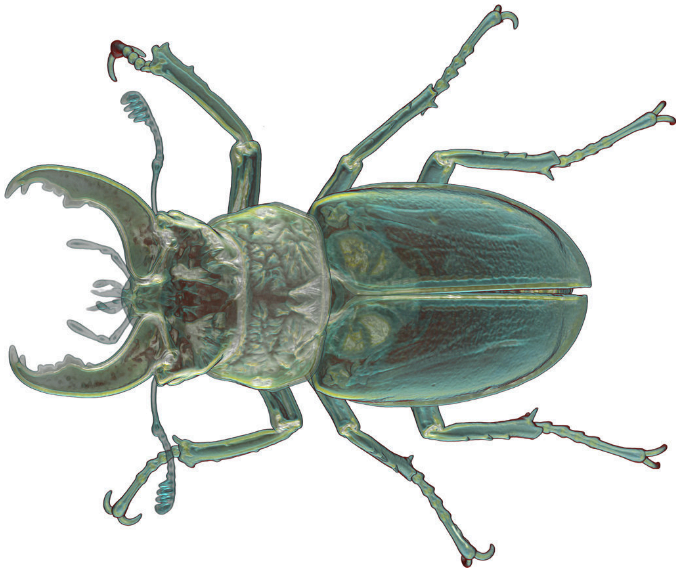
- Objects explicitly defined by boundary representations
- Polygon (triangle) mesh



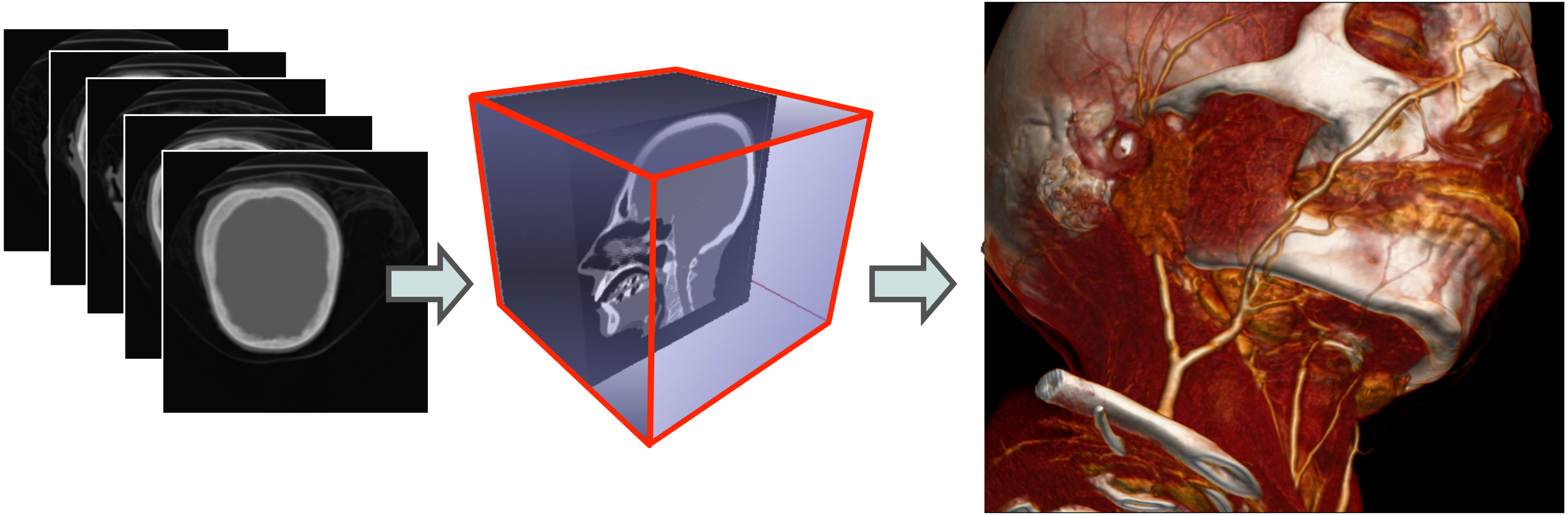
Volume Graphics

- Maintain a representation of volumetric object
- Different visual appearance by changing visual properties of voxels



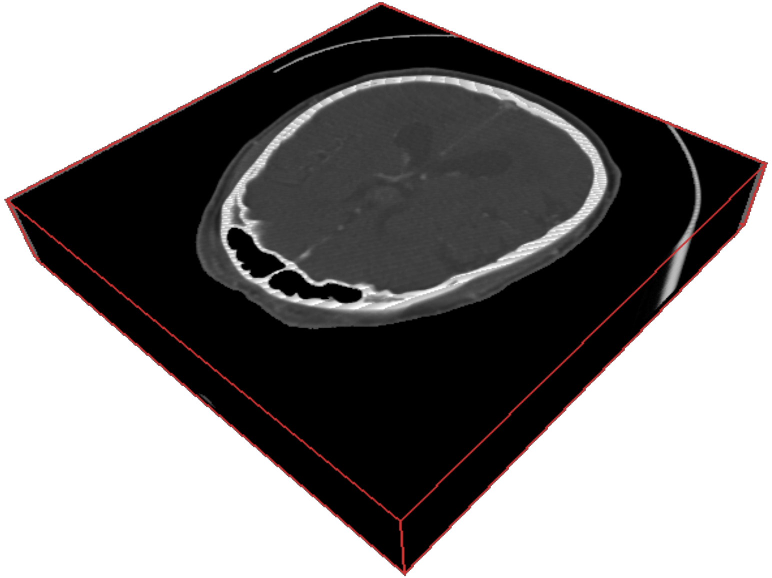


Volume Rendering



Volume Rendering

- Assign optical properties (color, opacity) via *transfer function*

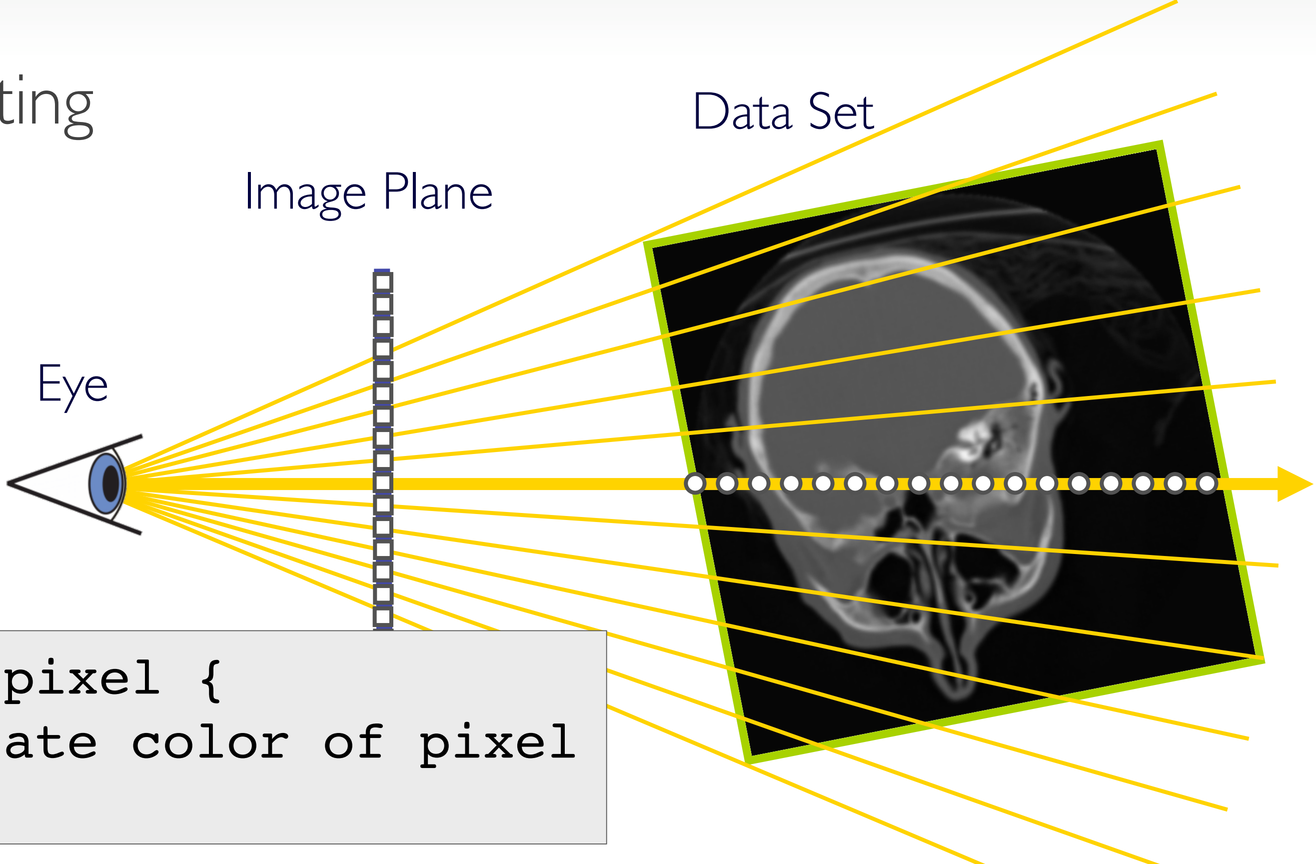


SliceDrop Demo

- http://slicedrop.com/

Volume Rendering

- Ray-casting

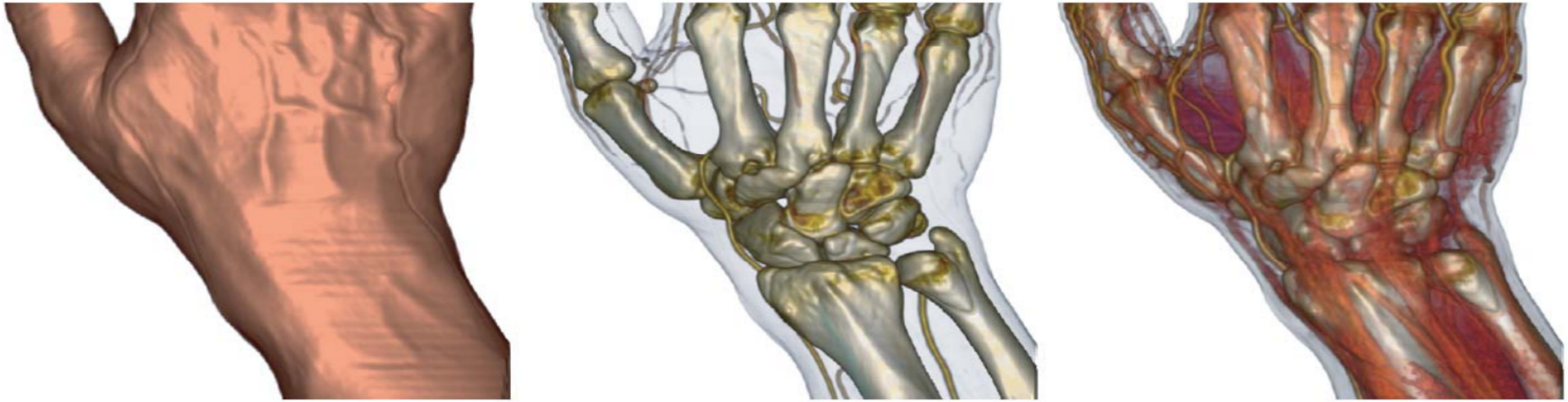



```
For each pixel {
   calculate color of pixel
}
```

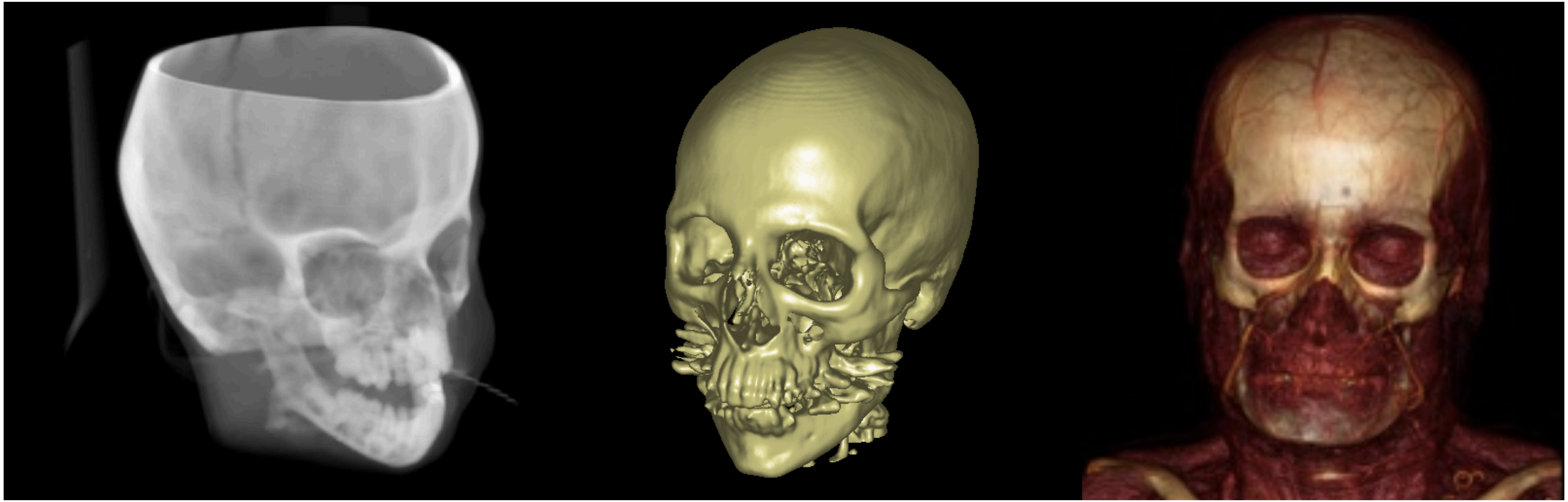
Classification – Transfer Functions

During Classification the user defines the *"look"* of the data.

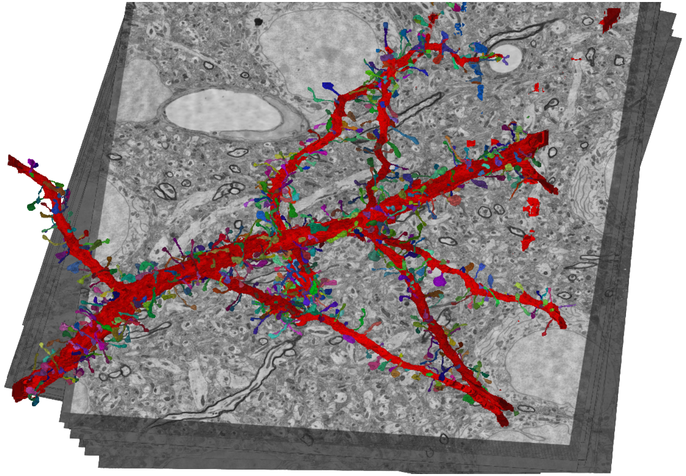
- Which parts are transparent?
- Which parts have what color?



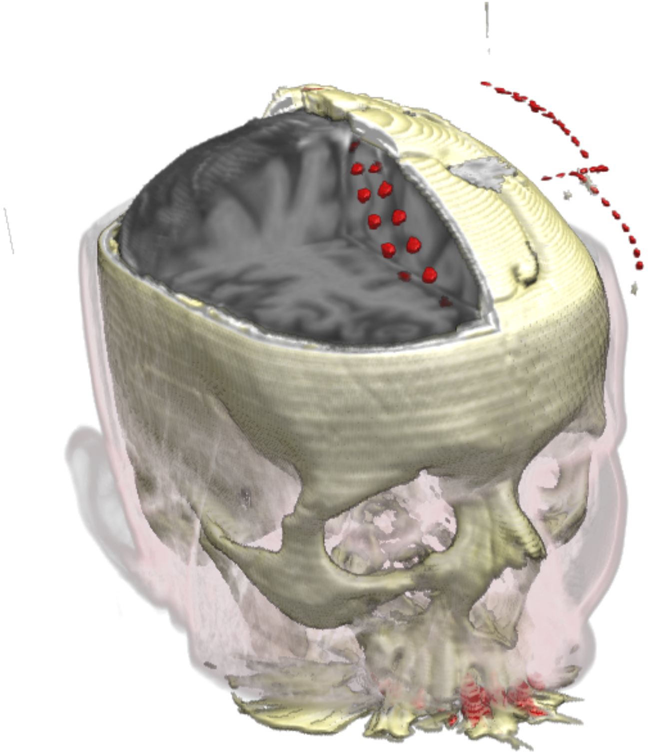
Render Modes

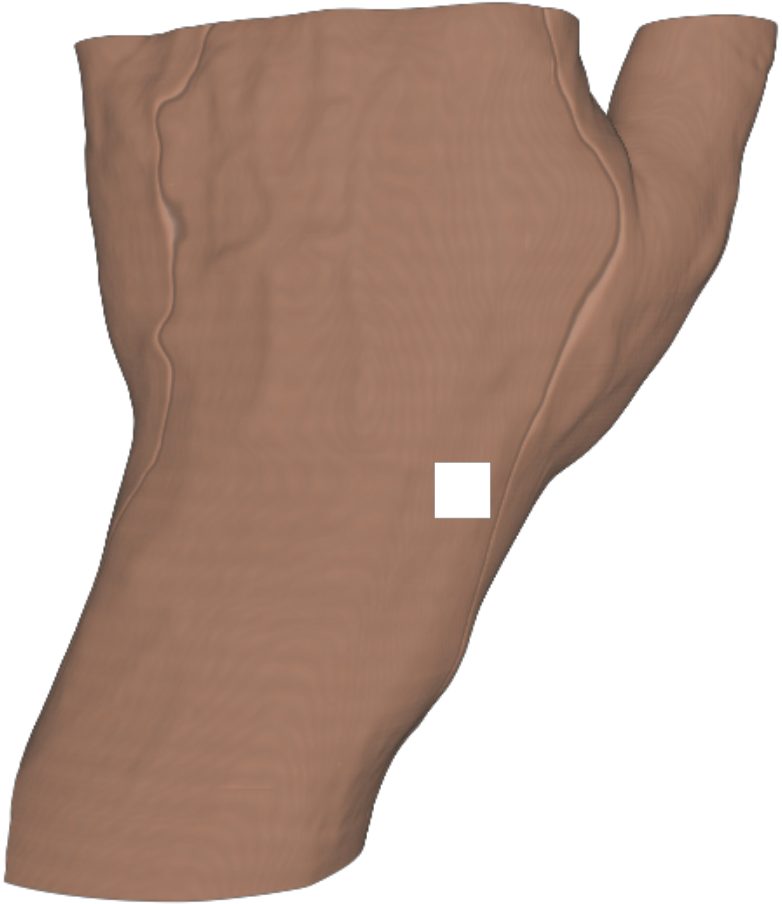


Examples



Segmented Volume Rendering



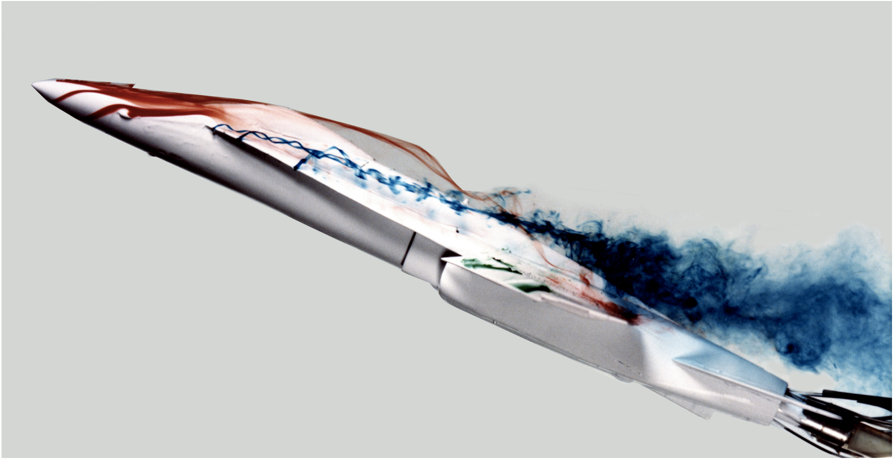


Flow Visualization

Flow Visualization

- Flow vis hundreds of years old
- Traditionally experimental flow vis

L. da Vinci (1452-1519)



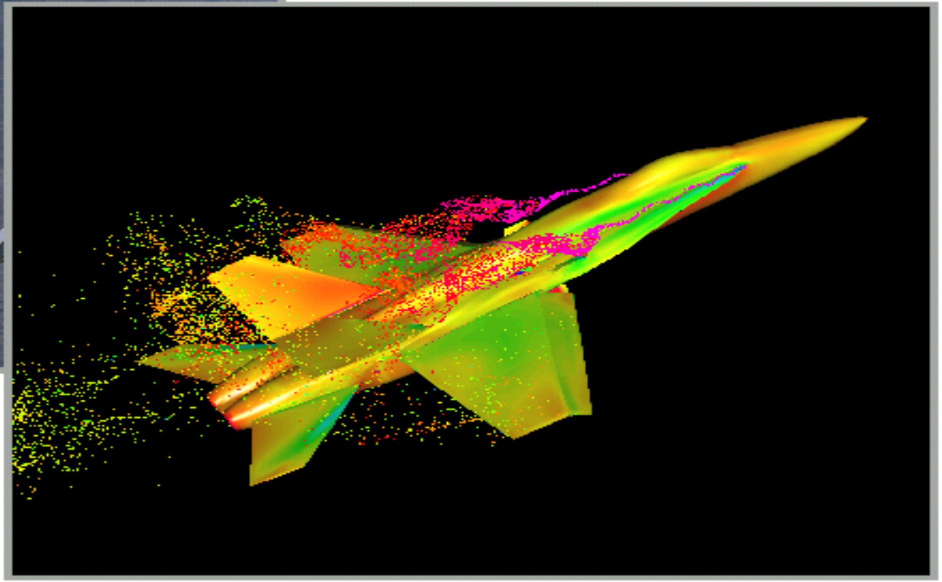
[Airplane wing vortice test]

Experimental Flow Vis

- Problems:
  - Flow is affected by experimental technique
  - Not all phenomena can be visualized
  - Expensive
  - Time consuming

Comparison with Reality

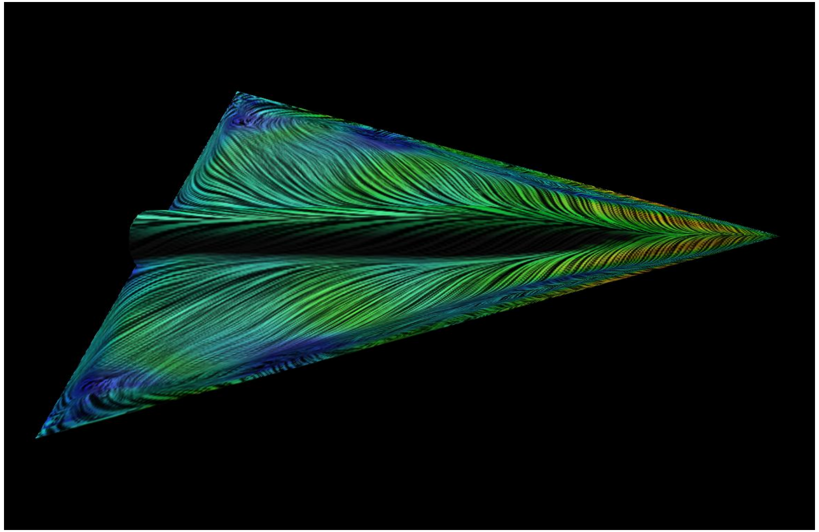
Simulation



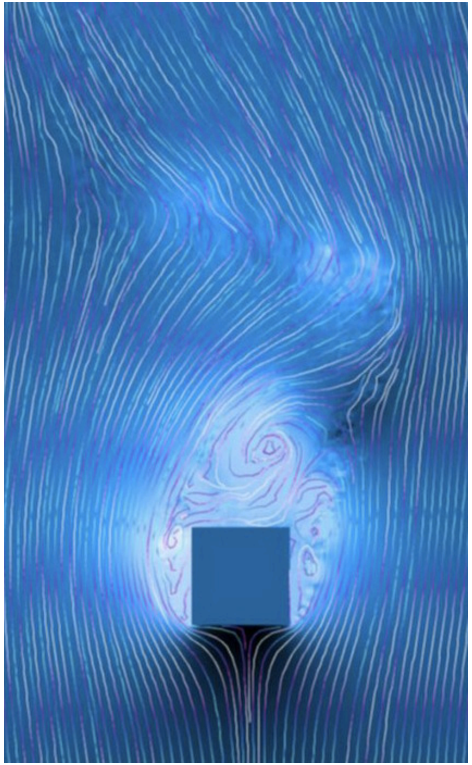
Experiment

2D/Surfaces/3D – Examples

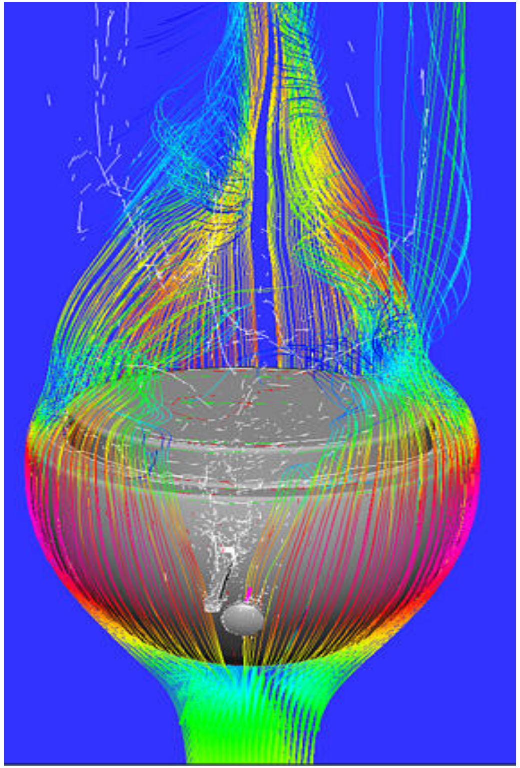
Surface



2D

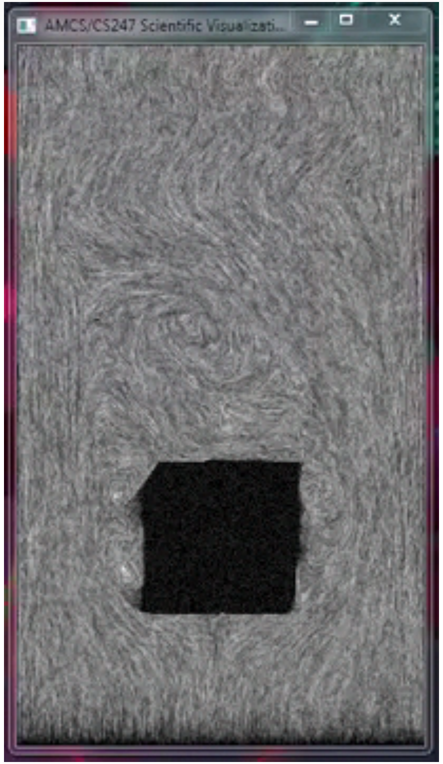


3D



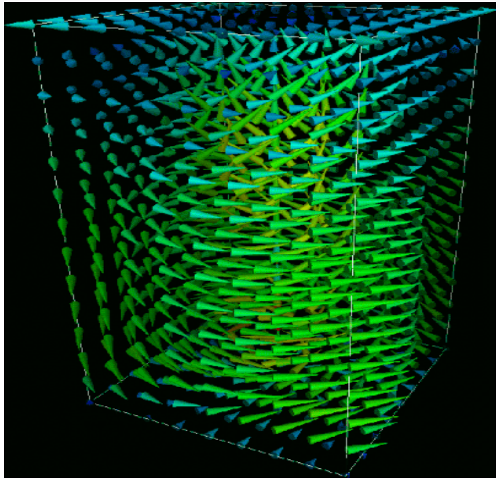
Steady vs. Time-Dependent Flow

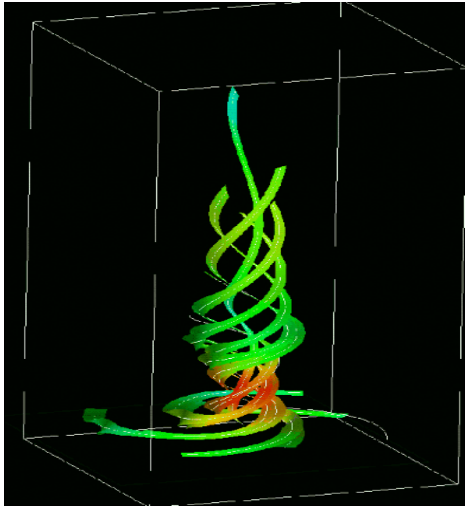
- Steady (time-independent) flow
  - Static over time
- Unsteady (time-dependent) flow
  - Flow itself changes over time



Direct vs. Indirect Flow Visualization

- Direct flow visualization:
  - Overview of current flow state
  - Visualization of vectors
- Indirect flow visualization:
  - Use intermediate representation: vector-field integration over time
  - Visualization of temporal evolution
  - Integral curves, integral surfaces

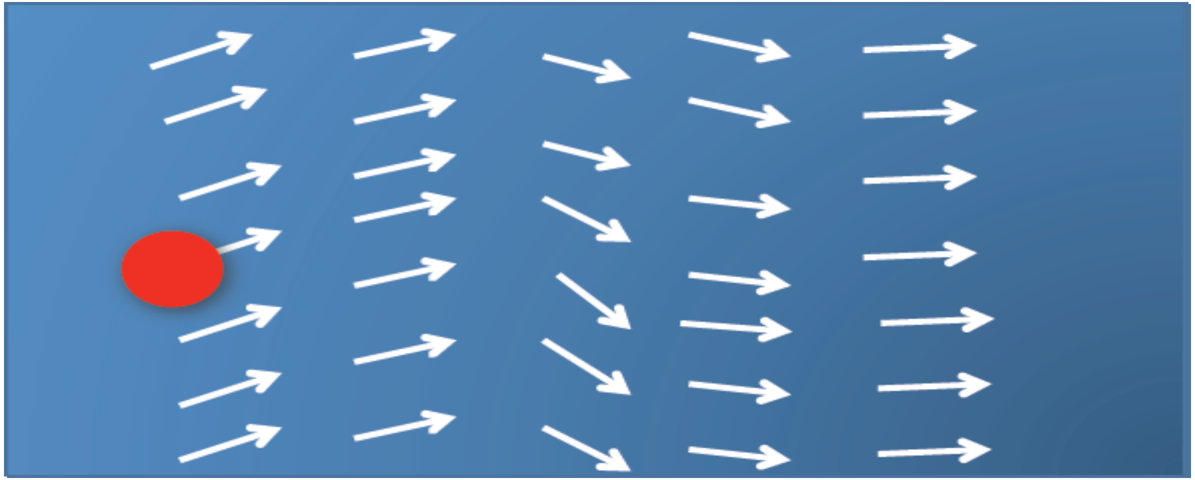




Particle Tracing

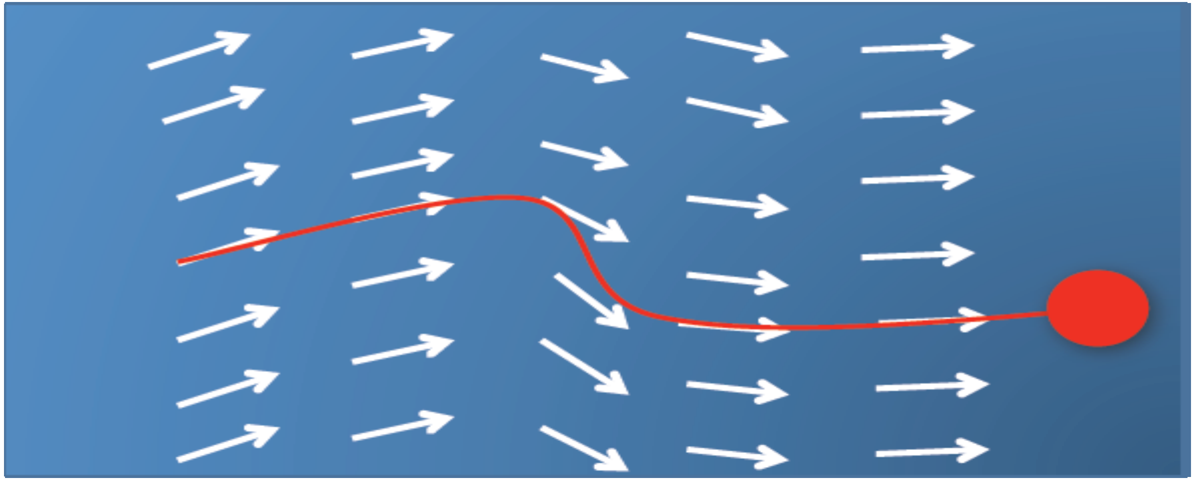
Courtesy Jens Krüger

Particle Tracing



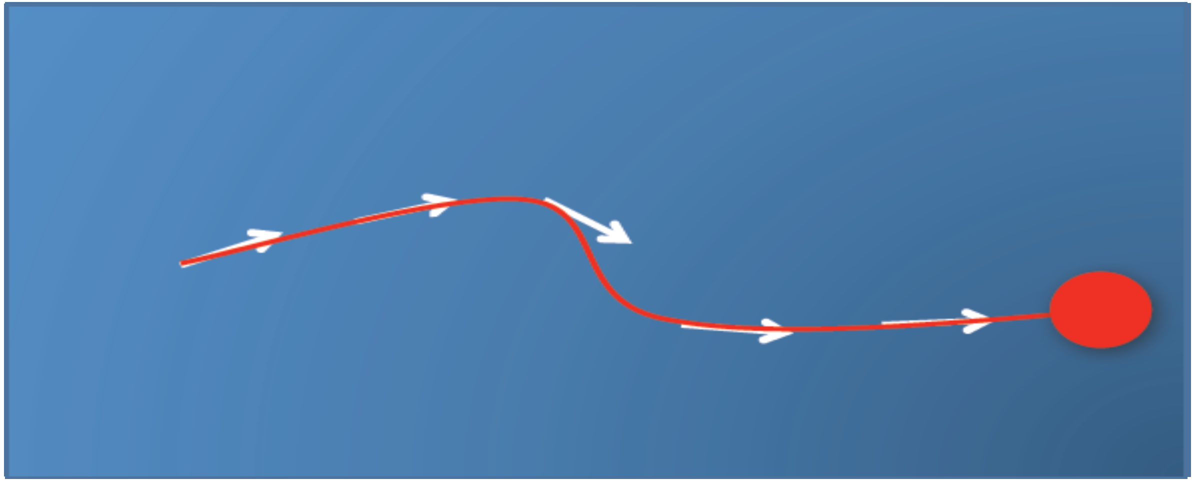
Courtesy Jens Krüger

Particle Tracing



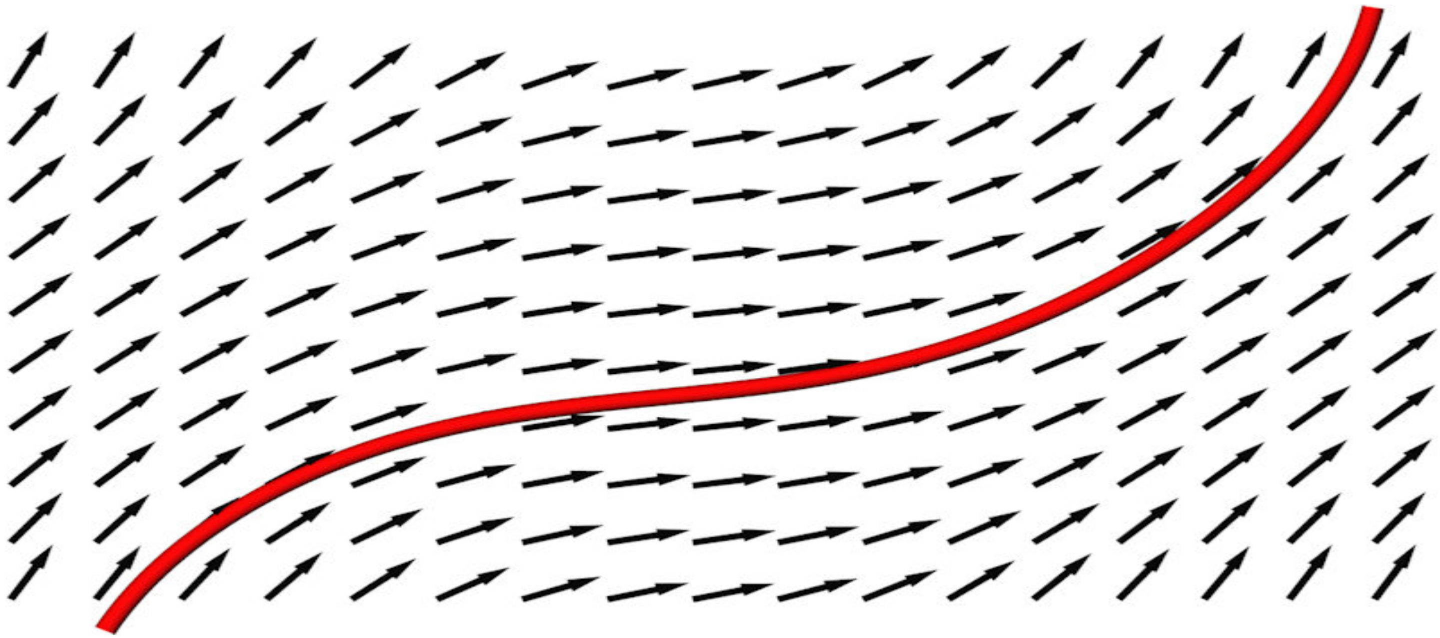
Courtesy Jens Krüger

Particle Tracing



Courtesy Jens Krüger

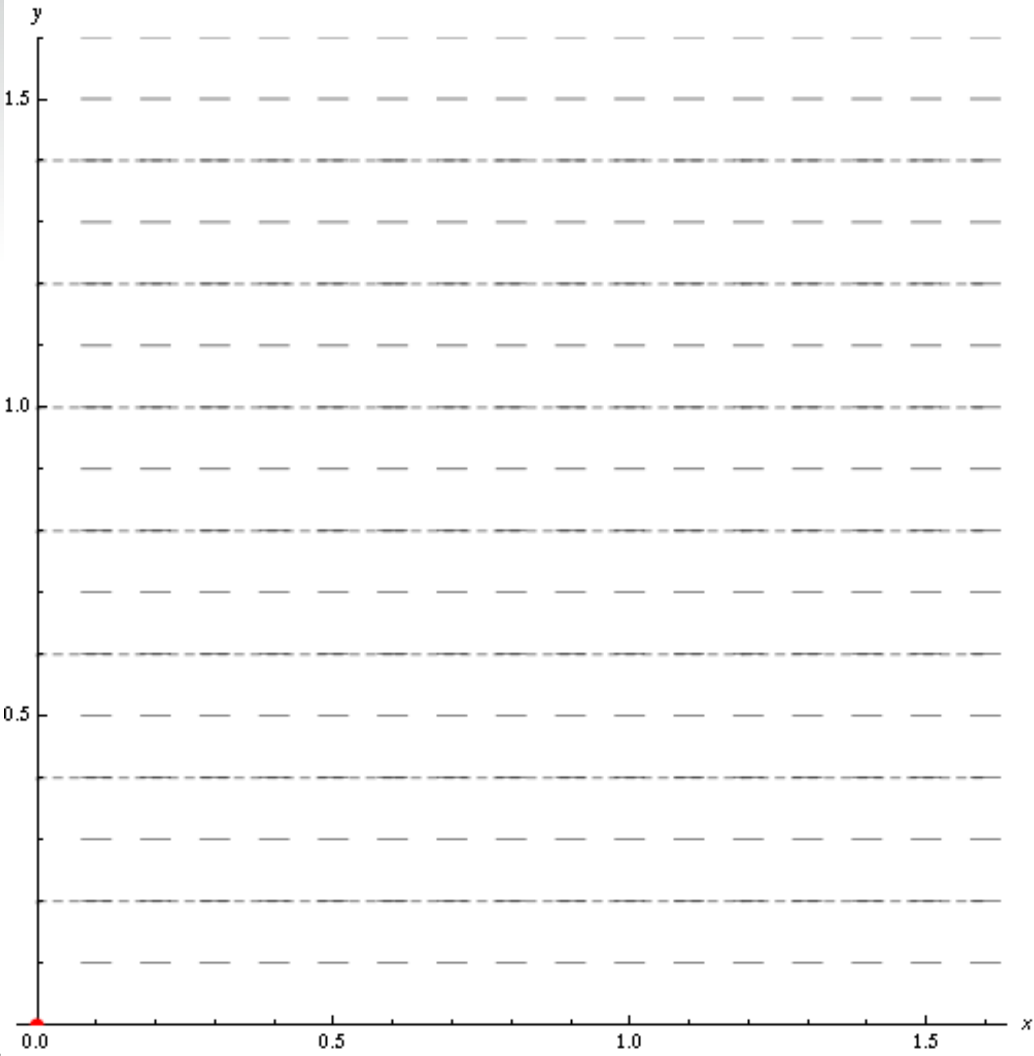
Integral Curves / Stream Objects



Integral Curves

- Stream lines
  - curve parallel to the vector field in each point for a fixed time
- Path lines
  - describes motion of a particles over the time in an unsteady flow field
- Streak lines
  - location of all particles set out at a fixed point at different times
- Time lines
  - location of all particles set out on a certain line at a fixed time

- Dashed line: Hedgehog/streamline
- Red line: pathline
- Blue line: streakline



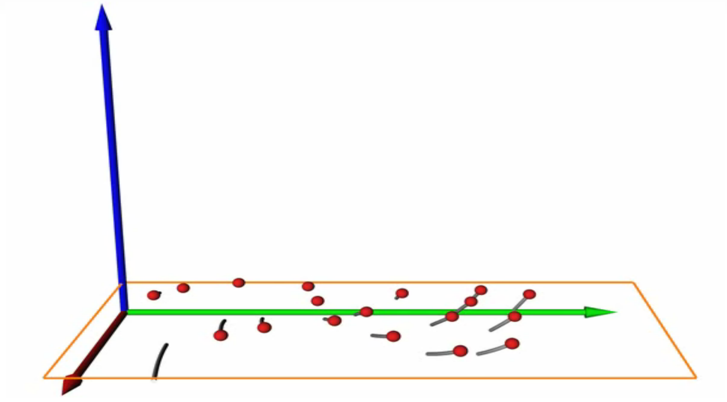
http://en.wikipedia.org/wiki/Streamlines,_streaklines,_and_pathlines

Stream Lines vs. Path Lines

stream lines

curve parallel to the vector field in each point for a **fixed time**

describes motion of a massless particle in an **steady** flow field

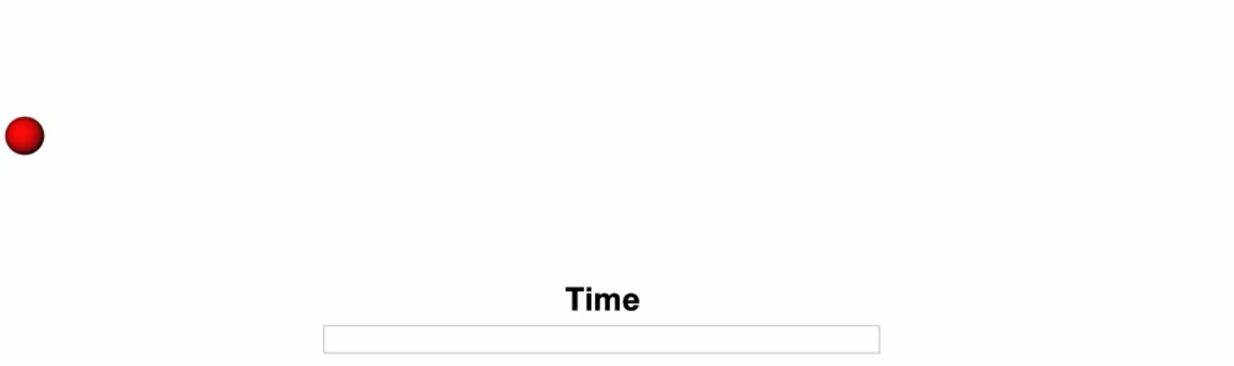


path lines

curve parallel to the vector field in each point **over time**

describes motion of a massless particle in an **unsteady** flow field

Streak Line



streak line

location of all particles set out at a fixed point at different times

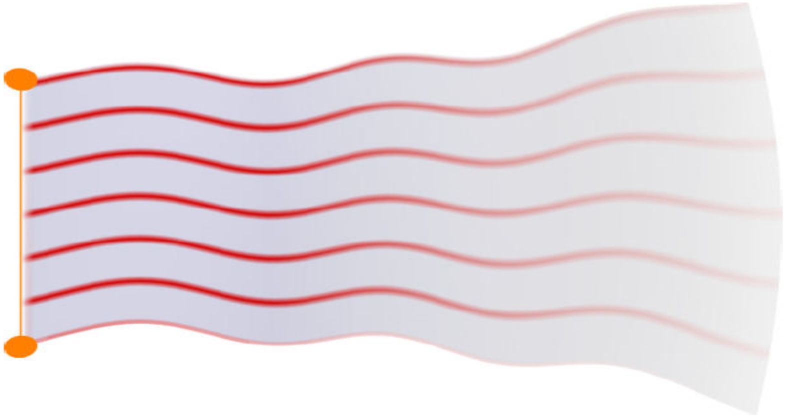
Time Line

time line

location of all particles set out on a certain line at a fixed time

Streak Lines vs. Time Lines

- (on a streak surface)



Streak Lines

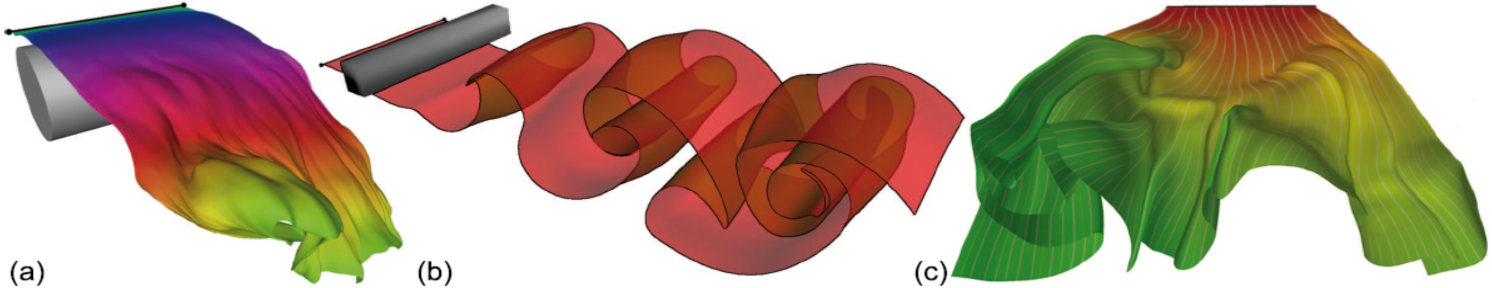
Time Lines

Real "Streak Surfaces"

- Artistic photographs of smoke

Surfaces Instead of Lines

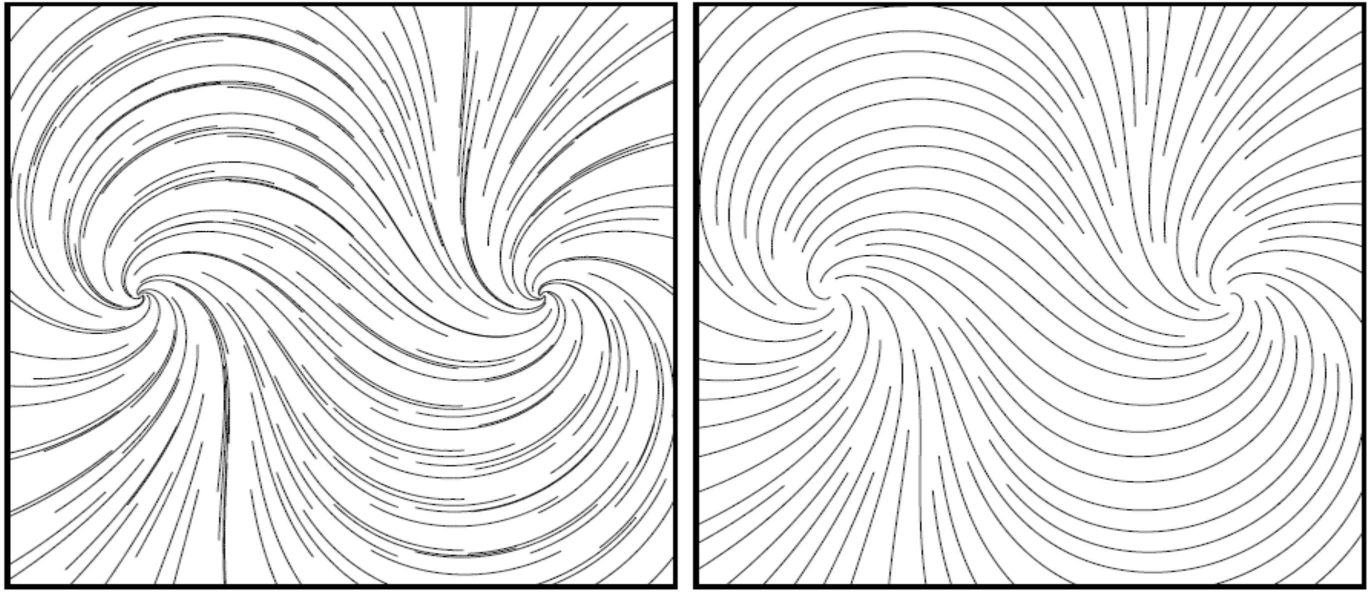
- Seeding from a line instead of from a point
- Example: streak surfaces



- Volumes: seeding from a surface instead of a line

Stream Line Placement

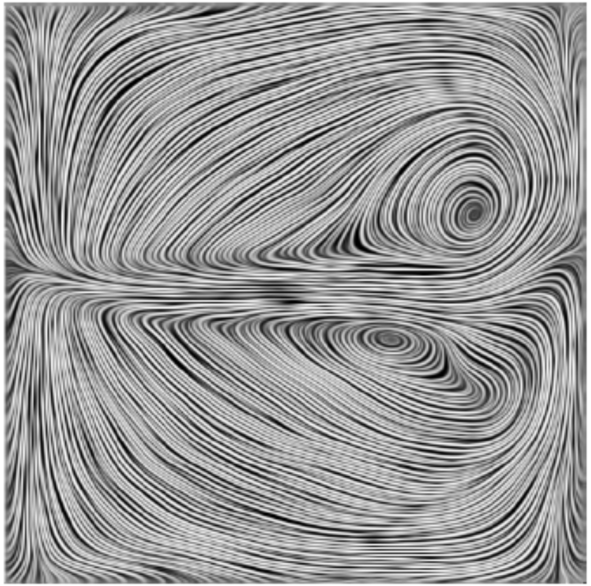
- Basic problem: finding seed points

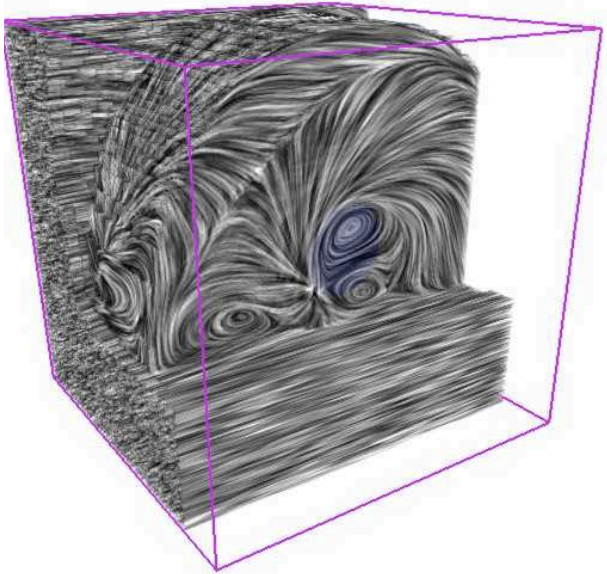


Dense Flow Visualization

- Line Integral Convolution (LIC)
  - Idea
    - Cover domain with a random texture
    - Blur (convolve) the input texture along the path lines
  - Look
    - Intensity along path lines highly correlated
    - No correlation between neighboring path lines

LIC





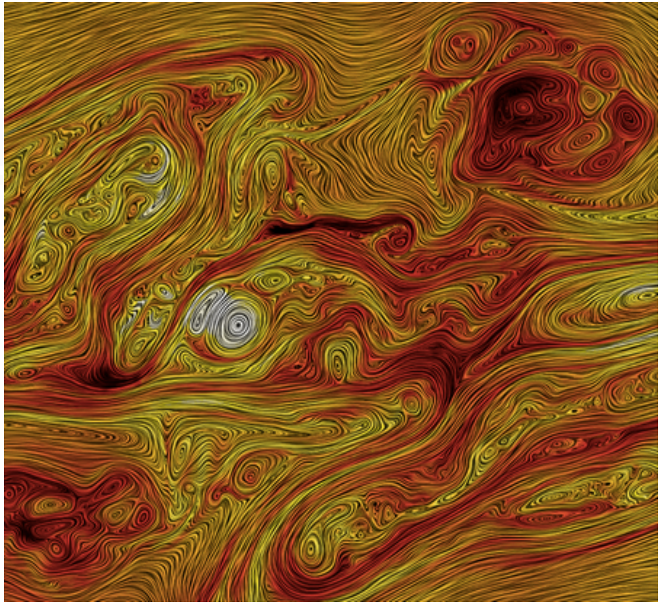
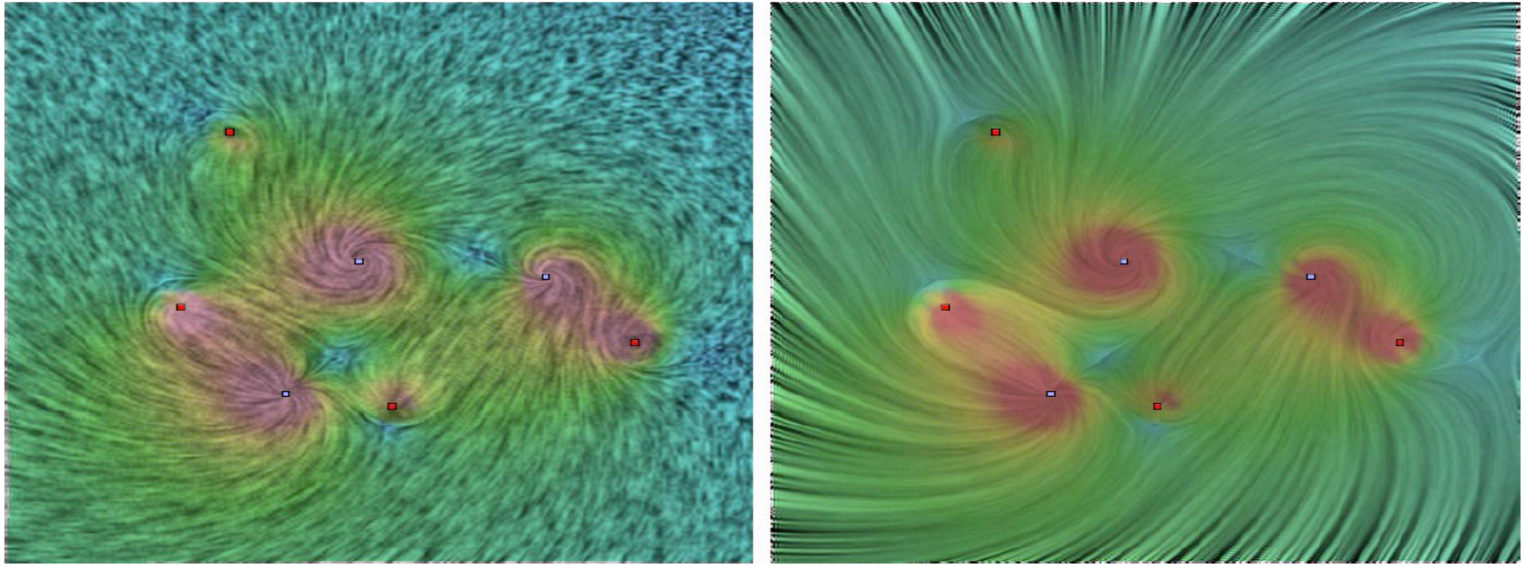


Image Based Flow Visualization

J. van Wijk: "Image Based Flow Visualization" in *Proceedings of ACM SIGGRAPH 2002*

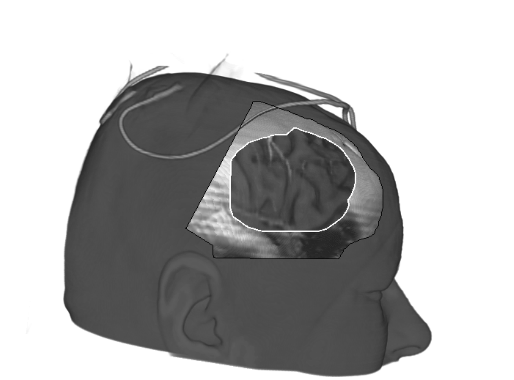


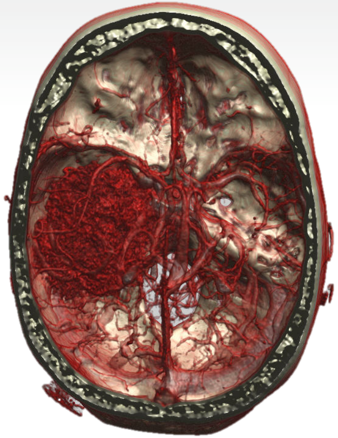
Application Example

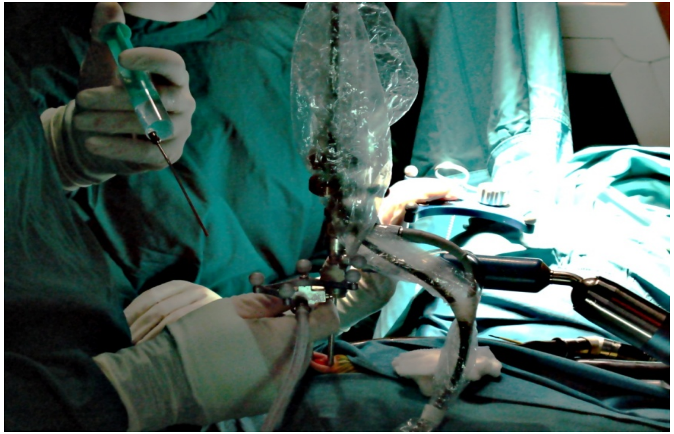
Medicine

Medical Visualization

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

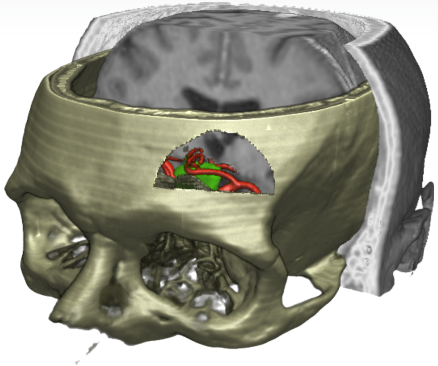


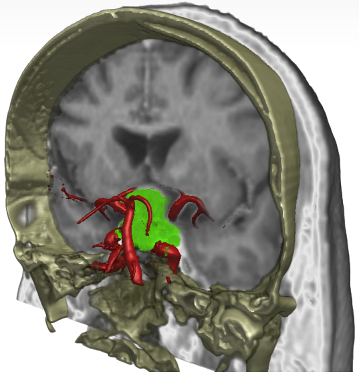


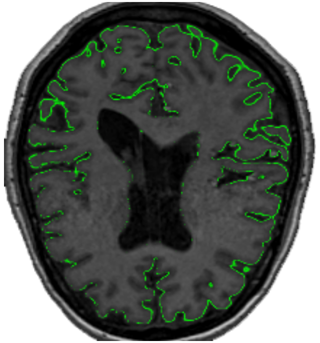


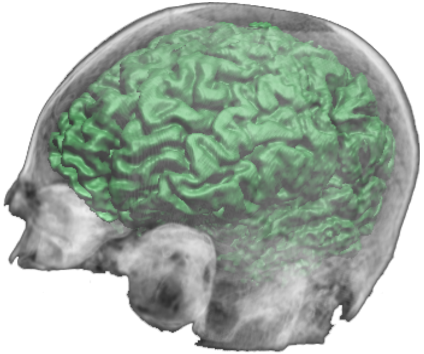
Medical Visualization

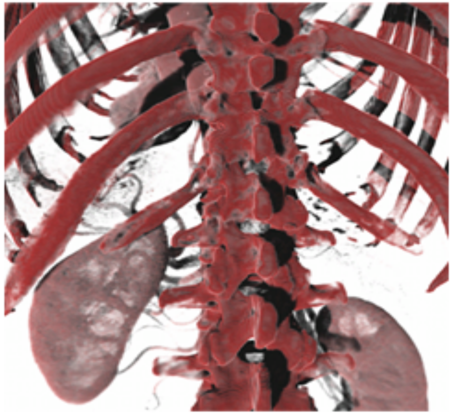
- Volume visualization
- Segmentation
- Analysis
- Measurements





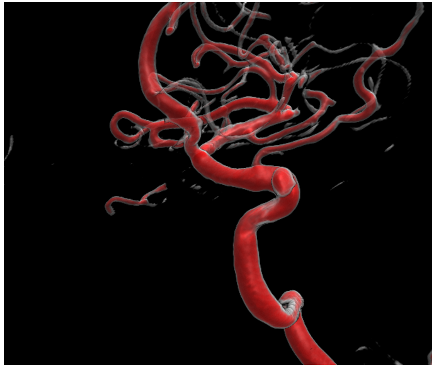


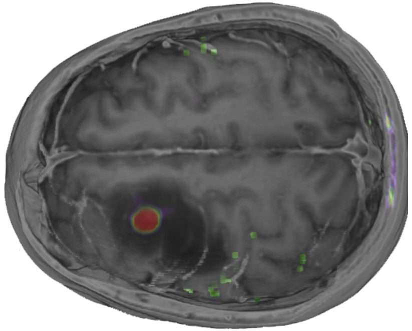


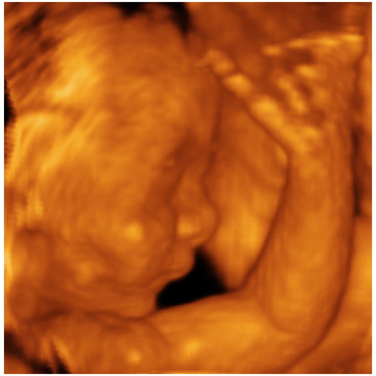


Medical Imaging Modalities

- Computed tomography: CT(A)
- Magnetic resonance imaging (MRI): MR(A)
- Ultrasound (US)
- Nuclear imaging (PET, SPECT, …)

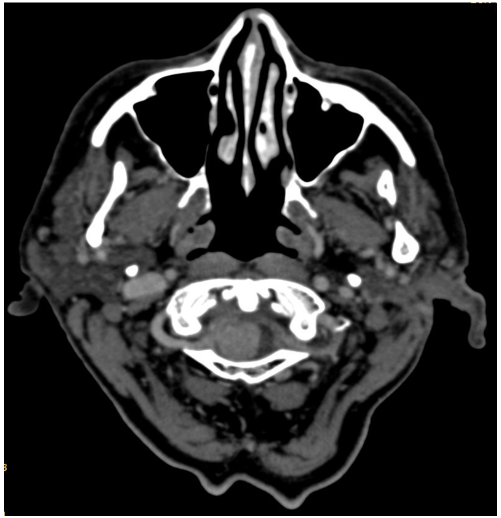






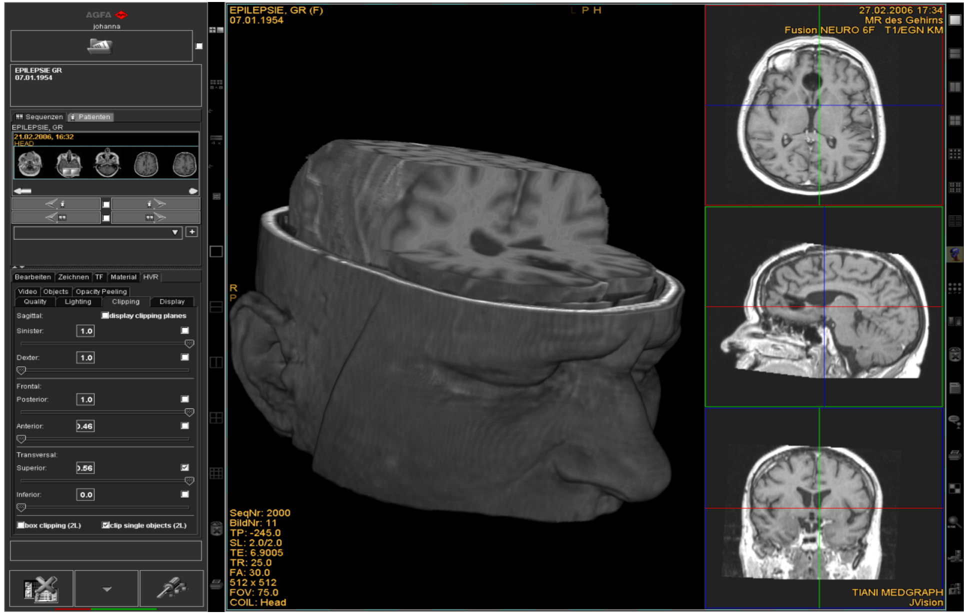
CT

- Computed Tomography
- 3D X-rays; reconstruction from many images



MRI

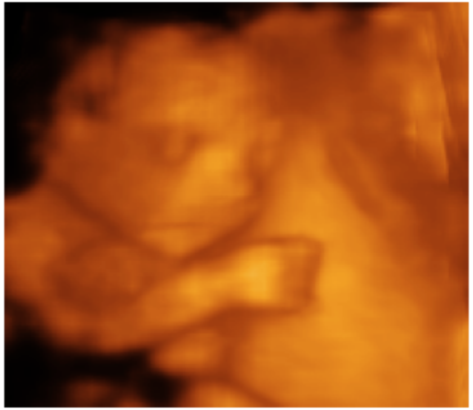
- Magnetic Resonance Imaging
- High contrast for soft tissues
- Stong magnetic and
  radio frequency fields
- Hydrogen nuclei
  align with magnetic fields
- Absorb radio-energy
- Release is detected



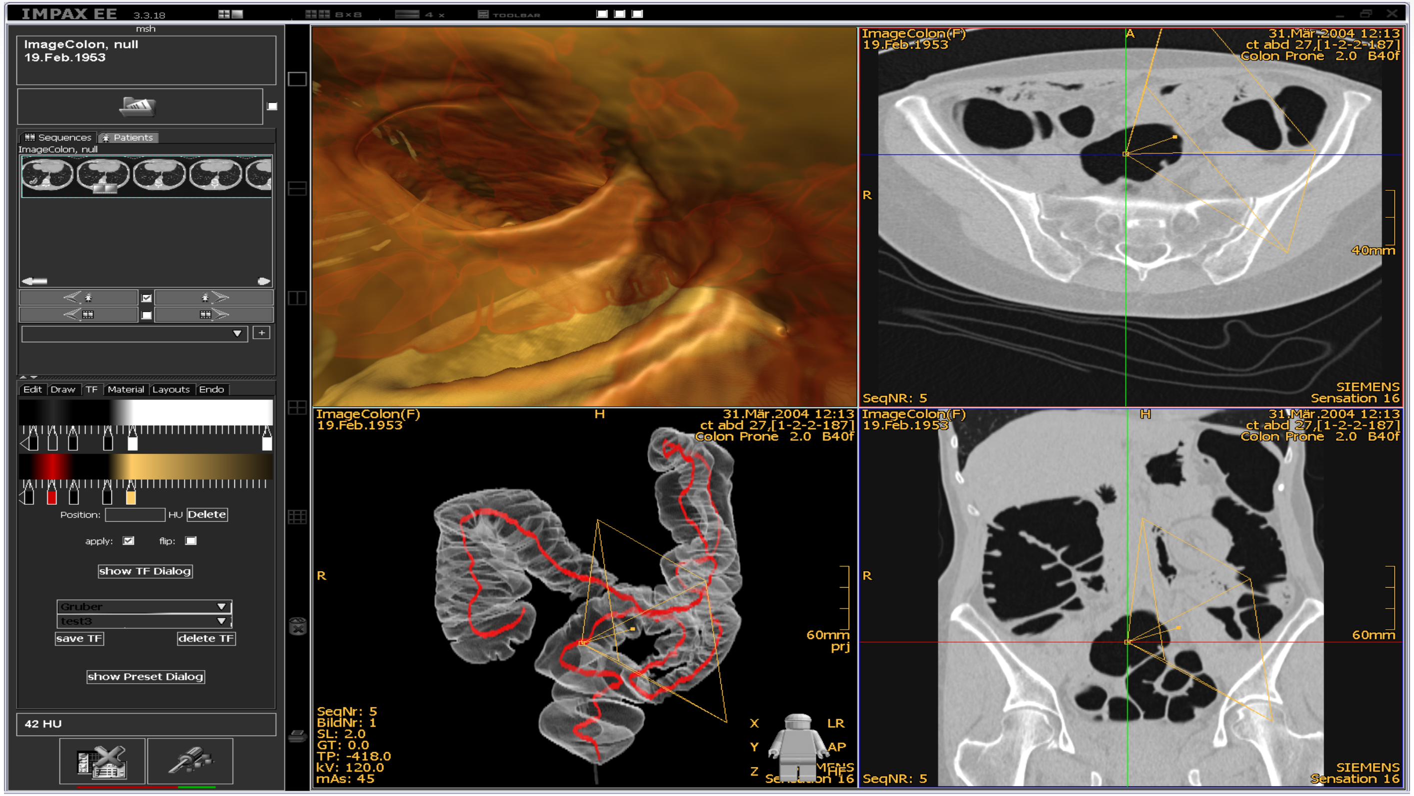
- fMRI, DTI, …

Ultrasound

- 2-18 MHz
- Measure timing and strength of echoes
- Tissue boundaries, texture
- Doppler ultrasound detects movement: blood flow, …



Medical Workstation Plugin Examples



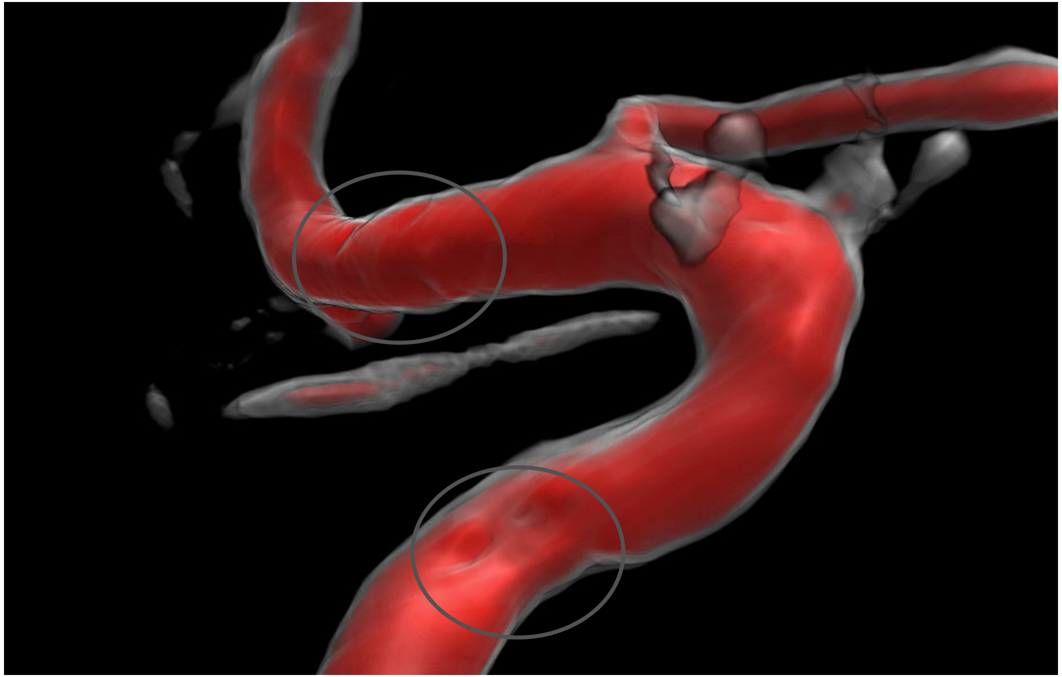
3D Visualization in Neurosurgery

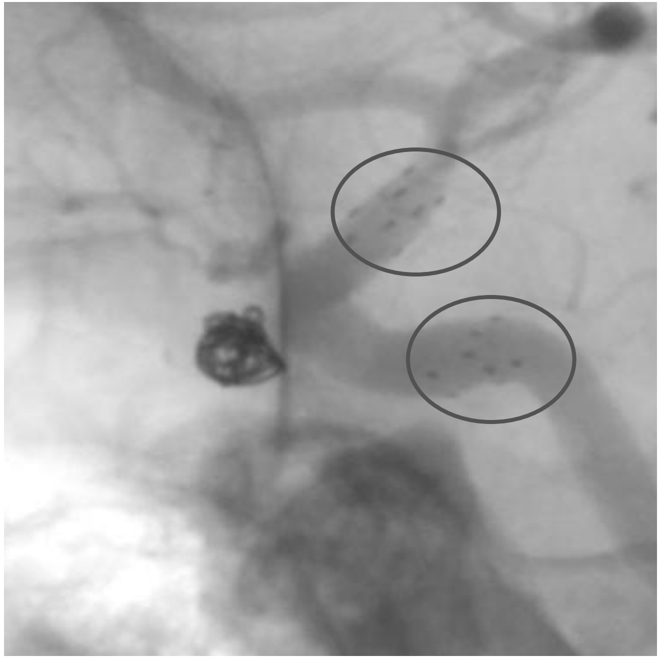
Planning of Neurosurgical Approaches

1. Minimal Invasiveness
2. Keyhole Approach
3. Tailored Approach

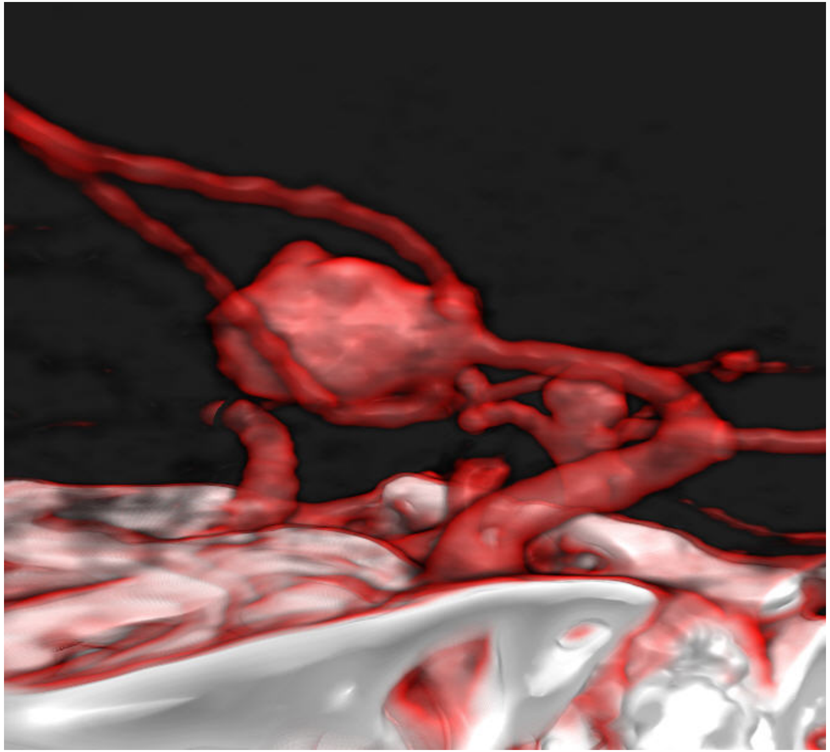
Dr. Stefan Wolfsberger,
AKH / Medical University Vienna

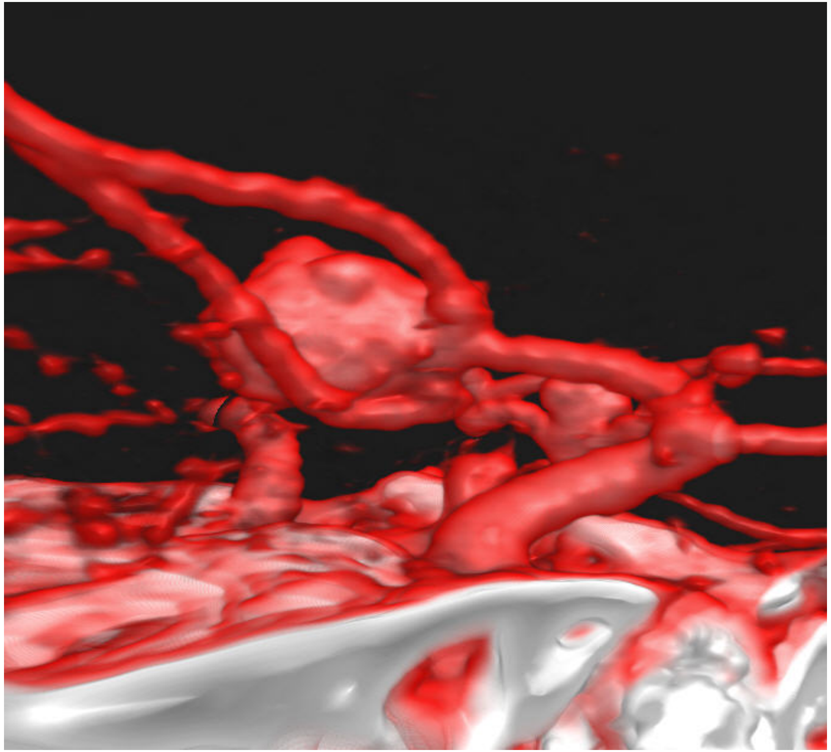
Stenosis: DSA (Digital Subtraction Angiography)





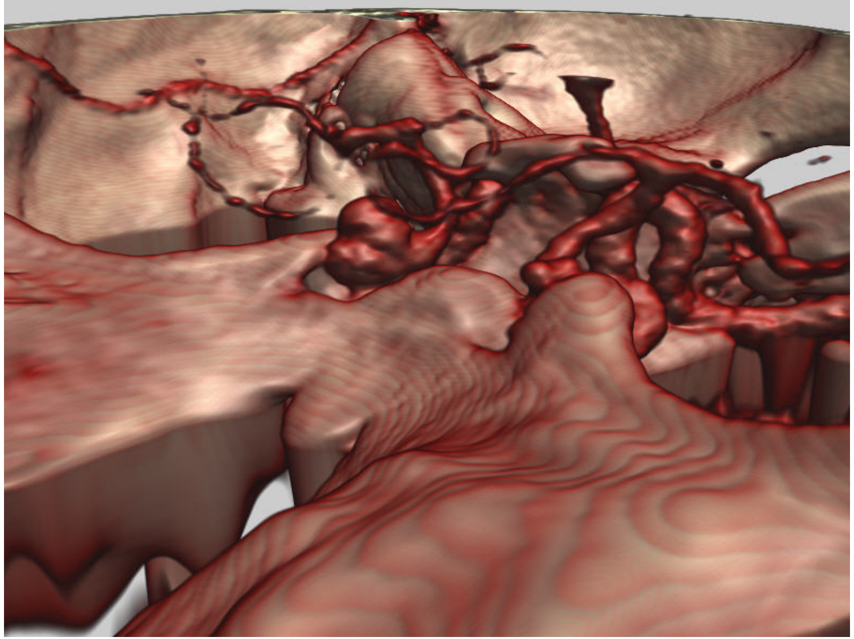
Aneurysm: CTA

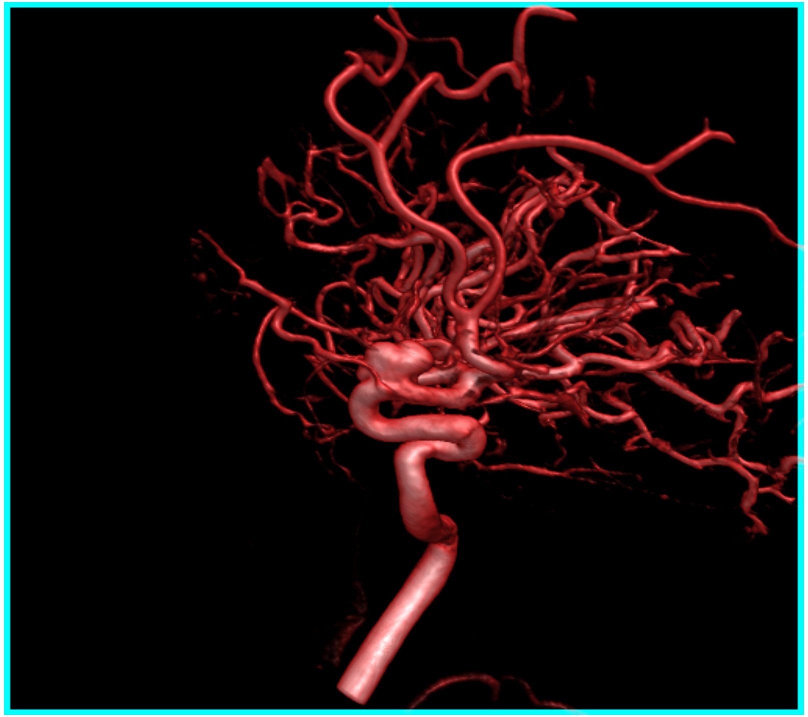




CTA, DSA

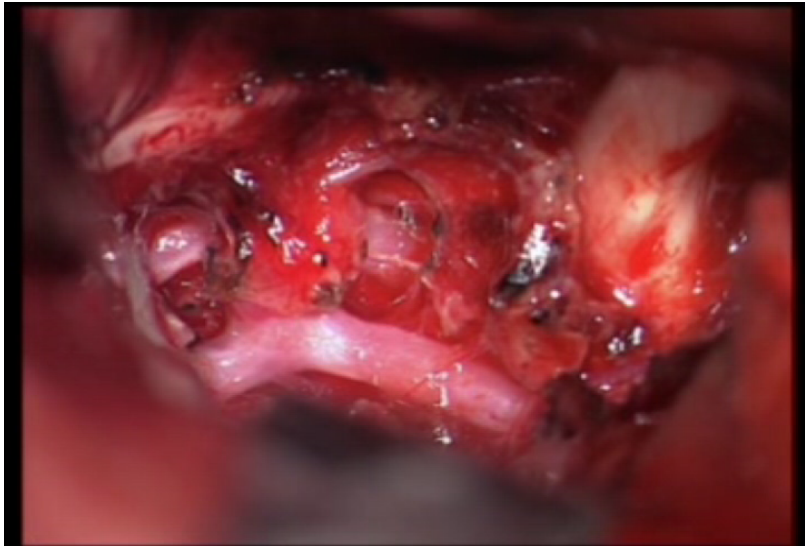
- Aneurysm

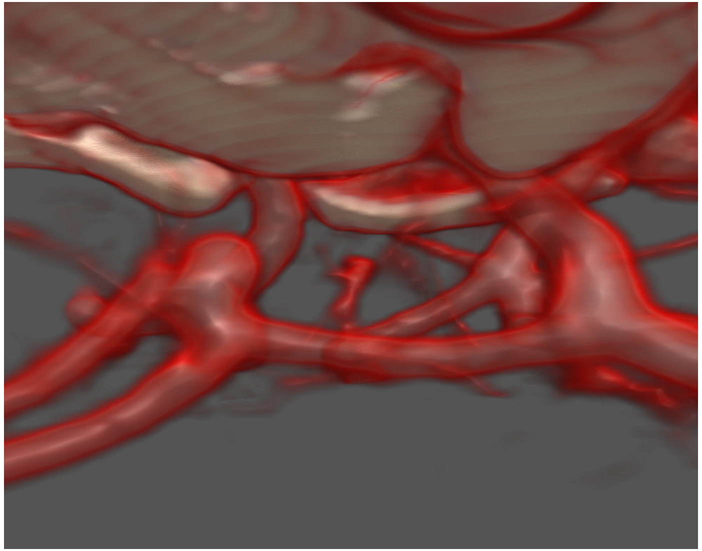




Aneurysm

- Intra-operative vs. CTA

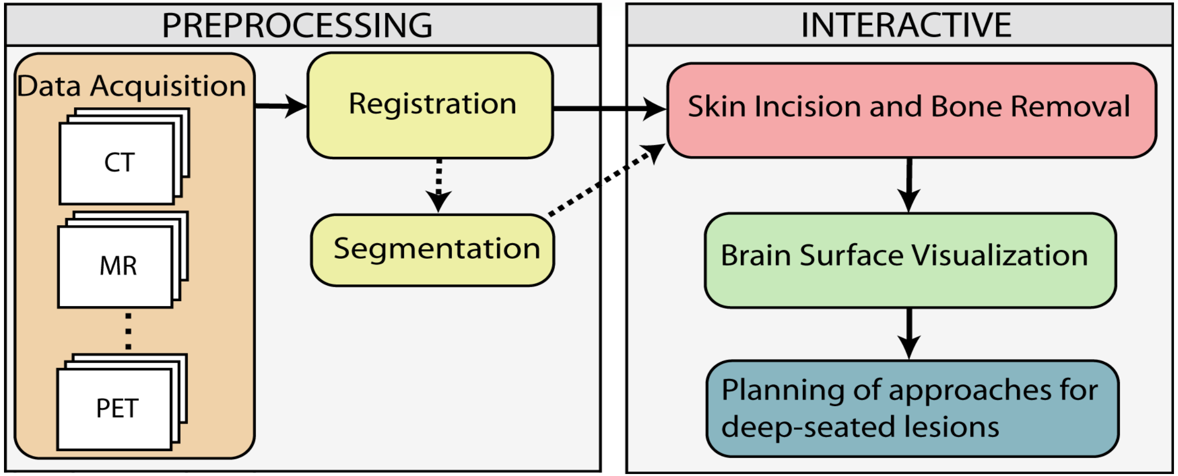




Application Example

Neurosurgical planning

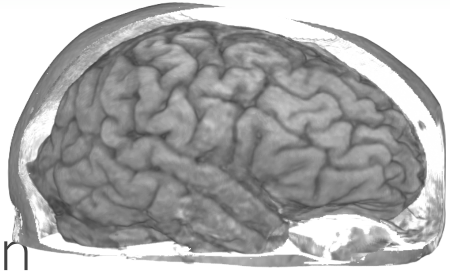
Preoperative Planning Workflow



- System built on GPU-based raycaster for segmented data
- Memory managment layer

Skull Peeling – Surgical Approach to the Brain

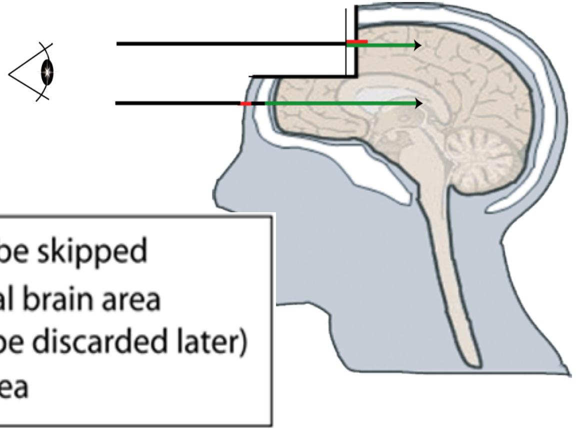
Problem:

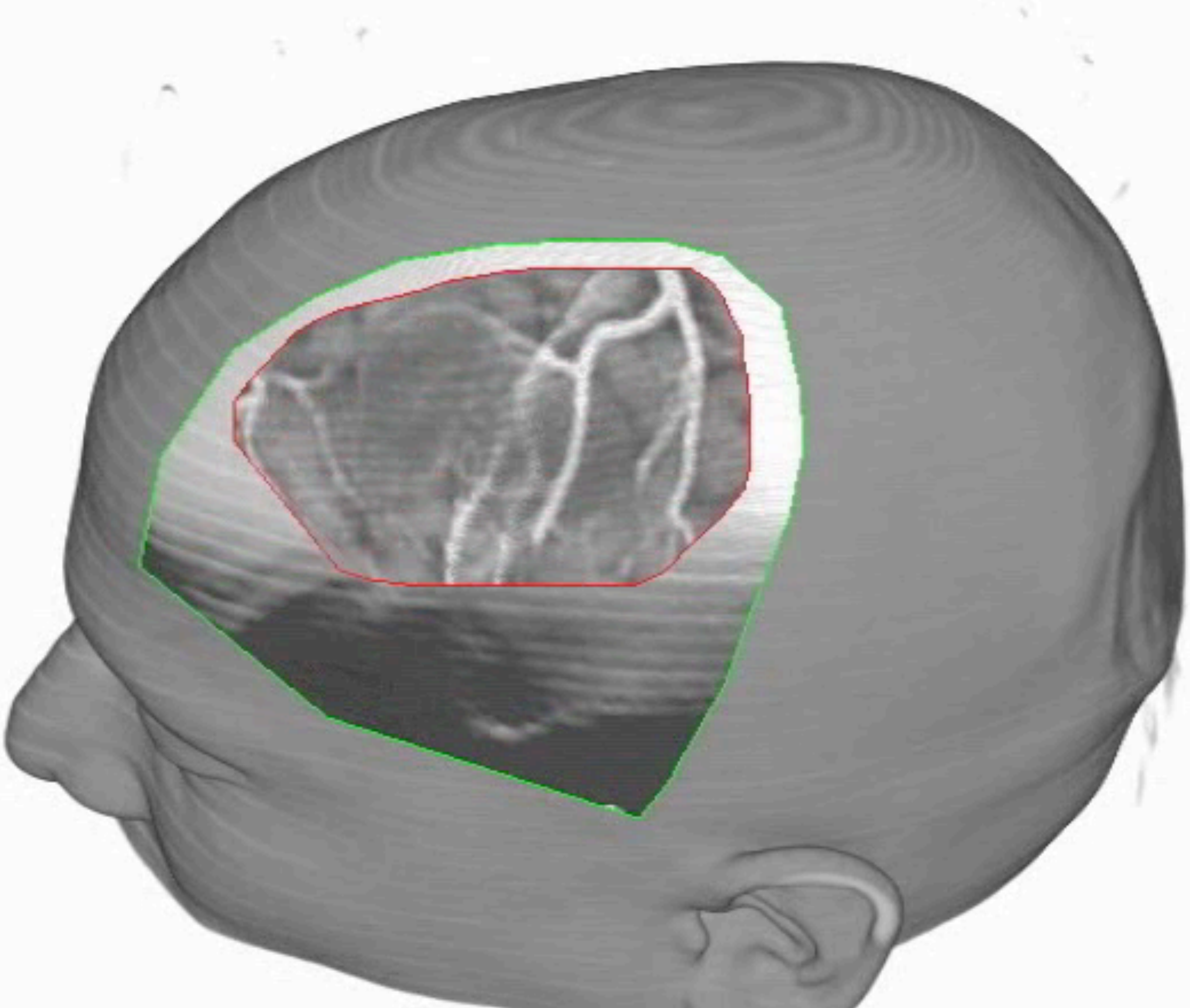


- Visualization of the brain‘s surface in volume rendering not possible without prior segmentation
- Segmentation still error prone and/or time consuming

Objective:

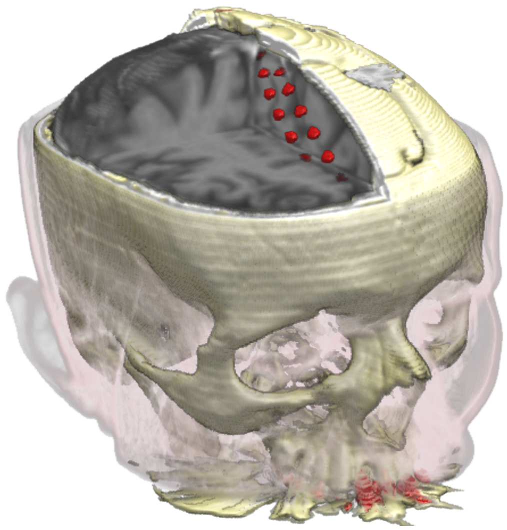
- Selectively remove structures obscuring the brain w/o segmentation





Segmented Multi-Volume Rendering – Deep Lesions

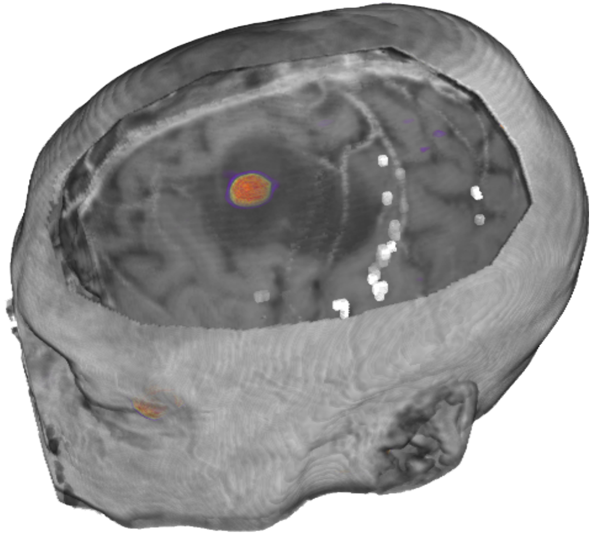
- Visualization of tumor and other important structures
- Requires segmentation information
- Each object has separate transfer function, clipping planes and render parameters

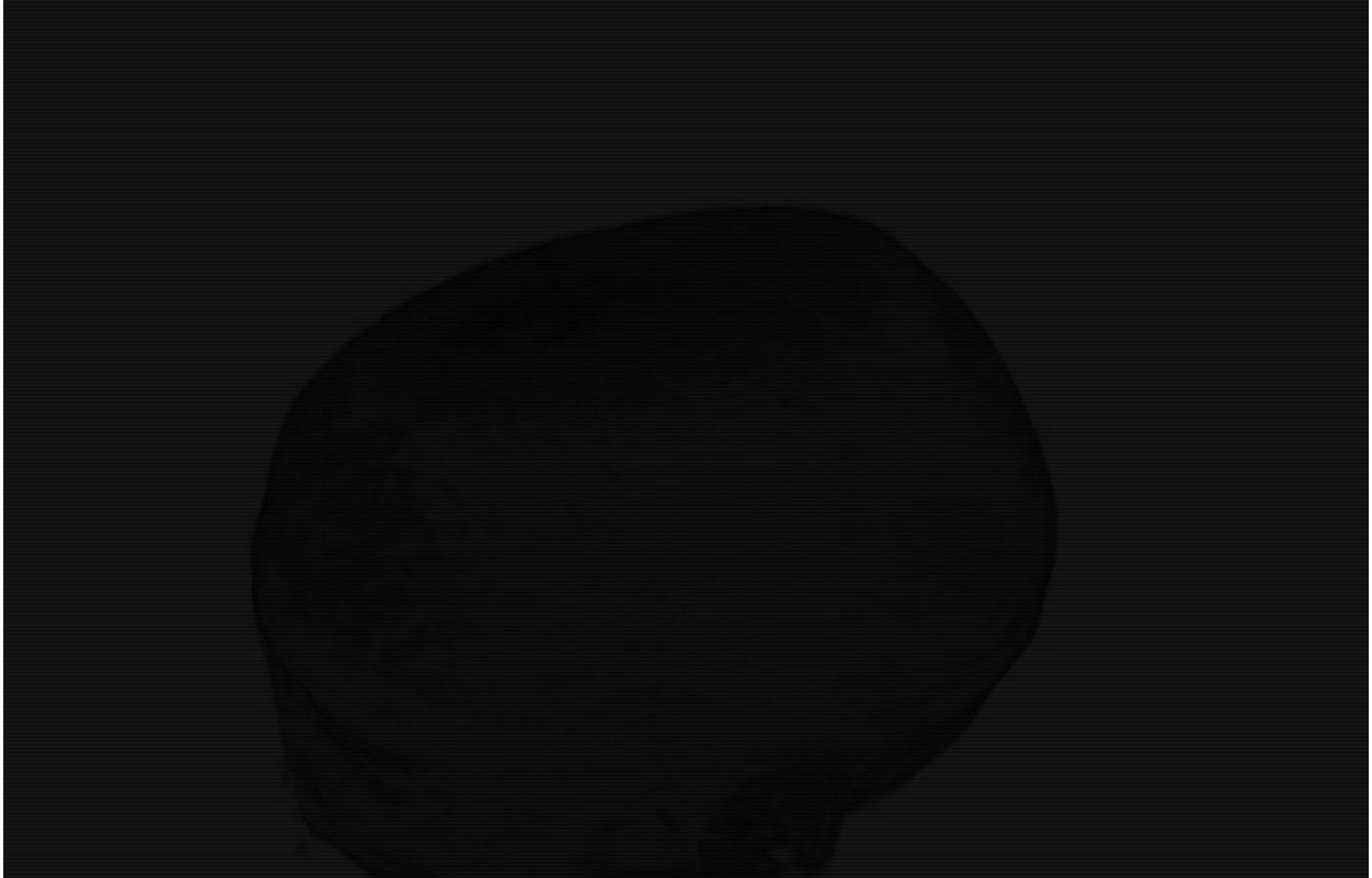


Multi-Volume Blending – Brain Surface Visualization

- Visualization of the brain and additional information (DSA, fMR, PET,…) after bone cover removal without prior segmentation
- Each volume has its own transfer function
- Different combination modes for different cases

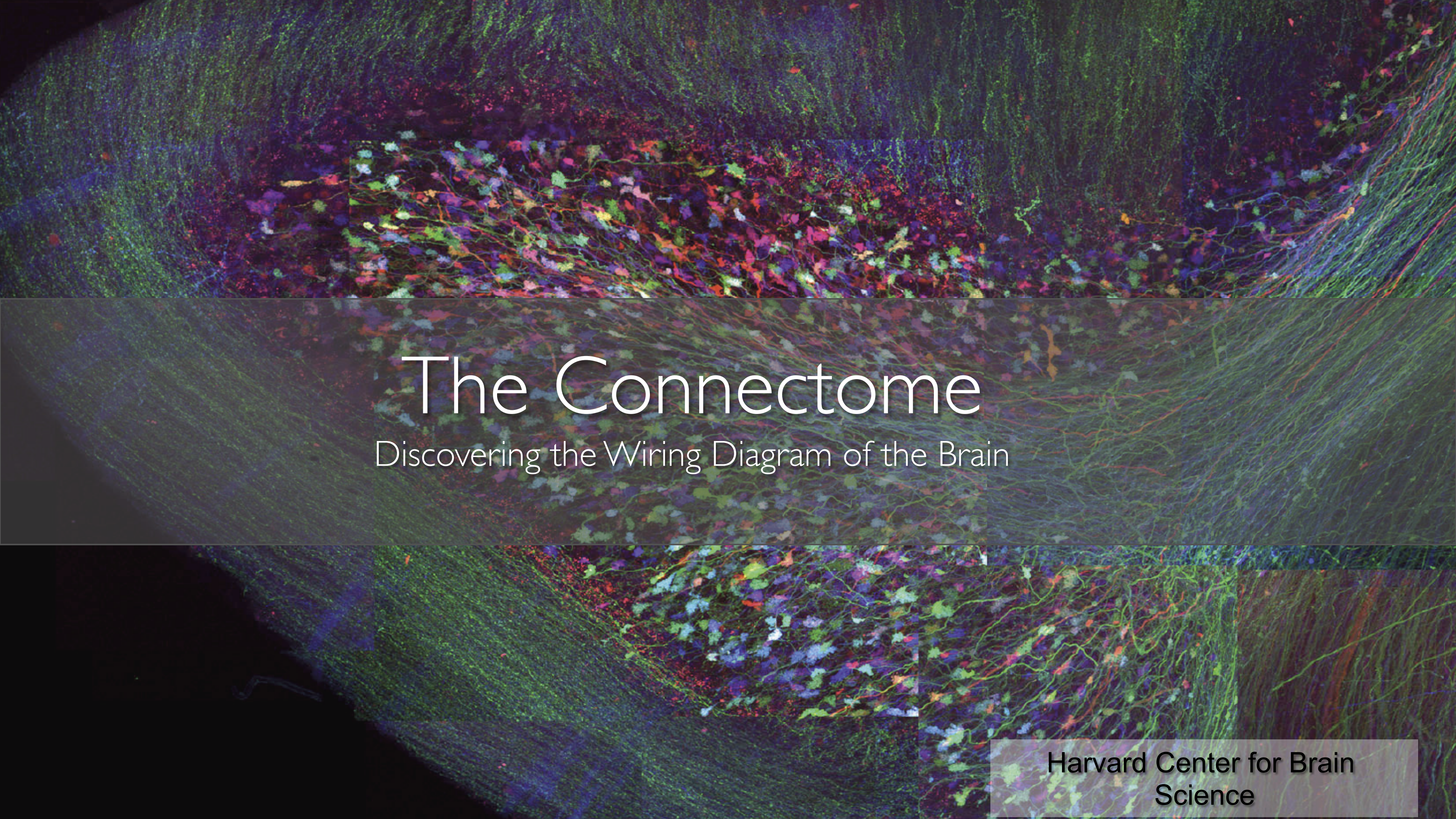
(e.g. MR-DSA, MR-PET)

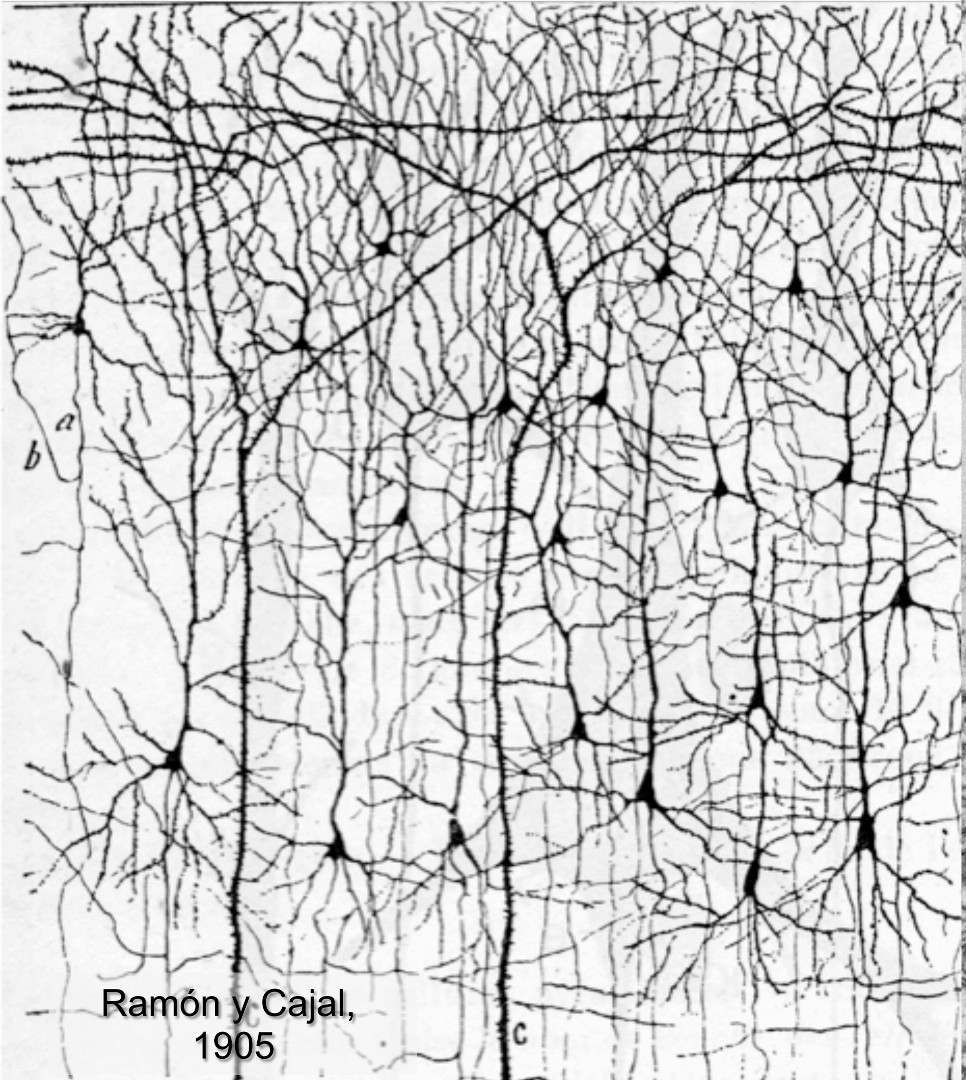




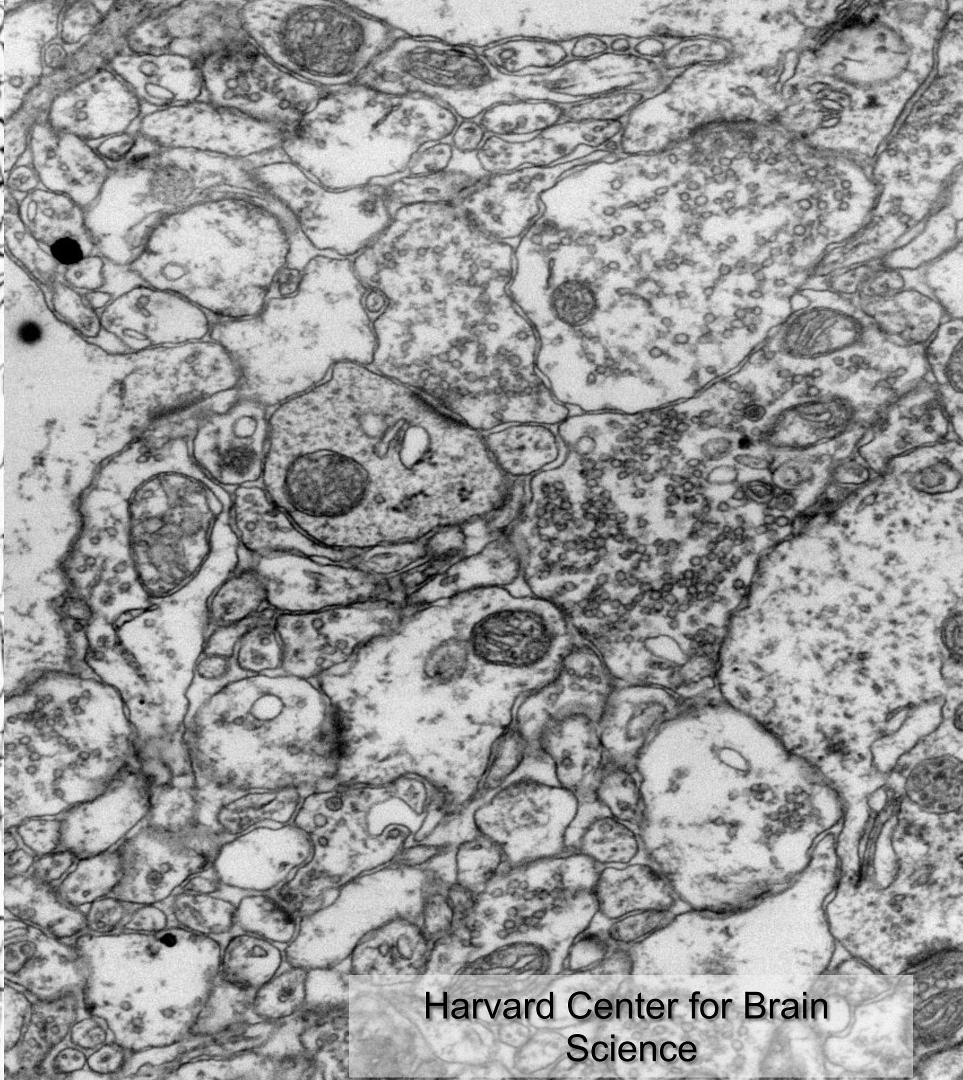
Application Example

Neuroscience

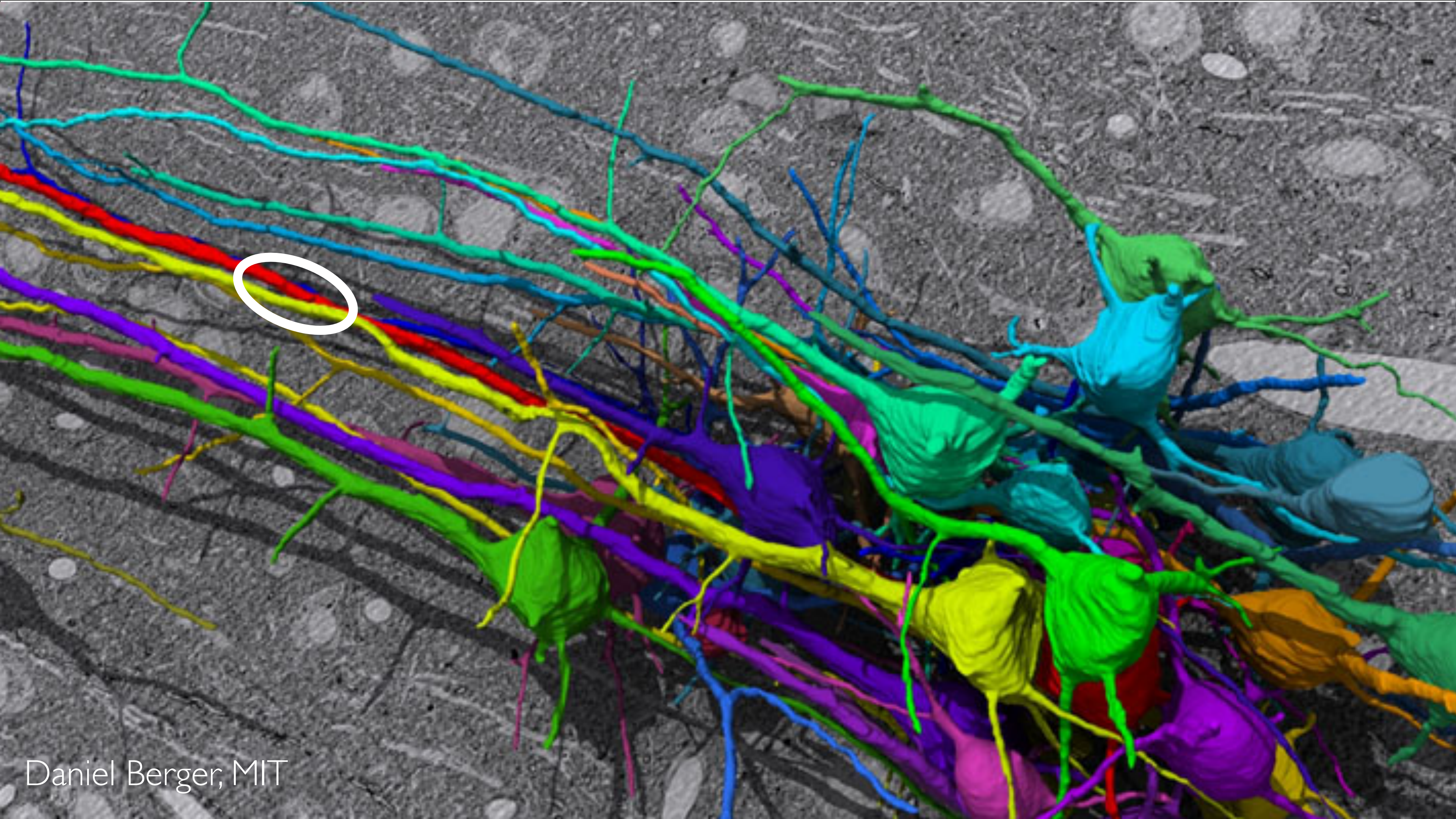

The Connectome
Discovering the Wiring Diagram of the Brain
Harvard Center for Brain Science

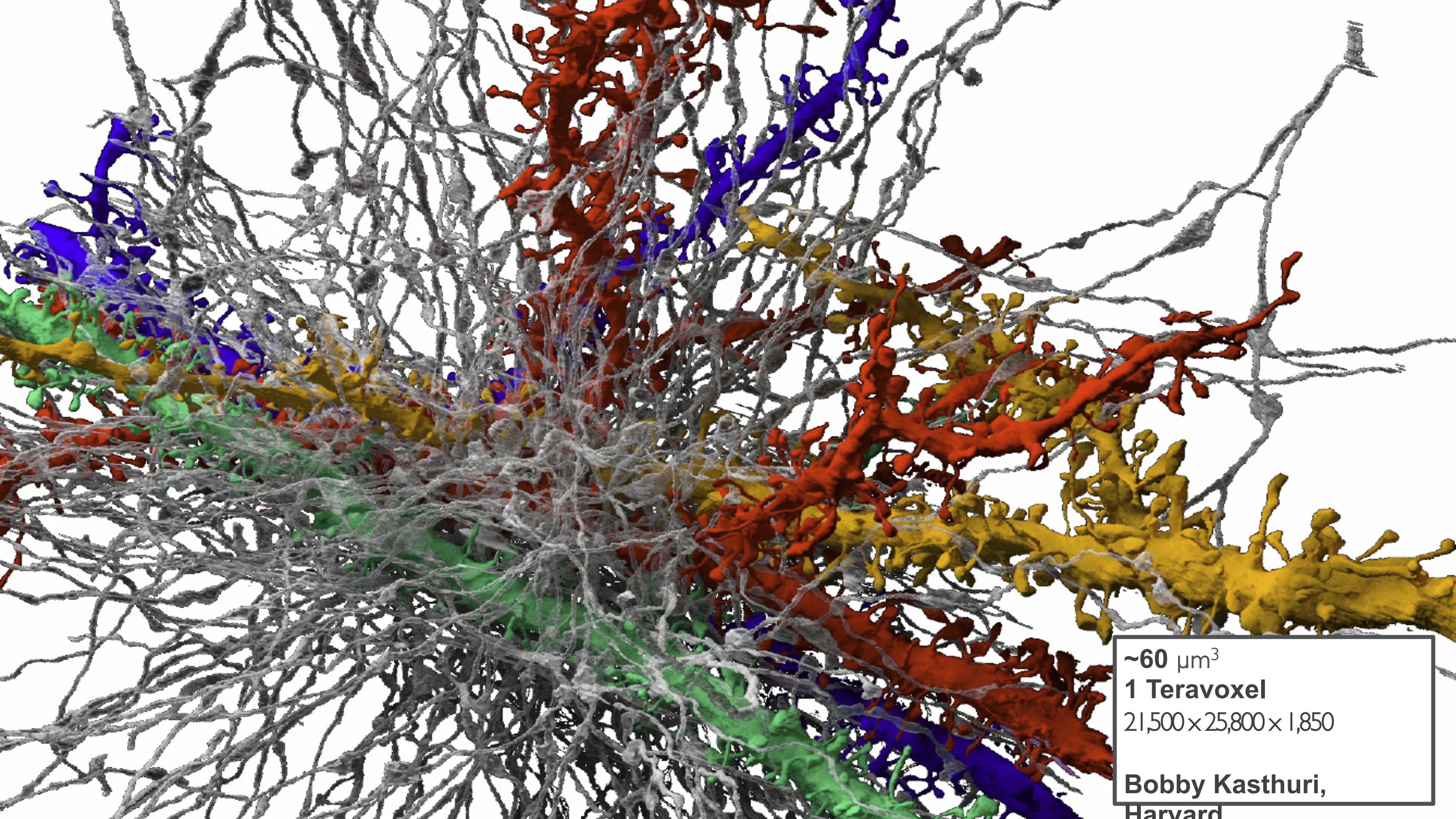


Ramón y Cajal,
1905

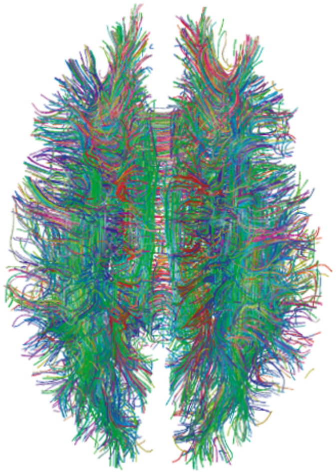


Harvard Center for Brain
Science

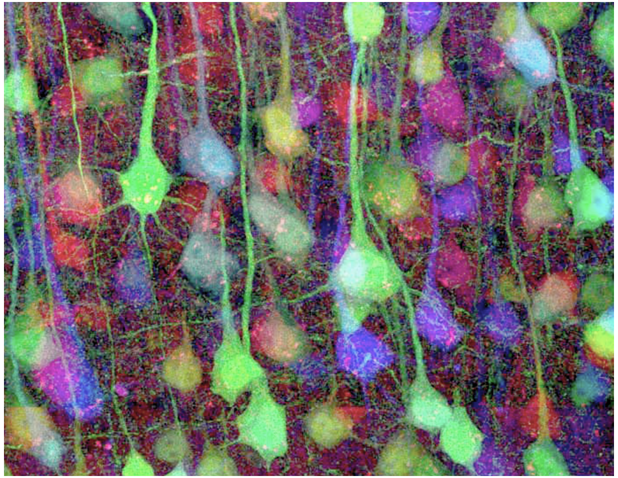

Daniel Berger, MIT


~60 μm^3
1 Teravoxel
21,500 × 25,800 × 1,850
Bobby Kasthuri,
Harvard

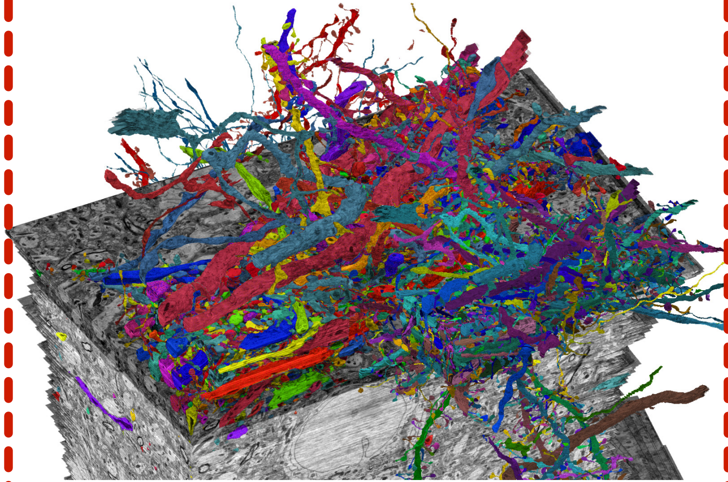
Connectomics



Macro



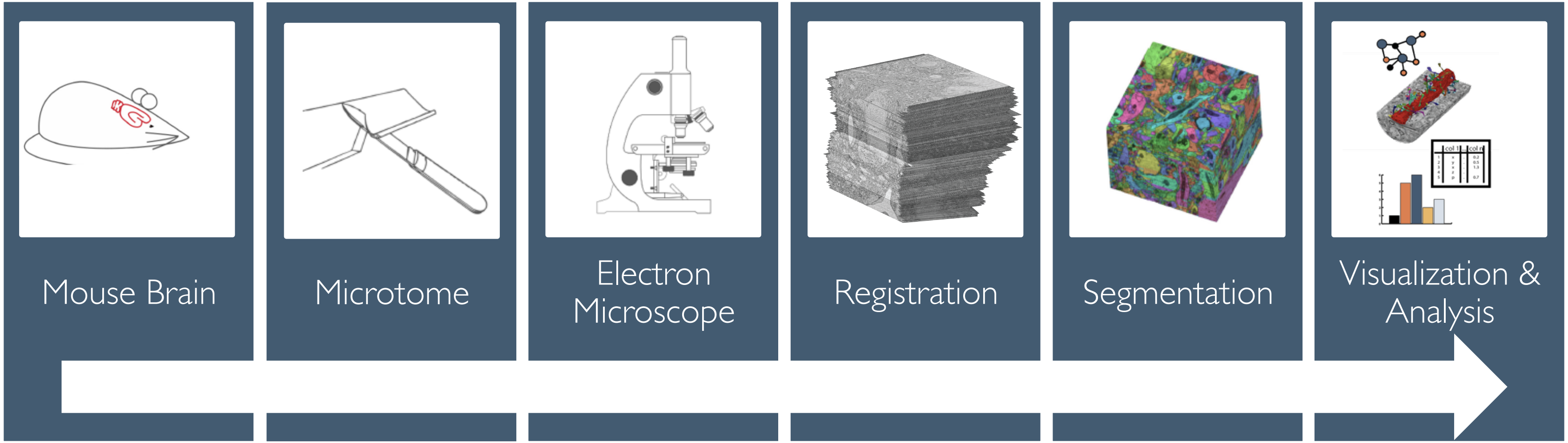
Meso



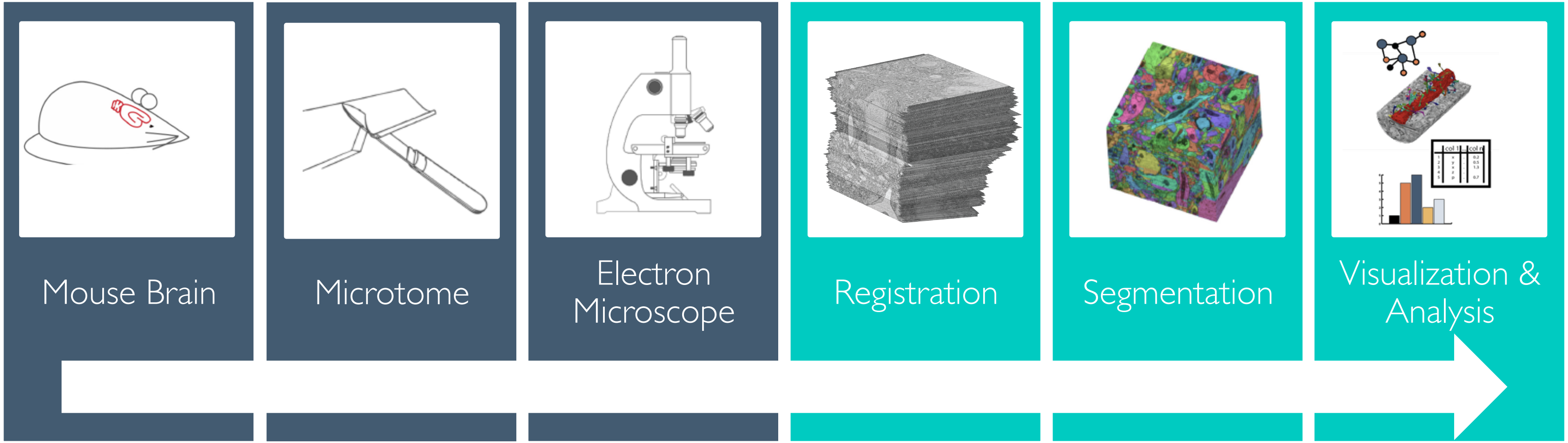
Micro/Nano

10^{-2} m ⟷ 10^{-9} m

Connectomics Workflow



Connectomics Workflow



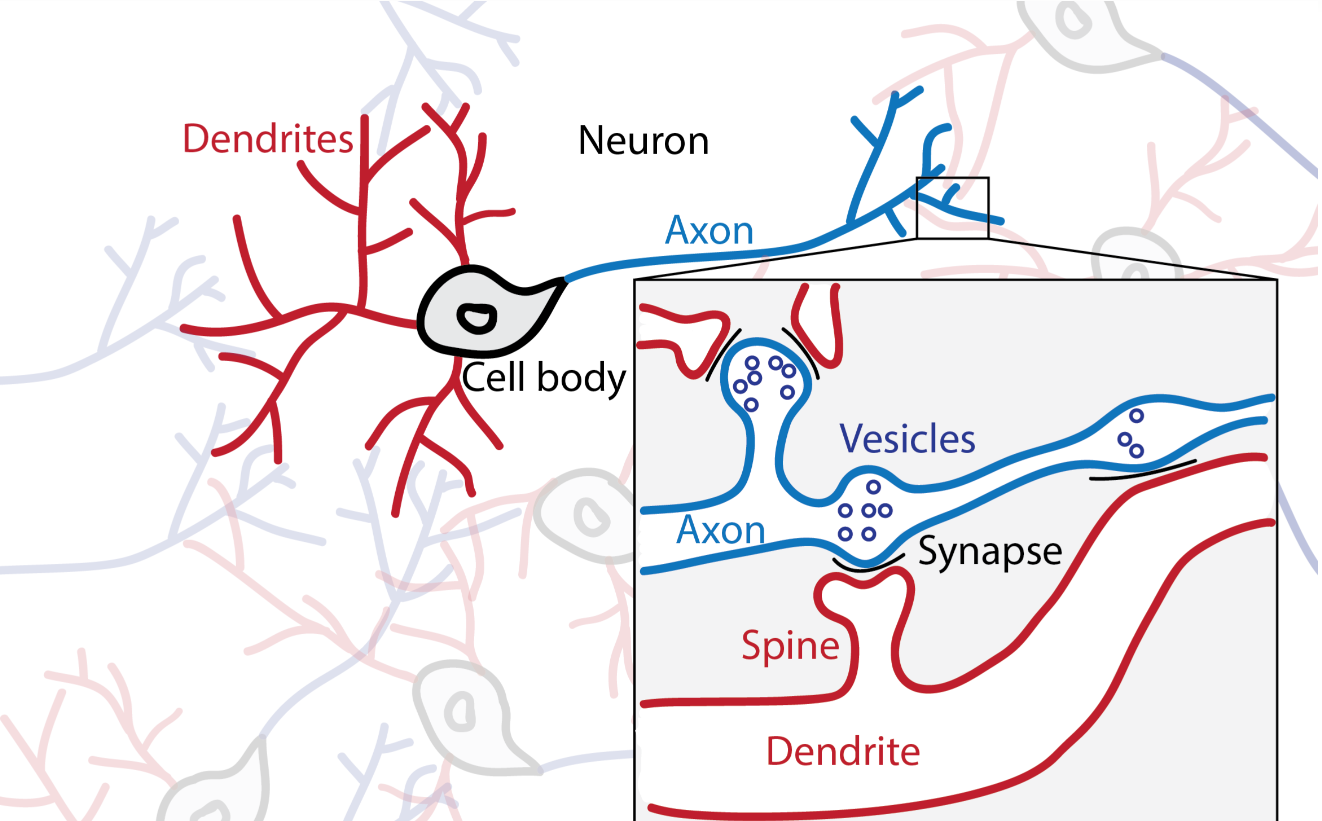
Electron Microscopy (EM) Volumes

- Pixel resolution : 3 to 5 nm
- Slice thickness : 30 to 50 nm

- 1 mm^3
  - 200k x 200k images x 20k slices
  - 40 Gpixels x 20k = 800 Tvoxels
  - 800 TB

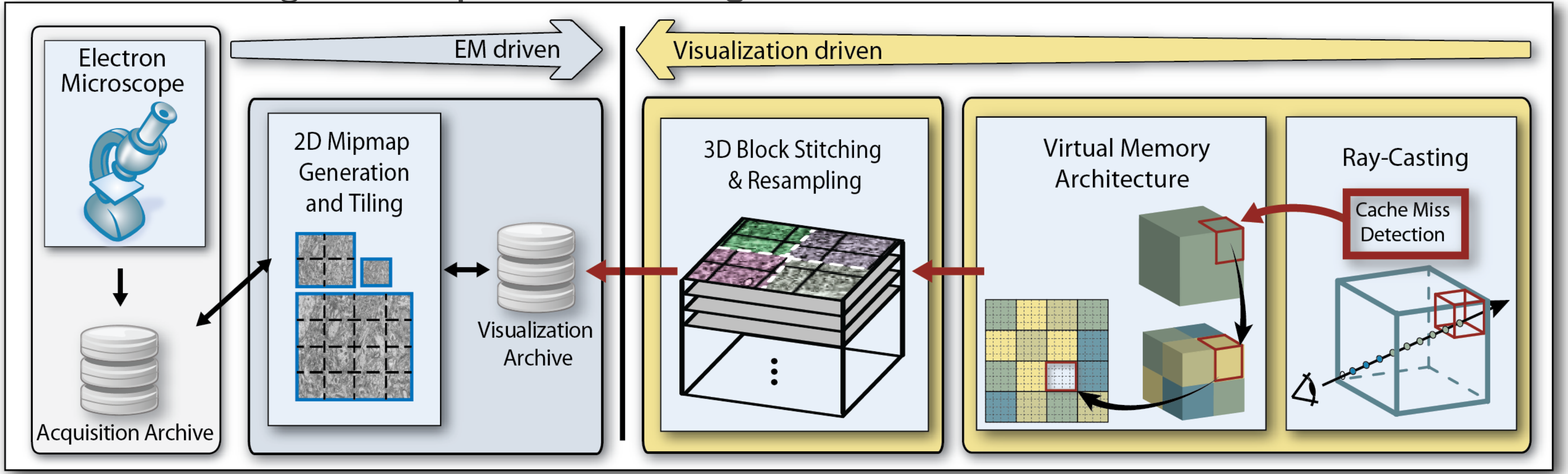
- 40 Mpixels / second
  - ~8 months

Neurons and Synapses



Petascale Volume Rendering

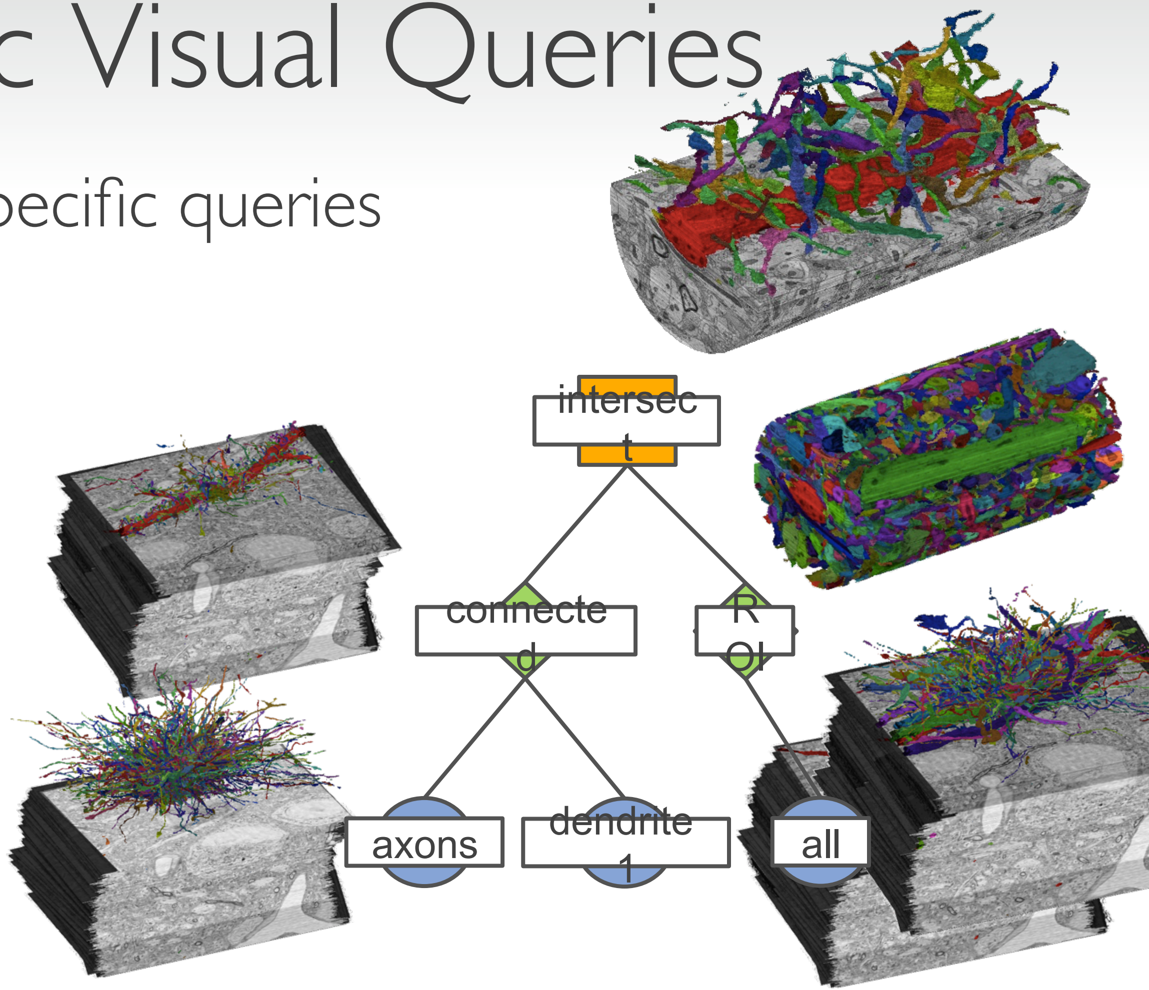
- Scalability:
  - Computational effort proportional to **visible data** and **screen resolution**
  - Working set **independent of original data size**



Dynamic Visual Queries

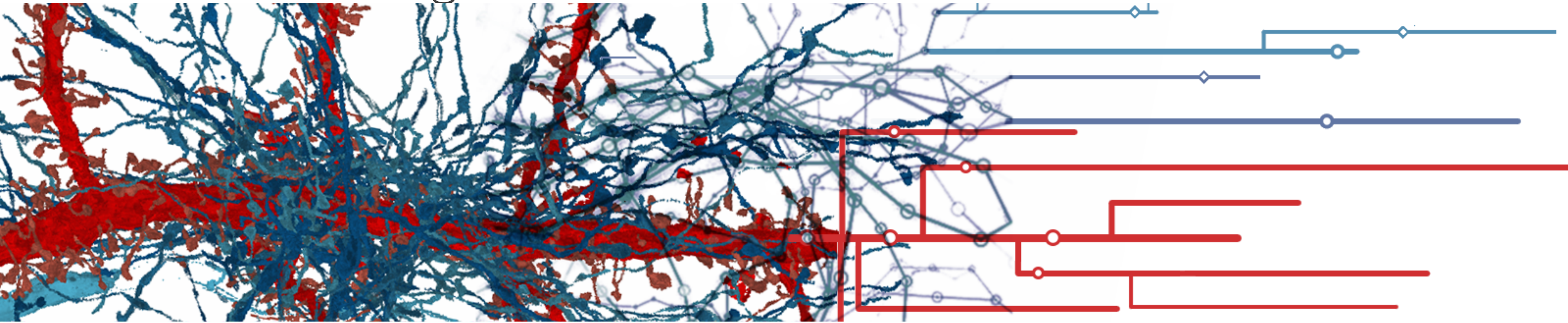
- Fully dynamic, domain-specific queries

- Components
  - Query algebra
  - Visual Set Creator



Neuronal Connectivity Analysis

- Connectivity analysis of ‘wiring diagram’
- Quick testing of hypotheses
- Scalable subway map inspired 2D visualization
- Linked with original 3D Data



Thank you.

- Thanks for material
  - Markus Hadwiger
  - Helwig Hauser
  - Eduard Gröller
  - Daniel Weiskopf
  - Torsten Möller
  - Ronny Peikert
  - Philipp Muigg
  - Christof Rezk-Salama

CS171 Reminders

- HW 3 and 4 due April 3rd
- Find team members for your final project
- Guest lectures on April 7 and 9