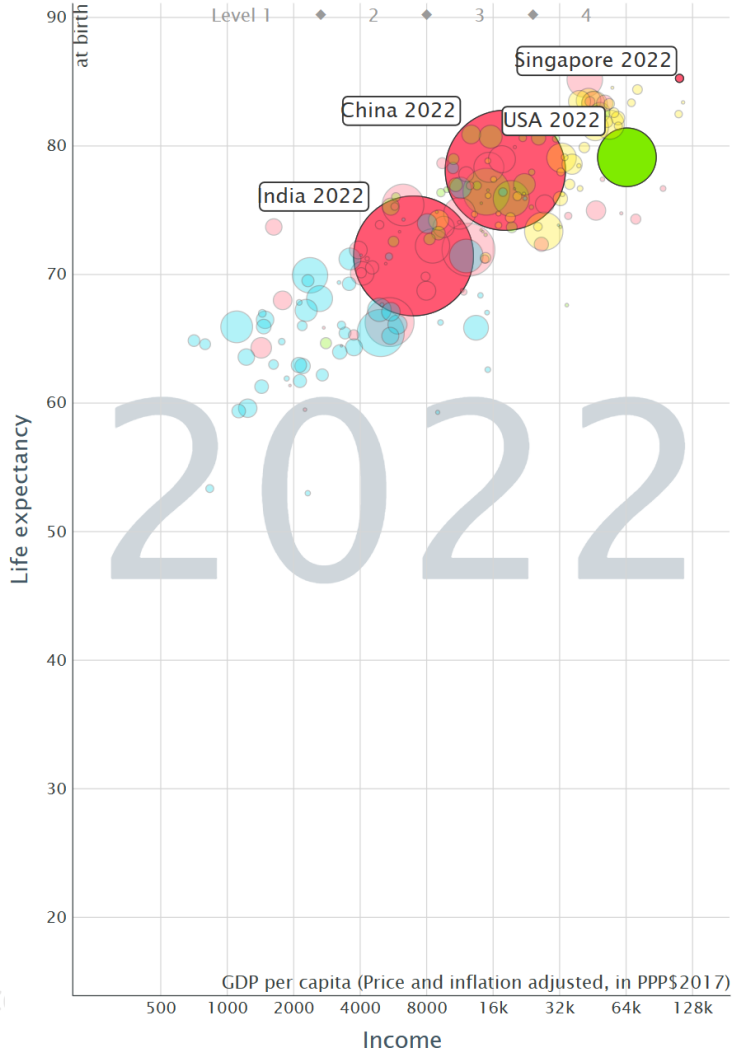
Visualization

Leonardo da Vinci's Codex Leicester: A New Edition

Studies of Turbulent Water shows Leonardo's understanding of how vortices move.Credit: Leonardo da Vinci, Studies of Turbulent Water, Royal Collection Trust/© Her Majesty Queen Elizabeth II 2019

What is Visualization? An example

- Gapminder: http://www.gapminder.org/world/



What is Visualization?

- For visual thinking and communication
- Techniques for creating images of data, in order to enable the data to be more easily, accurately and intuitively understood
- Knowledge Discovery + Knowledge Communication

Visualization Example

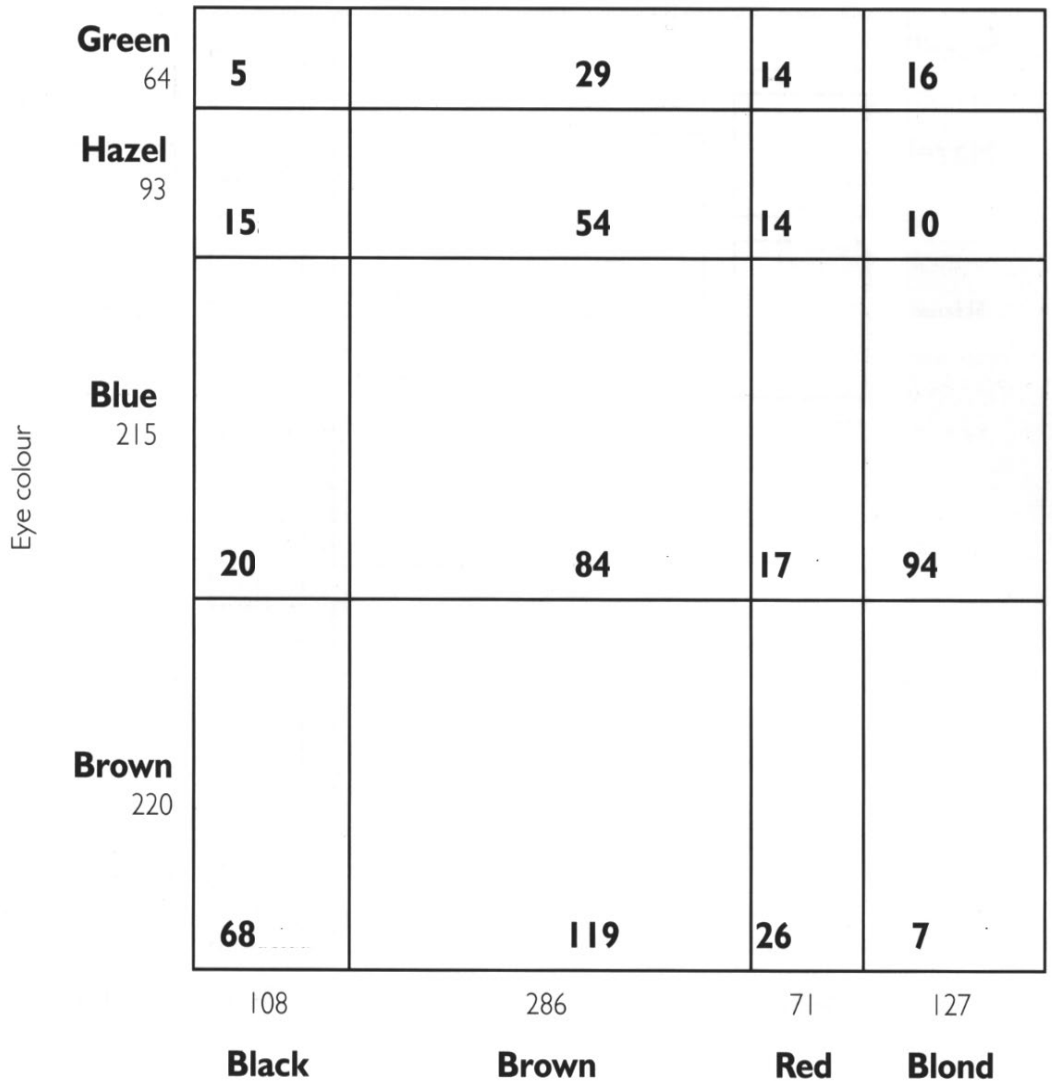
TABLE 2.1 Data concerning the hair and eye colour of 592 students

Eye colour	*Hair colour*				*Total*
	Black	*Brown*	*Red*	*Blond*	
Brown	68	119	26	7	220
Blue	20	84	17	94	215
Hazel	15	54	14	10	93
Green	5	29	14	16	64
Total	108	286	71	127	592

Robert Spence, Information Visualization, Addison -Wesley, 2001.

Visualization Example

- Column widths are defined by proportion of population having each hair color
- Row heights are likewise determined by the overall distribution of eye colors
- But hair color and eye color are not independent



Robert Spence, Information Visualization, Addison -Wesley, 2001.

Visualization Example

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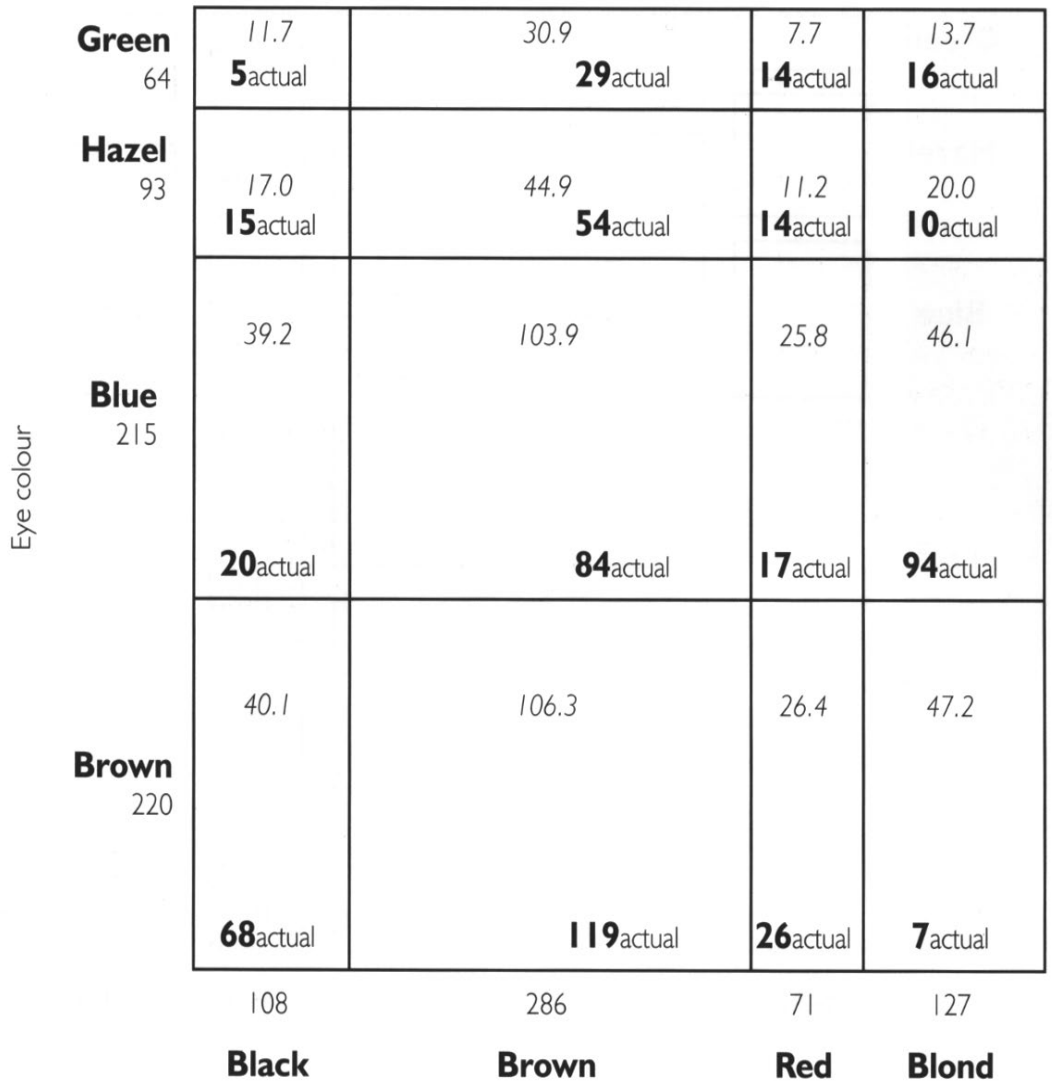
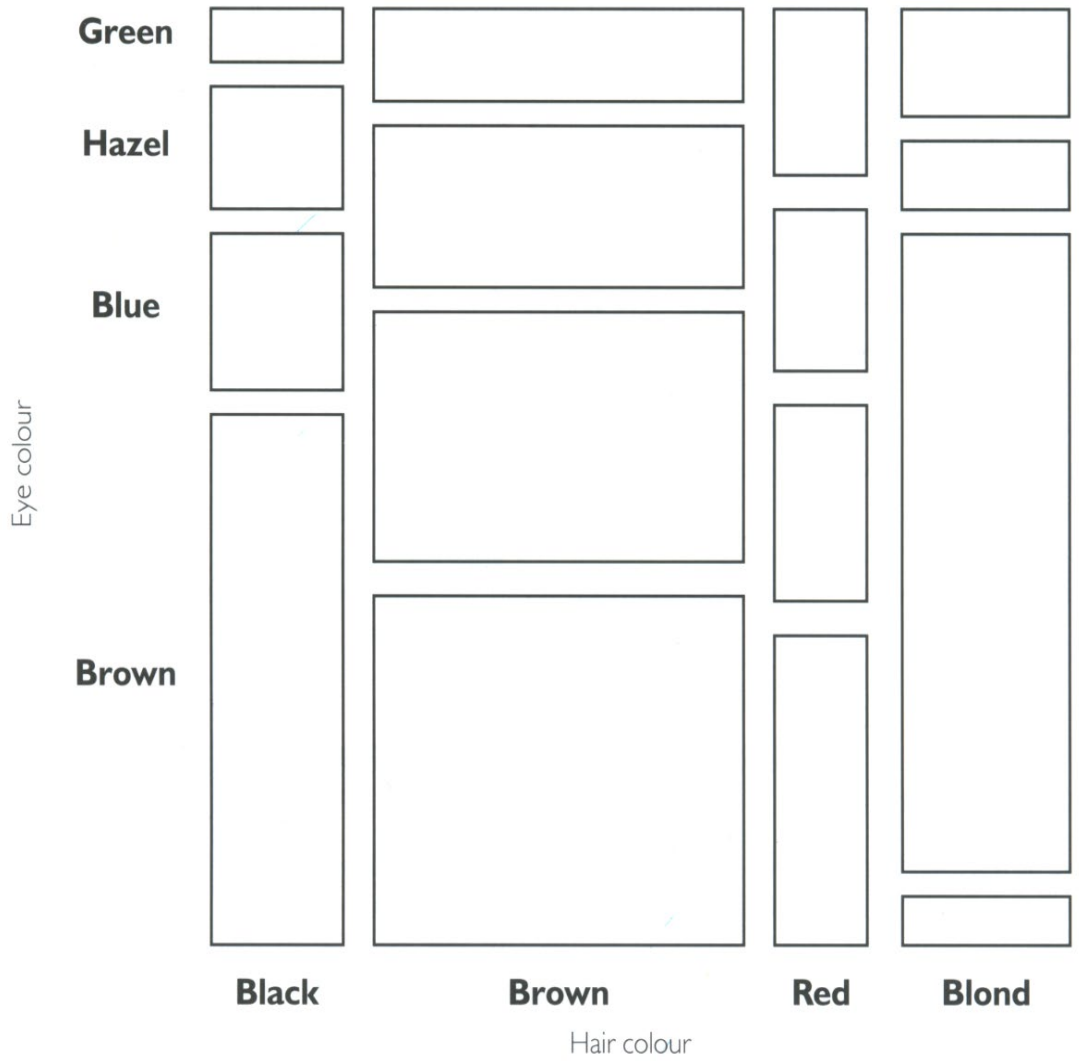


Robert Spence, Information Visualization, Addison -Wesley, 2001.

Visualization Example

- In this representation, the area of each rectangle is proportional to the number of observations in the corresponding pair of categories

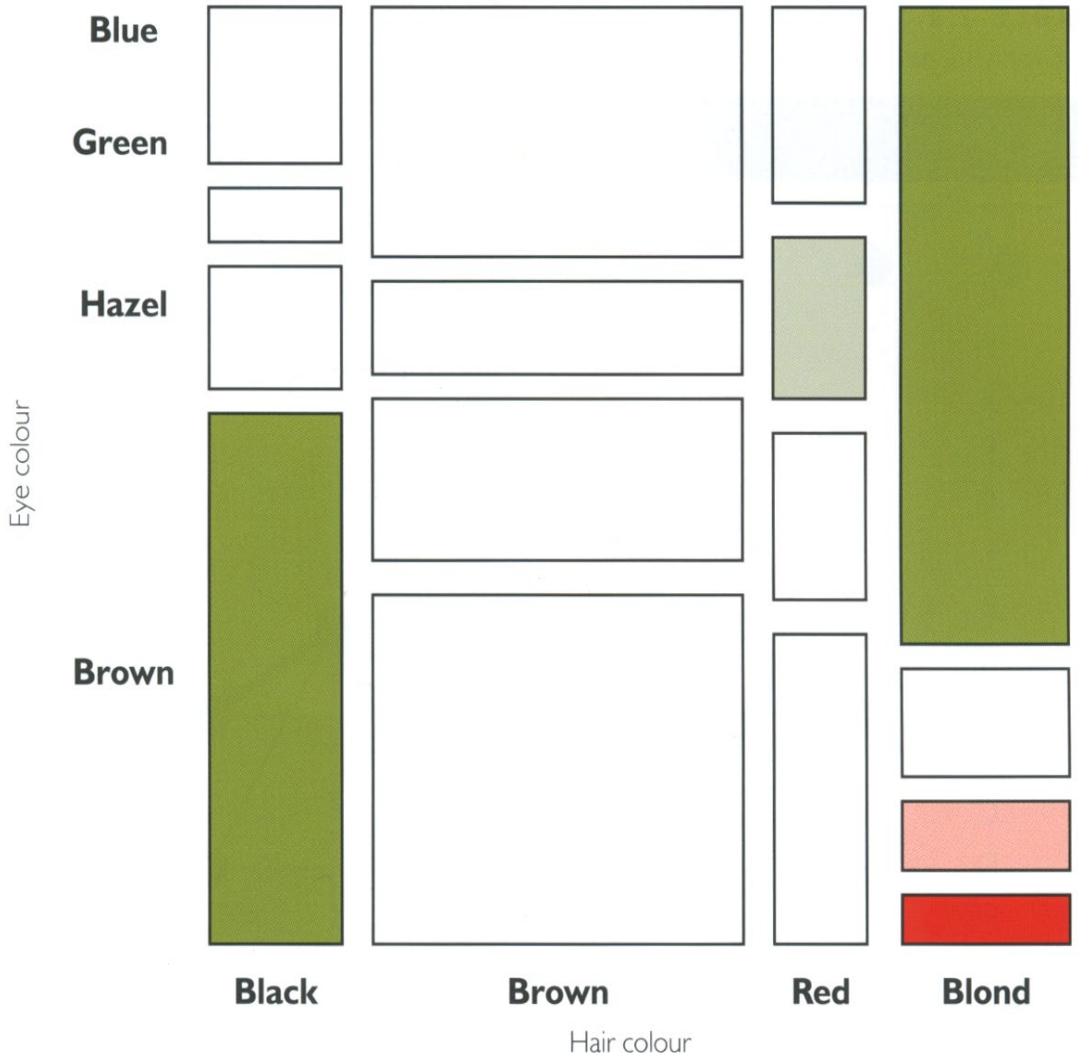


Visualization Example

- Rectangles are colored to indicate the deviation from the area that would have been indicated if the variables were independent

[green = more common;

red = less common]



Note: this may not be the optimal visualization design for this case, the color and the rectangle area are redundant – we could simply color the original gridded rectangles to convey area modulation (e.g., red means larger than the rectangle).

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Every day a staggering 2.5 exabytes of data is generated making our world increasingly difficult to understand.

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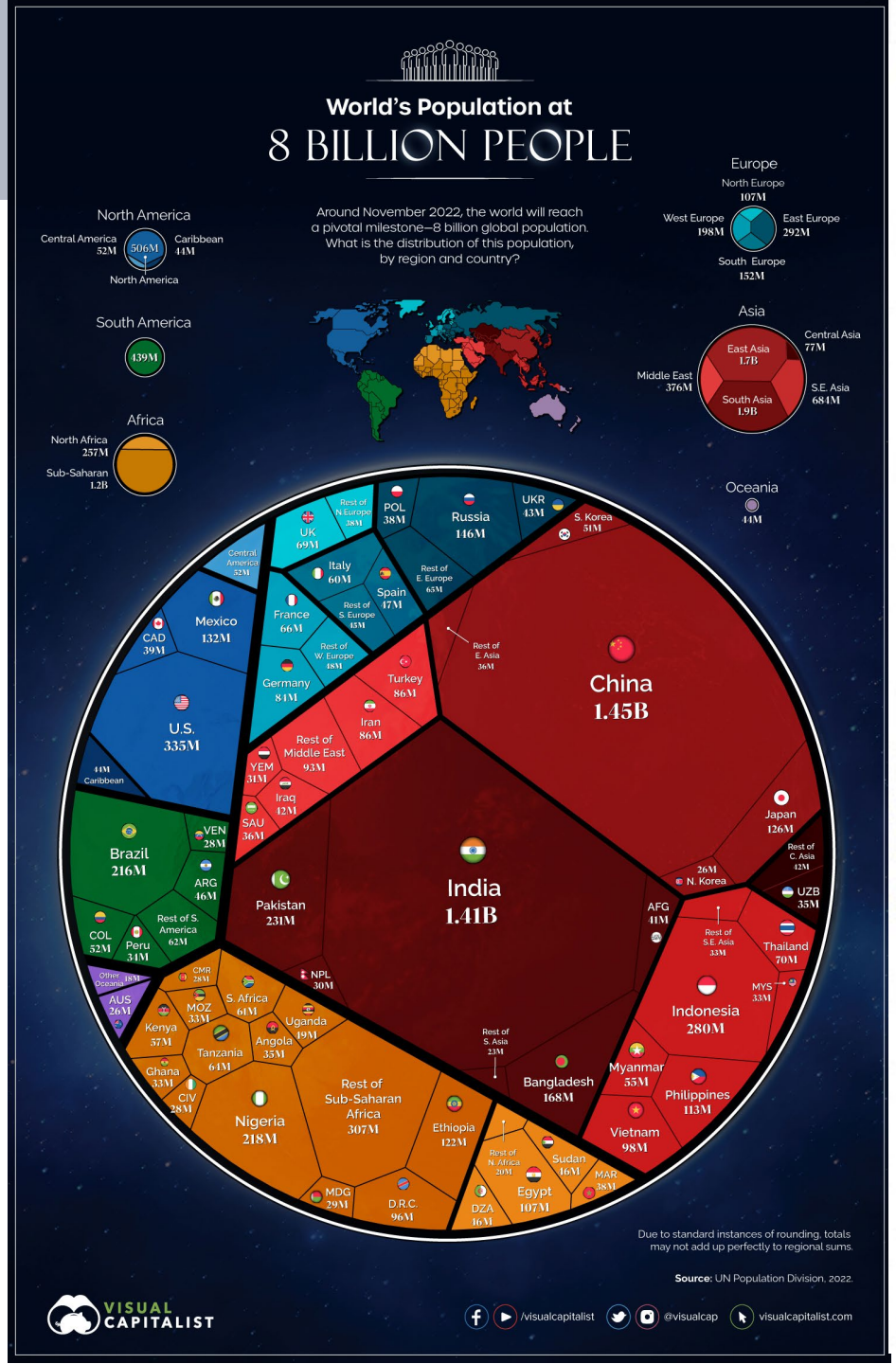
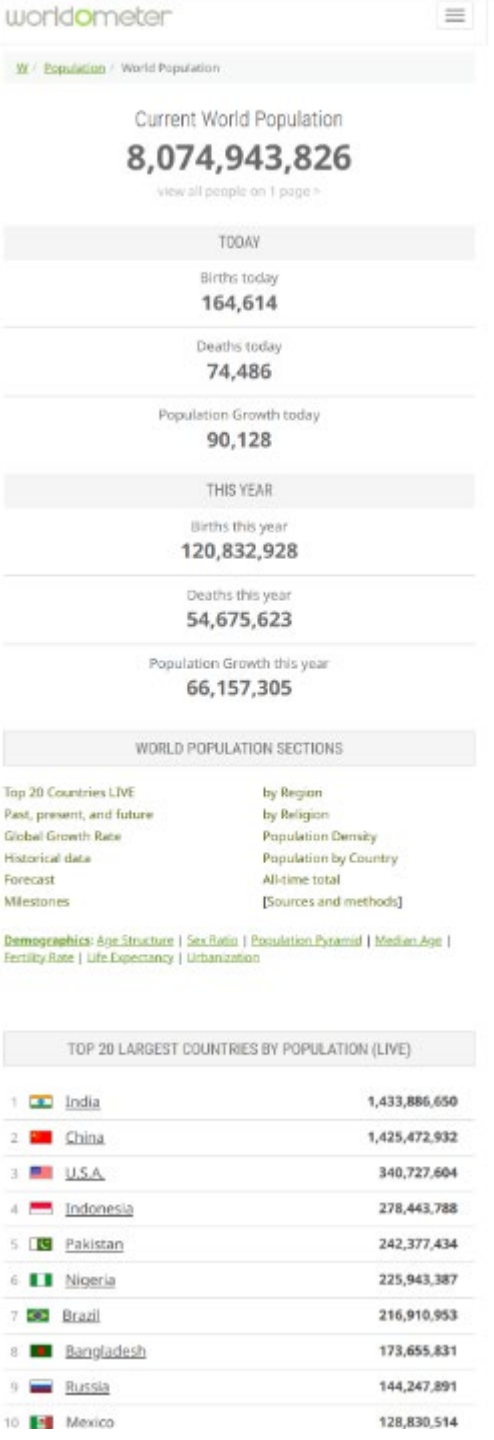
https://www.visualcapitalist.com/





Three Stages in Visualization

- Visual design
  - Deciding how best to depict the data
- Implementation
  - Developing algorithms to create the desired images
- Evaluation
  - Objectively determining the impact on task performance

History of Modern Visualization

- Being its own discipline for more than 30 years
  - First dedicated conferences: 1990 (co-founded by Arie Kaufman)
  - Conferences:
    - ACM SIGGRAPH occasionally publishes papers on visualization
    - **IEEE Visualization (SciVis, InfoVis, VAST), now IEEE VIS**
      - **VAST: Visual Analytics Science and Technology**
    - EuroVis
    - PacificVis
    - ChinaVis, and others
  - Journals:
    - ACM Transactions on Graphics occasionally publishes papers on visualization
    - **IEEE Transactions on Visualization and Computer Graphics** (Founding Editor-In-Chief: Arie Kaufman)
    - Computer Graphics Forum
    - Others

Basic Categories of Visualization

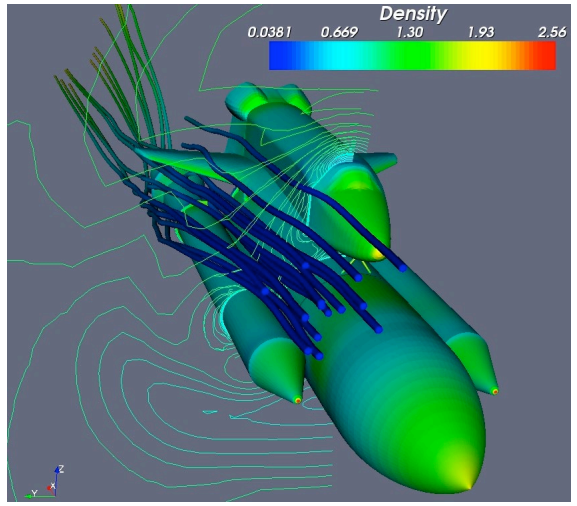
By domains:

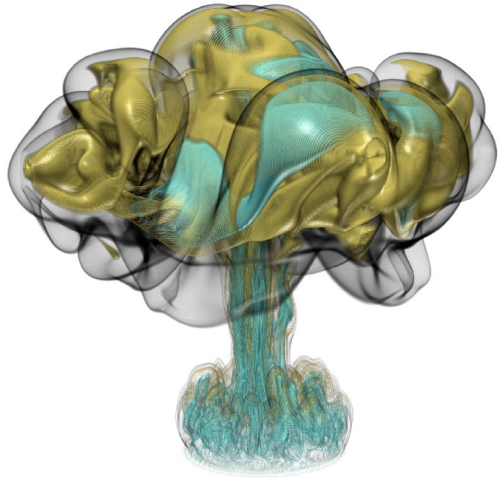
- Scientific Visualization
- Medical visualization
- Information Visualization
  - Applies to data that lacks an intrinsic spatial organization
- VAST

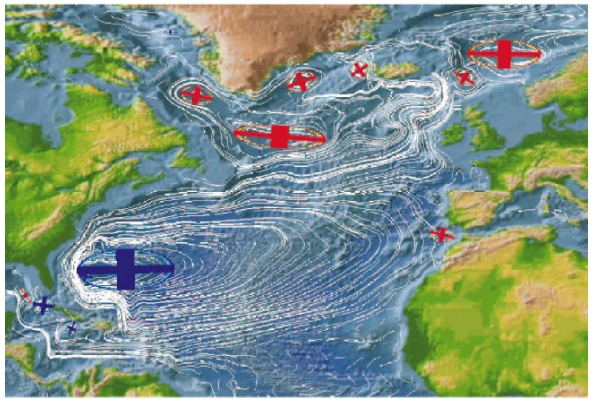
Scientific Visualization

use of computer graphics to create visual images which aid in understanding of complex, often massive numerical representation of scientific concepts or results.

- **Simulations:**
  - Mechanical engineering
  - Fluid dynamics
  - Air dynamics
  - Weather simulation
  - …

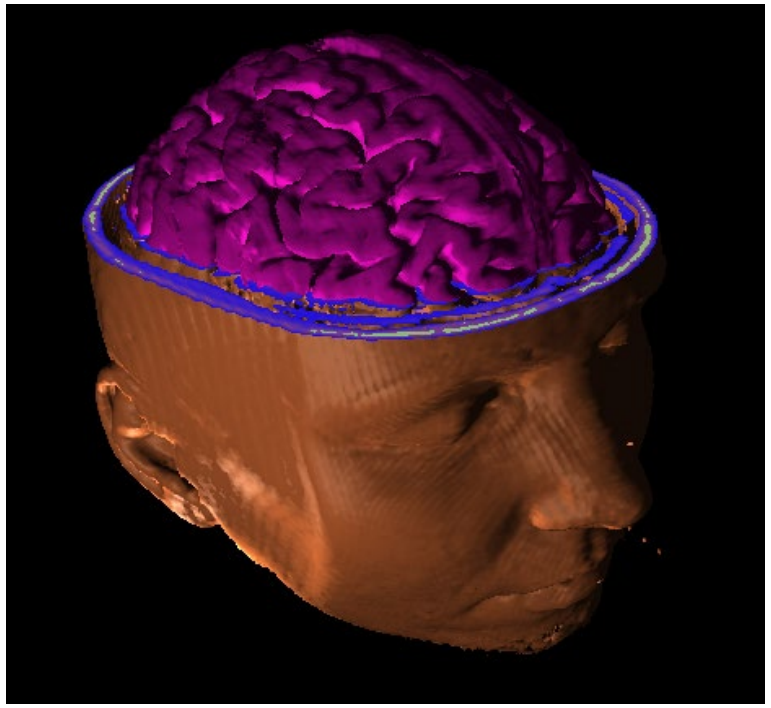


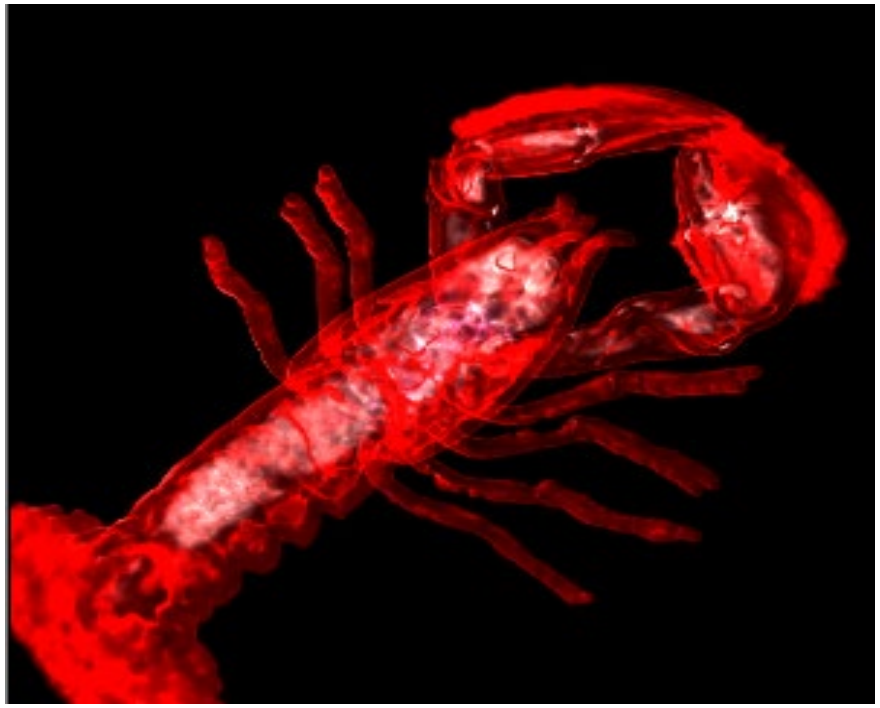




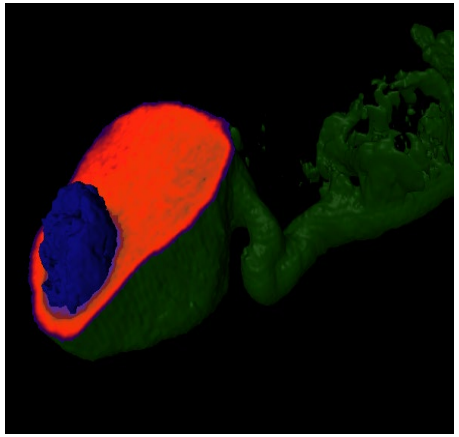
Medical visualization

Visualizing bio/medical imaging (starting from the 80s')
"Real Data" Visualization

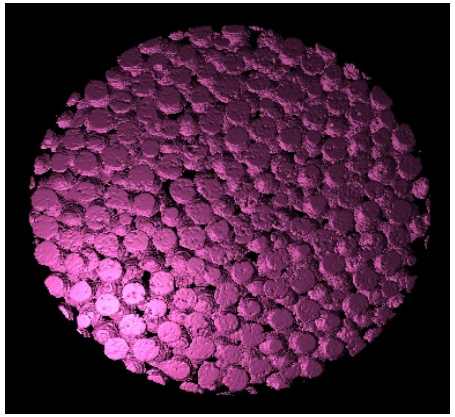




MRI / CT / PET / Ultrasonography



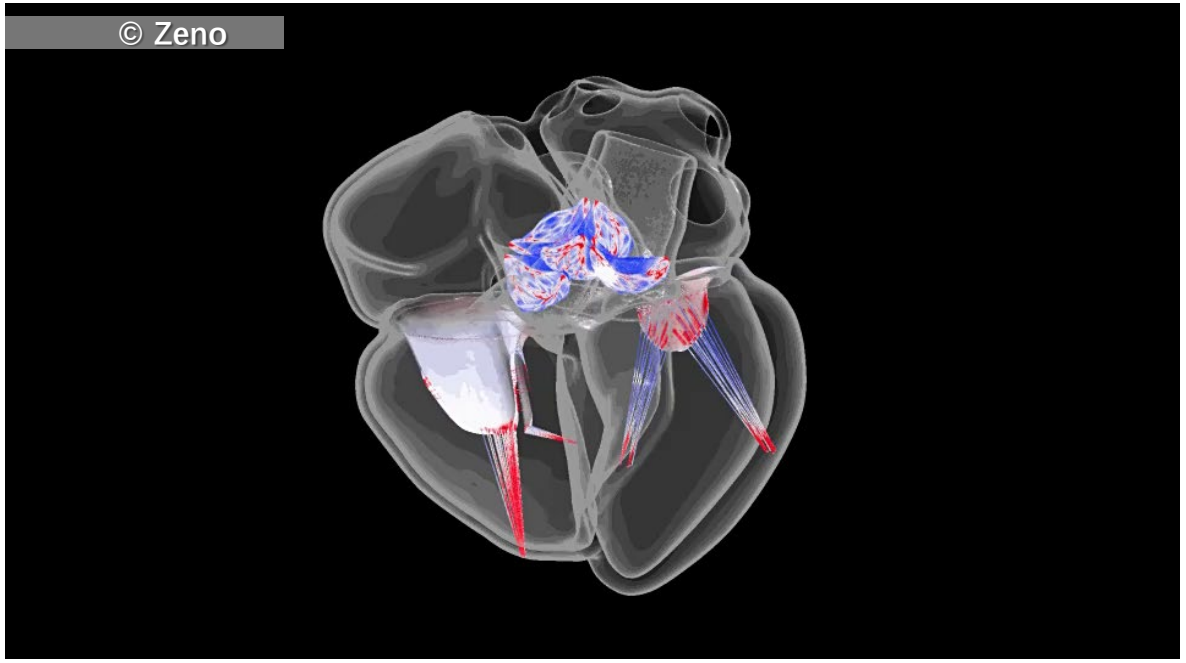
Confocal Microscopy



Micro-Tomography

Medical visualization

- “Synthetic Data” Visualization



Information Visualization

- Map Vis
- Mathematical vis
- Molecular vis
- Stock vis
- Financial Vis
- Politics Vis
- Flight routes vis
- Social networks vis
- Network vis
- Event Vis
- Traffic Vis
- Software Vis
- Text Vis
- Music visualization
- …

What else you can think of?

Data

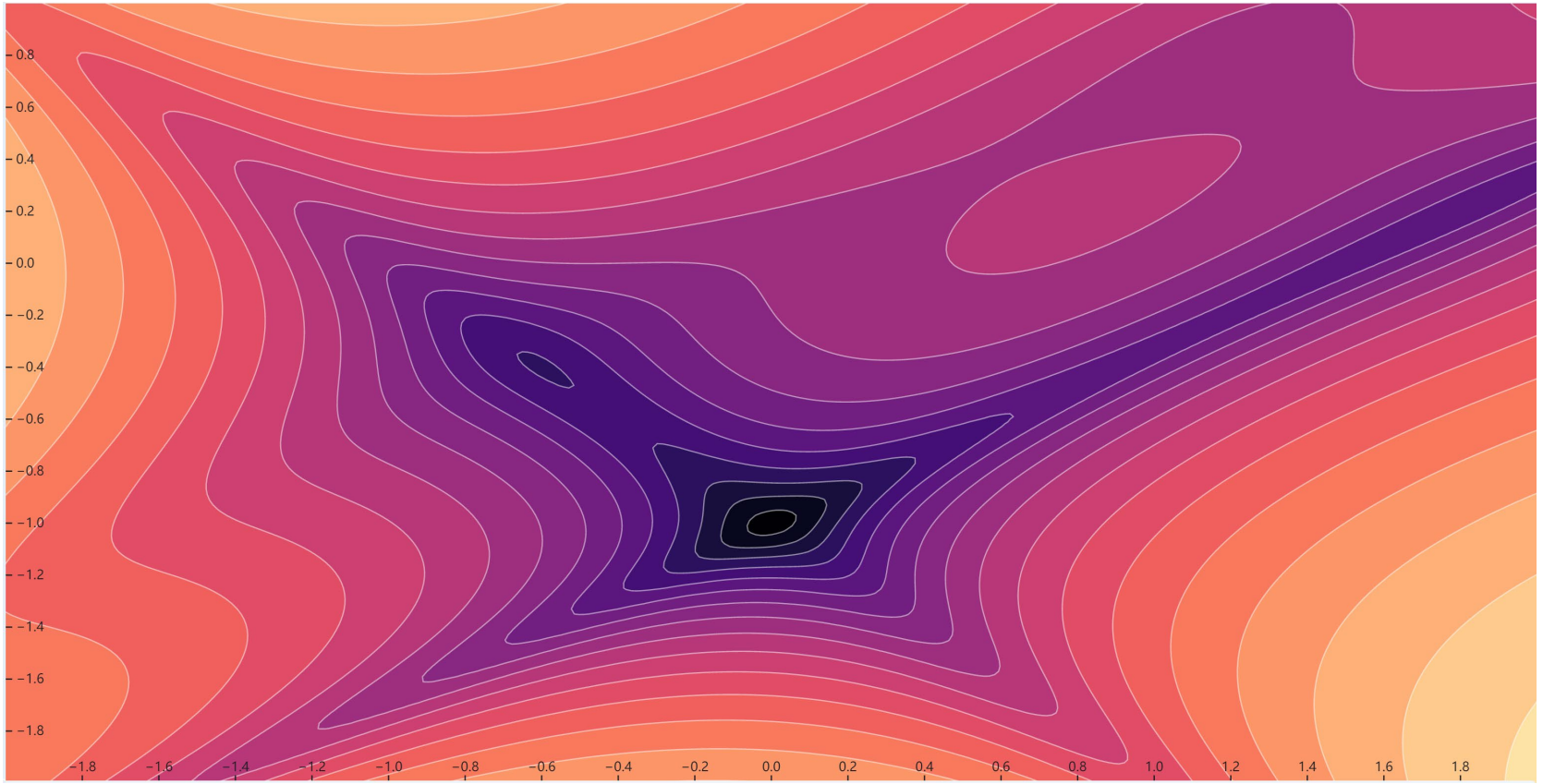
- **Data property**
  - Scalar
  - Vector
  - Tensor
- **Data struction**
  - **Spatial domain**
    - **Surface** data**:** Meshes or parametric representations
    - **Volume** data, further, storage pattern:
      - Rectilinear grids (medical data, e.g., CT, MRI datasets; or scientific simulation)
      - Curvilinear grids (scientific simulation)
      - Unstructured grids (scientific simulation)
  - **Spatiotemporal domain:**
    - data sequence
  - **Non-spatial structural data (information) :**
    - table, graph, tree, flow …

Scalar Field Visualization (here 2D domain)

- given by a function $f(x_1, \cdots, x_n)$: $R^n \Rightarrow R$ with *n* independent variables x_i
- High fields, temperatures, pressures, potential energy, eigenvalues, etc
- Draw contour lines

1	1	1	1	1
1	2	3	2	1
1	3	3	3	1
1	2	3	2	1
1	1	1	1	1

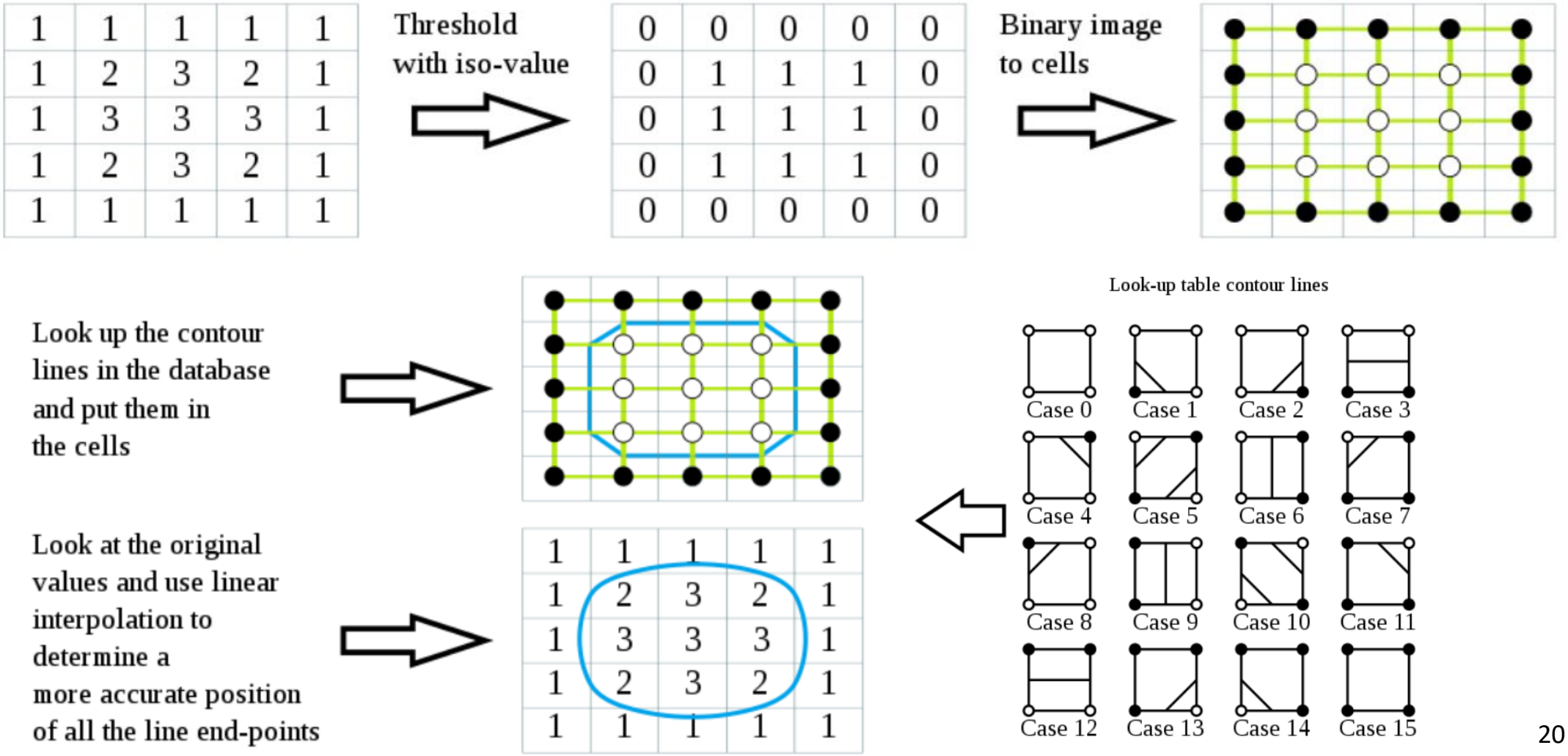
$F(x) = c$ (contour value)



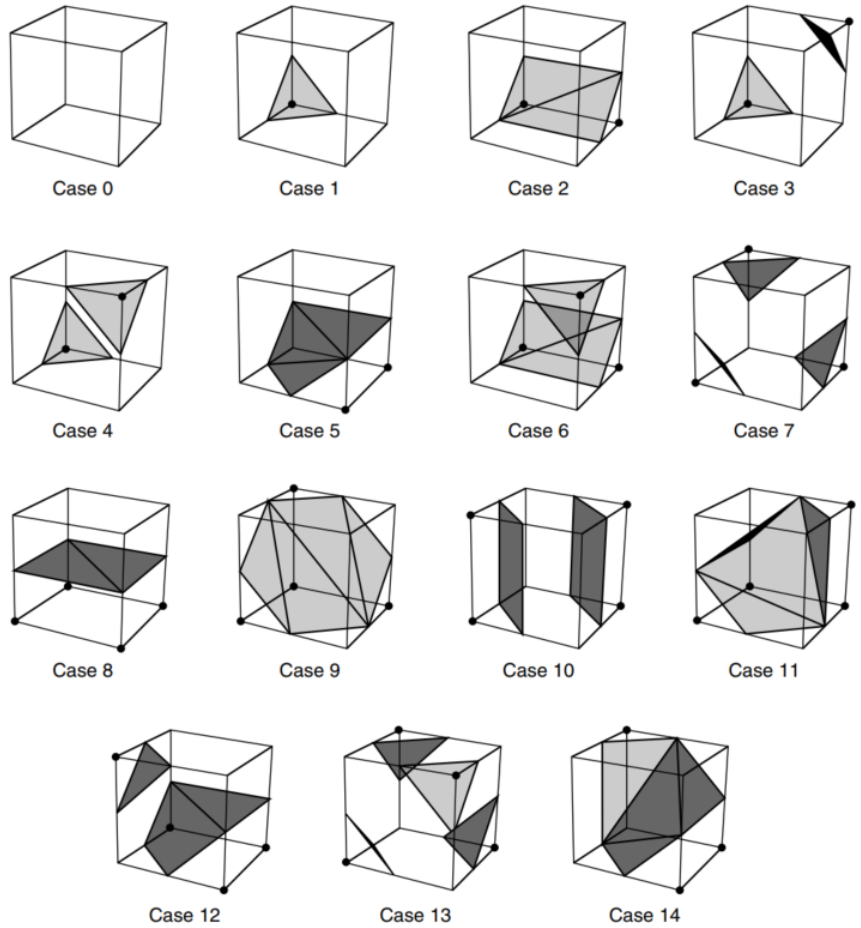
Example in d3.js

Scalar Field Visualization (here 2D domain)

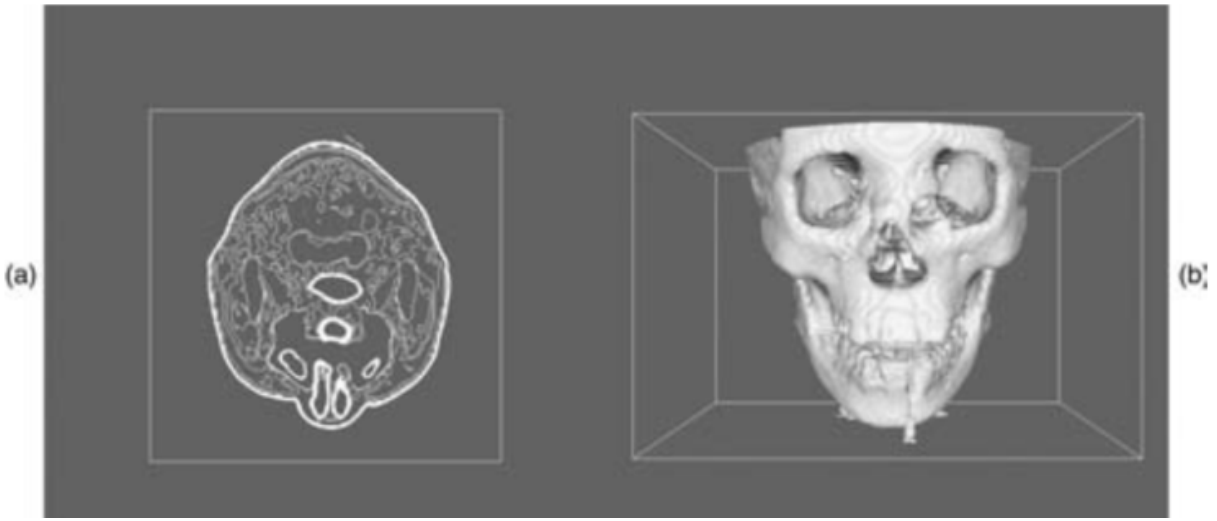
- Marching squares https://en.wikipedia.org/wiki/Marching_squares



3D Scalar Field (Volume)



Marching cubes cases for 3D isosurface generation

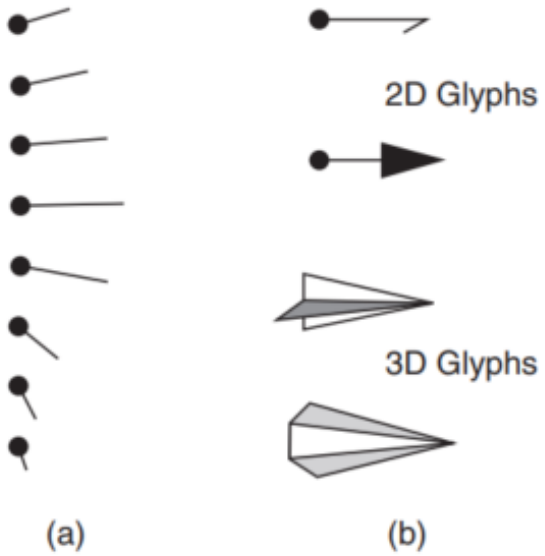


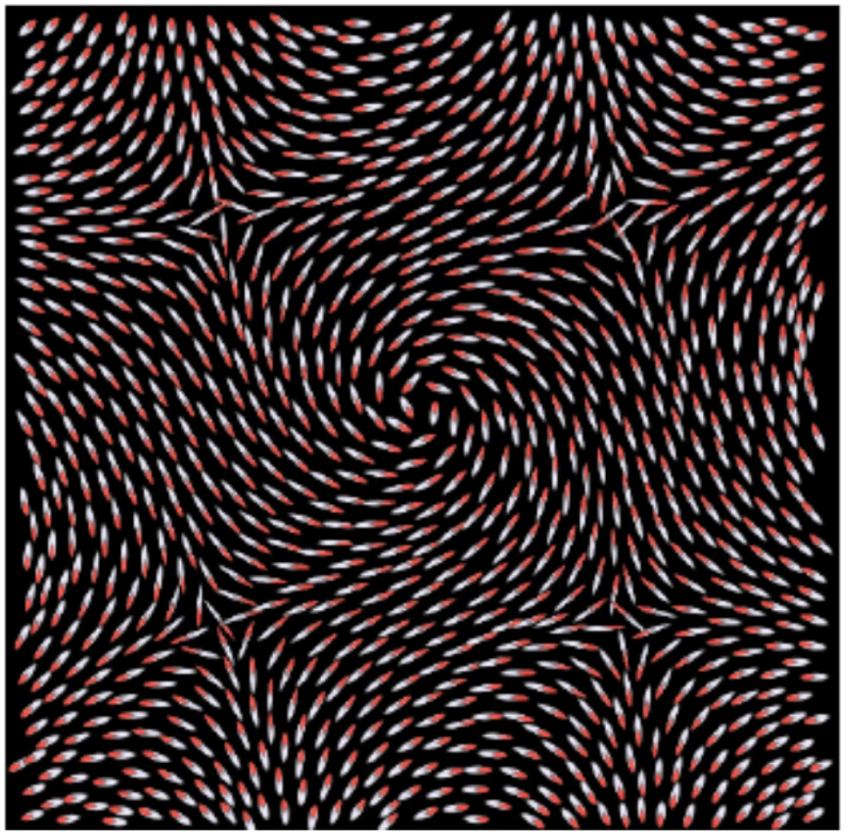
(a) 2D contours (b, c, d) 3D iso-surfaces
From The Visualization Handbook, p13

Vector Field

Glyphs

- A natural vector visualization technique is to draw an oriented, scaled line for each vector in a dataset
- The line begins at the point with which the vector is associated and is oriented in the direction of the vector components (v_x, v_y, v_z)

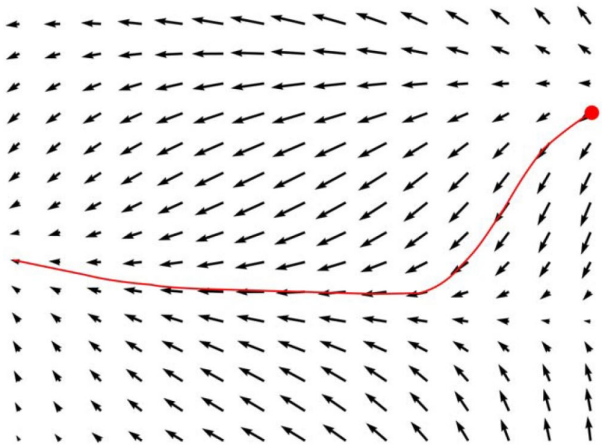


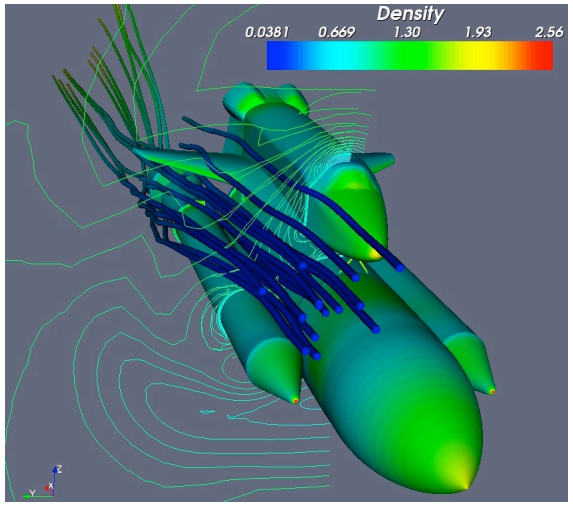


Vector Field

Streamlines

- integral curves along a path s satisfying the equation $s = \int_t \vec{V}\, ds,$ with $s = s(x,t)$

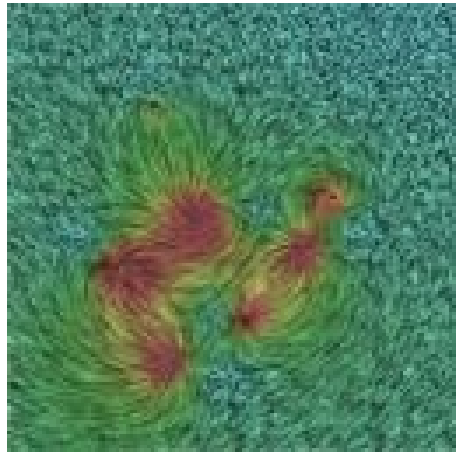




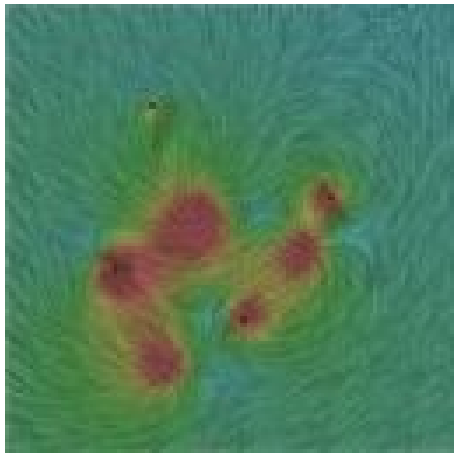
- Displacement of a point
  - differential format $d\vec{x} = \vec{V}dt$
  - integral format $\vec{x}(t) = \int_t \vec{V}dt$
  - discrete format $\overrightarrow{x_{i+1}} = \overrightarrow{x_i} + \overrightarrow{V_i}\Delta t$

Vector Field

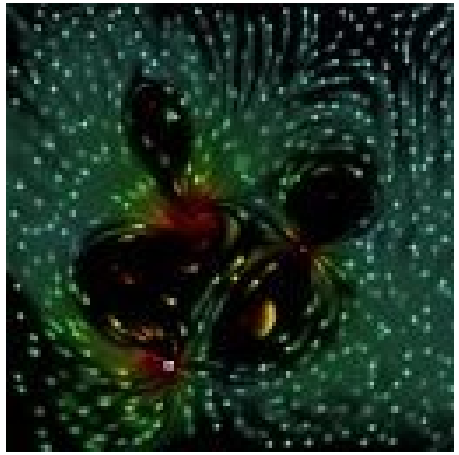
Flow Visualization: a big subject!



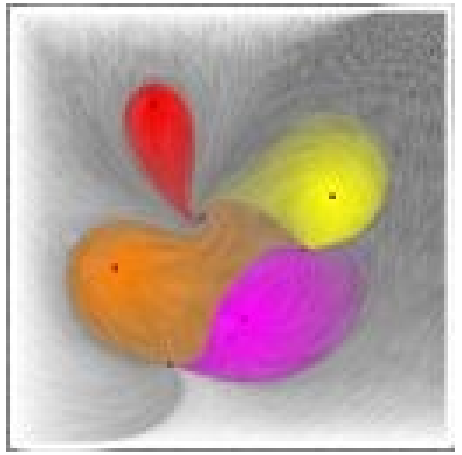
Spot noise



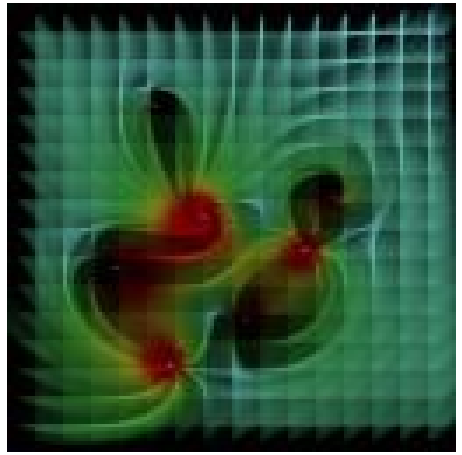
LIC



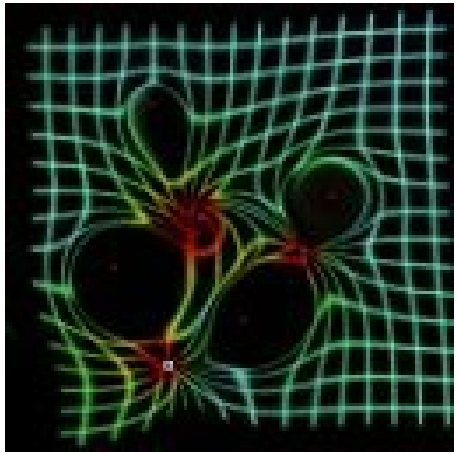
Particles



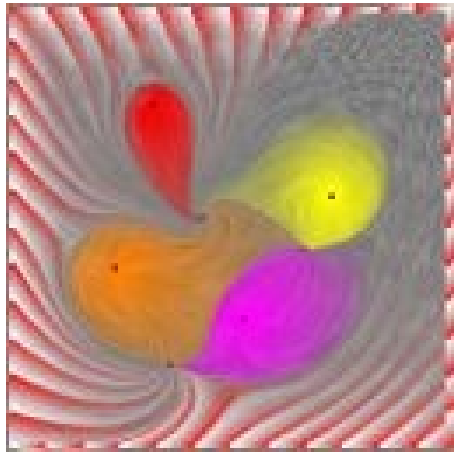
Topology



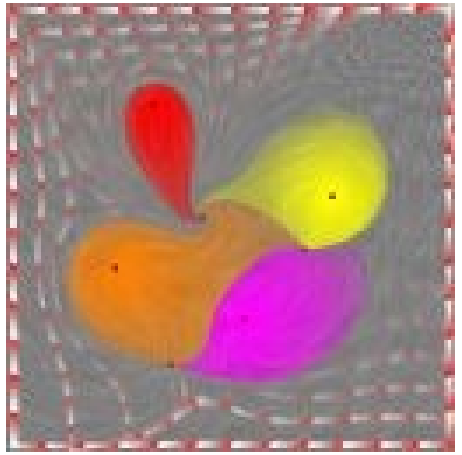
Smeared



Warped



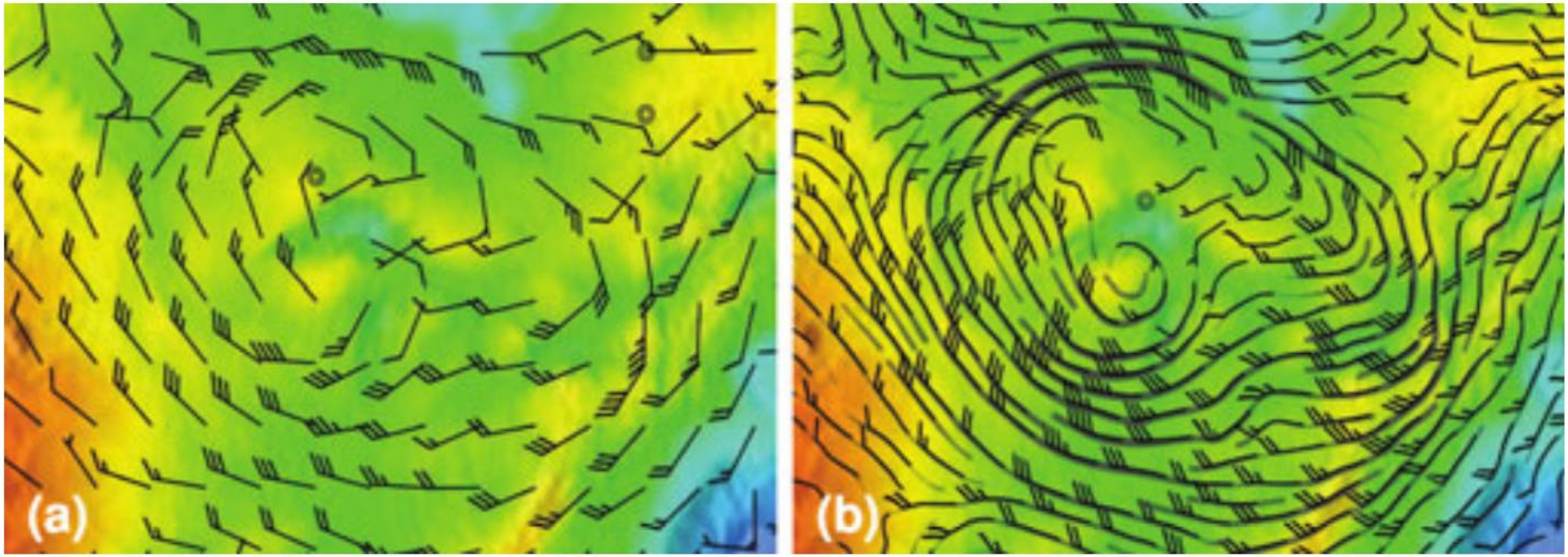
Streamlines



Timelines

Jarke J. van Wijk, Image Based Flow Visualization http://www.win.tue.nl/~vanwijk/ibfv/

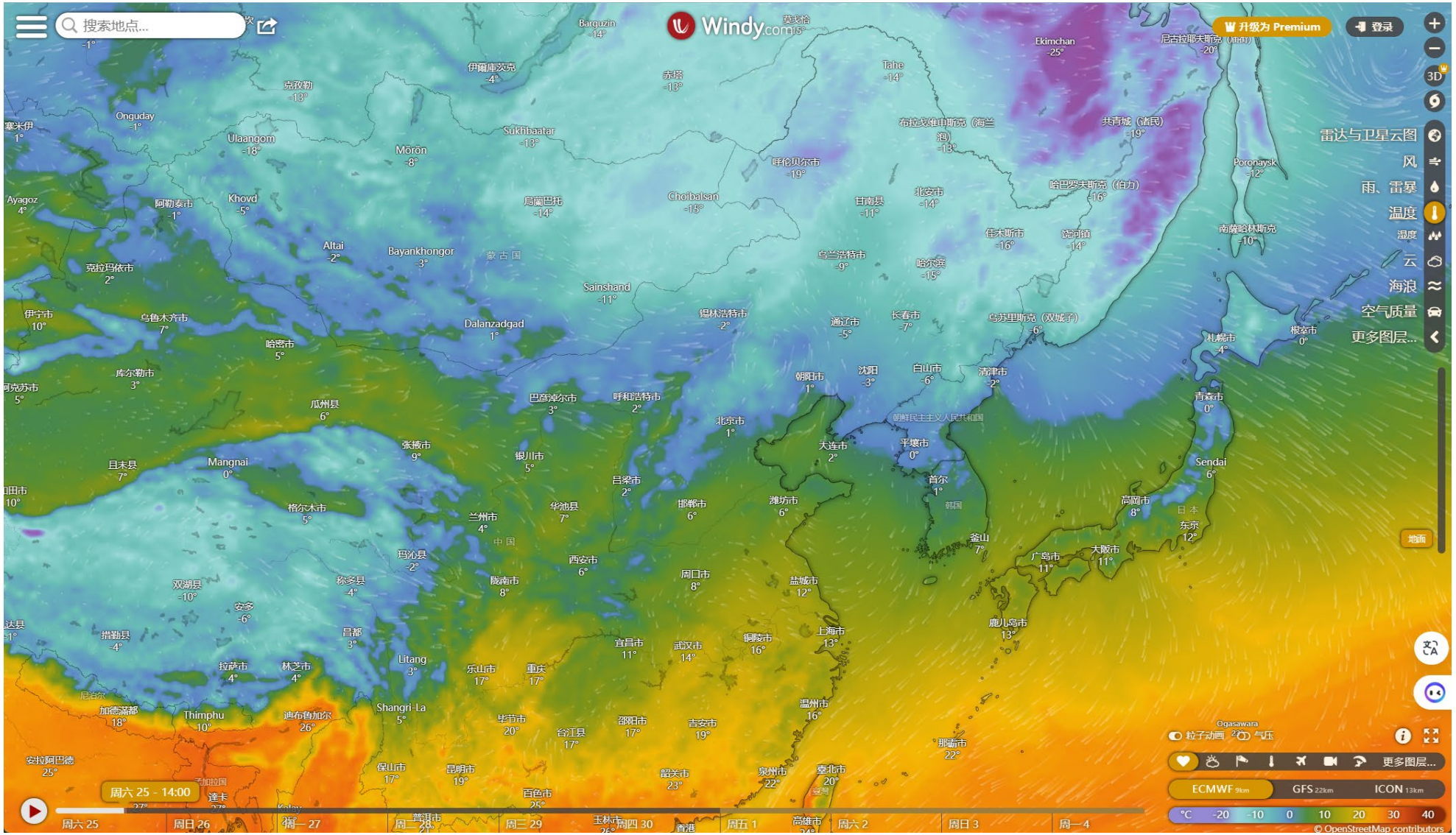
Scalar Field & Vector Field



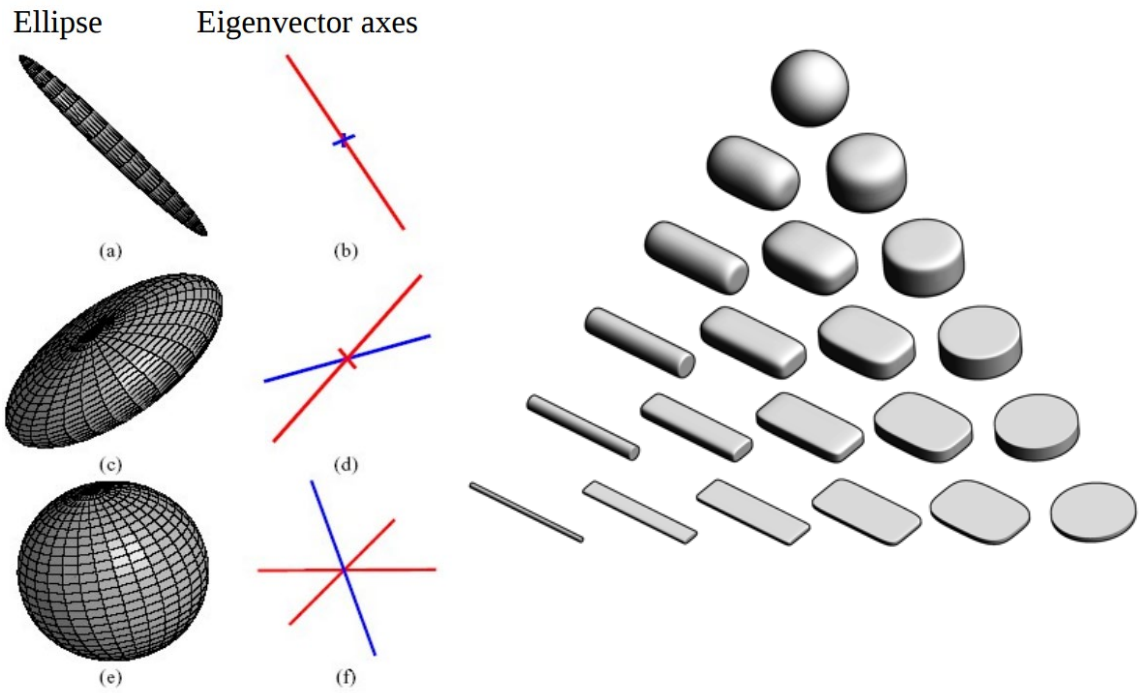
A wind and temperature field depicted by (a) traditional wind barbs and (b) a combination of streamlines and wind barbs. From *D. H. F. Pilar and C. Ware, "Representing flow patterns by using streamlines with glyphs," IEEE Trans. Vis. Comput. Graph., vol. 19, no. 8, pp. 1331–1341, Aug. 2013.*

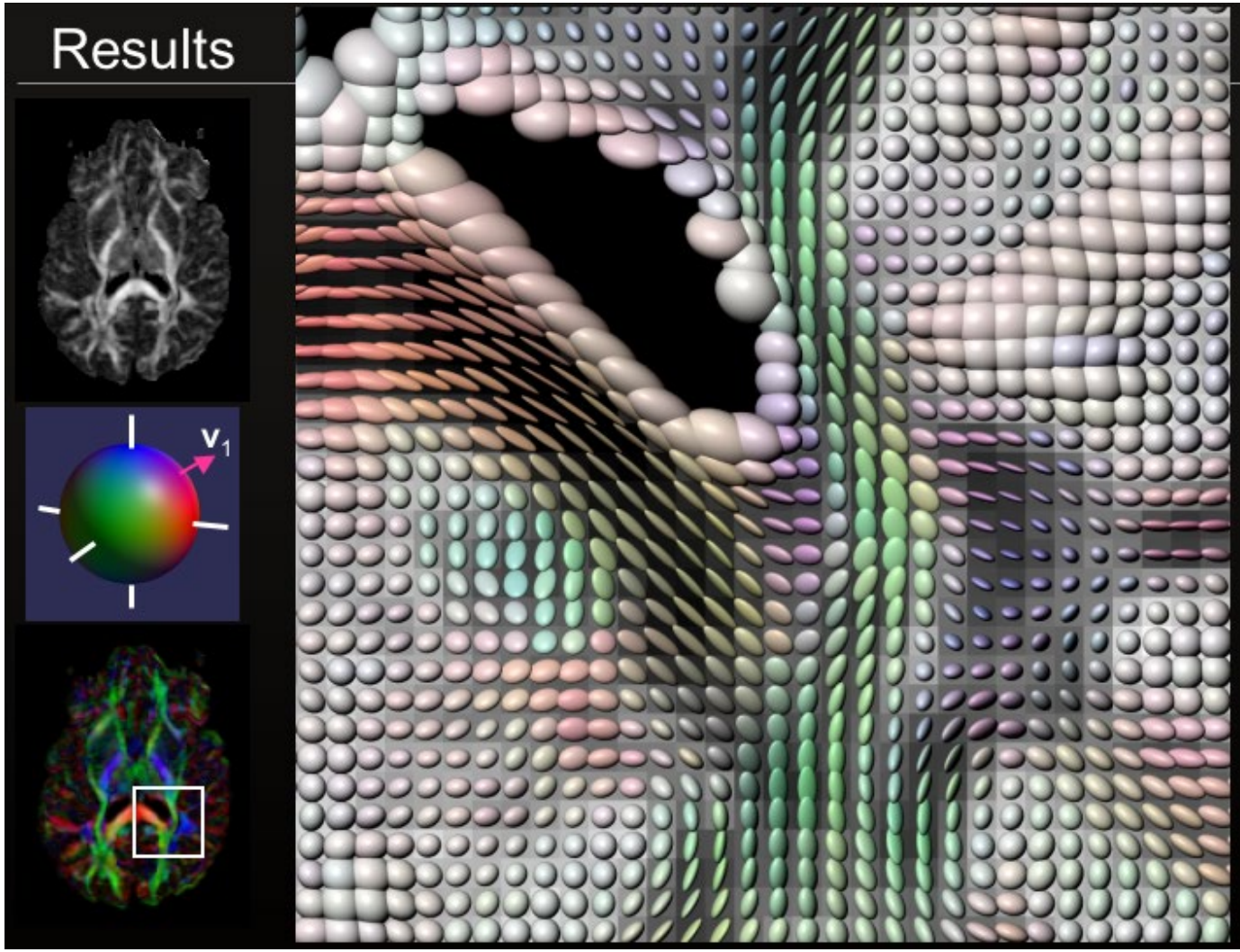
Scalar Field & Vector Field

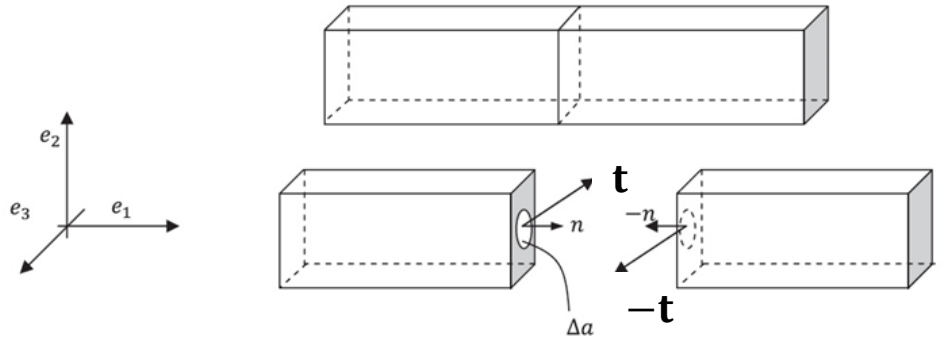
- https://www.windy.com/



Tensor Field Visualization (by glyphs)



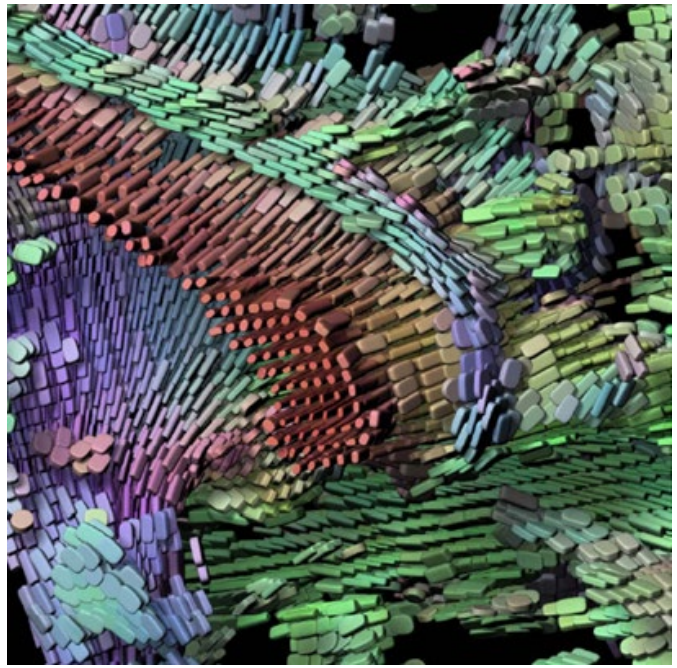




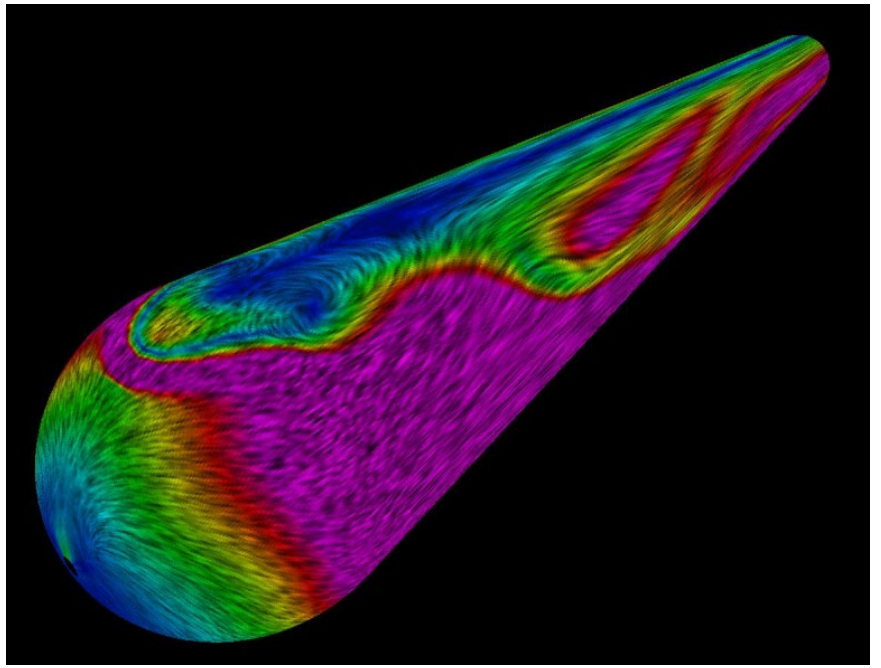
Cauchy Stress tensor $\boldsymbol{\sigma}$ (interface normal -> traction): $\mathbf{t} = \boldsymbol{\sigma}\mathbf{n}$

Tensor Field Visualization

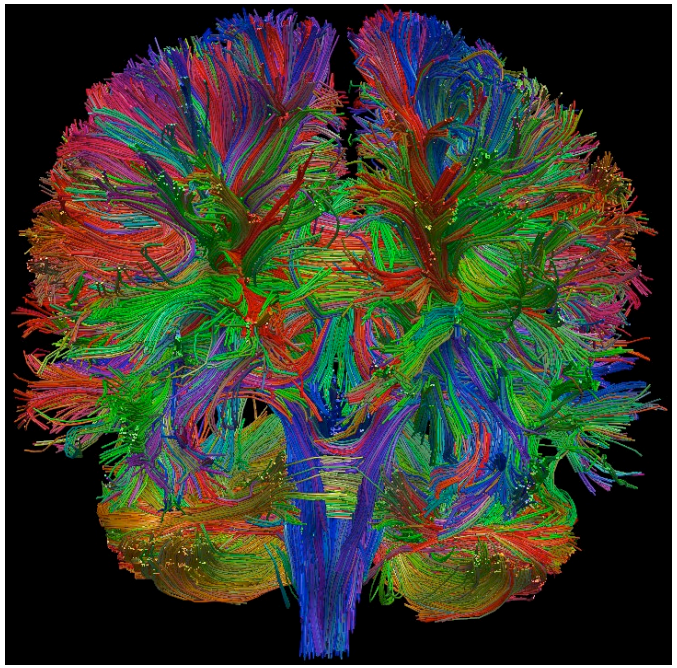
Another big subject!



Glyph-based



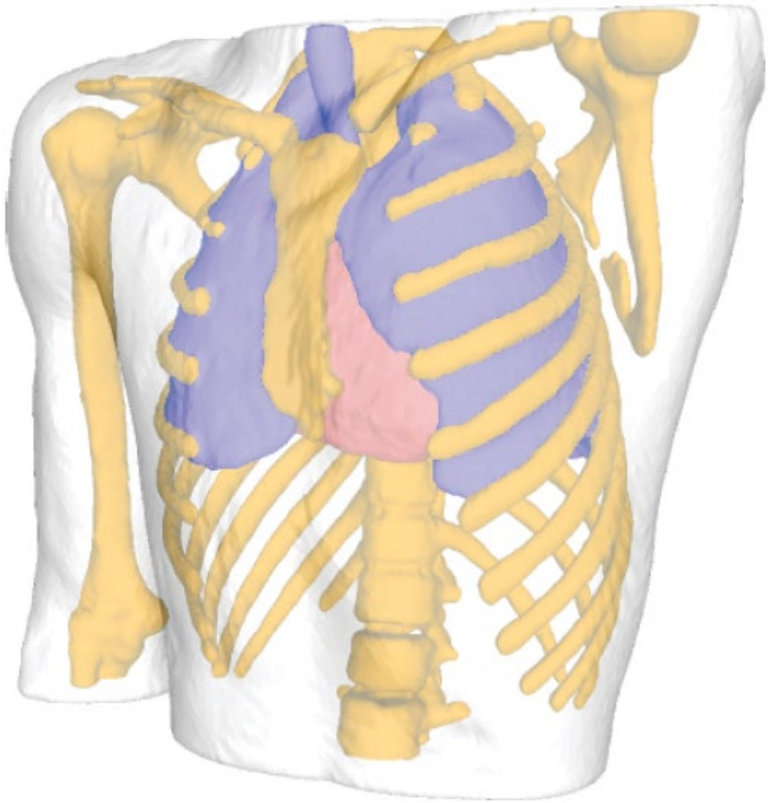
Texture-based



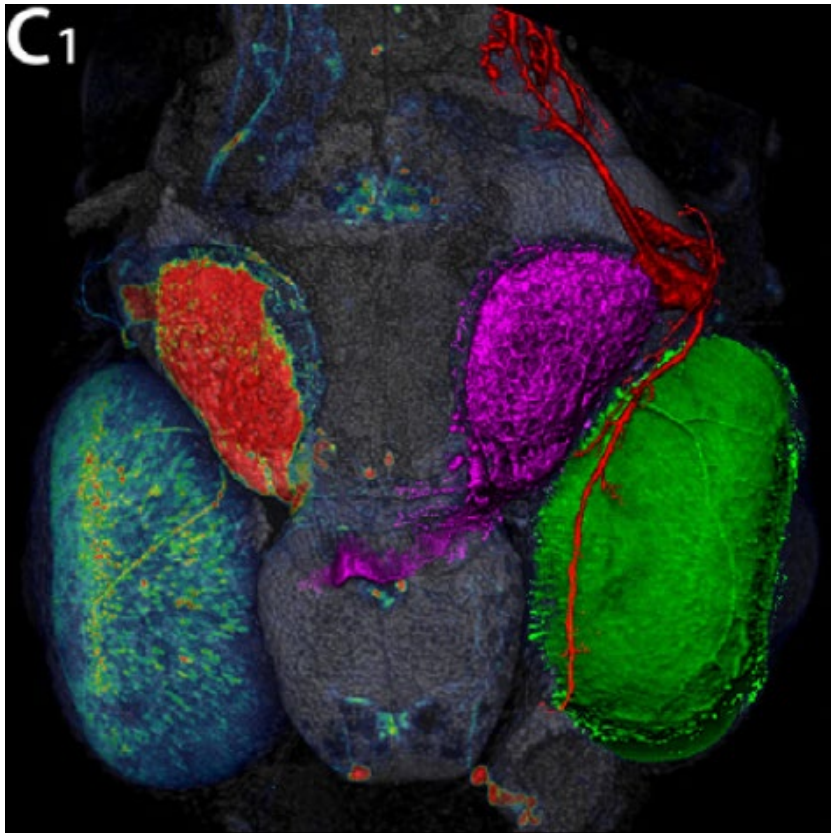
Geometry-based

https://homepages.inf.ed.ac.uk/tkomura/cav/last.pdf

Surface vs. Volume Visualization



Scalar field visualization 3D
Iso-surfacing



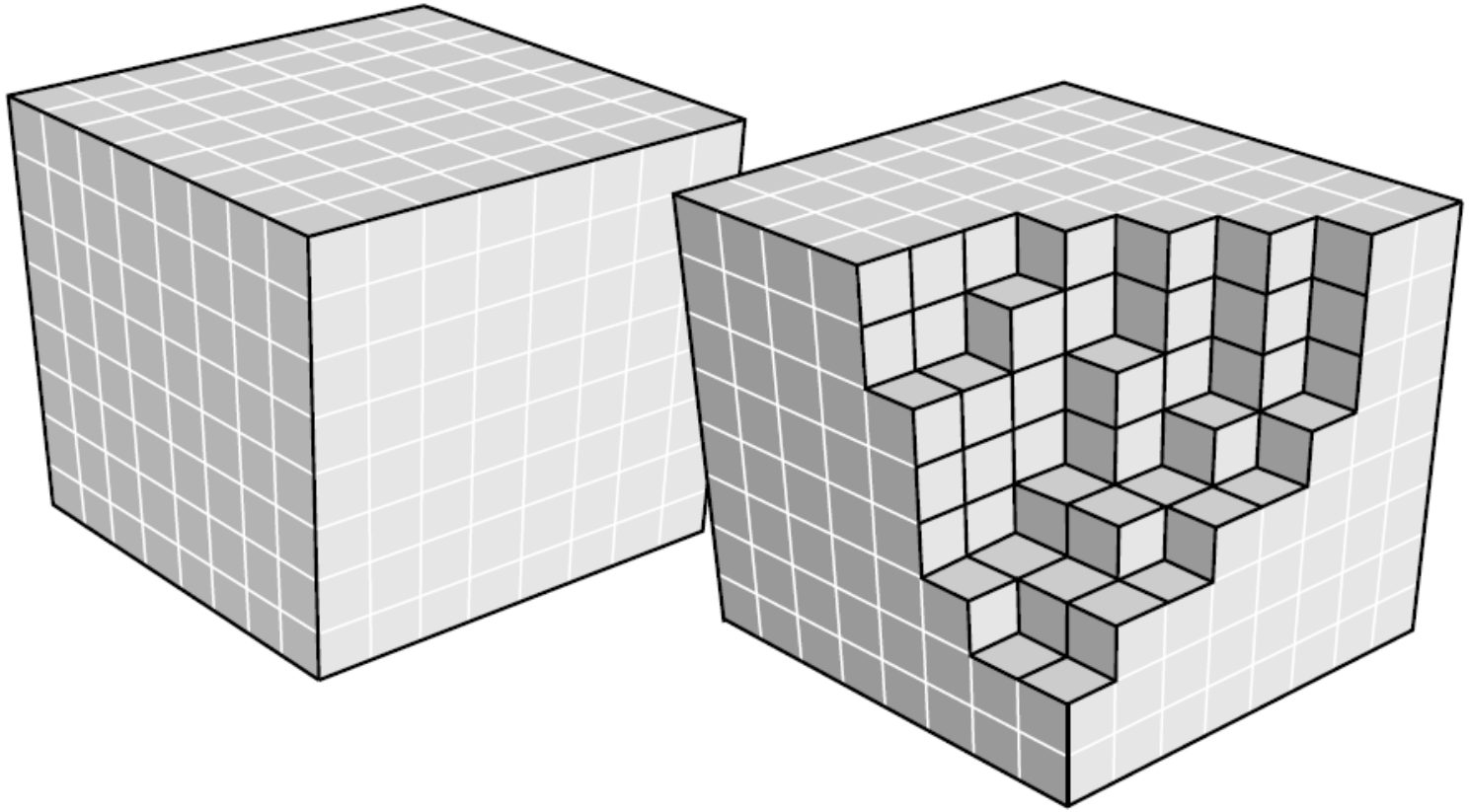
Volume Rendering
Zebra fish head (image by Fluorender)

Volume Visualization

Some pictures are from
https://www.powershow.com/view/aff1f-ODc5Z/Volume_Rendering_powerpoint_ppt_presentation

Voxels

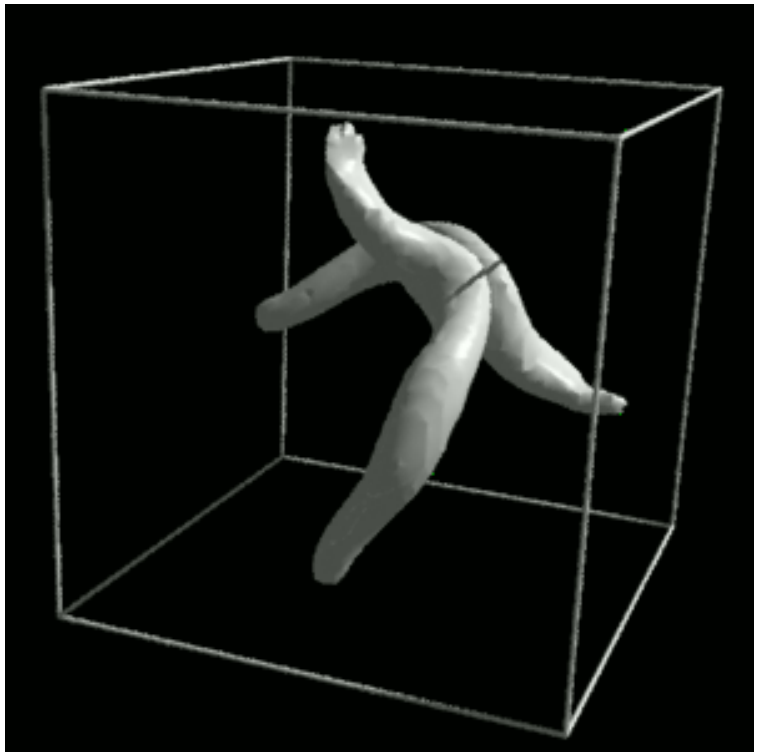
- Voxels constituting a volumetric object after it has been discretized.



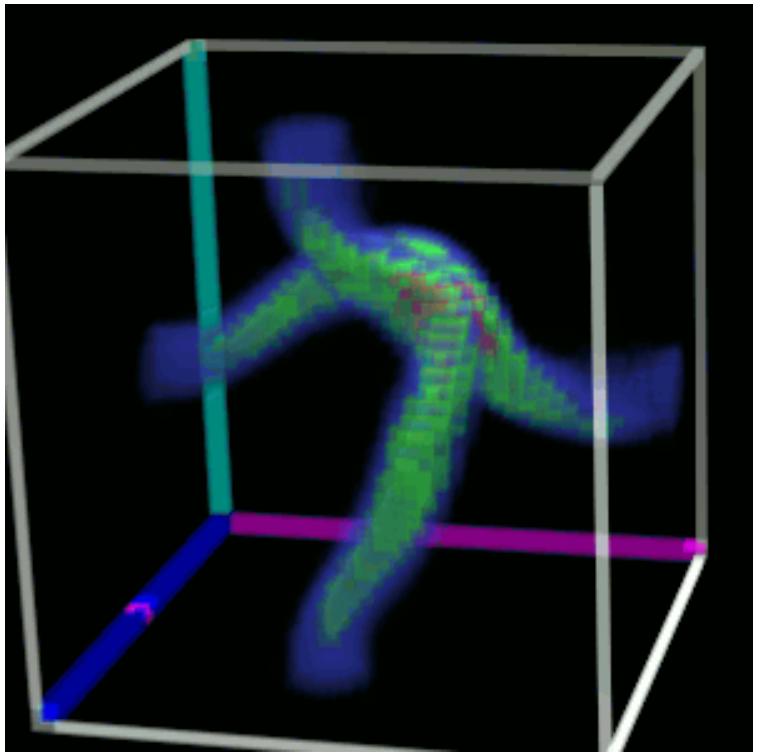
From SIGGRAPH Course 2004: Real-Time Volume Graphics

Surface Rendering vs Volume Rendering

- Some data is more naturally modeled as a volume, not a surface
- Volume rendering: render the volume directly



Ray-traced isosurface $f(x, y, z) = c$



Same data, rendered as a volume

Contrasts

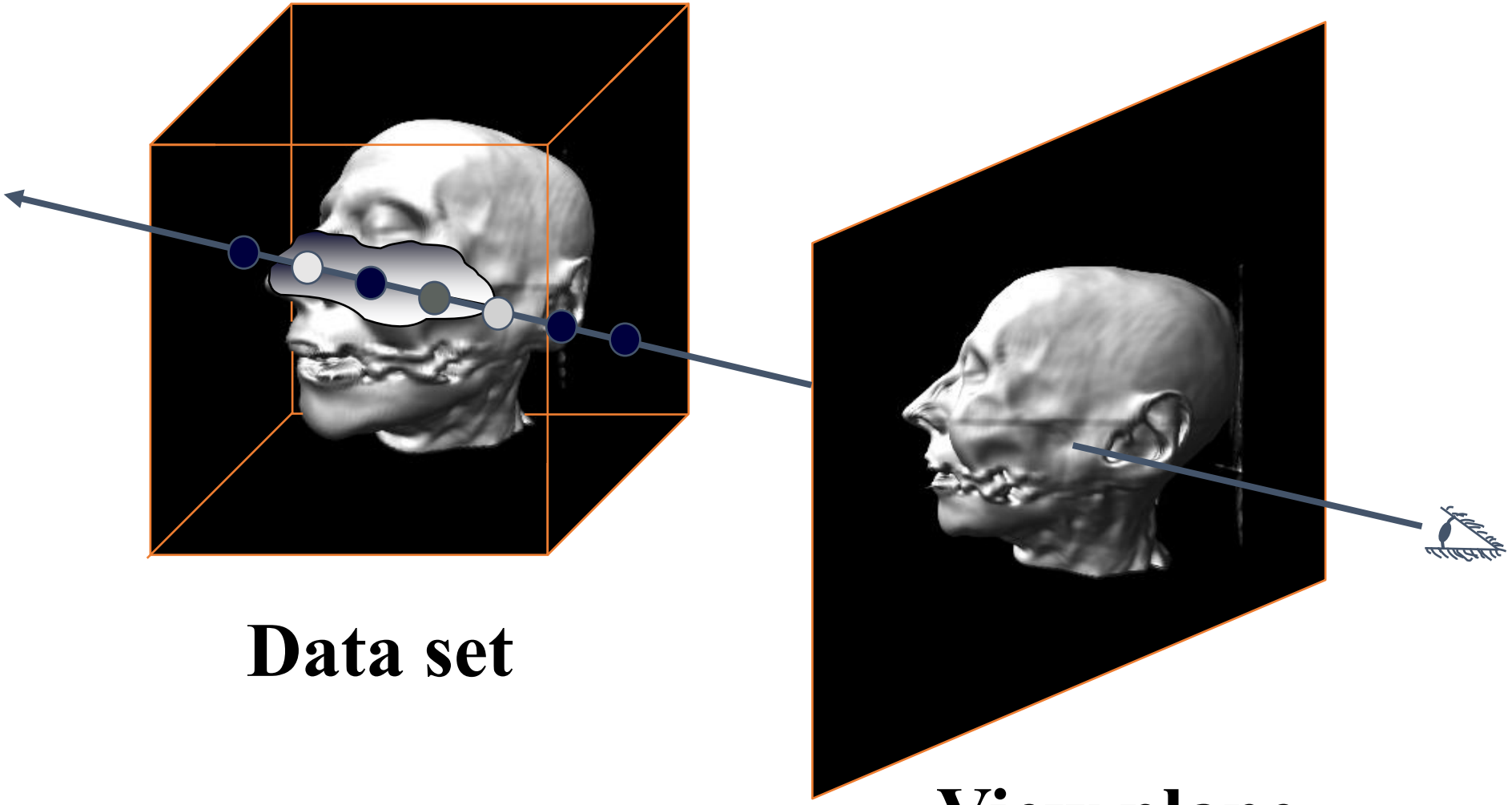
Surface Rendering

- Data is converted to surface primitives (e.g. triangles), which are then drawn.
- Everything you see is a 2D surface, embedded in a 3D space. The conversion to geometrical primitives may lose or disguise some data.
- Good for opaque objects

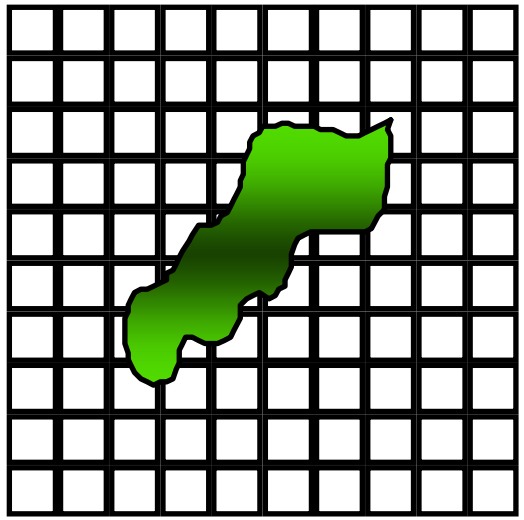
Volume Rendering

- No need to extract surface primitives
- Data consists of one or more (supposedly continuous) fields in 3D
- This volume is rendered directly, like a blob of colored jello. Data is less likely to be hidden.

Ray Casting: pixel order volume rendering



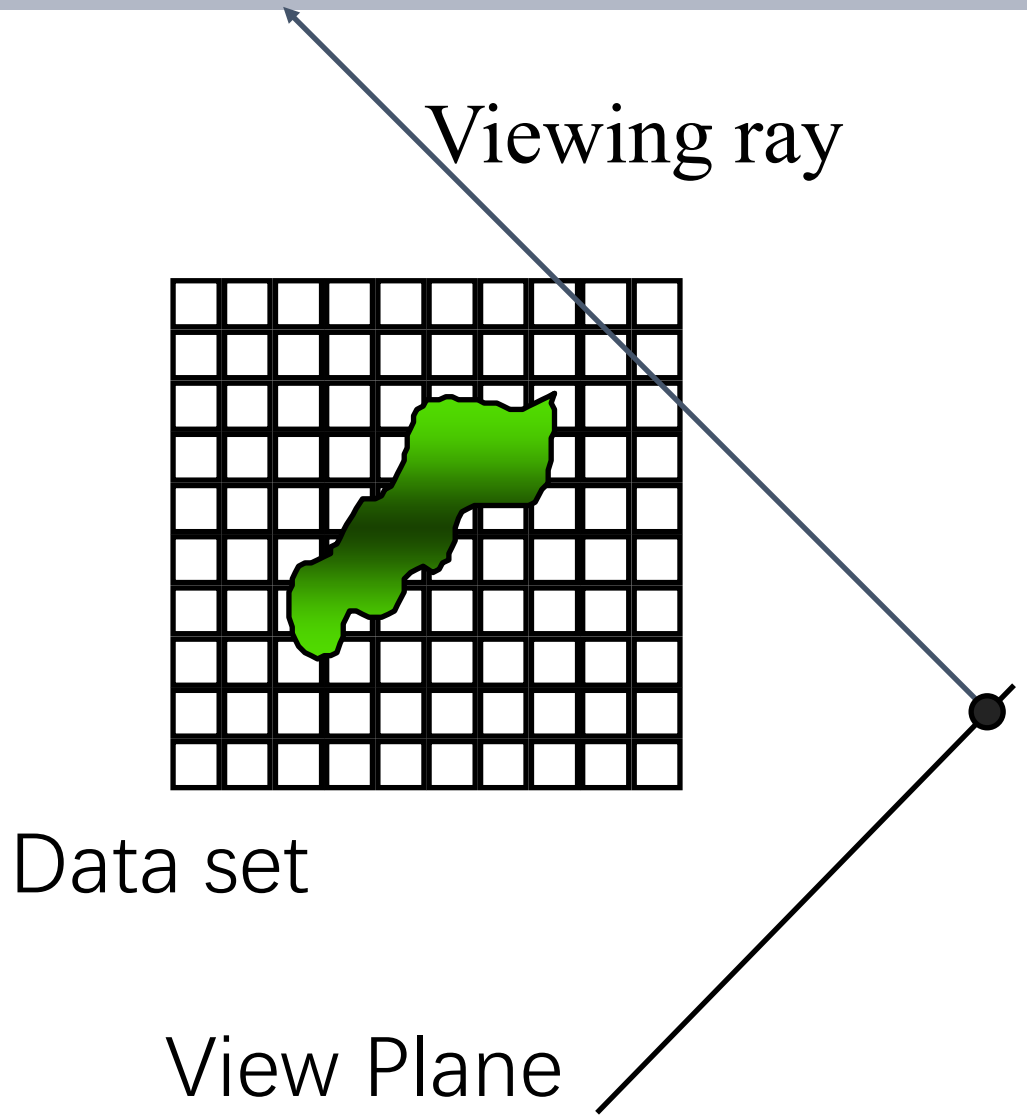
Basic Ray-Casting Algorithm



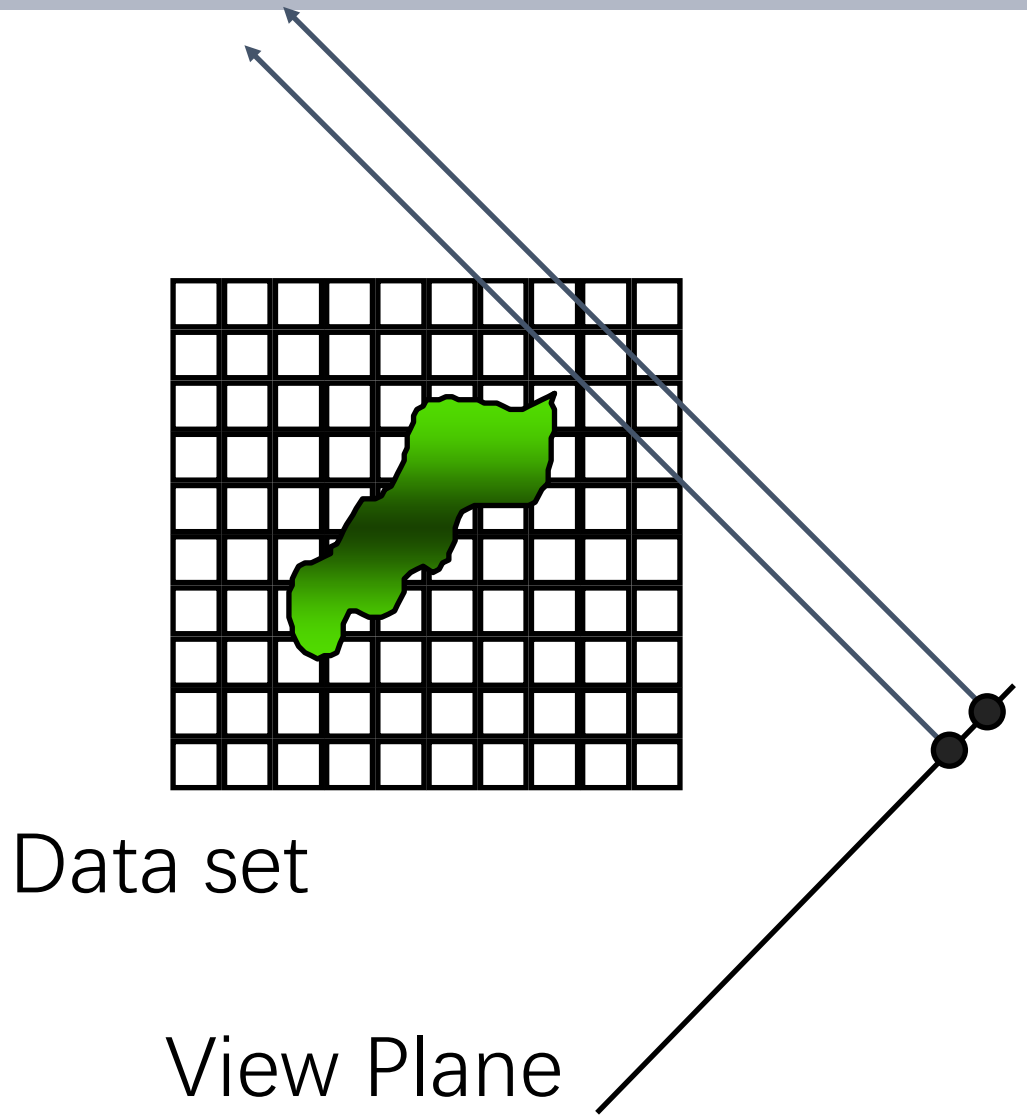
Data set

View Plane

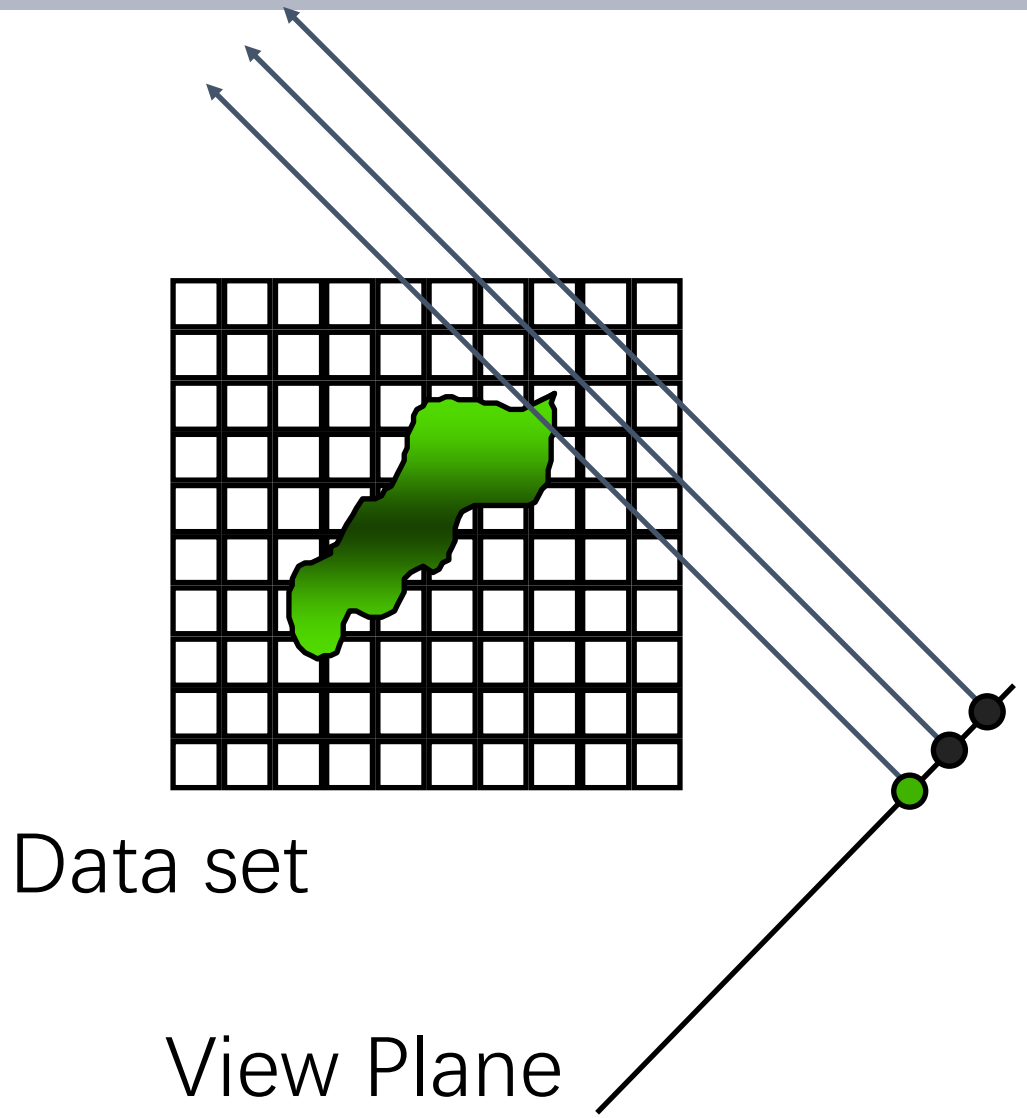
Basic Ray-Casting Algorithm



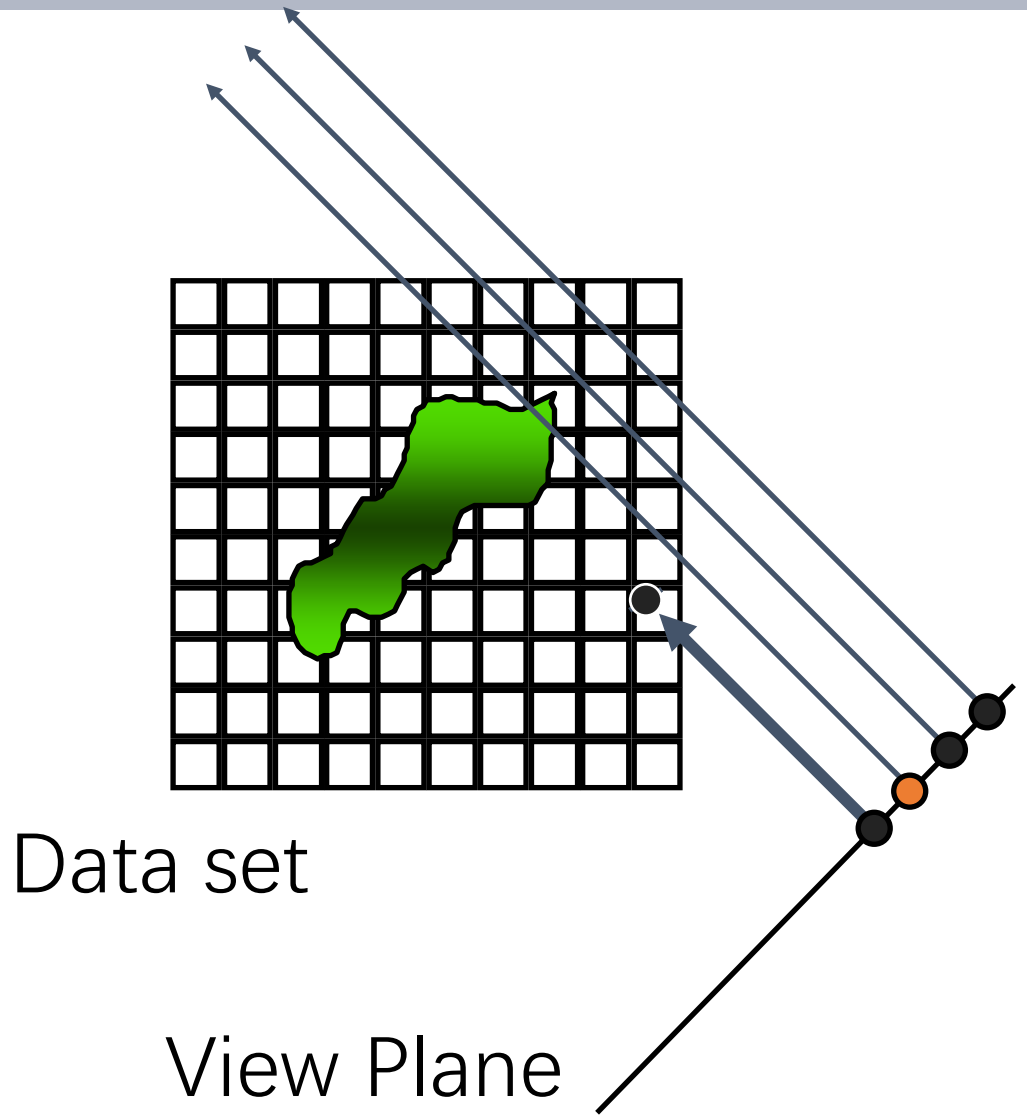
Basic Ray-Casting Algorithm



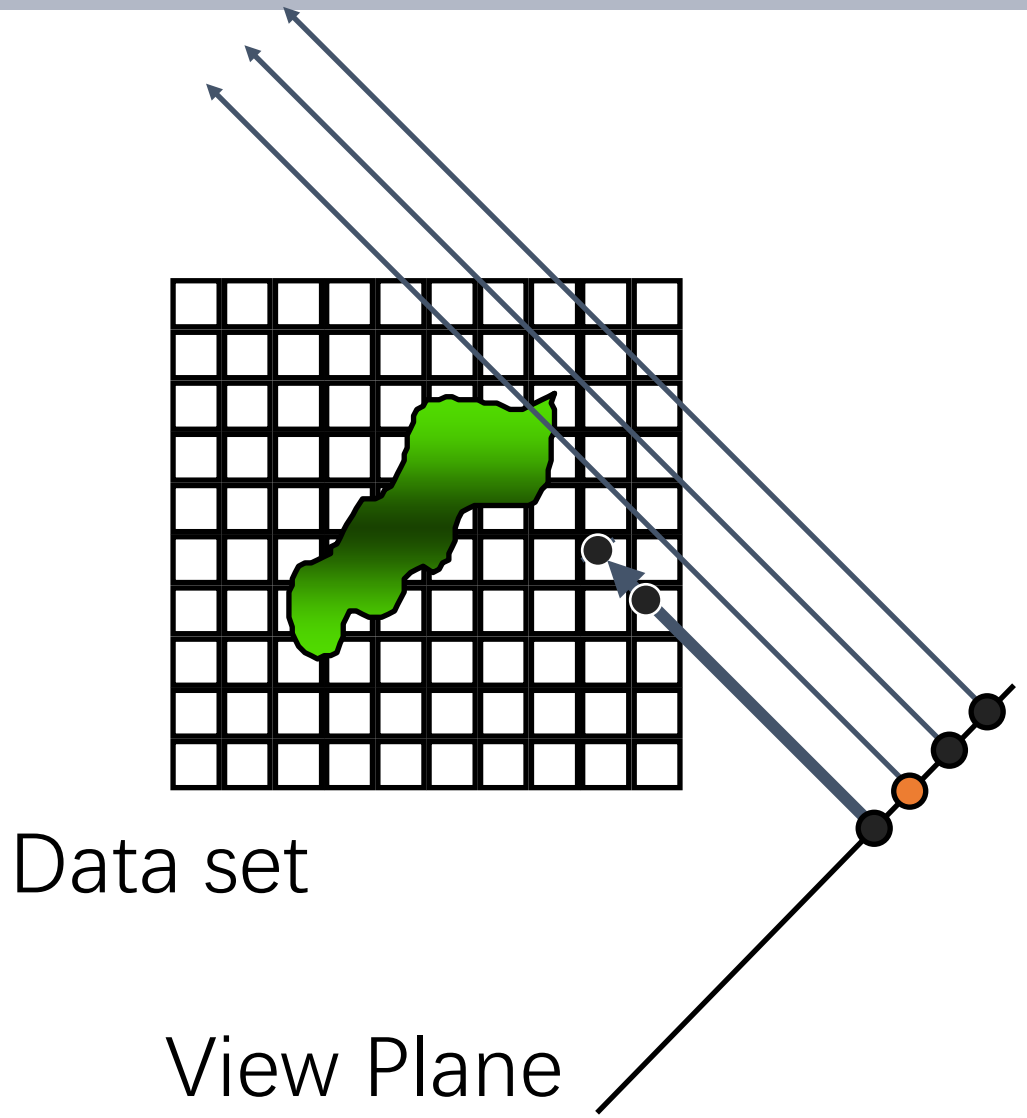
Basic Ray-Casting Algorithm



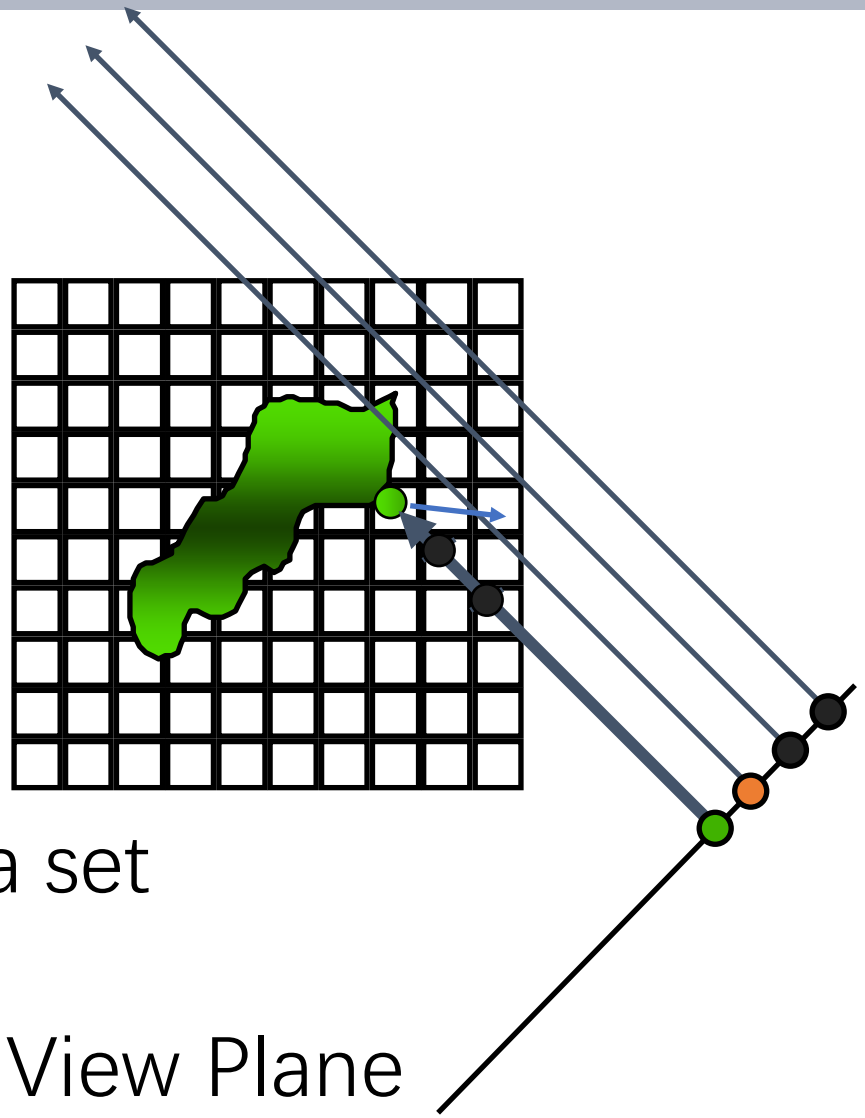
Basic Ray-Casting Algorithm



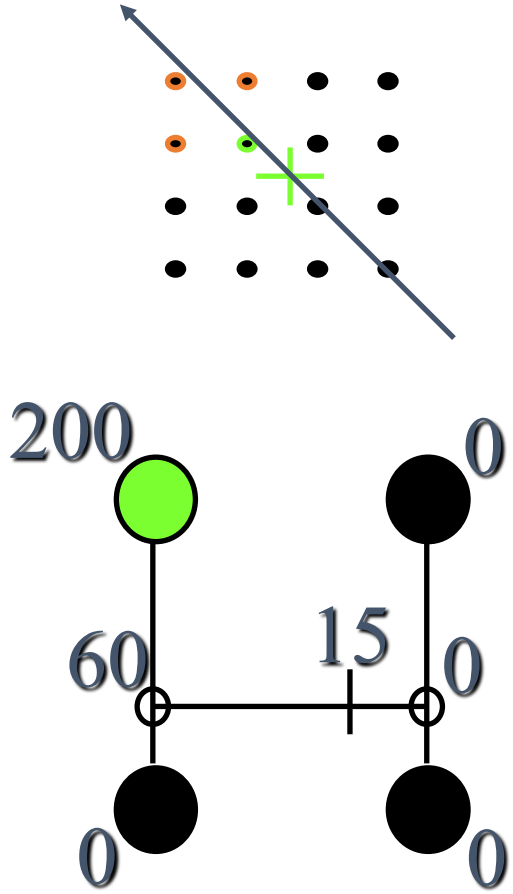
Basic Ray-Casting Algorithm



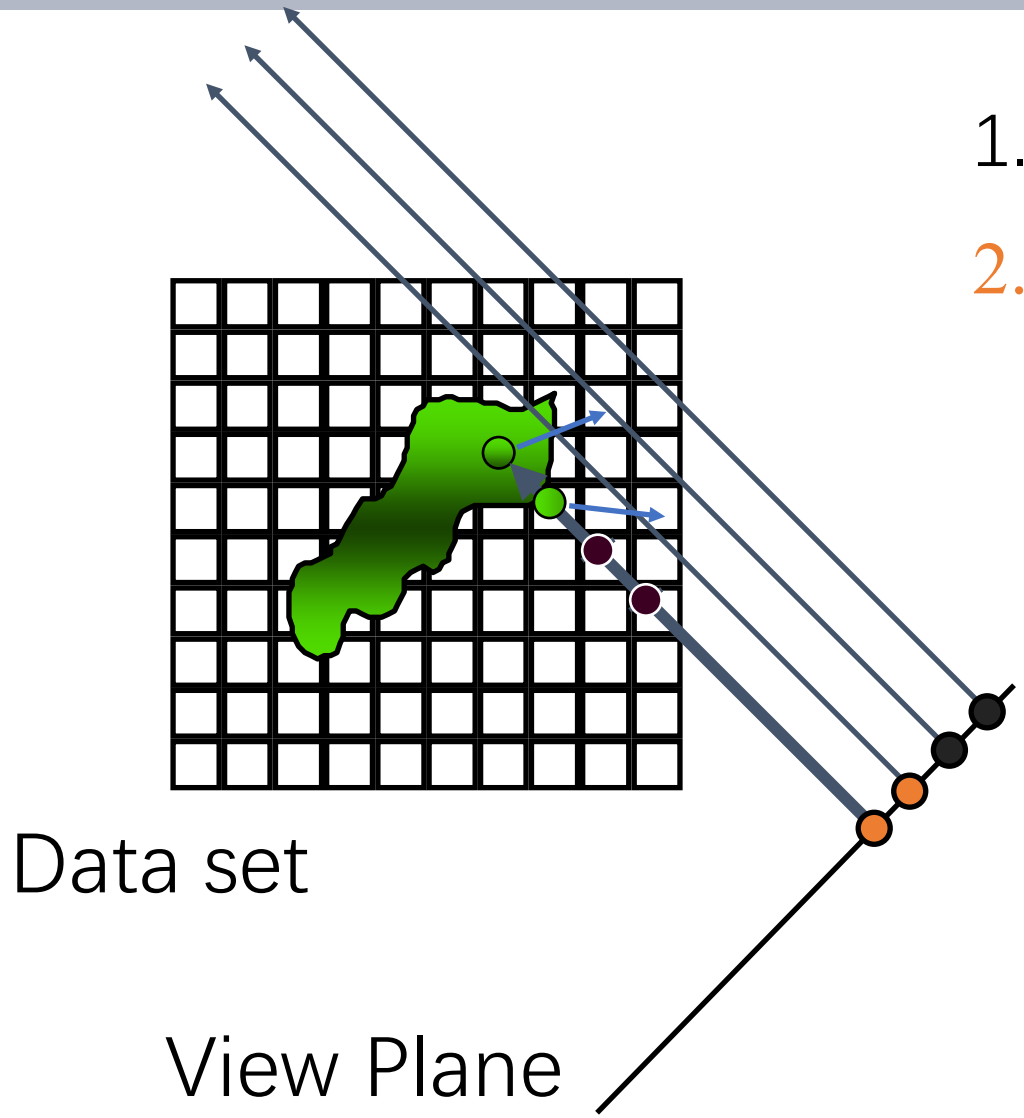
Basic Ray-Casting Algorithm



1. Interpolation

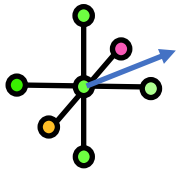


Basic Ray-Casting Algorithm



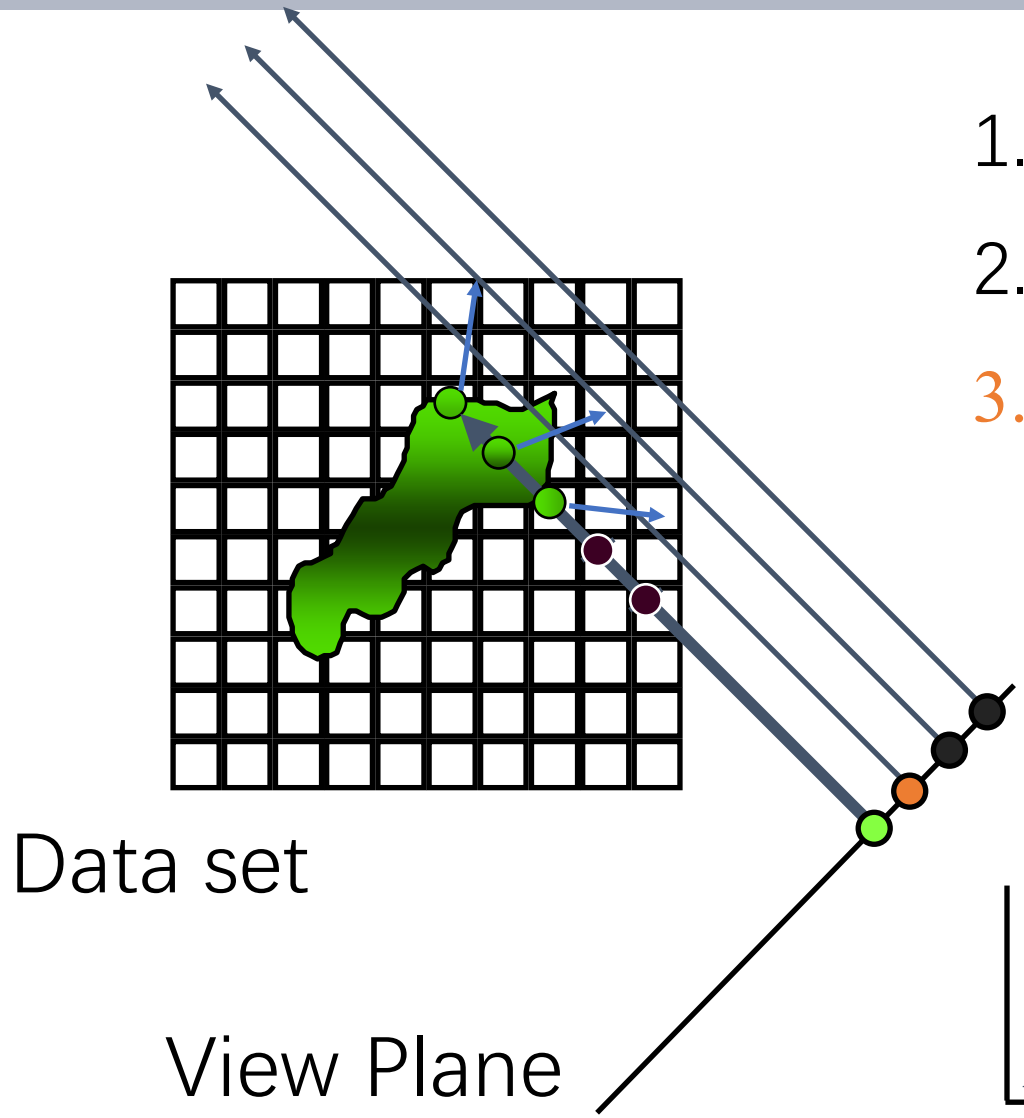
1. Interpolation

2. Gradient estimation

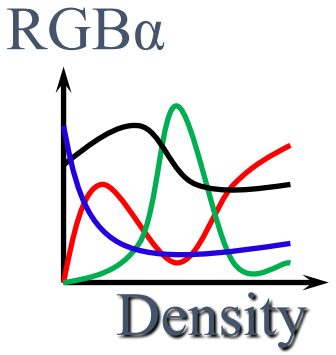


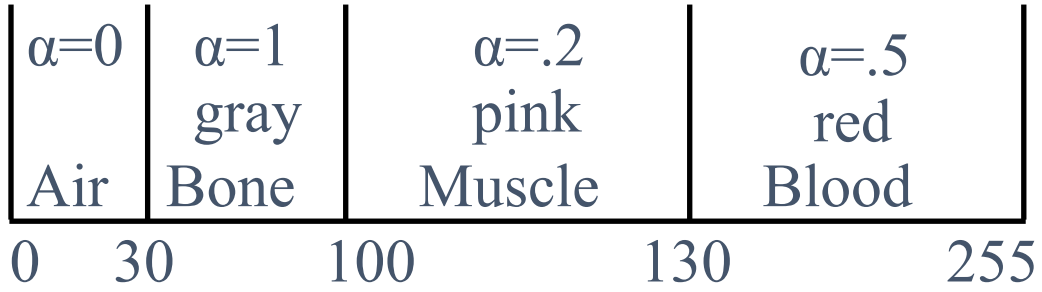
Estimated Gradient
$= (\Delta x, \Delta y, \Delta z)$

Basic Ray-Casting Algorithm

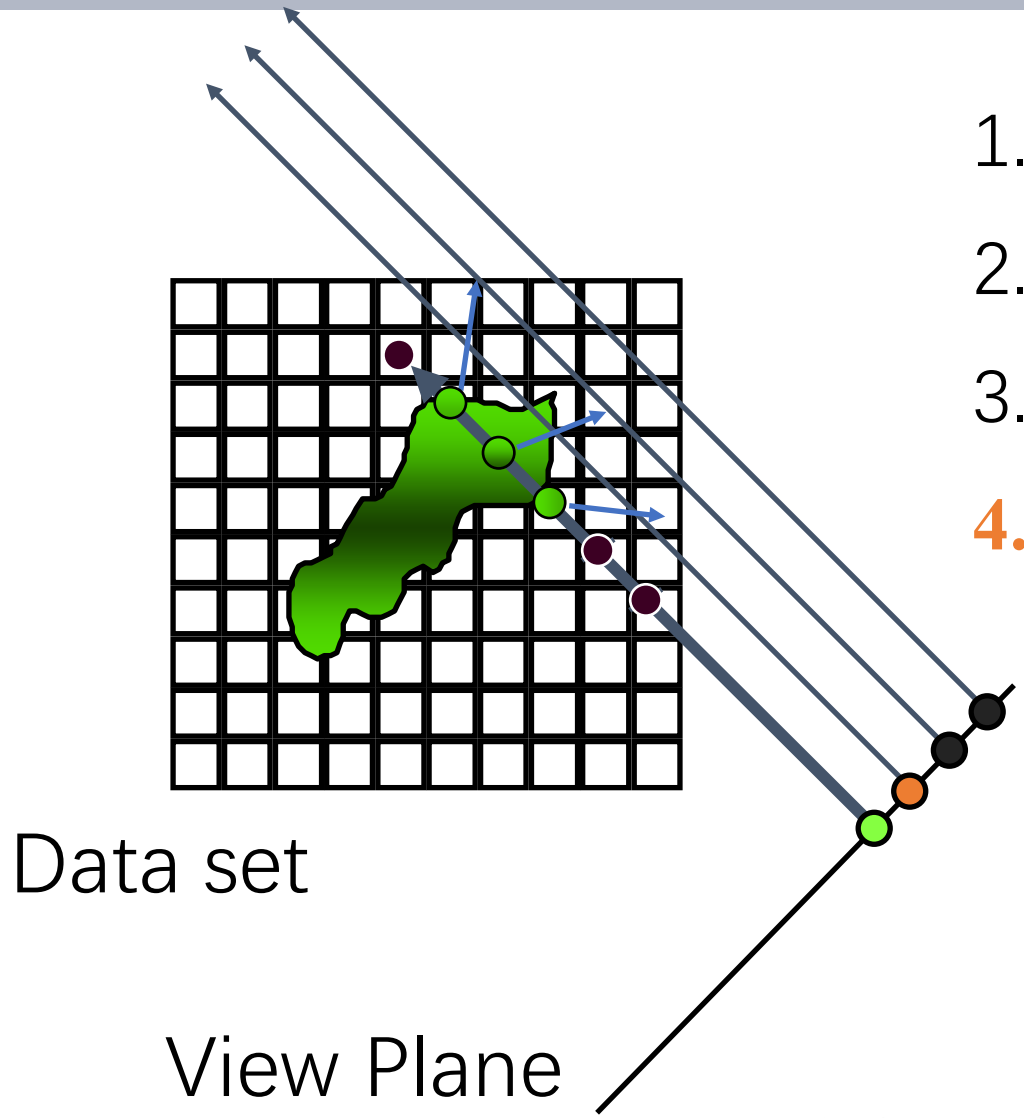


1. Interpolation
2. Gradient estimation
3. Classification (by Transfer Function)

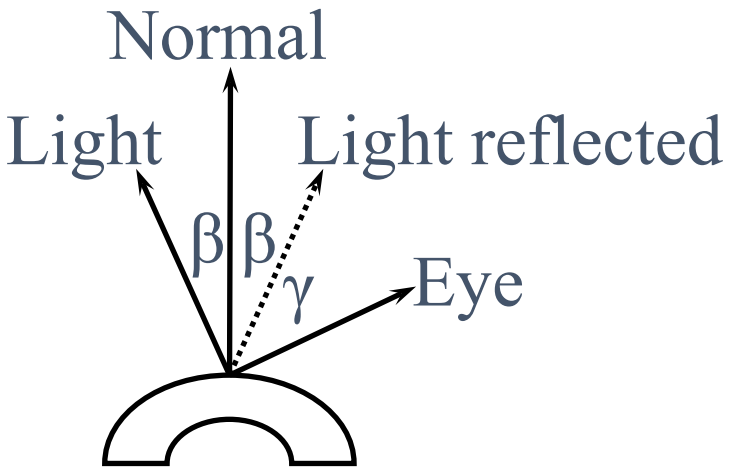




Basic Ray-Casting Algorithm

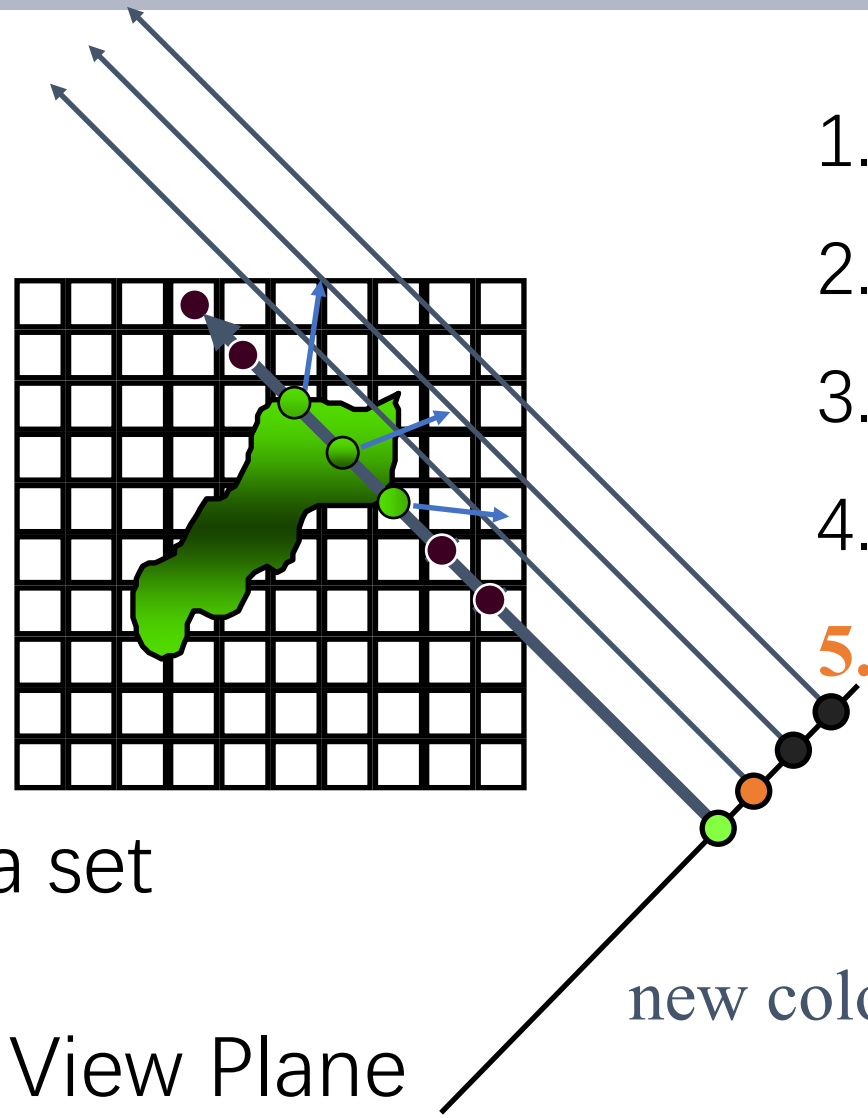


1. Interpolation
2. Gradient estimation
3. Classification
4. **Shading**



$$\text{Light Intensity} = \text{Intensity} \bullet \cos(\gamma)$$

Basic Ray-Casting Algorithm

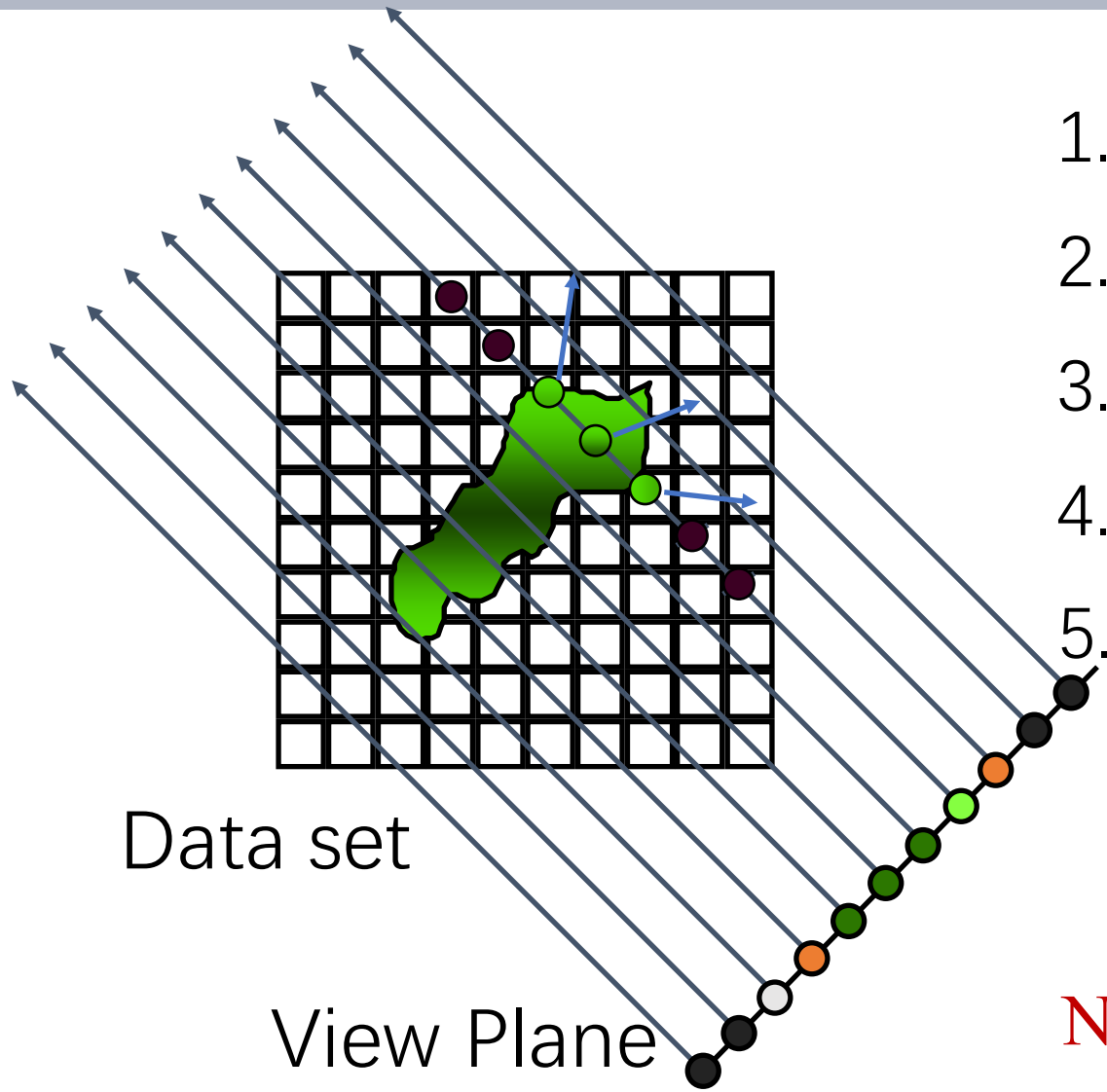


1. Interpolation
2. Gradient estimation
3. Classification
4. Shading
5. **Compositing**

$$\text{new color} = \text{front color} \cdot \text{front } \alpha + \text{back color} \cdot (1 - \text{front } \alpha)$$

$$\text{new } \alpha = \text{front } \alpha + \text{back } \alpha \cdot (1 - \text{front } \alpha)$$

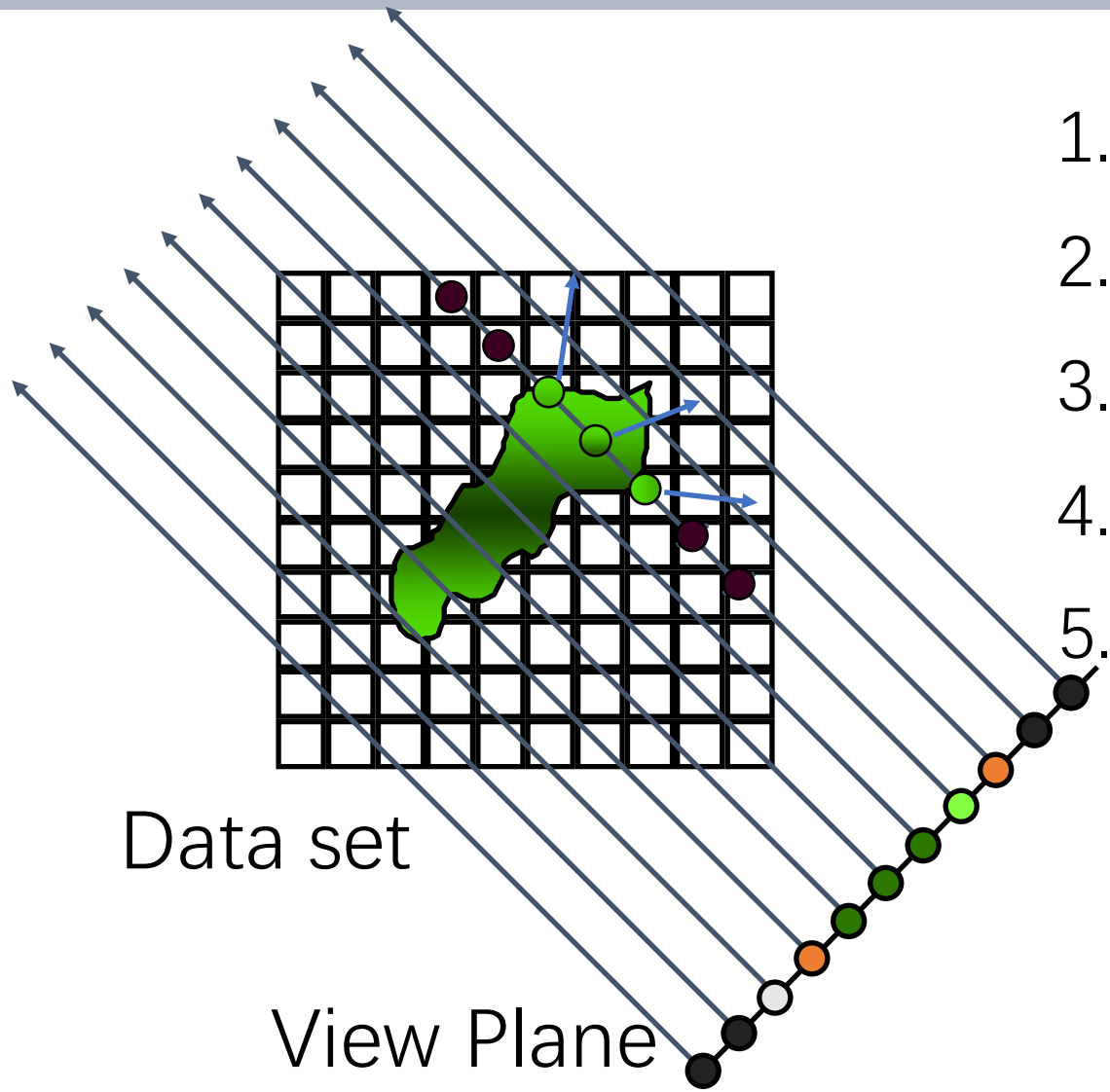
Basic Ray-Casting Algorithm



1. Interpolation
2. Gradient estimation
3. Classification
4. Shading
5. Compositing

Note: early ray termination when reaching full opacity

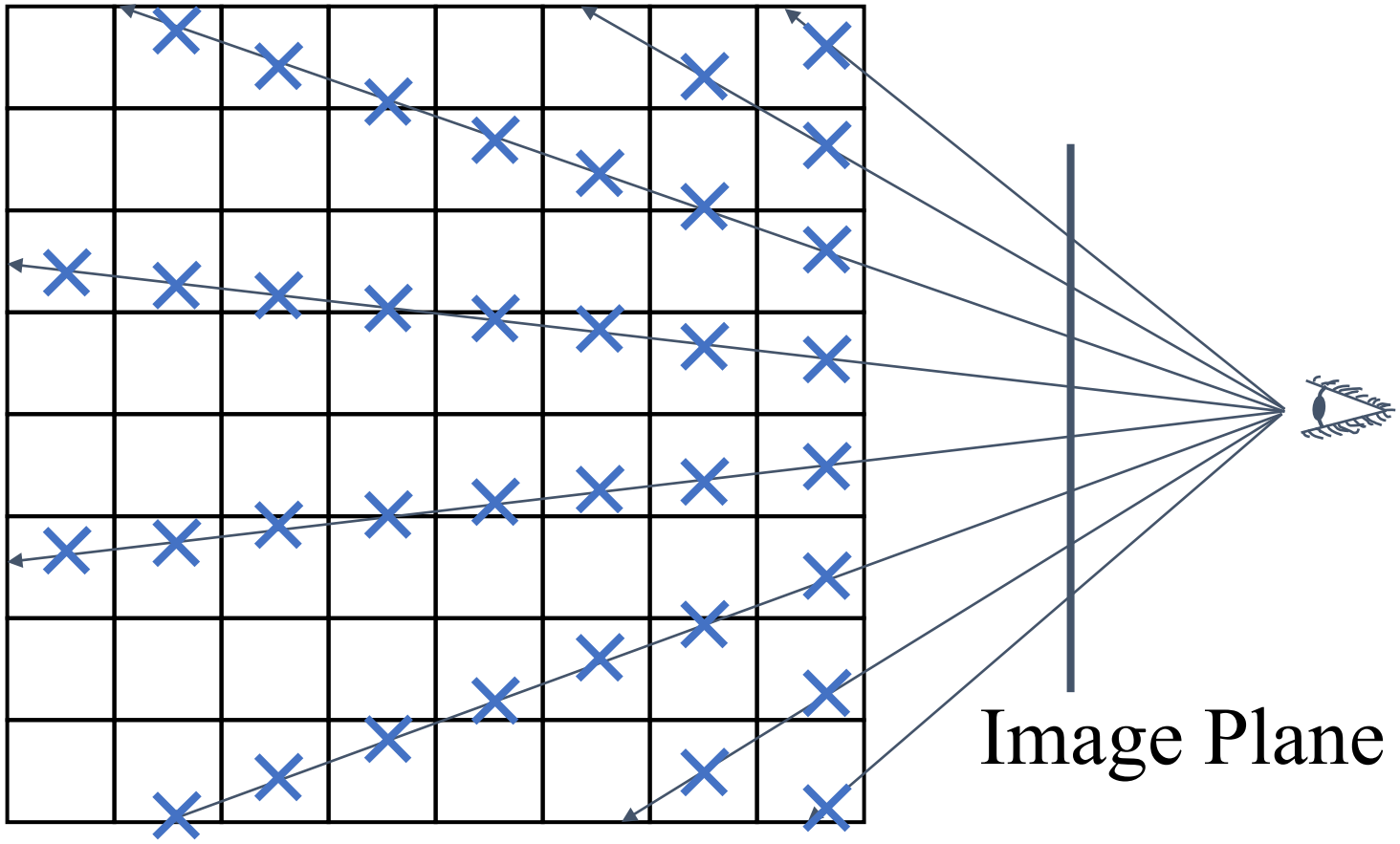
A variant: classification first



1. Classification
2. Interpolation
3. Gradient estimation
4. Shading
5. Compositing

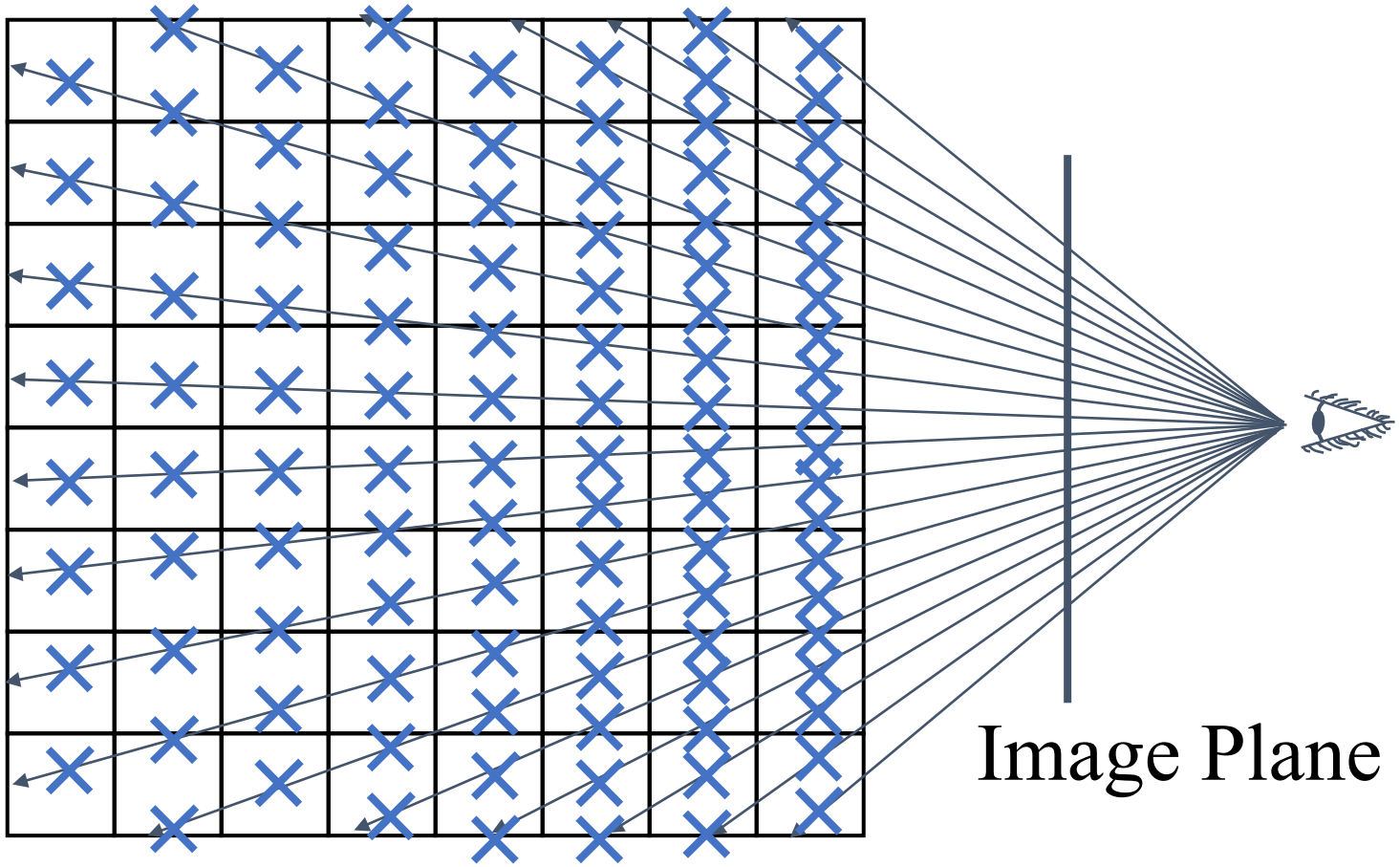
Perspective Projection

Aliasing!



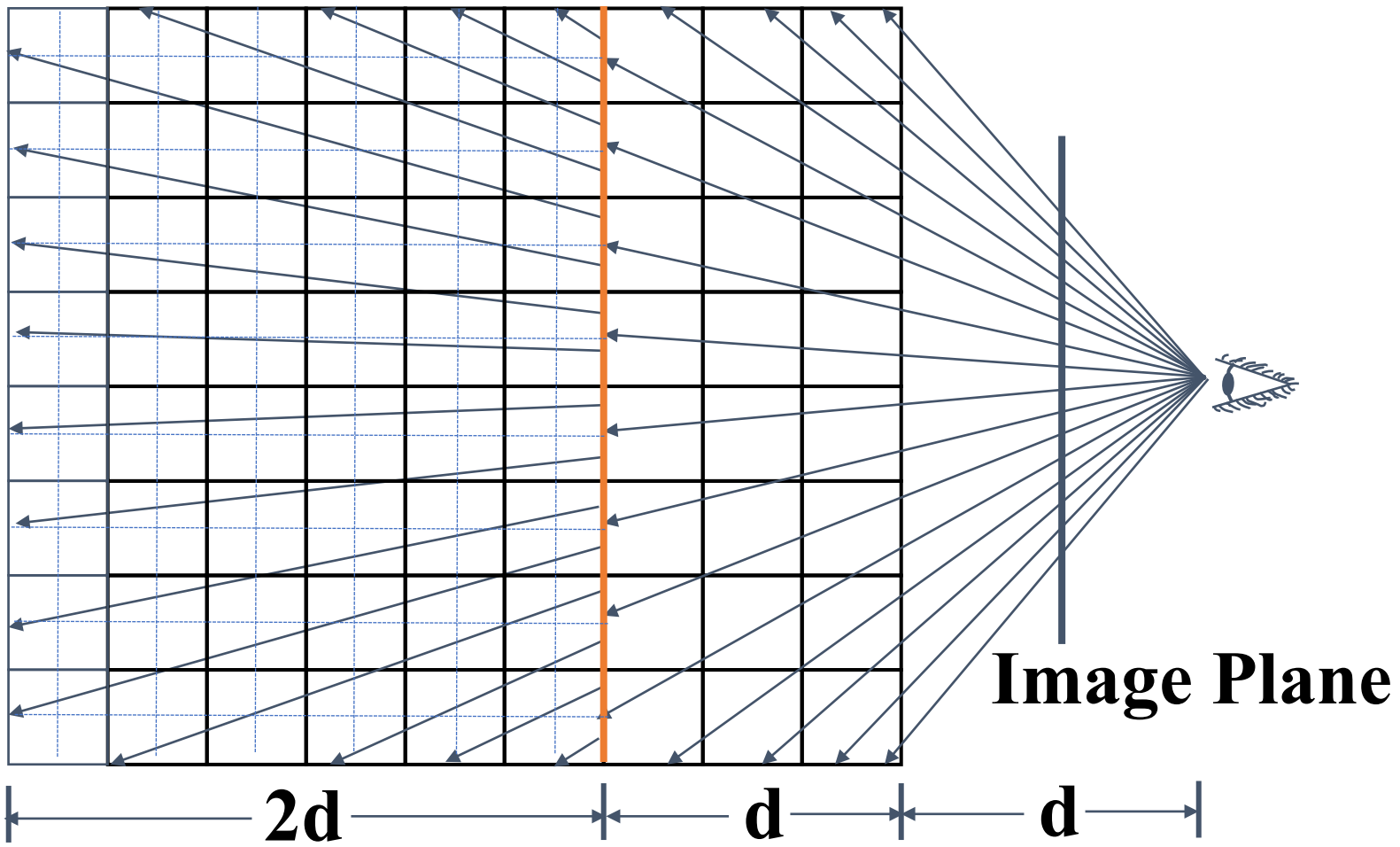
Super sampling

Too Expensive!



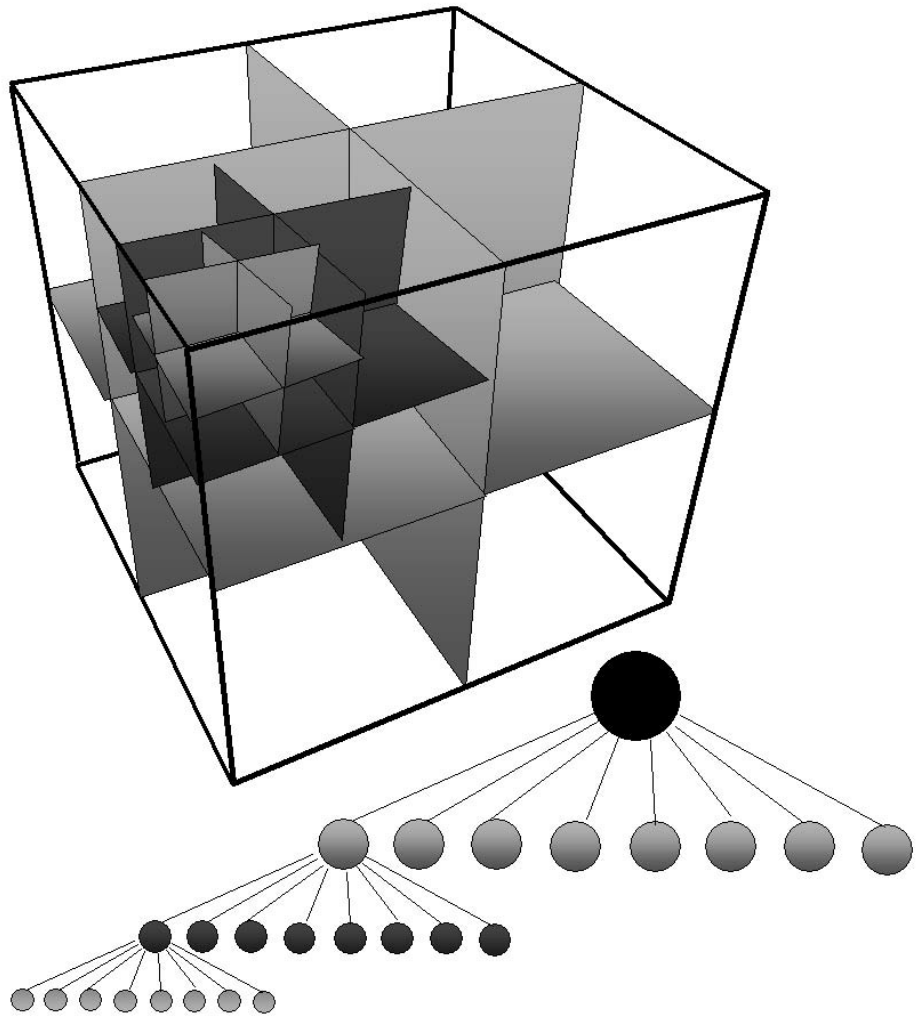
Adaptive Sampling

Kreeger, Dachille, Chen, Bitter, Kaufman, VolVis 98



Accelerated Volume Rendering

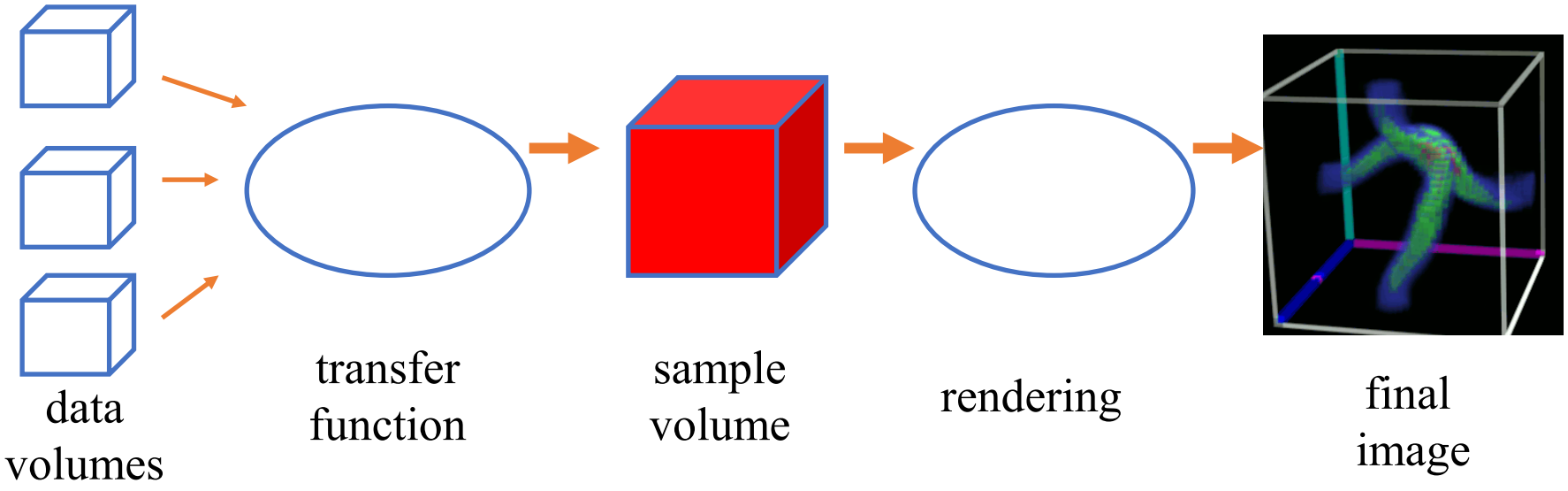
- Multiple/adaptive resolution (like MIPMAP)
- Empty Space Leaping
  - Volume segmentation
  - Octree or BSP space subdivision
- Early ray termination



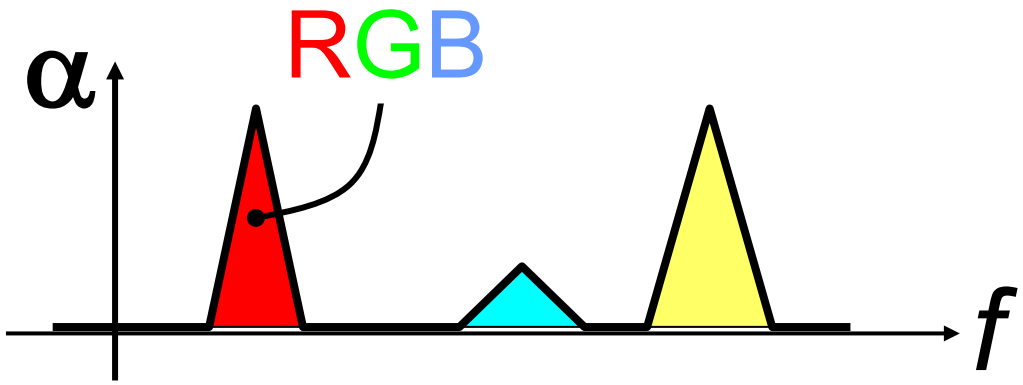
Octree decomposition of a volume

Transfer Functions (TFs)

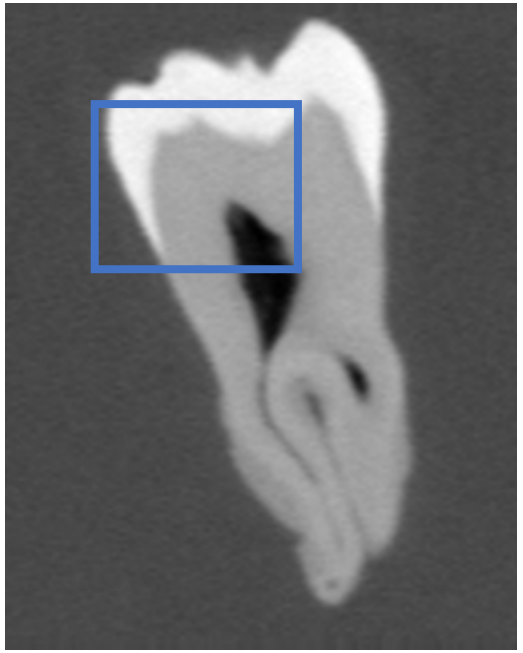
- The transfer function takes (multiple) scalar data values as input, and outputs RGBA
- It gets applied to every voxel (or interpolation among a few)
- It can be very simple (a color lookup table) or very complicated



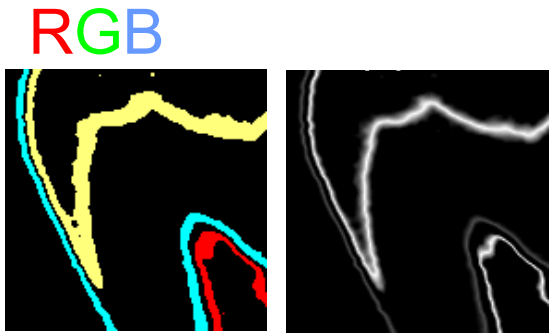
Transfer Functions (TFs)



- Simple (usual) case: map data value f to color and opacity
- More complicated case: add consideration of gradients and other properties
- Still a difficult task to design an effective TF!

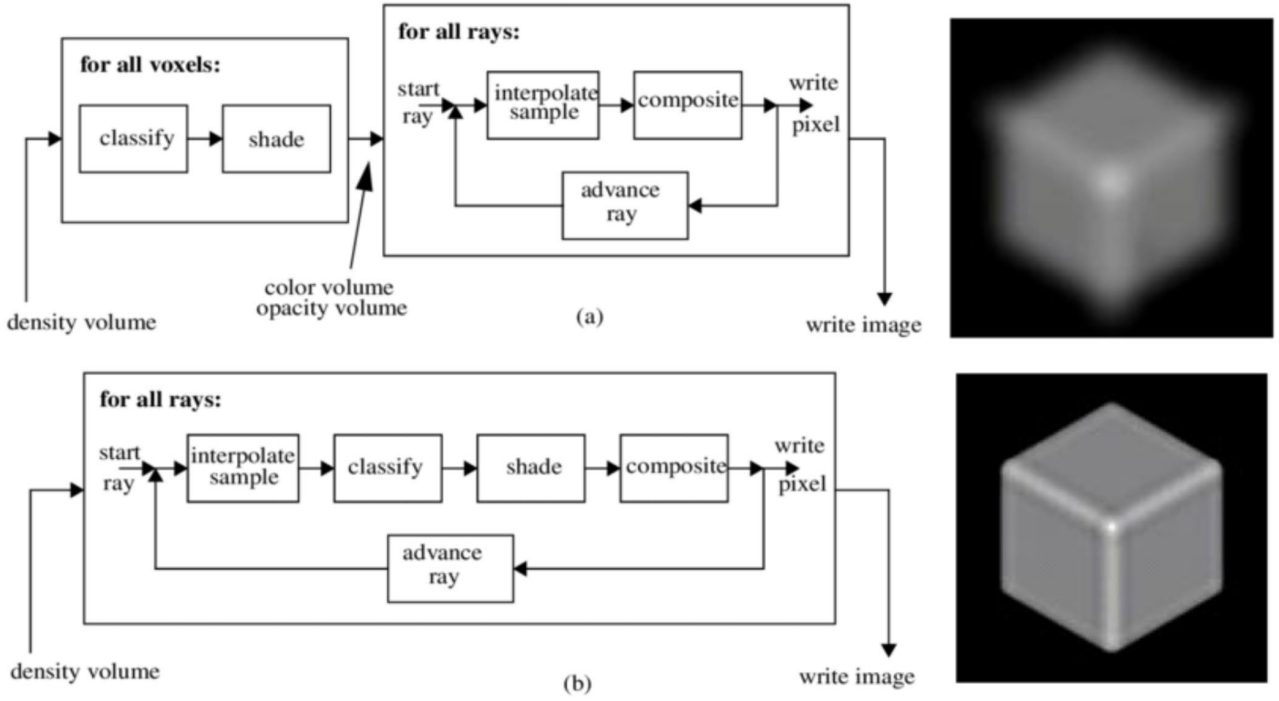


Human Tooth CT

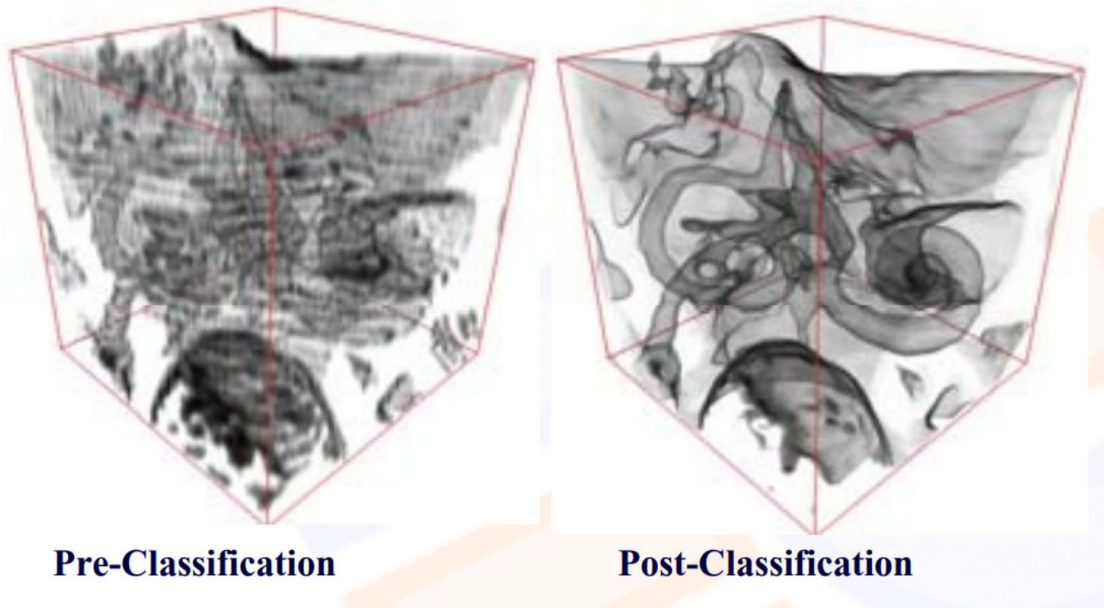


Shading,
Compositing…

Pre-classification or Post-classification



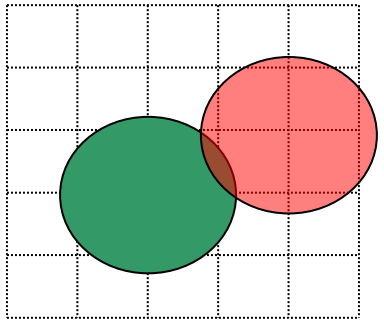
Two standard volume rendering pipelines. (a) Pre-shaded volume rendering: The raw density volume is first classified and shaded, and the volume renderer then interpolates the resulting color and opacity volumes and composites the sample values for image generation. On the right: A cube (8 3 voxels) rendered with splatting from a pre-shaded color and opacity volume (a Gaussian filter of radial extent 2.0 was used for interpolation). (b) Post-shaded volume rendering: The volume renderer interpolates the raw density volume, and these sample values are then classified and shaded and composited for image generation. On the right: The cube of (a) is rendered from the density volume with a raycaster and trilinear interpolation in post-shaded mode.



Volume Splatting: Voxel order volume visualization

- Volume = field of 3D interpolation kernels
  - One kernel at each grid voxel
- Each kernel leaves a 2D footprint on screen
  - Voxel contribution = footprint ·(C, opacity)
- Weighted footprints accumulate into image

voxel kernels



screen

screen footprints = *splats*

Volume Splatting

- Volume = field of 3D interpolation kernels
  - One kernel at each grid voxel
- Each kernel leaves a 2D footprint on screen
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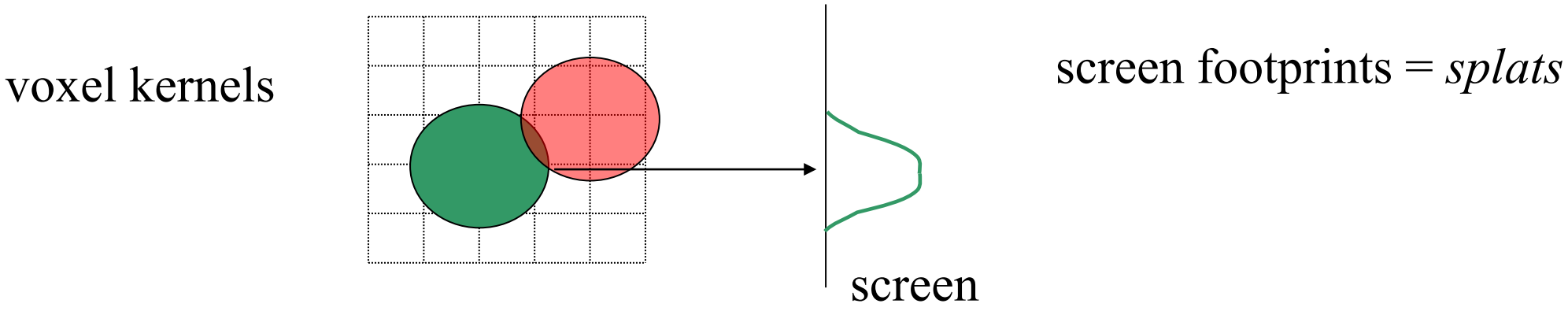
- Weighted footprints accumulate into image



Volume Splatting

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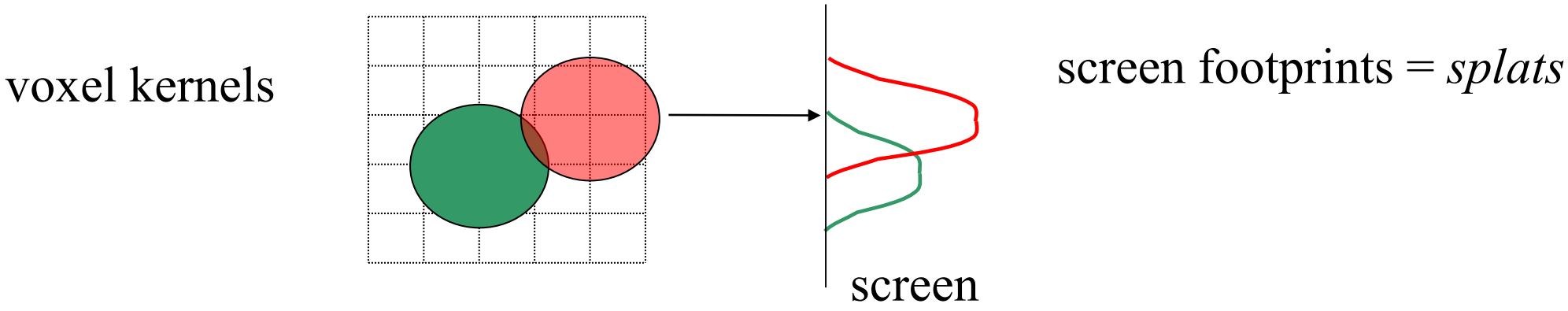
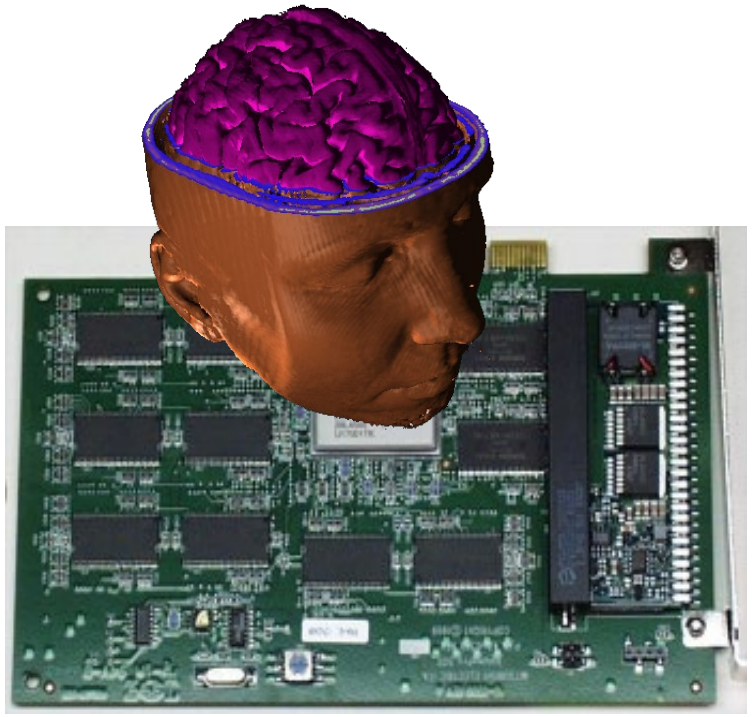


Special Purpose Hardware

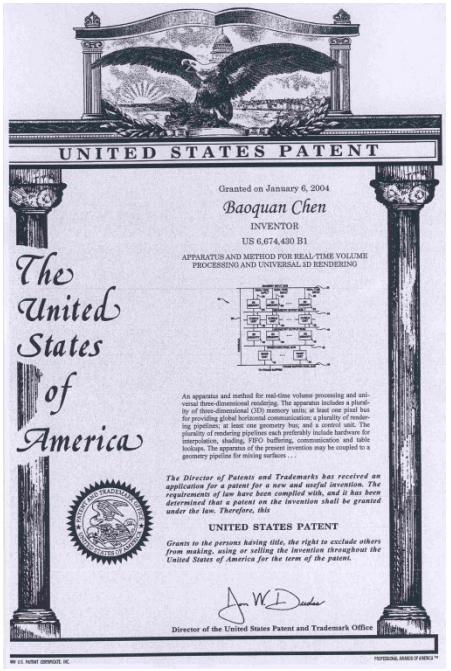


第五代*Cube*芯片设计与实现

- VolumePro (MITSUBISHI ELECTRIC), 1999
- Cube Engine (JRC Japan Radio Co.,Ltd.), 2000

- US Patent：6,674,430: “Apparatus and Method for Real-Time Volume Processing and Universal 3D Rendering” (共同发明人: Arie Kaufman, Baoquan Chen, Ingmar Bitter, Frank Dachille, Kevin Kreeger)

- US Patent：7,133,041: “Apparatus and Method for Volume Processing and Rendering” (共同发明人: Arie Kaufman, Baoquan Chen, Ingmar Bitter, Frank Dachille, Kevin Kreeger)


UNITED STATES PATENT

Granted on January 6, 2004

Baoquan Chen

INVENTOR

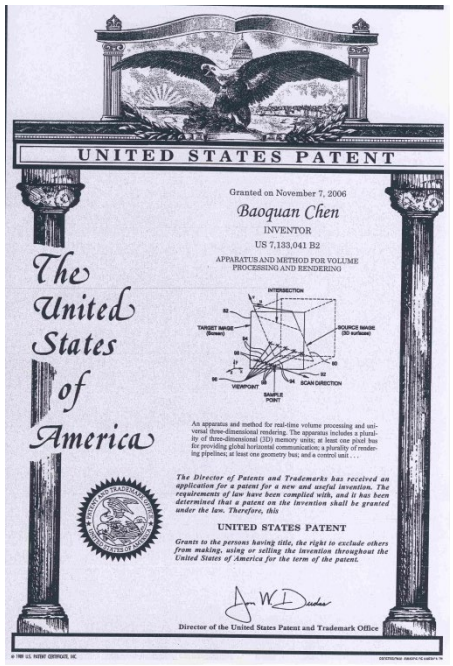
US 6,674,430 B1

APPARATUS AND METHOD FOR REAL-TIME VOLUME PROCESSING AND UNIVERSAL 3D RENDERING

The United States of America

UNITED STATES PATENT

Director of the United States Patent and Trademark Office


UNITED STATES PATENT

Granted on November 7, 2006

Baoquan Chen

INVENTOR

US 7,133,041 B2

APPARATUS AND METHOD FOR VOLUME PROCESSING AND RENDERING

The United States of America

UNITED STATES PATENT

Director of the United States Patent and Trademark Office

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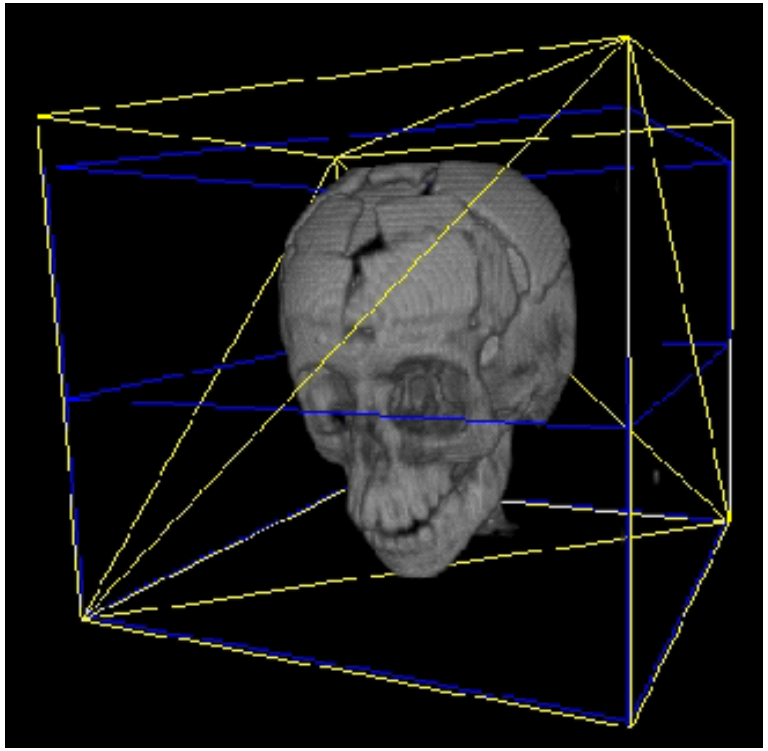
TERARECON, INC

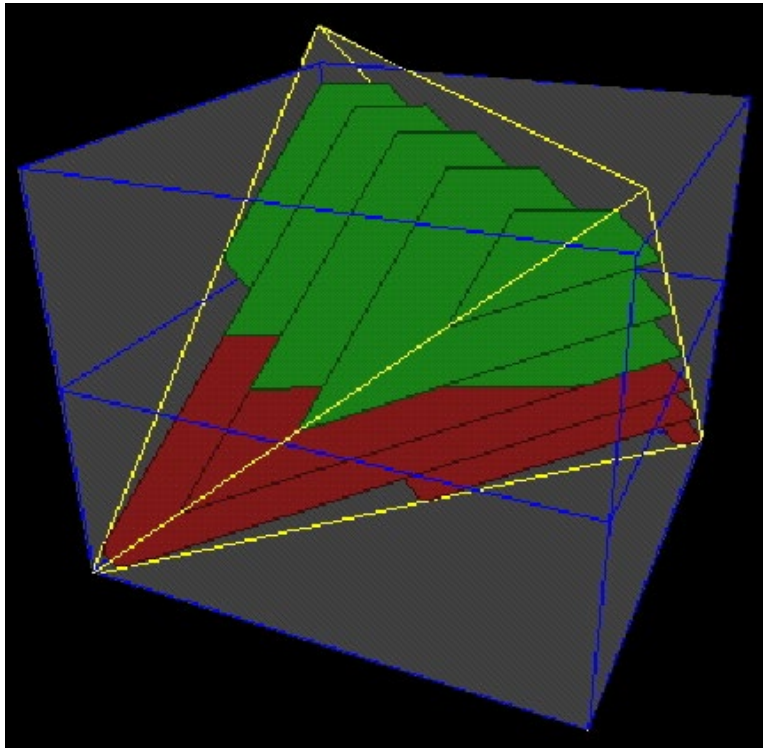
JRC Japan Radio Co.,Ltd.

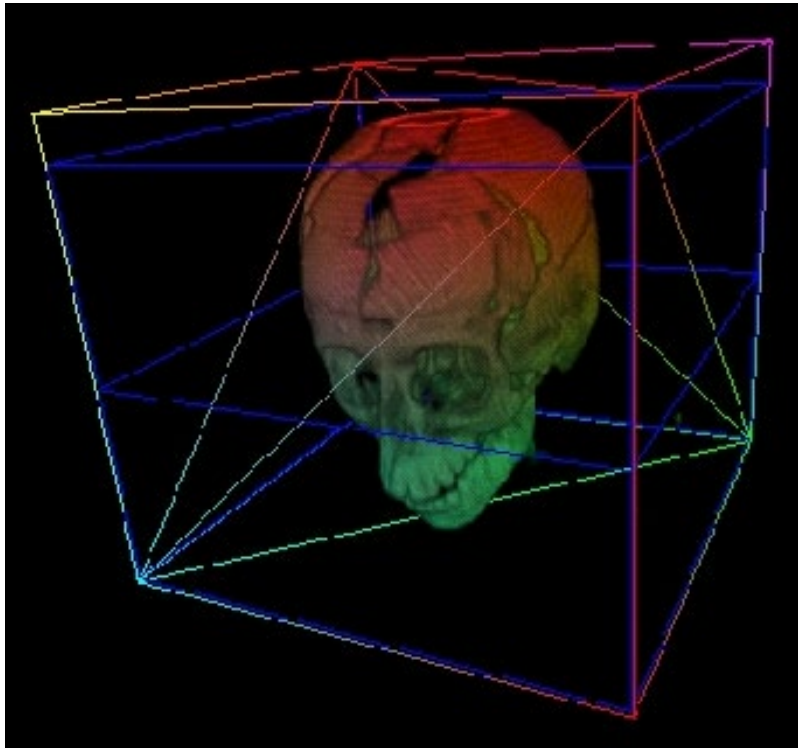
VIATRONIX V3D - The new imaging reality

Using Conventional Graphics Hardware

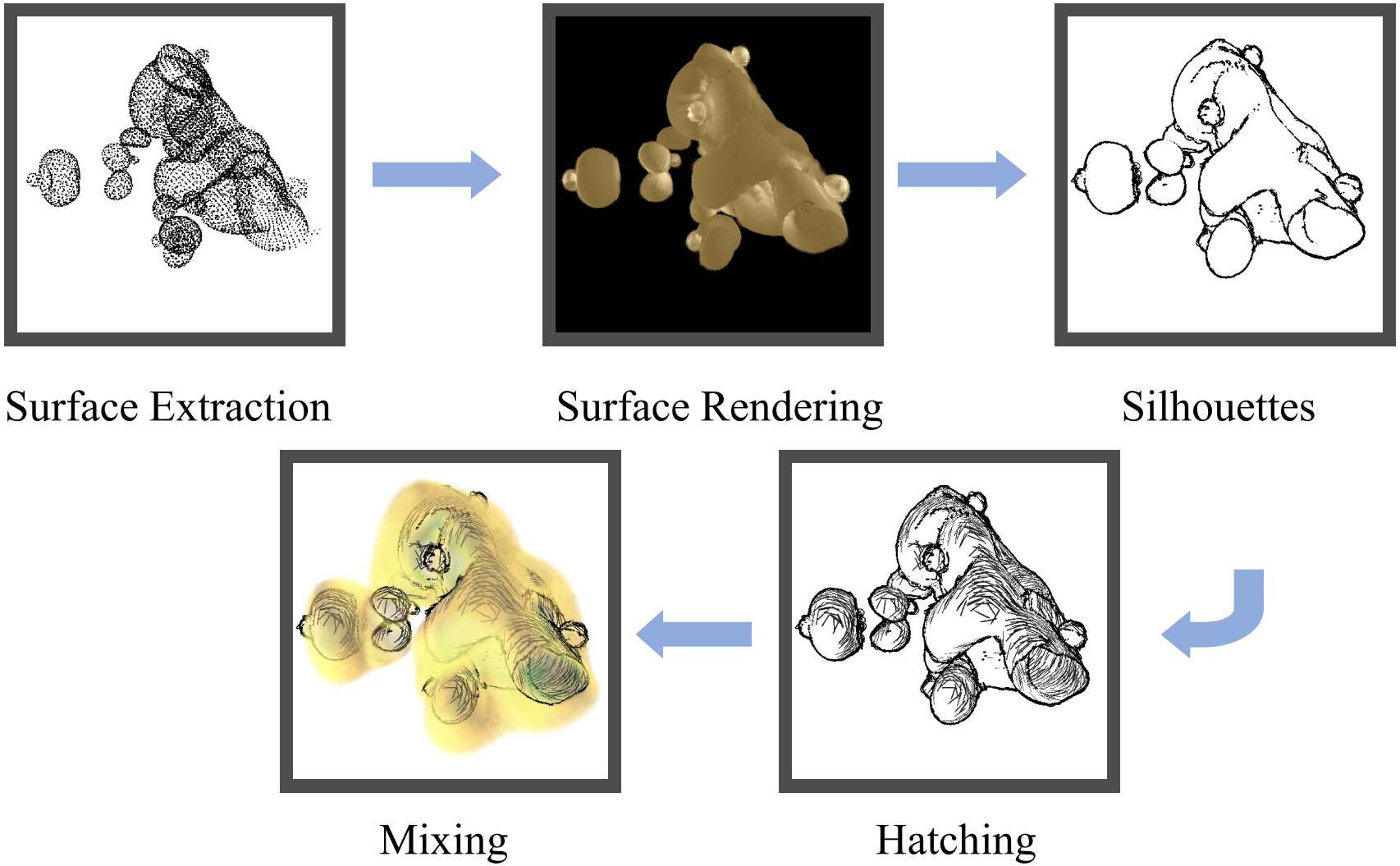
Cutting parallel planes into the volume and composite texture-mapped planes in order





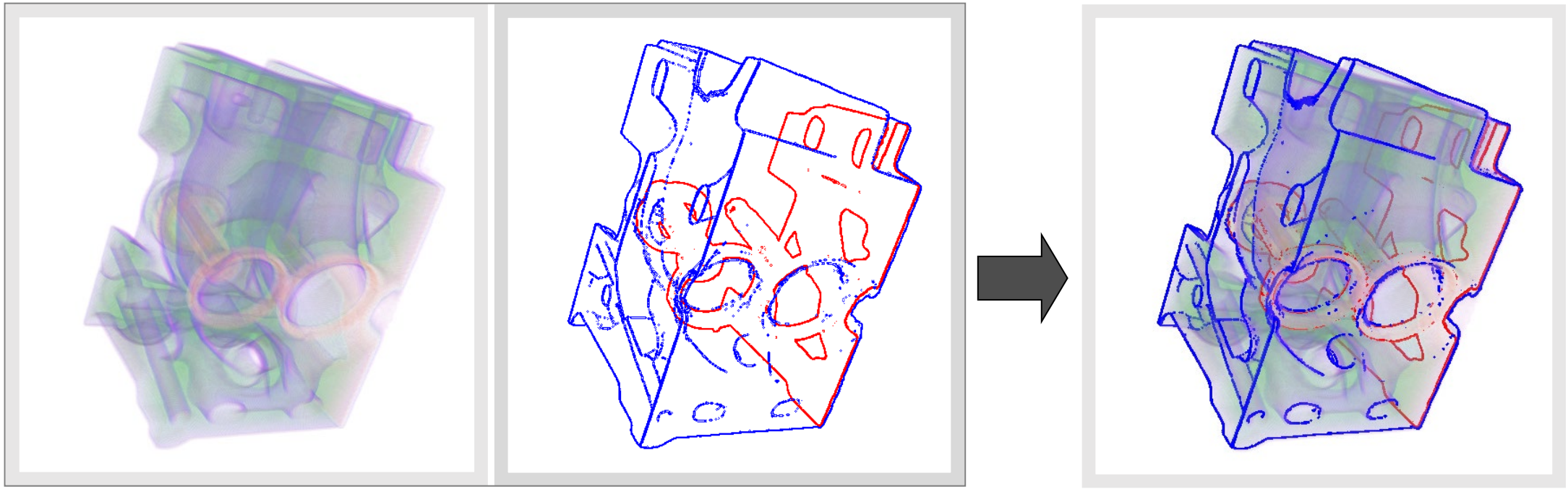


Mixing Surfaces with Volume

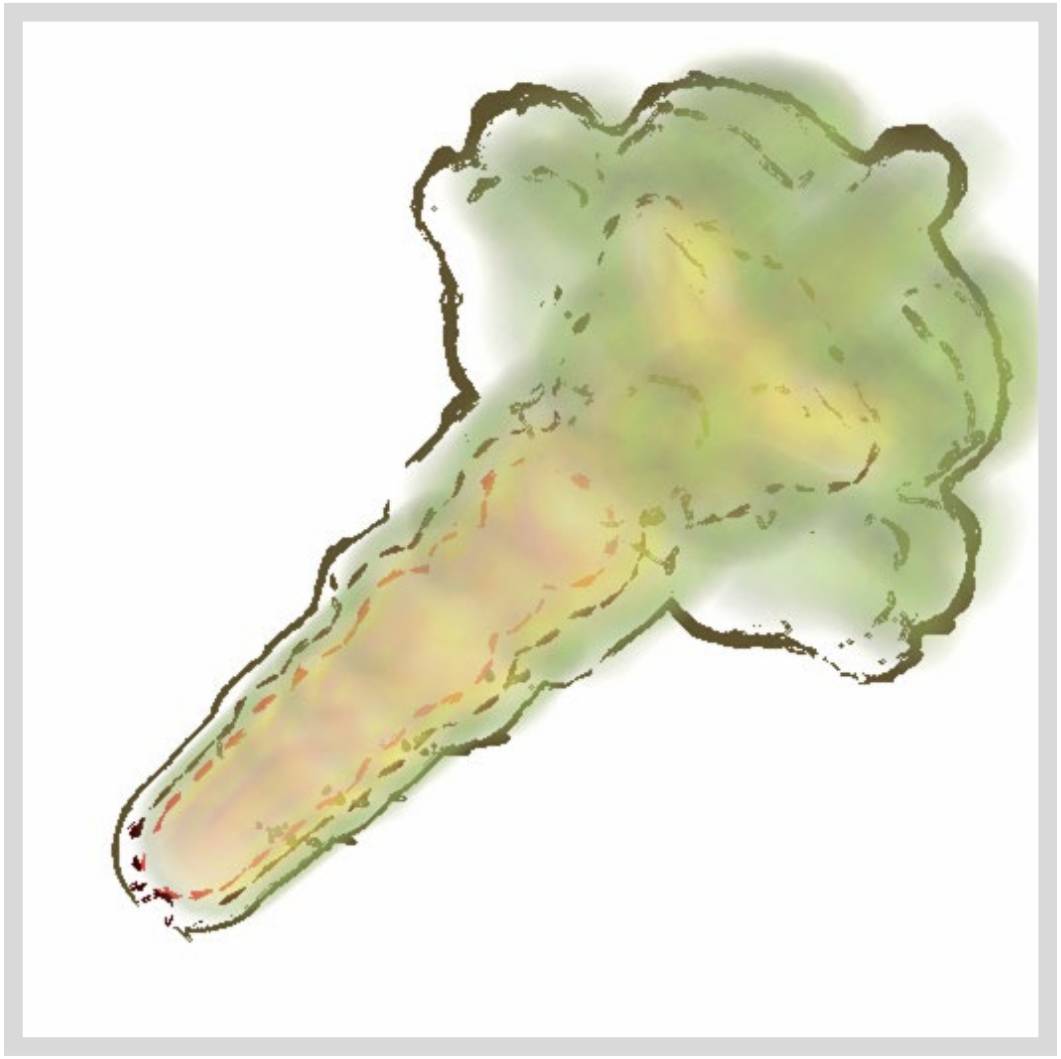


Illustrating Surfaces in Volume. Xiaoru Yuan and Baoquan Chen. Joint EUROGRAPHICS - IEEE TCVG Symposium on Visualization, May 19-21, 2004, Constanz, Germany. http://cfcs.pku.edu.cn/baoquan/docs/20180621152621466265.pdf

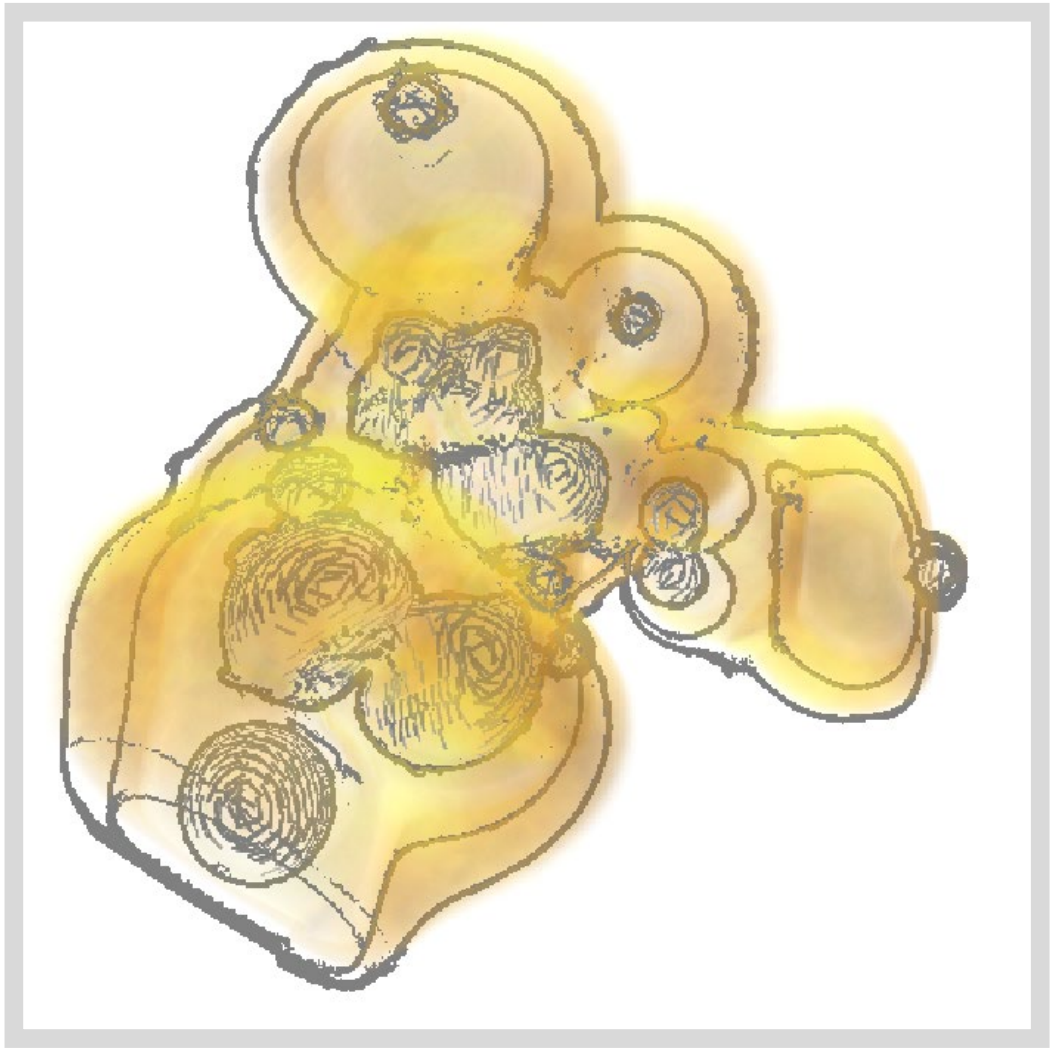
Mixing Surfaces with Volumes



Mixing Surfaces with Volumes



Simulation of fuel injection



Physical simulation of a high potential protein

Thanks