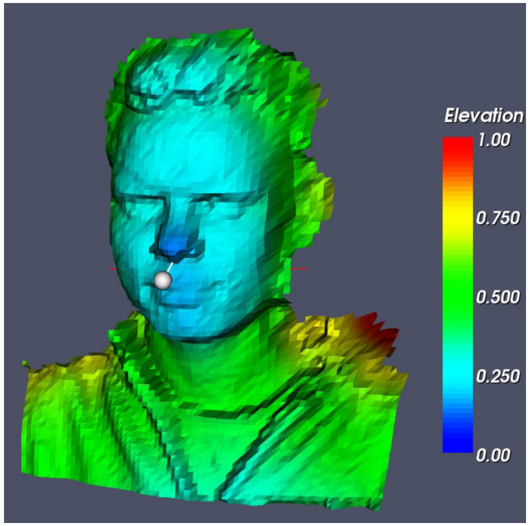
CS 775: Advanced Computer Graphics

Lecture 11: Volume Graphics

Volume Graphics

- Volume data - Attributes
  - Scalar data
  - Single value at each point
  - Challenges:
    - How to visualize (render)?
    - What to visualize?
    - Do we need surfaces?



Heightfields

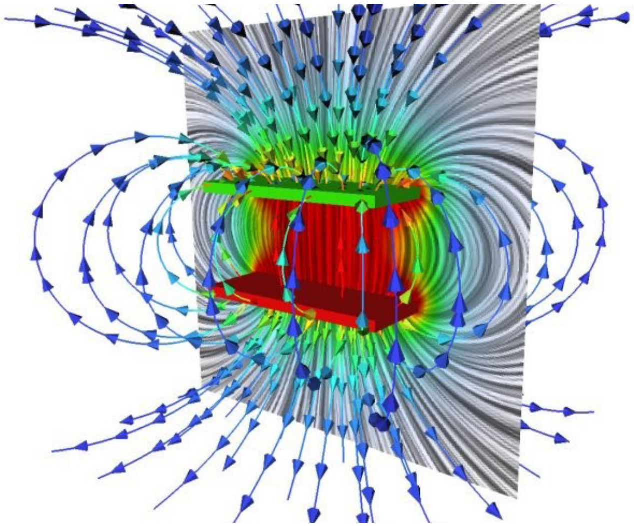
http://www.inf.ed.ac.uk/teaching/courses/vis/

Volume density (MRI)

Volume Graphics

- Volume data - Attributes
  - Vector data
  - Vector value at each point
  - Challenges:
    - How to visualize (render)?
    - Time varying visualization?
    - Streamlines or sections?

Magnetic field visualization



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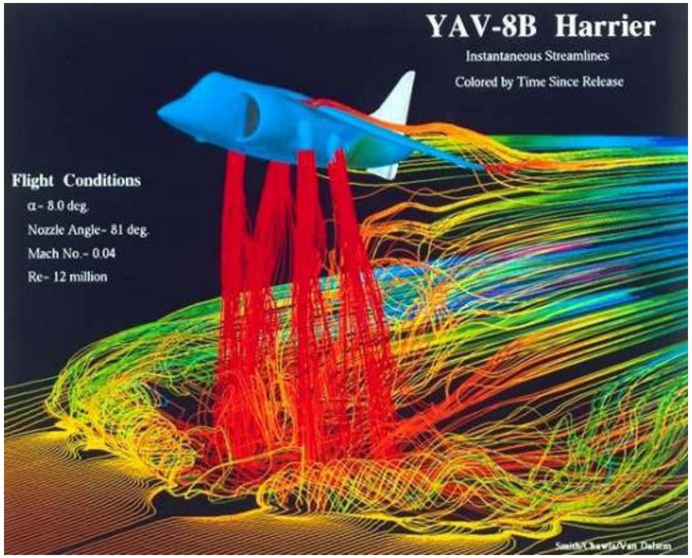
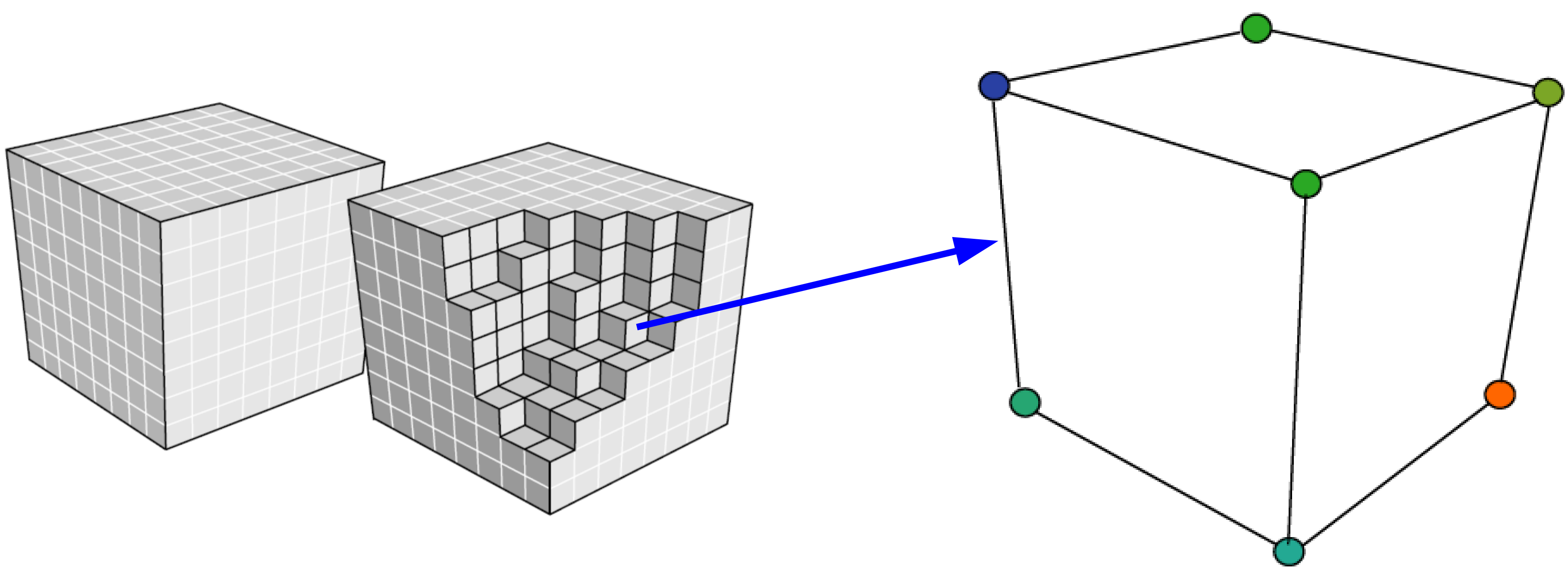
Wind flow visualization



NASA Ames

Volume Graphics

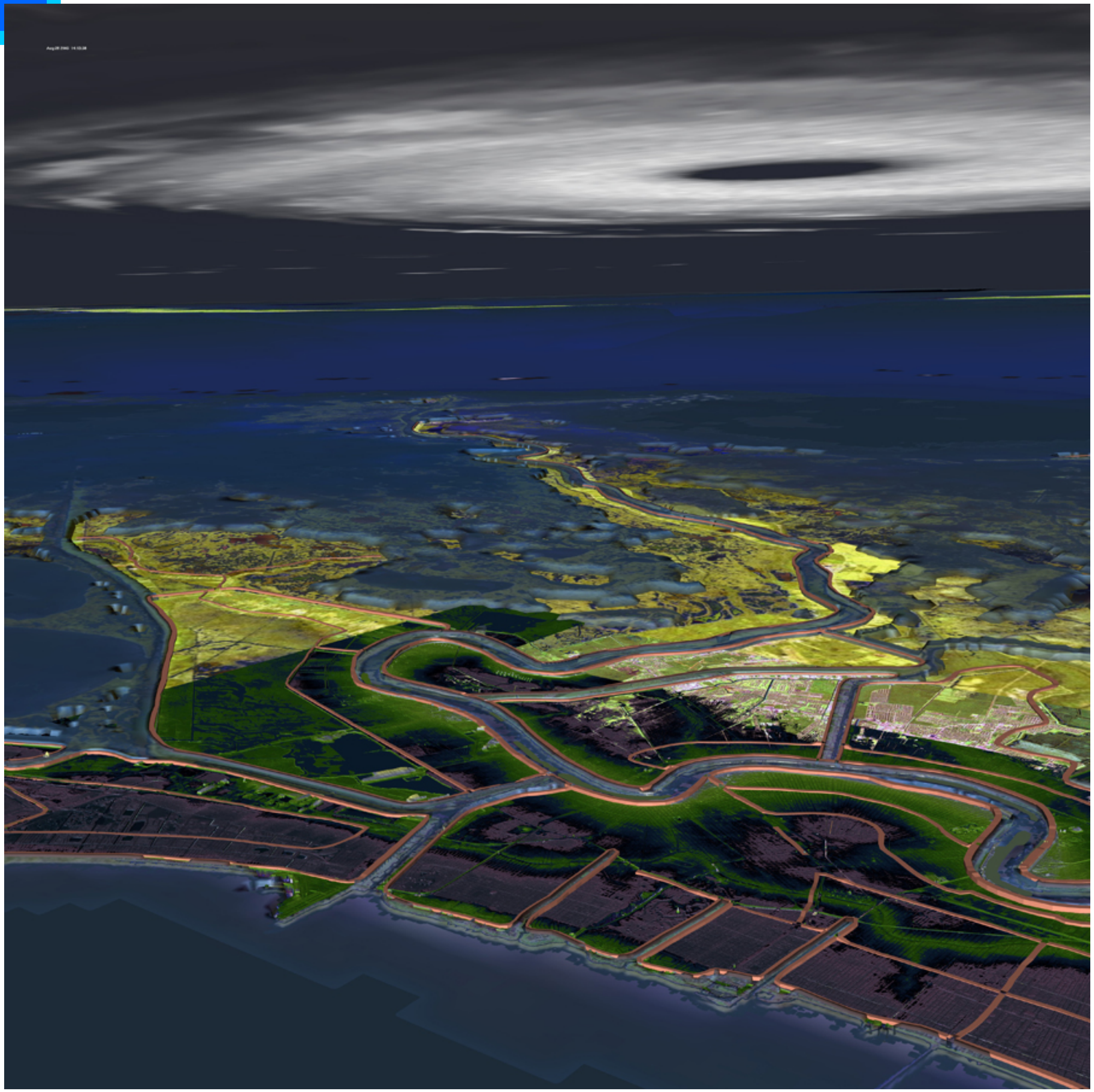
- Volume data - Structure
  - We need a (topological/geometric) structure for volume data.
  - Voxels – discretize space.



Volume Graphics

- Scalar data visualization
  - Colour Mapping
  - Map scalar value to a colour range
    - Colour Look-Up Table or LUT

Volume Graphics



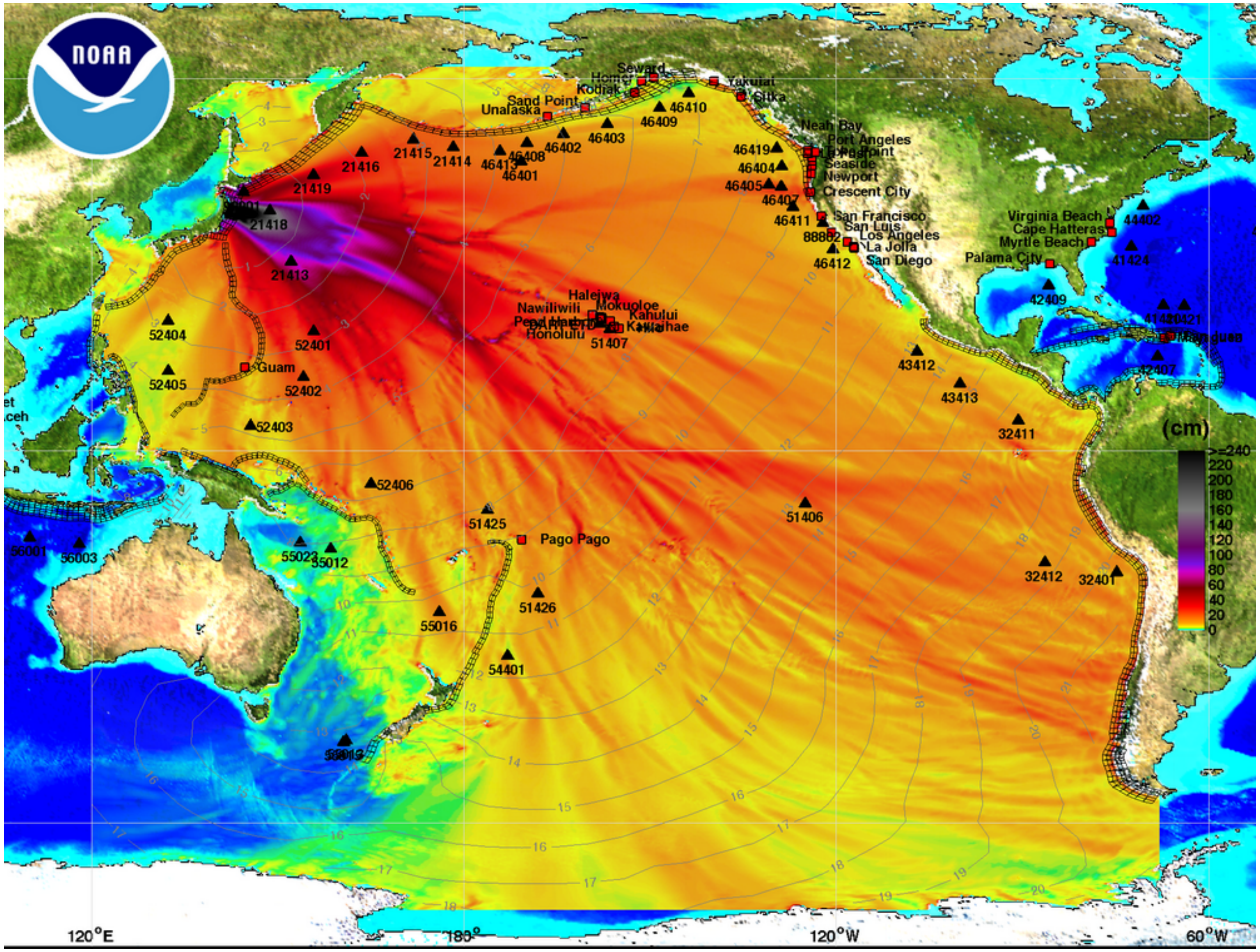
These scientific visualizations of Hurricane Katrina were created at the LSU Laboratory of Creative Arts + Technology (LCAT) by the CCT sci-viz group.

New Orleans Perspective from Lake Pontchartrain, LIDAR elevation, GOES-12 satellite imagery, and Adcirc sea elevation and levee system, AUG 26 - AUG 31st.

The LIDAR heightfield is color coded: yellow/green for land above sea level, blue at sea level and violet below sea level. The land above sea level in New Orleans was formed by the Mississipippi River naturally flooding and depositing sediment. The natural levee that surrounds the river can be seen in green as well as the Gentilly, Metairie Ridge. The height of the storm surge is indicated by dark blue. The Adcirc levee system is shown in pink.

Image courtesy of sciviz.cct.lsu.edu.

Volume Graphics



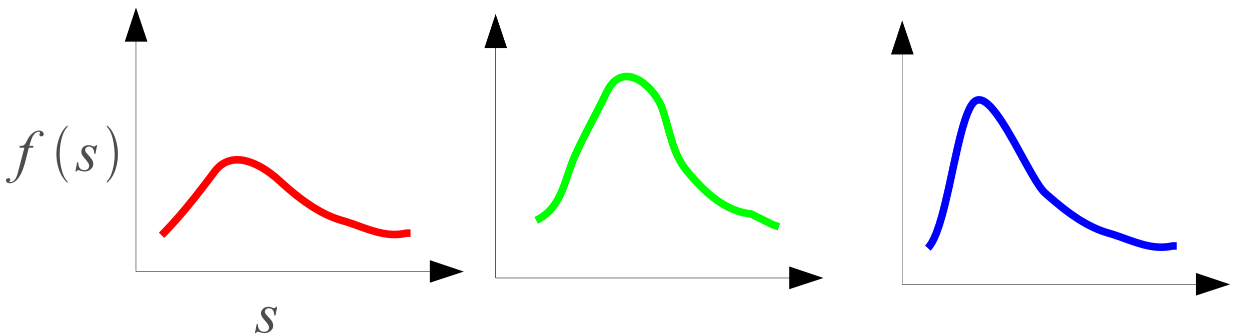
Tsunami Wave Height Visualization

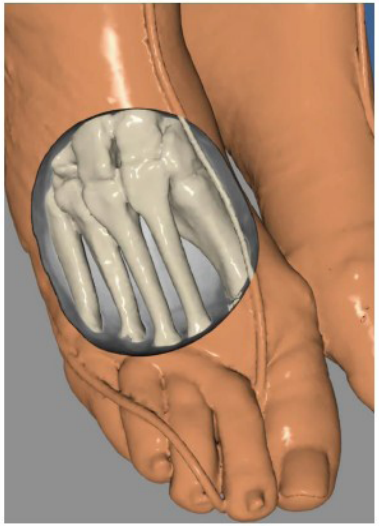
Model runs from the Center for Tsunami Research at the NOAA Pacific Marine Environmental Laboratory show the expected wave heights of the tsunami as it travels across the Pacific basin. The largest wave heights are expected near the earthquake epicenter, off Japan. The wave will decrease in height as it travels across the deep Pacific but grow taller as it nears coastal areas. In general, as the energy of the wave decreases with distance, the near shore heights will also decrease (e.g., coastal Hawaii will not expect heights of that encountered in coastal Japan).

Image courtesy of http://www.nnvl.noaa.gov/MediaDetail.php?MediaID=680&MediaTypeID=1

Volume Graphics

- Scalar data visualization
  - Colour Mapping
  - Map scalar value to a colour range
    - Colour Look-Up Table or LUT
    - Transfer Functions, $f(s)=c$

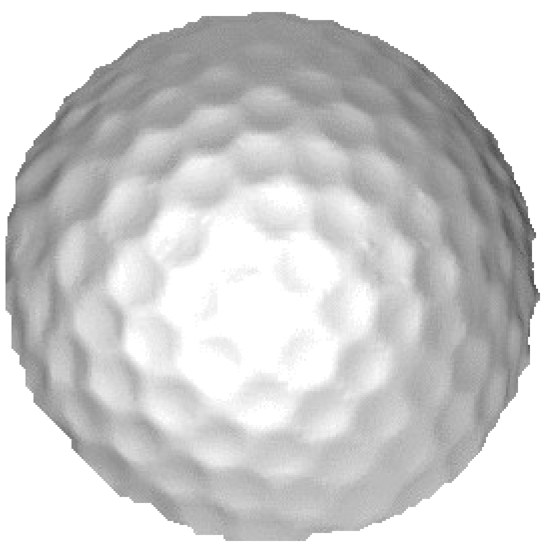




Design f() to giving to convert volume density to give appropriate colour values.

Volume Graphics

- Scalar data visualization
  - Transfer function design is often non-trivial!

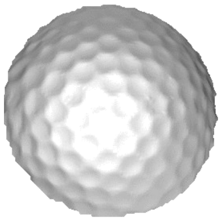


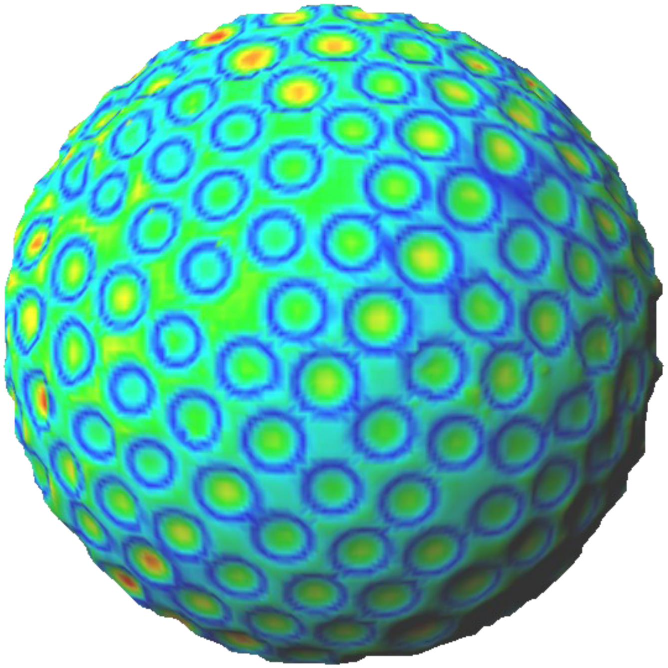
http://www.inf.ed.ac.uk/teaching/courses/vis/

Are the dimples on this golf ball evenly distributed?

Volume Graphics

- Scalar data visualization
  - Transfer function design is often non-trivial!





Are the dimples on this golf ball evenly distributed?

No. (Why?)

Transfer function used:

Colour map each point based on scalar distance from regular sphere.

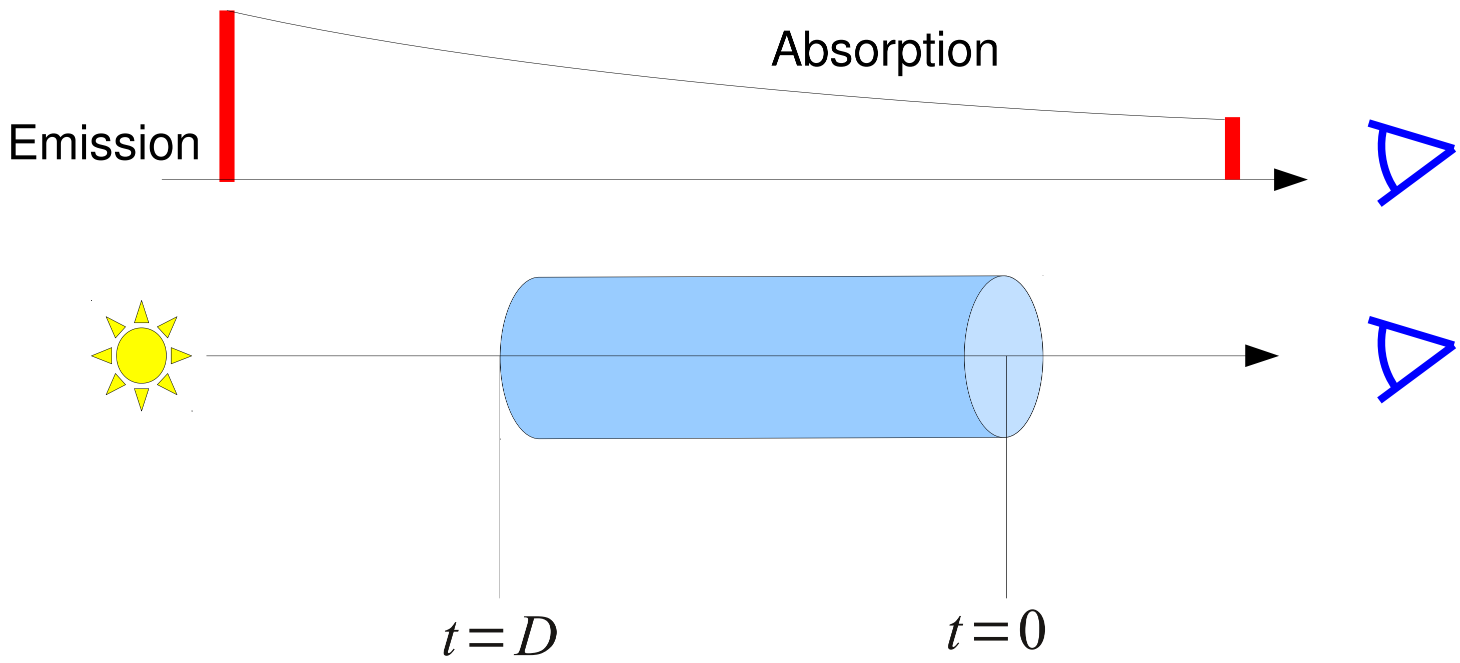
http://www.inf.ed.ac.uk/teaching/courses/vis/

Volume Graphics

- Volume Rendering
  - *Direct* Volume Rendering
    - Colour mapping and transfer functions are instances.
    - In general evaluate how light behaves inside the volume
    - Absorption only
    - Emission only
    - Absorption and Emission
    - Single Scaterring and/or shadowing
    - Multiple Scaterring

Volume Graphics

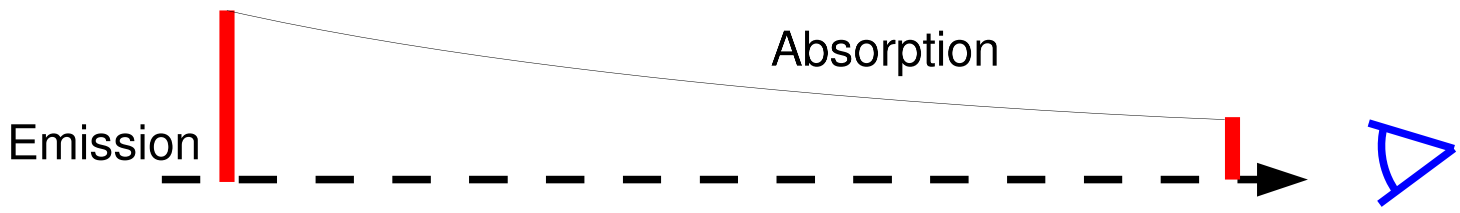
- The Volume Rendering Integral
  - Evaluate along a ray



  - No scattering – no reflections, refractions

Volume Graphics

- The Volume Rendering Integral
  - Evaluate along a ray



  - If there is constant absorption along the ray, amount of radiant energy reaching the eye

$$c' = c \, . \, e^{-\kappa D}$$

  - If absorption depends on position,

$$c' = c \, . \, e^{-\int_0^D \kappa(t)\,dt}$$

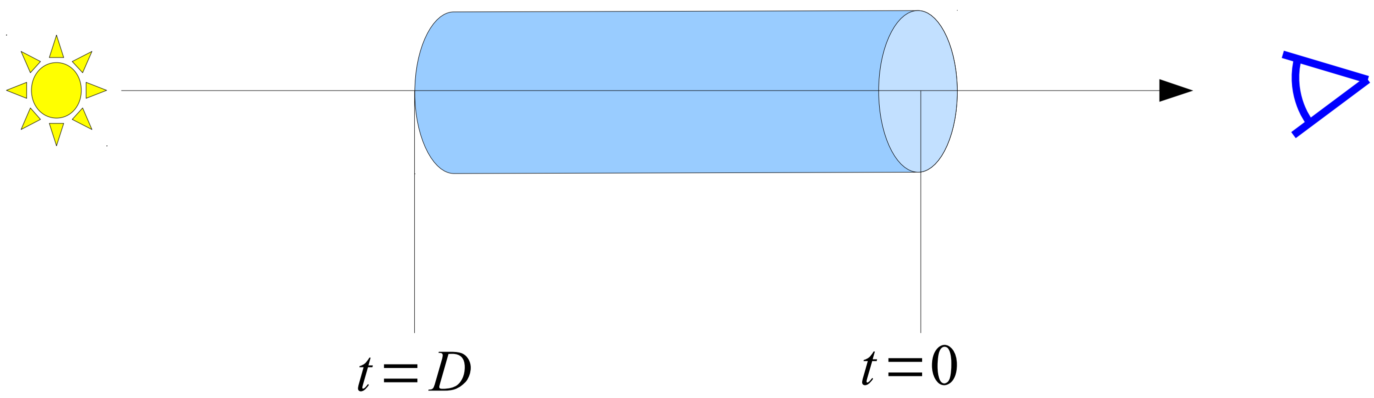
  - Integral over the absorption coeffcient is called the *optical depth*

$$\tau(d_1, d_2) = \int_{d_1}^{d_2} \kappa(t)\,dt$$

Volume Graphics

- The Volume Rendering Integral
  - Evaluate along a ray

$$I(D) = I_o e^{-\tau(0,D)} + \int_0^D c(t)\, e^{-\tau(0,t)}\, dt$$

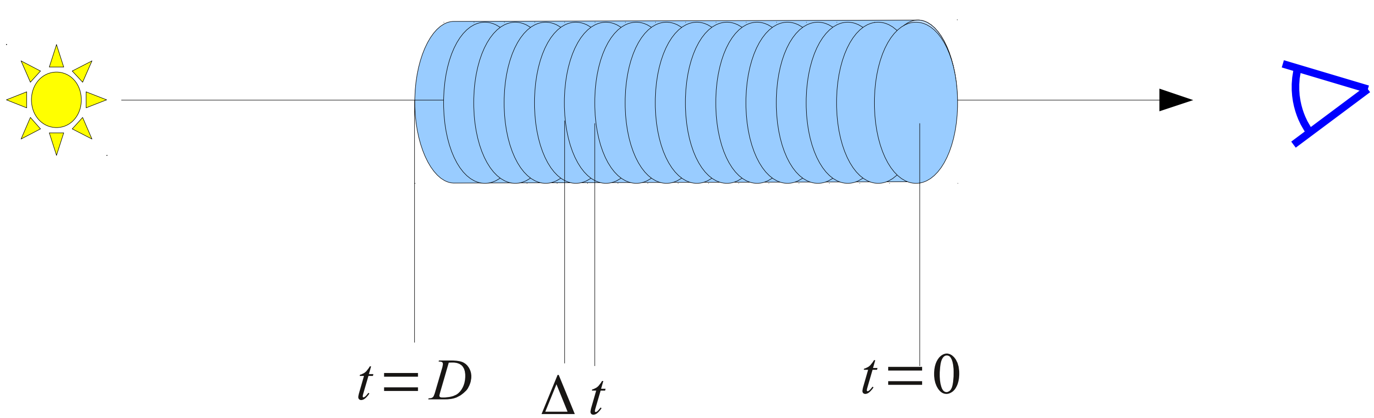


Volume Graphics

- The Volume Rendering Integral
  - Sample along a ray

$$\tau(0,t) \approx \tilde{\tau}(0,t) = \sum_{i=0}^{\lfloor t/\Delta t \rfloor} \kappa(i.\Delta t)\Delta t$$

$$e^{-\tilde{\tau}(0,t)} = \prod_{i=0}^{\lfloor t/\Delta t \rfloor} e^{-\kappa(i.\Delta t)\Delta t}$$

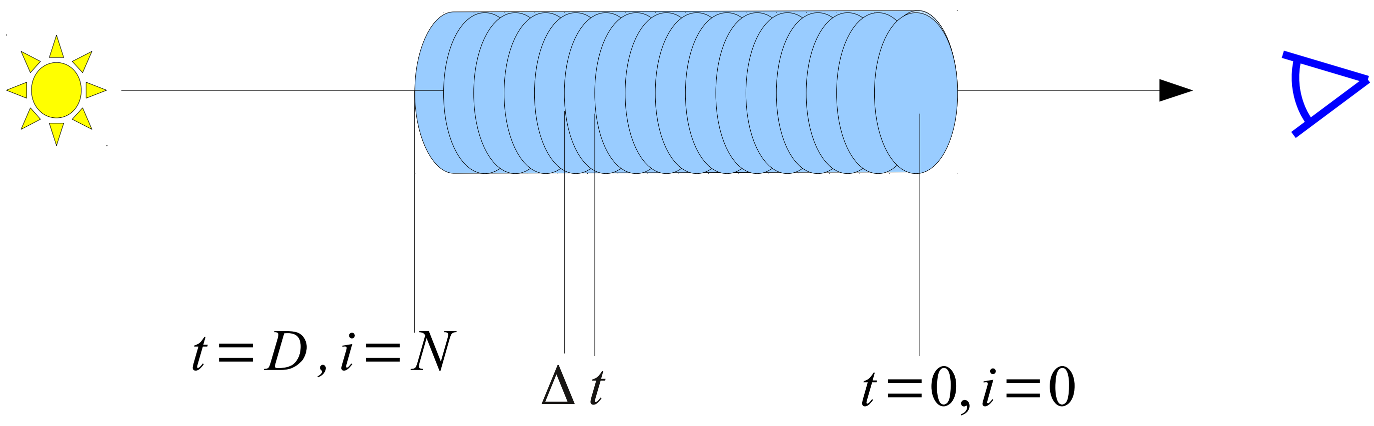


Volume Graphics

- The Volume Rendering Integral
  - If emitted color of the i-th ray segment

$$C_i = c(i.\Delta t)\Delta t$$

$$\tilde{C} = \sum_{i=0}^{N} C_i e^{-\tilde{\tau}(0,i-1)} = \sum_{i=0}^{N} C_i \prod_{j=0}^{i-1} e^{-\kappa(j.\Delta t)\Delta t}$$



Volume Graphics

- Ray Casting
  - Alpha compositing/blending with the optical depth approximated by opacity

$$A_i = 1 - e^{-\kappa(i.\Delta t)\Delta t}$$

$$\tilde{C} = \sum_{i=0}^{N} C_i \prod_{j=0}^{i-1} (1 - A_j)$$

  - Doable in OpenGL, has hardware support.
  - 3D textures can hold the data in GPU memory.

Back to Front Alpha Blending

$$C'_i = C_i + (1 - A_i) C'_{i+1}$$

$$i : (N-1) \rightarrow 0$$

Front to Back Alpha Blending

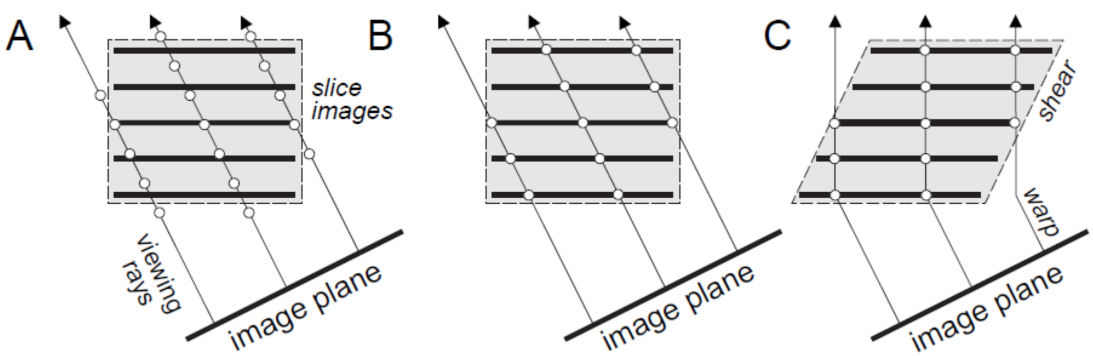
$$C'_i = C'_{i-1} + (1 - A'_{i-1}) C_i$$

$$A'_i = A'_{i-1} + (1 - A'_{i-1}) A_i$$

$$i : 1 \rightarrow N$$

Volume Graphics

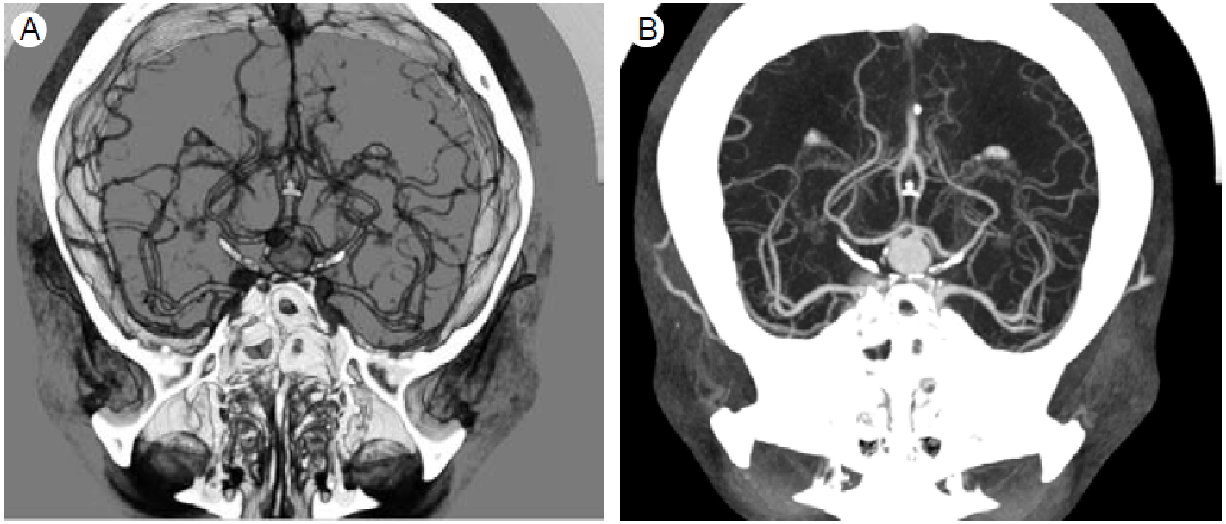
- Shear-Warp
  - Shear the volume so that projection on some intermediate plane is orthographic.
  - Project each data slice and warp final image to actual projection plane.



What about perspective viewing?

Volume Graphics

- Maximum Intensity Projection (MIP)



- Resampling in the volume
  - We are resampling within the volume for rendering.
  - What about aliasing?
  - Trilinear interpolation is common.

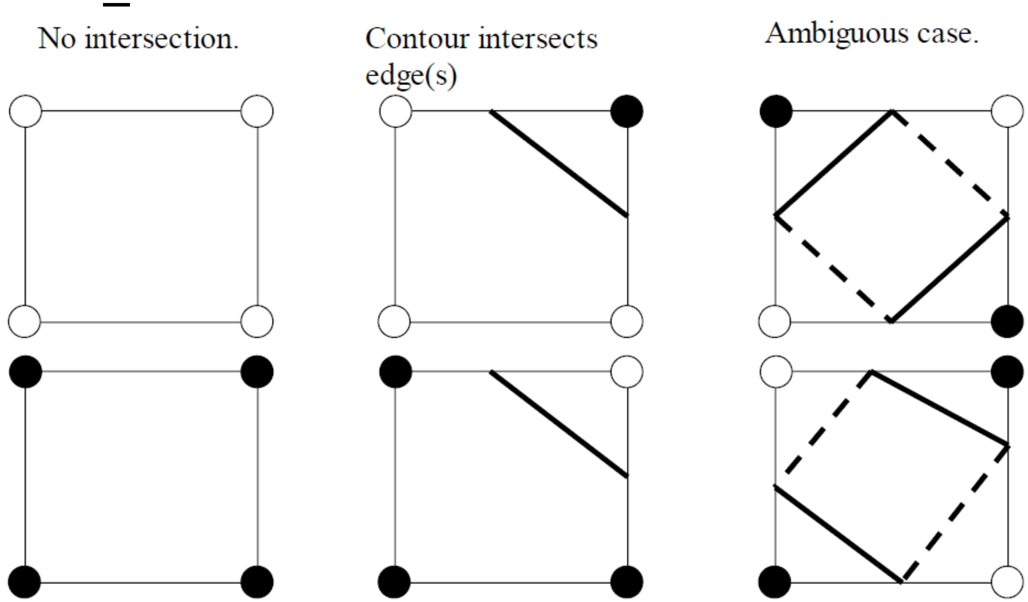
Volume Graphics

- Iso-surface contouring
  - Surfaces of constant scalar value
  - Transition boundaries
  - Find to contour corresponding to the iso-contour value of 5

0	1	1	3	2
1	3	6	6	3
3	7	9	7	3
2	7	8	6	2
1	2	3	4	7

Volume Graphics

- Iso-surface contouring
  - Marching squares algorithm
  -



0	1	1	3	2
1	3	6	6	3
3	7	9	7	3
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1	2	3	4	7

  - For each cell: 4 vertices, 2 states – 2^4 combinations

Volume Graphics

- Iso-surface contouring
  - Marching squares algorithm
    - Select a cell
    - Calculate inside/outside state of each vertex
    - Determine which edge is intersected
    - Move (or march) to next cell until all cells are visited

0	1	1	3	2
1	3	6	6	3
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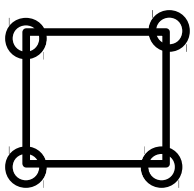
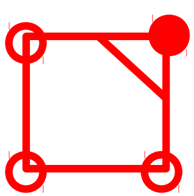
Volume Graphics

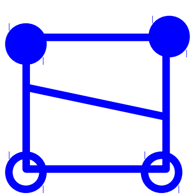
- Iso-surface contouring
  - Marching squares algorithm



No intersection



Contour intersects 2 edges
(no ambiguity)



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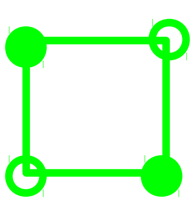

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Volume Graphics

- Iso-surface contouring
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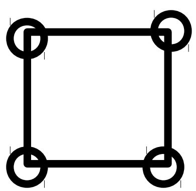

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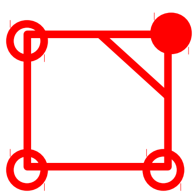

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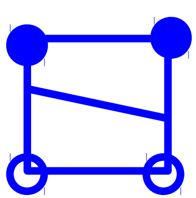

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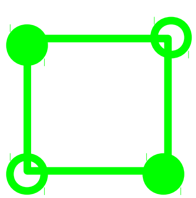

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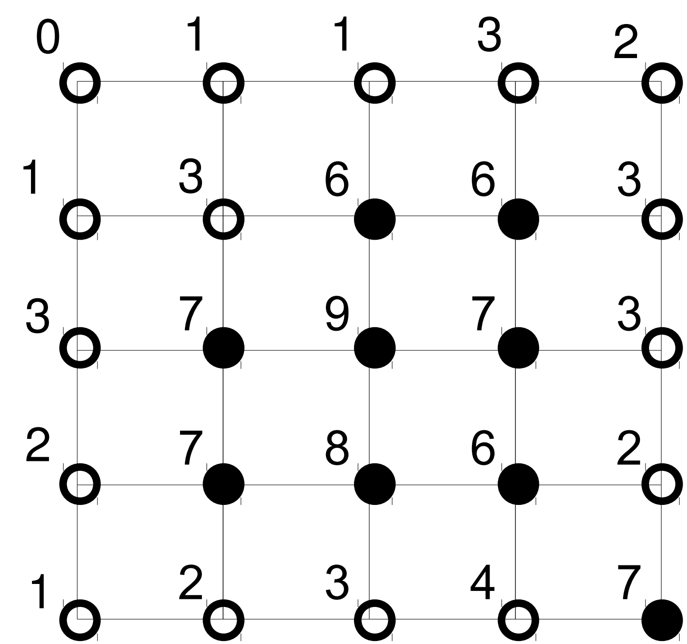

Volume Graphics

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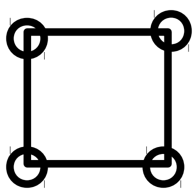

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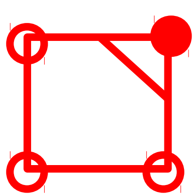

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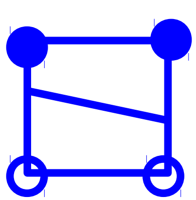

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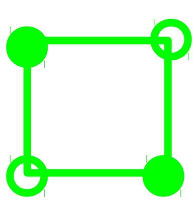

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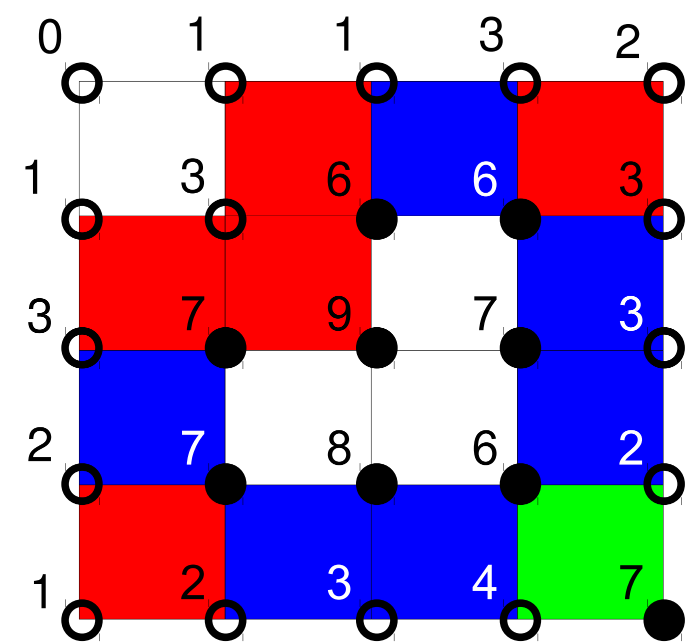
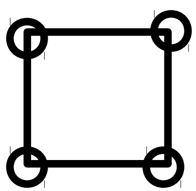


Volume Graphics

- Iso-surface contouring
  - Marching squares algorithm



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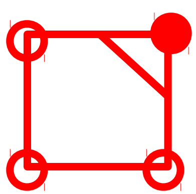

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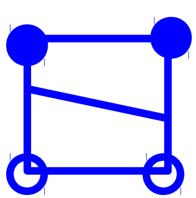

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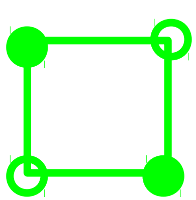

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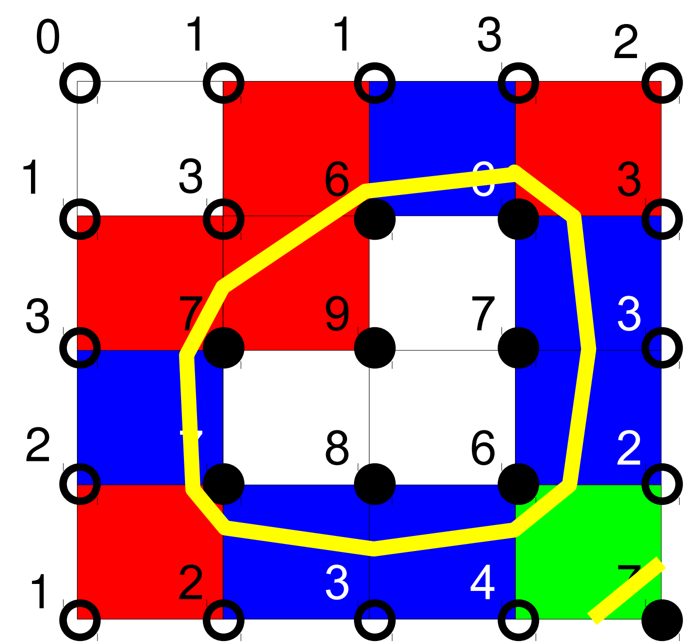

Volume Graphics

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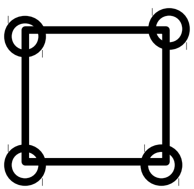

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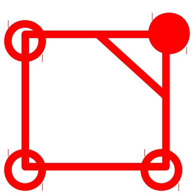

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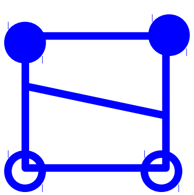

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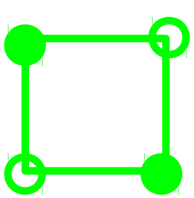

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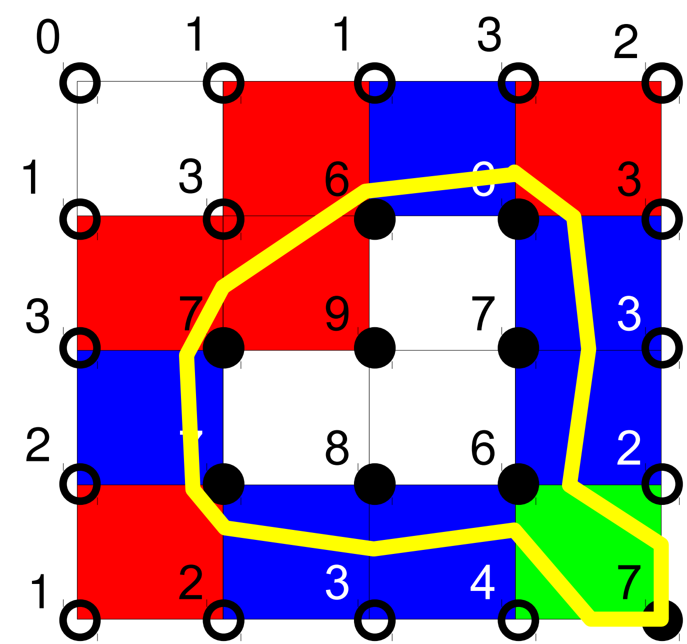
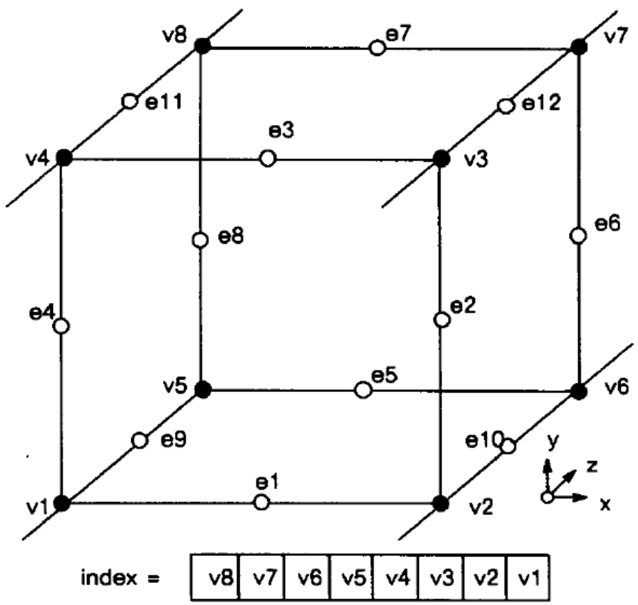
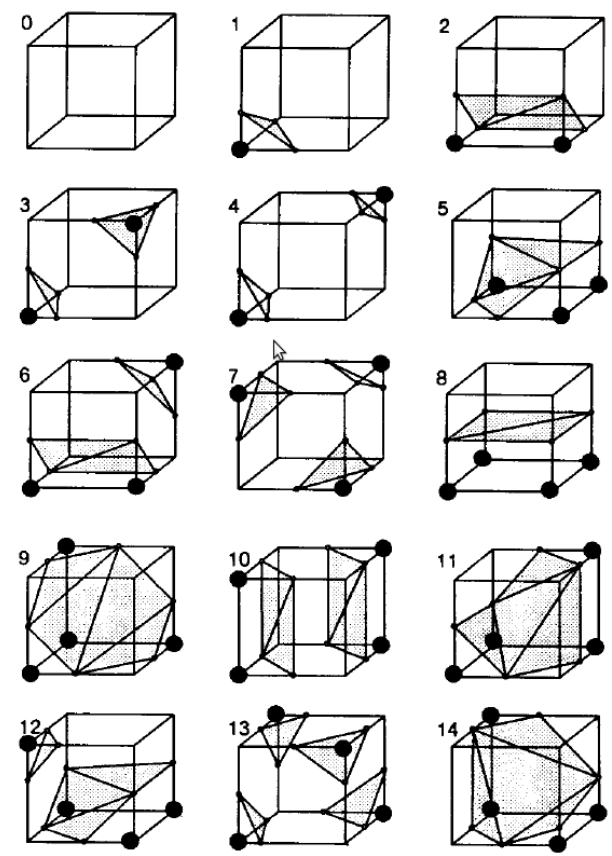


Volume Graphics

- Iso-surface contouring
  - Marching cubes algorithm





Ambiguous cases

- 3,6,10,12,13 – split or join ?

Volume Graphics

- Volumes are also important in simulation
  - Simulations on a grid – Fire, fluid flow, explosions
  - Volumetric finite elements – thickness of materials
  - How do volumes interact with surfaces?
    - Water poured into a glass
    - Fire burning logs of wood
    - Visualizing Cancer cell growth
    - Do we model only physics – or do we get into rate kinetics, mass transport, electrolytic barrier potentials?
  - Other representations of volume/surface data : *Point clouds*