Scientific Visualization
Scientific Datasets

• Gaining insight into scientific data by representing the data by computer graphics

• Scientific data sources
  ➢ Computation
    Real material simulation/modeling (e.g., molecular dynamics simulation, electronic calculations)
    Solving differential equations (e.g., fluid dynamics, electro-magnetic field)
    Climate modeling

  ➢ Experiment
    Medical and biological: magnetic resonance imaging, computer tomography, confocal microscopy,
    Other data: 3D laser scanner, atomic force microscopy, seismic tomography
Data Challenges

• Scale
  ➢ MRI dataset: \(256^3 = 16\) MB per slice (each slice is 3 micron thick)
  How many slices to cover a particular organ
  ➢ A million-atom simulation: \(7\) GB per step (each step is 1 femtosecond)
  How many steps to simulate a particular physical/chemical/biological phenomenon

• Dimensionality
  ➢ 3D volume data
  ➢ 4D space-time data

• Scalar, vector and tensor data
  ➢ Density or temperature distribution
  ➢ Data from flow dynamics
  ➢ Stress-strain data
Scalar Visualization Techniques
Scalar Dataset

- A single quantity that can be expressed as a function of position in space
  \[ S = S(x,y,z) \]
  
  Array \( S \) represents data at discrete locations in space

- Describe the value at any continuous location by defining an interpolation function \( F(x,y,z) \)

- Volume data (MRI, confocal, finite element modeling)

- Represented through regular grids
  If irregular grids, preprocessing of data to regular grid

- Each data element (cube or cell) often called **voxel**
Different Rendering Techniques

- Simple approaches
  - Symbols, Color mapping, Contour display

- Isosurface rendering
  - Marching cubes algorithm, Fast extraction approaches

- Implicit surfaces
  - Particle sampling, Dividing cubes algorithm, Shape function interpolation

- Volume slicing
  - Clipping, Sampling planes, Interactive clipping, Clip objects

- Volume rendering
  - Object-oriented, Image-oriented, Hybrid techniques
Simple Approaches
Symbols or Off-Path Displays

- Useful for displaying one or two dimensional scalar data
  - Temperature distribution along a rod or on sheet

- Off-path displays
Color Mapping: Lookup Table

- Useful for scalar visualization in 1D, 2D or 3D
- Map scalar data to colors to display on the screen
- Lookup table:
  - Holds an array of colors (RGB components)
  - Scalar values serve as indices
  For each $s_i$, there is index $i$

$$i = n \left( \frac{s_i - \text{min}}{\text{max} - \text{min}} \right)$$
Color Mapping: Transfer Function

- **Transfer function**
  - An expression that maps the scalar value into a color specification
  - Mapping to separate intensity values of R, G and B

- A lookup table is a discrete sampling of a transfer function
Examples of Color Mapping

Mean January air temperature on the Earth's surface

Data: NCEP/NCAR Reanalysis Project, 1958-1997 Climatologies
Multiscale Color Mapping

Two-level mapping:

Fine-level scale uses the red and blue colors to represent the positive and negative differences with magnitude up to 0.002 (in units of \( \text{Å}^{-3} \)).

Coarse-level scale adds green color component to red and blue colors to map the positive and negative differences with magnitudes higher than 0.002.
Contour Display

• Common method for displaying scalar data across a surface
• Contour lines: represent a constant value across the surface (isovalue lines)
Edge Tracking Algorithm

• Select an element or cell
  Consider a 4-vertex quadrilateral element with scalar values $S_1, S_2, S_3$ and $S_4$

• If all $S_i$’s $>$ $S_{iso}$ or all $S_i$’s $<$ $S_{iso}$, no contour line passes through the element

• Otherwise, start at the first pair of vertices, determine if the isovalue exists along the edge
  If one vertex value $>$ $S_{iso}$ while the other vertex value $<$ $S_{iso}$, isovalue exists, in either order
  If not, proceed in either clockwise or anticlockwise order until an edge containing the isovalue is found

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• Once an edge with $S_{iso}$ is found between vertices $i$ and $j$, compute isovalue location along the edge by linear interpolation

\[
x = x(i) + fac \ast (x(j) - x(i))
\]

\[
y = y(i) + fac \ast (y(j) - y(i))
\]

Where \( fac = \left( \frac{S(j) - S_{iso}}{S(j) - S(i)} \right) \)

➢ This isovalue location will be the first point of the contour line

   Default location: mid point

• Examine each subsequent edge until the next edge containing an isovalue is found and repeat previous step

➢ Connect these two points to form the contour segment

➢ Use shape function to give isolines some curvature.
Marching Squares Algorithm

- Select a square element or cell
  - Values at four corners
    - Below isovalue (marked)
    - Above isovalue (unmarked)

- Calculate inside or outside state of each vertex of the cell

- Determine the topology state of the cell by referring to a case table that has a list of all possible configurations
  - Each square is either inside, outside or intersected
  - 2D cell index: 4-bit, $2^4$ (16) cases

- Calculate the contour location (via interpolation) for each edge in the case table
  - No or one intersection per edge
Cases of 2D Cells (Squares)

By complementary and rotational symmetries (equivalence), the number of the basic cases is reduced to 4
2D Ambiguous Cases

- Ambiguous cases:
  - 5, 10
- Contour ambiguity arises when adjacent vertices in different states but diagonal vertices in the same state
- Break contour
  - Join contour
- Both are valid
Contour Lines of MRI Data

Contour display of MRI data of a human head (single image and a stack of four images)

2D contour

3D contour

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