Volume Visualization

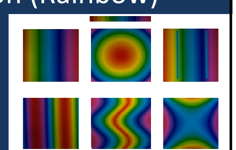
Choices (Surface, Volume)
Choosing
Applying (Tools)

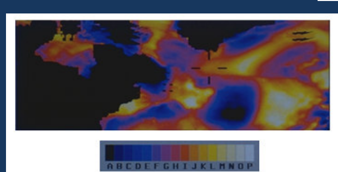
2D Scalar Techniques

- Pseudocolor maps
- Contour lines and bands
- ~~Height fields~~
- Textures
- Transparency
- ~~(Glyphs)~~

Spectrum Approximation (Rainbow)

- Not Perceptual
  - Ordering (Roy G. Biv)
  - JNDs vary (random banding)
- Uncontrolled luminance

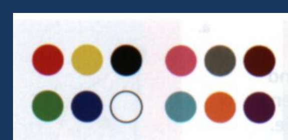




See reasons above

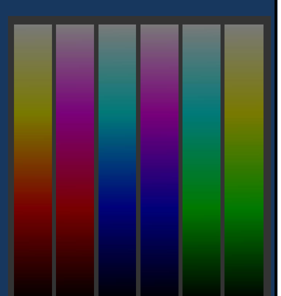
Nominal Coding

- May be a better choice than rainbow for labeling
- Ware suggests using these colors, from left to right:



Blackbody Radiation and Kin

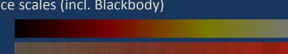
- Heated-object scale
  - Each of R,G,B up in 1/3
- Longer path than grayscale
- Perceptually Ordered
  - 1st, 3rd, and last?
  - Ordinal scale
- Not linear JNDs here →
  - Not for Interval sets
  - Could be "linearized"



Pseudocolor for Maps: What is it good for?

- Single Scalar Fields
  - Nominal: Labeling up to 12 ranges
    - Based on these colors →

  - Ordinal
    - Perceiving shape of maximal/minimal areas
    - Increasing-luminance scales (incl. Blackbody)
    - Opponent scales
    - Saturation scales



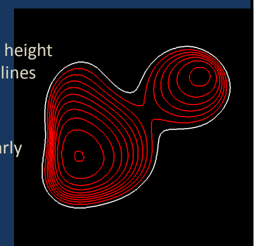
  - Ordinal with Special Values
    - ← Double-ended scales (perhaps with middle zone)
  - ***Not* Interval / Ratio**
    - **Up to 20% *average* errors**

Pseudocolor for Maps: Rules of Thumb

- More detail → Luminance variation required
  - Avoid obscuring shape → Isoluminant
- Ordered: opponent or saturation, not hue
  - Even smoothly-changing hues seem abrupt
  - May not match actual data boundaries → miscategorize
- Nominal: use Ware's 12 colors
- Ware: Upward spiral in color space (Blackbody)
  - Each hue higher luminance than the prior
  - Color change reduces luminance contrast effects
- Watch for R/G and B/Y color blindness

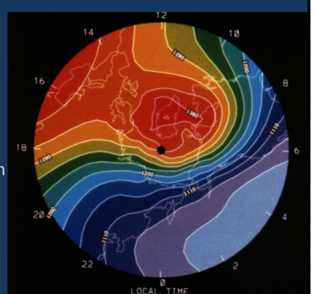
Contours

- Lines drawn along isovalues in data
- Example:
  - Red contours at regular steps in height
  - White line drawn every ten red lines
- Benefits:
  - Can show quantitative data clearly
    - Interval/Ratio data display
  - Can reveal 2D shape of specific regions (land mass)



Combining Contours and Bands

- Two Contours
  - Isothermals
  - Land/sea borders
- Bands
  - Isothermals
  - Group and Distinguish
- Labels
  - Indicate values
  - Contrasting Surround

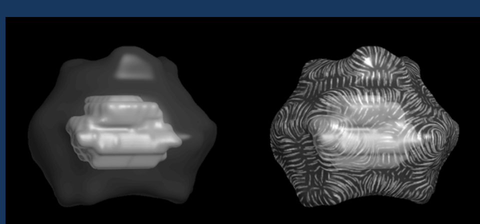


Contours and Bands Summary

- Both indicate regions
  - Contour by showing the boundaries
  - Bands by showing the interiors
- Benefits
  - Good for showing 2D shape of important features
  - Provide quantitative (interval, ratio) measurements
  - Varying width can indicate slope to some extent
- Negatives
  - Miscategorize if levels not at relevant data values

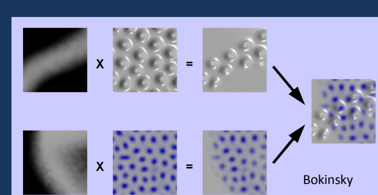
Texture Improves Surface Comp.

- Victoria Interrante



Data-Driven Spots Texture

- Intensity: Presence of texture modulated by data
- Surface normal adjustment: Geometric Detail



Frequency Content / Appearance

- Texture for labeling
  - More numerous than colors
  - Need large patches to see

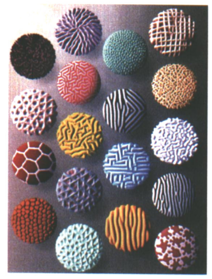


Figure 5.20 Textures from Witkin and Kass (1991).

Texture Characteristics

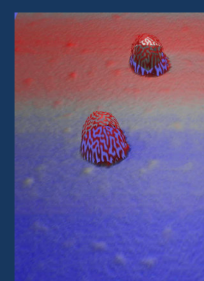
- Can improve understanding of surface shape
  - Required to make transparent surface shape perceptible
- Effective for:
  - Nominal: different textures for different areas
  - Ordinal: Presence of the texture
  - Interval: Orientation
- Can be used to show multiple data sets
  - Mixture of similar texture elements
  - Presence of particular texture element indicates data
  - More on this topic in “multivariate” lecture

Transparency: Use with Caution

- Translucent surface
  - Impression of front surface
  - Lose shape of front surface
  - Difficult to compare shapes
- Only makes sense in 3D
  - 2D → mix with background

“Screen-door” transparency

- Erode portion of surface
  - Preserves perception of shape
  - Enables comparison

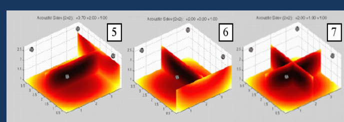


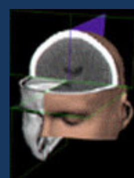
Transparency Characteristics

- Often obscures perception of closest object
  - May be useful for visualizing uncertainty
  - Useful when foreground object is not important (gives context)
- Enables comparison of 2+ objects
  - Requires texture to perceive first-object shape

3D → 2D: Cutting Planes

- One or more slices through the volume
- Along grid axes or arbitrary axes
- May be set in context of the 3D data
- Apply 2D visualization techniques
  - Relative benefits of 2D mappings apply



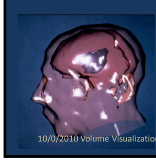


Cutting Plane Characteristics

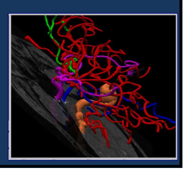
- Strengths
  - Same as strengths of 2D techniques in the planes they display data
  - Enable measurements along important axes
  - Enable display of interval/ratio fields
  - Can show fuzzy boundaries at surfaces they cross
- Weaknesses
  - Show miniscule subset of the data
  - Do not indicate 3D shape of non-symmetric objects
    - or surprising asymmetries in supposedly-symmetric objects
  - Either occlude each other or require transparency

Isovalue surfaces and other Extracted surfaces

- Produce 2D surface in 3D…
  - By following an iso-density contour at a threshold, or
  - Based on the surface of an object in the volume, or
  - By seeking ridge of maximum (valley of minimum), or
  - Using blood-vessel extraction software, or …
- Apply 2D visualization techniques on the surfaces
  - Not height mapping. Why?
  - Only isoluminant colormaps. Why?



Pure Transparency Hides Surface Shape



Exploded Views

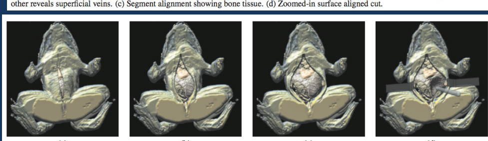
- Bruckner and Gröller, Vis 2006

Medical Illustration Inspired

- Correa et al., Vis 2006

(a) (b) (c) (d)

Fig. 7: Retractor operator applied to a CT foot dataset. (a-b) Surface alignment with two different layer depths, one revealing bone, and the other reveals superficial veins. (c) Segment alignment showing bone tissue. (d) Zoomed-in surface aligned cut.



(a) (b) (c) (d)

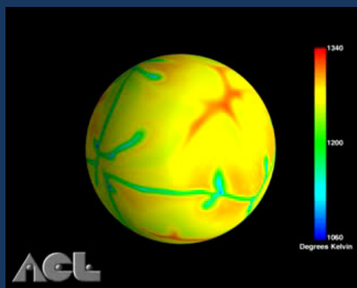
Fig. 10: (a-c) Retractor operator used to simulate dissection of a segmented frog dataset. (d) A plier operator is applied to the internal organs, while simultaneously retracting the skin. Geometric models are embedded in the scene to show the placement of the operators.

Translucent & Opaque Surface

- Kevin Mongomery, Visualization 1998.

Here, transparent surface is less important (only setting the frame) and is low-frequency and symmetric.

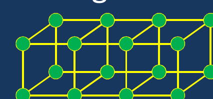
Isosurface + Spherical Surface



Extracted Surface Characteristics

- Strengths
  - Same as strengths of 2D techniques on surfaces
  - Enable display of interval/ratio fields
  - Indicate 3D shape of even non-symmetric objects
  - Perception of 2D surfaces in 3D is what visual system is tuned for
- Weaknesses
  - Cannot show fuzzy boundaries very well
  - Can emphasize noise in any case and artifact if not at useful level
  - Show miniscule subset of the data
    - this is a strength if it is the relevant subset
  - Either occlude each other or require transparency

Direct Volume Rendering Terms



- Voxel
  - Volume Element
  - Basic unit of volume data
- Interpolation
  - Trilinear common, others possible

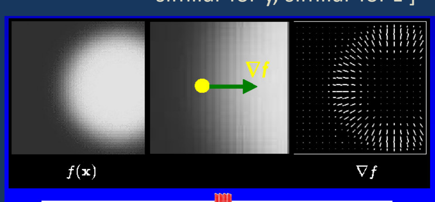
- Compositing
  - "Over" operator
  - Transfer function (later)

- Gradient
  - Direction of greatest change (see next slide)

Gradient: Derived vector field

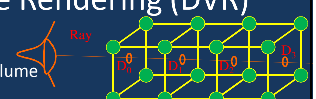
- $\nabla f(x,y,z) = [d/dx, d/dy, d/dz]$

  $\approx [\, (f(x+1,y,z) - f(x-1,y,z))/2,$ similar for y, similar for z]



Direct Volume Rendering (DVR)

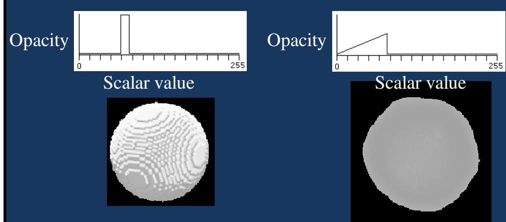
- Basic Idea:
  - Integrate through volume



- "Every voxel contributes to the image"
- No intermediate geometry extraction (faster)
- More flexible than isosurfaces
  - May be X-ray-like
  - May be surface-like
  - Results depend on the transfer function (see next)

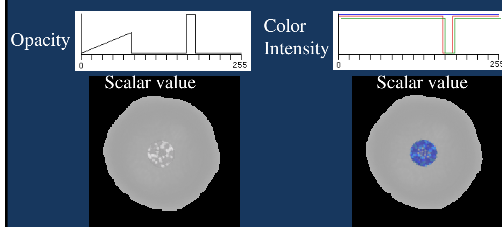
Transfer Function

- Maps from scalar value to opacity

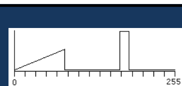


Transfer Function

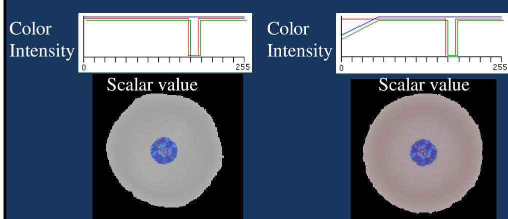
- Opacity and color maps may differ



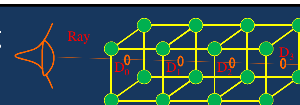
Transfer Function



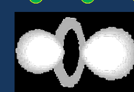
- Different colors, same opacity



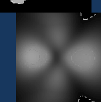
Common Mixing Functions



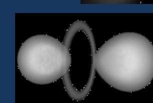
- Maximum Intensity Projection (MIP)
  Value = max(D_0, D_1, D_2, D_3)



- X-ray-like (inverse of density attenuation)
  Value = clamp(sum(D_0, D_1, D_2, D_3))

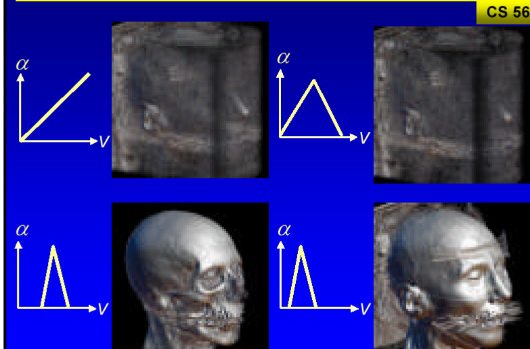


- Composite (back-to-front, no color)
  Value(i) = D_i + (Value(i+1) * (1-D_i))
  (*over* operator)



Setting Transfer Function: Hard

CS 5630

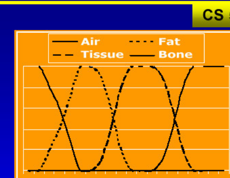


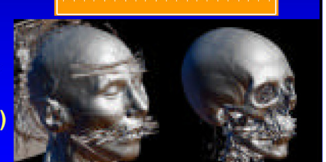
Physical based transf. func.s

CS 5630

Material Classification

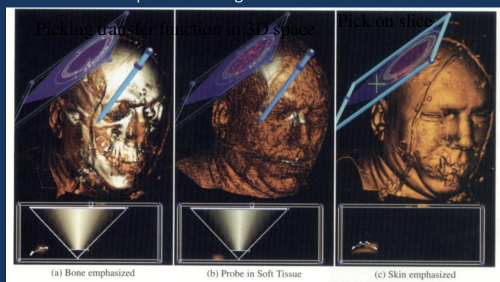
- Use a probability, rather than a threshold.
- Bayesian estimate
- Zone centered
- We know the x-ray absorptions of the materials (bone, ...)



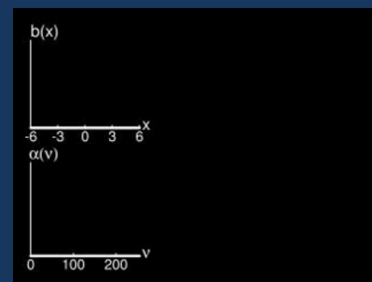


Picking 3D transfer functions

- Kniss, Kindlmann, Hansen; Vis 2001, “Interactive Volume Rendering Using Multi-Dimensional transfer Functions and Direct Manipulation Widgets”

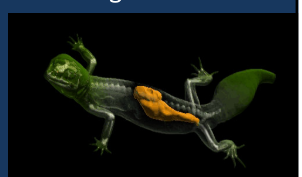


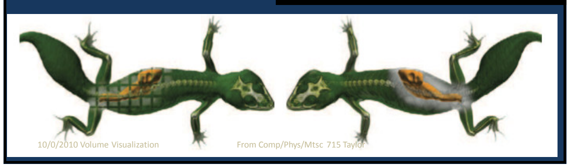
Demonstration of Kniss Transfer Function Generator



Importance-Driven Volume Rendering

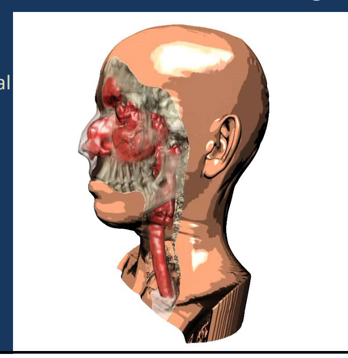
- Viola, Kanitsar, Groller, Vis ‘04
  - Segment volume into objects
  - Indicate relative importance of each object
  - Auto-generate cut-away views





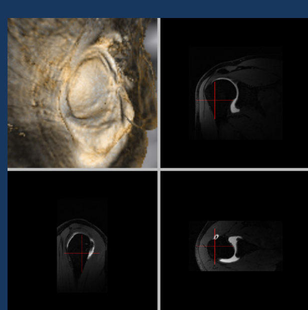
Importance-Driven Volume Rendering

- Vis 2005
  - Bruckner et. al
  - VolumeShop



Flexible-Occlusion Rendering

- David Borland



Flexible-Occlusion Rendering

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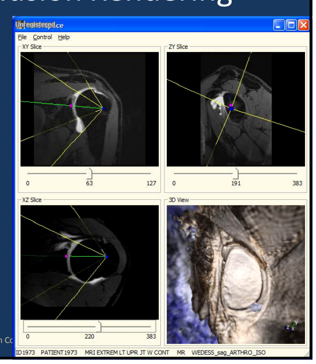
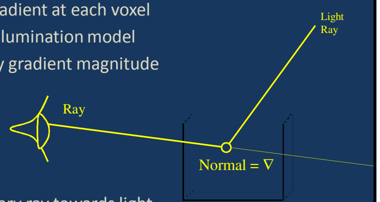


Adding Lighting and Shadows

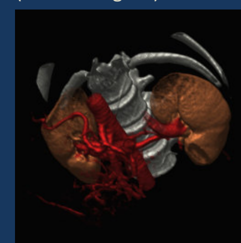
- Lighting
  - Compute Gradient at each voxel
  - Use Phong illumination model
  - May scale by gradient magnitude



- Shadows
  - Cast secondary ray towards light
  - Attenuate using transfer function

Adding Color

- Transfer function can include color (density label)
- Can vary color by location (to label organs)



Exotic Transfer Functions 3

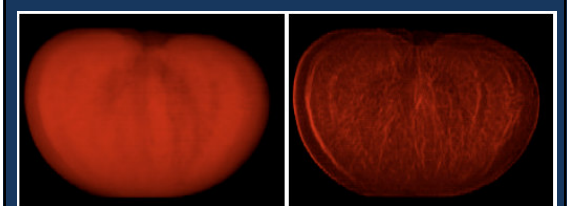
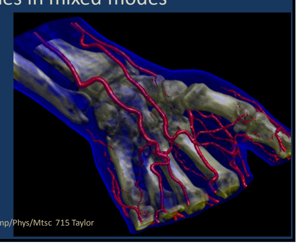


Figure 10. Standard atmospheric volume rendering of tomato. **Figure 11.** Boundary and silhouette enhanced tomato.

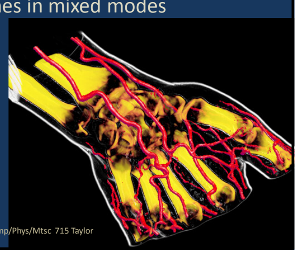
Mixed-Mode Rendering

- Markus Hadwiger, Christoph Berger, Helwig Hauser, Vis 2003
- Renders Segmented Volumes in mixed modes
- Hand
  - Skin: Shaded DVR
  - Bone: Shaded DVR
  - Blood Vessels: Shaded DVR



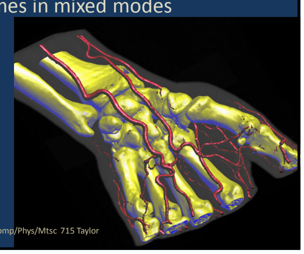
Mixed-Mode Rendering

- Markus Hadwiger, Christoph Berger, Helwig Hauser, Vis 2003
- Renders Segmented Volumes in mixed modes
- Hand
  - Skin: NPR contour/MIP
  - Bone: DVR
  - Blood Vessels: Tone shading



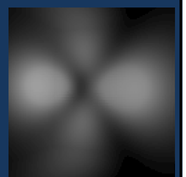
Mixed-Mode Rendering

- Markus Hadwiger, Christoph Berger, Helwig Hauser, Vis 2003
- Renders Segmented Volumes in mixed modes
- Hand
  - Skin: MIP
  - Bone: Tone shading
  - Blood Vessels: Isosurface

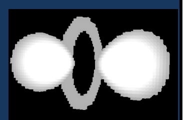


DVR Char: X-ray + MIP

- Strengths
  - X-ray is like traditional radiography
  - Every voxel contributes to image
  - Can show fuzzy boundaries

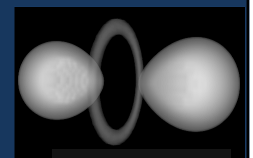


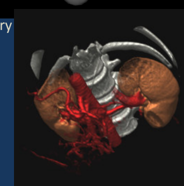
- Weaknesses
  - Visual system not tuned for this
  - Can be hard to interpret correctly



DVR Char: Surface-like

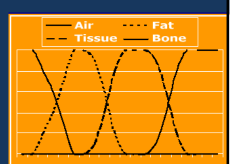
- Unlit compositing
  - Strengths
    - Opaque surfaces occlude others
    - Can show fuzzy boundaries
  - Weaknesses
    - May confuse surface perception machinery
    - Similar, but not exactly like, surfaces
- Lit, colored surfaces
  - Very like isosurfaces
  - Similar strengths & weaknesses
  - Done for speed reasons





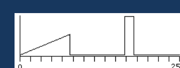
DVR Char: Physically-based

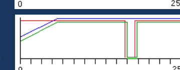
- Strengths
  - Extracts known materials from the data
  - Can show fuzzy boundaries
- Weaknesses
  - Fuzzy volumes hard to see

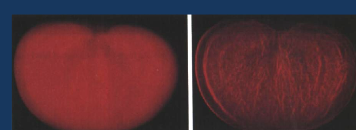


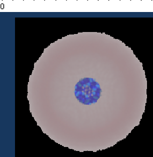
DVR Char: Custom & Exotic

- Strengths
  - Lots of flexibility
  - Can be tuned to particular task
- Weaknesses
  - Artifacts due to function may overwhelm data
  - Need to carefully consider what you're seeing









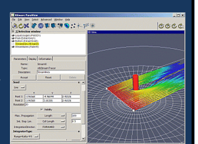
Stereo and Motion

- Perceiving volume data is *very difficult*
- All available depth cues should be used
- Stereo and Motion are important depth cues
  - Motion
    - Animation
    - User-controlled motion of object
    - Head tracking
  - Especially powerful is stereo + head tracking

Available Toolkits

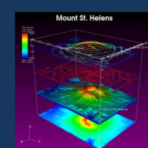
- Visualization Applications
  - ParaView, VisIt, EnSight, Tecplot, ImageSurfer, DataTank, Volview
- Computation/Analysis + Visualization
  - ImajeJ, NIH Image, Scion for PC (ImageJ), MATLAB, and Mathematica
- Programming Toolkits
  - The Visualization ToolKit (VTK), Insight ToolKit (ITK), VisAD and Vis5D (also "visualization spreadsheet"), SCIRun
- Graphical Programming Toolkits
  - VisTrails, Open Data Explorer (OpenDX), Iris Explorer (now marketed by NAG), Advanced Visual Systems (AVS/Express), Amira

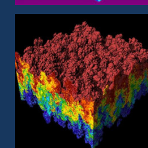
Visualization Applications (1/7)



- ParaView
  - http://www.paraview.org
  - Kitware, Inc. and Sandia are primary developers
  - Based on VTK
  - Open-source, freely-available
  - Scriptable and extensible
  - Runs on desktop or parallel computers
  - We'll be using this in homeworks for the class

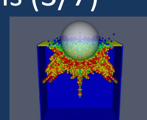
Visualization Applications (2/7)

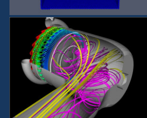


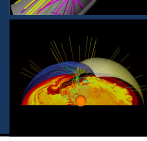


- VisIt
  - http://www.llnl.gov/visit
  - From LLNL
  - Designed for very large datasets
  - Based on VTK
  - Open-source, freely available
  - Scriptable and extensible

Visualization Applications (3/7)

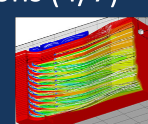


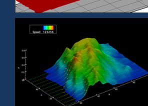


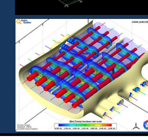


- EnSight
  - http://www.ensight.com
  - Commercial software
  - Company based in Apex, NC
  - RENCI has a few licenses for this software
  - Meshing modules available
  - Interfaces for popular CFD codes

Visualization Applications (4/7)



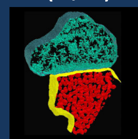


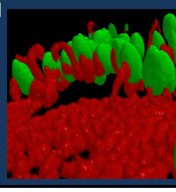


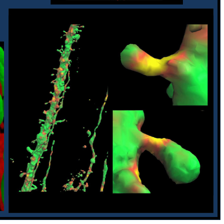
- Tecplot
  - http://www.tecplot.com
  - Commercial software
  - SDK for developers
  - Scriptable

Visualization Applications (5/7)

- ImageSurfer
  - http://www.imagesurfer.org
  - Designed for multivariate 3D bio
  - Can handle time-varying data
  - VTK-based





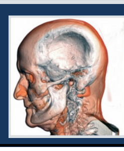


Visualization Applications (6/7)

- DataTank
  - Can read data files
  - Couples to simulation
  - Query and computation on data sets supported
  - http://www.visualdatatools.com

Visualization Applications (7/7)

- VolView
  - http://www.volview.com
  - Kitware, Inc.
  - Based on VTK
  - Commercial
  - 30-day trial
  - Targeted for medical



Computation/Analysis + Vis 1/2

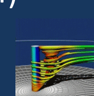
- ImageJ
  - http://rsbweb.nih.gov/ij
  - Acquire, display, edit, enhance, analyze and animate images
- NIH Image and Scion (earlier versions)
  - http://rsb.info.nih.gov/nih-image
  - Developed by the NIH for the Macintosh
  - Filtering, measure area, particle analysis, measurement tools, etc.

Computation/Analysis + Vis 2/2

- MATLAB
  - http://www.matlab.com
  - 2D and 3D plots, isosurfaces, streamlines, color maps
  - Image analysis and filtering
- Mathematica
  - http://www.wolfram.com
  - Data plotting, isosurfaces, vector visualization, color maps

Programming Toolkits (1/4)

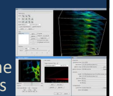
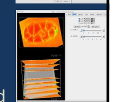
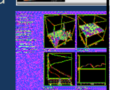
- Visualization Toolkit (VTK)
  - http://www.vtk.org
  - Open-source, object-oriented free software
  - Written in C++, with Tcl, Python, and Java language bindings
  - Large collection of visualization algorithm implementations, file readers, and display programs
  - Documentation and support provided by Kitware
  - Book, example code, and tutorials available
  - Higher level than OpenGL, tuned for visualization
  - Data pipeline model
  - Aimed at programmers



Programming Toolkits (2/4)

- Insight ToolKit (ITK)
  - http://www.itk.org
  - Sponsored by the National Library of Medicine
  - For segmentation and registration of visible human
  - Open-source, object-oriented free software
  - C++ libraries, heavily templated
  - Kitware is involved in the development
    - Should work well with VTK (there are filters to go from VTK to ITK and vice versa)
  - UNC is also involved in the development
  - Example code and applications available
  - Aimed at programmers

Programming Toolkits (3/4)

- VisAD and Vis5D
  - http://www.ssec.wisc.edu/~billh/visad.html
  - Freely available toolkit developed by Bill Hibbard at the University of Wisconsin for geospatial data (also works for other data types: VisBio)
  - Java component library for interactive and collaborative visualization
  - Tutorials available online
  - "Visualization spreadsheet" for certain operations and data sets, no programming necessary
  - Distributed collaboration built in, to enable multiple scientists at different locations to work together

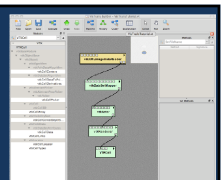
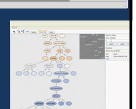
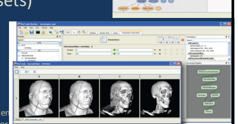
Programming Toolkits (4/4)


- SCIRun
- http://software.sci.utah.edu/scirun.html
- Open-source workbench from Utah
- Visual programming + custom modules
- Couples modeling, simulation and visualization
- Handles steering of parallel simulations

Graphical Programming Toolkits

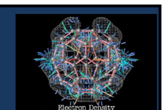
- Aim to provide easy-to-use interface between data and visualization
- Aim to be used directly by scientists
- Collection of pre-built modules implement various visualization techniques
- Try to be extensible, but not as easy to extend as the programming toolkits (where you can easily insert your own code)

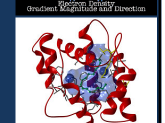
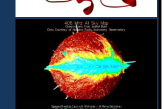
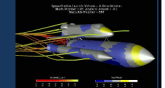
VisTrails

- From Utah
  - http://www.vistrails.org
  - Open-source scientific workflow management system
  - VTK modules integrated, simulation and analysis modules can be added
  - Tracks versions of workflows (save snapshots of different parameter sets)
  - Data exploration spreadsheet
  - Visualization by analogy

OpenDX

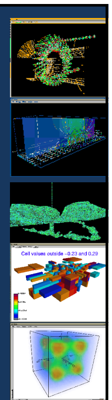


- Open Data Explorer
  - http://www.opendx.org
  - Was IBM Data Explorer
  - Freely-available, open source software, earlier was commercial.
  - Book and support available from vizsolutions.com
  - Mail lists and user group

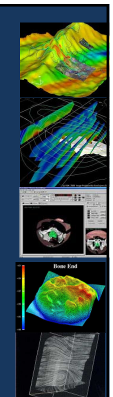
Iris Explorer

- http://www.nag.com/welcome_iec.asp
- Purchased, supported software
- Online user manuals
- Online tutorials



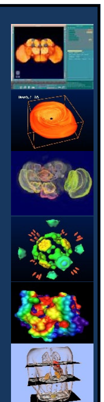
AVS and AVS/Express

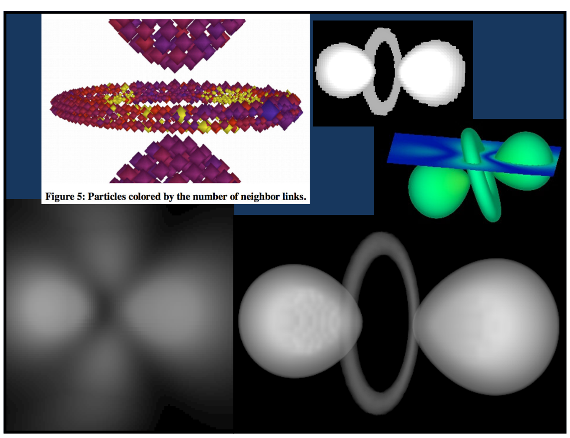
- http://www.avs.com
- Commercial, supported software
- AVS 5.0 is continuation of earlier software running on Unix platforms
- AVS/Express is a new, incompatible product that also runs on Windows
- Online tutorials and manuals, good help and within-program information



Amira

- http://www.amiravis.com
- 3D visualization and volume modeling
- Segmentation tools
- Commercial, supported software
- Online user's guide, tutorials, reference guide
- Rachael Brady uses at Duke
- Free trial





References

- "Orientation", "Four Image Textures", "Color + Height Texture": Chris Weigle's Oriented Slivers
- "Other Texture Dimensions" and "Image + Geometric Textures": Alexandra Bokinsky's Data-Driven Spots
- "Height + Color + Intensity": Adam Seeger's combined SEM/AFM visualization with the nanoManipulator
- Others: Colin Ware, "Information Visualization"

Credits

- Descriptions of volume rendering techniques, colored volume renderings, Shear-Warp: David Ebert's visualization course.
- Direct Volume Rendering example, Translucent Surfaces: UNC-CH GRIP project slide archives.
- Basket Weave: Gitta Domik
- Curvature-directed Strokes, Animation Motion and Stereo: Victoria Interrante, 1996.
- Even-tessellation textures: Penny Rheingans, 1996.

Credits

- Terms, Gradient, DVR Approaches, Splatting, Ray Casting, Texture Mapping, Setting Transfer Function slides: Chris Johnson
- Transfer Function discussion: Paul Bourke: http://local.wasp.uwa.edu.au/~pbourke/oldstuff/volume/
- Isosurface + Spherical Surface: James S. Painter, 1996.
- Translucent Isosurfaces: Lloyd A. Treinish, 1988.

Credits

- Color- & Size-changing Glyphs: Patricia J. Crossno, 1999.
- Exotic Transfer Functions: Ebert & Rheingans, 2000.
- 1D curves in 3D: Zoe J. Wood, Visualization 2000.
- 0D curves in 3D: Keller & Keller p. 131.
- Data-Driven Spots: Alexandra Bokinsky

Credits

- Bhaniramka, P., C. Zhang, et al. (2004). Volume Interval Segmentation and Rendering. IEEE Symposium on Volume Visualization and Graphics 2004, Austin, Texas, IEEE Press. 55-62.