Comp/Phys/Apsc 715

3D (Volume) Scalar Fields:

Direct volume rendering, Slices, (Textured) Isosurfaces, Glyphs

Example Videos

- Confocal visualization tool
- Rendering surfaces as peaks in DVR

Overview

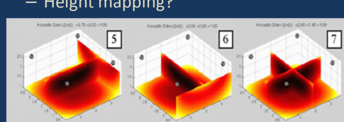
- List of techniques
  - Appropriateness discussion for each
  - Implementation description for some
- Importance of stereo and motion
- Two examples

List of Techniques

- Displaying surfaces in the volume
  - Cutting planes (perhaps animated)
  - Isovalue surfaces
    - Making translucent surfaces perceptible
- Direct Volume Rendering
  - X-ray, Maximum Intensity Projection (MIP)
  - "Surface-extracting" transfer functions
    - Shading, shadows
    - Color for segmentation
- Glyphs

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
  - Height mapping?

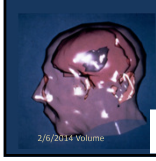


Cutting Plane Characteristics

- 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

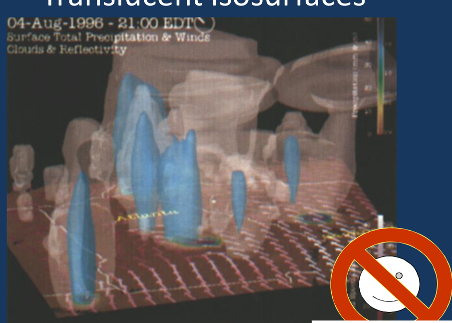
Isovalue surfaces and other Extracted surfaces

- 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?)
  - Usually using isoluminant colormaps. (Why?)



Pure Transparency Hides Surface Shape


Translucent Isosurfaces



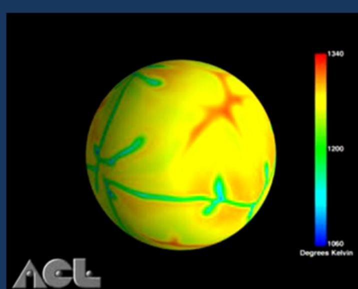
Pure Transparency Hides Surface Shape

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



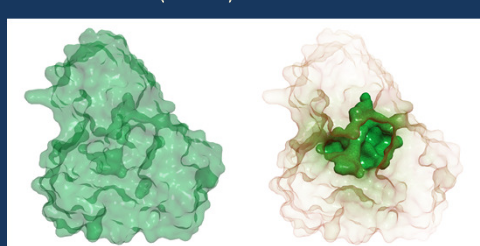
Link to movie

Terra in this directory

Rainbow color map never optimal

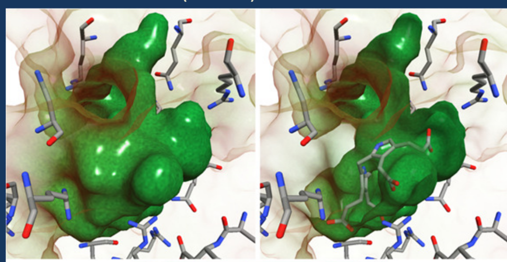
Ambient Occlusion Opacity Mapping

- David Borland (RENCI)



AOOM + Props + Backface

- David Borland (RENCI)



Exploded Views

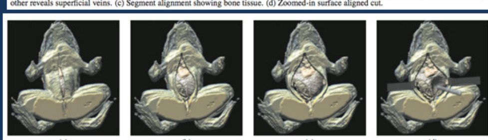
- Bruckner and Gröller, Vis 2006 bruckner.avi

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.

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

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Making Translucent Perceptible

- Add textured features
  - Replace translucent surface with opaque bands
  - Add strokes of opaque texture to the surface
  - Add patterns of opaque texture to the surface
- Add motion
  - Animation of the object
  - User-controlled viewpoint or object orientation change
- Add stereo
  - Stereo + head-tracking is much better than the sum of the parts

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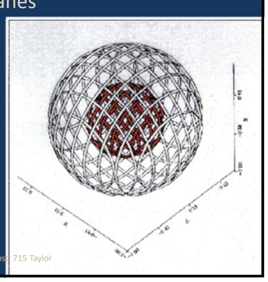
Basket Weave

- Calculate contour lines at cross-sections parallel to coordinate planes
- Draw opaque bands
- Example from SIGGRAPH Education Workshop in 1988



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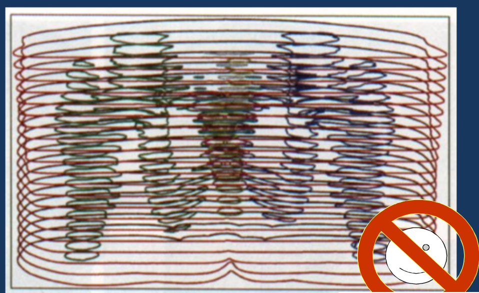
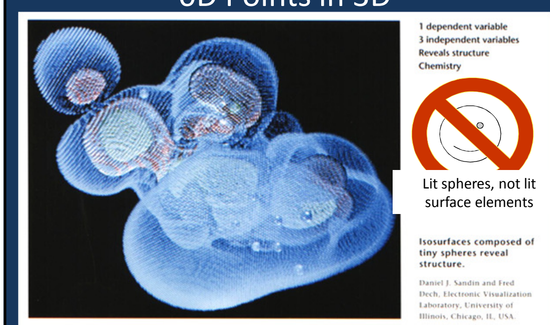
1D curves in 3D



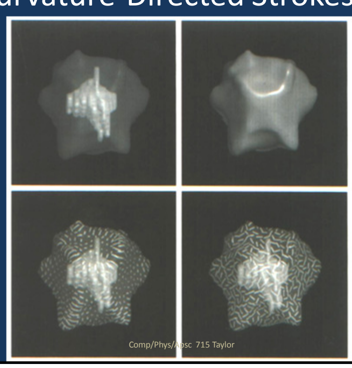
Unlit lines and high density

0D Points in 3D



Lit spheres, not lit surface elements

Curvature-Directed Strokes



Even-tessellation texture

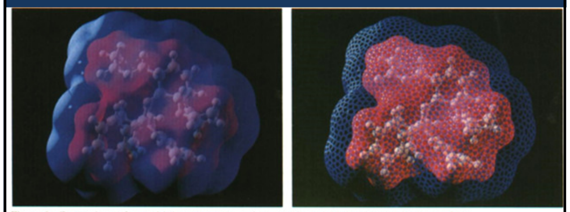
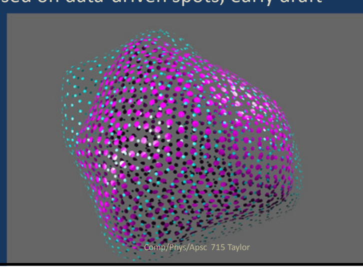


Figure 6. Comparison of a) multiple transparent surfaces to b) multiple opacity-modulating surfaces.

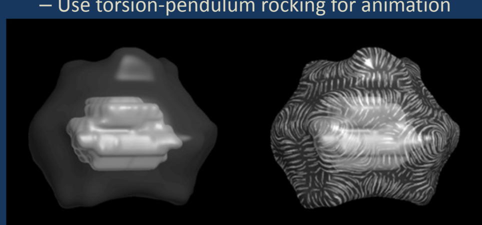
Spotted Tumor Surfaces

- David Borland, Chris Weigle, Russ Gayle
  - Based on data-driven spots, early draft

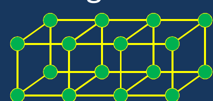


Animation, Motion, and Stereo

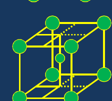
- Adding additional depth cues helps greatly
  - Stereo + Head-tracking is the most effective
  - Use torsion-pendulum rocking for animation



Direct Volume Rendering Terms



- Voxel
  - Volume Element
  - Basic unit of volume data



- Interpolation
  - Trilinear common, others possible
- Compositing
  - "Over" operator
  - Transfer function (later)

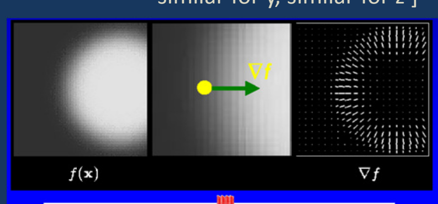
- Gradient
  - Direction of greatest change (see next slide)

Gradient: Derived vector field

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

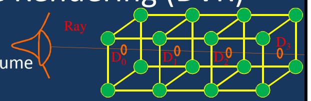
  $\approx [\ (f(x+1,y,z) - f(x-1,y,z))/2,$

  similar for y, similar for z]



Direct Volume Rendering (DVR)

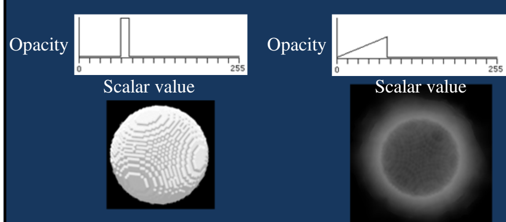
- Basic Idea:
  - Integrate through volume



- "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)

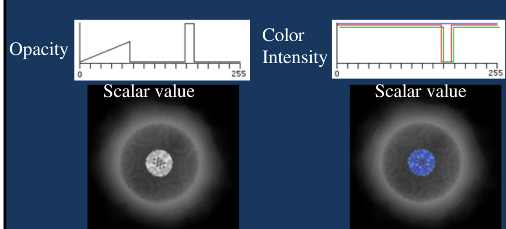
Transfer Function

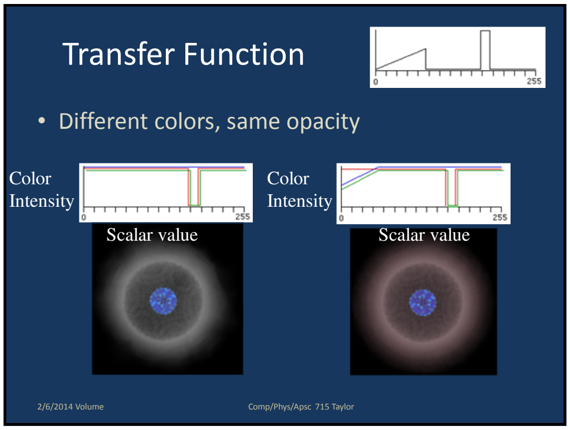
- Maps from scalar value to opacity



Transfer Function

- Opacity and color maps may differ




Transfer Function
0
255
• Different colors, same opacity
Color
Intensity
0
255
Scalar value
Color
Intensity
0
255
Scalar value
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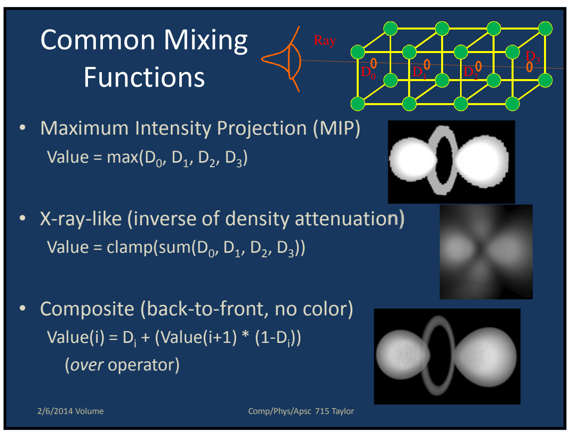
Common Mixing Functions
Ray
D_0
D_1
D_2
D_3
• Maximum Intensity Projection (MIP)
Value = max(D_0, D_1, D_2, D_3)
• X-ray-like (inverse of density attenuation)
Value = clamp(sum(D_0, D_1, D_2, D_3))
• Composite (back-to-front, no color)
Value(i) = D_i + (Value(i+1) * (1-D_i))
(*over* operator)
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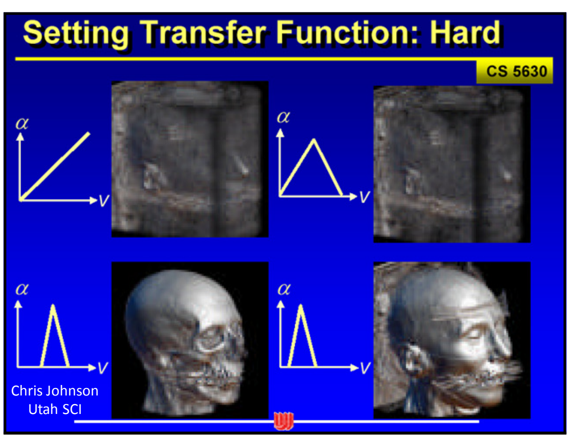
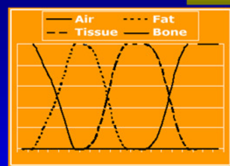

Setting Transfer Function: Hard
CS 5630
α
V
α
V
α
V
α
V
Chris Johnson
Utah SCI

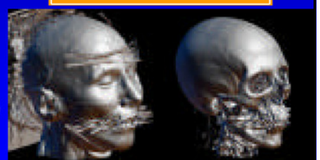
Physical based transf. func.s

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, ...)





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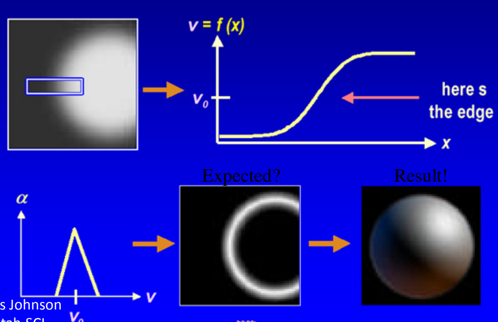
Transfer function unintuitive

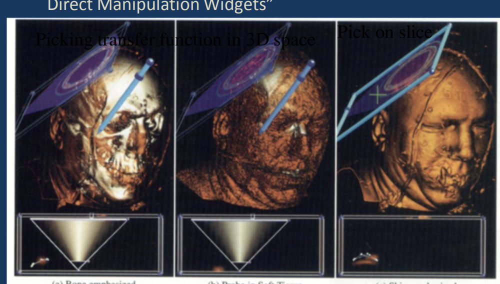
CS 5630



Chris Johnson
Utah SCI

Picking 3D transfer functions

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



(a) Bone emphasized (b) Probe in Soft Tissue (c) Skin emphasized

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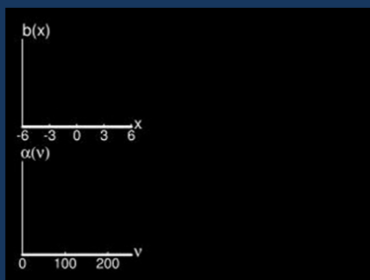
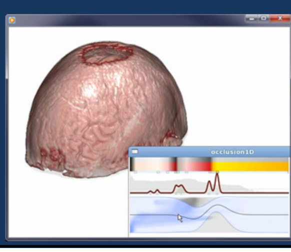
Demonstration of Kniss Transfer Function Generator



Occlusion Spectrum

- Carlos Correa, VisWeek
- Occlusion spectrum for volume rendering

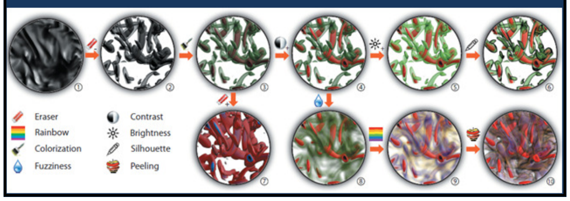


More Transfer-Function Design

- Vis 2006: viddivx.avi (Salama)
  - 2D transfer function design
- Volume transfer function generation
- Vis08-TbTFs: Texture-based volume rendering

WYSIWYG Volume Visualization

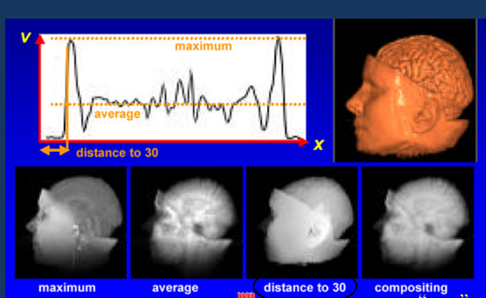
- Guo, Mao, Yuan; TVCG 2011
  - Brushing in volume determines visible voxels there
  - Statistics on brushed voxels + clusters → features
  - Tunes transfer function to produce desired effect



Direct Volume Rendering: How Is it Done?

- Image (eye-screen) order
  - Ray Casting
- Object (volume being displayed) order
  - Splatting
  - Texture-mapping

Ray Casting



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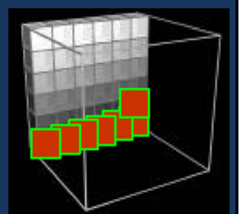
Splatting (Westover)

- Render image one voxel at a time:
  - Apply transfer function
  - Determine image extent of voxel
  - Composite



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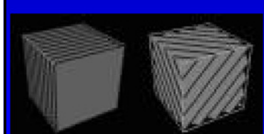
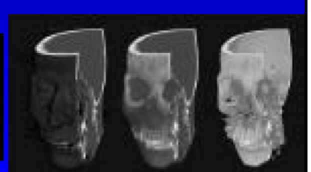
Texture-mapping (Object Order)

CS 5630

Exploits certain graphics hardware
- "Texture-memory": fast trilinear interp.
- volume data sampled by parallel slices
- slices composited in hardware





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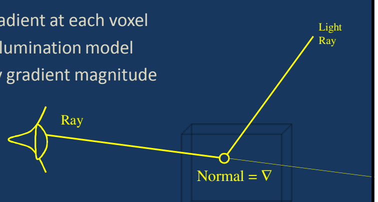
Adding Lighting and Shadows

- 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

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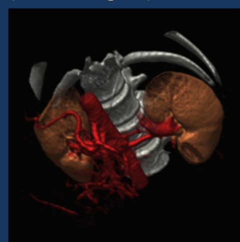
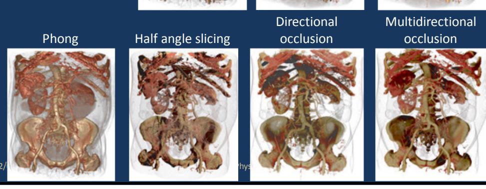
Adding Color

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



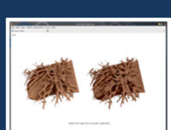
Advanced Illumination Models

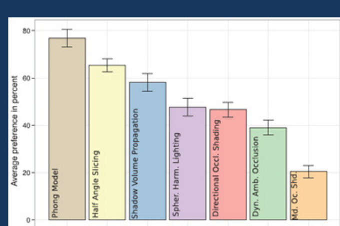
- Lindemann & Ropinski
  - TVCG 2011



Advanced Illumination Models

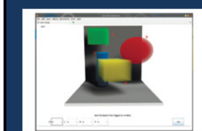
- Lindemann & Ropinski, TVGC 2011
  - Subjective preference (larger is better)
  - Which liked?

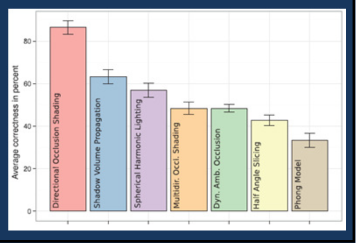




Advanced Illumination Models

- Lindemann & Ropinski, TVGC 2011
  - Relative size perception error (larger is better)
  - Rank sizes

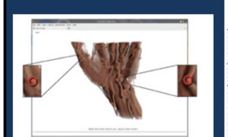


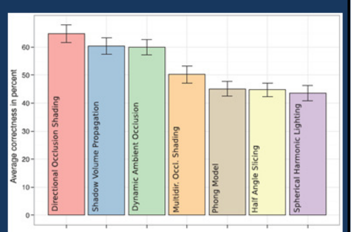


2/6/2014 Volume

Advanced Illumination Models

- Lindemann & Ropinski, TVGC 2011
  - Relative depth perception error (larger is better)
  - Which closer?

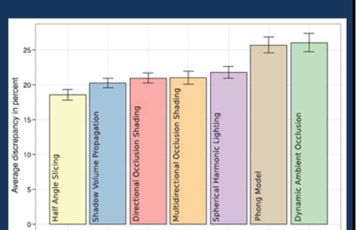




2/6/2014 Volume

Advanced Illumination Models

- Lindemann & Ropinski, TVGC 2011
  - Absolute depth perception error (smaller is better)
  - How far?



2/6/2014 Volume

Illumination Illuminated

- Rankings
  - Phong preferred, then HAS
  - Directional Occlusion overall best
  - HAS best for absolute depth
- Implications
  - What looked best didn't perform best
  - Best technique depended on task
  - Test techniques on tasks

Exotic Transfer Functions

- Ebert & Rheingans, Visualization 2000

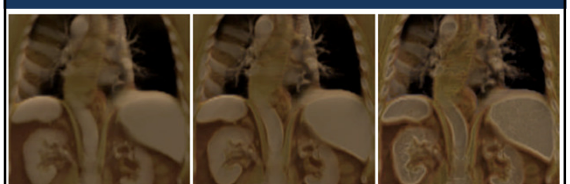


Figure 2. Gaseous illumination of color-mapped CT volume.
Figure 3. Color-mapped gaseous illumination with boundary enhancement.
Figure 4. Silhouette and boundary enhancement of CT volume.

Exotic Transfer Functions 2

- Ebert & Rheingans, Visualization 2000

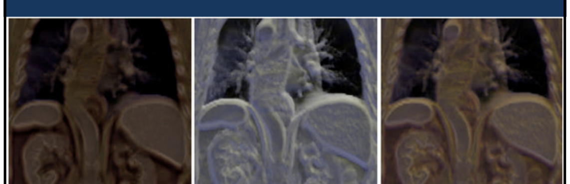


Figure 6. Distance color blending and halos around features of CT volume.
Figure 7. Tone shading in CT volume. Surfaces toward light receive warm color.
Figure 8. Tone shading in colored volume. Surfaces toward light receive warm color.

Exotic Transfer Functions 3

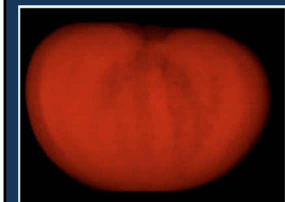


Figure 10. Standard atmospheric volume rendering of tomato.

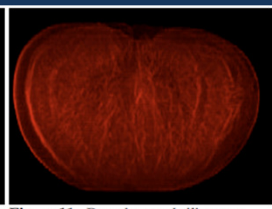
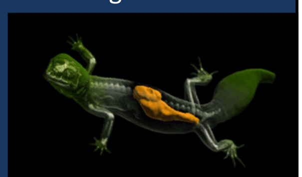


Figure 11. Boundary and silhouette enhanced tomato.

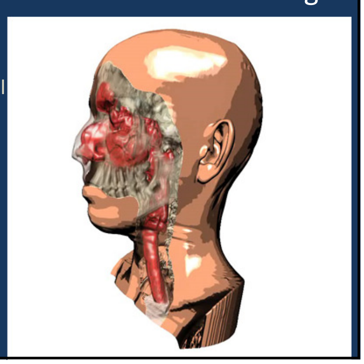
Importance-Driven Volume Rendering

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



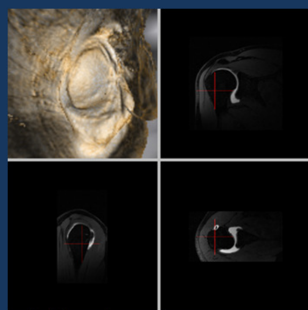
Importance-Driven Volume Rendering

- Vis 2005
  - Bruckner et. al
  - VolumeShop



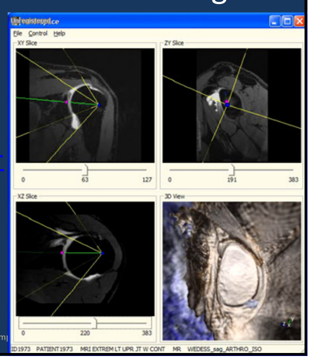
Flexible-Occlusion Rendering

- David Borland
- UNC Chapel Hill



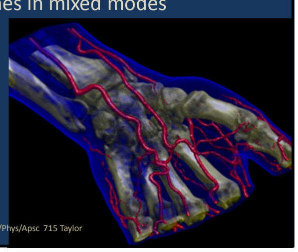
Flexible-Occlusion Rendering

- David Borland
- UNC Chapel Hill
- Link to video
- 1973 repeat in folder



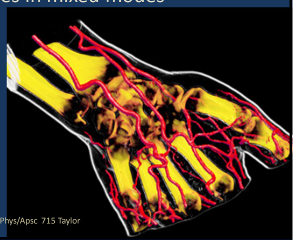
Mixed-Mode Rendering

- 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



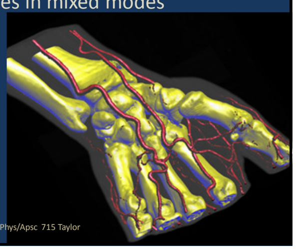
Mixed-Mode Rendering

- 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



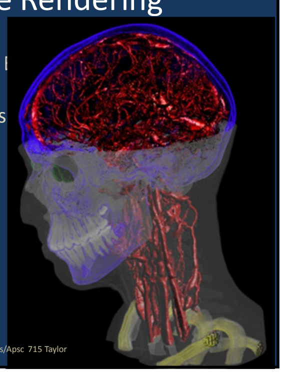
Mixed-Mode Rendering

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



Mixed-Mode Rendering

- Markus Hadwiger, Christoph
  Hauser, Vis 2003
- Renders Segmented Volumes
- Head
  - Skin: MIP (clipped)
  - Teeth: MIP
  - Blood Vessels: Shaded DVR
  - Eyes: Shaded DVR
  - Skull: Contour Rendering
  - Vertebrae: Shaded DVR



Mixed-Mode Rendering

- Volume Interval Segmentation and Rendering.
- Bhaniramka, P., C. Zhang, et al. (2004).
- Isosurfaces and intervals
- Render both together

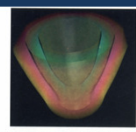


Figure 8. Boundary surface with silhouette enhancement

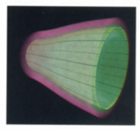


Figure 9. Boundary surface with 1D texture mapping

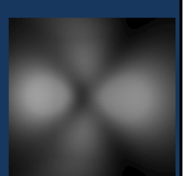
Pure Transparency Hides Surface Shape

DVR Characteristics

- Transfer function determines characteristics
  - X-ray-like and MIP
  - Surface-like
    - without lighting
    - lighting, color, and shadows
  - Physically-based with soft edges
  - Custom and exotic transfer functions
- Each has different strengths and weaknesses
  - Try to discuss each group of these

DVR Char: X-ray + MIP

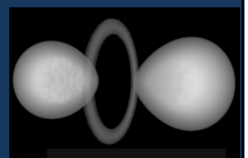
- Strengths
  - X-ray is like traditional radiography
  - Every voxel contributes to image
  - Can show fuzzy boundaries

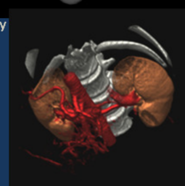


- Weaknesses
  - Visual system not tuned for this
  - Can be hard to interpret correctly

DVR Char: Surface-like

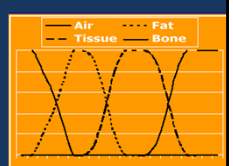
- Unlit compositing
  - Strengths
    - Opaque surfaces occlude others
    - Can show fuzzy boundaries
  - Weaknesses
    - May confuse surface perception machinery
    - Similar, but not exactly like, surfaces
- Lit, colored surfaces
  - Just like isosurfaces
  - Similar strengths & weaknesses
  - Done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





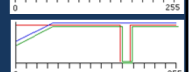
DVR Char: Physically-based

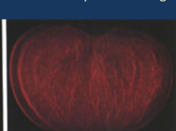
- Strengths
  - Extracts known materials from the data
  - Can show fuzzy boundaries
- Weaknesses
  - Fuzzy volumes hard to see

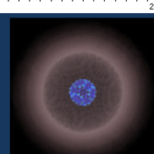


DVR Char: Custom & Exotic

- 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



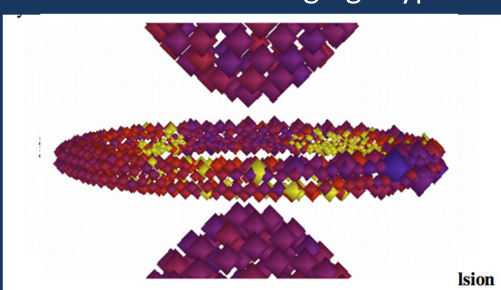




Glyphs

- Discrete icons drawn throughout the volume
- Icon characteristics vary based on data
  - Size
  - Color
  - Shape
- Can be a huge variety of these
- Two examples seen here

Color- & Size-changing Glyphs

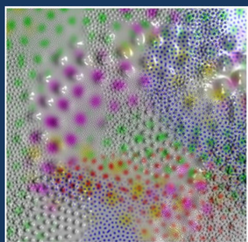


lsion

radi Figure 5: Particles colored by the number of neighbor links.

Scaled Data-Driven Spheres

- Do Bokinsky's Data-Driven Spots generalize to 3D?
- Yes! – see Multivariate Visualization lecture



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Glyph Characteristics

- Hard to generalize, since can be so varied
  - Glyph volume display still a research area
- Strengths
  - Glyph itself is a surface in space, understood as such
  - Can see around near glyphs to far ones (into volume)
- Weaknesses
  - Frequency can't be too high: need separate glyphs with space between them
  - Overall surface normal for extracted surfaces not preattentively seen

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Summary

- 2D Reduction
  - Slices
    - Good: Same as 2D data display
    - Bad: Miniscule subset of data, occlude one another
  - Isovalue (or other) extracted surfaces
    - Good: Can show interval/ratio using 2D techniques on top of them, [other characteristics are like those of a height field]
    - Bad: No fuzzy boundaries, Can emphasize noise, Obscuration
- Volume display techniques
  - Direct Volume Rendering
    - Completely depends on the transfer function used
  - Glyphs
    - Good: Are 2D surfaces in space, Can see past first
    - Bad: Low-frequency data only, No overall surface normal

Stereo and Motion

- Perceiving volume data is *very difficult*
- All available depth cues should be used
- Stereo and Motion are important depth cues
  - Motion
    - Head tracking
    - User-controlled motion of object
    - Animation (torsion pendulum)
- Stereo + Head Tracking is especially powerful

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Examples

- Many views of hydrogen
- Molecular lattice defects

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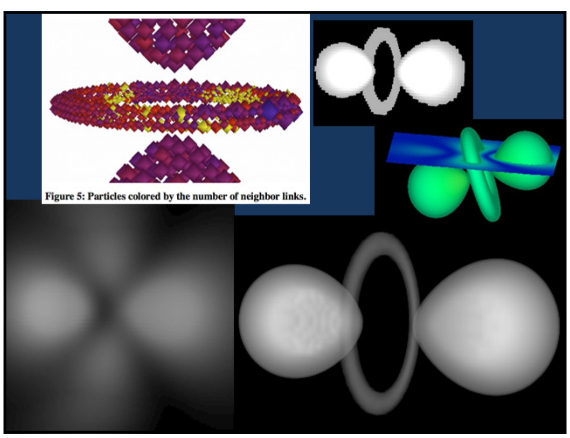

Detection and Visualization of Anomalous Structures in Molecular Dynamics Simulation Data

- Mehta, et. al. Vis 2004
  - Lattice defect in stick, slice and X-ray projection
  - When slice passes through defect

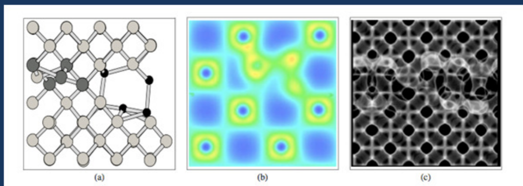

Figure 10: Dataset D1 (a) Original Marked Lattice with two defects (b) Slicing showing shape of one defect (c) Volume rendering showing both defects.

Detection and Visualization of Anomalous Structures in Molecular Dynamics Simulation Data

- Mehta, et. al. Vis 2004
  - Lattice defect in stick, slice and X-ray projection
  - When slice passes through defect

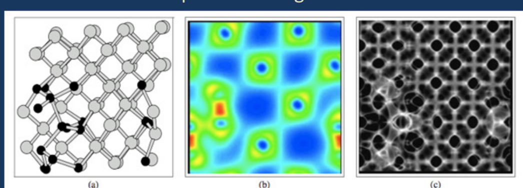

Figure 11: Dataset I2 (a) Original marked lattice (b) Slicing (c) Volume rendering

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.