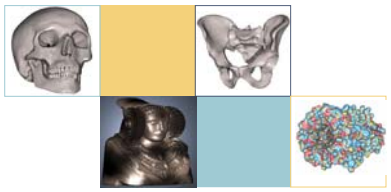
Saliency-guided Graphics & Visualization



Amitabh Varshney
Department of Computer Science
University of Maryland at College Park

When in doubt, predict that the present trend will continue

Merkin's Maxim

Current Trends

1. Data complexity is rising

Model	Bunny	Happy Buddha	Pieta	St. Matthews Statue	Ste. Pierre Cathedral
Year	1994	1996	1998	2000	2002
# Points	34,947	543,642	7.2 million	127 Million	220 million
Size	200 KB	3 MB	43 MB	762 MB	1.9 GB

Anecdotal evidence suggests Super-Moore's Law increases

Current Trends

1. Data complexity is rising: Statistical Point Geometry

Murder Scene Visualization

A. Kalaiah and A. Varshney, *ACM Transactions on Graphics*, April 2005

Current Trends

2. Rendering Realism is Improving

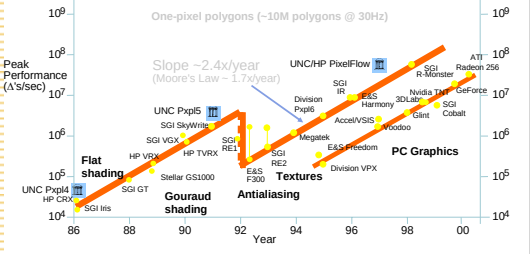
No Scattering (62.5 fps) With Scattering (27.3 fps) : 42K vertices

X. Hao and A. Varshney, *ACM Transactions on Graphics*, April 2004

Current Trends

3. Graphics processing capabilities are increasing

Parallelism, Streaming, Interleaved ALUs and memory

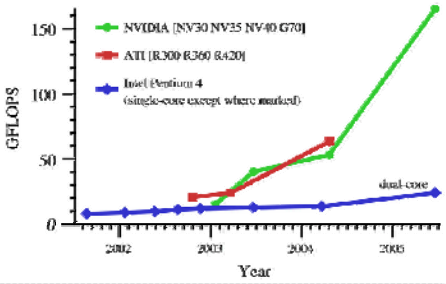


Graph Courtesy: John Poulton, UNC

Current Trends

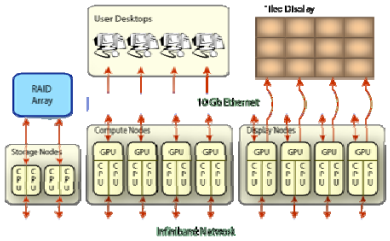
3. Processing capabilities are increasing

Parallelism, Streaming, Interleaved ALUs and memory



Courtesy Ian Buck, John Owens

Maryland GPU-CPU Cluster

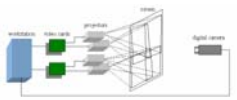


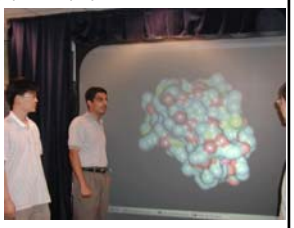
Build upon the synergies in coupling GPUs (Graphics Processing Units), CPUs, displays, and storage to address a variety of computational and scientific problems

Current Trends

4. Displays are improving

Working towards a 50+ megapixel display





Ultrasonic trackers allow direct interaction with the display wall

Current Trends: Summary

1. Modeling: more
2. Rendering: better
3. Processing: greater
4. Displays: bigger

We are rapidly making progress towards handling very large models with impressive detail and realistic lighting.

These trends will limit comprehensibility of 3D scenes

Visual Abstractions

- Arrows are a convenient visual abstraction of motion
- How about visual abstractions of geometry?

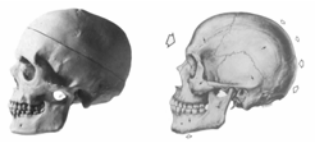
Model of Myoglobin made by A. A. Barker (Cambridge, UK) in 1966 for £210. Currently owned by Dr. Britton Chance

Summary (thus far ...)

- Decoupling physical realism from visual representation can be very powerful
- Identify what is important for the task (Saliency)
- Emphasize salient attributes

Photographs and Illustration

- Photorealism does not necessarily improve comprehension
  - our mental model of shape is not strictly physically accurate



from The Guild Handbook of Scientific Illustration by Hodges, 1989

Compelling Vis Examples: 1

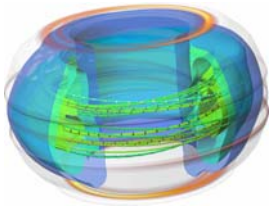
LineDrive Maps

www.mapblast.com Standard vs Line Drive

Agrawala & Stolte, SIGGRAPH 2001

Compelling Vis Examples: 2

DIII-D Tokamak Plasma Disruption



Kruger, Schnack, Sanderson, Jorgensen, 2003. Simulation performed using the NIMROD code at the National Energy Research Center. Visualization produced using the SCIRun Problem Solving Environment (Chris Johnson, Utah).

Differences and Unifying Principles

- The first one uses deeply-researched design principles to generate real-time maps
- The second is a carefully crafted visualization to primarily learn and educate
- In both cases
  - Results convey important features in a clean and visually consistent way
  - They emphasize *salient features* and suppress others
  - They are parsimonious visualizations and they make the few resources work extra hard (space, color, …)

How Can We Advance Further?

- Define and use *saliency*
- What visualization variables aren't doing enough for us?
  - Geometry / Data Representations – perhaps
  - Texture, Color, Glyphs – perhaps
  - Transfer Functions – perhaps
  - ***Lighting*** – thus far mostly overlooked in Visualization

Directing Visual Attention by Light

Joseph's Bloody Coat Brought to Jacob, Velasquez 1630

Is Consistent Lighting Necessary?

- Nature has one dominant light source
- Evolution might have endowed us with an ability to discern inconsistency in illumination
- Just as it has inconsistency in perspective

The Presentation in the Temple by Gentile da Fabriano (1423)

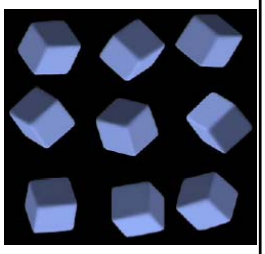
Analysis of Perspective by Chris Tyler, Smith-Kettlewell Institute

Illumination Inconsistencies

Recent research suggests that illumination consistency is *not* resolved at the low-level human vision

Find the cube lit inconsistently with respect to others:

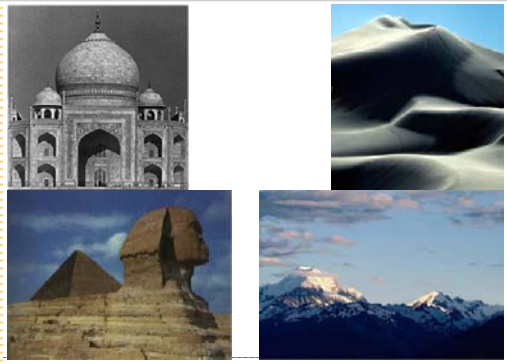
On average, users take 8 seconds to answer and are then wrong 30% of the time



Illumination inconsistencies are not perceptually salient

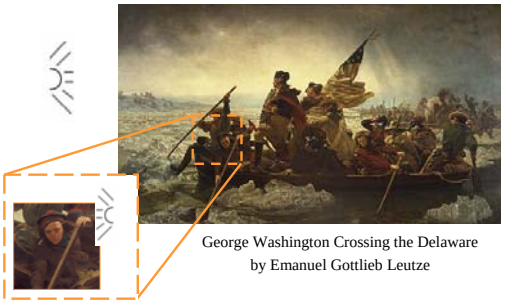
Ostrovsky, Sinha, Cavanagh, *Perception 2005*

Illumination Inconsistencies



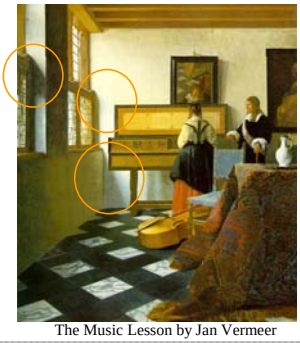
Ostrovsky, Sinha, Cavanagh, *Perception 2005*

Discrepant Lighting in Art



George Washington Crossing the Delaware by Emanuel Gottlieb Leutze

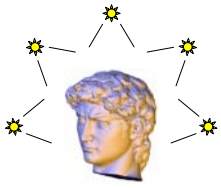
Discrepant Lighting in Art



The Music Lesson by Jan Vermeer

Discrepant Lighting

- Scientific visualization need not strive for photorealism
- Discrepant lighting can yield compelling results
- Light Collages: Allow local lighting parameters to be defined independently at local regions

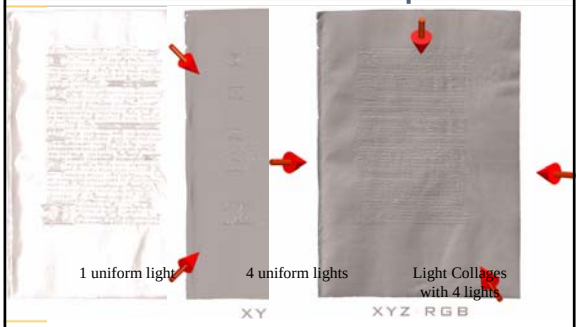


Lee, Hao, Varshney, IEEE Visualization 2004

Light Collages Overview

- Segmentation
- Light Placement and Assignment to patches
- Silhouette Enhancement
- Proximity Shadows

Results - Manuscript



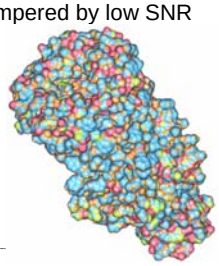
Manuscript courtesy of Paul Debevec, USC and XYZ RGB Inc.

Lee, Hao, Varshney, *IEEE TVCG 2006* (to appear)

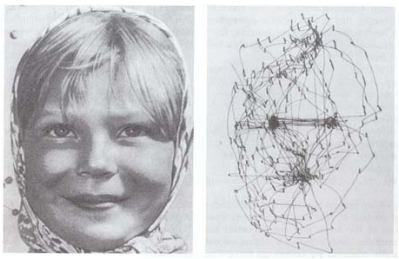
Lighting can be Distracting

As datasets and displays increase in size:

- Too many visual distractions
- Lots of low-information inconsequential detail
- Visual discovery hampered by low SNR



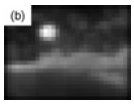
What is Salient?



from [Yarbus 1967]

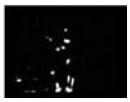
Related Work

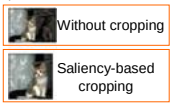
- Image saliency maps
  - Tsotsos *et al.* 95, Milanese *et al.* 94, Itti *et al*. 98, Rosenholtz 99



Itti *et al.* PAMI 98

- Applications: compression and cropping
  - Privitera and Stark 99, Chen *et al*. 03, Suh *et al*. 03



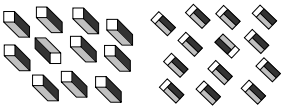


Suh *et al.* UIST 03

Related Work

3D object

- A distinctive 3D structure pops out pre-attentively



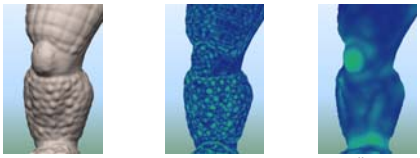
from [Enns and Rensink 90]

- Curvature
  - Watanabe and Belyaev *Eurographics 01*
  - Hisada *et al. Eurographics 02*
- Eye tracking
  - Howlett *et al. APGV 04*

Mesh Saliency

Center-Surround Mechanism

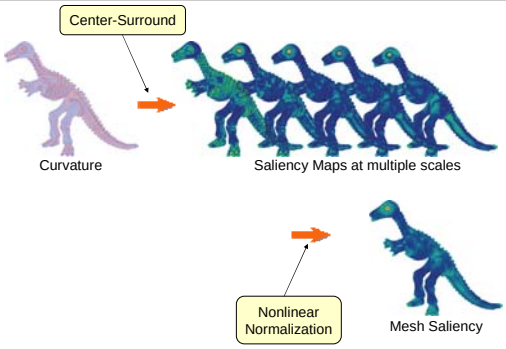
– Identify regions different from their surrounding



Curvature Saliency

Lee, Varshney, Jacobs, *SIGGRAPH 2005*

Saliency Computation Overview



C. Lee, A. Varshney, D. Jacobs, *SIGGRAPH 2005*

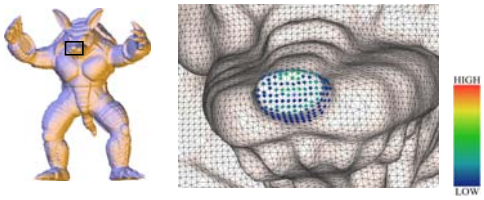
Center-Surround Operator

Gaussian-weighted average is:

$$G(\mathscr{C}(v),\sigma)=\frac{\sum_{x\in N(v,2\sigma)}\mathscr{C}(x)\exp[-\|x-v\|^2/(2\sigma^2)]}{\sum_{x\in N(v,2\sigma)}\exp[-\|x-v\|^2/(2\sigma^2)]}$$

$\mathscr{C}(x)$: Mean curvature at vertex v

Gaussian Weights

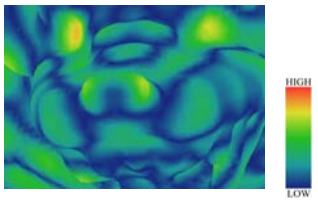


Center-Surround Operator

Saliency map at each scale i is:

$$\mathscr{S}_i(v)=|G(\mathscr{C}(v),\sigma_i)-G(\mathscr{C}(v),2\sigma_i)|$$

$\sigma_i \in \{2\varepsilon,3\varepsilon,4\varepsilon,5\varepsilon,6\varepsilon\}$, $\varepsilon = 0.3\%$ of the diagonal of the object



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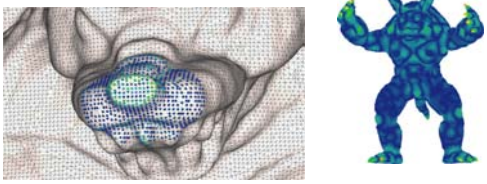
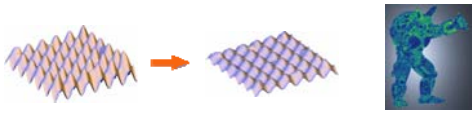
$\sigma_i \in \{2\varepsilon,3\varepsilon,4\varepsilon,5\varepsilon,6\varepsilon\}$ $\quad \mathscr{S}_i \in \{\mathscr{S}_0,\mathscr{S}_1,\mathscr{S}_2,\mathscr{S}_3,\mathscr{S}_4\}$

$\varepsilon = 0.3\%$ of the diagonal of the object

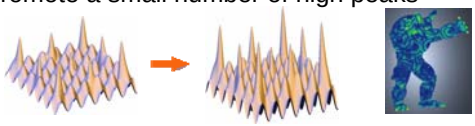


Nonlinear Normalization

Suppress a large number of similar peaks



Promote a small number of high peaks



Nonlinear Normalization

The suppression operator is defined as:

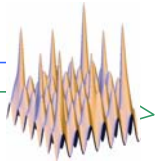
$$S(\mathscr{S}_i) = (M_i - \bar{m}_i)^2 \mathscr{S}_i$$

M_i : The maximum saliency value

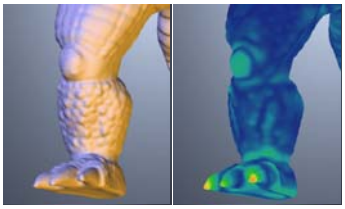
$\bar{m}_i$: The average of the local maxima

The final saliency map is:

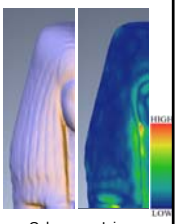
$$\mathscr{S} = \sum_i S(\mathscr{S}_i)$$



Mesh Saliency Results



Stanford Armadillo

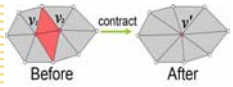


Cyberware Isis

Mesh Simplification

Qslim [Garland and Heckbert *SIGGRAPH 97*]

- Contracts edges until we get desired level of detail



- Uses quadric error for determining the order of contraction

Saliency-guided Simplification

Scale the quadric error by the saliency to preserve more triangles for salient regions

Cyberware Male

Mesh Saliency

Simplification Results

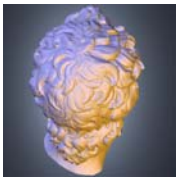
Simplification by Qslim (4K tris)

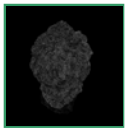
Simplification guided by Saliency (4K tris)

Saliency-guided Viewpoint Selection

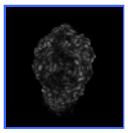
- Find the viewpoint that maximizes the sum of the visible saliency
- Gradient-descent-based optimization method for efficiency
  - Start with random points (1% of sample directions)
  - Try only 6% of 12K sample directions

Viewpoint Selection

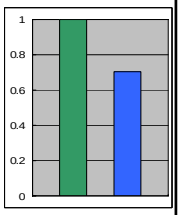




Curvature



Saliency



Viewpoint Selection Results

Curvature-based Viewpoint Selection

Curvature

Saliency-based Viewpoint Selection

Saliency

Viewpoint Selection Results

Curvature-based Viewpoint Selection

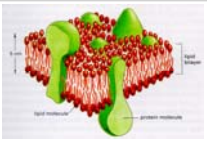
Curvature

Saliency-based Viewpoint Selection

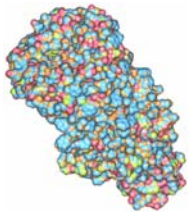
Saliency

Membrane Ion Channels

- Proteins that regulate the flow of ions into and out of the cell membranes



- Nearly a third of the top 100 pharmaceutical drugs target the ion-channels (including Alzheimer's disease, Parkinson's disease, epilepsy, schizophrenia, stroke, and cystic fibrosis)

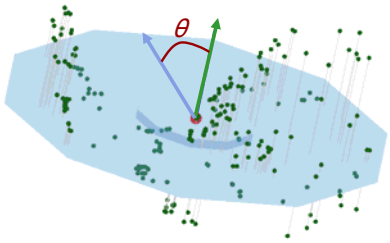


E.Coli Mechanosensitive Ion Channel (data from S. Sukharev at UMD and R. Guy, NIH)

Saliency for Molecular Surfaces

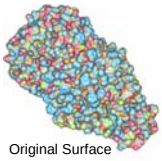
Multi-scale Principal Component Analysis

Center Surround

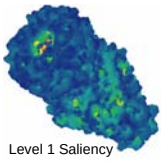


θ is proportional to Molecular Surface Saliency

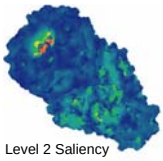
Saliency for Molecular Surfaces



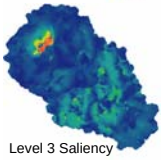
Original Surface



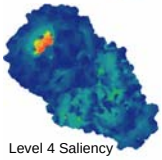
Level 1 Saliency



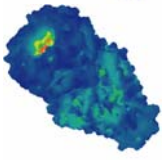
Level 2 Saliency



Level 3 Saliency



Level 4 Saliency

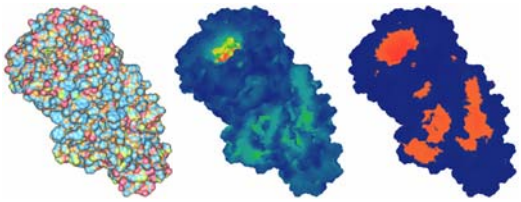


Composite Saliency

Lee, Kim, Varshney, Dagstuhl 2005

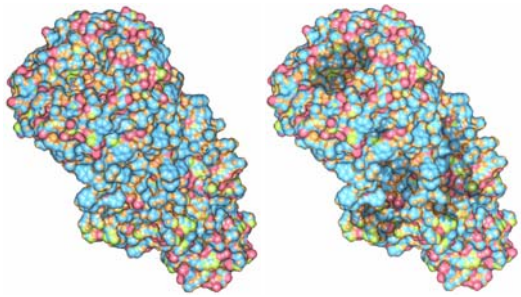
Salient Lighting

- Compute saliency at multiple scales and sum
- Threshold top third and non-linearly enhance
- Change lighting contrast based on saliency



Original Surface | Composite Saliency | Thresholded Saliency

Salient Lighting



Summary and Future Directions

- Current trends are leading us towards a crisis of visual overload
- Studying the history of consumer illustration, scientific illustration, and art can provide helpful directions of thought
- Find what is Salient
  - Task and User independent
  - Task and/or user dependent
- Emphasize it
  - Using lighting, abstractions, view parameters, simplifications, …
- Validate it
  - Eye trackers could be very helpful here

A Parting Thought

In signs, one sees an advantage for discovery that is greatest when they express the exact nature of a thing briefly and, as it were, picture it; then, indeed, the labor of thought is wonderfully diminished.

Gottfried Wilhelm von Leibniz

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