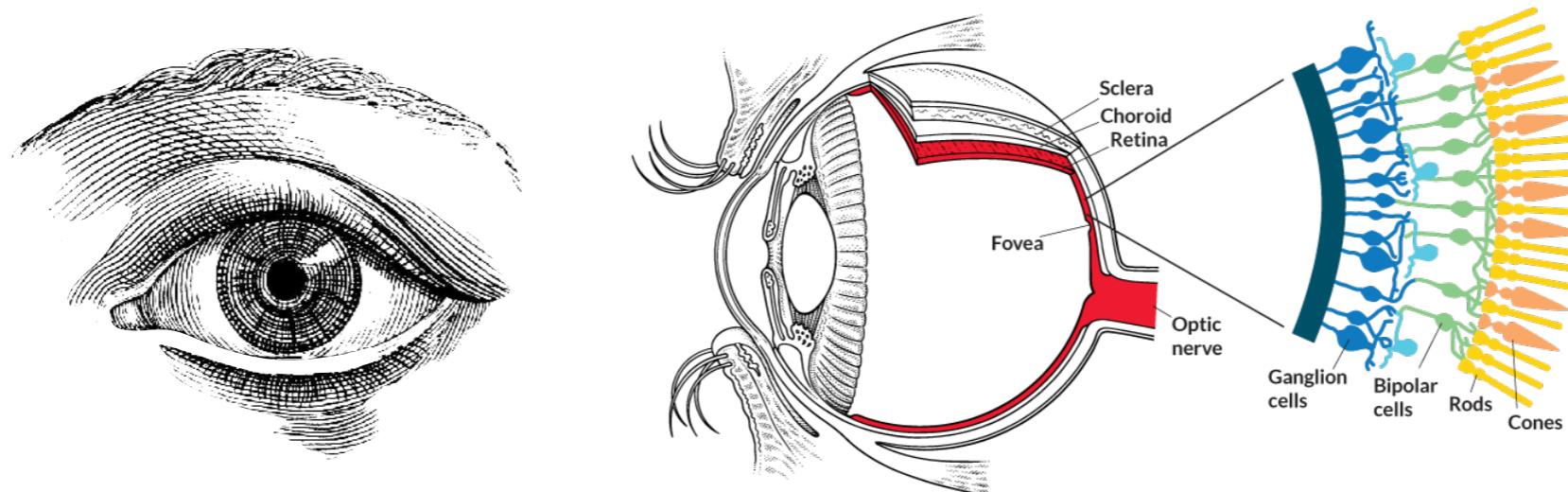


Perceptual Capacities and Constraints in AR/VR for the visualization of 3D biomedical image data



EYE: TONY GRAHAM/GETTY IMAGES, ADAPTED BY J. HIRSHFELD; WEBVISION.MED.UTAH.EDU

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Computer Assisted Radiology and Surgery (CARS)
18.06.2019

VIRTUAL REALITY: IMMERSION



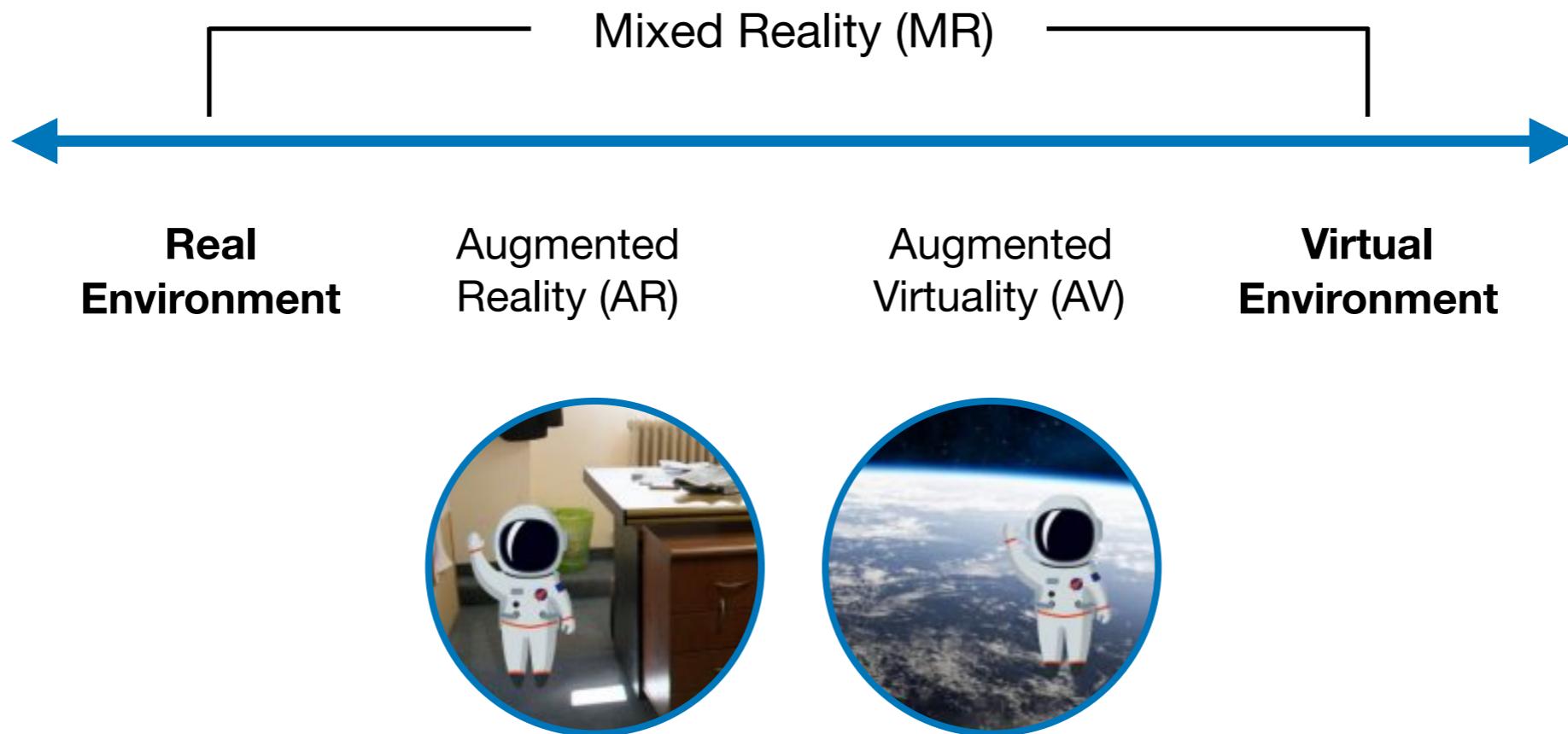
ESA Astronaut, Claudio Haignere, operates the COGNI hardware aboard ISS during Expedition 3. Adapted image courtesy of CNES. © 2016



NASA Astronaut, David Saint-Jacques, operates a virtual reality headset aboard ISS. Adapted image courtesy of ESA, NASA. © 2019

**VR headsets are also employed in surgical planning.
Is Augmented Reality tied to Virtual Reality?**

SOME DEFINITIONS



(AR) real world is improved by digital data

(AV) mostly computer generated but have some real world imagery added

(VE) totally simulated by technology

[Simplified representation of a "virtuality continuum". Adapted from Milgram and Kishino. 1994]

How does the current state of the art looks like?

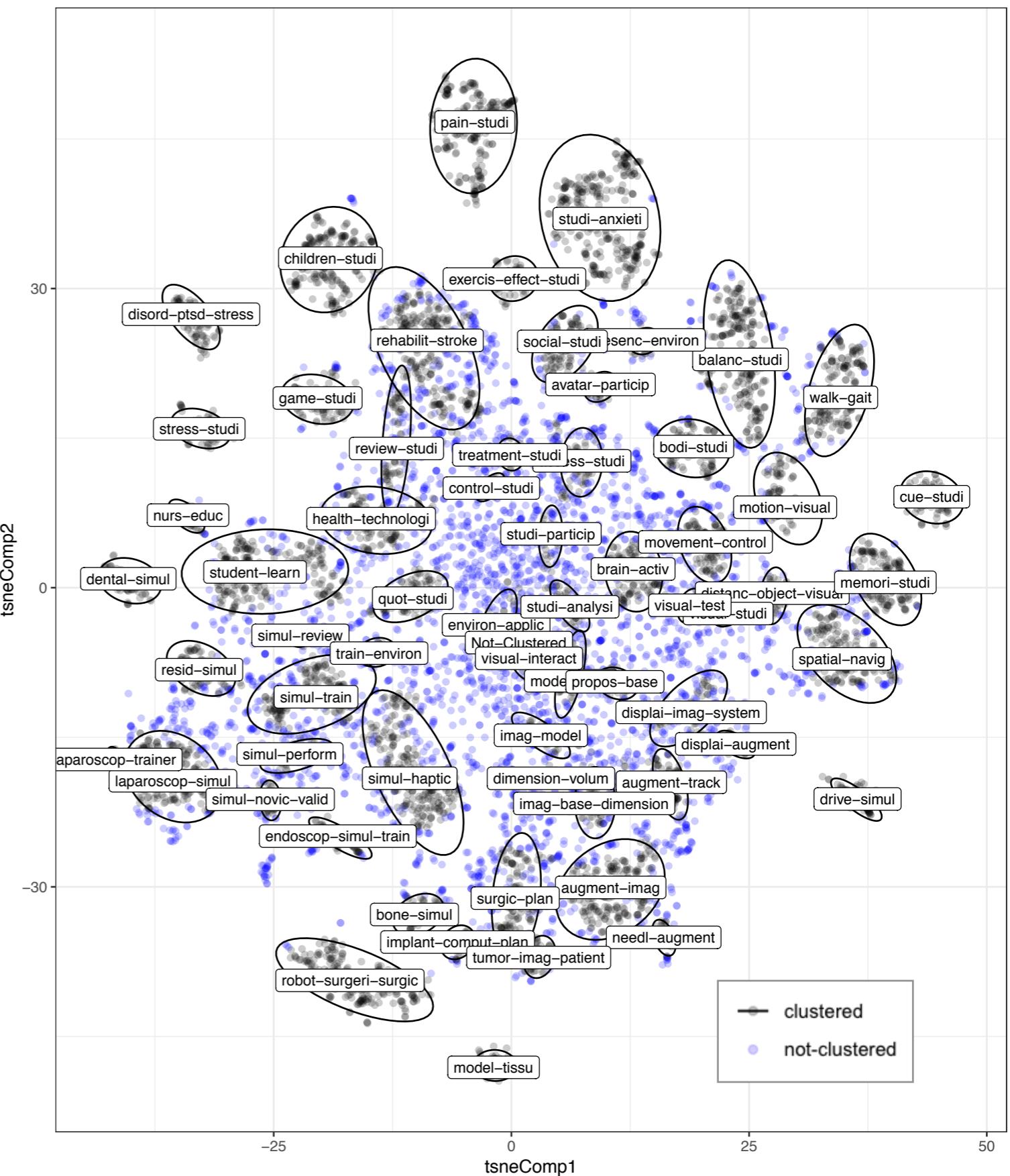
THE RELATED WORK LANDSCAPE

1. **Query:** (augmented OR virtual) AND reality
2. **Construct a bag-of-words** per article
3. **Dimensionality reduction** using t-SNE
4. **Unsupervised clustering** using HDBSCAN
5. **Naming the clusters**

10 049 articles

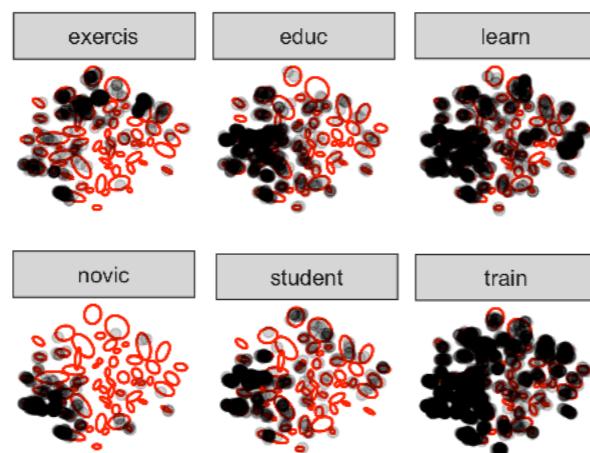
- learning, trainers and simulators
- surgery, surgical planning (tumor, needle, tissue)
- large amount of studies
- disorder PTSD stress
- driving simulator

[Adjutant: an R-based tool to support topic discovery
for systematic and literature reviews. Crisan et al 2018]

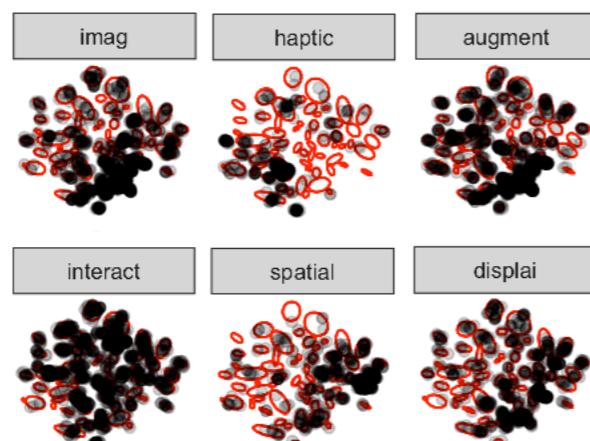


THE RELATED WORK LANDSCAPE

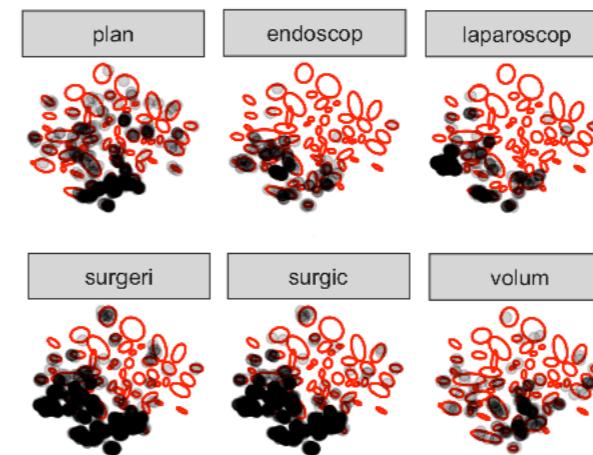
Learning, trainers and simulators



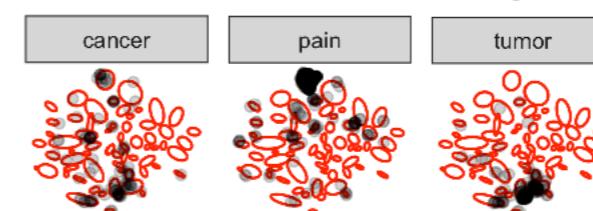
Augmentation and interaction



Surgery, surgical planning, etc



Cancer and pain



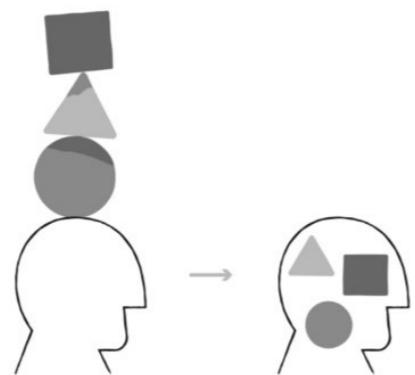
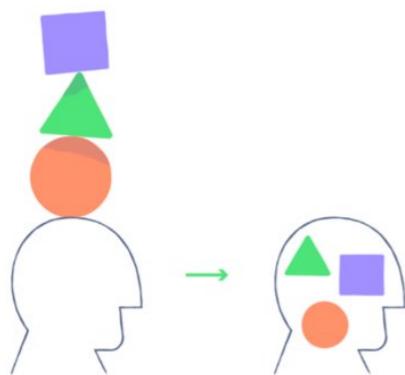
Regardless of AR/VR, there are challenges associated to visualizing 3D data

ASPECTS OF VISUAL PERCEPTION AND VISUAL COMMUNICATION



- Pre-attentive stage: objects, linear features, and textures are recognized without conscious attentions
- Attentive stage: low-level features are interpreted

[Illustrating a more human brand. Illustrations from Dropbox Design]



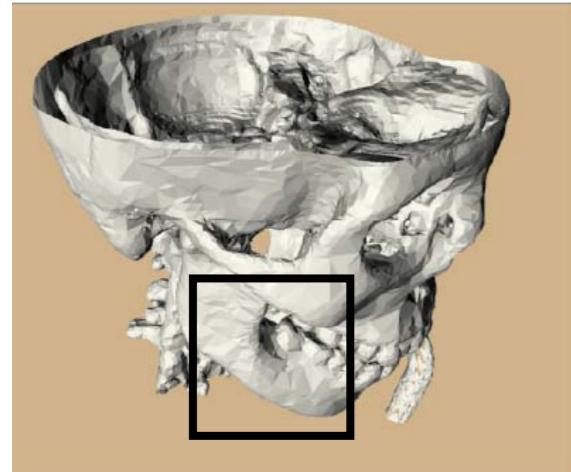
1. what is the color **used for?**
2. what type of imagery needs **to be colored?**
3. what can we assume about **the display?**
4. what can we assume about **the user?**
5. what can we assume about **the task?**
6. **which channel is most relevant?**

[What's so hard about categorical color? Stone. StoneSoup Consulting]

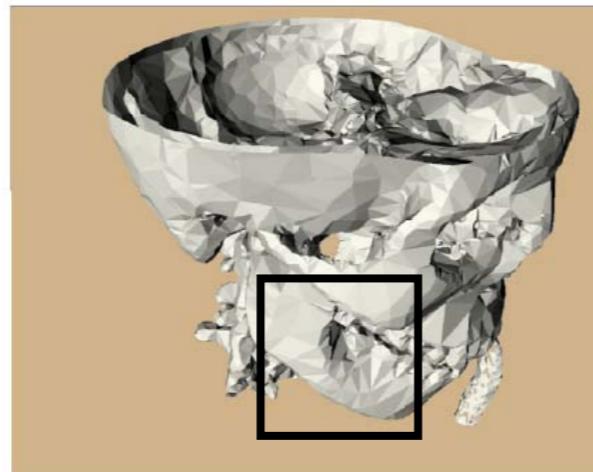
[Illustration by Z Graham]

7. what can we assume about the data?

RELATIONSHIP OF DATA AND VISUALIZATION



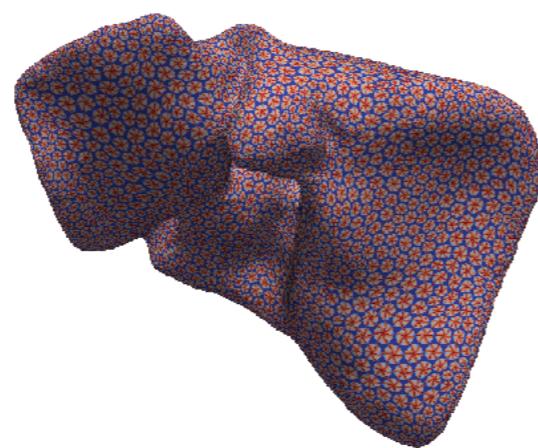
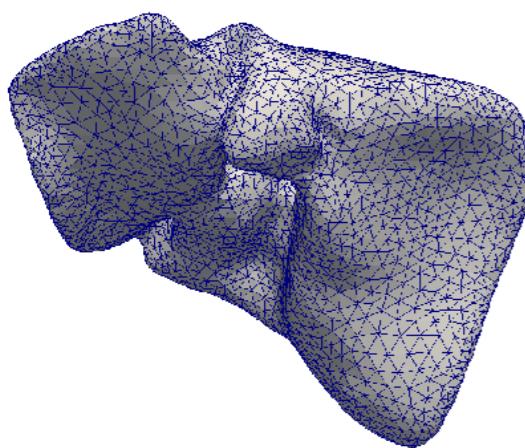
75% decimated
(142K flat shaded triangles)



90% decimated
(57K flat shaded triangles)

- Example in data compression: surface decimation or simplification reduces the number of mesh elements and the file size, but increases the error

[Mesh decimation using VTK. Knapp 2002]



- Example data constraints: The order of tetrahedral elements, e.g. tetrahedral (left) and quadratic (right)

[First and second order tetrahedra with two data representations.
Created from the inhaled state for a patient liver 3D-IRCADb-02]

Which tasks are commonly addressed in medical visualization?

COMMON TASKS IN MEDICAL VISUALIZATION

- **Viewing**

- overview of anatomy

- **Exploration**

- zoom on local structures
- browsing slices for better diagnosis (e.g. CT data)
- orientation of the data for better evaluation (axial, coronal, sagittal)

- **Filtering**

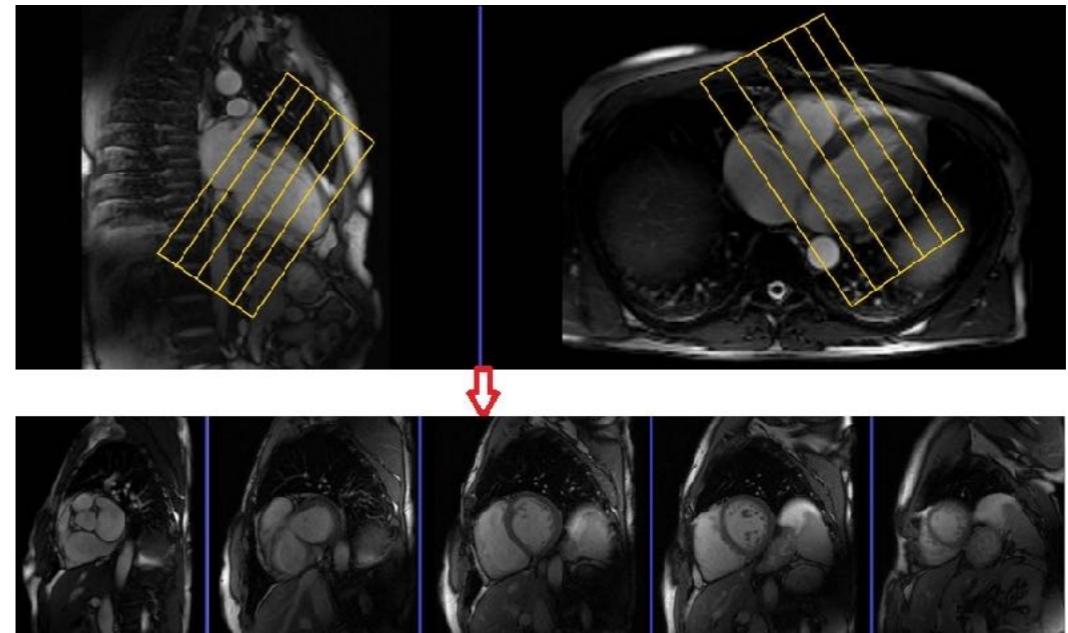
- windowing as a simple transform from pixel intensity values to grey values (e.g. CT data)
- removing occluding structures
- actual usage of a filtering algorithm with a linear scale (e.g. opacity)

- **Quantitation**

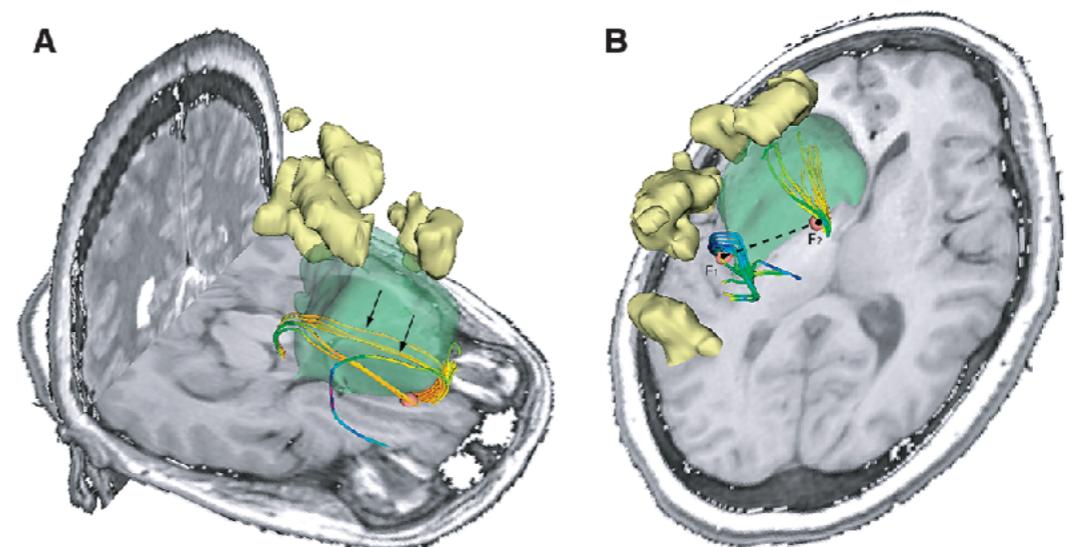
- standardization of the signal (e.g. fluorescence)
- image analysis for a Region Of Interest or ROI
- distance measurement between two points

- **Information addition**

- manual delineation or segmentation (polygon, free-hand, etc)
- annotation and/or labelling (symbol, text, etc)



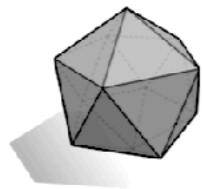
[Multi-slice view of an MRI. Courtesy of mrimaster.com]



[3D slicing for intra-operative neuronavigation.]

Elhawary et al. 2011]

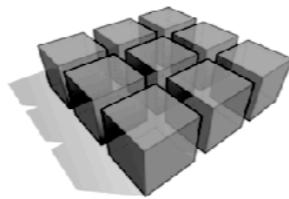
SURFACE VISUALIZATION



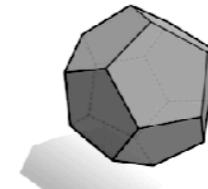
Triangle meshes
[MacNeal 1949]



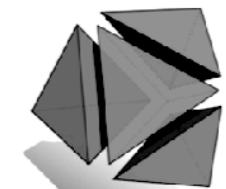
Point clouds
[Liu et al 2012]



Regular grids
[Newton 1693]



Polygon meshes
[Alexa & W. 2011]



Tetrahedral meshes
[Desbrun et al 2008]

[ddg.cs.columbia.edu]

- **Mesh processing**

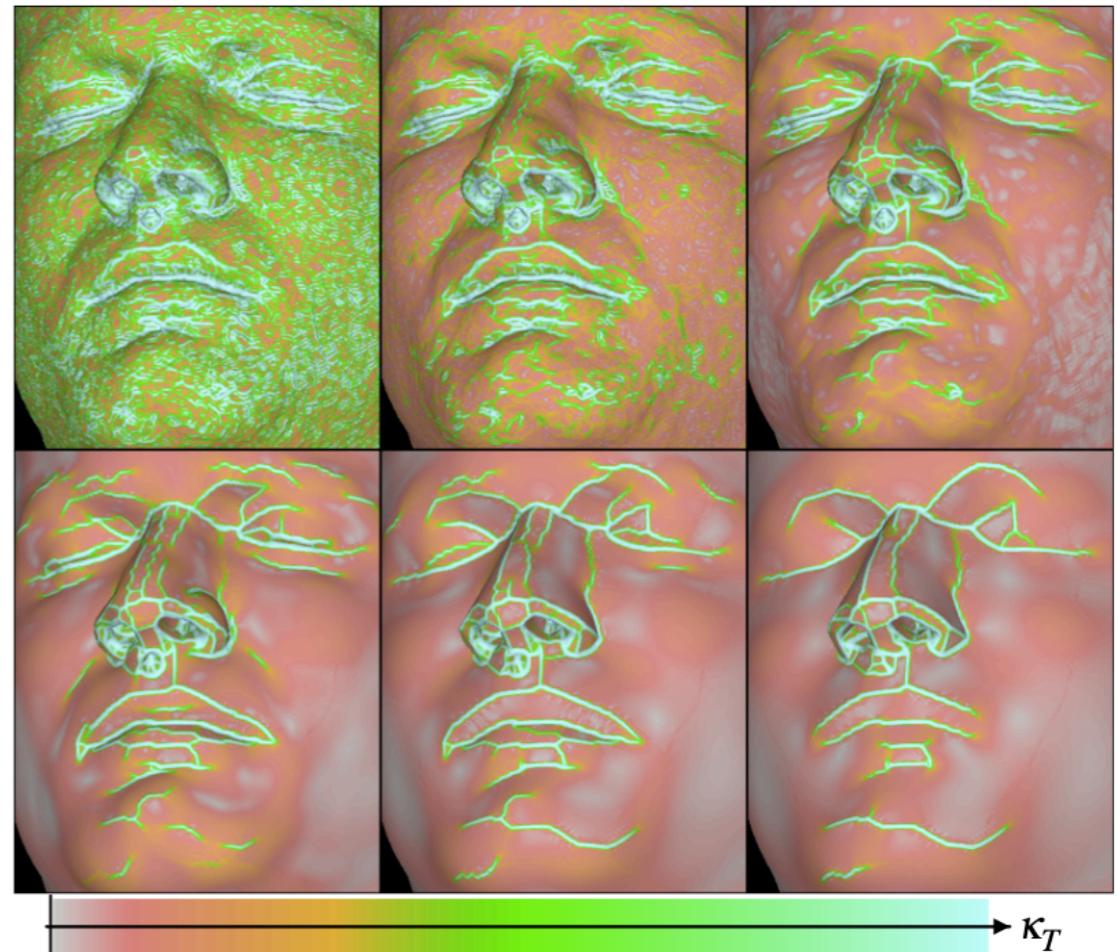
- extraction: marching cubes, isosurface, etc
- simplification: reduce the number of elements, or the complexity of the geometry
- smoothing: add edges and vertices to provide a finer scale
- discretization: curvature, Laplace operators, mappings, conformal geometry, etc

- **Relevant encodings**

- Lambertian shading to reveal smooth shapes
- specular shading to reveal fine surface details
- texture to represent continuous surface variables
- etc

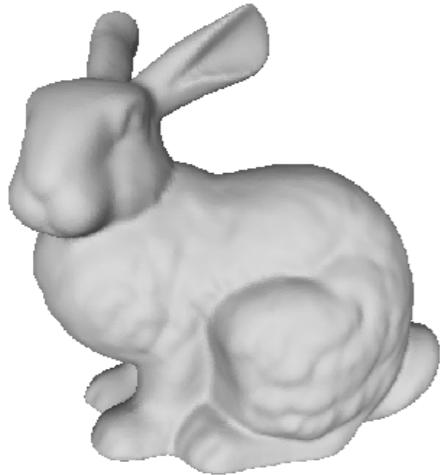
- **Light**

- provide control to move or to rotate light source (e.g. specular light reflected off regions of interest)

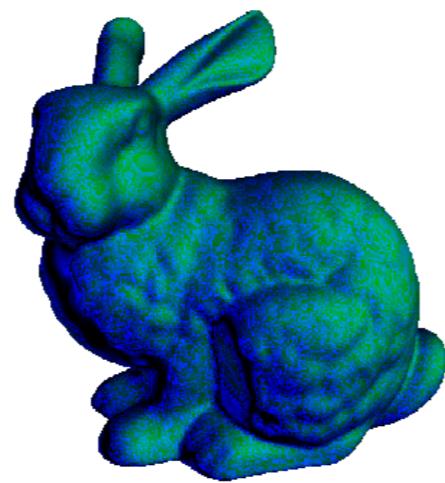


[Courtesy of Kindlmann et al. 2003]

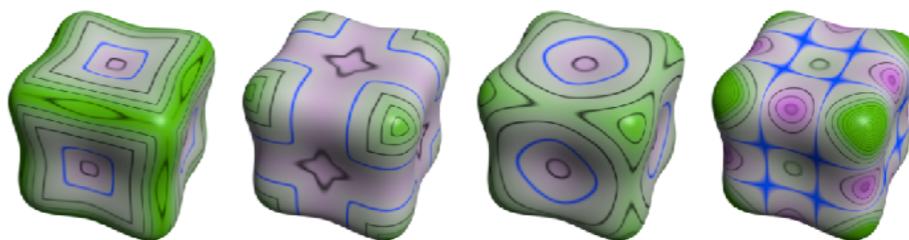
TASK-RELATED SURFACE VISUALIZATIONS



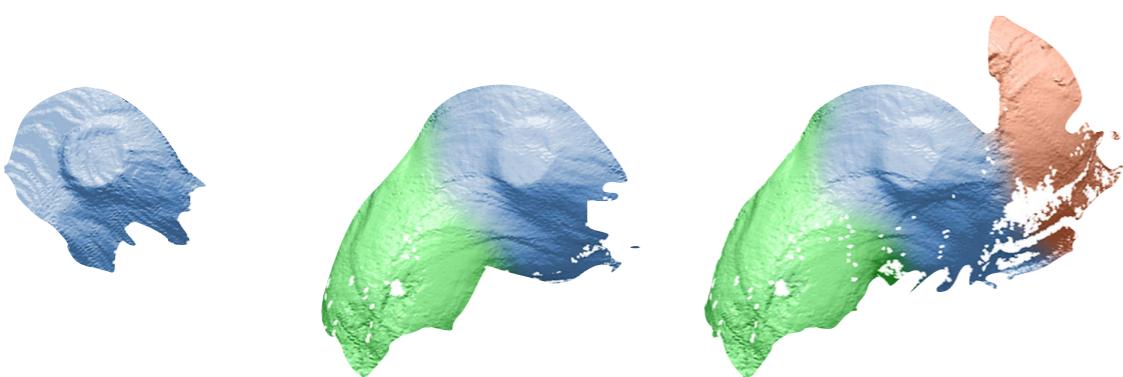
[Curvature using the squared-sum of each normal]



- Enhance perception of curvature information with curvature-directed strokes, or with curvature measures (e.g. principal, second principal, mean, and gaussian)



[Courtesy of Kindlmann et al. 2003]



[Stitching laparoscopic image data. Reichard et al. 2017]

- Improve color encoding with colorblind-friendly categorical colors (e.g. Color Blind 10 color palette)



[Courtesy of Kindlmann et al. 2003]

Improve your visualization by creating different iterations and ask yourself which addresses best the task

VOLUME VISUALIZATION

- **Physics-based**

- aerial perspective, modulates color based on distance (depth)
- illumination-based (shading, shadowing effects, ambient occlusion)



Original

Silhouette criteria

Unsharp-masking

[Svakhine et al. 2009]

- **Illustrative techniques**

- do not aim to mimic the real world, but instead borrow from art and illustrations (boundary emphasis, toon shading, feature lines, etc)



Raycasting



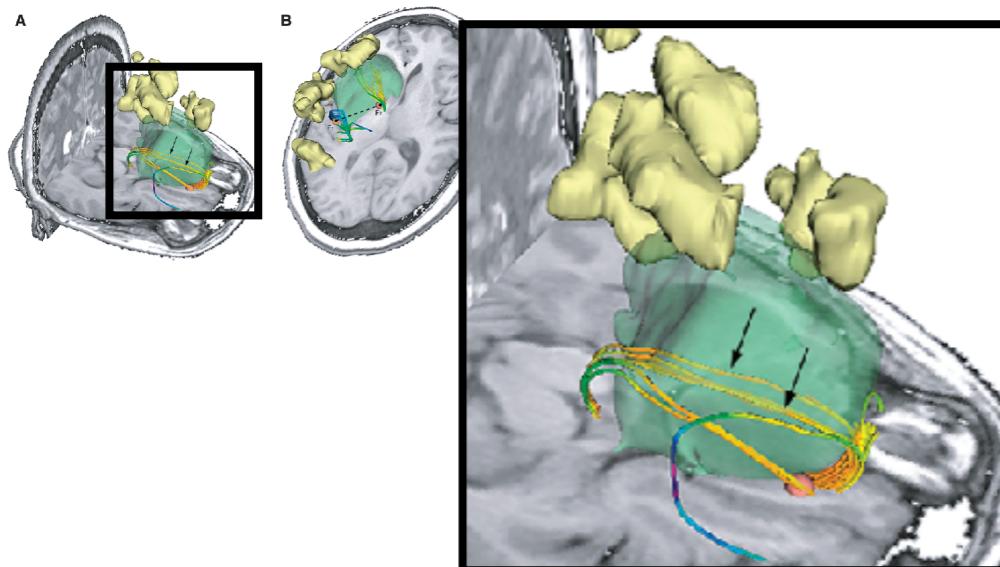
Direction occlusion shading

[Šoltészová et al. 2010]

- **Relevant encodings**

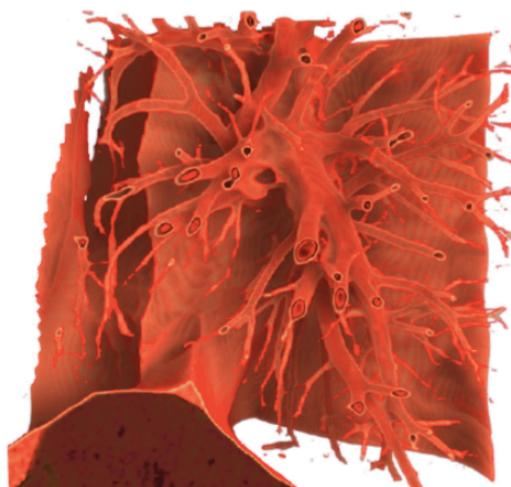
1. Use directional occlusion shading to perceive depth and size in stereo vision [Lindemann and Ropinski 2011]
2. Specular highlights on the screen, reflections, or over-illuminated areas affect the correct perception of the data [Díaz et al. 2015]
3. Head tracking and stereoscopy are beneficial to volume analysis tasks

TASK-RELATED VOLUME VISUALIZATIONS



- Enhance depth perception by exploiting hue-based distance perception using a chromadepth color encoding. Difficult to see fine details: interactivity?

[Intraoperative Real-Time Querying of White Matter Tracts During Frameless Stereotactic Neuronavigation. Elhawary et al. 2011]



Directional occlusion shading



half-angle slicing

- Directional occlusion shading is independent of the light source direction, while half-angle slicing incorporates the incoming light direction. More natural/suitable in this case!

[An experimental study on the effects of shading in 3D perception of volumetric models. Díaz et al. 2015]

Always reconsider your task!

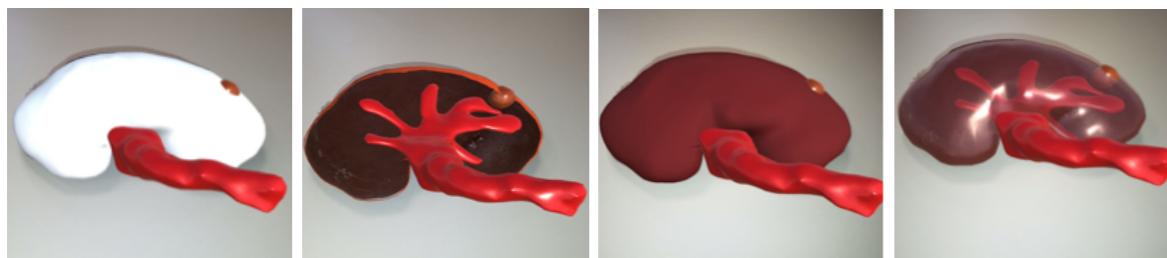
PERCEPTUAL LIMITATIONS IN SURGICAL AR

- **Relevance of visualization**

- hasn't been much considered in the literature
- the main focus is on legitimate problems: registration accuracy, realtime processing, etc
- the quality of the surgeon's perception has been commonly overlooked

- **Quantitative evaluation framework**

- help identify and quantify problems
- assess the perceptual fidelity in laparoscopic AR [Stoyanov et al. 2008]
- test the importance of appropriate encodings, renderings, and content for the augmentation



- **What to display?**

- What? How? When? [Kersten-Oertel et al. 2013]
- How? By adopting task-oriented visualizations
- What? and when? May be solved via context-aware AR (e.g. sensor feedback, or surgical phase)



[Hattab et al. 2019 *In preparation*]

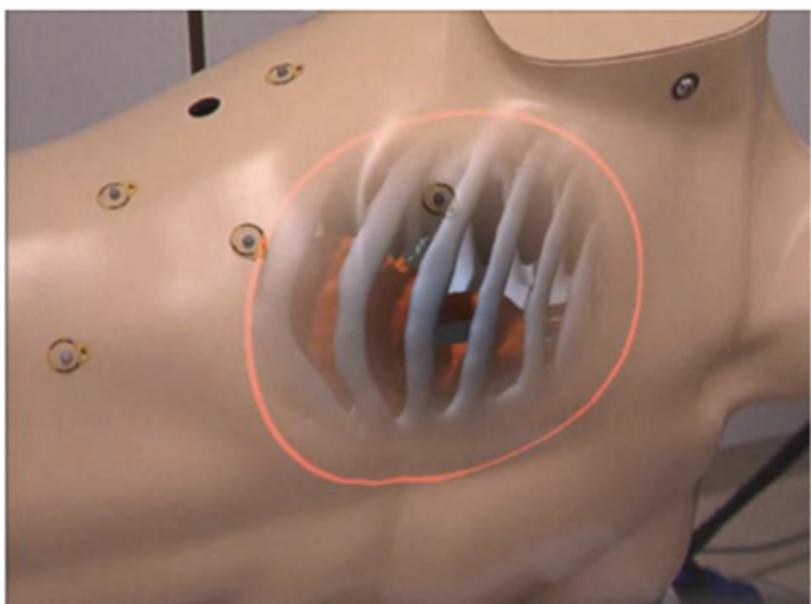
Which type of augmentation is widely used?

STRONGEST CUES IN DEPTH PERCEPTION

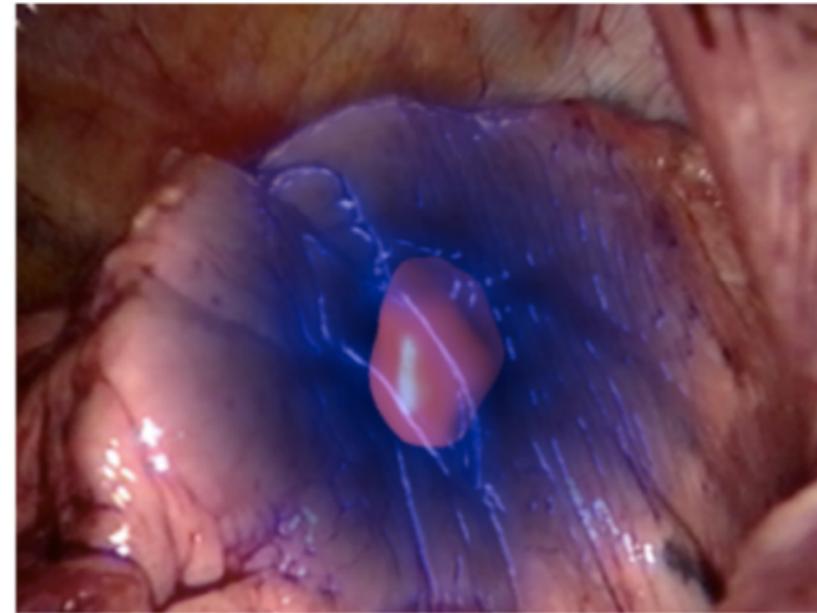
The most widely used augmentation approach is a **simple superimposition of the real endoscopic image**

- **Occlusion**

- most important cue
- common approach: virtual windowing
- Cons: partial obstruction of the scene
- Alternative: inverse realism (super-hero see-through like vision)
- only informs about the order, not about the distance



[Bichlmeier et al. 2007]



[Lerotic et al. 2007]

- **Motion parallax**

- weaker than occlusion
- provides relative distance (valuable in surgery)
- difficult to enforce
- common approach: tracking the surgeon's head

Other cues or even other senses might supplement strategies to enforce depth perception

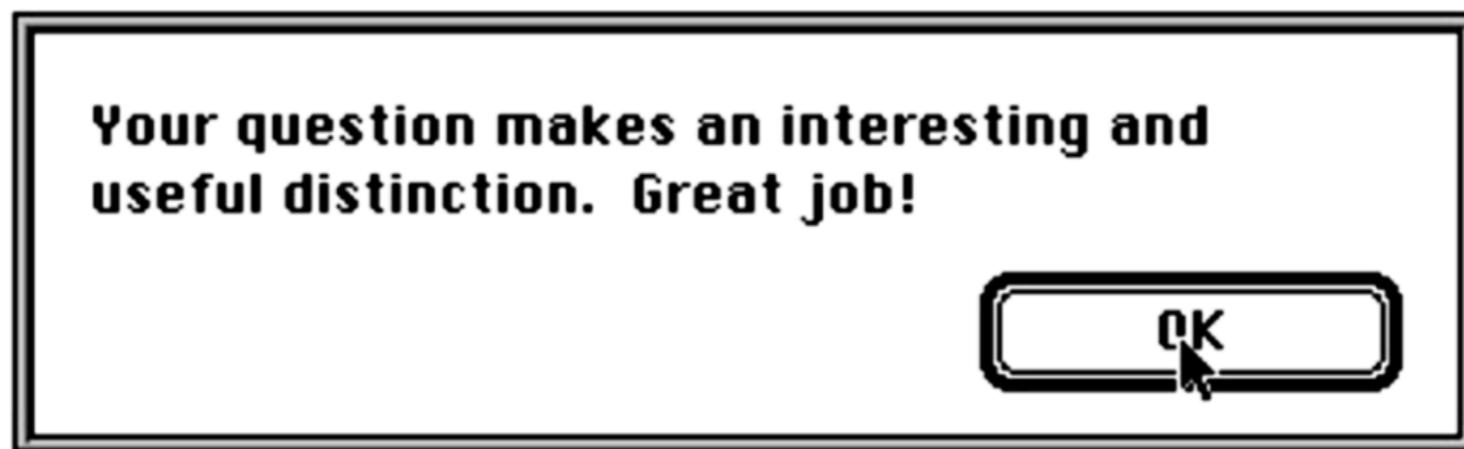
IMPORTANCE OF INTERACTIVITY

Reliability: real-time accuracy control in any situation

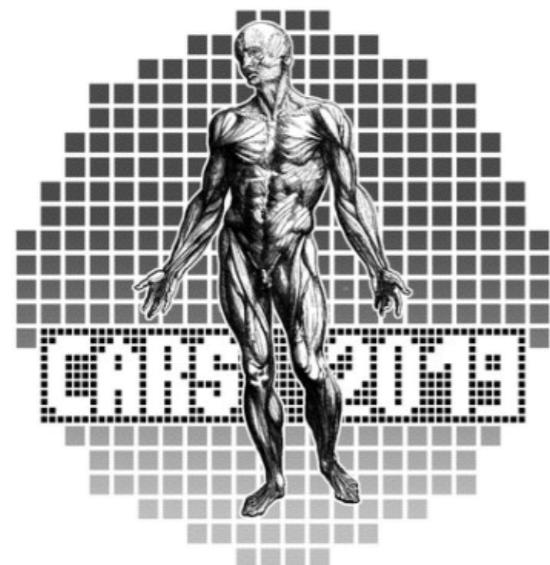
Usability: strict minimum of interaction by surgeon

Interoperability: generic data and protocols are used to guarantee the largest compatibility with other equipment.

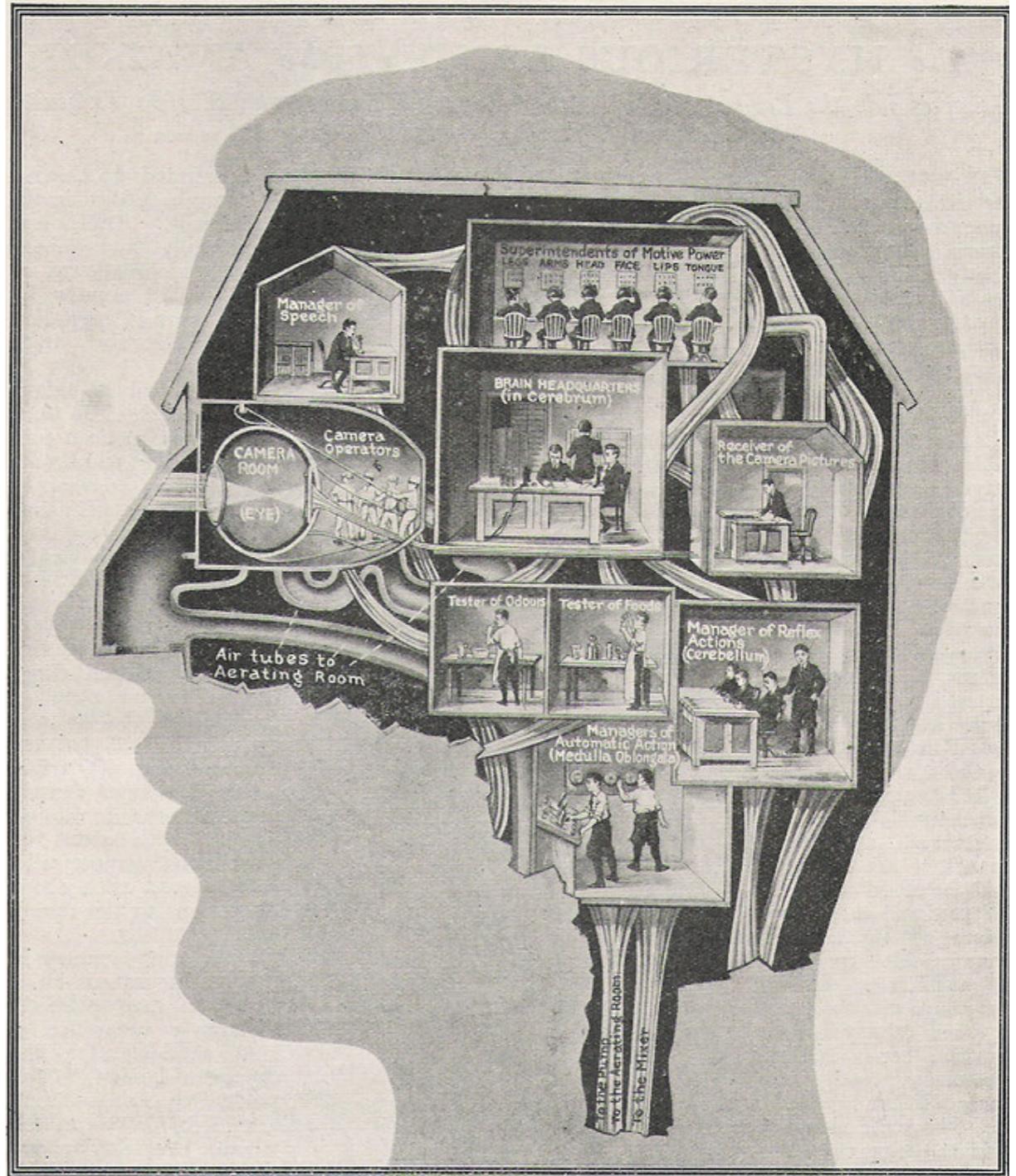
[Sielhorst et al. 2006]



[Persuasive Technology: Using Computers to Change What We Think and Do. B.J. Fogg]



INTUITIVE
SURGICAL®



[Control room. Cassell's Children's Book of Knowledge]

bit.ly/cars-tutorial