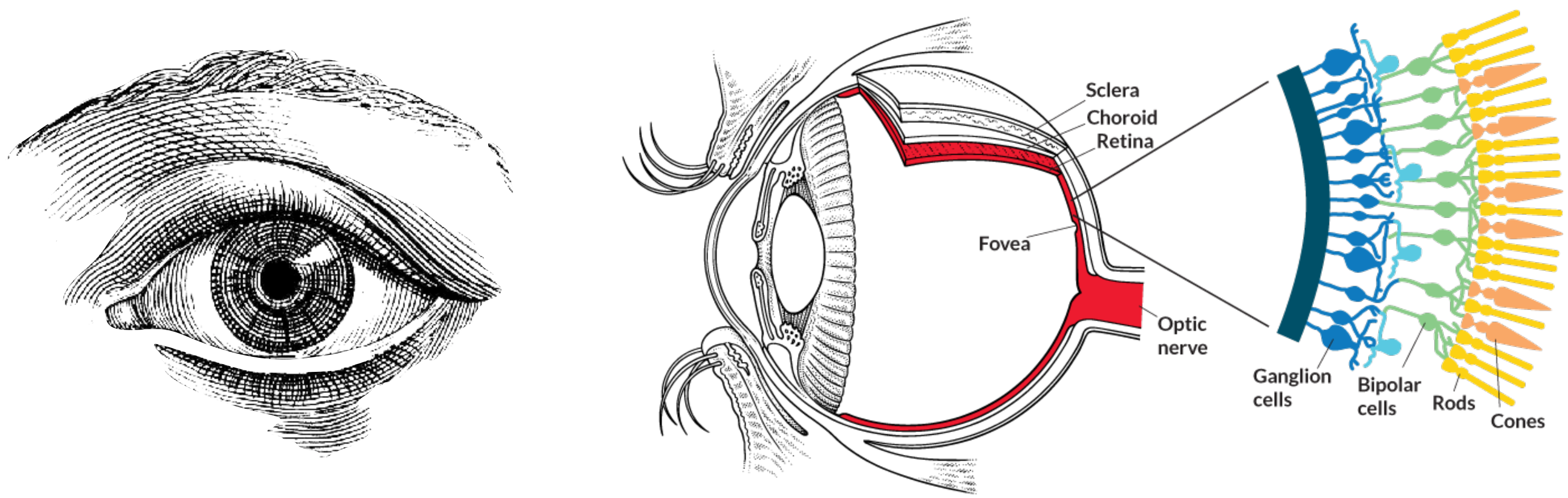
Perceptual Capacities and Constraints in AR/VR for the visualization of 3D biomedical image data



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, Claudie 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

Mixed Reality (MR)

Real Environment | Augmented Reality (AR) | Augmented Virtuality (AV) | **Virtual Environment**

(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?

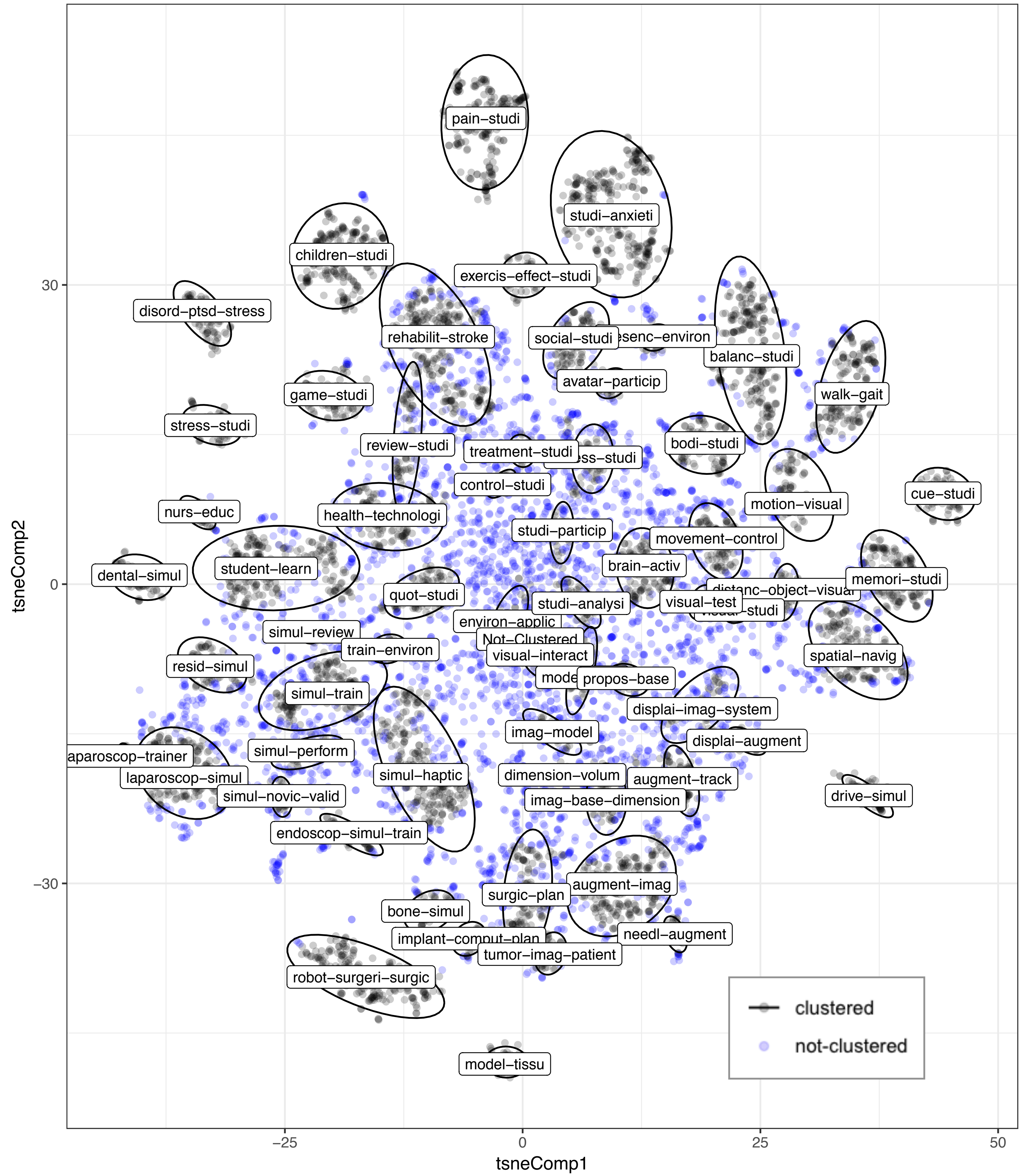
The Related Work Landscape

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

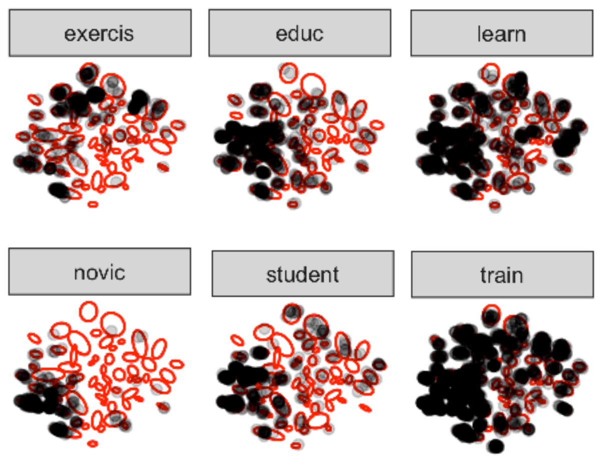
- learning, trainers and simulators
- surgery, surgical planning (tumor, needle, tissue)
- large amount of studies
- disorder PTSD stress
- driving simulator

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

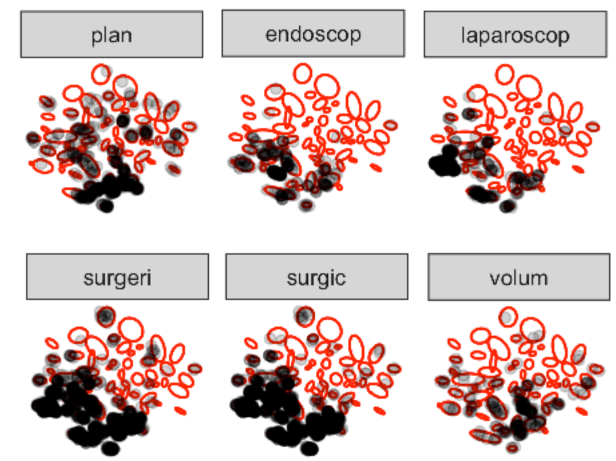


The Related Work Landscape

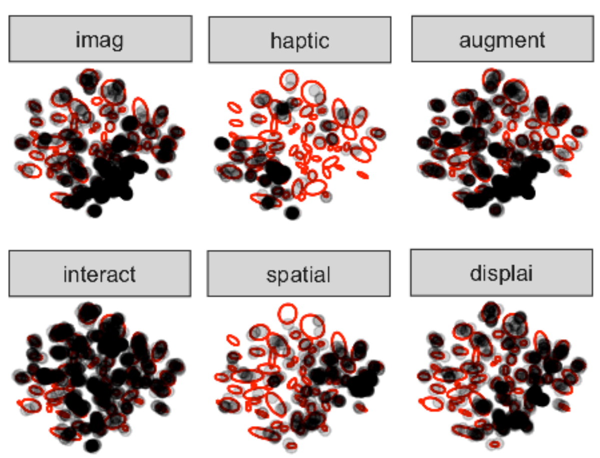
Learning, trainers and simulators



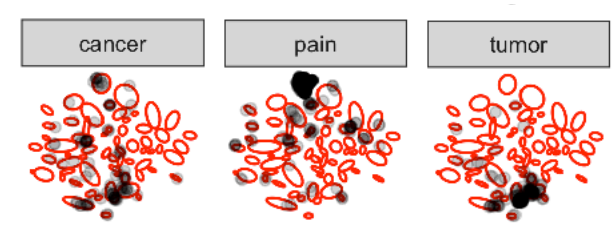
Surgery, surgical planning, etc



Augmentation and interaction



Cancer and pain

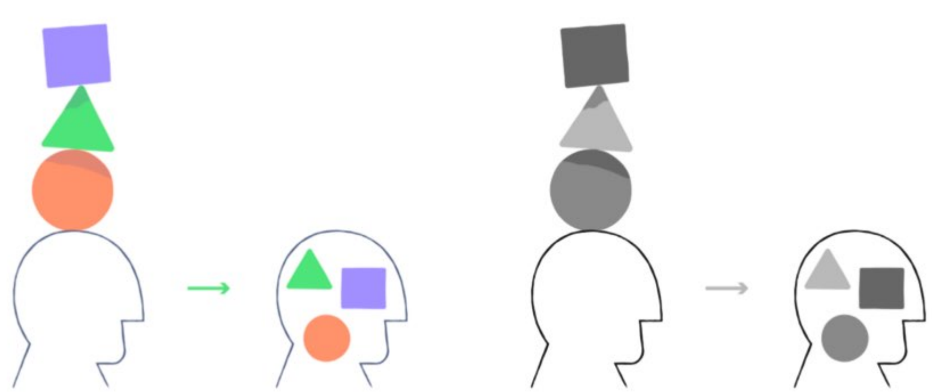


Regardless of AR/VR, there are challenges associated to visualizing 3D data

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]



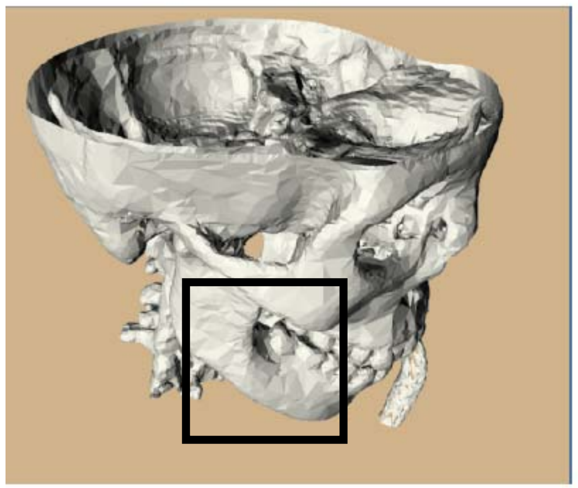
1. what is the color **used for**?
2. what type of imagery needs **to be colored**?
3. what can we assume about **the display**?
4. what can we assume about **the user**?
5. what can we assume about **the task**?
6. **which channel is most relevant?**

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

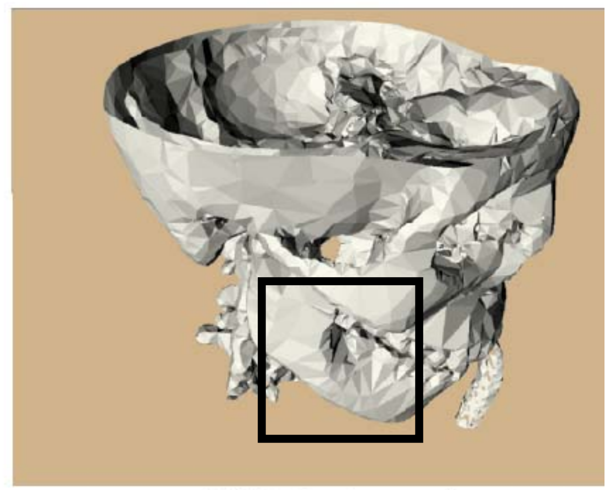
[Illustration by Z Graham]

7. what can we assume about the data?

Relationship of Data and Visualization



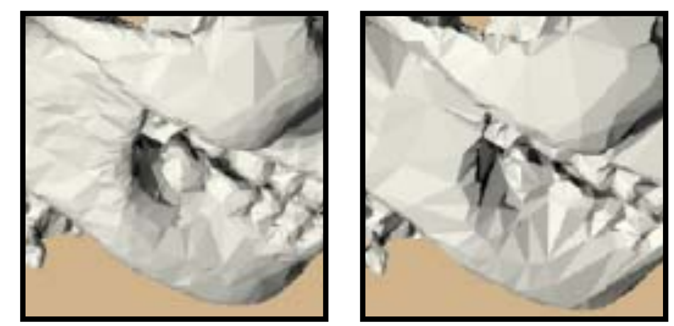
75% decimated
(142K flat shaded triangles)

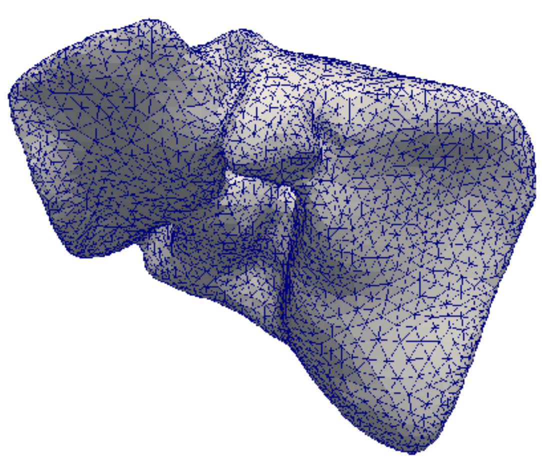


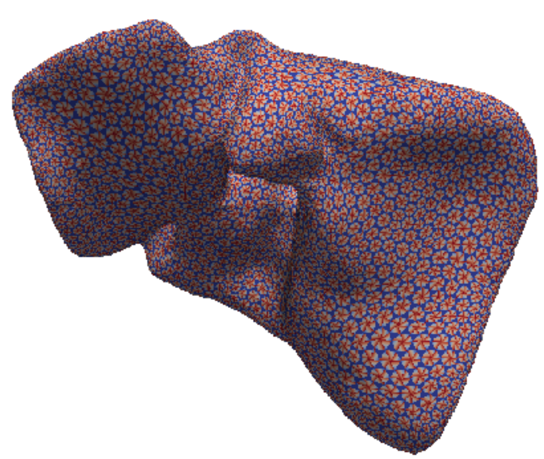
90% decimated
(57K flat shaded triangles)

- 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

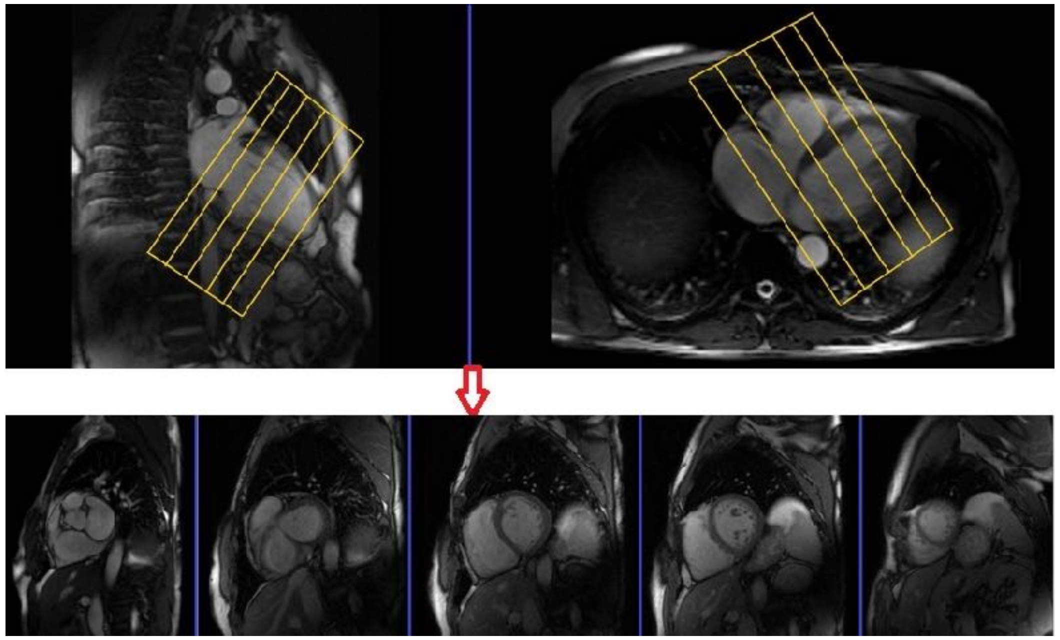
- **Viewing**
  - overview of anatomy

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

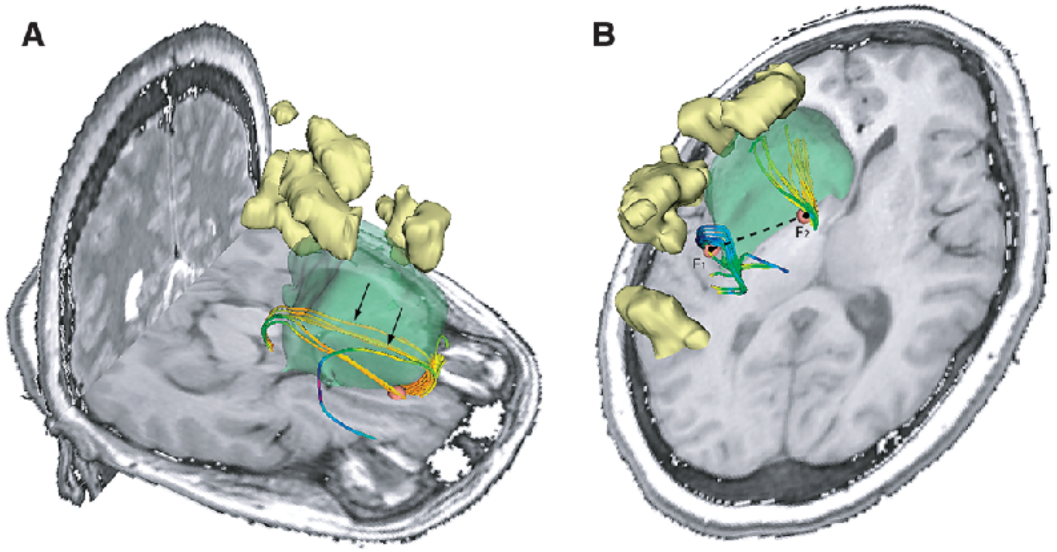
- **Filtering**
  - windowing as a simple transform from pixel intensity values to grey values (e.g. CT data)
  - removing occluding structures
  - actual usage of a filtering algorithm with a linear scale (e.g. opacity)

- **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)



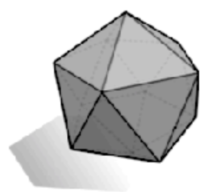
[Multi-slice view of an MRI. Courtesy of mrimaster.com]



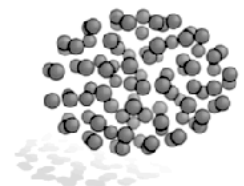
[3D slicing for intra-operative neuronavigation.

Elhawary et al. 2011]

Surface Visualization

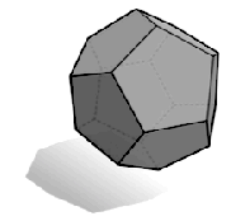


Triangle meshes
[MacNeal 1949]

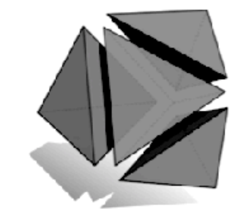


Point clouds
[Liu et al 2012]

Regular grids
[Newton 1693]



Polygon meshes
[Alexa & W. 2011]



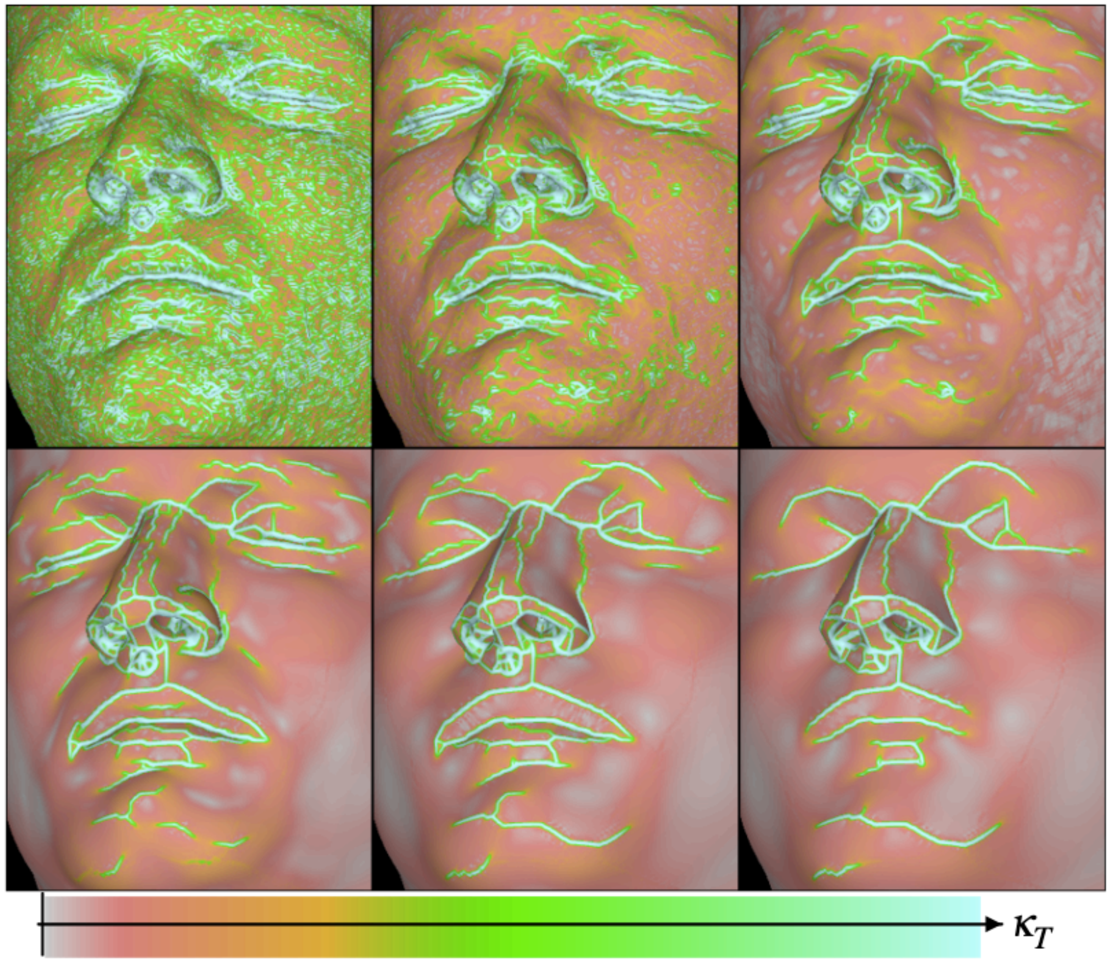
Tetrahedral meshes
[Desbrun et al 2008]

[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

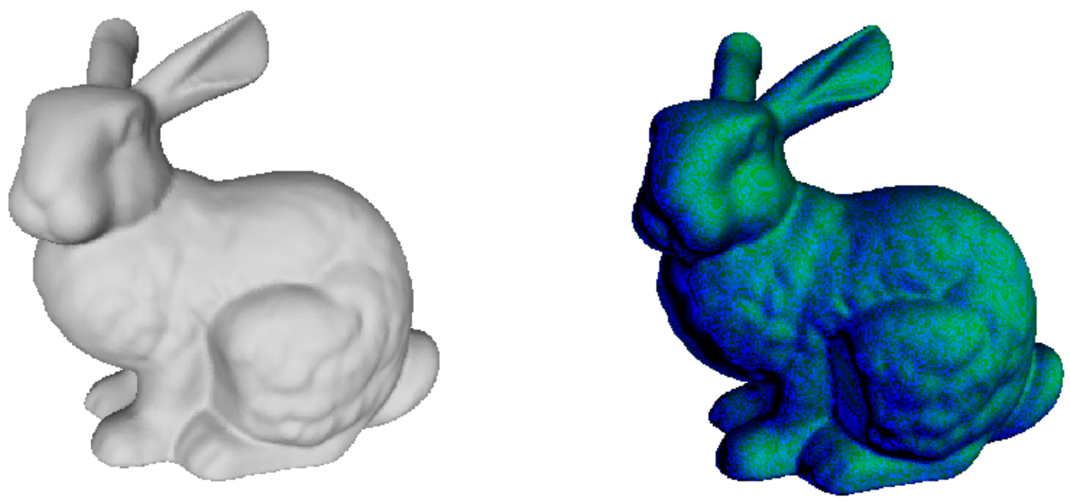
- **Relevant encodings**
  - Lambertian shading to reveal smooth shapes
  - specular shading to reveal fine surface details
  - texture to represent continuous surface variables
  - etc

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



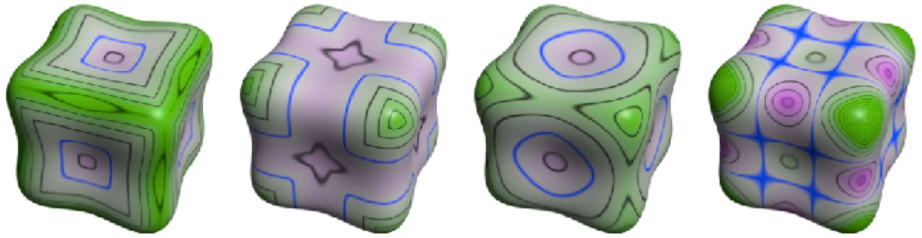
[Courtesy of Kindlmann et al. 2003]

Task-Related Surface Visualizations

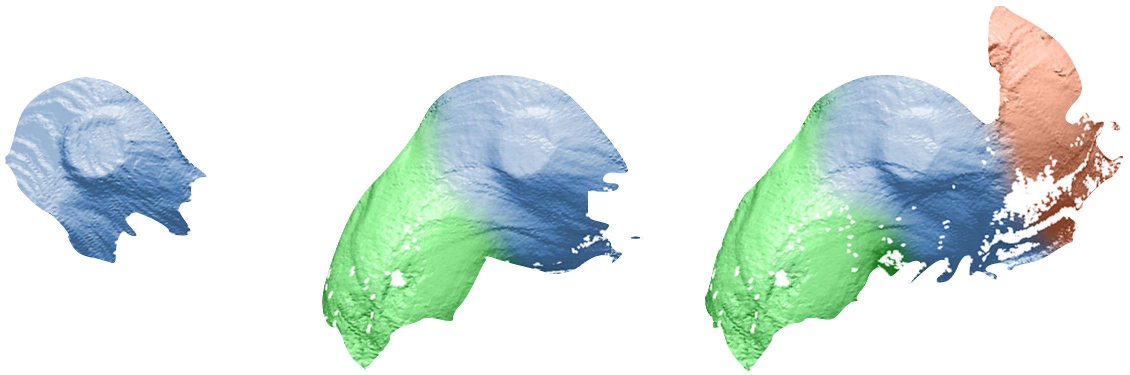


[Curvature using the squared-sum of each normal]

- 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)

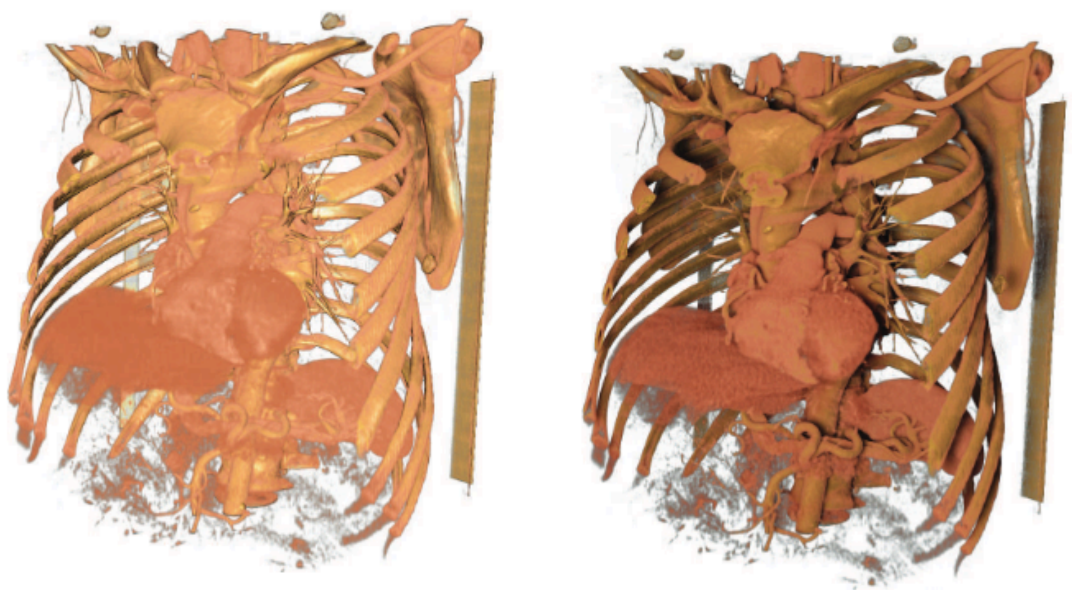
[Courtesy of Kindlmann et al. 2003]

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)

- **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]

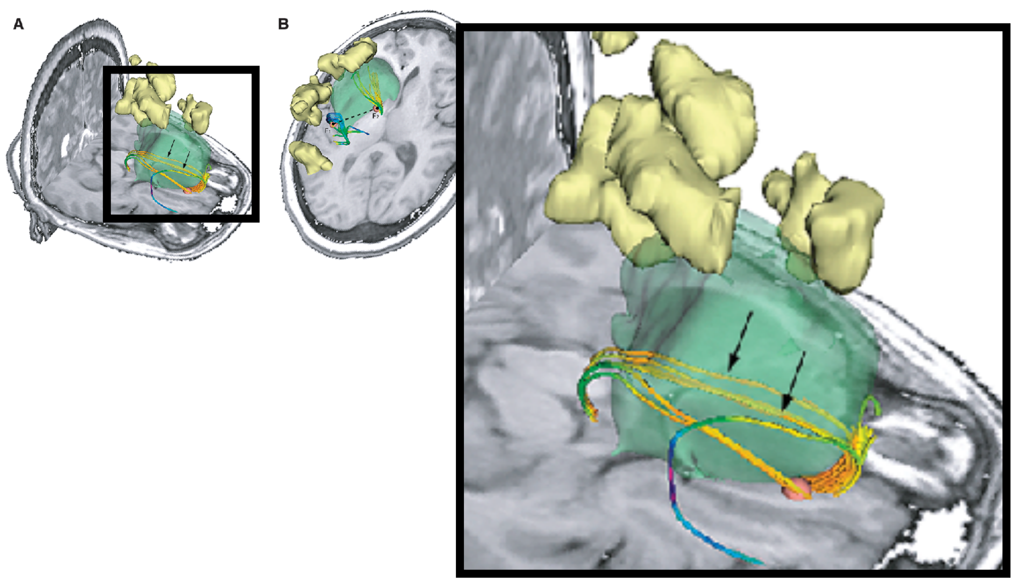
Original   Silhouette criteria   Unsharp-masking

[Svakhine et al. 2009]

- **Relevant encodings**

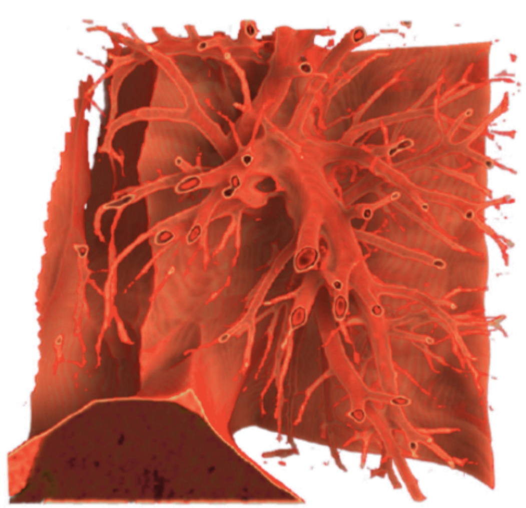
1. Use directional occlusion shading to perceive depth and size in stereo vision [Lindemann and Ropinski 2011]
2. Specular highlights on the screen, reflections, or over-illuminated areas affect the correct perception of the data [Díaz et al. 2015]
3. Head tracking and stereoscopy are beneficial to volume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

Task-Related Volume Visualizations

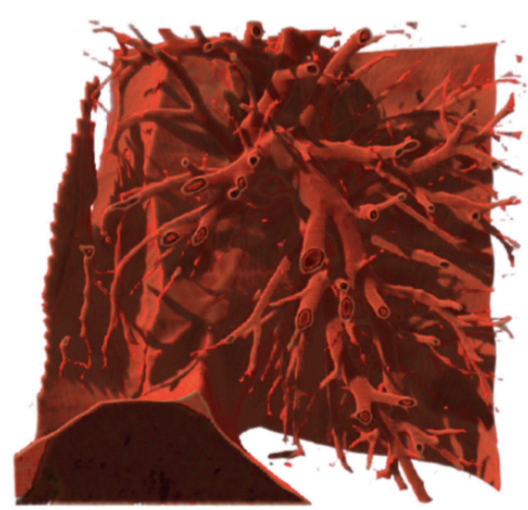


- Enhance depth perception by exploiting hue-based distance perception using a chromadepth color encoding. Difficult to see fine details: interactivity?

[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!

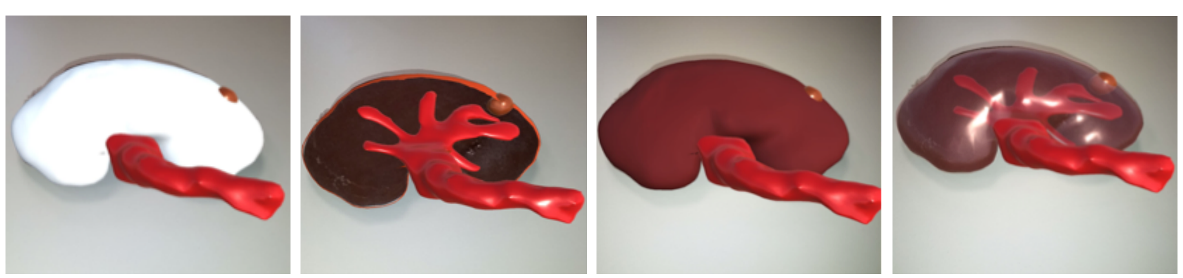
[An experimental study on the effects of shading in 3D perception of volumetric models. Díaz et al. 2015]

Always reconsider your task!

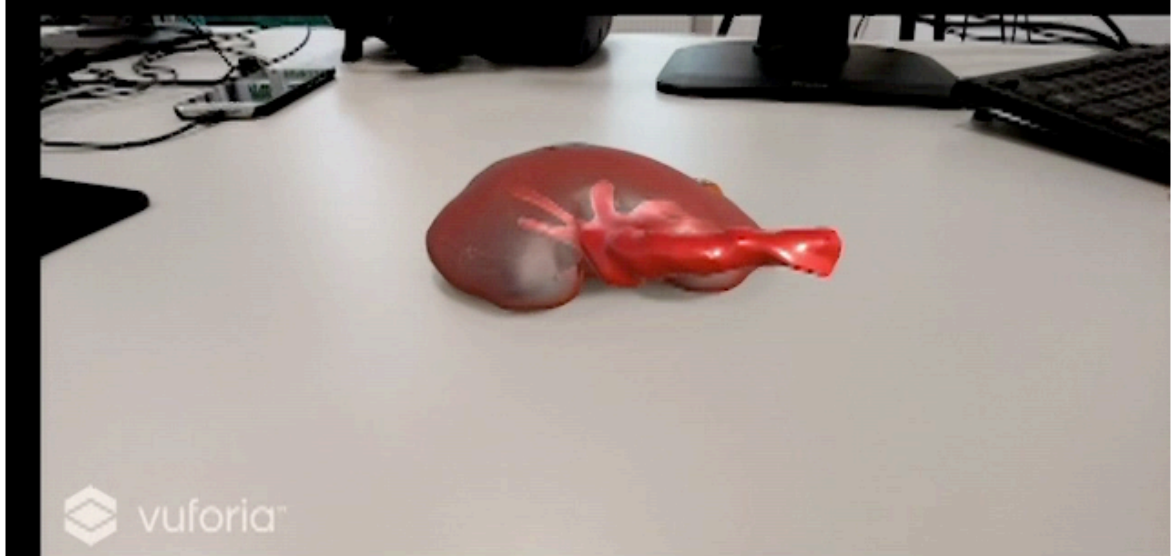
Perceptual Limitations in surgical AR

- **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 laporoscopic 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)



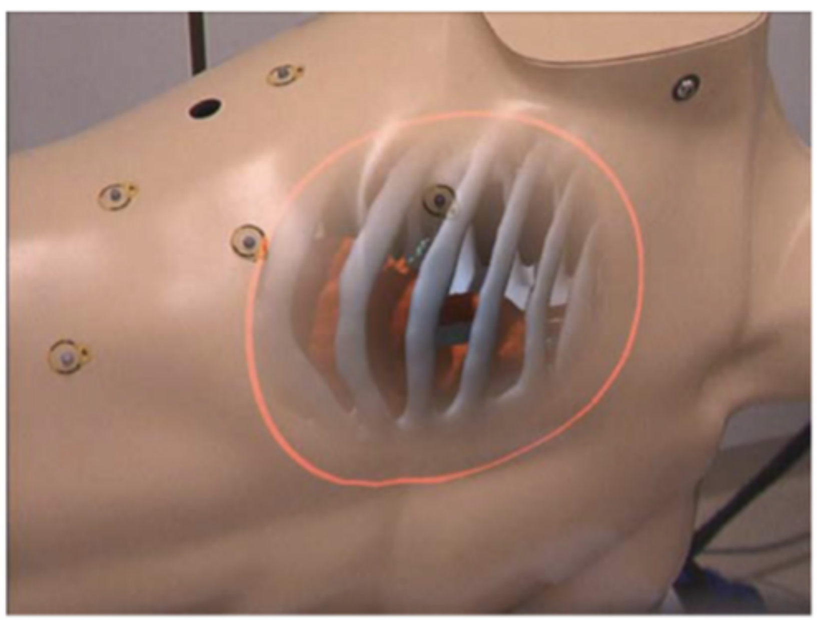
[Hattab et al. 2019 *In preparation*]

Which type of augmentation is widely used?

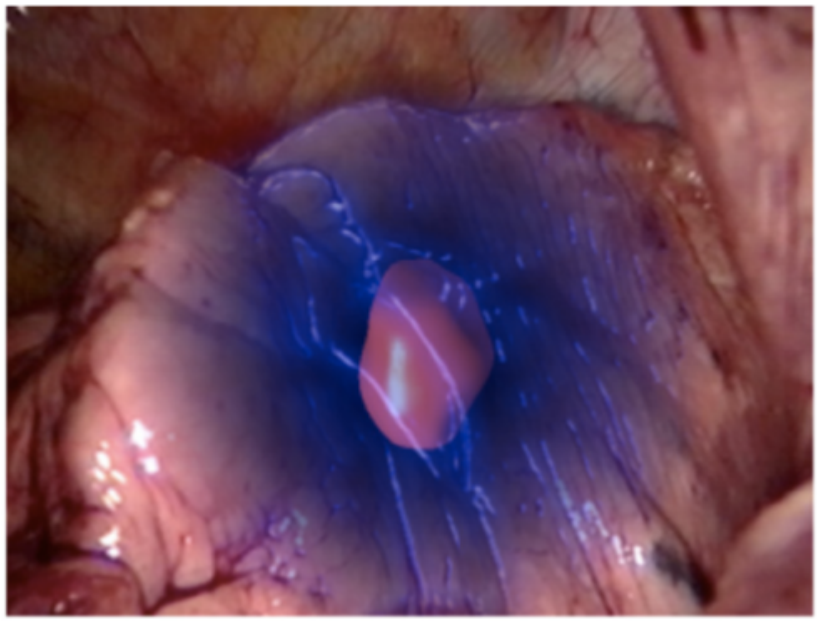
Strongest Cues in Depth Perception

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 surgeons 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]

NCT

CARS 2019

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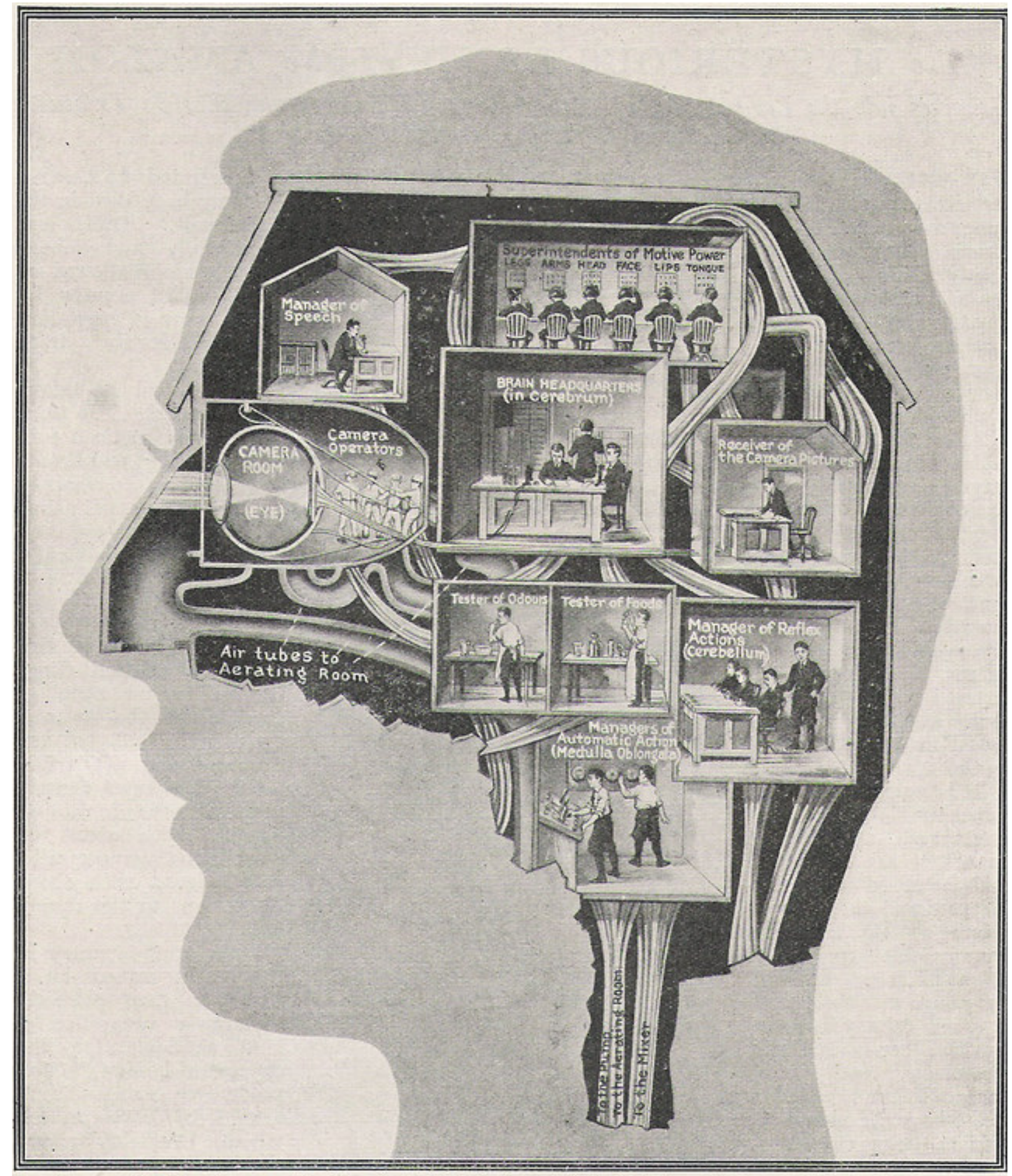

[Control room. Cassell's Children's Book of Knowledge]

bit.ly/cars-tutorial