PA214 / Visualization II

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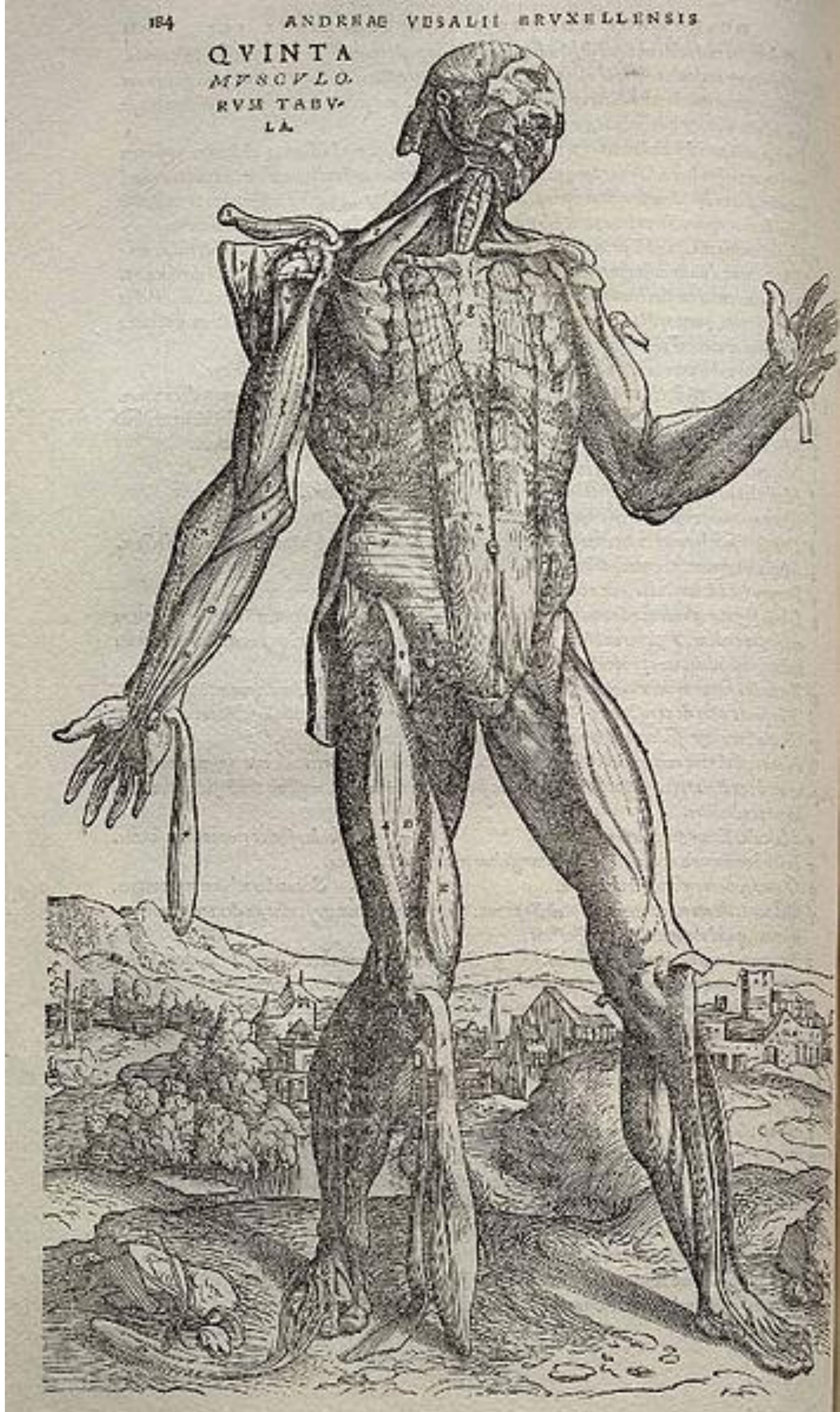
Visualization of Medical Data

HCI LAB   visitlab

Goals of Medical Visualization

- Education
- Diagnosis
- Treatment planning
- Treatment guidance
- Doctor-patient communication



De Humani Corporis Fabrica by Vesalius, 1543

In This Lecture

- A brief tour through the zoo of medical data and their visualization!

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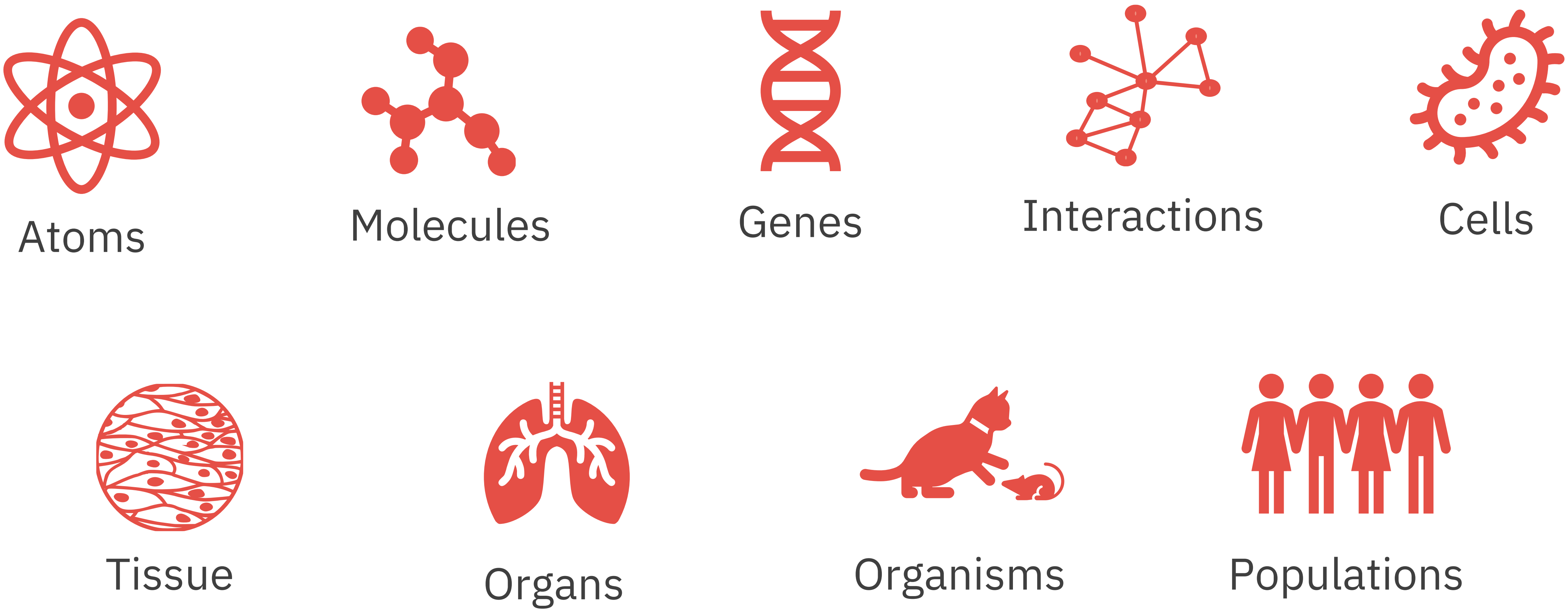
Scales


Atoms
Molecules
Genes
Interactions
Cells
Tissue
Organs
Organisms
Populations

Tissue

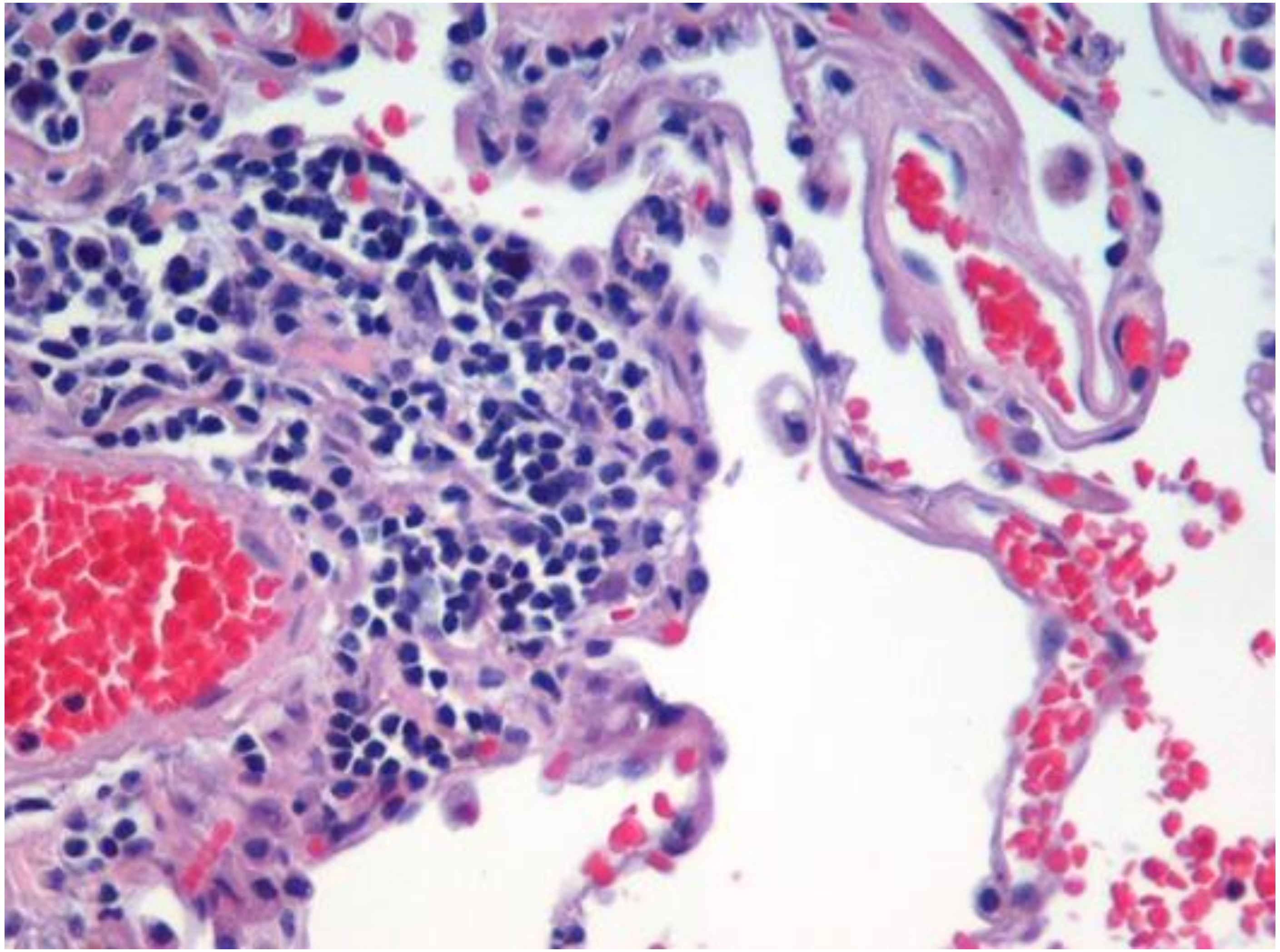
Samples of Human Tissue

- **Excretion**: urine, stool, mucus, vomit, saliva
- **Excision**:
  - Puncture: blood, lung fluid, amniotic fluid, ...
  - Scraping: cheek, mouth, uterine cervix, ...
- **Biopsy**:
  - Taking out piece of tissue as a whole
  - Bone marrow, brain, skin, liver, ...

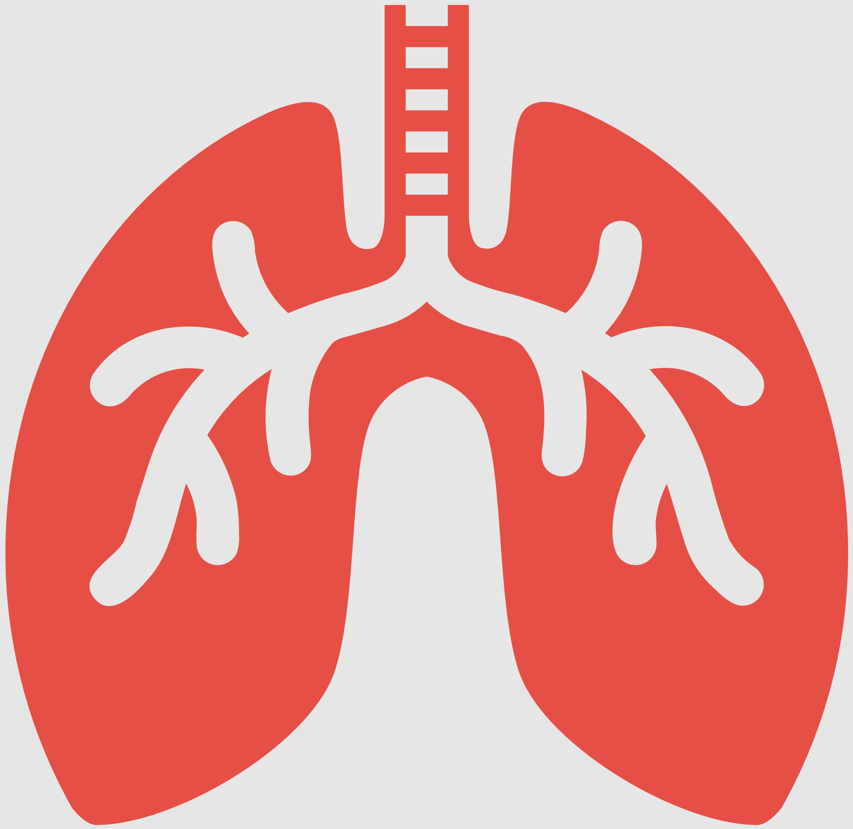
Resulting Data

- Images (e.g., histopathology)
- Tables (e.g., blood values)

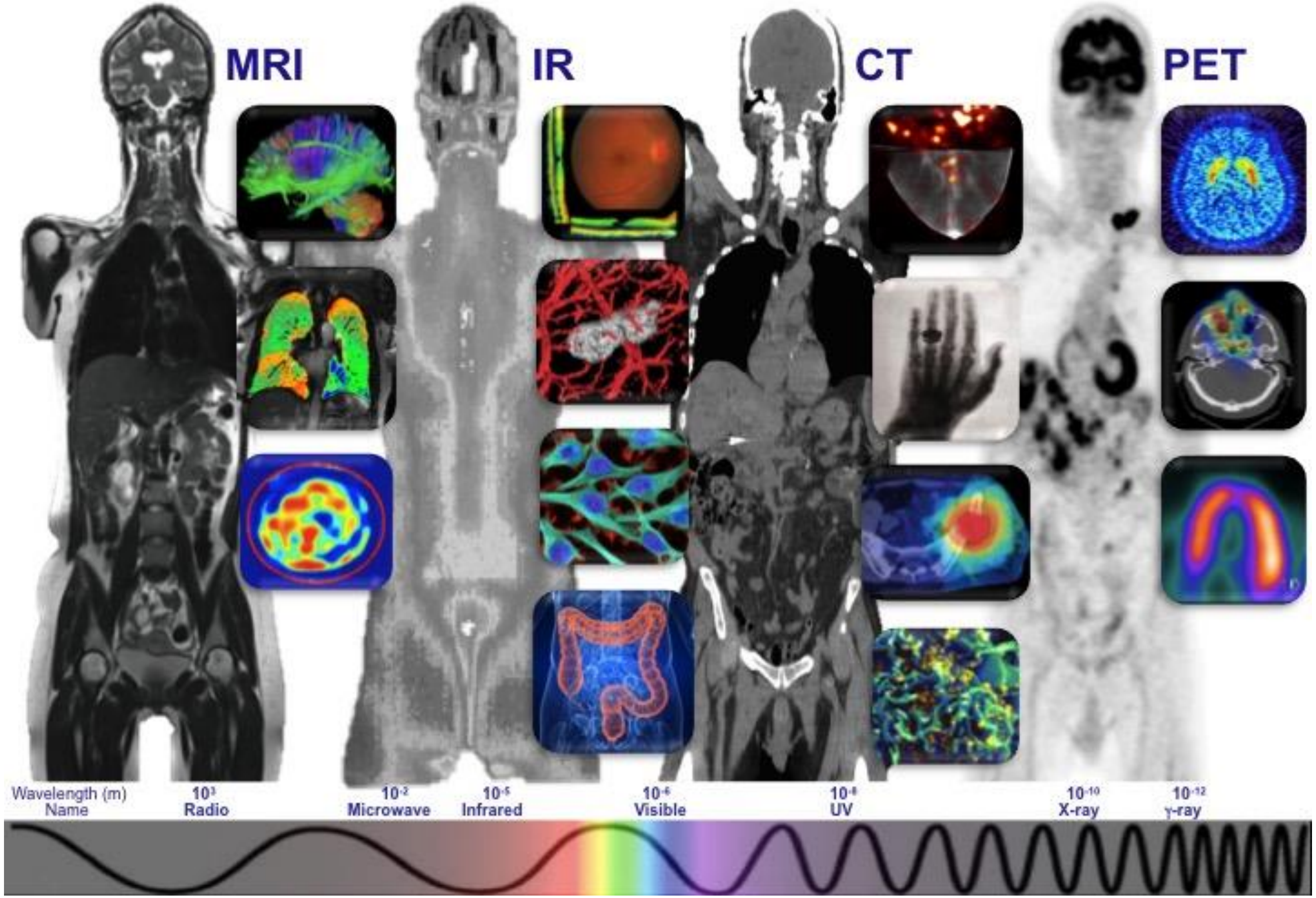
Human lung tissue stained with hematoxylin and eosin



Organ



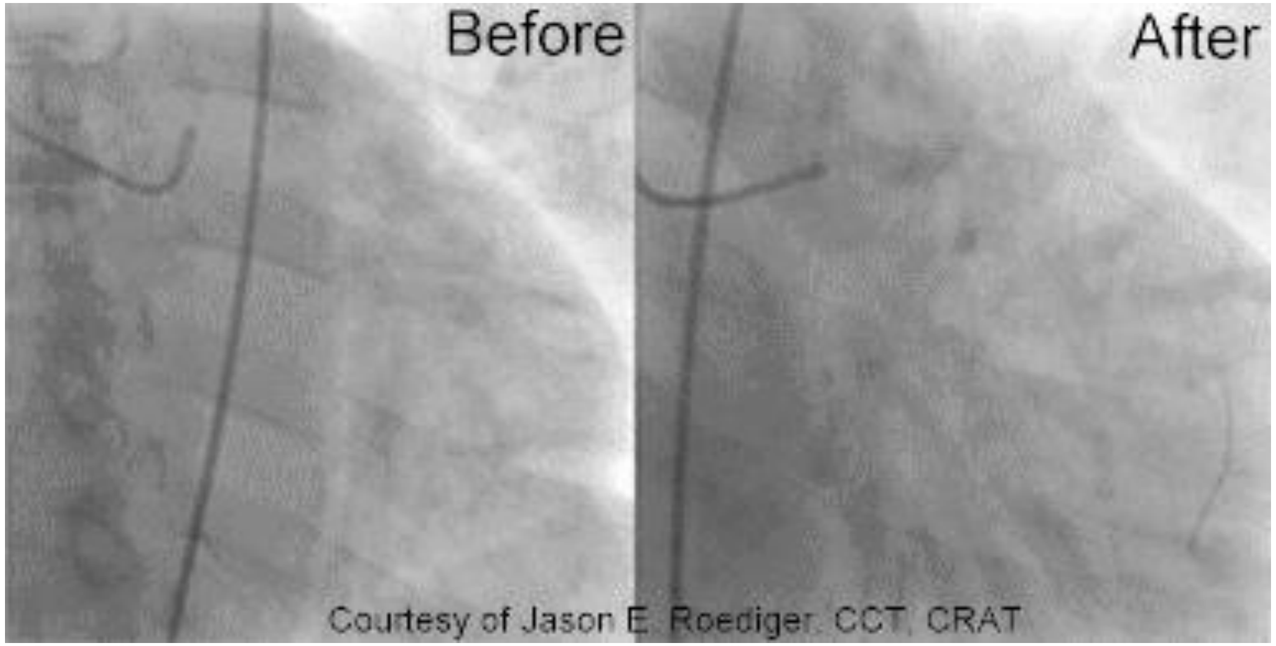
Medical Imaging



X-ray

- Radiation: electromagnetic waves (ionizing!)
- Varying tissue absorption leads to image contrast
- Standard, Fluoroscopy, Angiography, Mammography

Mikael Häggström, M.D. CC0, via Wikimedia Commons

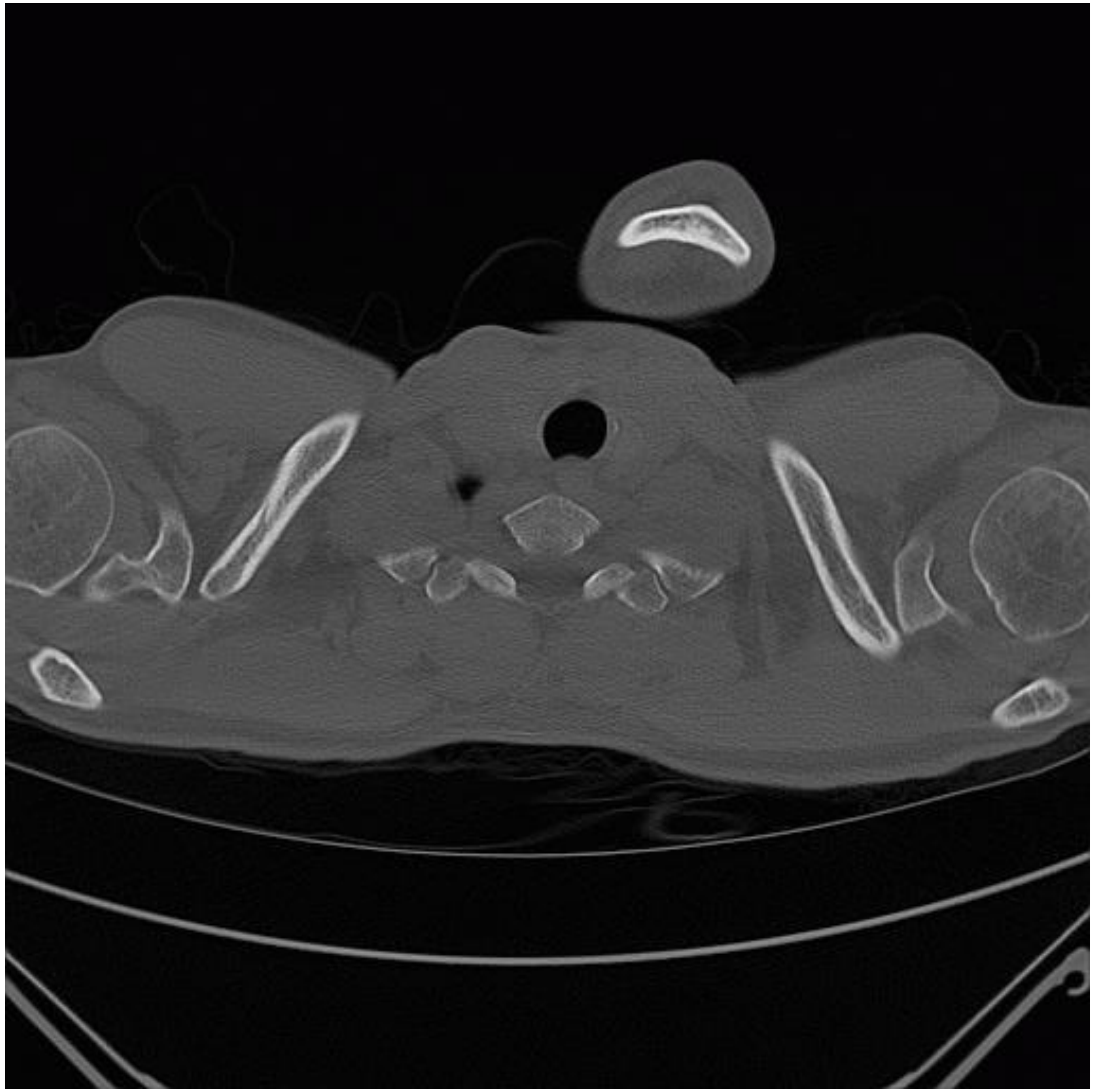


CardioNetworks: Jer5150, CC BY-SA 3.0, via Wikimedia Commons

Computed Tomography (CT)

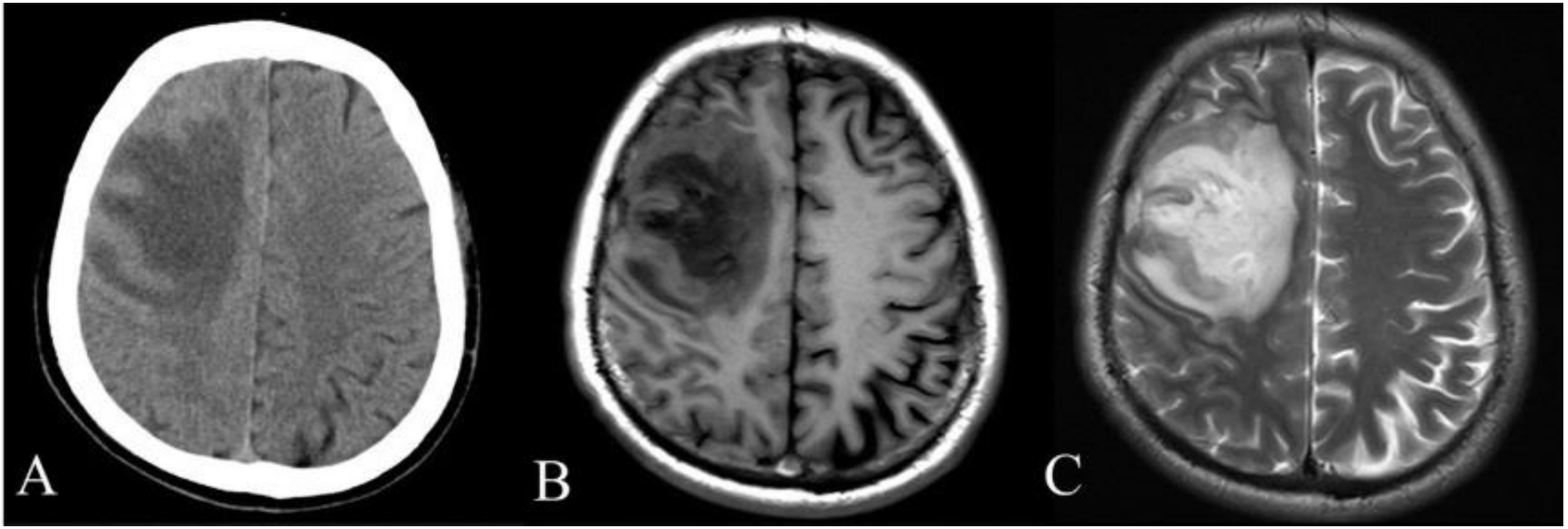
- X-ray tube rotating around the body
- Reconstruction: stack of 2D slices
- Intensity: Hounsfield Units (HU)

Tissue	HU
Air	-1000
Fat	-120 to -90
Water	0
Bone (cortical)	500 to 1900



Magnetic Resonance Imaging (MRI)

- Magnetic field, gradient, and radiofrequency pulse (non-ionizing!)
- fMRI, MR Spectroscopy, MR angiography, …



Wei-yuan Huang, Gang Wu, Feng Chen, Meng-meng Li and Jian-jun Li, CC BY 4.0, via Wikimedia Commons

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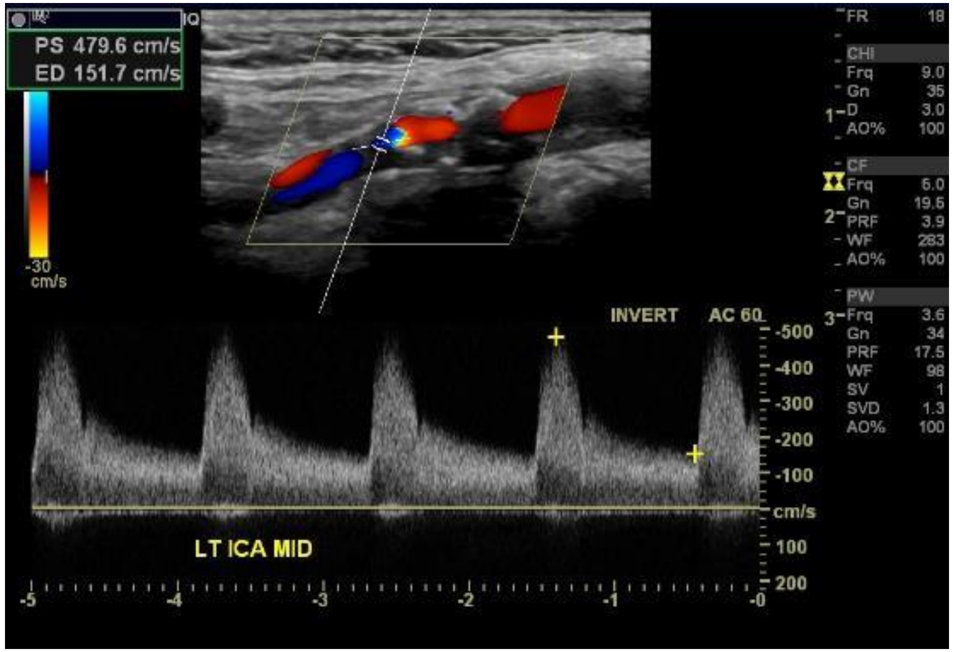
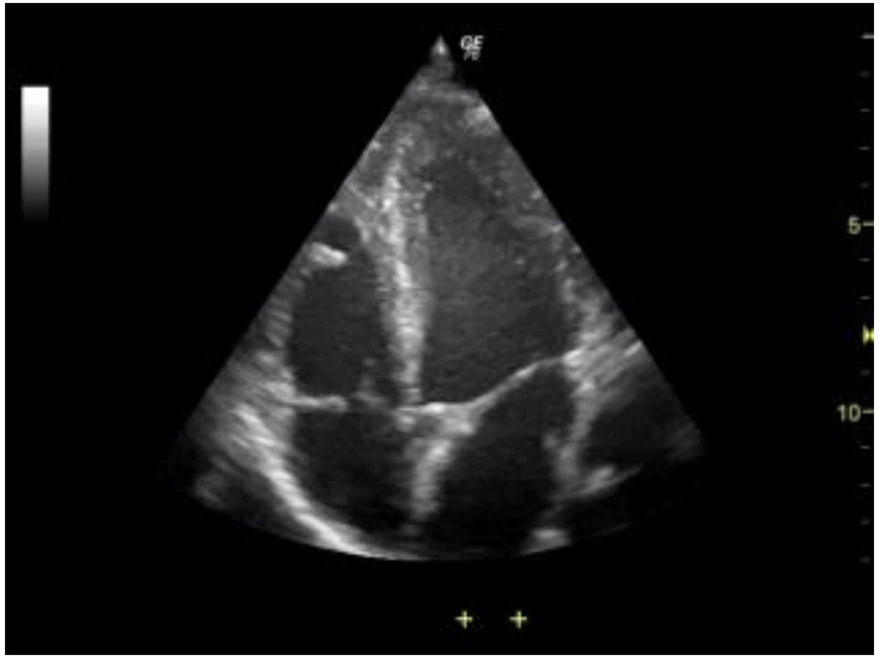
Medical Ultrasound

- High frequency sound waves (inaudible)
- Pulses of ultrasound sent through tissue and echo caught
- 2D, time-varying, 3D, Doppler (blood flow), ...



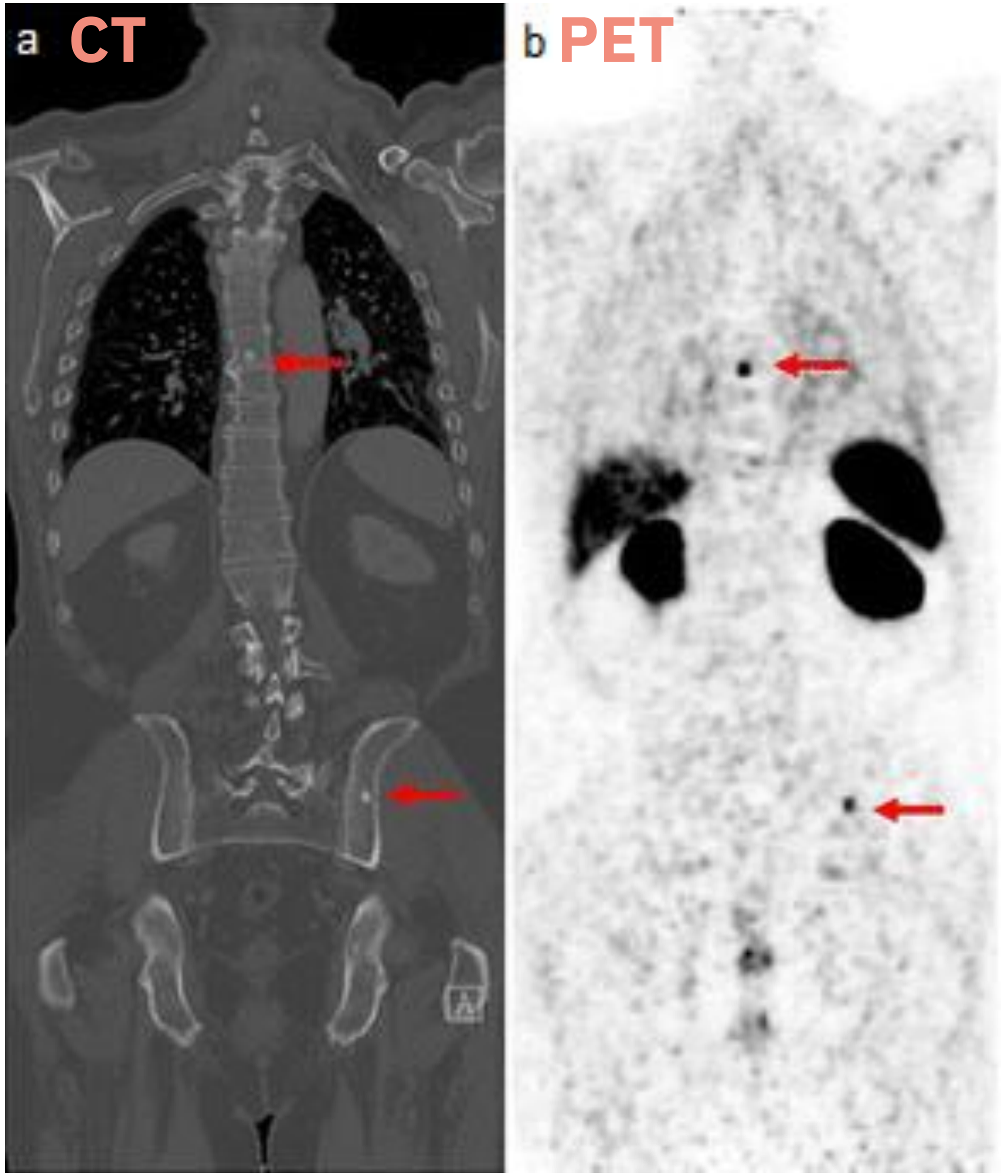
Mme Mim, CC BY-SA 3.0, via Wikimedia Commons



Fruehaufsteher2, CC BY-SA 3.0, via Wikimedia Commons

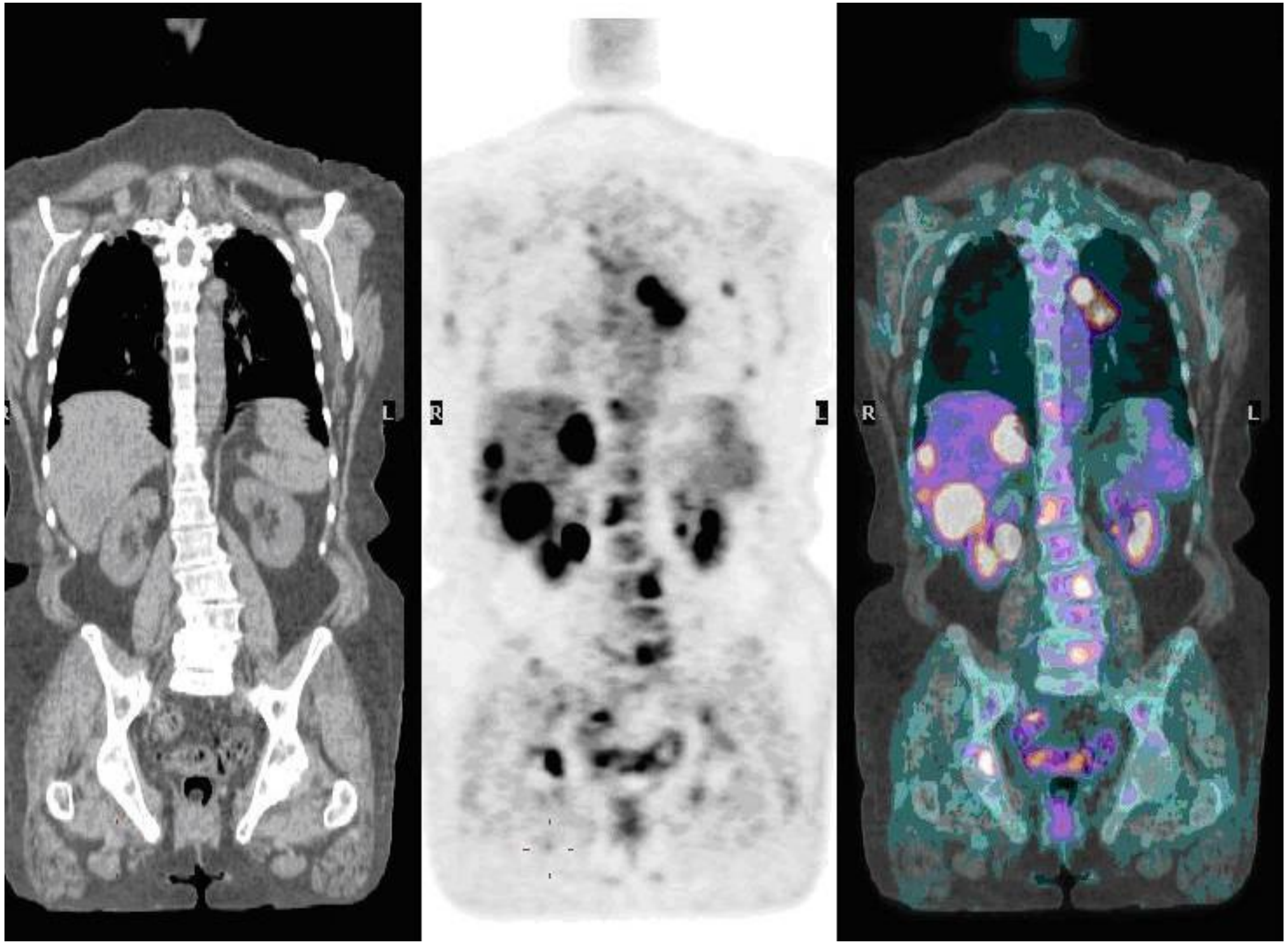
Nuclear Imaging: PET/SPECT

- Patient generates radiation through radioactive tracer injection
- Scintigraphy (2D), Single-Photon Emission Computed Tomography SPECT (3D), Positron Emission Tomography (PET) (3D)
- Functional imaging: metabolic processes, blood flow, regional chemical composition, absorption…



Hybrid: PET/CT, PET/MR, SPECT/CT, ...

- Integrated hardware to acquire multiple imaging modalities



Organism

Whole-Body MRI, CT, PET

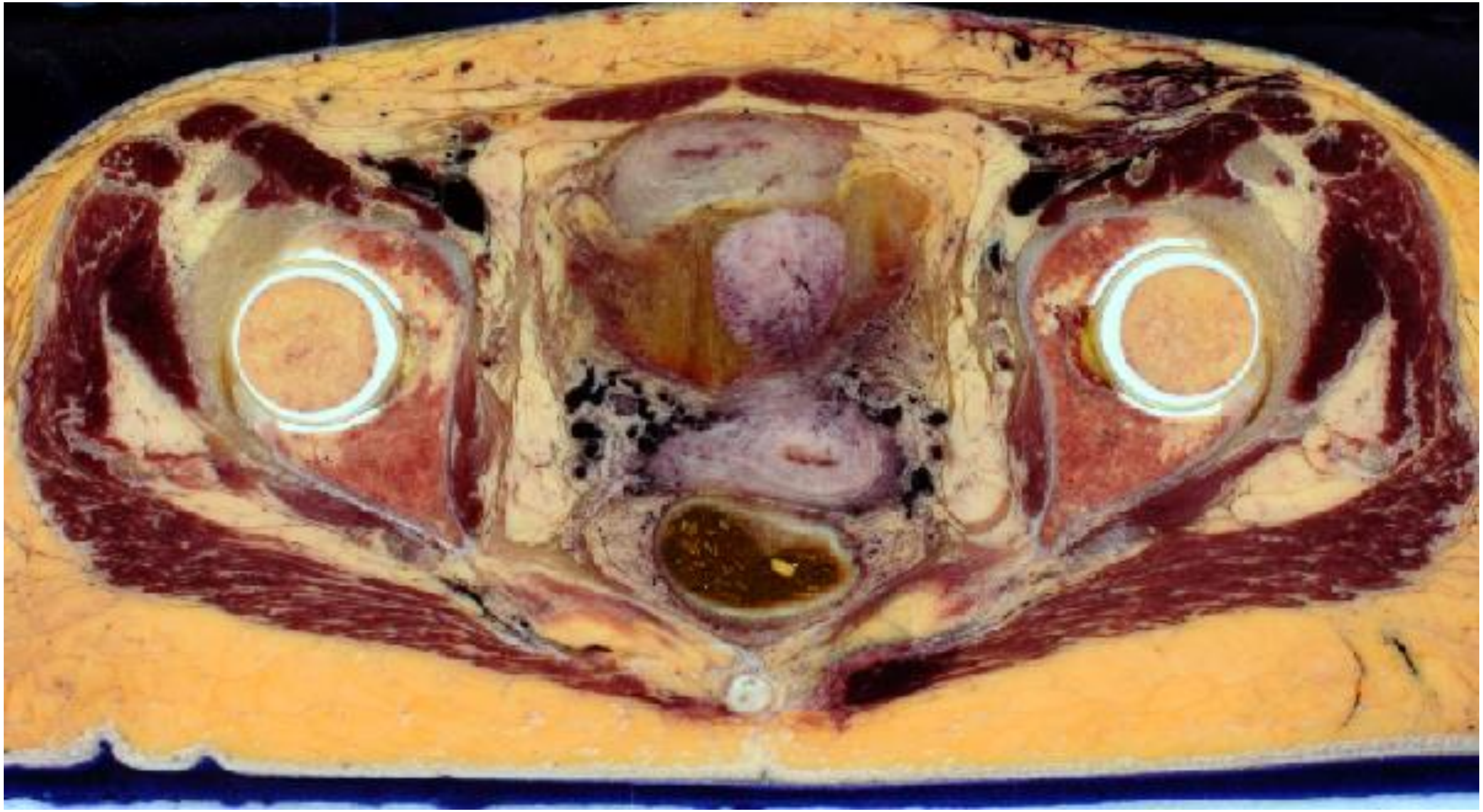
- Not very commonly done
- Indications: trauma or metastases detection

Cryosection

- Very large scale histology
- Frozen embedded sections
- No microscopes needed!

This image was created by a US government project in the National Library of Medicine, a branch of NIH. The original image was modified by user:Looie496, Public domain, via Wikimedia Commons

Visible Korean Human female

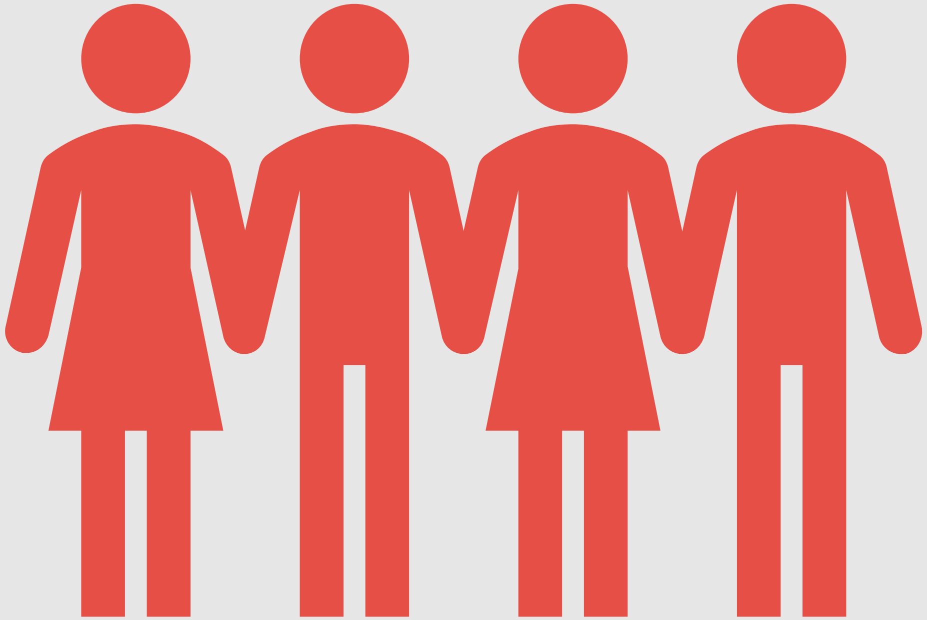


Resolution: 5616 x 2300
0.2 mm between every slice

Electronic Health Records (EHR)

- Collection of patient health information
- For example: medical history, medication, test results, allergies, radiology images, personal statistics, billing information

Population



Screening

- Discovering disease among population without symptoms
- Systematic testing of individuals at risk to benefit from further investigation or preventative measures
- Examples: cholesterol measurements (cardiovascular disease risk), mammography (breast cancer)

Cohort Studies

- Medical research studying a large number of subjects over time (longitudinal)
- Cohort: a group of people who share a defining characteristic
- Examples: cohort people born in Rotterdam in 1980-1985, cohort of gynecological cancer patients, ...
- Data: self-reported interviews, medical examinations, imaging

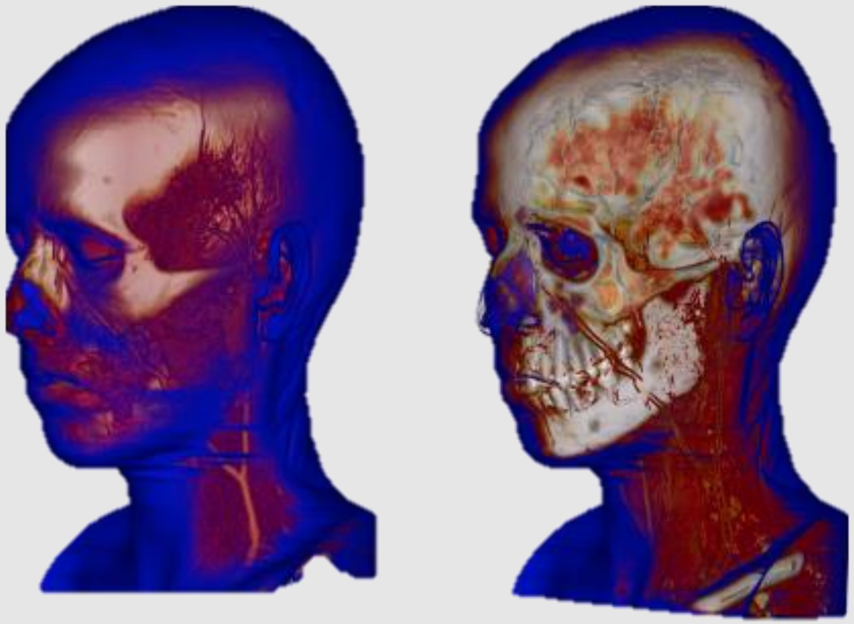
Preim, Bernhard, Paul Klemm, Helwig Hauser, Katrin Hegenscheid, Steffen Oeltze, Klaus Toennies, and Henry Völzke. "Visual analytics of image-centric cohort studies in epidemiology." In *Visualization in medicine and life sciences III*, pp. 221-248. Springer, Cham, 2016.

Public Health

- Studying the population in order to prevent disease
- Aim: encouraging behavior and policy chance, limit acute disease outbreak, reduce chronic diseases and injuries
- Data over time and locations (spatio-temporal)

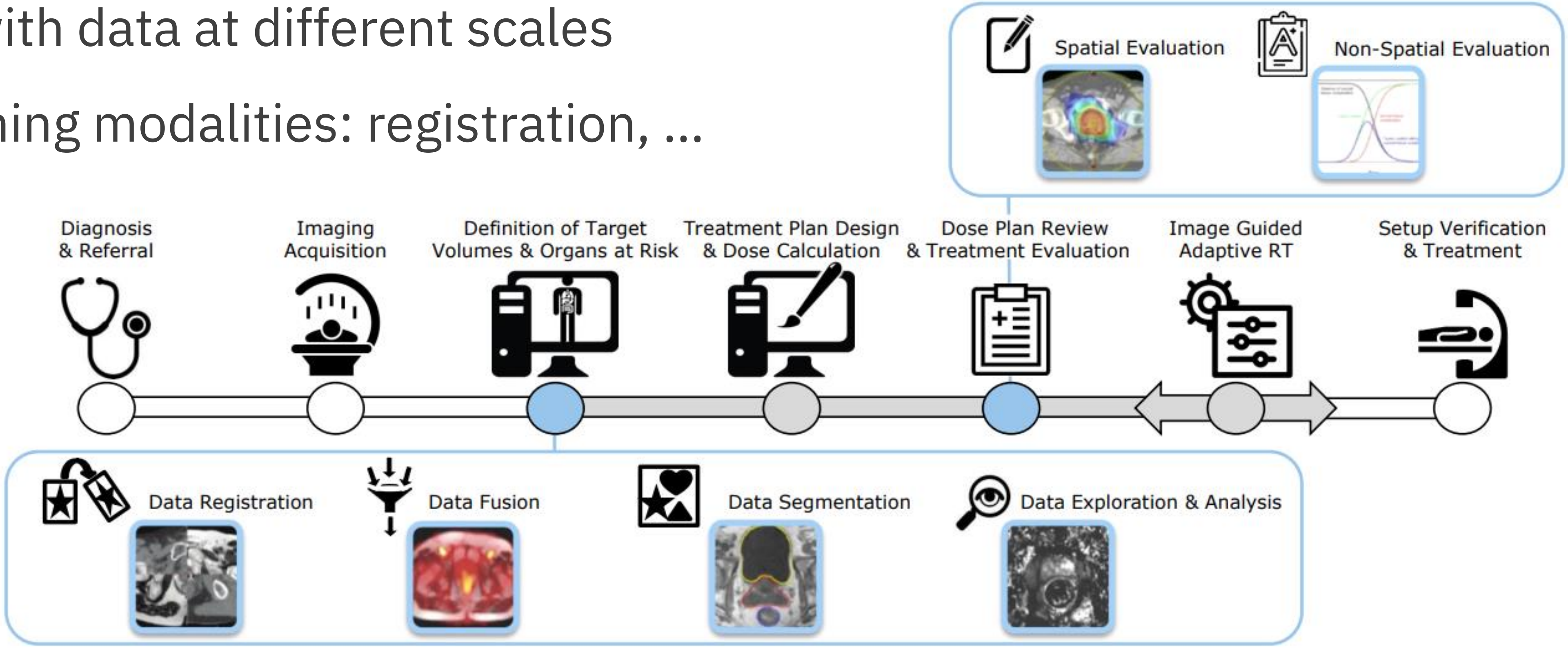
Bernhard Preim and Kai Lawonn. "A survey of visual analytics for public health."
In *Computer Graphics Forum*, vol. 39, no. 1, pp. 543-580. 2020.

Visualization Approaches for Spatial Data



Spatial Data Visualization Challenges in Medicine

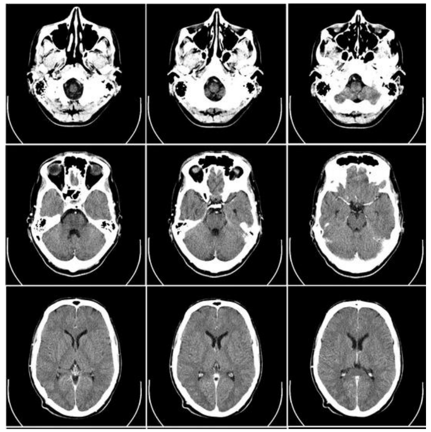
- Artifacts, noise, uncertainty
- Integration with data at different scales
- When combining modalities: registration, …
- Occlusions



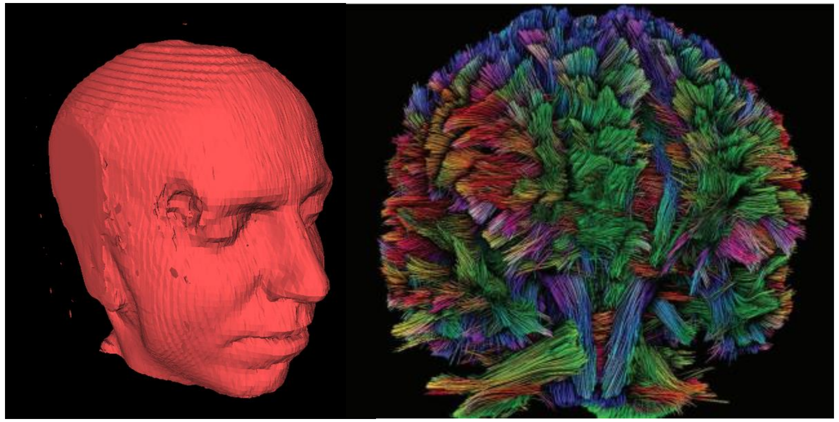
The steps of the workflow of radiotherapy planning [Raidou et al. 2019]

Spatial Data Visualization Approaches

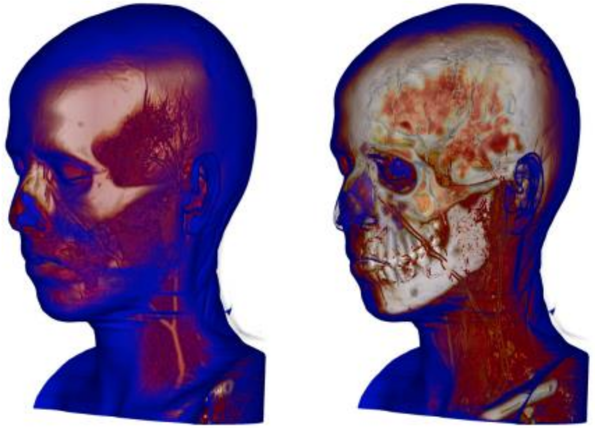
Slices



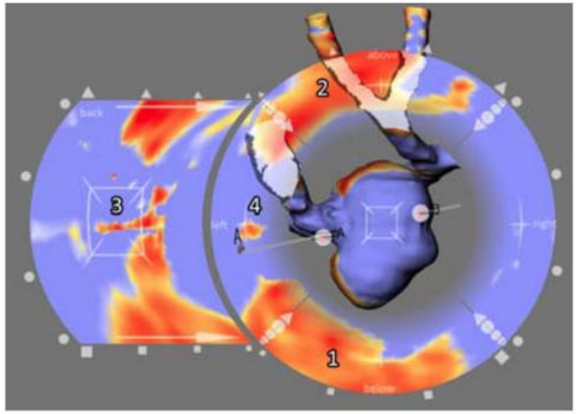
Surface,
Spatial Features

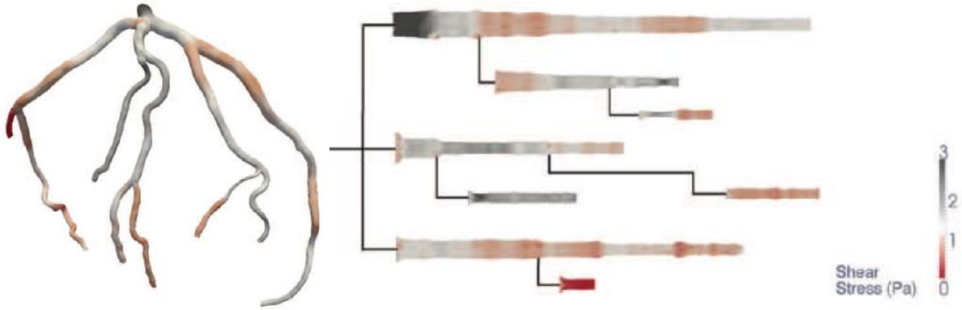


Volume Rendering

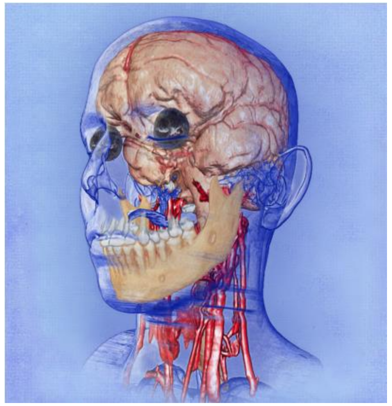


Reformation, Abstraction





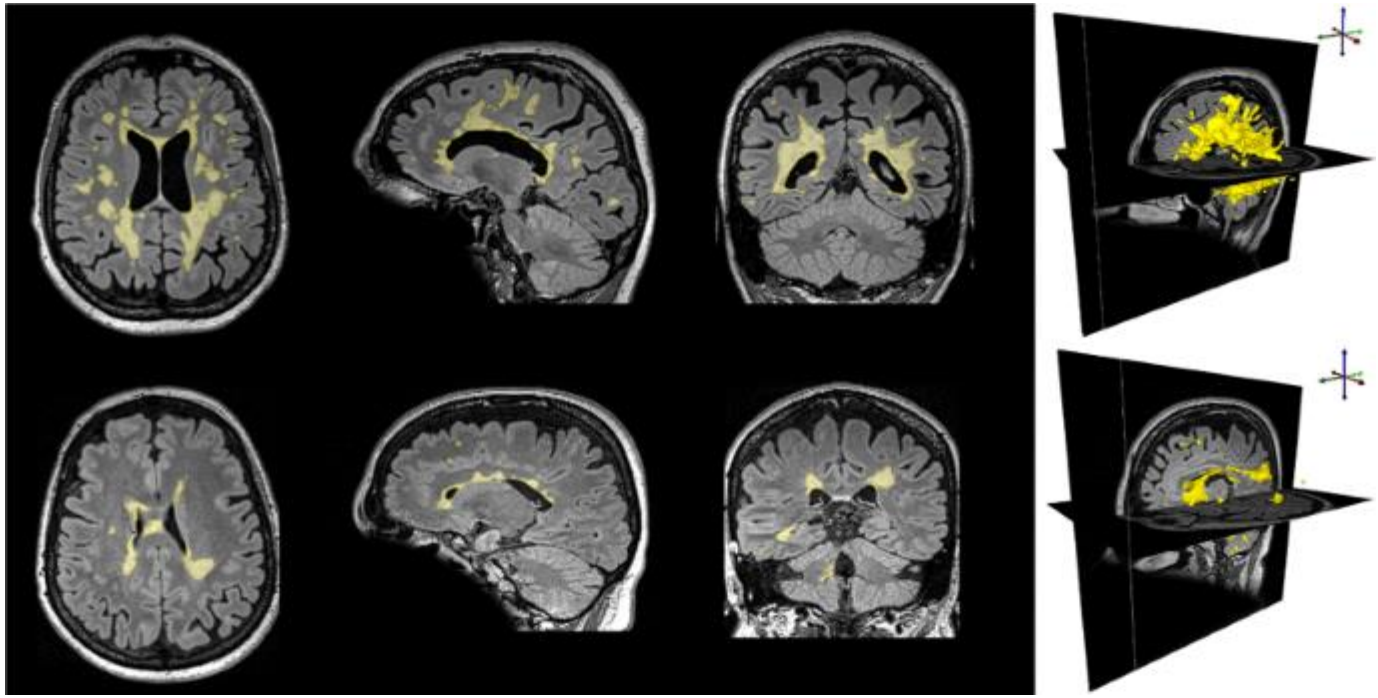
Illustrative

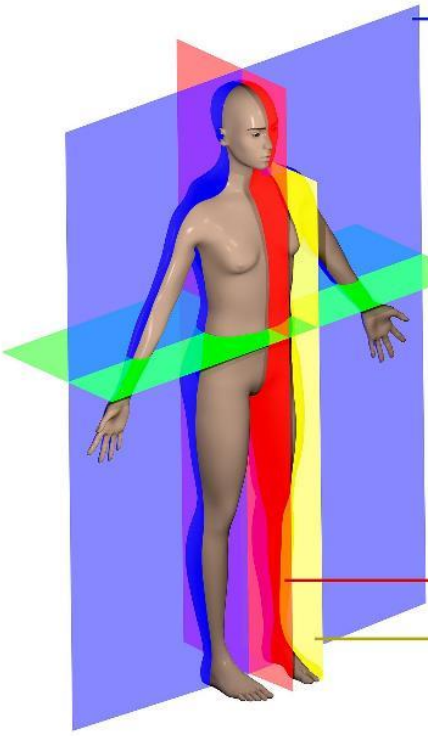


Slices

- Baseline visualization

Axial Sagittal Coronal

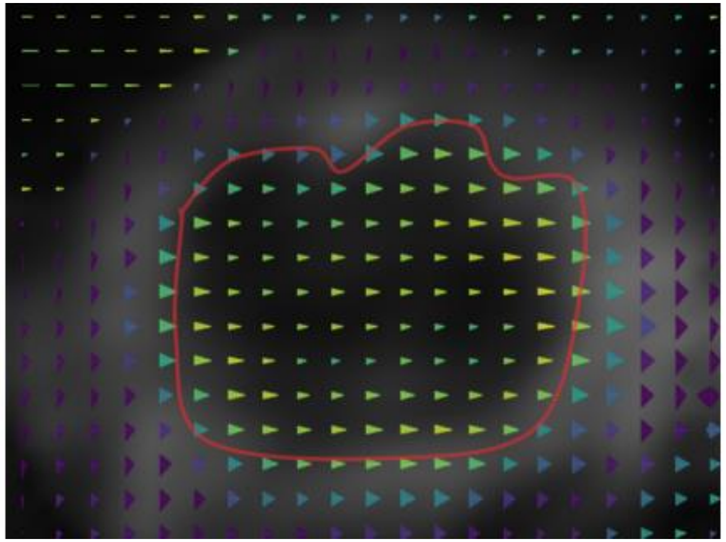


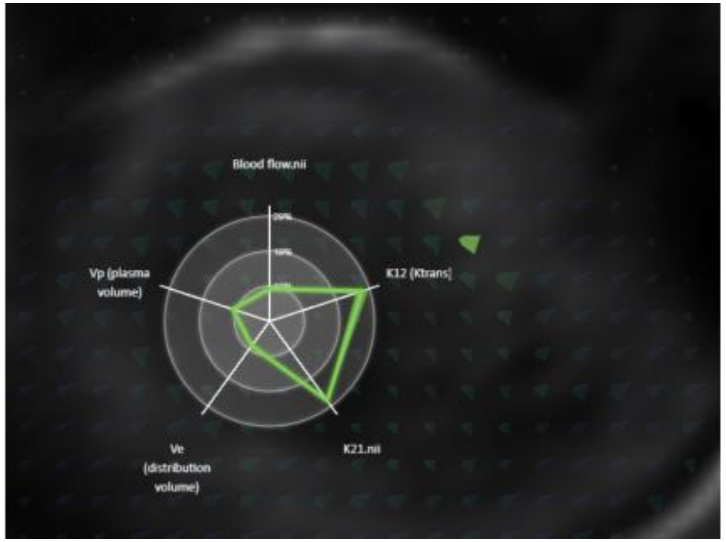


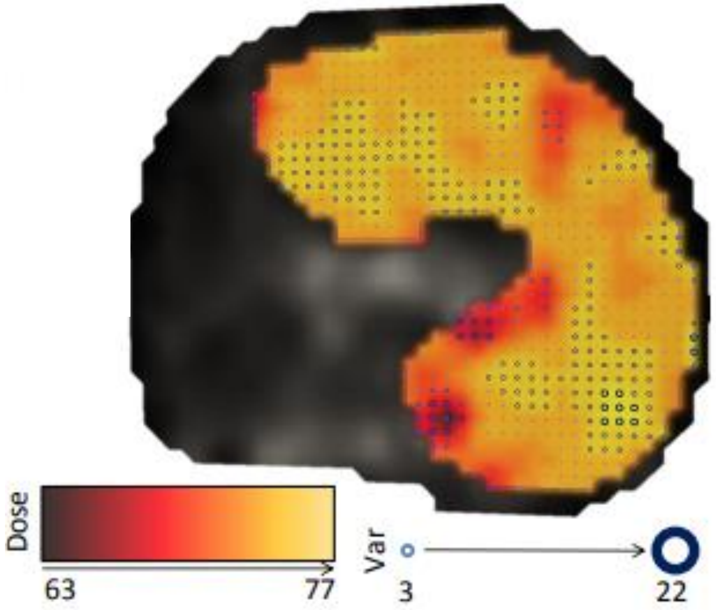
[Lesjak et al., 2018]

Slices

- Additional data: colormaps, glyphs
- Problem with occlusions – linked views





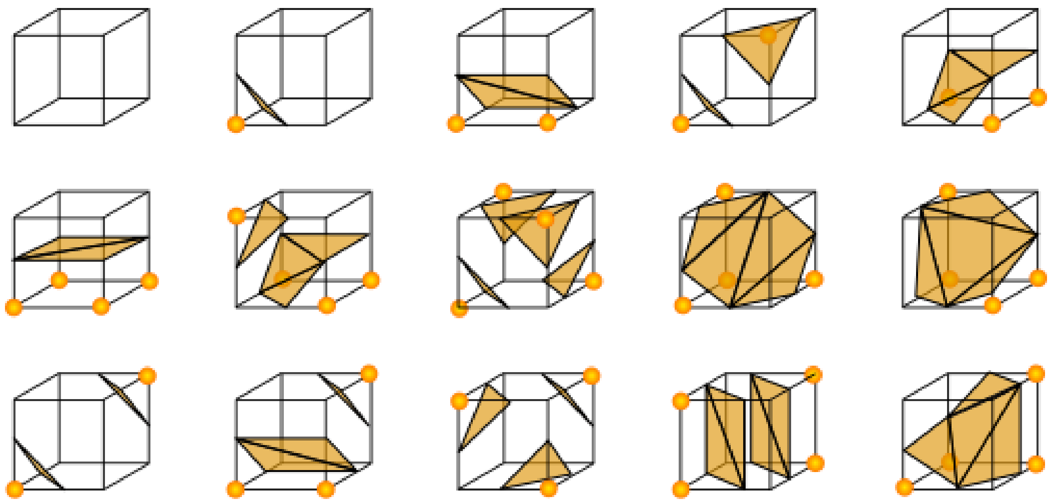


[Mörth et al., 2020]

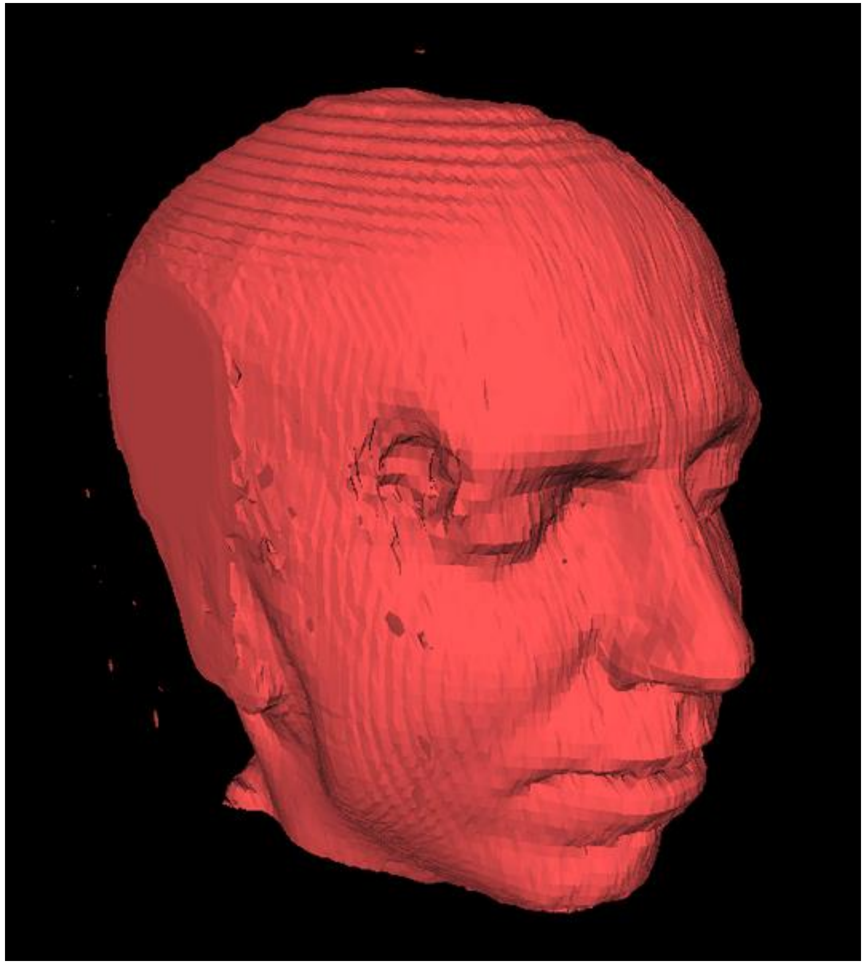
[Raidou et al., 2016]

Surface – Construction

- Result of thresholding or segmentation
- Marching cubes, Lorensen & Cline 1987



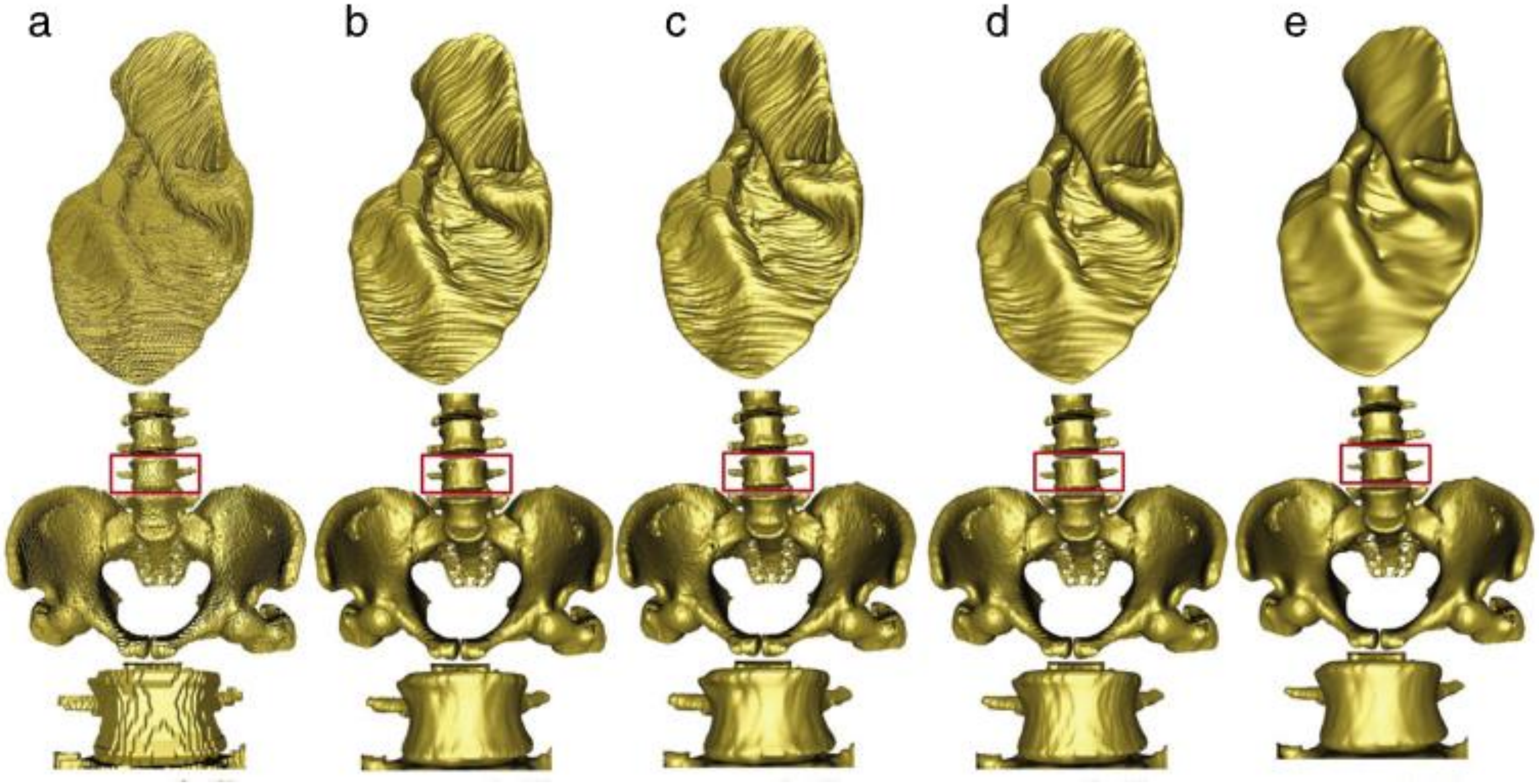
Marching cubes for iso-surface generation
Jmtrivial via Wikimedia Commons



Dake via Wikimedia Commons

Surface – Smoothing

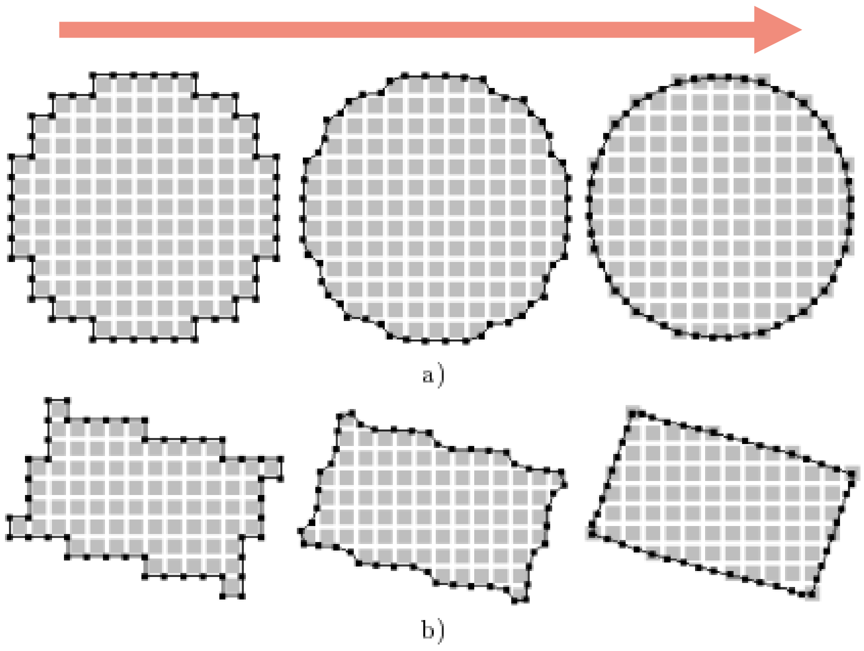
- Basic low pass filters lead to shrinkage -> Imprecision



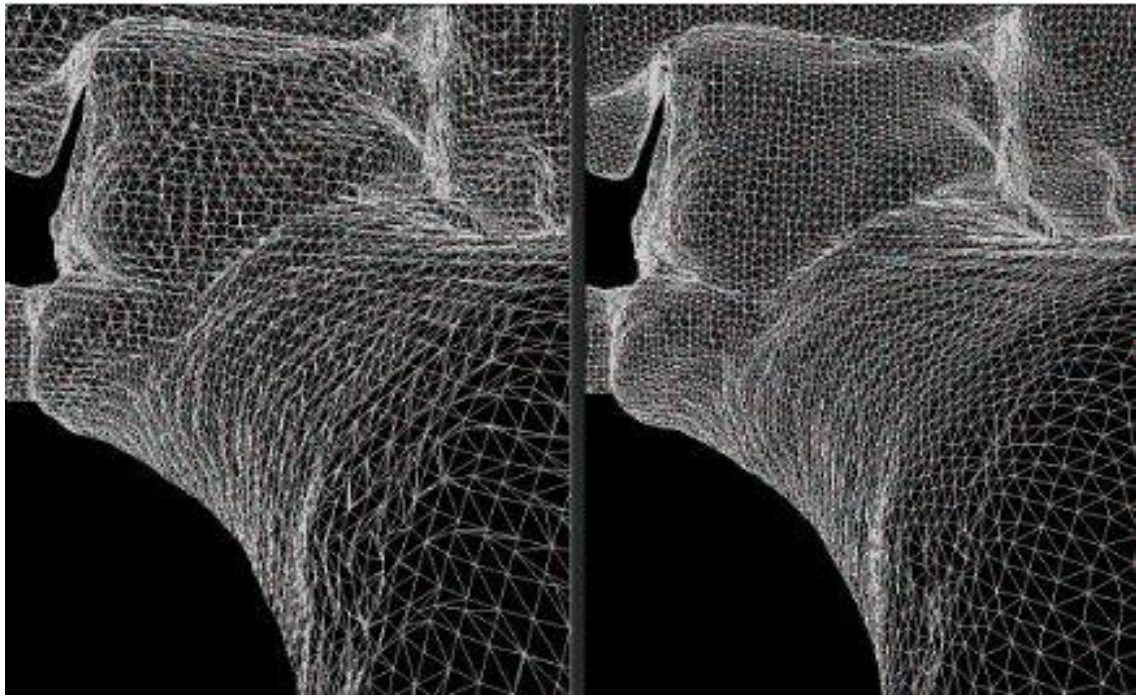
Comparison of multiple smoothing algorithms applied to MC (a) [Wei et al., 2015]

Surface – Construction/Smoothing

- Constrained elastic surface nets, Gibson 1998
- Start with binary mask border –> relaxation constrained to size of one voxel



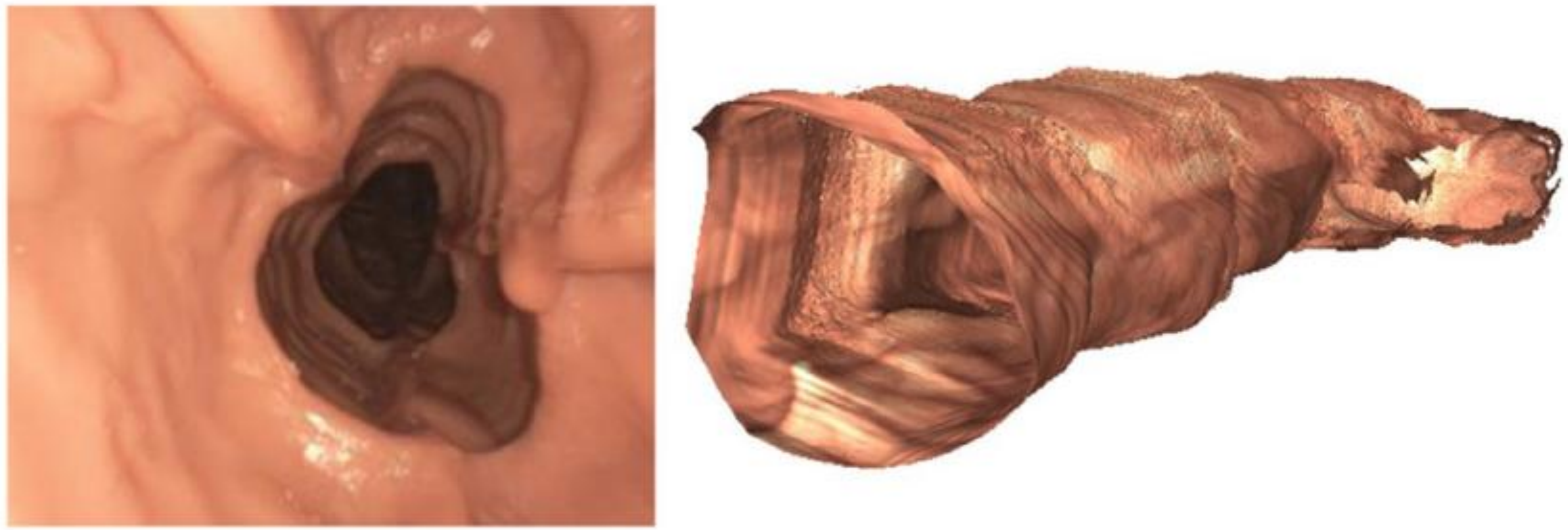
Gibson, 1998



Marching cubes vs. Surface nets
[Bruin et al., 2000]

Surface – Construction

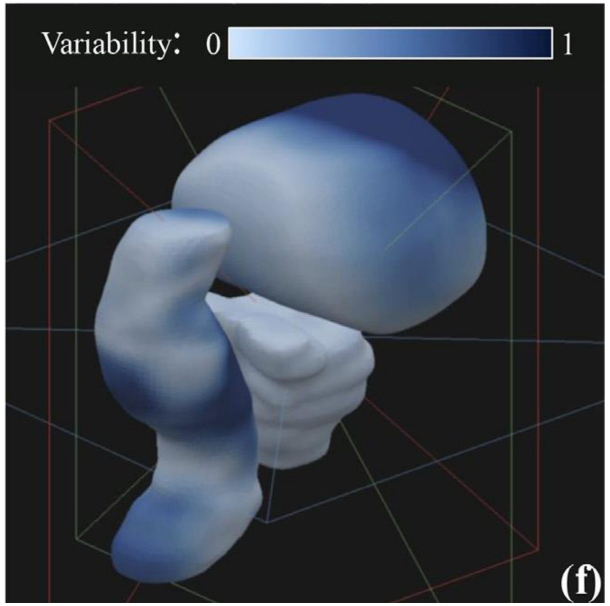
- Reconstruction from camera (e.g., endoscopy)
- Point cloud extraction + triangulation/fitting



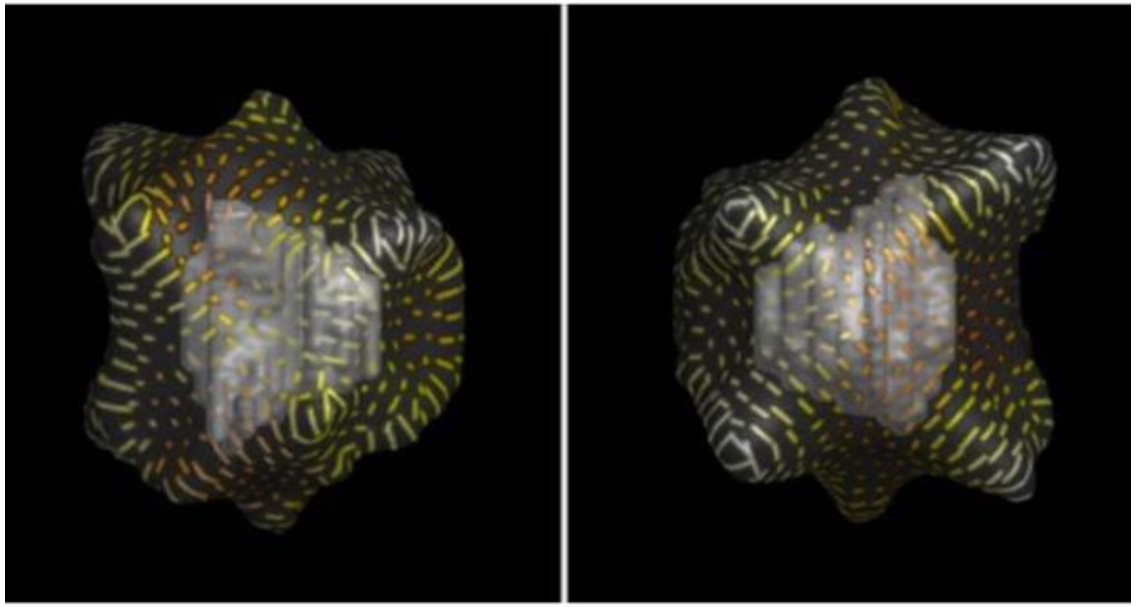
[Ma et al., 2021]

Surface – Mapping Additional Data

- Colormaps, glyphs, limited by occlusions & shading



Pelvic organs – shape variability

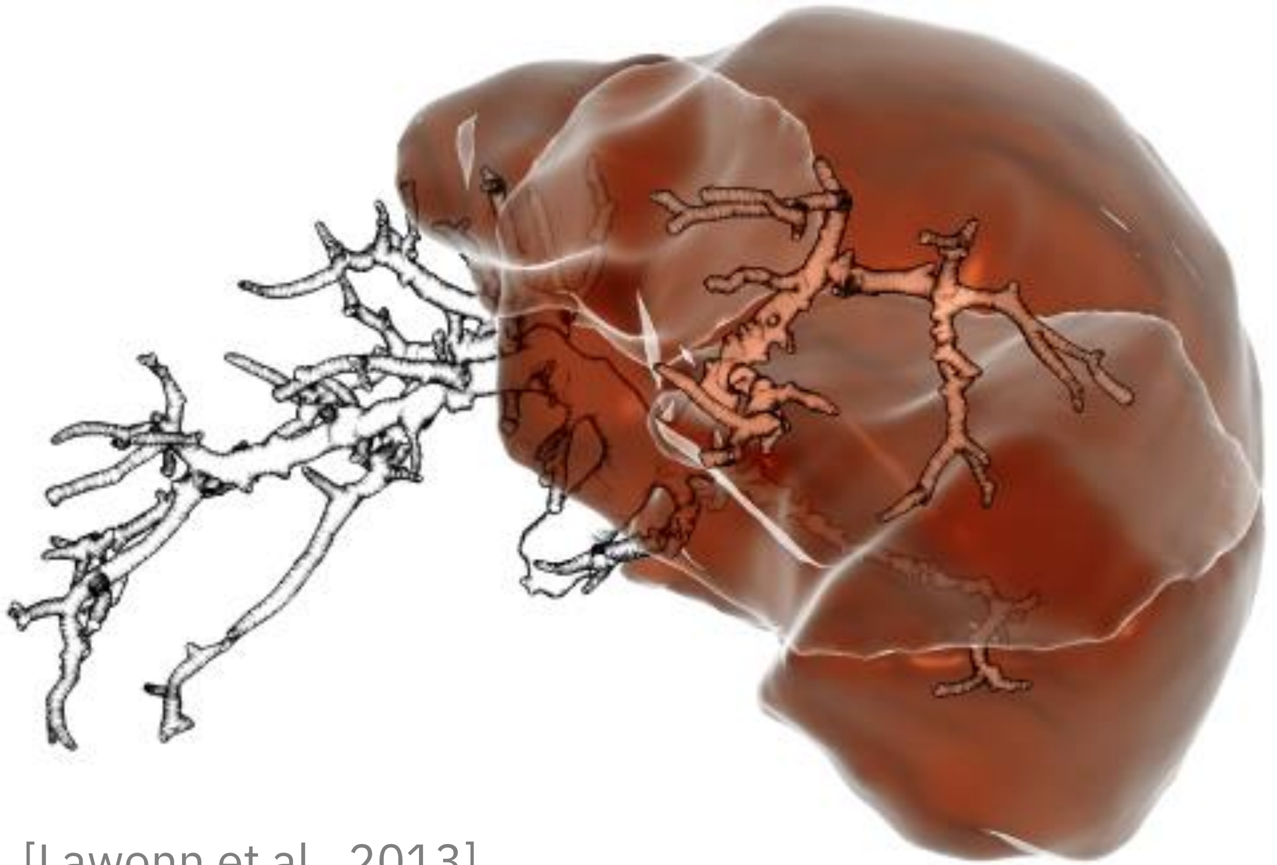


Tumor + iso-surface of radiation dose with curvature-oriented glyphs
[Iterrante et al., 1997]

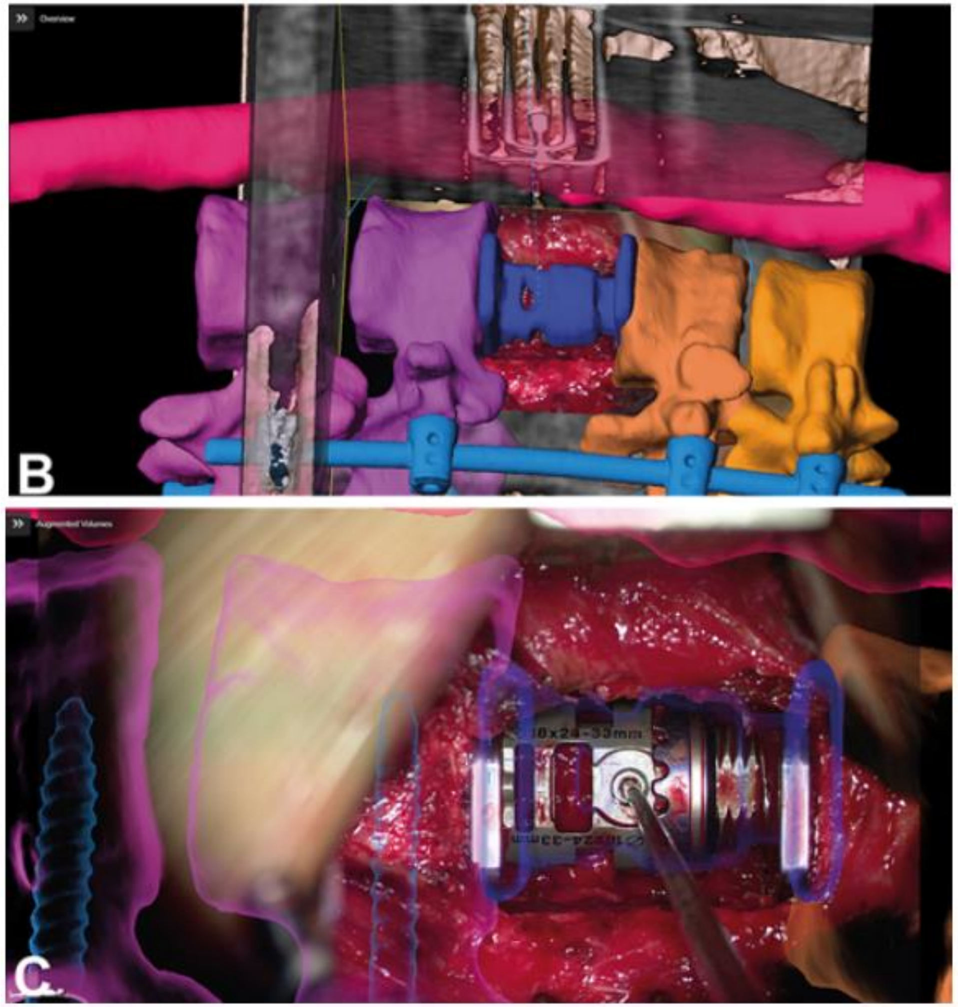
Comparison of 2 faces

Illustrative Approaches

- Hatching, stippling, silhouettes



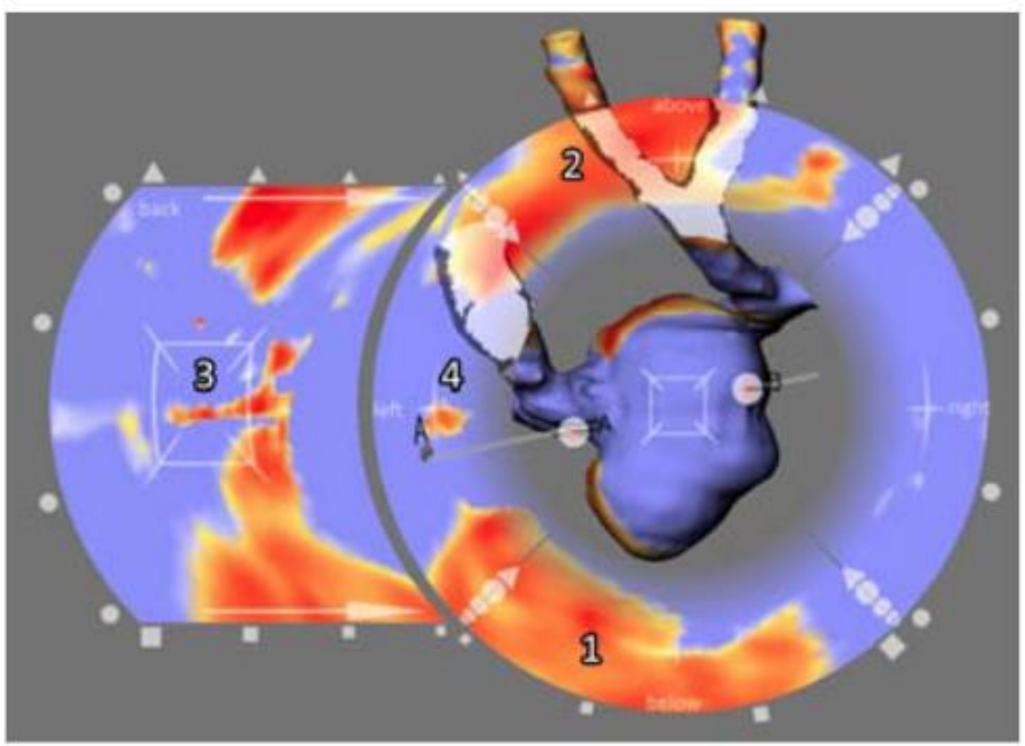
[Lawonn et al., 2013]



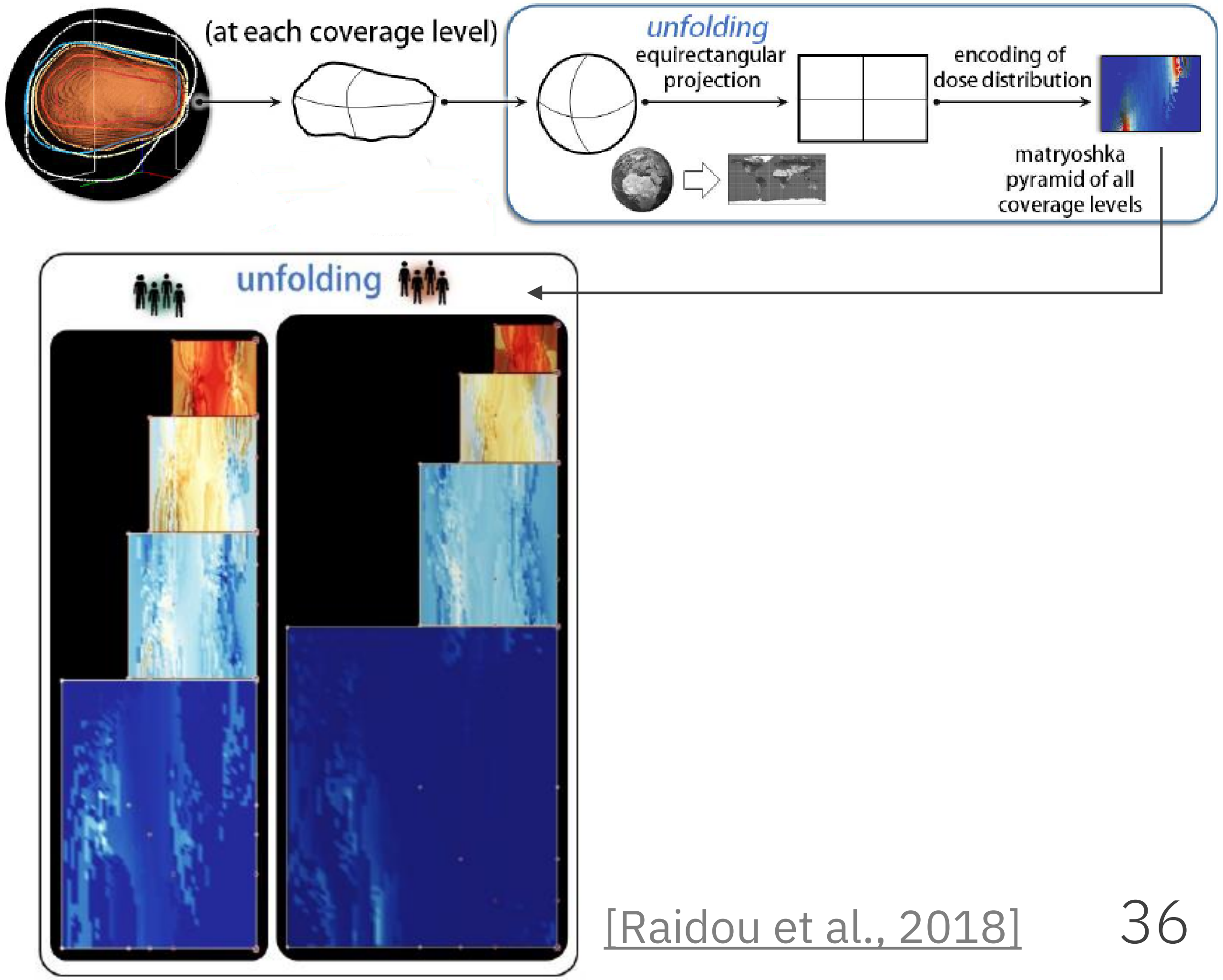
[Carl et al., 2019]

Projections and Reformations

- Flattening to deal with occlusion, better comparison



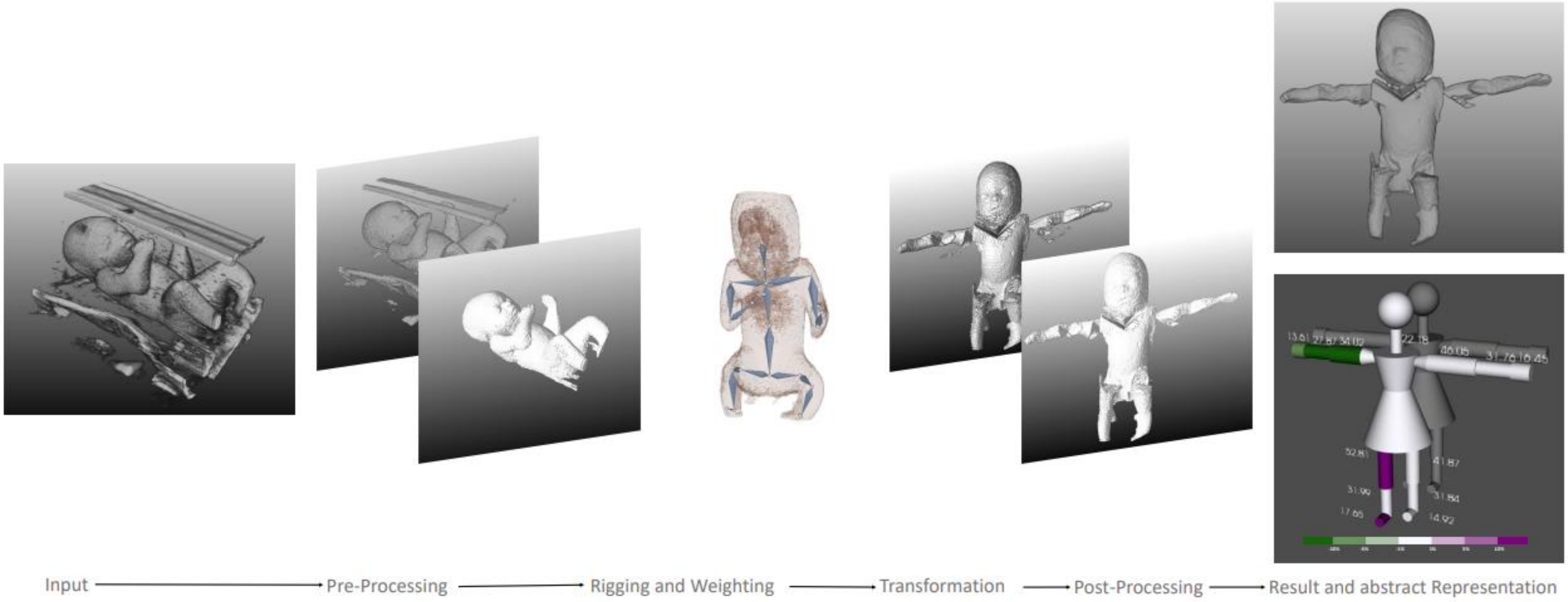
[Neugebauer et al., 2009]



[Raidou et al., 2018]

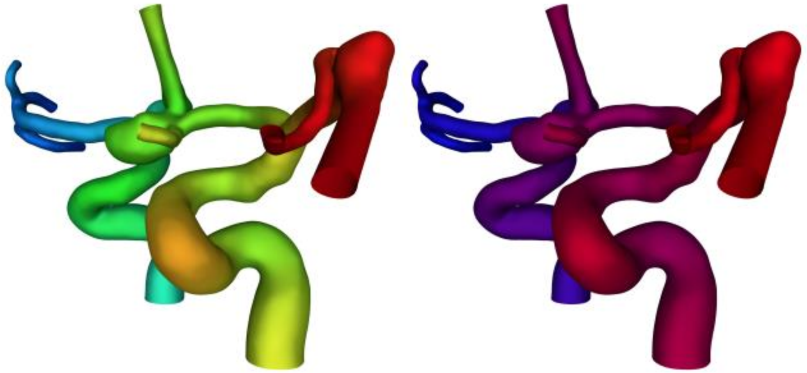
Projections and Reformations

- Pose standardization



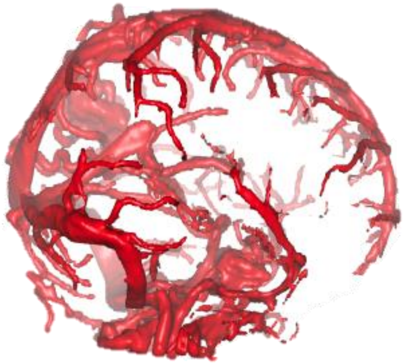
[Mörth et al., 2019]

Vasculature – Depth Perception



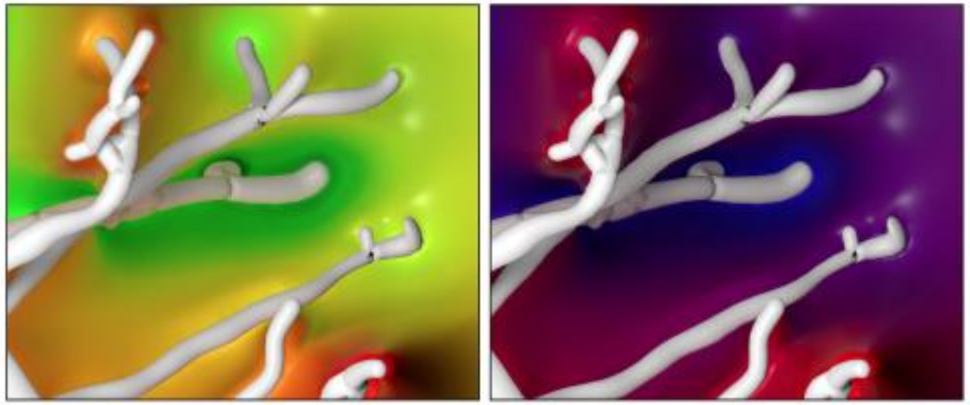
Chromadepth Psedo-Chromadepth

[Behrendt et al., 2017]



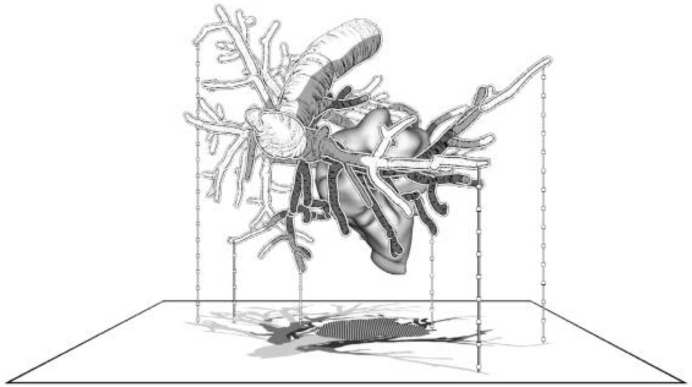
Fog

[Titov, 2020]



Void space surfaces

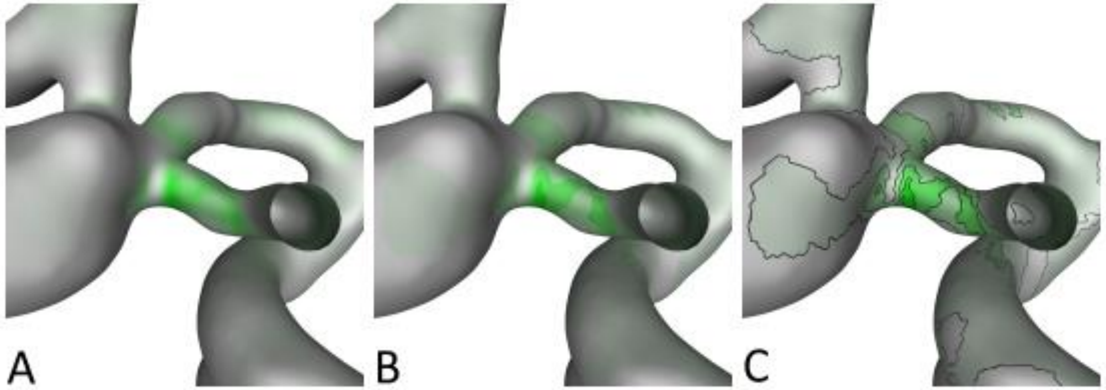
[Kreiser et al., 2021]



Hatching, outlines, shadows

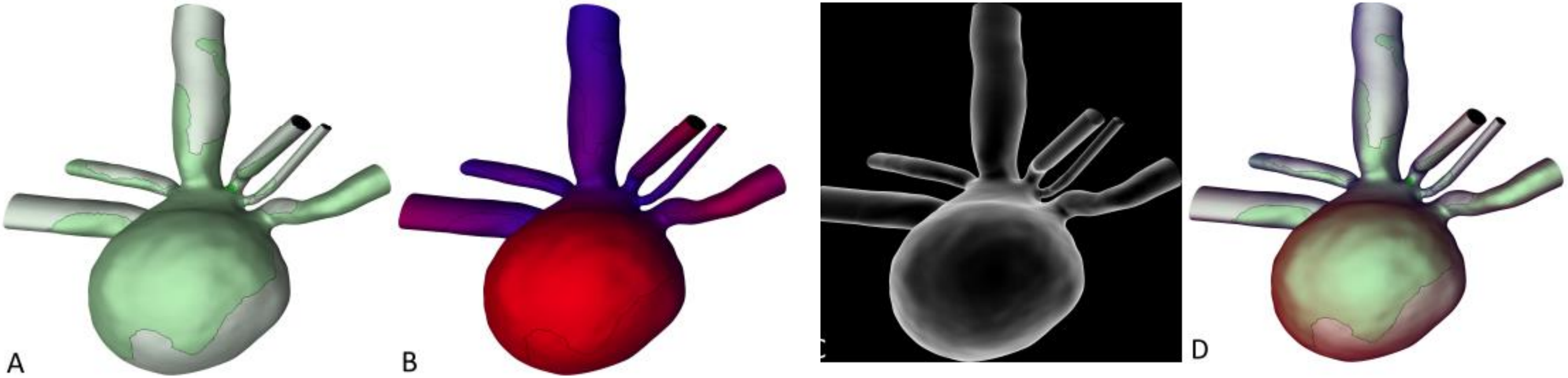
[Lawonn et al., 2015]

Vasculature – Additional Data



Wall shear stress on a vessel

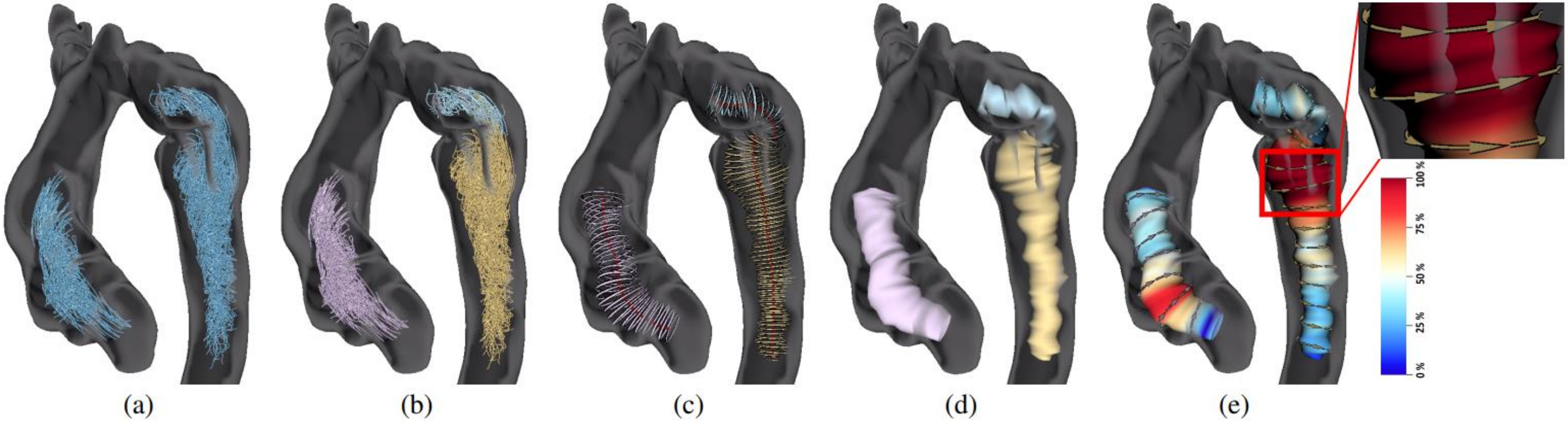
[Behrendt et al., 2017]



Composition (d) of stress & distance mappings (a, b) using a mask based on Fresnel reflection effect (c)

Vasculature – Blood Flow

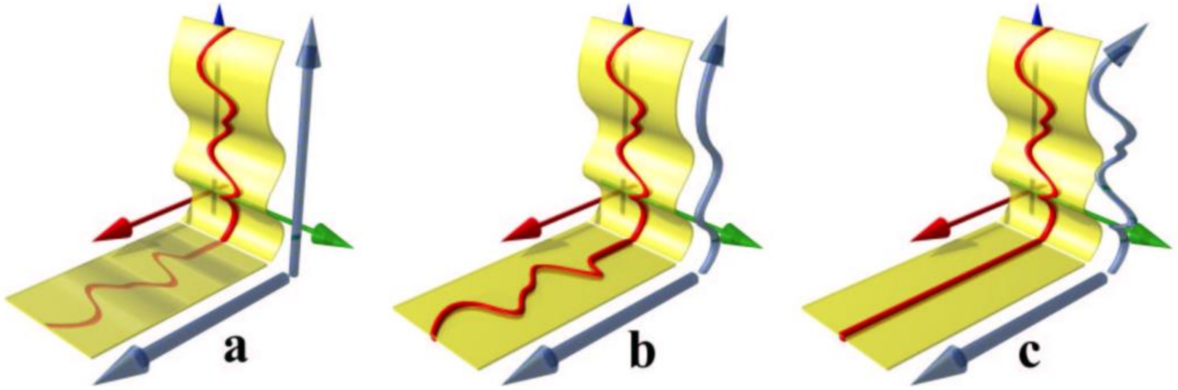
- Fluid dynamics simulations, 4D PC-MRI
- Arrows, streamlines, stream surfaces with textures or glyphs

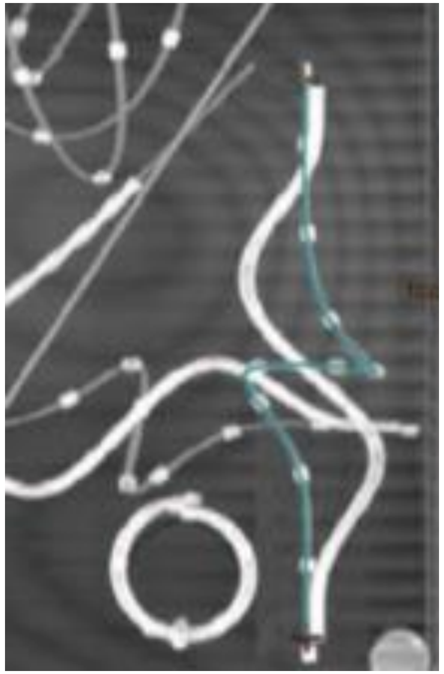


[Meuschke et al., 2016]

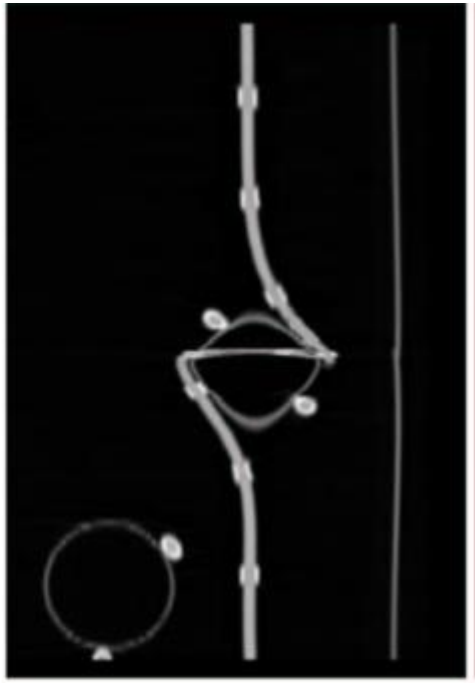
Projections and Reformations

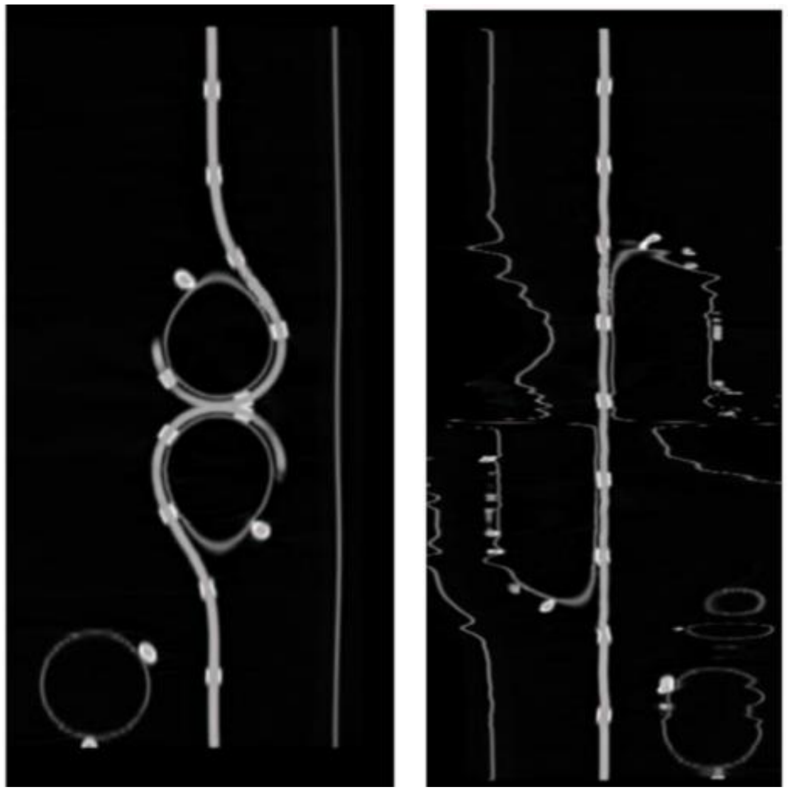
- Curved planar reformations
- Projection, stretching, straightening





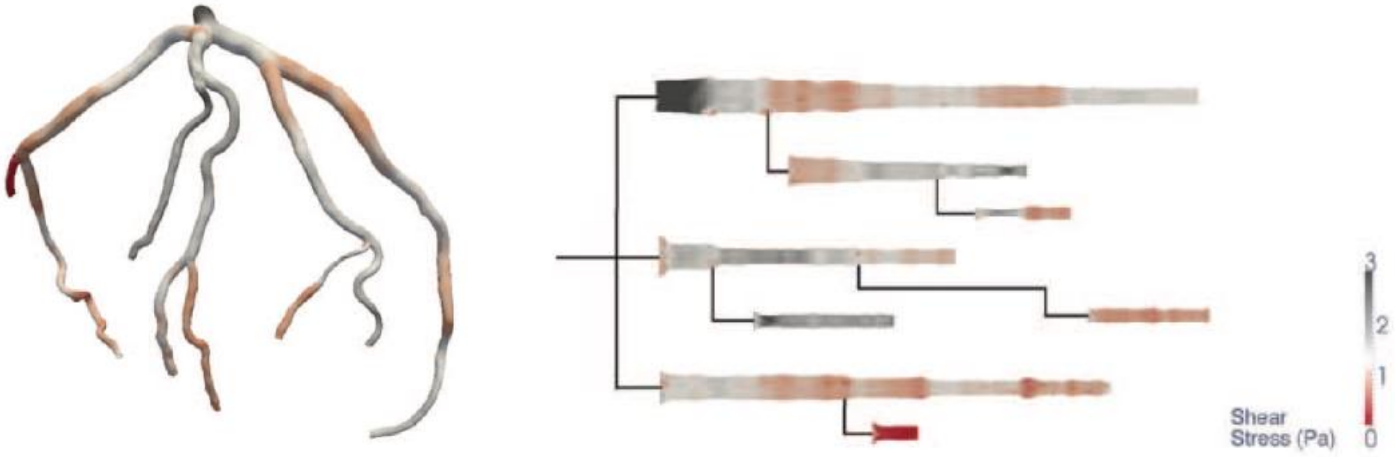
Ofirglazer at English Wikipedia,



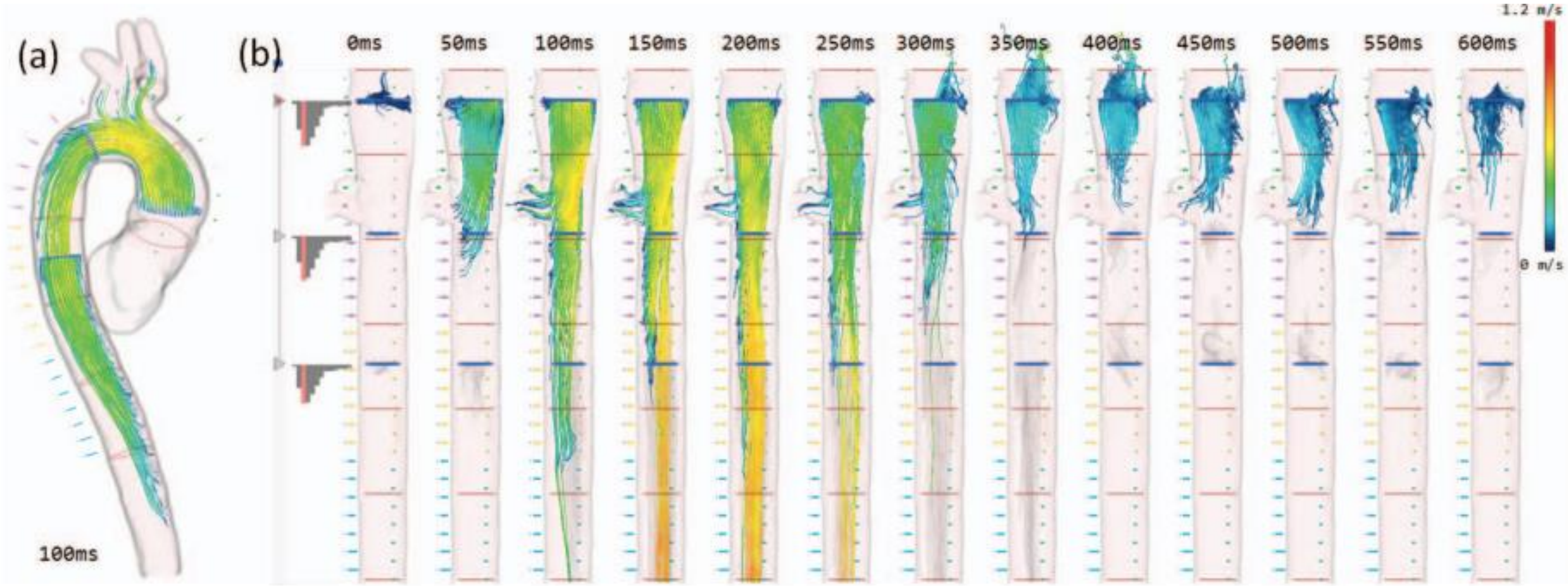


[Kanitsar et al., 2002]

Projections and Reformations



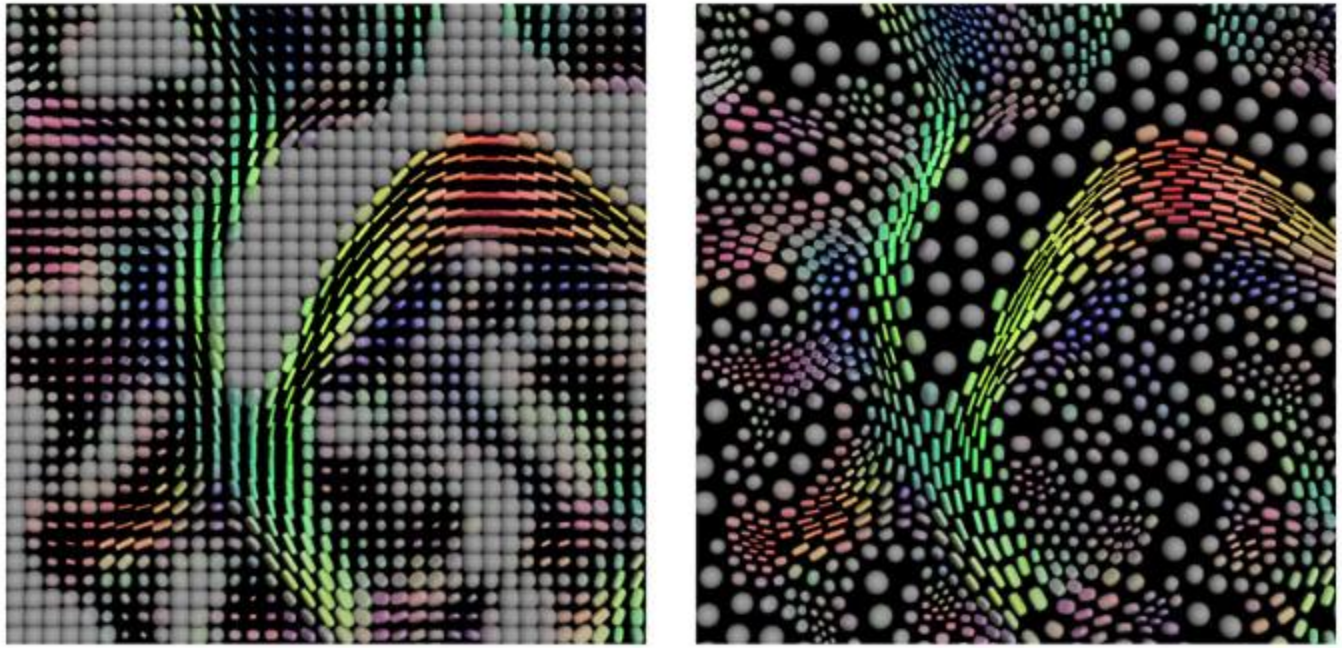
[Borkin et al., 2011]



[Angelelli & Hauser, 2011]

Brain Connectivity

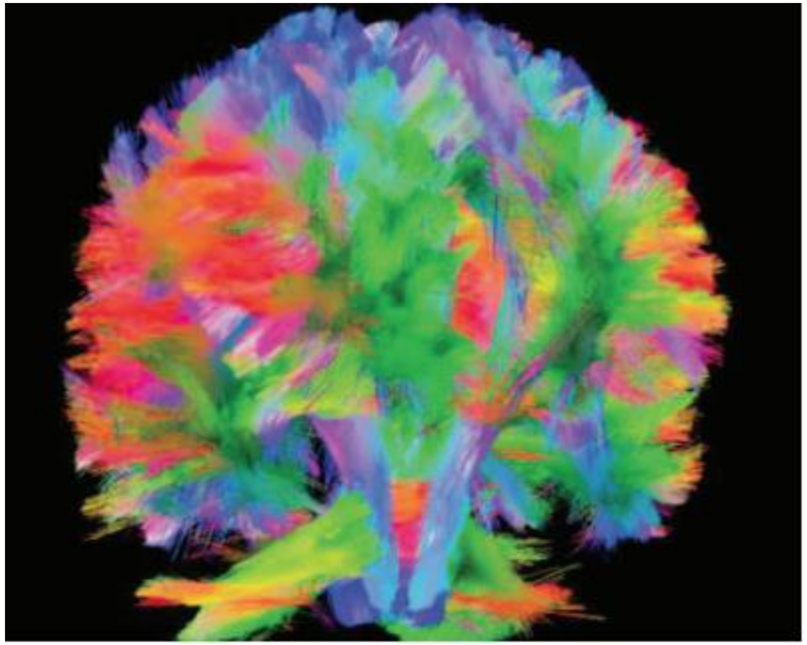
- Based on diffusion MRI
- Glyph based representations vs. fibers tracking



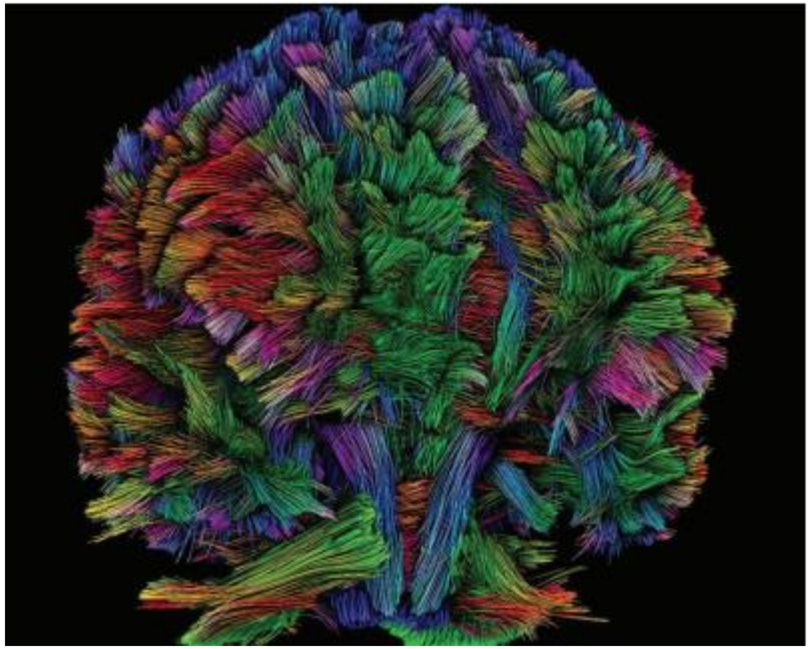
Glyph representations of diffusion tensor
[Schultz & Vilanova, 2018]

Brain Connectivity – Fiber Tracking

- Streamlines/stream tubes



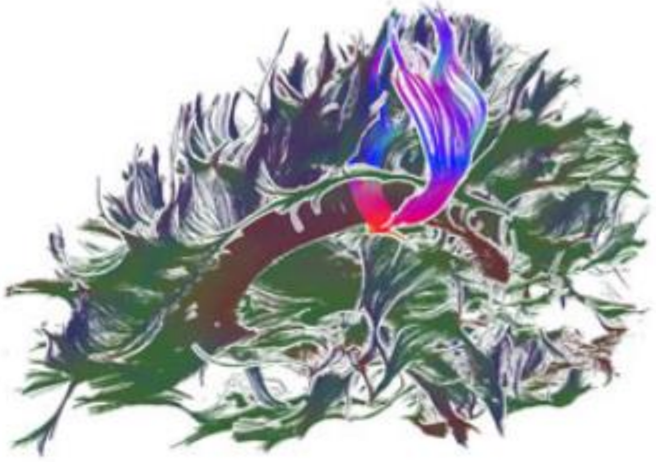
Illuminated lines



Ambient Occlusion

Line rendering colored according to local tangent direction

[Eichelbaum et al., 2013]

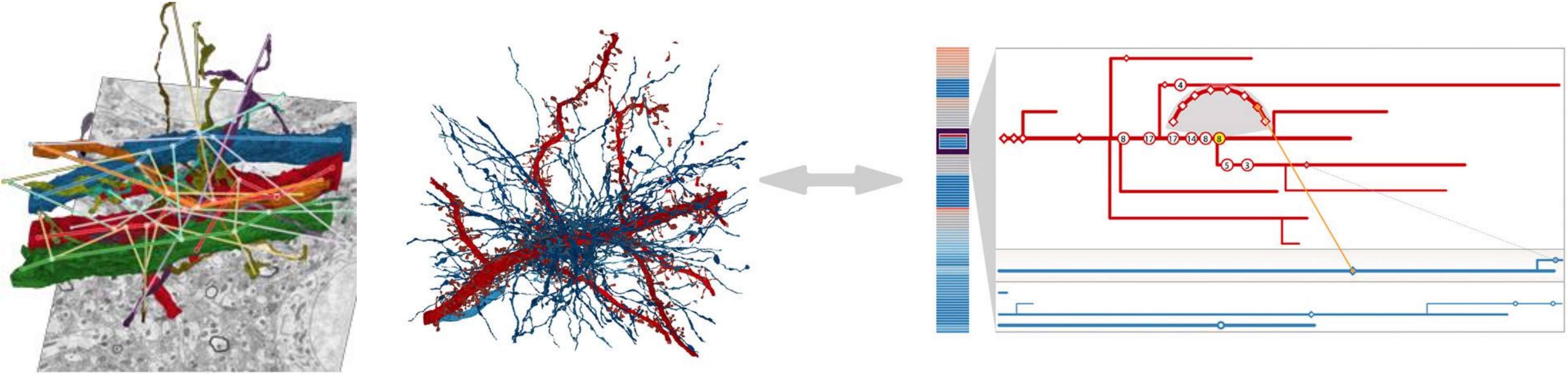


Fiber tract contraction
+ white halos

[Everts et al., 2013]

Neuronal Connectivity

- Abstraction



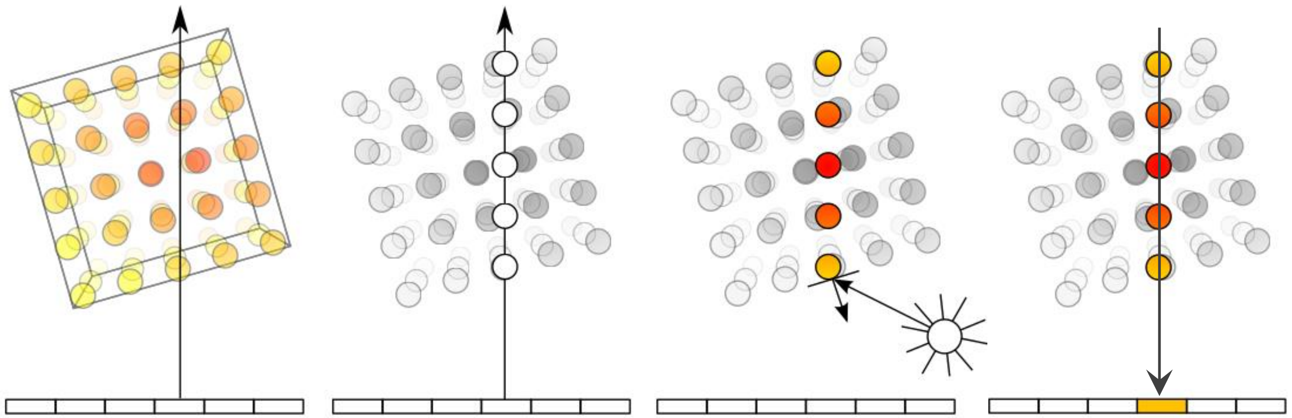
Subway map metaphor for neuronal connectivity

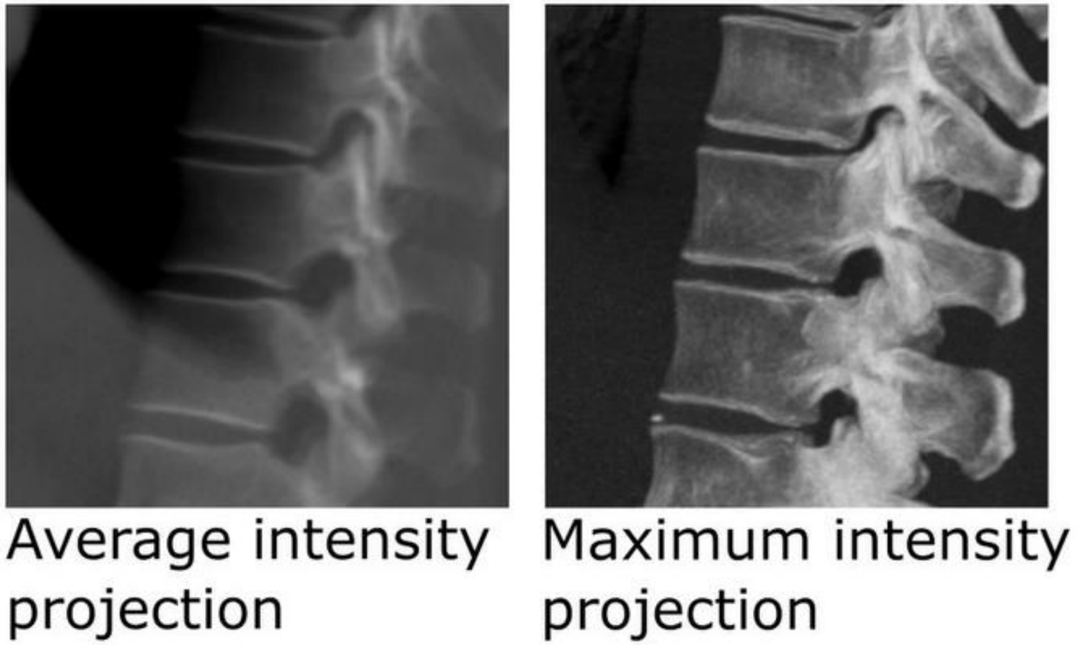
[Al-Awami et al., 2014]

Direct Volume Rendering

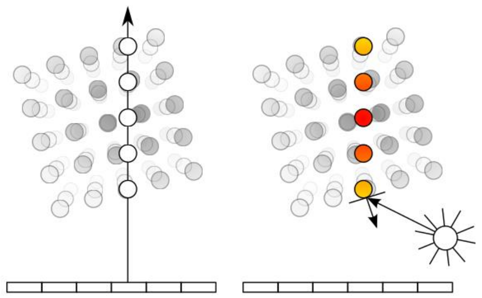
- Projecting 3D volume onto 2D screen
- Typically using ray-casting

- Basic approach – maximum/average intensity projection – not very “3D”

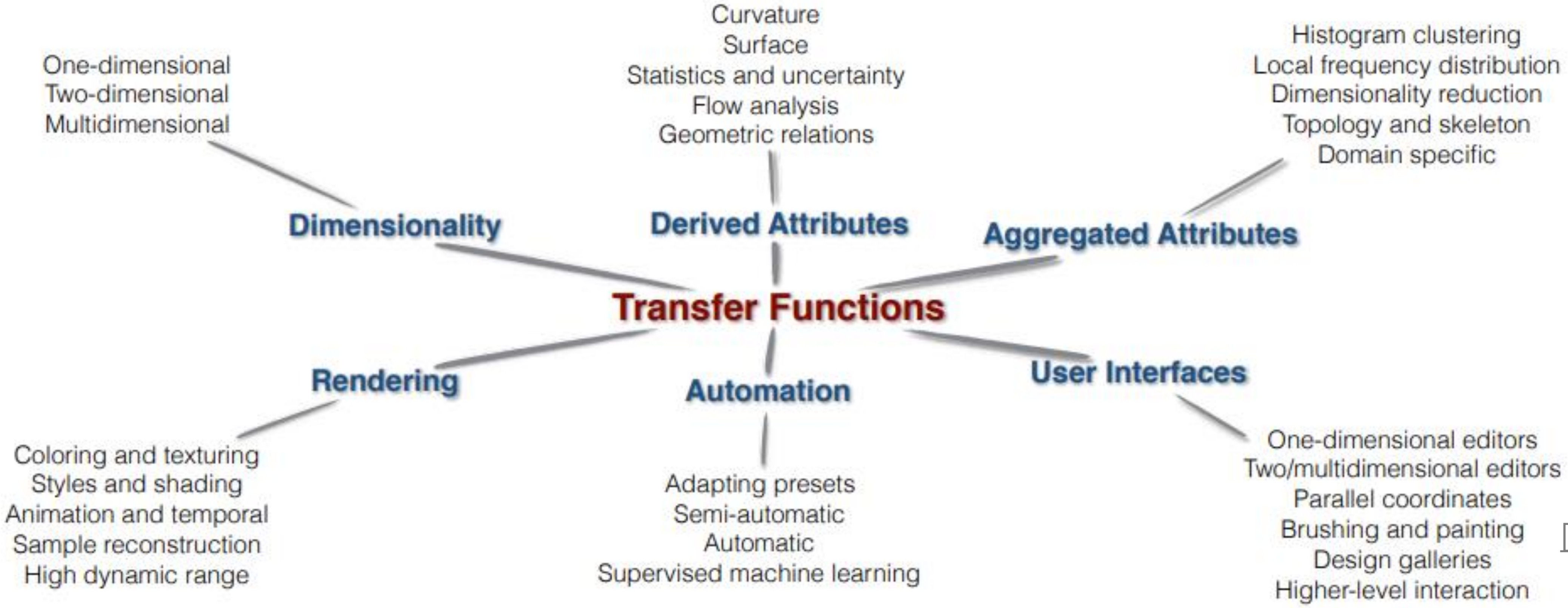




Transfer Functions



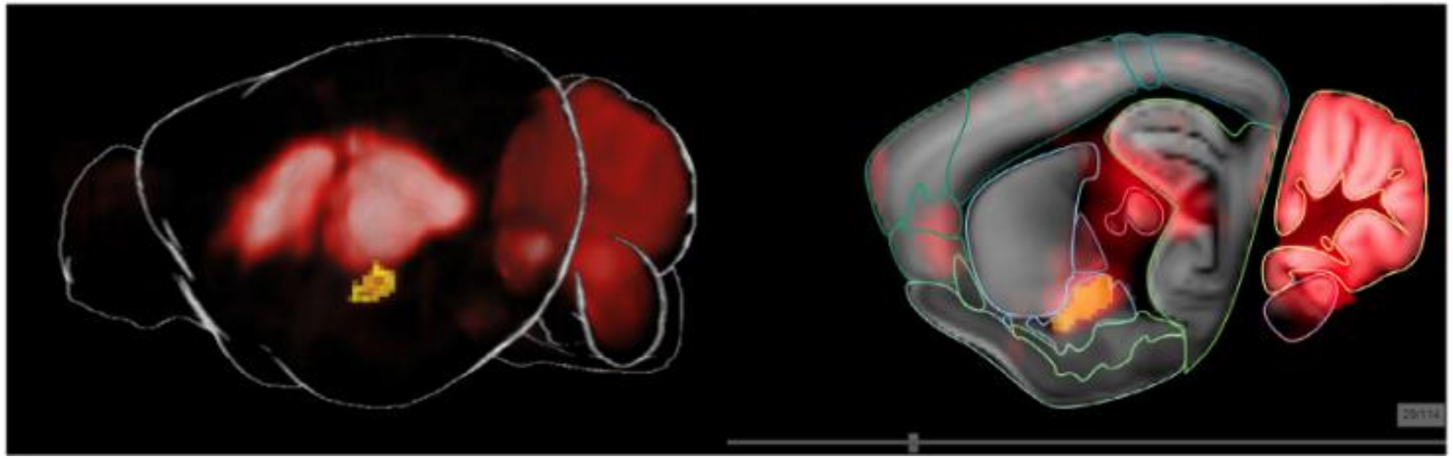
- Define opacity and color of each voxel
- 1D – classification based on material density (intensity) of the voxel
- Multidimensional – additional attributes, e.g., gradient or curvature



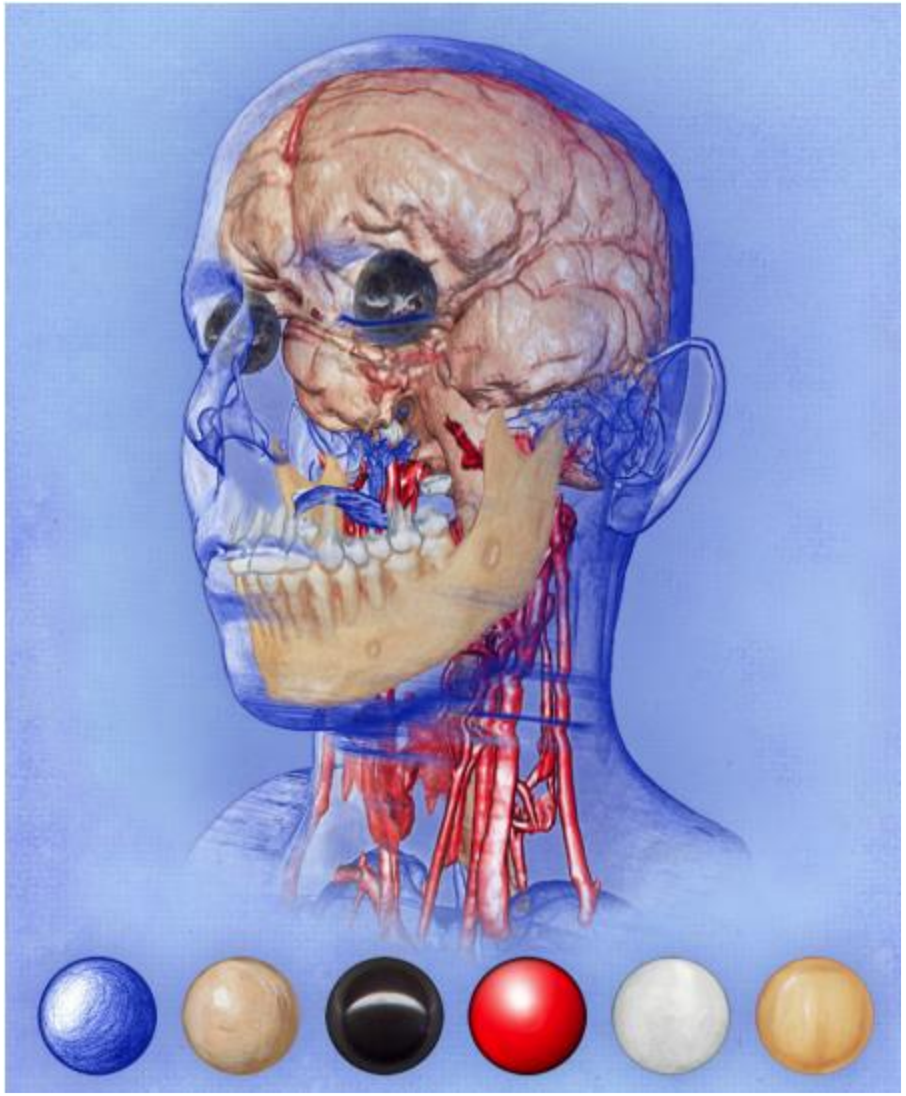
[Ljung et al., 2016]

Illustrative Techniques

- Silhouettes, hatching , style transfer

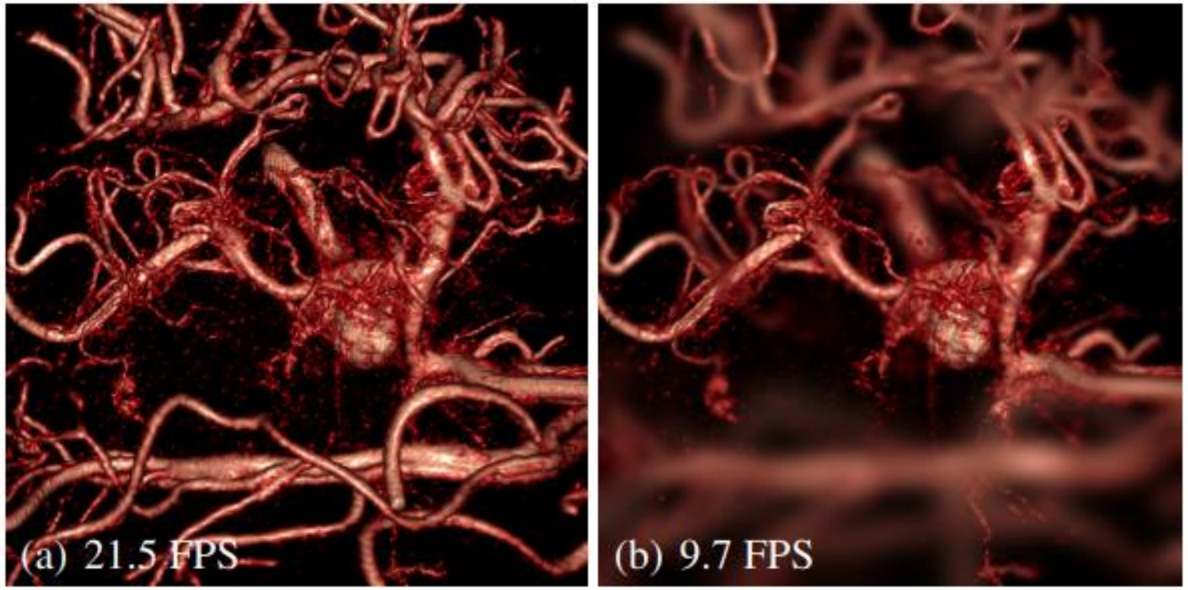


[Ganglberger et al., 2019]



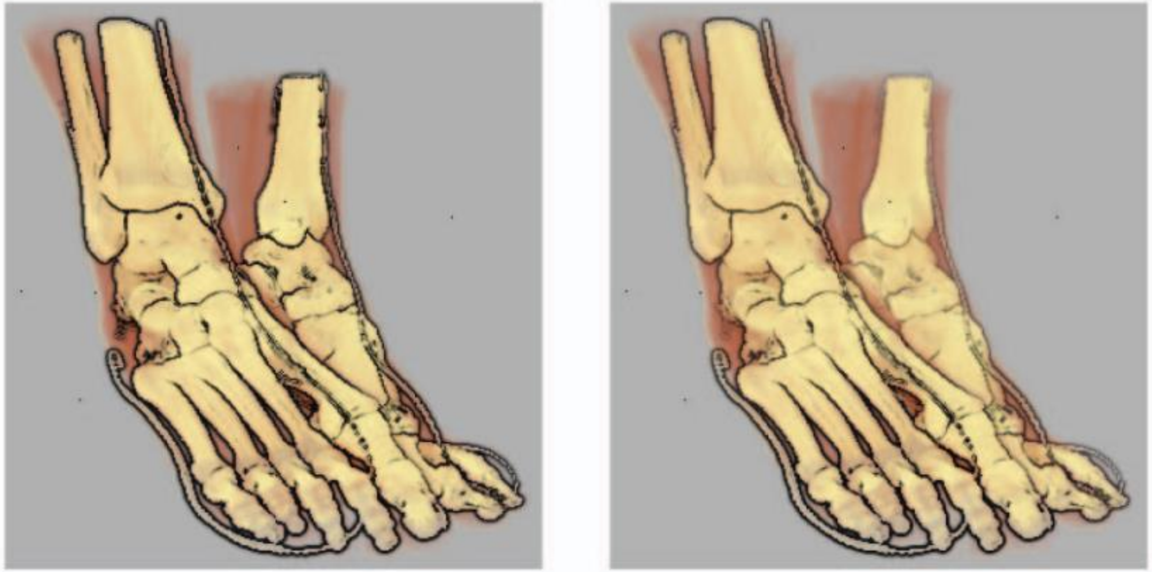
[Bruckner & Gröller, 2007]

Depth Perception



Depth of field simulation

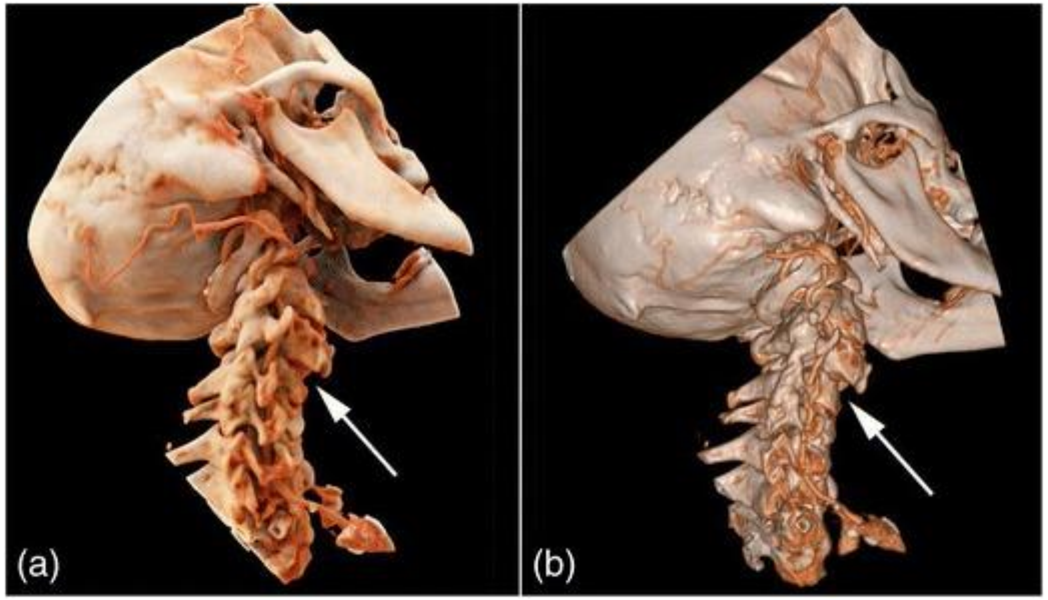
[Schott et al., 2011]

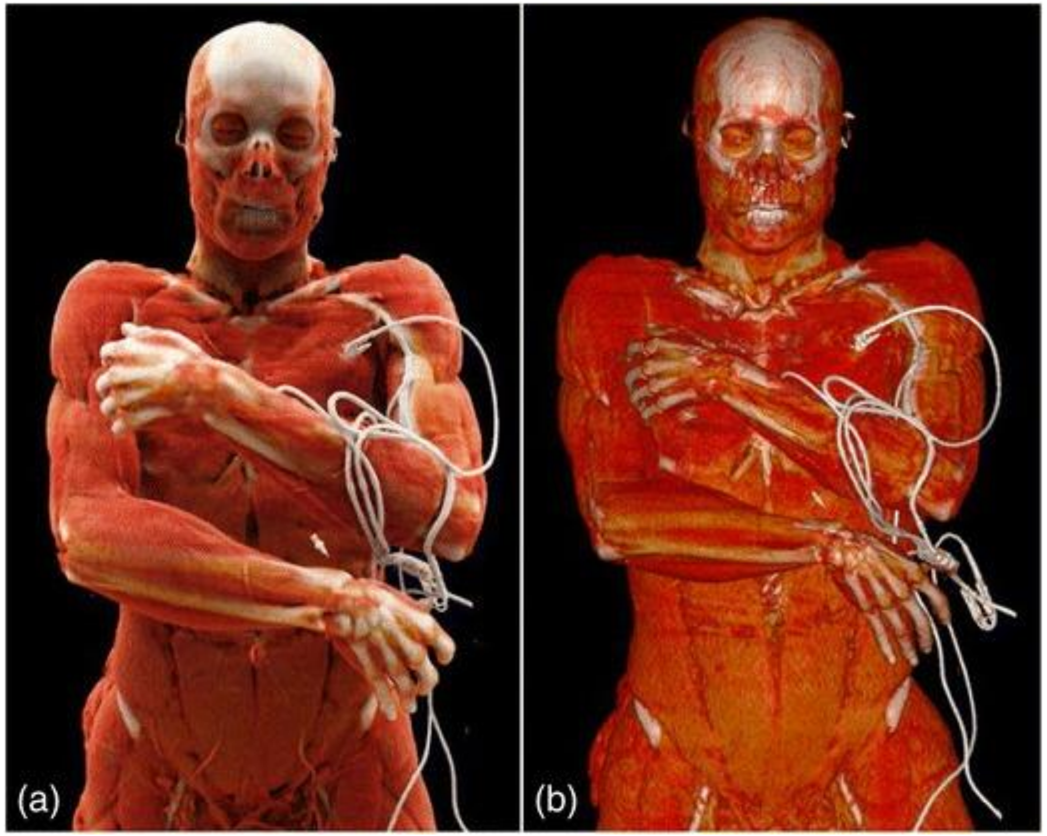


Depth dependant silhouettes and blurring

[Svakhine et al., 2009]

Lighting – Cinematic Rendering



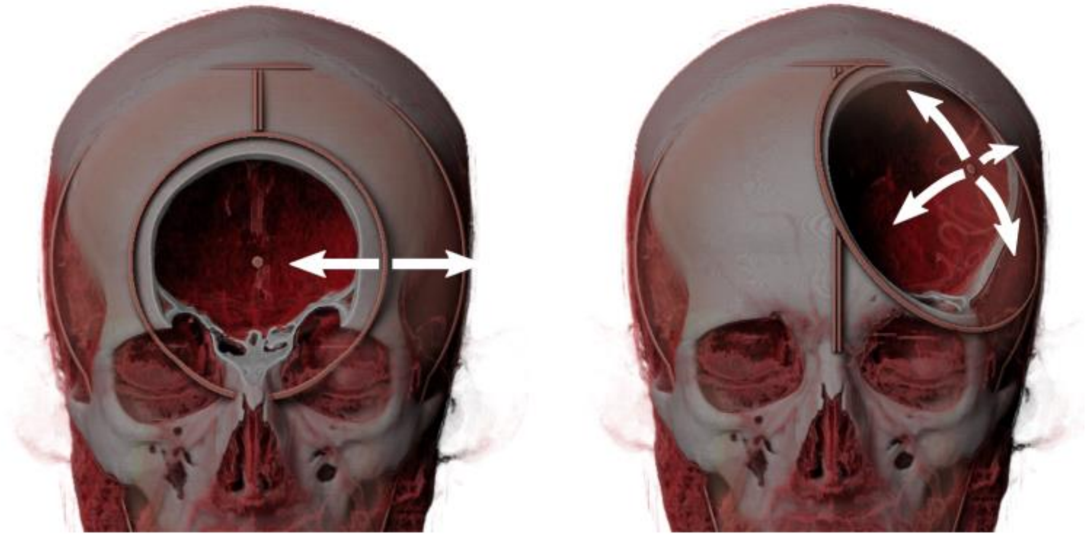


- Conventional VR – local illumination
- Cinematic rendering – simulates physical light scattering

[Dappa et al., 2016]

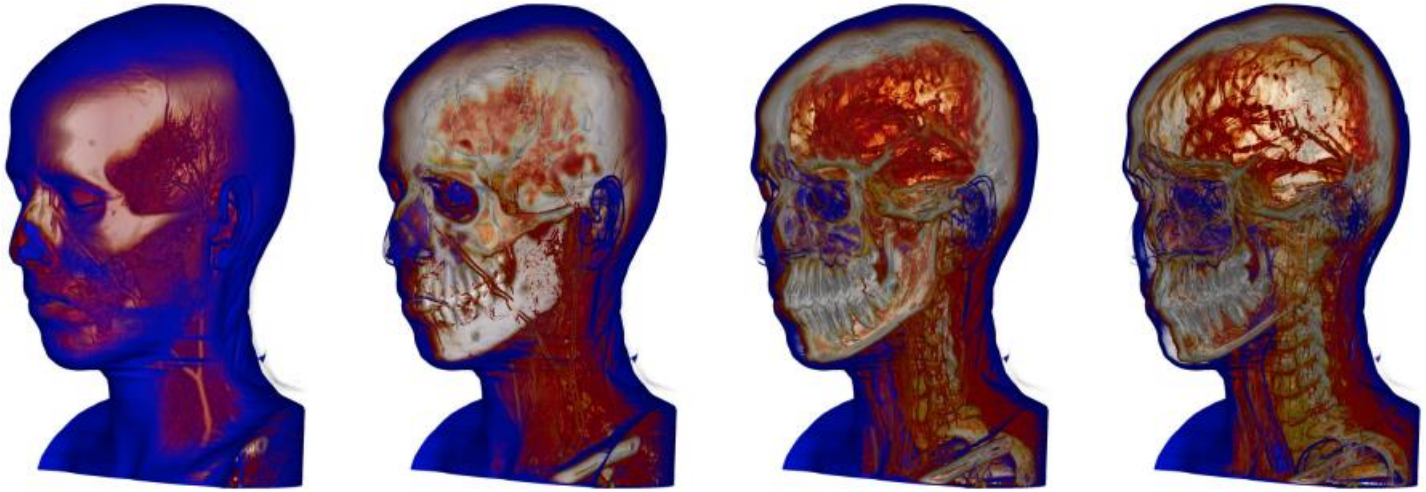
Smart Visibility

- Peel aways
- Exploded views
- Importance driven TFs
- Lenses



[Stoppel & Bruckner, 2018]

[Bruckner & Gröller, 2006]



[Bruckner et al., 2005]

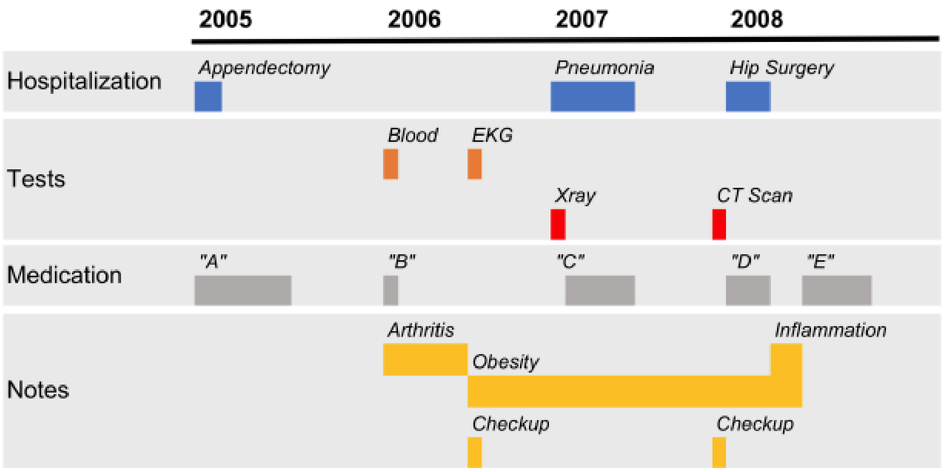
Visualization Approaches for Non-Spatial Data

Visualization Challenges

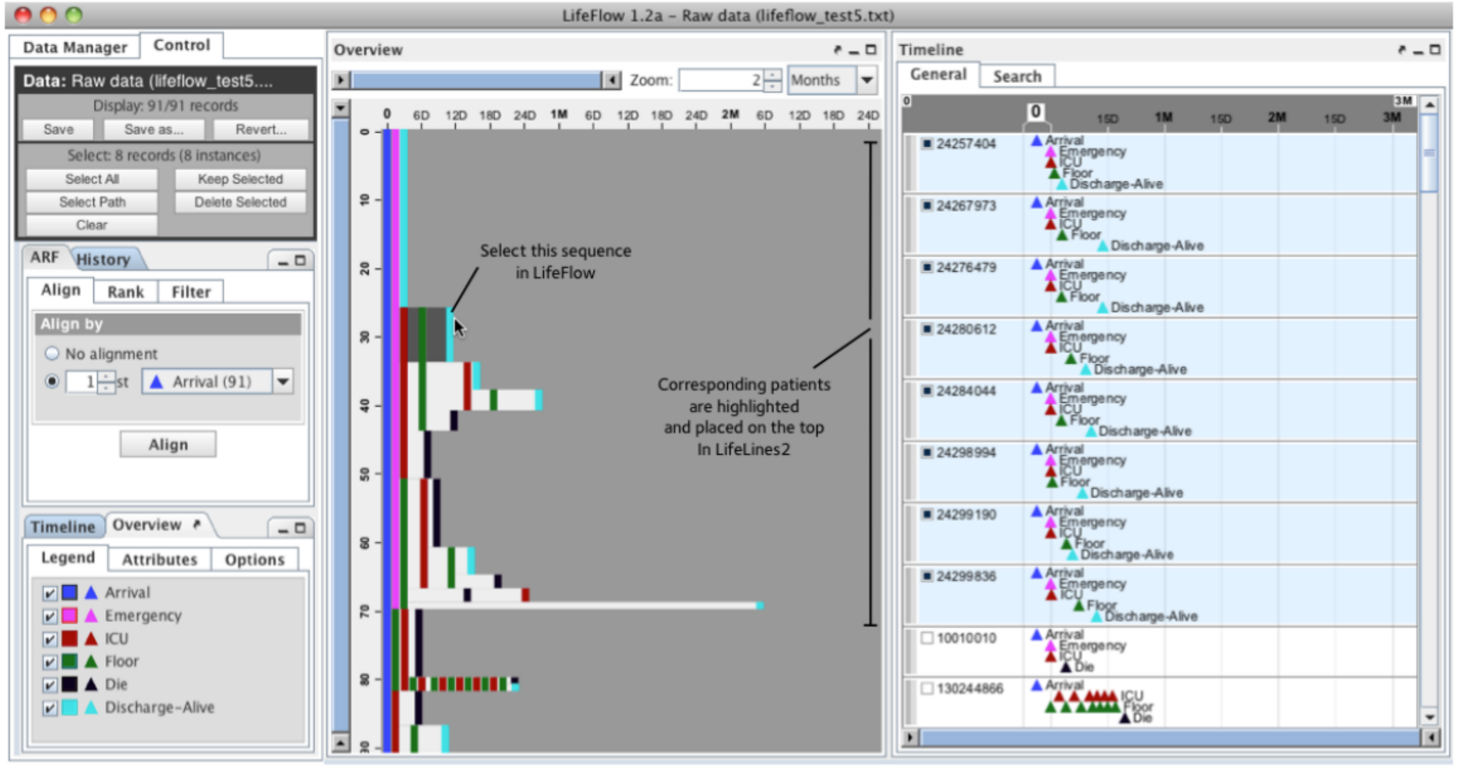
- Datasets too large for visual inspection of all individuals/data points
- Combination with statistical and/or machine-learning based analysis
- Data quality: missing values, standardization, ...

Electronic Health Records

- Visualizing patient histories – LifeLines by Plaisant & Schneiderman, 2003



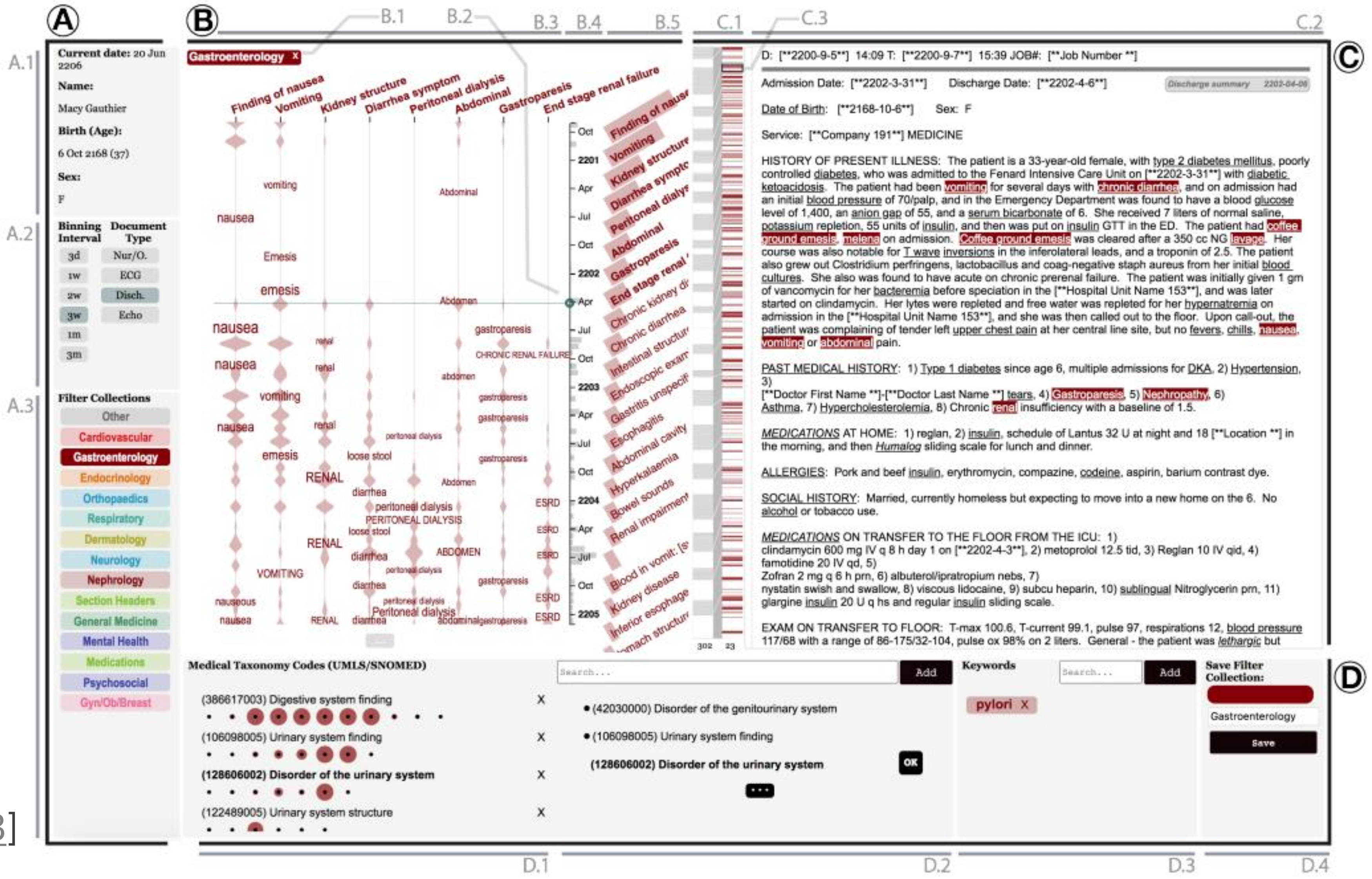
LifeLines



[Wongsuphasawat et al., 2011]

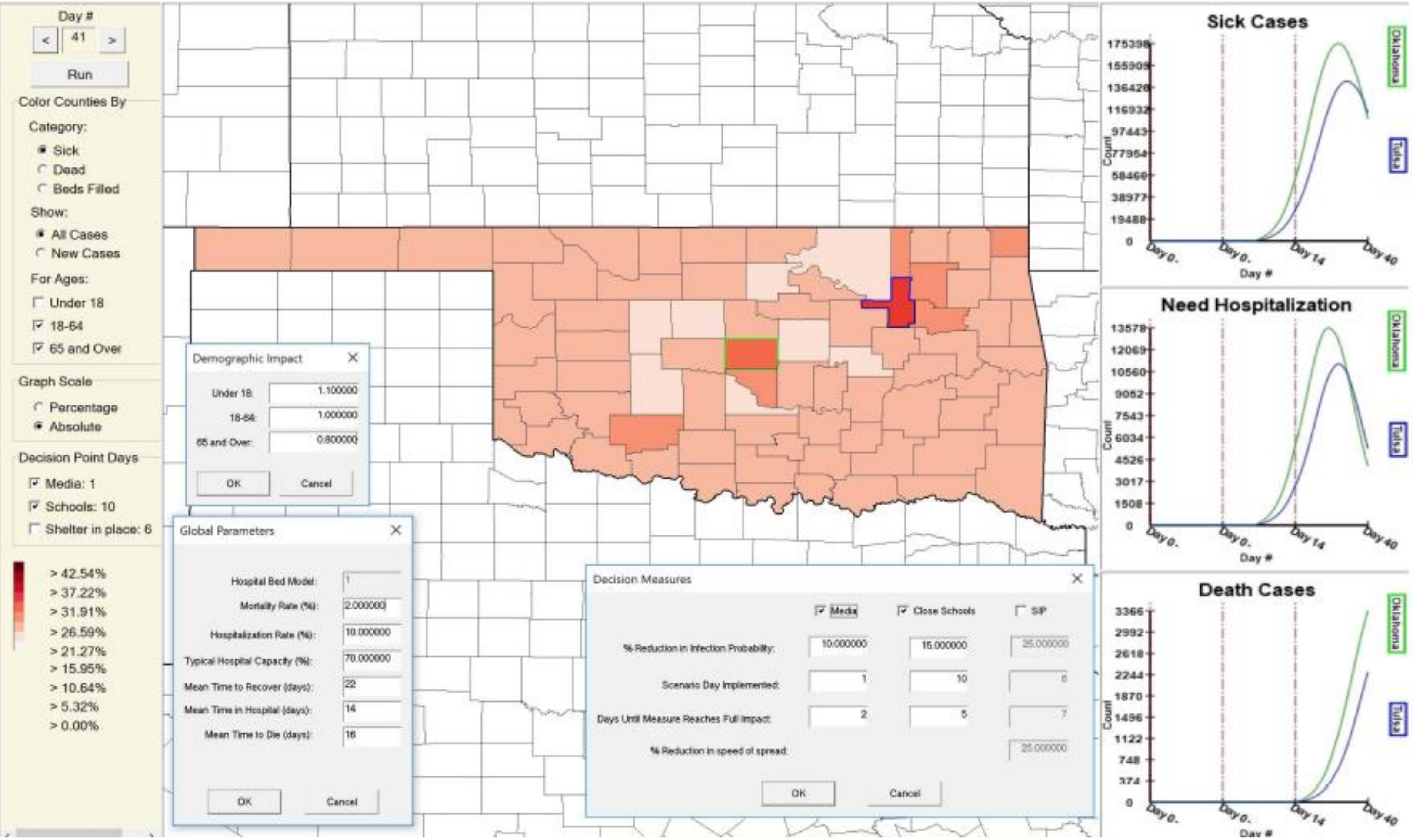
Electronic Health Records

- Visualizing medical texts



Doccurate [Sultanum et al. 2018]

Public Health

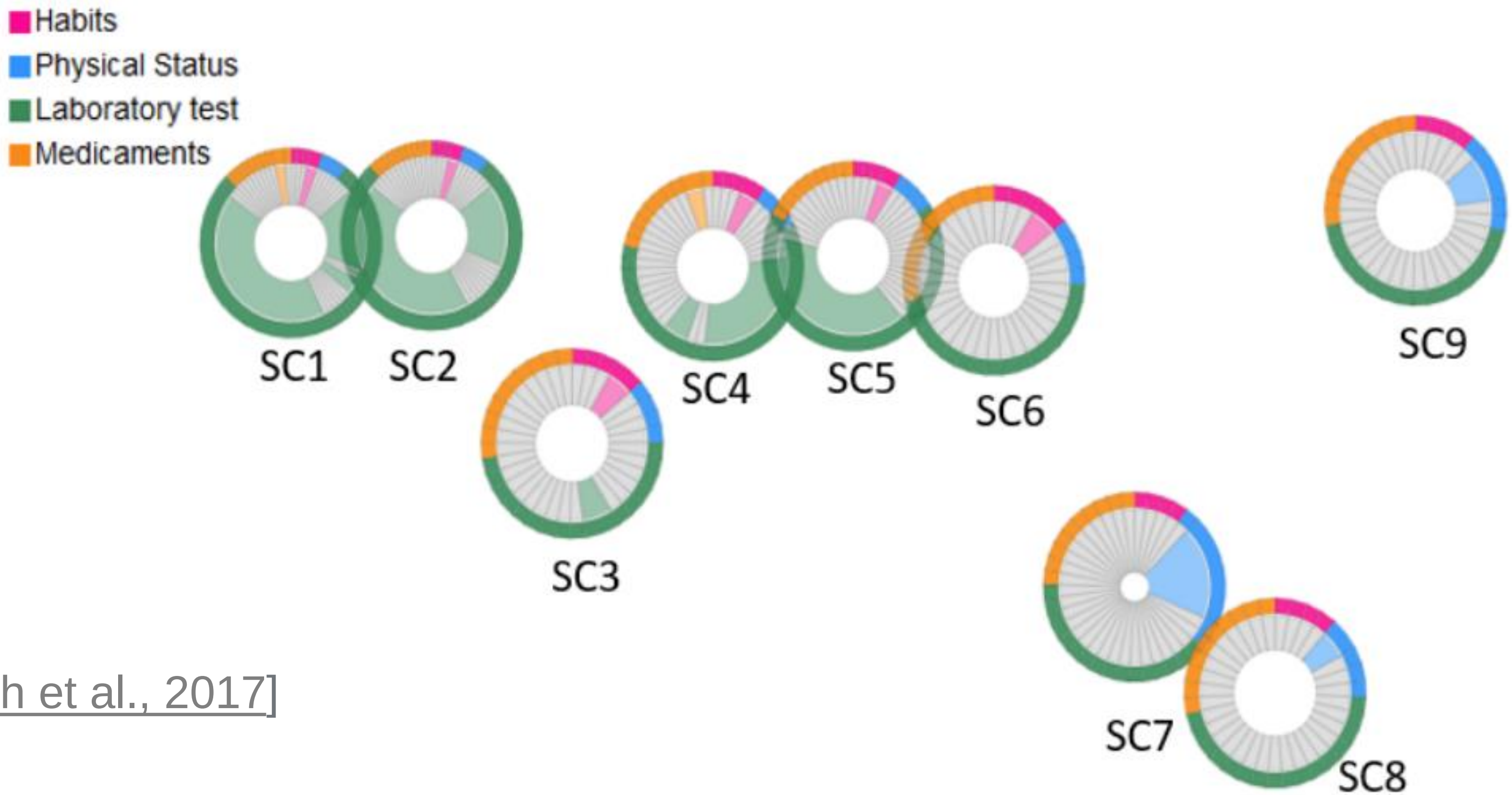


[Afzal et al., 2020]

Martin Krzywinski: A pandemic of bad charts
https://www.youtube.com/watch?v=_YGmfsKL8N8&ab_channel=HelenaKlaraJambor

Cohort Studies

- Feature extraction, dimensionality reduction, clustering, …



[Alemzadeh et al., 2017]

Visual Analytics – Bringing It All Together

“Flavors” of Visualization

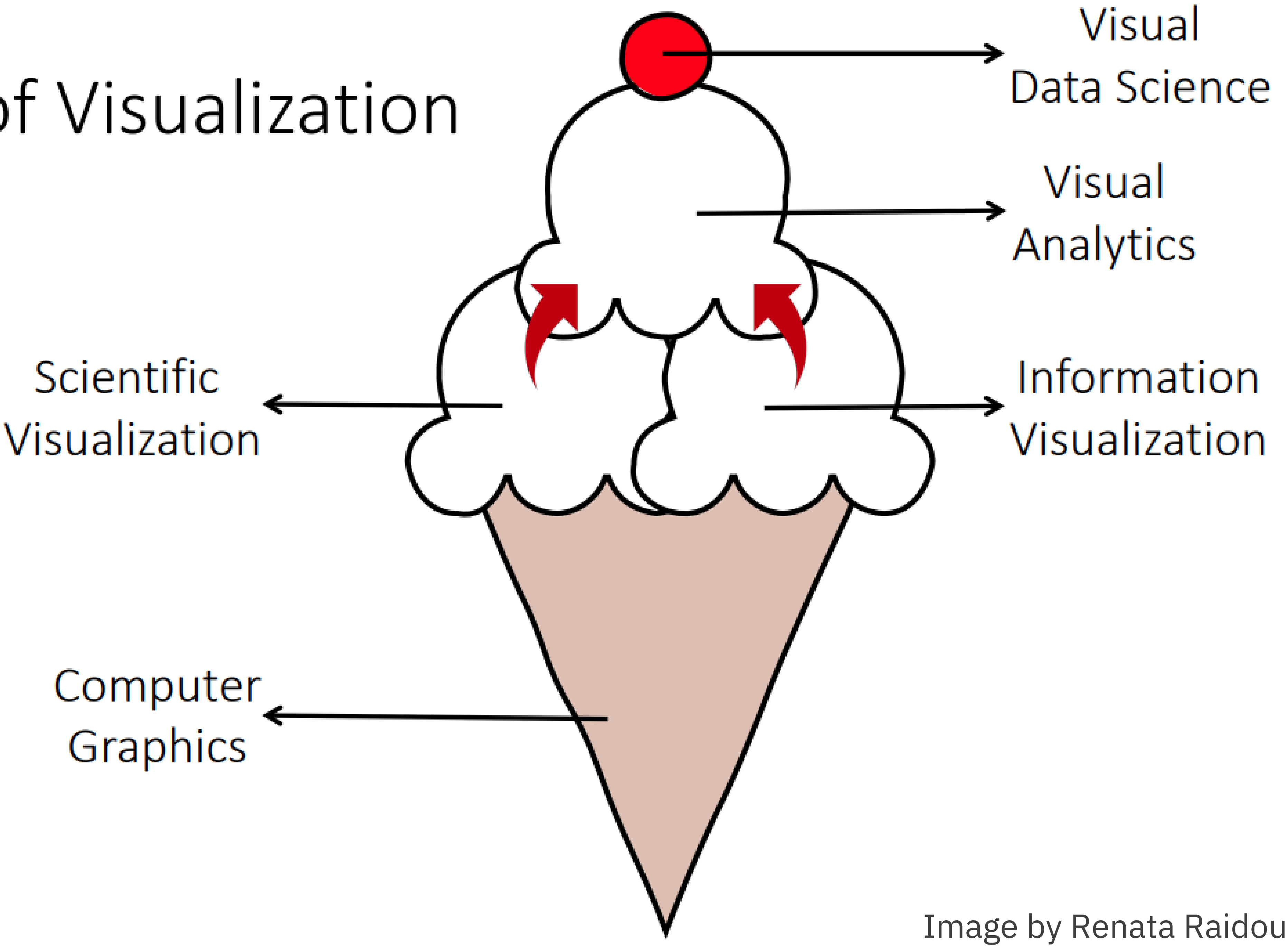
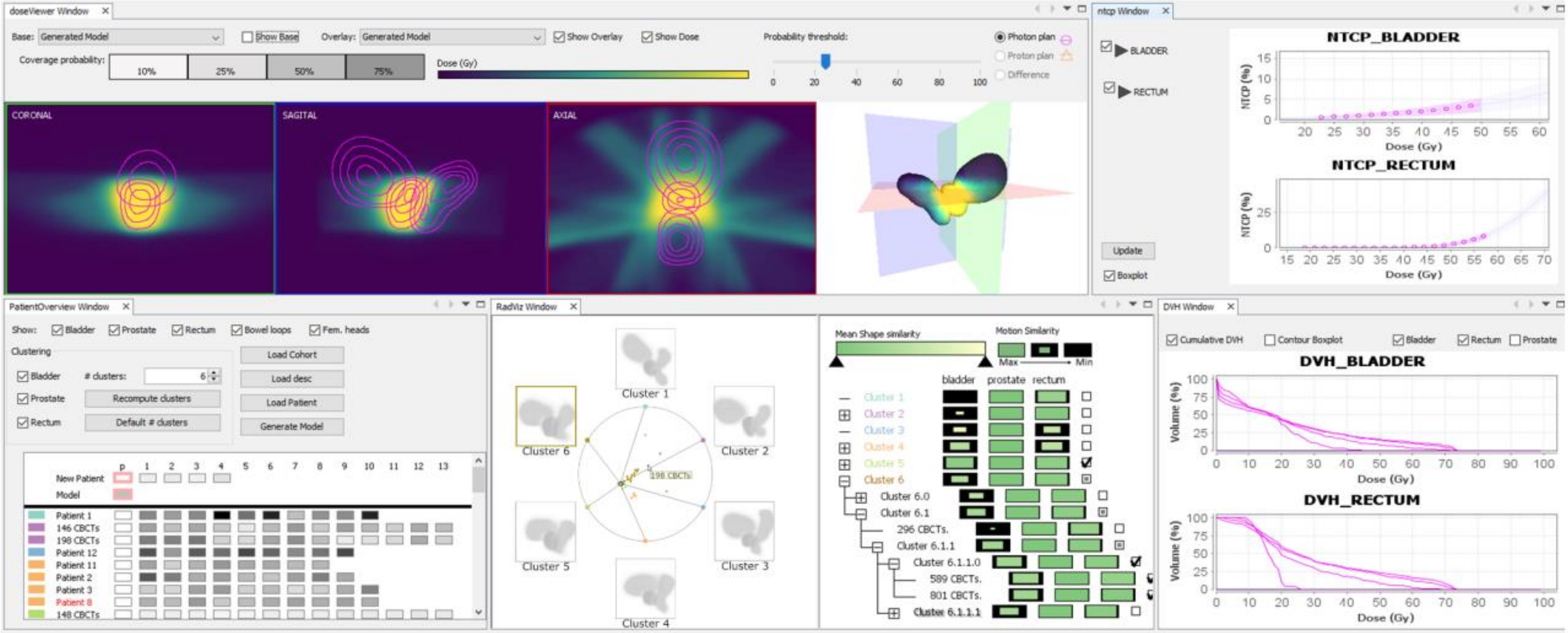


Image by Renata Raidou

Visual Analytics



Spatial data, abstractions, infovis techniques, statistical analysis, clustering, ...

Closing Remarks

Evaluation & Translation to Practice

- Appropriateness depends on target user and task
  - Requirement analysis
- Task completion evaluation
  - E.g., which of two points on blood vessel tree is closer
  - Correctness – essential for decision making
  - Time
- User engagement – e.g., for communication tasks
- Long-term evaluation might be necessary but rarely done
- Limited adoption to clinical practice

https://gdpr-info.eu/issues/personal-data/

Open Challenges

- Bridging data across multiple scales (omics + medical data)
- Uncertainty in medical data
- Data size
- Explainable AI
- Patient empowerment
- Constant adaptation to new data/technologies

Medical Data = Sensitive Personal Data

- Remember that this belongs to people, treat it with respect
- Follow regulations, check if you aren’t sure
- Medical collaborators may have additional restrictions

https://gdpr-info.eu/issues/personal-data/

Acknowledgement

- Noeska Smit, University of Bergen, Norway (Medical Data Overview)