

PA214 / Visualization II

Katarína Furmanová

Visualization of Medical Data

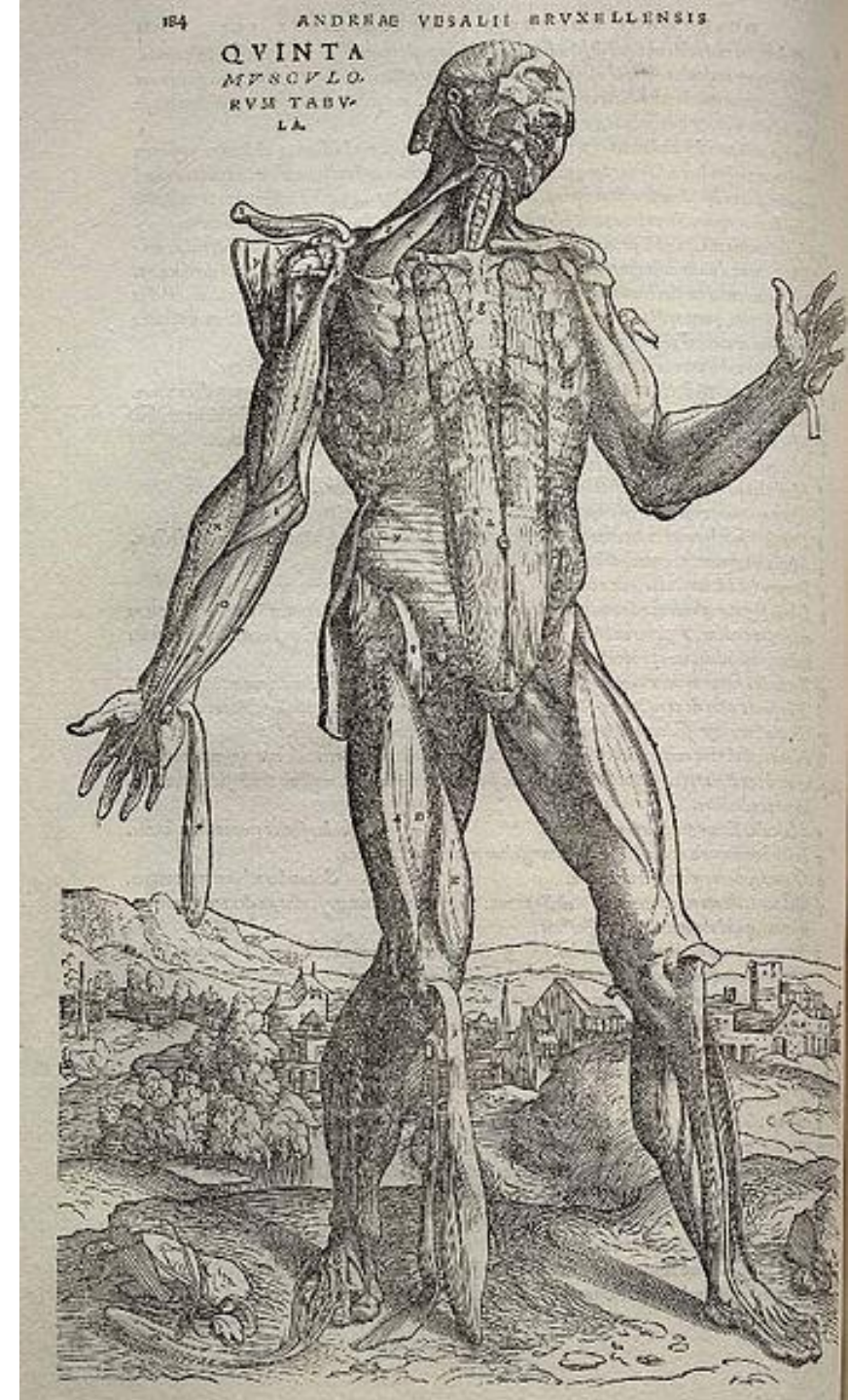
HCI^{LAB}

∴. visitlab

Goals of Medical Visualization

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

De Humani Corporis Fabrica by Vesalius, 1543



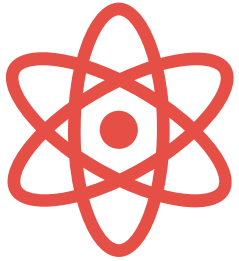
In This Lecture

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

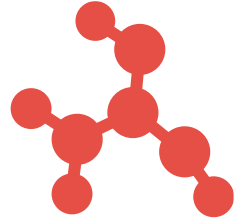


Saginaw Future Inc., CC BY 2.0, via Wikimedia Commons

Scales



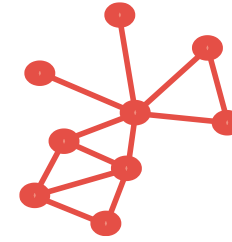
Atoms



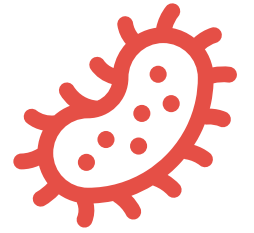
Molecules



Genes



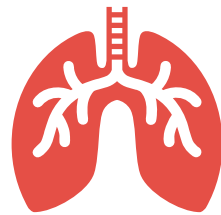
Interactions



Cells



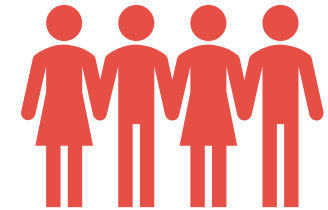
Tissue



Organs



Organisms



Populations

Tissue



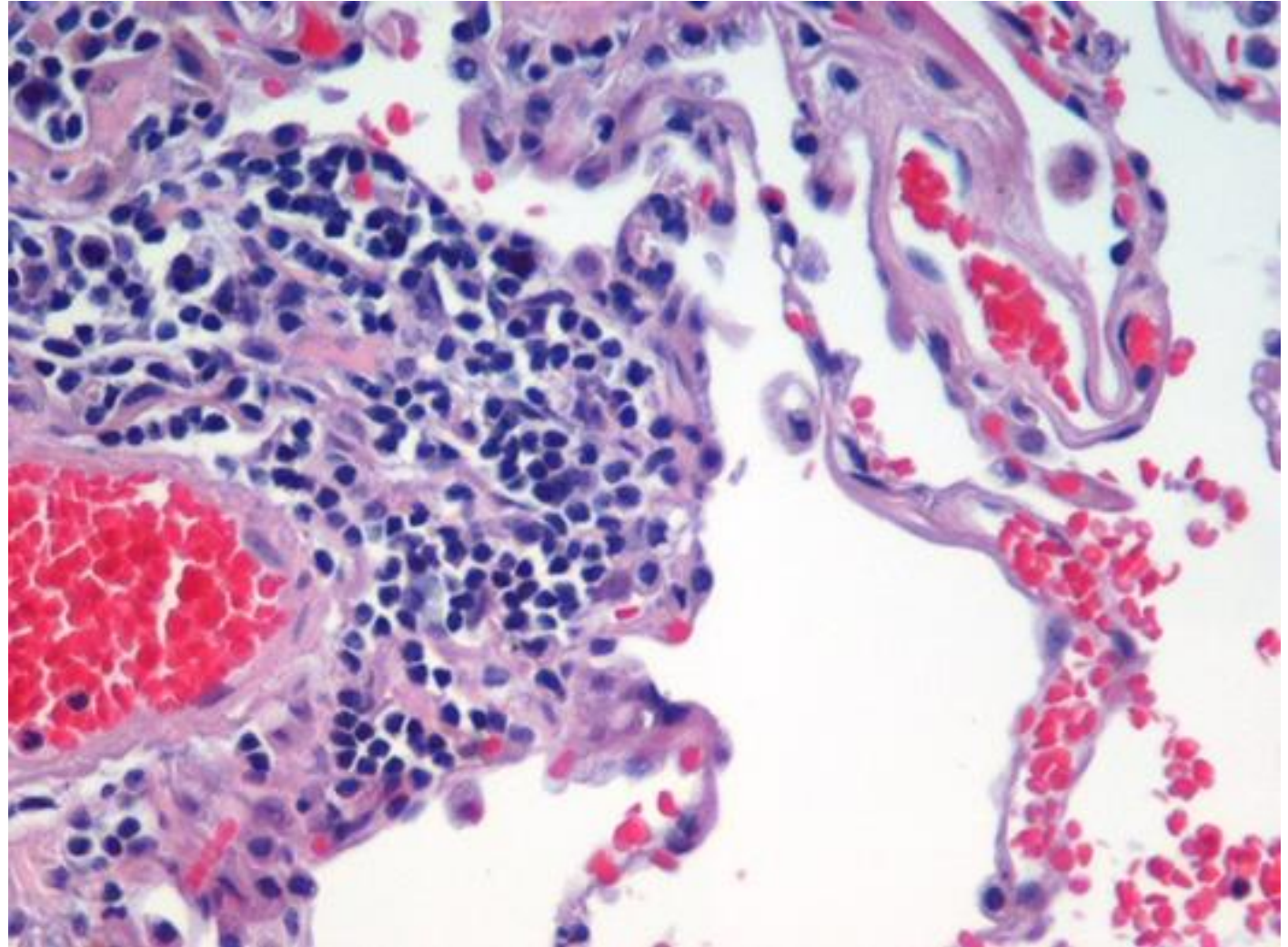
Samples of Human Tissue

- **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,

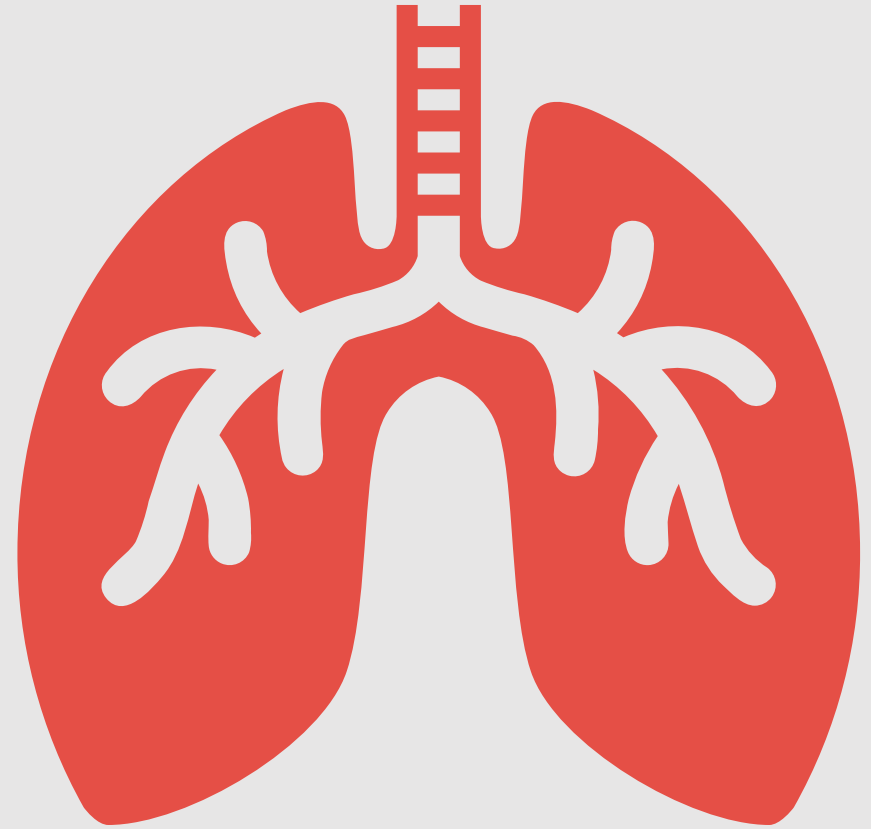
Resulting Data

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

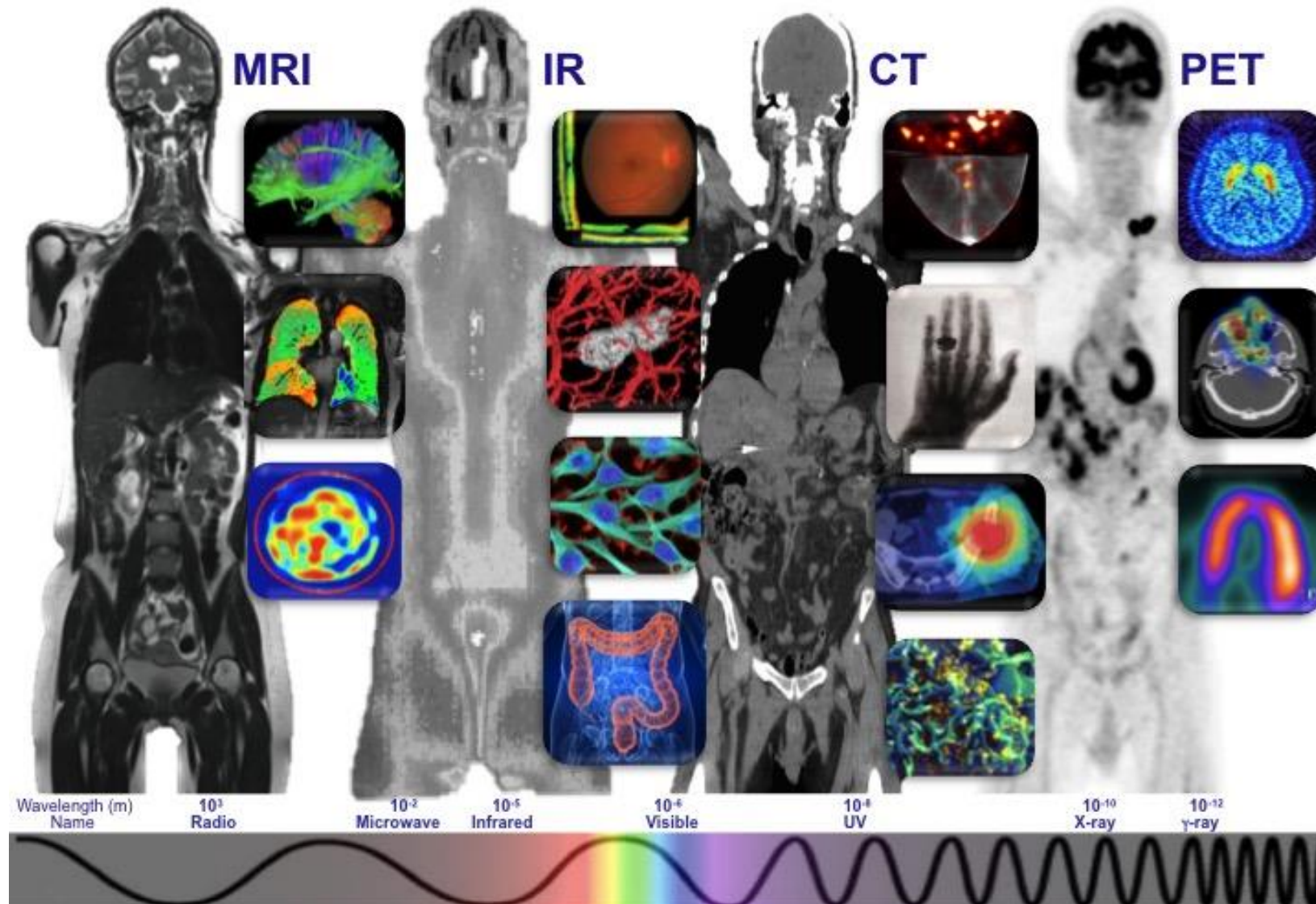
Human lung tissue stained with hematoxylin and eosin



Organ



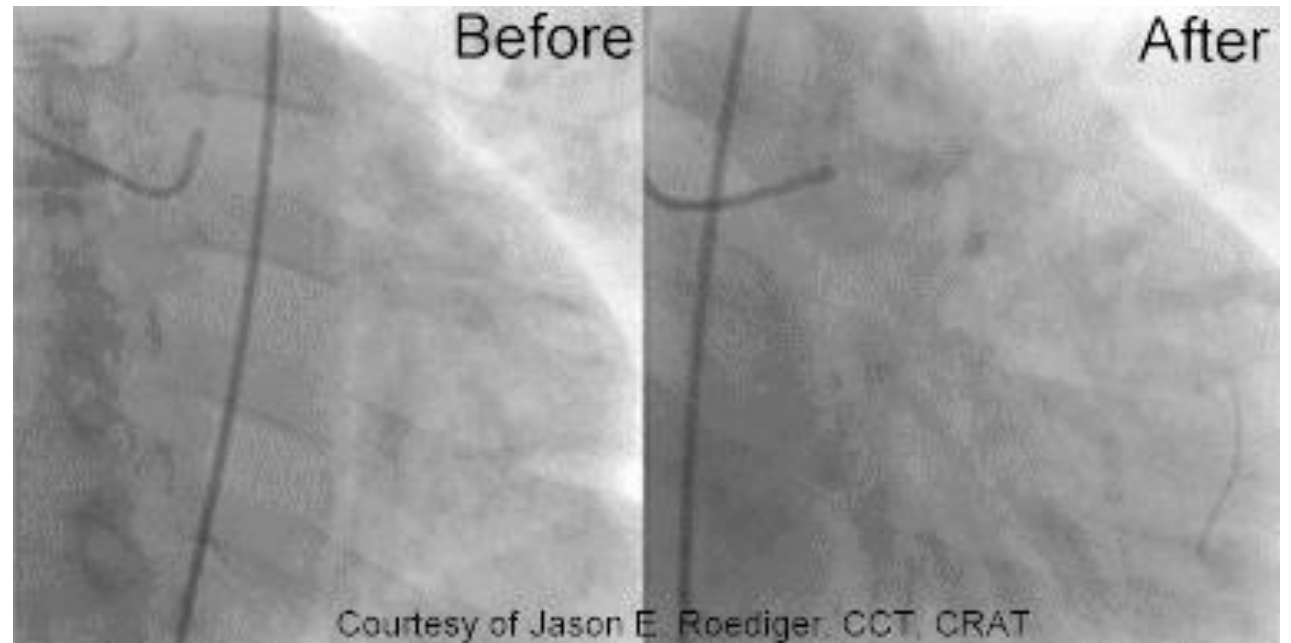
Medical Imaging



Martin Tornai, CC BY 4.0, via Wikimedia Commons

X-ray

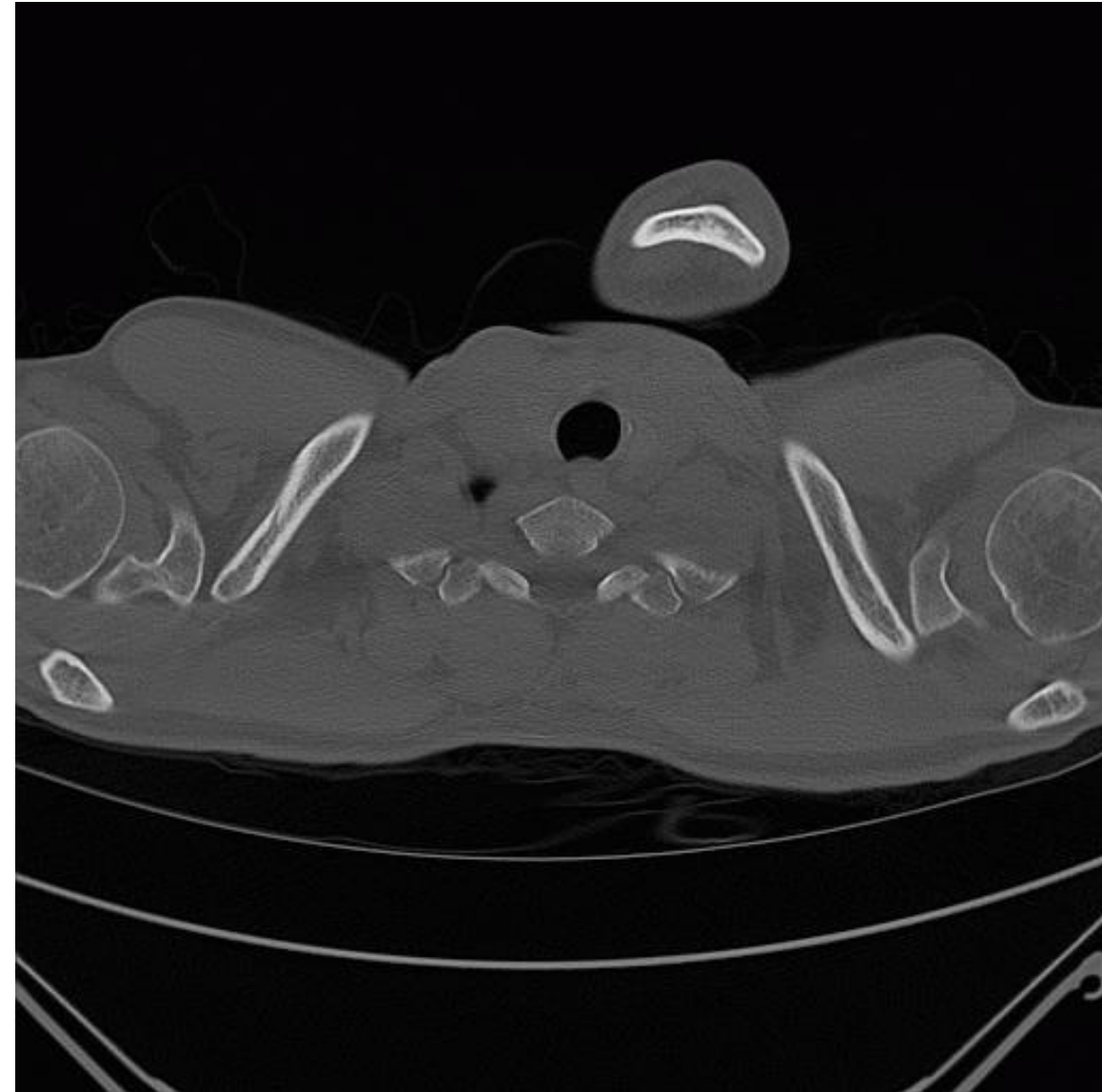
- Radiation: electromagnetic waves (ionizing!)
- Varying tissue absorption leads to image contrast
- Standard, Fluoroscopy, Angiography, Mammography



Computed Tomography (CT)

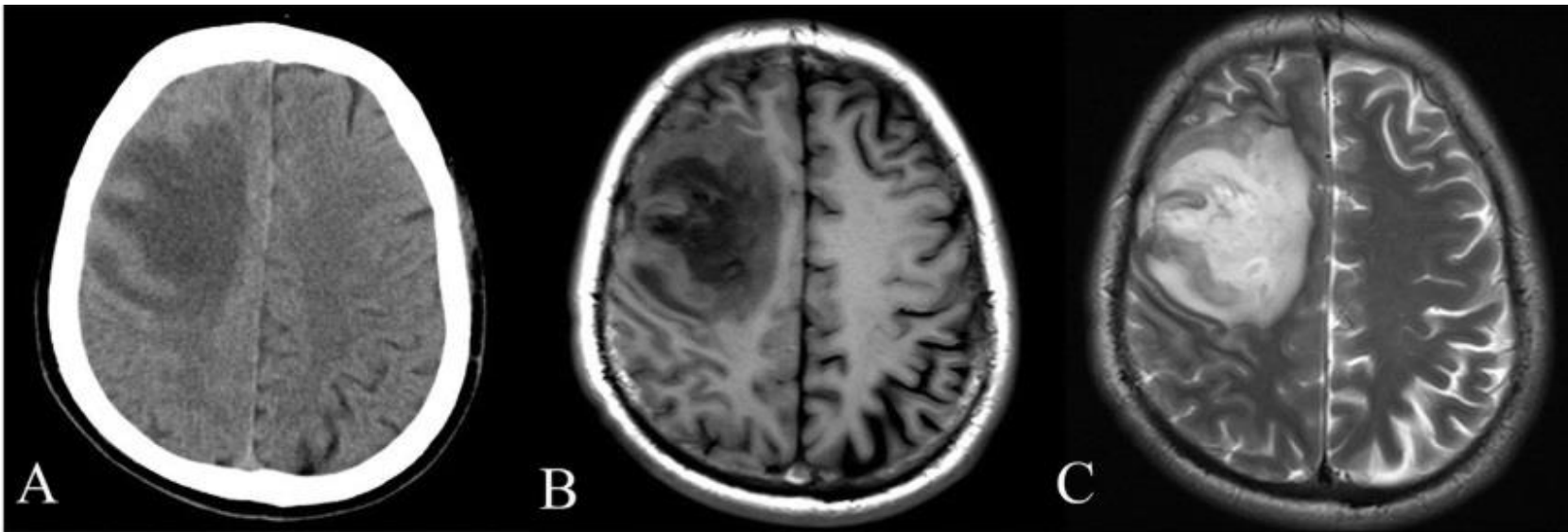
- X-ray tube rotating around the body
- Reconstruction: stack of 2D slices
- Intensity: Hounsfield Units (HU)

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

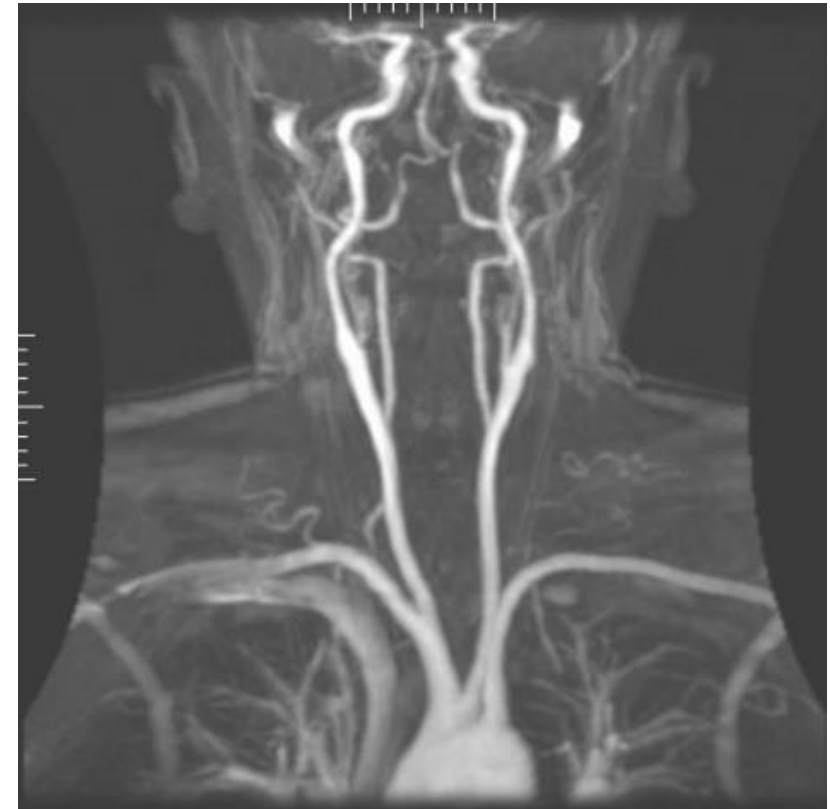


Magnetic Resonance Imaging (MRI)

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



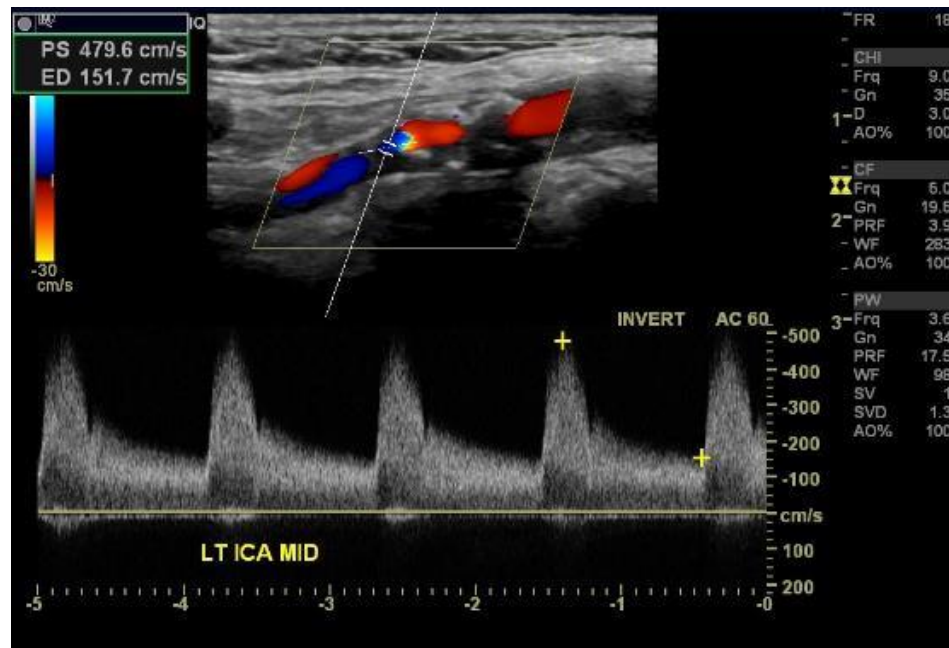
[Wei-yuan Huang, Gang Wu, Feng Chen, Meng-meng Li and Jian-jun Li, CC BY 4.0, via Wikimedia Commons](#)



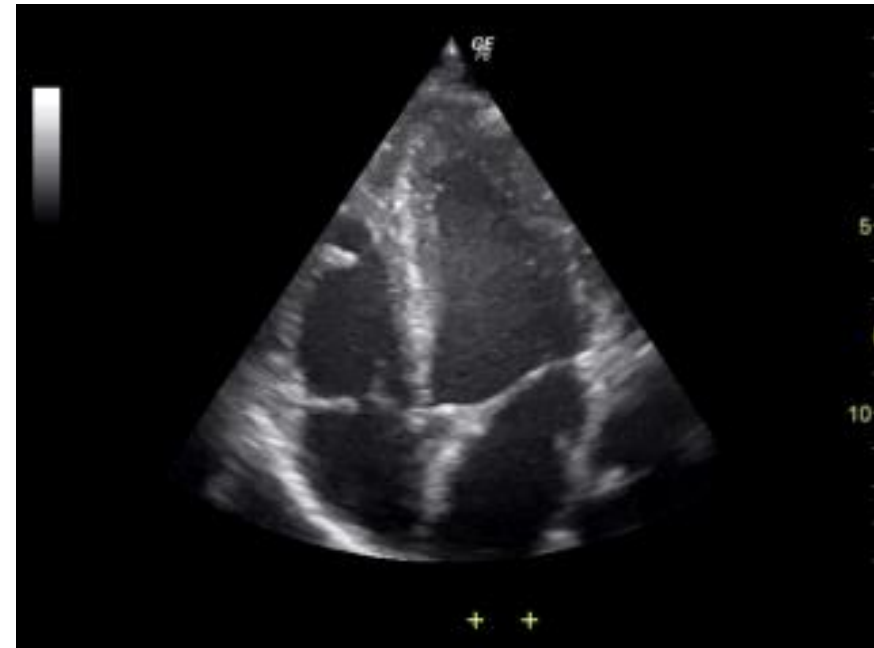
[Ofirglazer at English Wikipedia, CC BY-SA 3.0, via Wikimedia Commons](#)

Medical Ultrasound

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



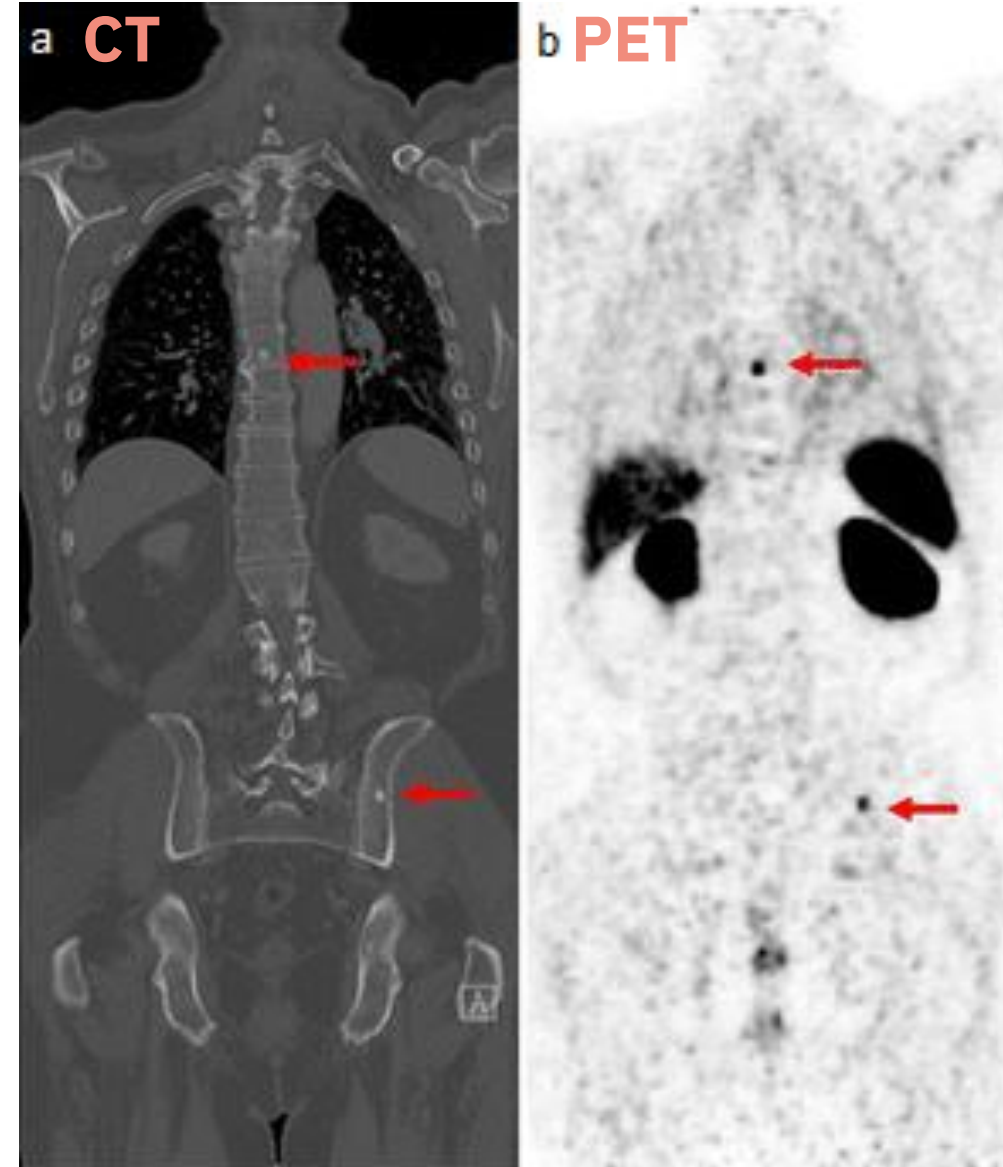
Mme Mim, [CC BY-SA 3.0](#), via Wikimedia Commons



Fruehaufsteher2, [CC BY-SA 3.0](#), via Wikimedia Commons

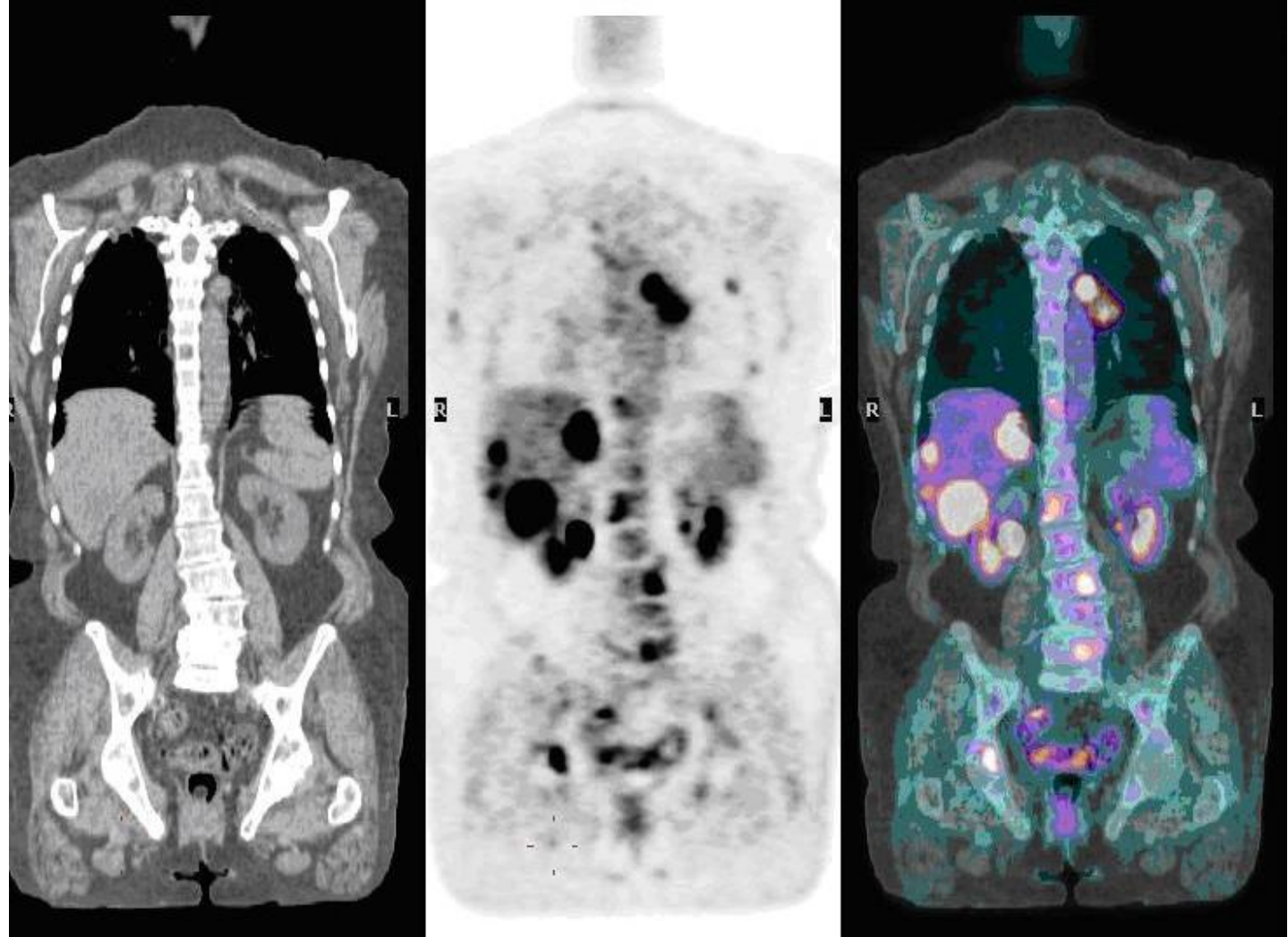
Nuclear Imaging: PET/SPECT

- 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

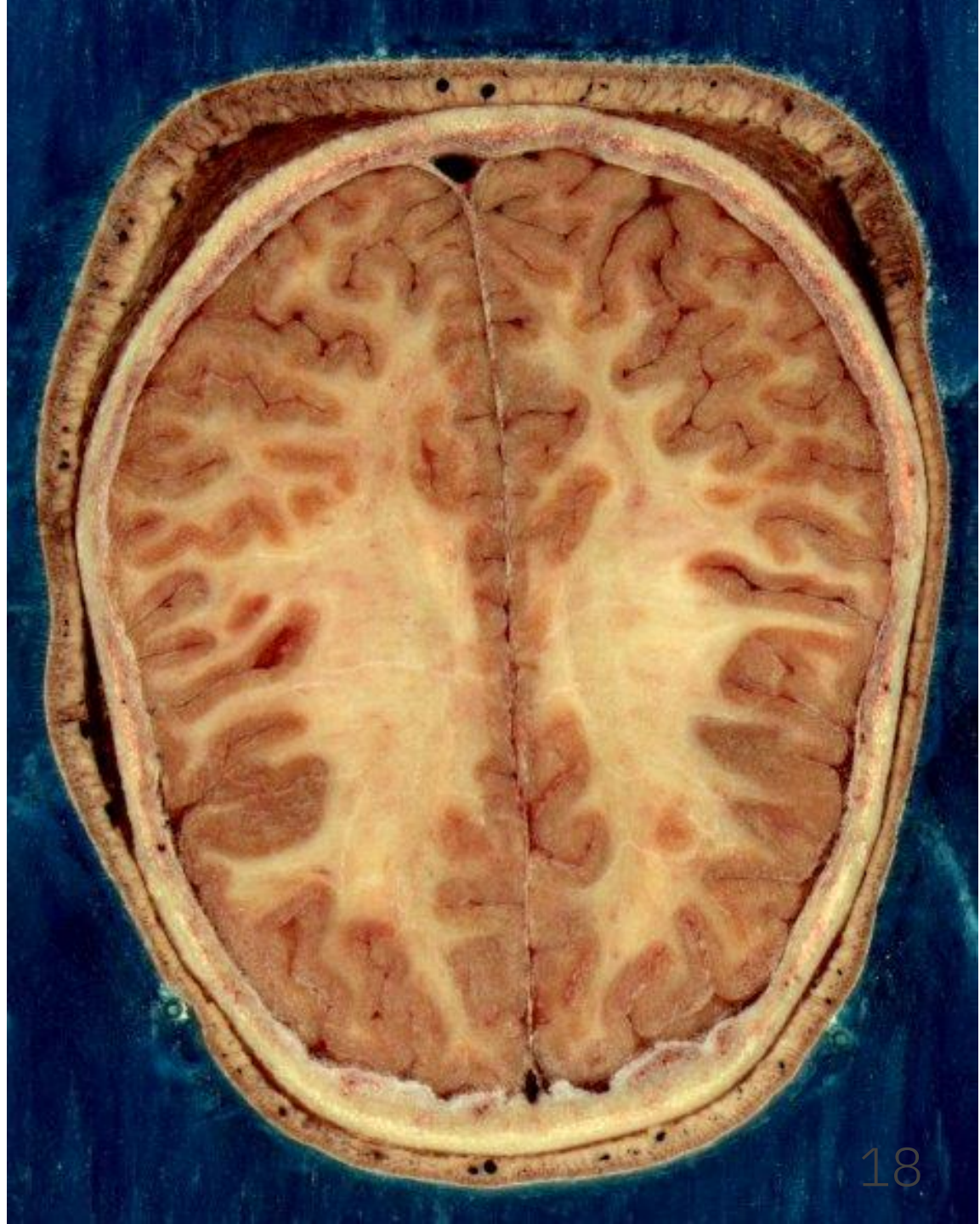


Whole-Body MRI, CT, PET

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

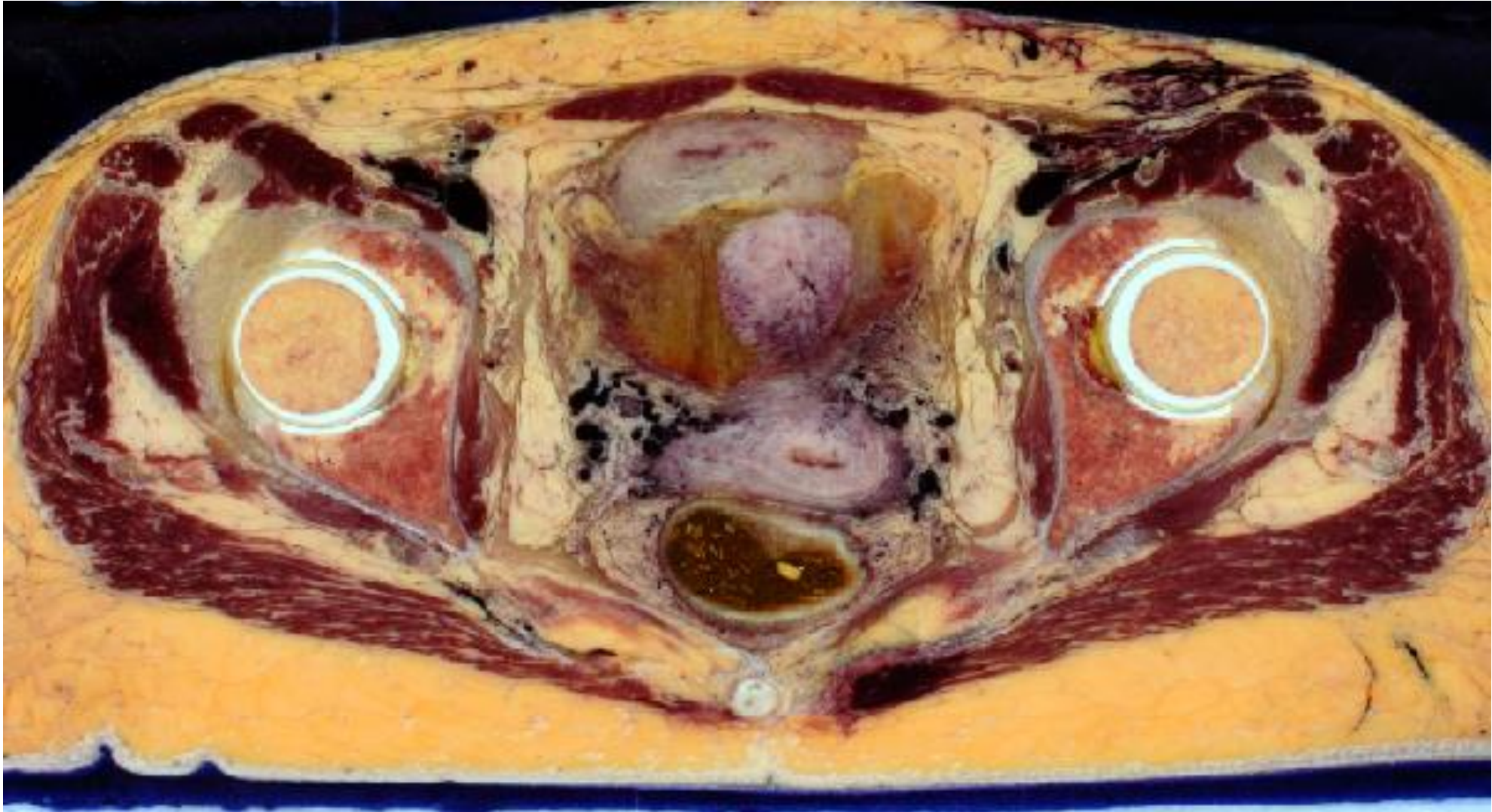
Cryosection

- 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

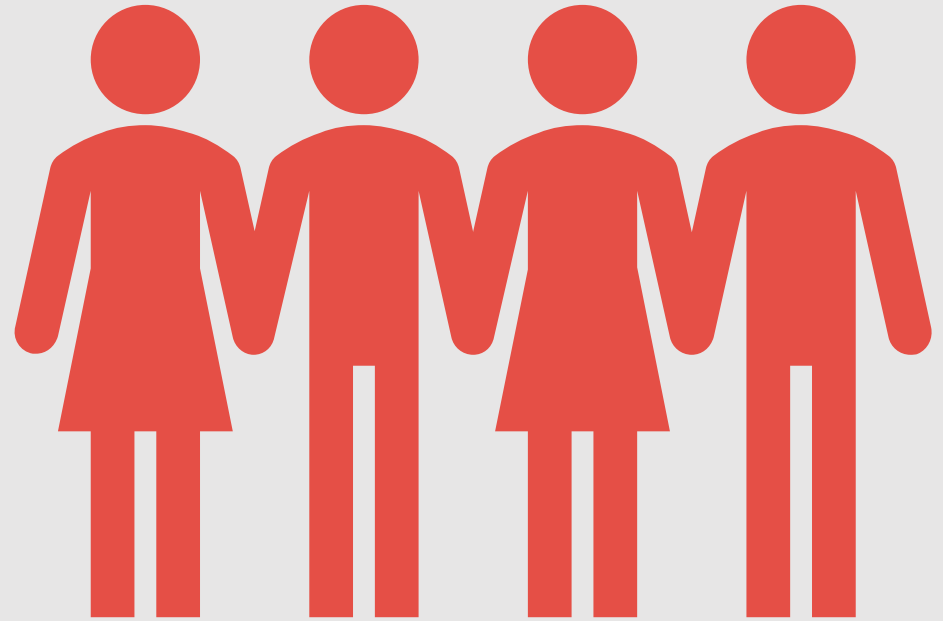


Resolution: 5616 x 2300
0.2 mm between every slice

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

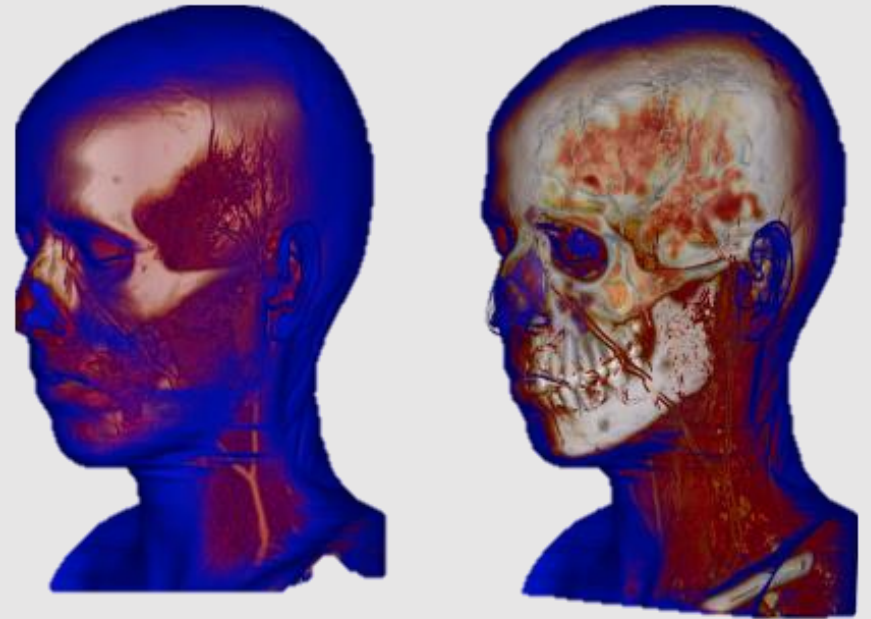
- Medical research studying a large number of subjects over time (longitudinal)
- Cohort: a group of people who share a defining characteristic
- Examples: cohort people born in Rotterdam in 1980-1985, cohort of gynecological cancer patients, ...
- Data: self-reported interviews, medical examinations,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

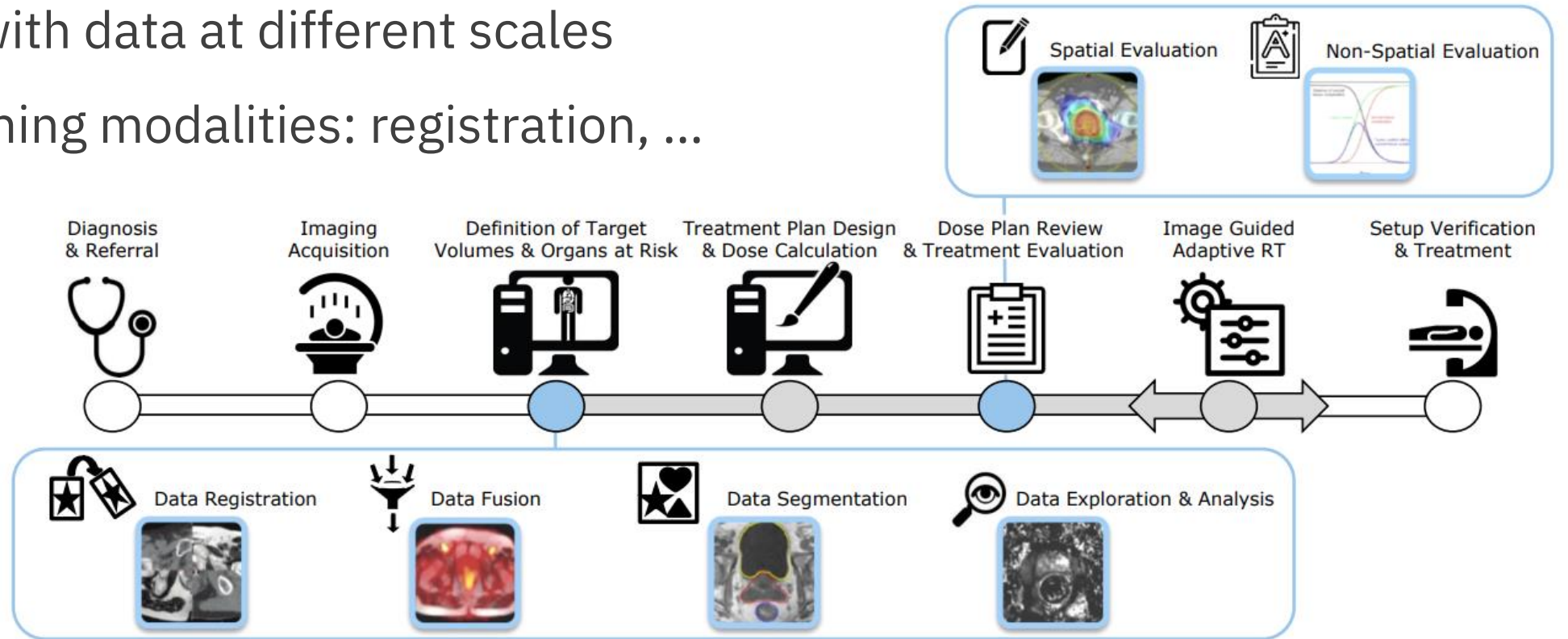
- Studying the population in order to prevent disease
- Aim: encouraging behavior and policy change, limit acute disease outbreak, reduce chronic diseases and injuries
- Data over time and locations (spatio-temporal)

Visualization Approaches for Spatial Data



Spatial Data Visualization Challenges in Medicine

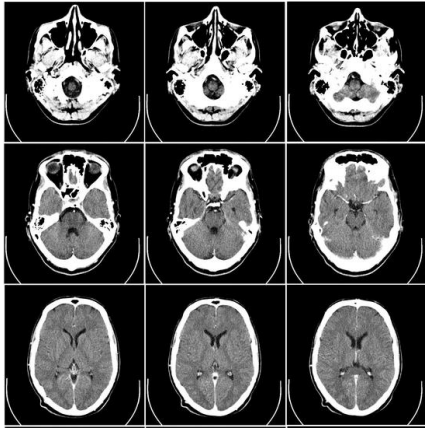
- Artifacts, noise, uncertainty
- Integration with data at different scales
- When combining modalities: registration, ...
- Occlusions



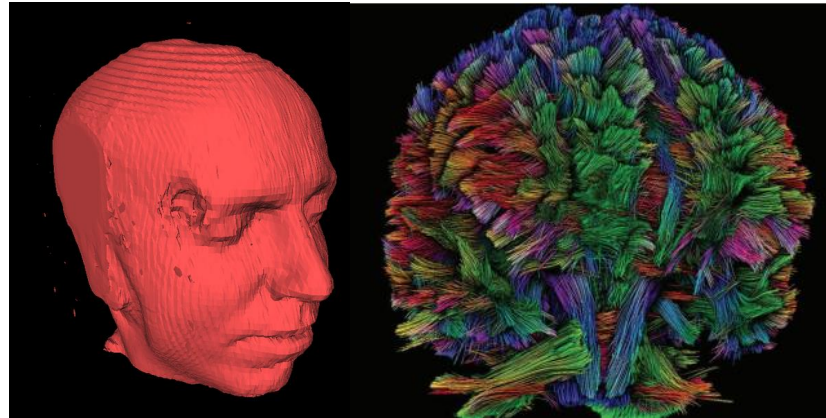
The steps of the workflow of radiotherapy planning [Raidou et al. 2019]

Spatial Data Visualization Approaches

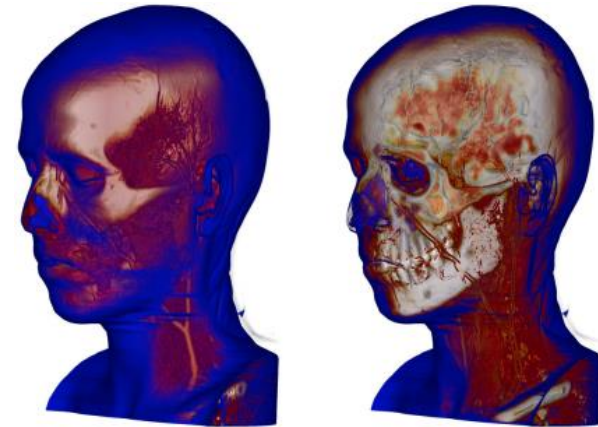
Slices



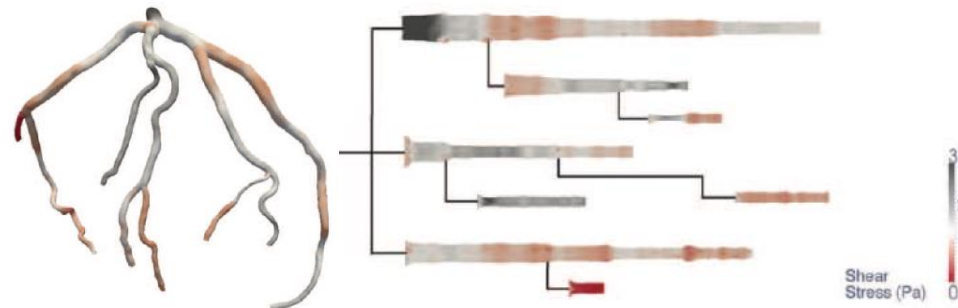
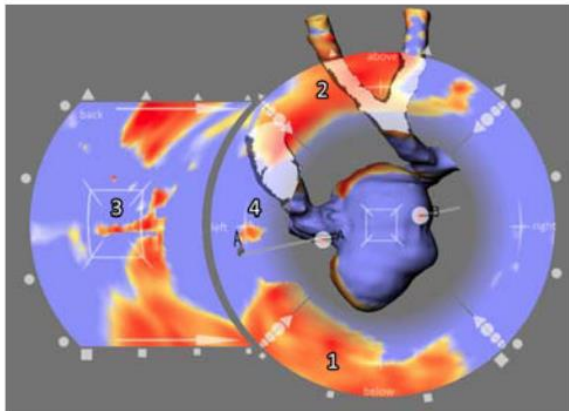
Surface,
Spatial Features



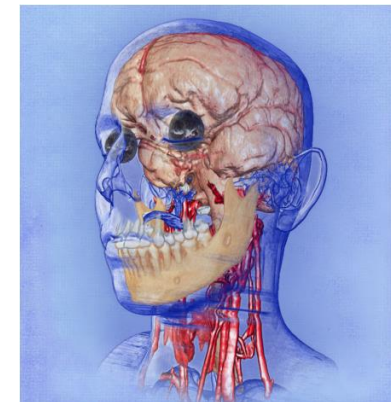
Volume Rendering



Reformation, Abstraction

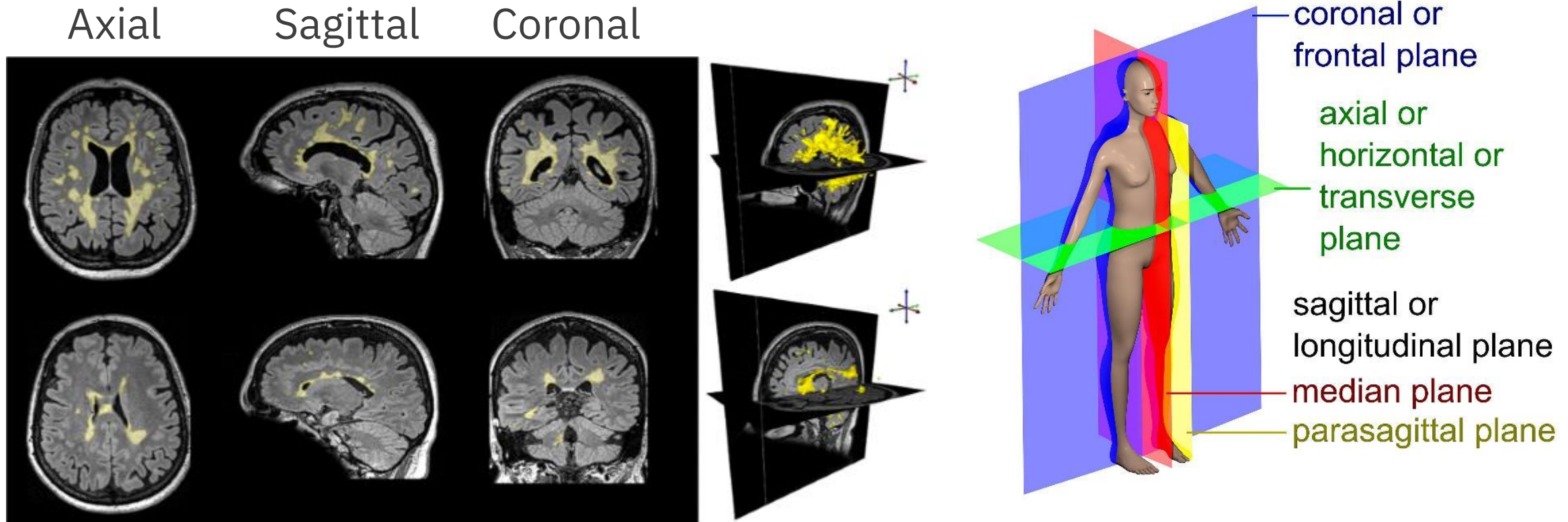


Illustrative



Slices

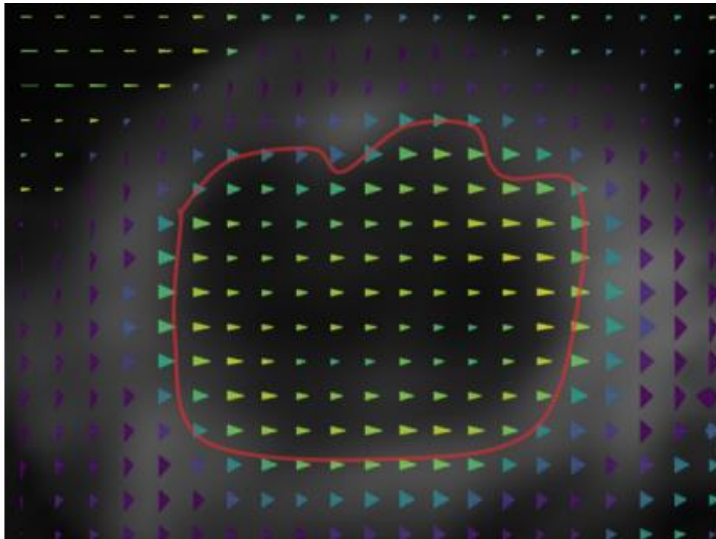
- Baseline visualization



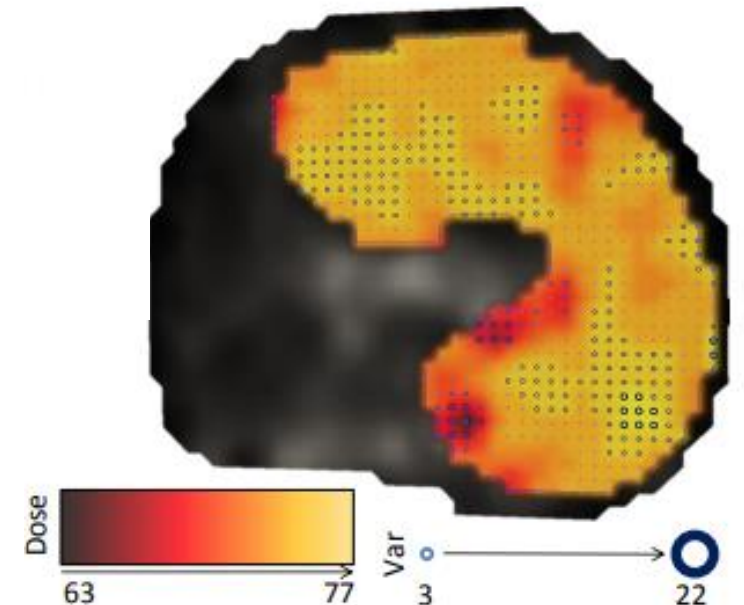
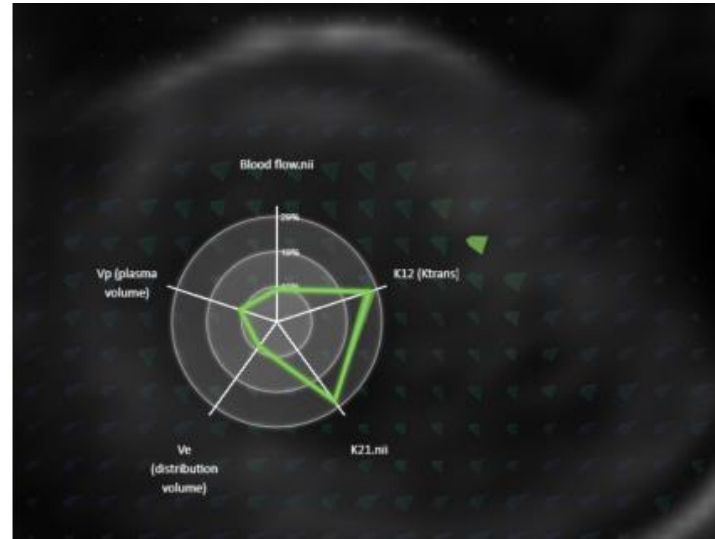
[Lesjak et al., 2018]

Slices

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



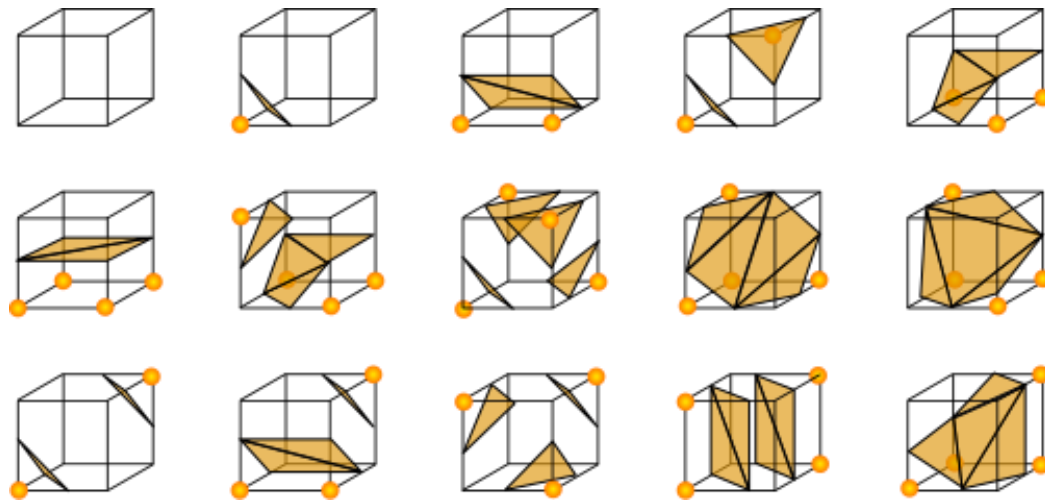
[Mörth et al., 2020]



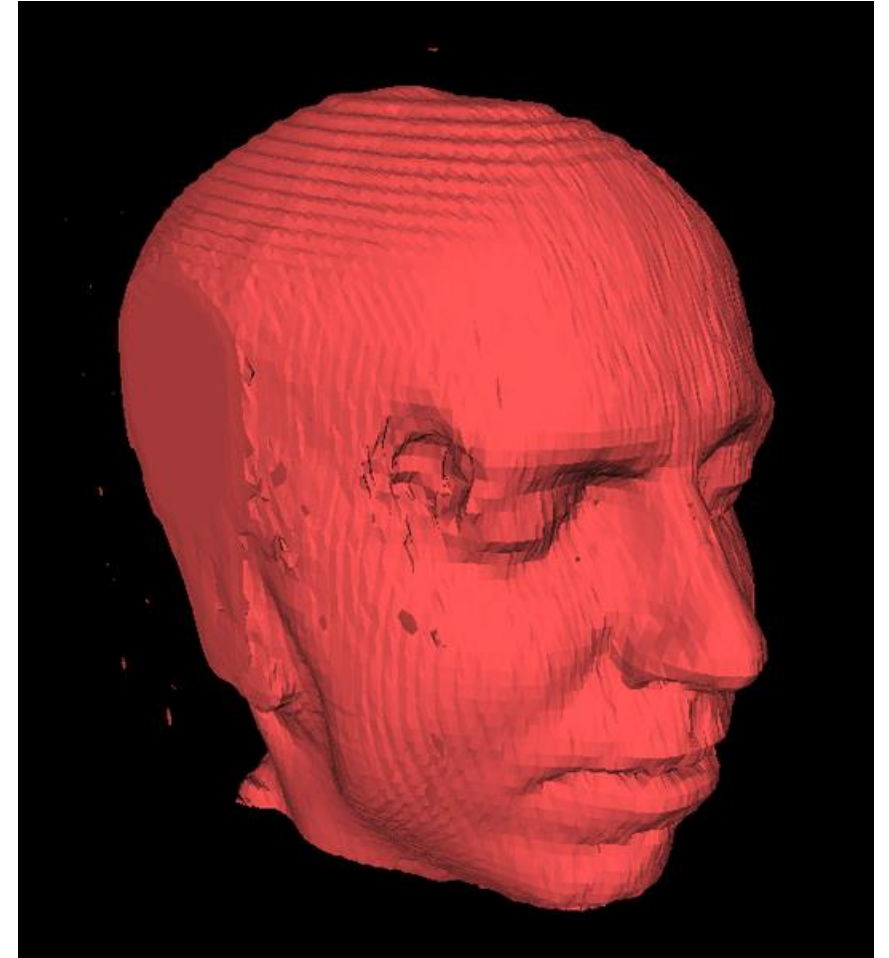
[Raidou et al., 2016]

Surface – Construction

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



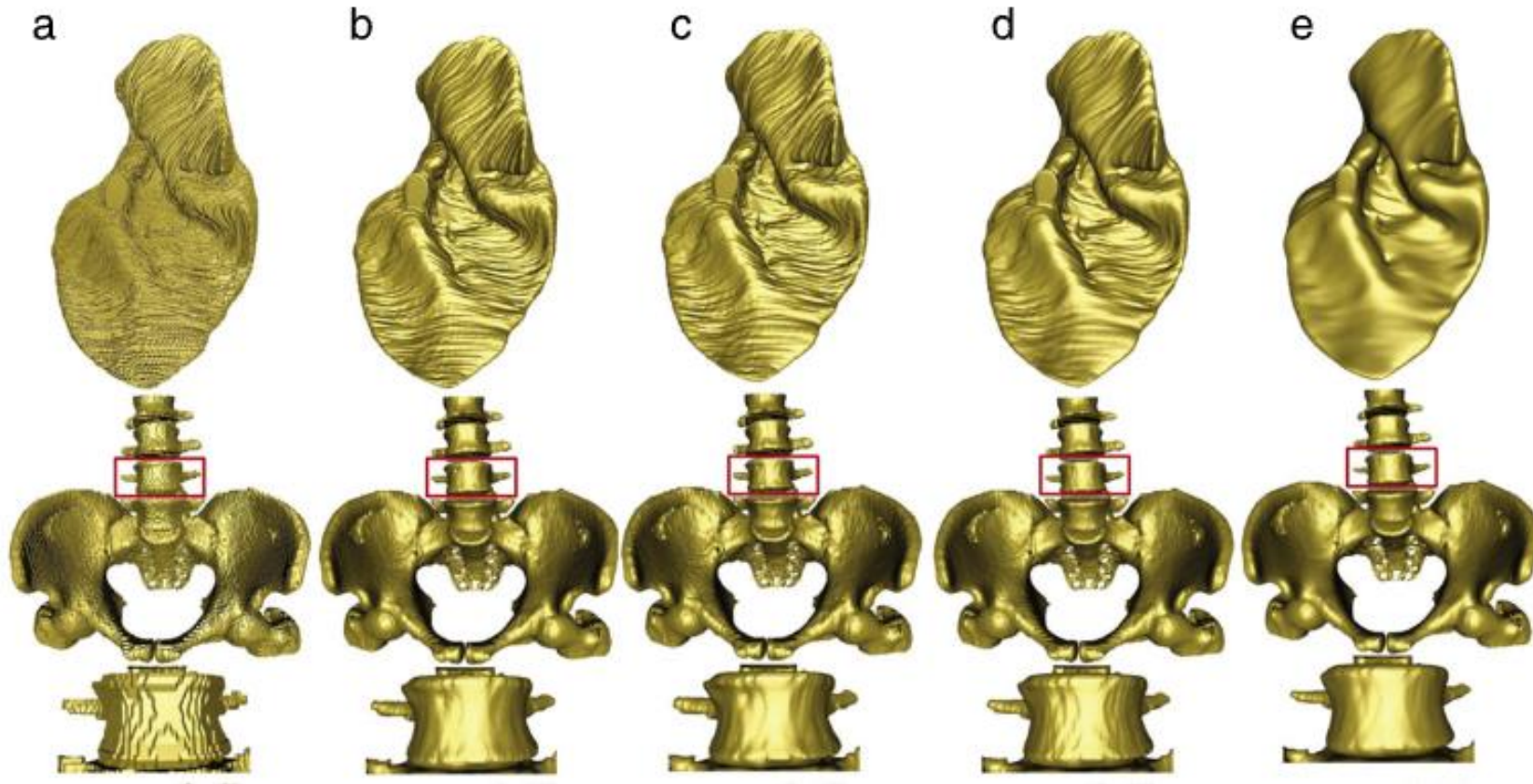
Marching cubes for iso-surface generation
[Jmtrivial via Wikimedia Commons](#)



[Dake via Wikimedia Commons](#)
CC BY SA 2.5

Surface – Smoothing

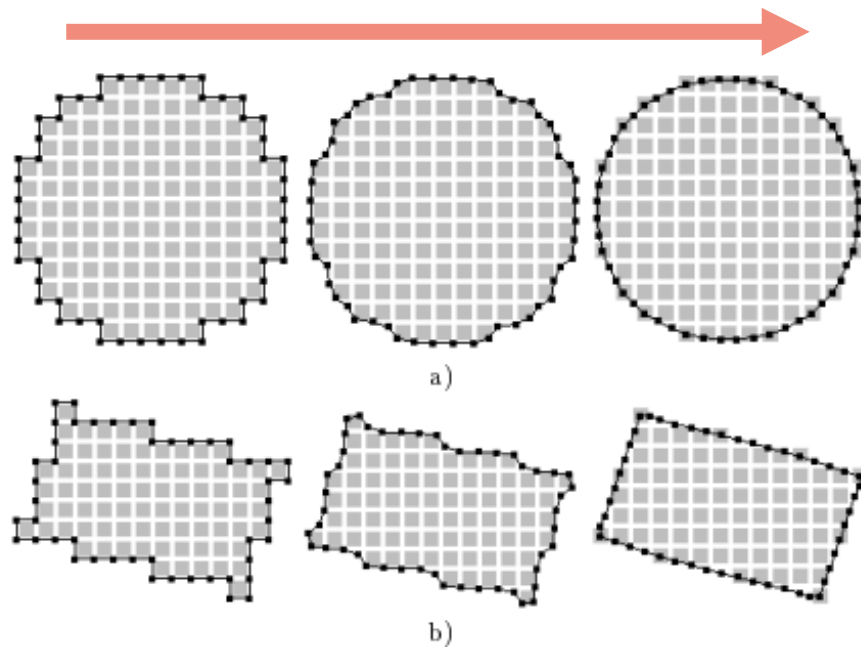
- Basic low pass filters lead to shrinkage -> Imprecision



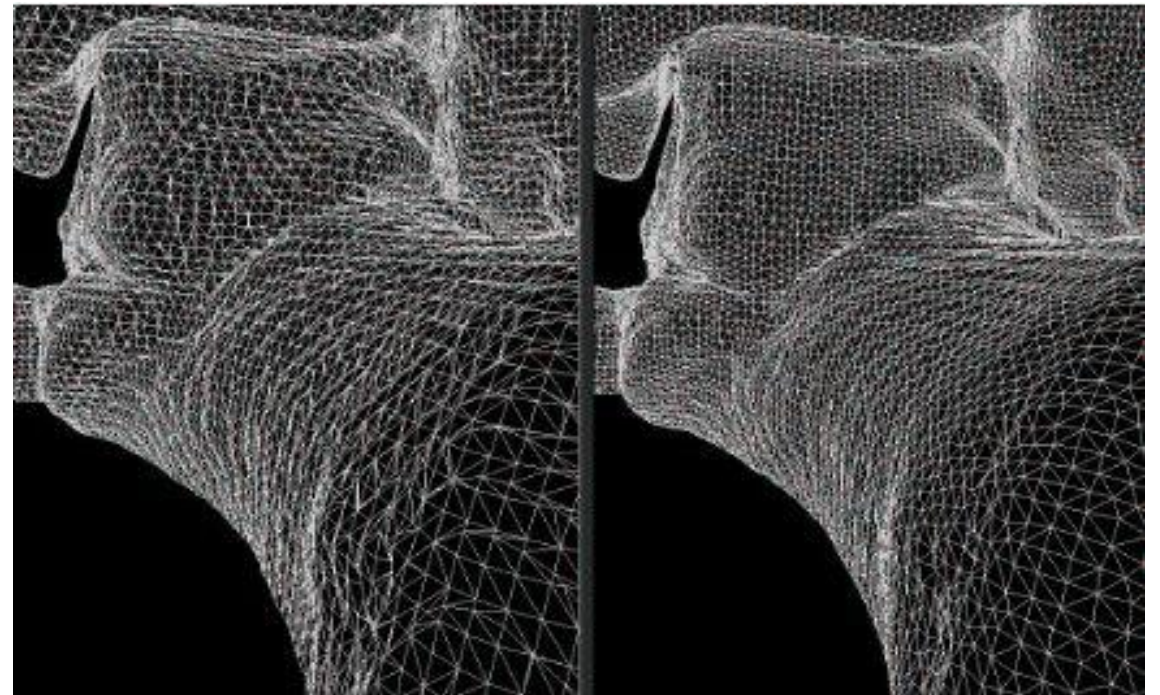
Comparison of multiple smoothing algorithms applied to MC (a) [Wei et al., 2015]

Surface – Construction/Smoothing

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



Gibson, 1998

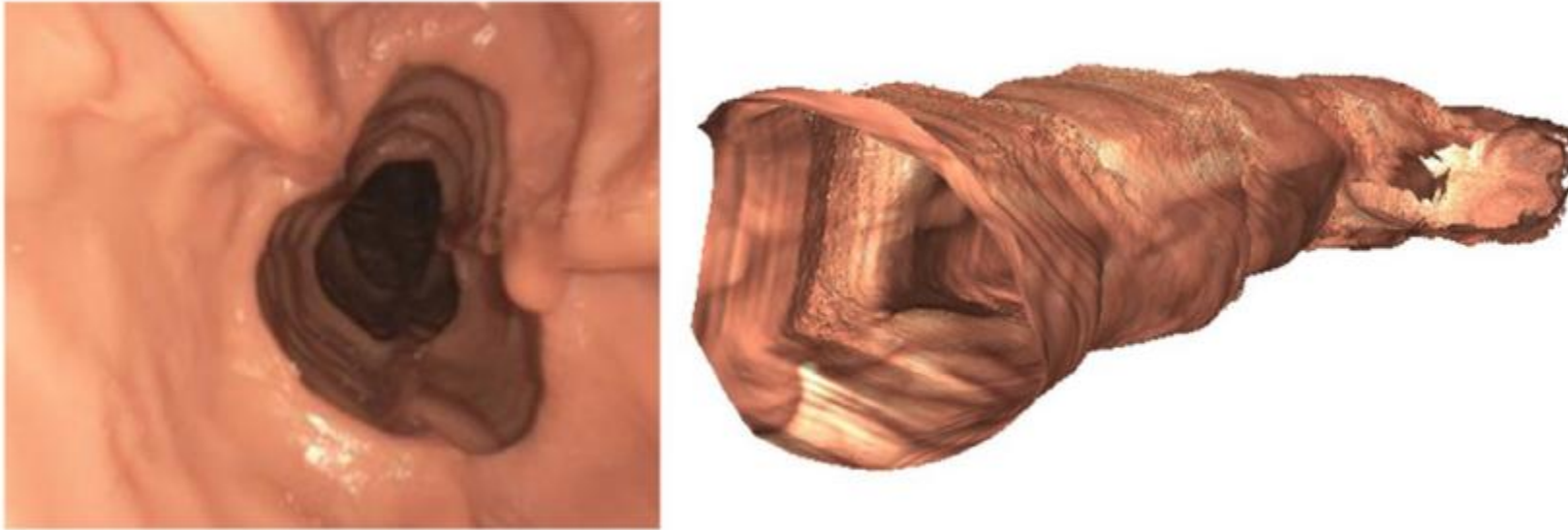


Marching cubes vs. Surface nets

[Bruin et al., 2000]

Surface – Construction

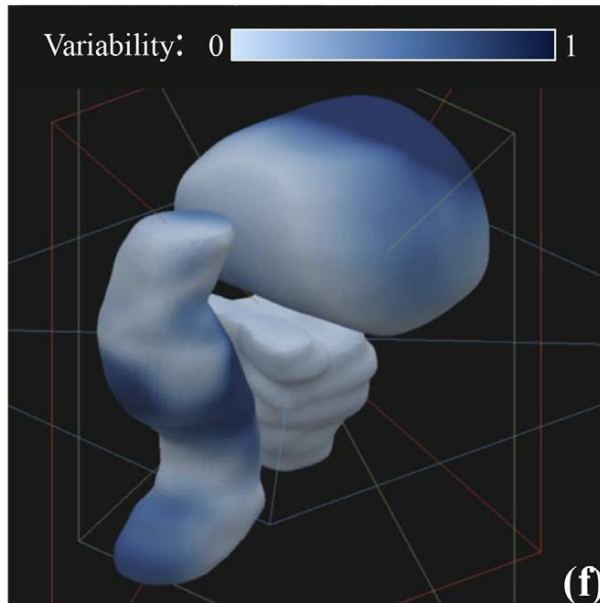
- Reconstruction from camera (e.g., endoscopy)
- Point cloud extraction + triangulation/fitting



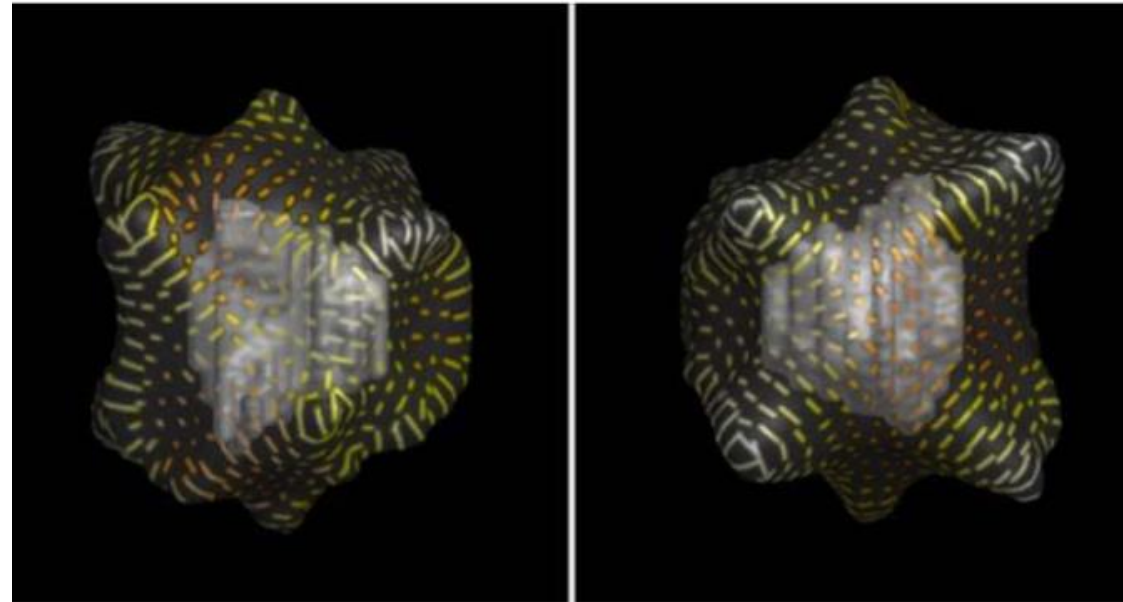
[Ma et al., 2021]

Surface – Mapping Additional Data

- Colormaps, glyphs, limited by occlusions & shading



Pelvic organs – shape variability



Tumor + iso-surface of radiation dose with curvature-oriented glyphs

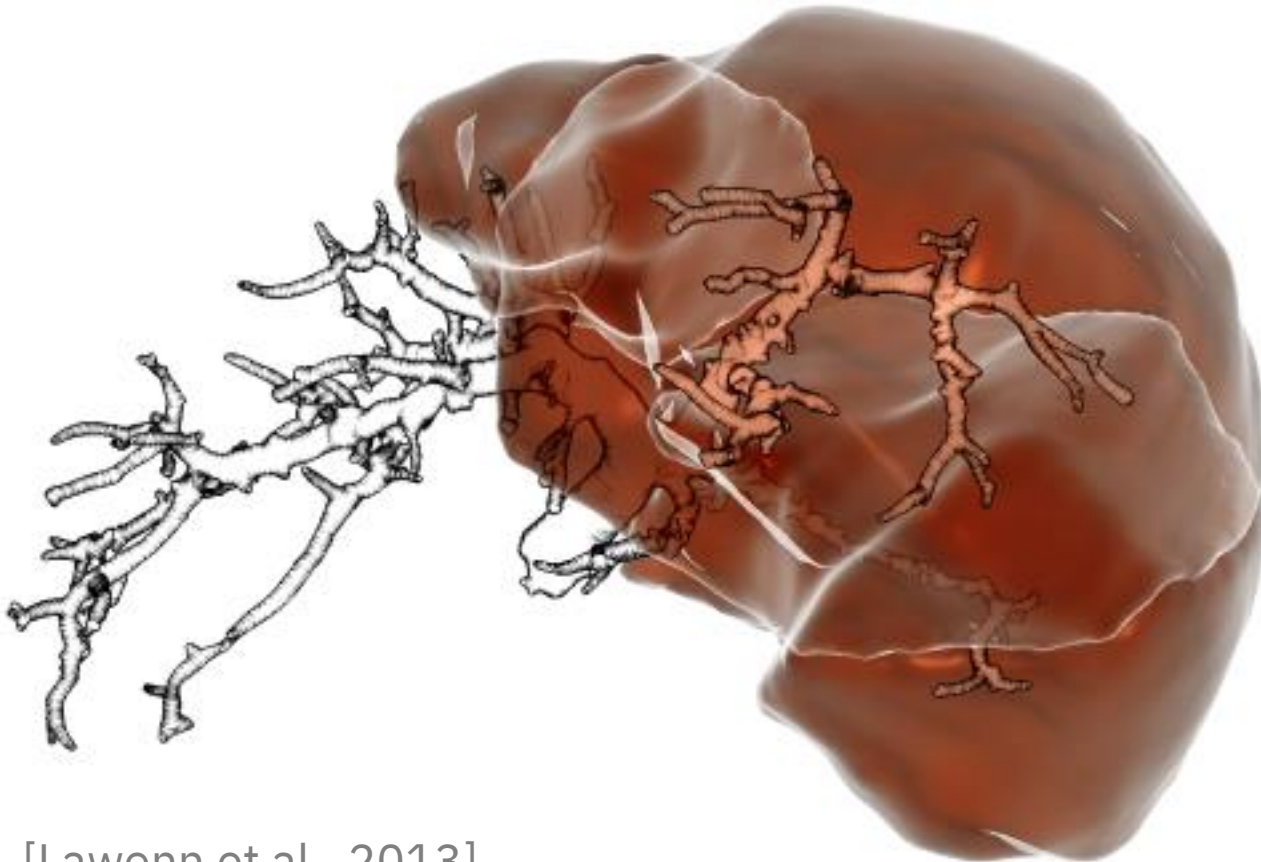
[Iterrante et al., 1997]



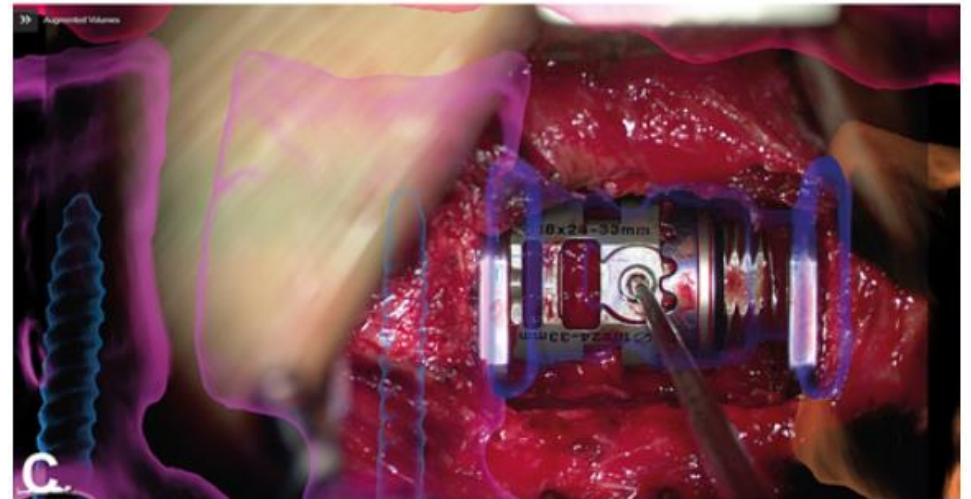
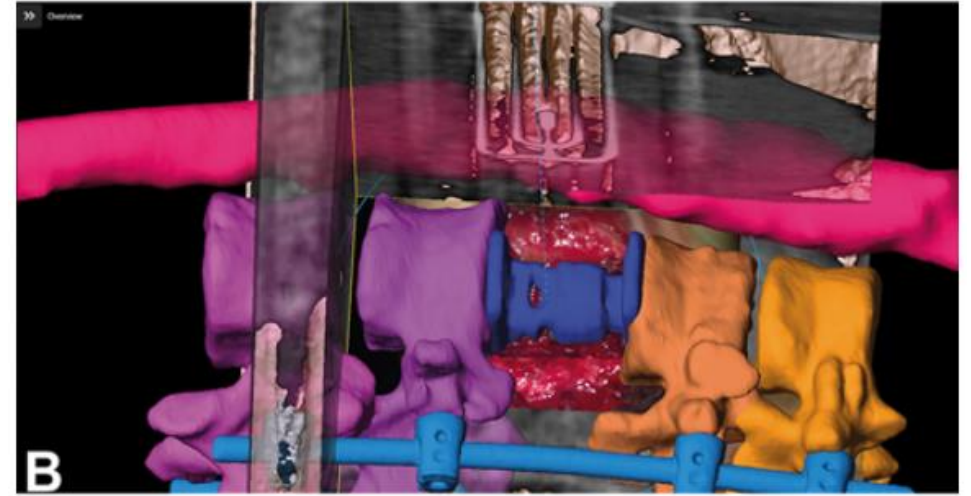
Comparison of 2 faces

Illustrative Approaches

- Hatching, stippling, silhouettes



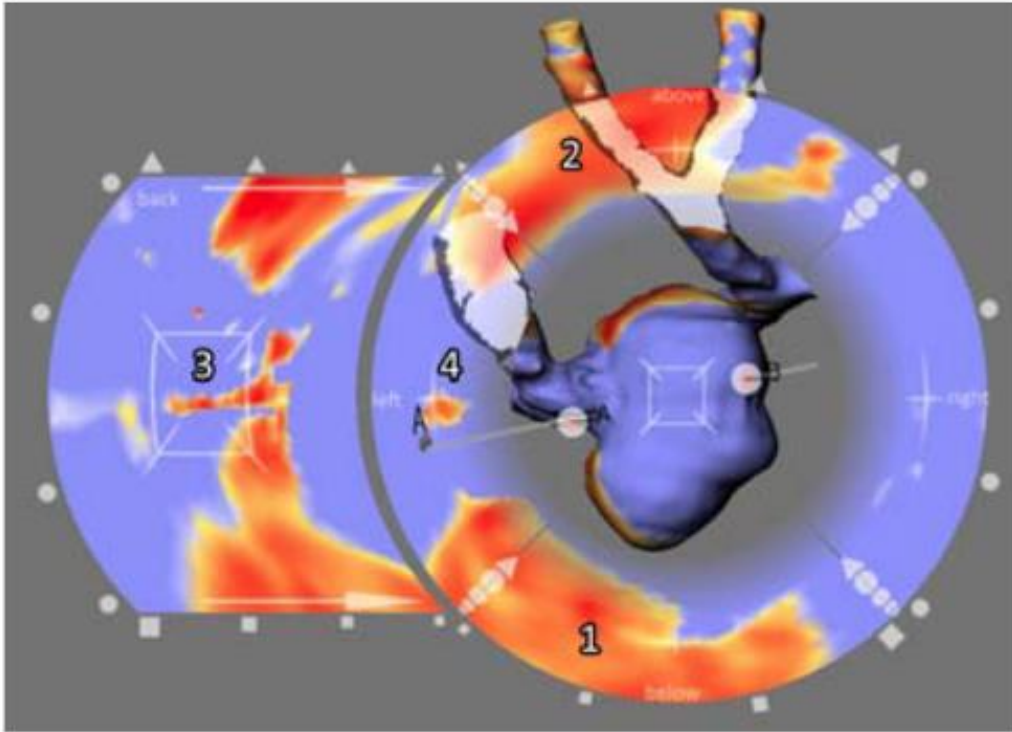
[Lawonn et al., 2013]



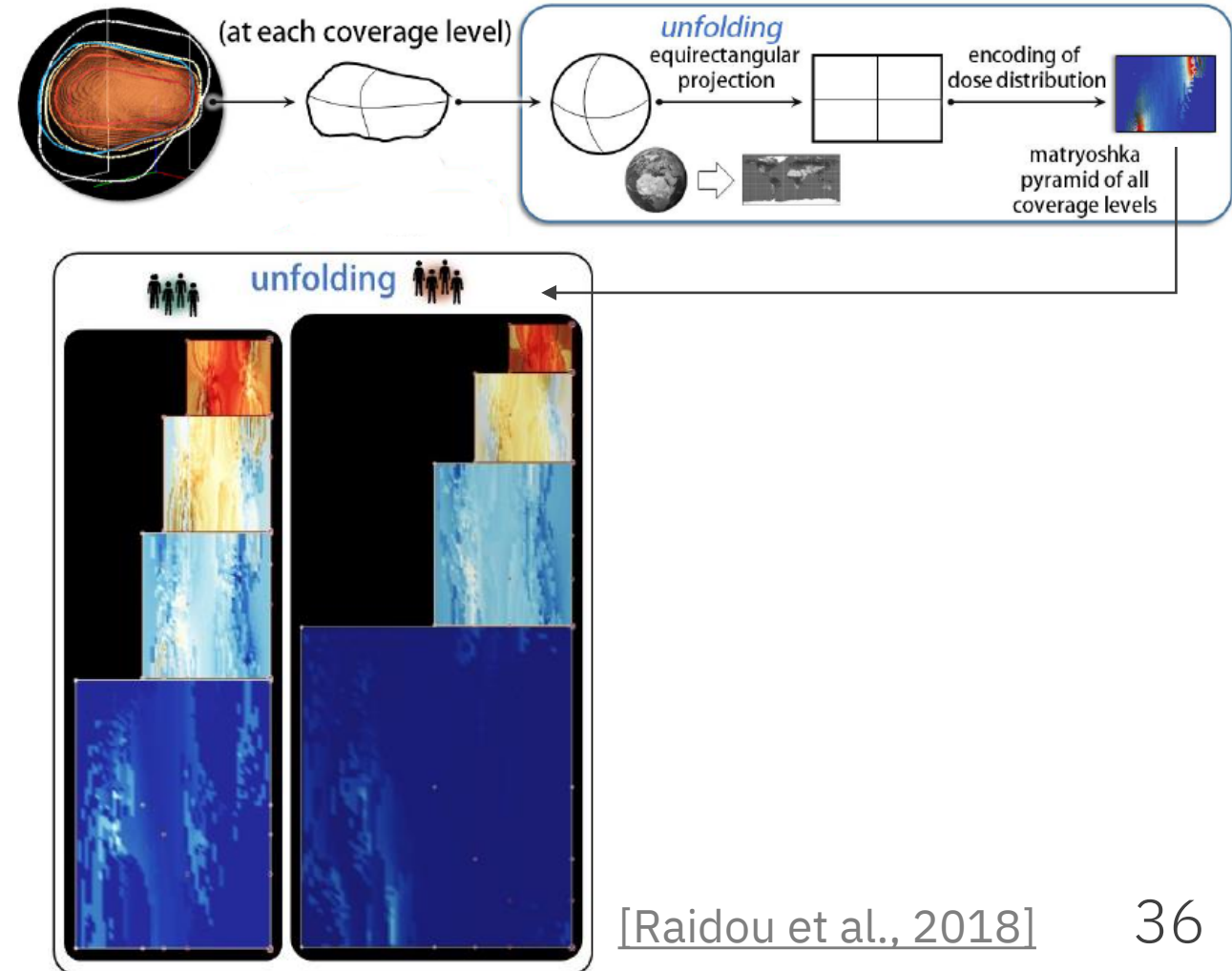
[Carl et al., 2019]

Projections and Reformations

- Flattening to deal with occlusion, better comparison



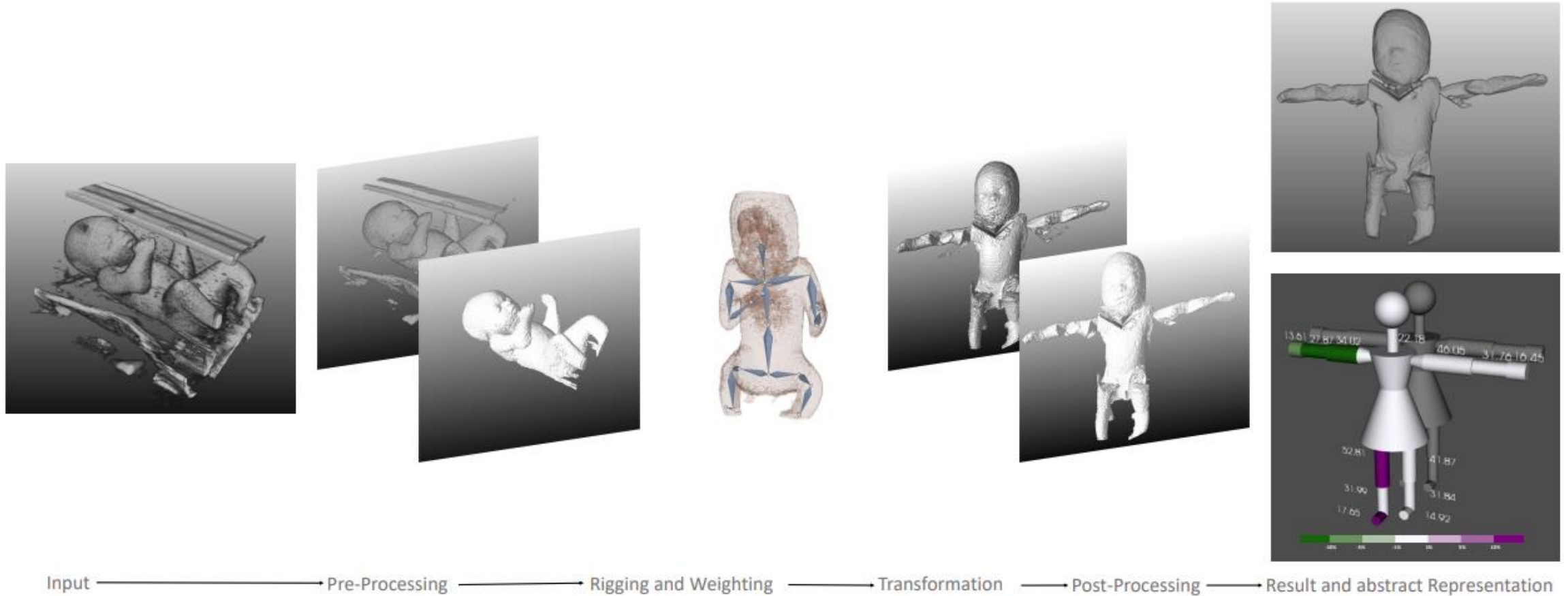
[Neugebauer et al., 2009]



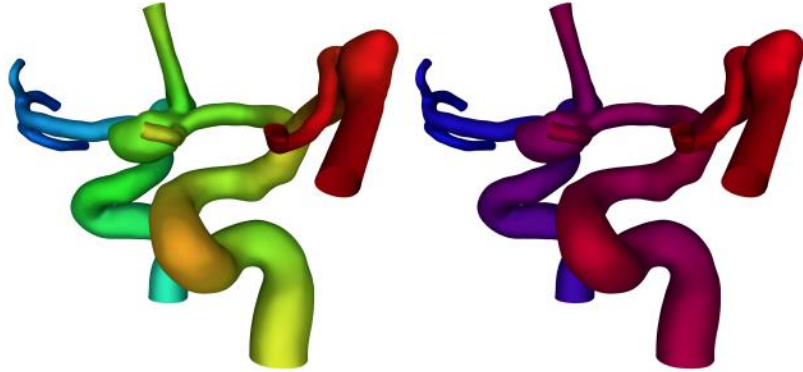
[Raidou et al., 2018]

Projections and Reformations

- Pose standardization



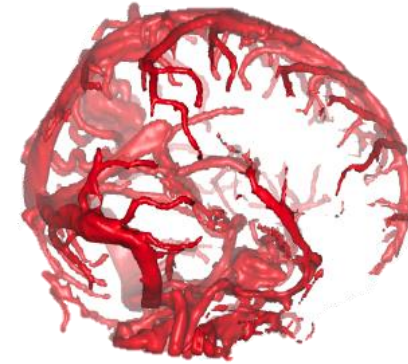
Vasculature – Depth Perception



Chromadepth

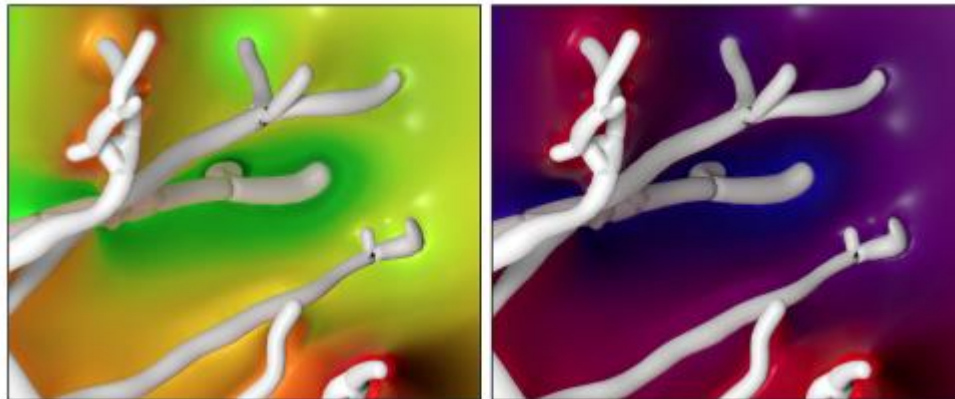
[Behrendt et al., 2017]

Psedo-Chromadepth



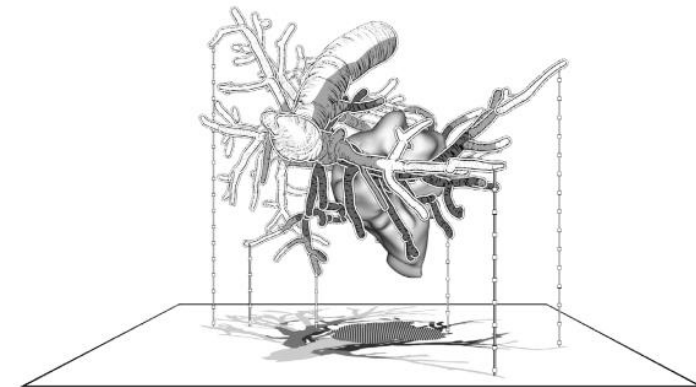
Fog

[Titov, 2020]



Void space surfaces

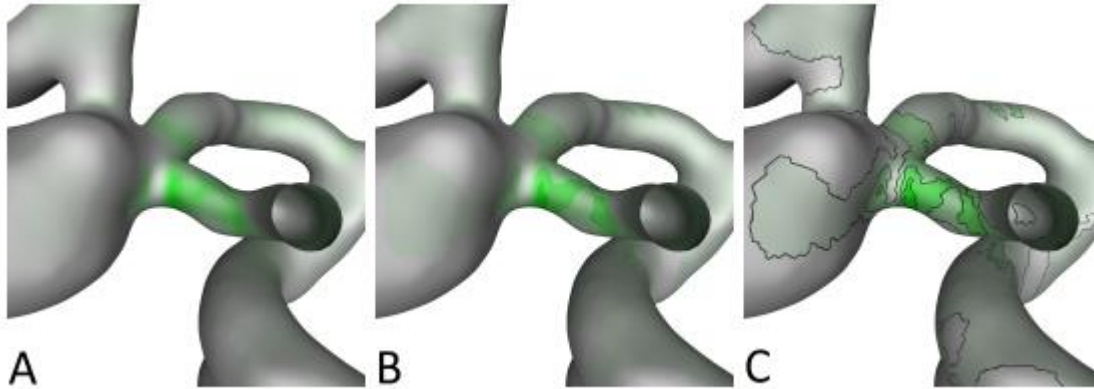
[Kreiser et al., 2021]



Hatching, outlines, shadows

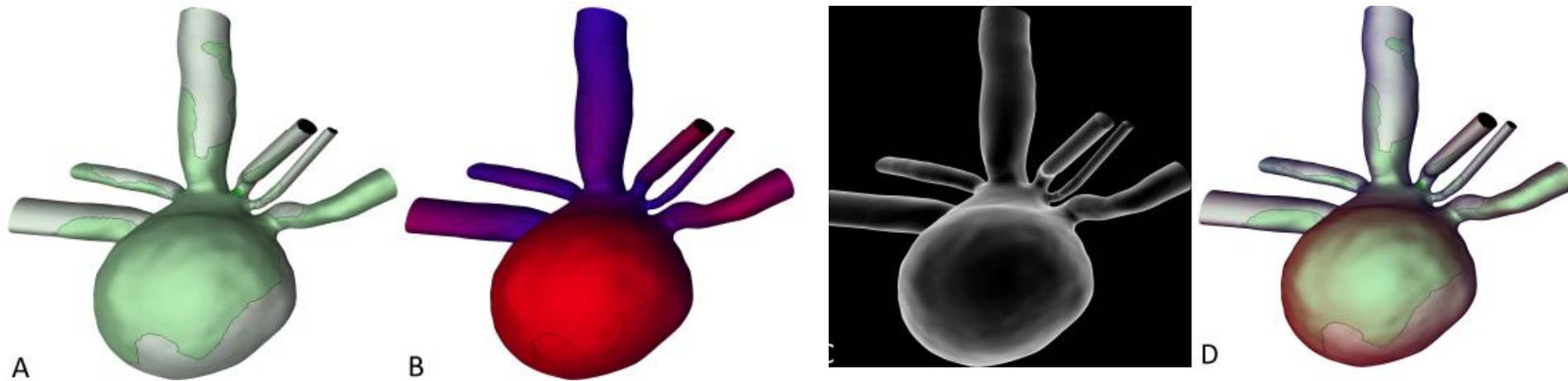
[Lawonn et al., 2015]

Vasculature – Additional Data



Wall shear stress on a vessel

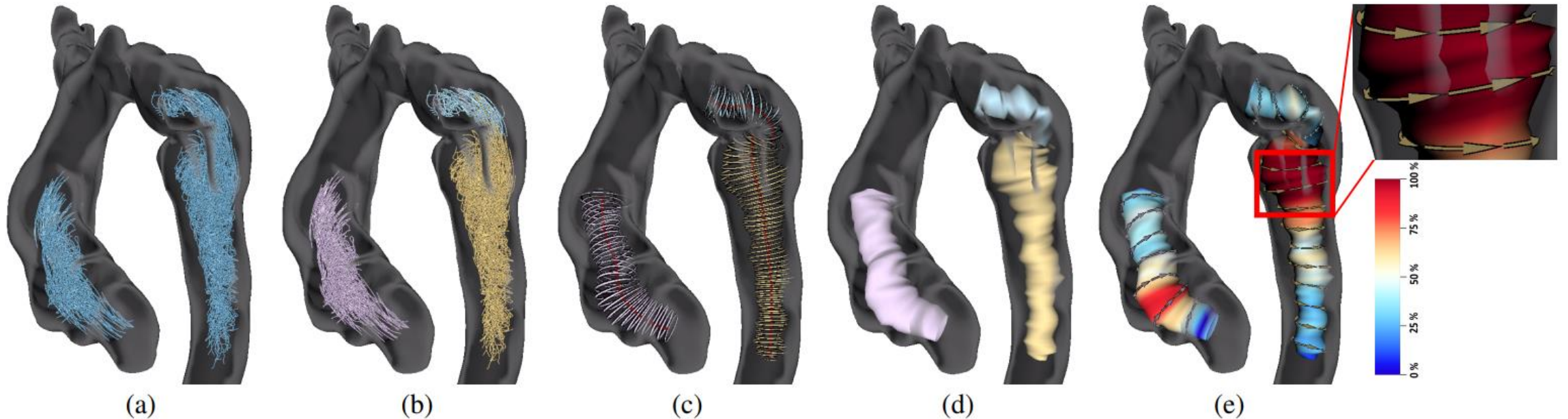
[Behrendt et al., 2017]



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

Vasculature – Blood Flow

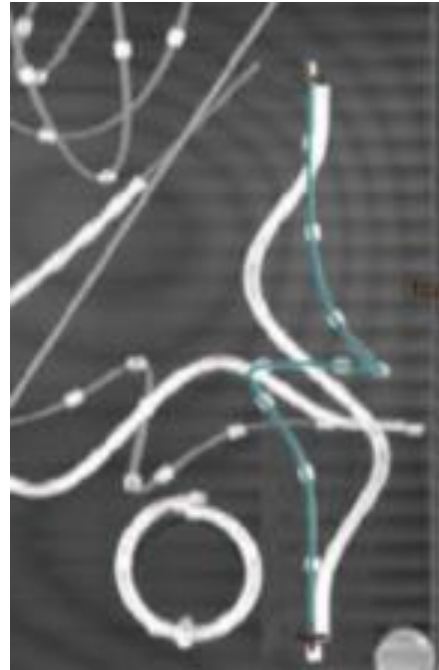
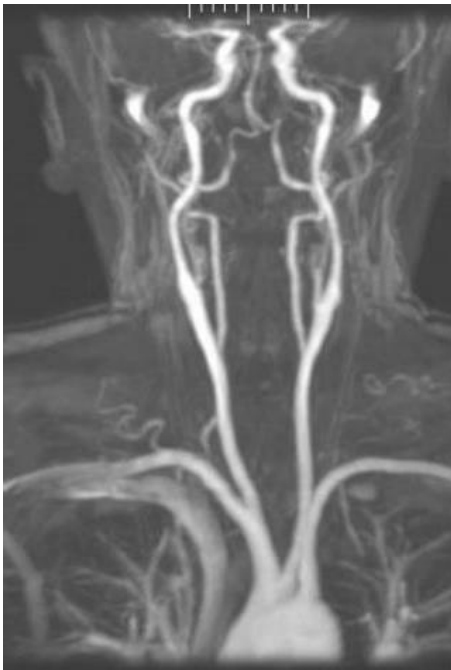
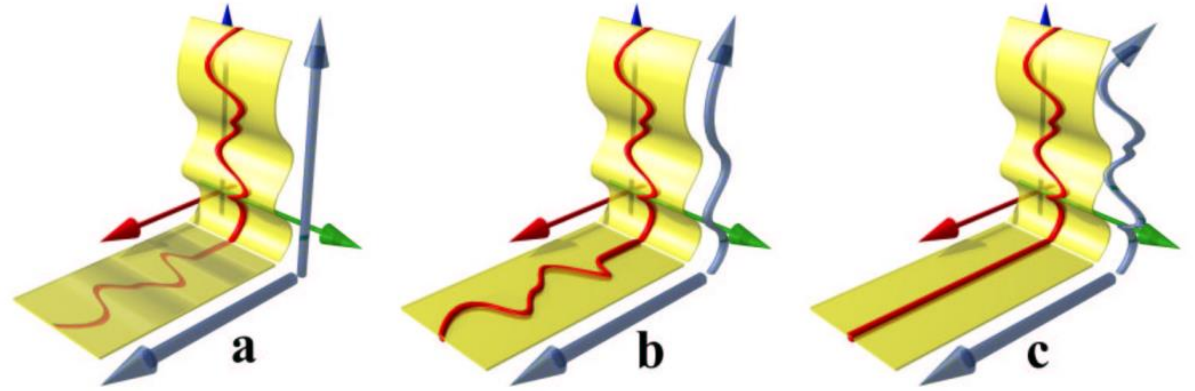
- Fluid dynamics simulations, 4D PC-MRI
- Arrows, streamlines, stream surfaces with textures or glyphs



[Meuschke et al., 2016]

Projections and Reformations

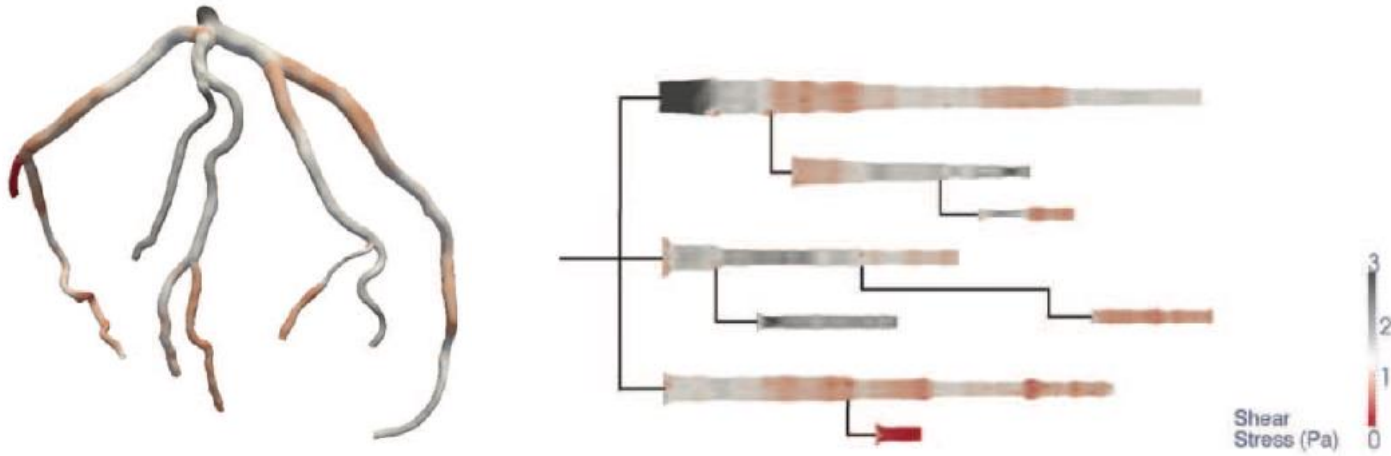
- Curved planar reformations
- Projection, stretching, straightening



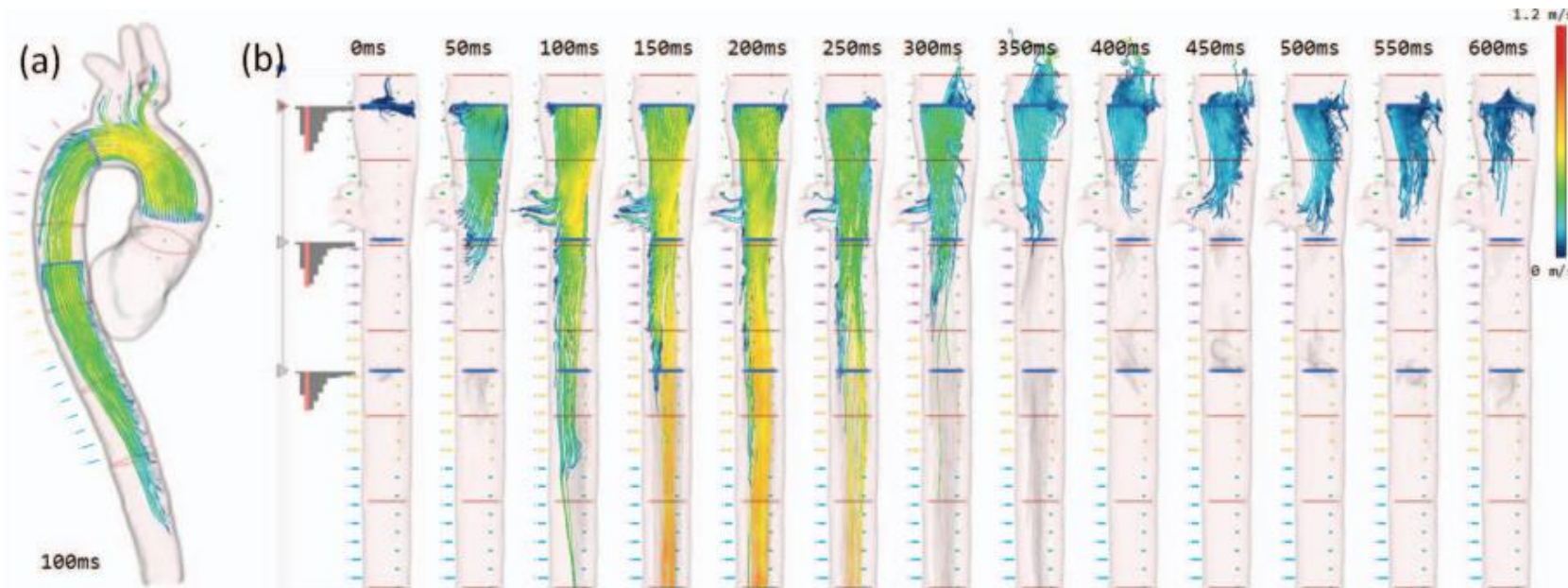
[Ofirglazer at English Wikipedia](#),
CC BY-SA 3.0, via Wikimedia Commons

[Kanitsar et al., 2002]

Projections and Reformations



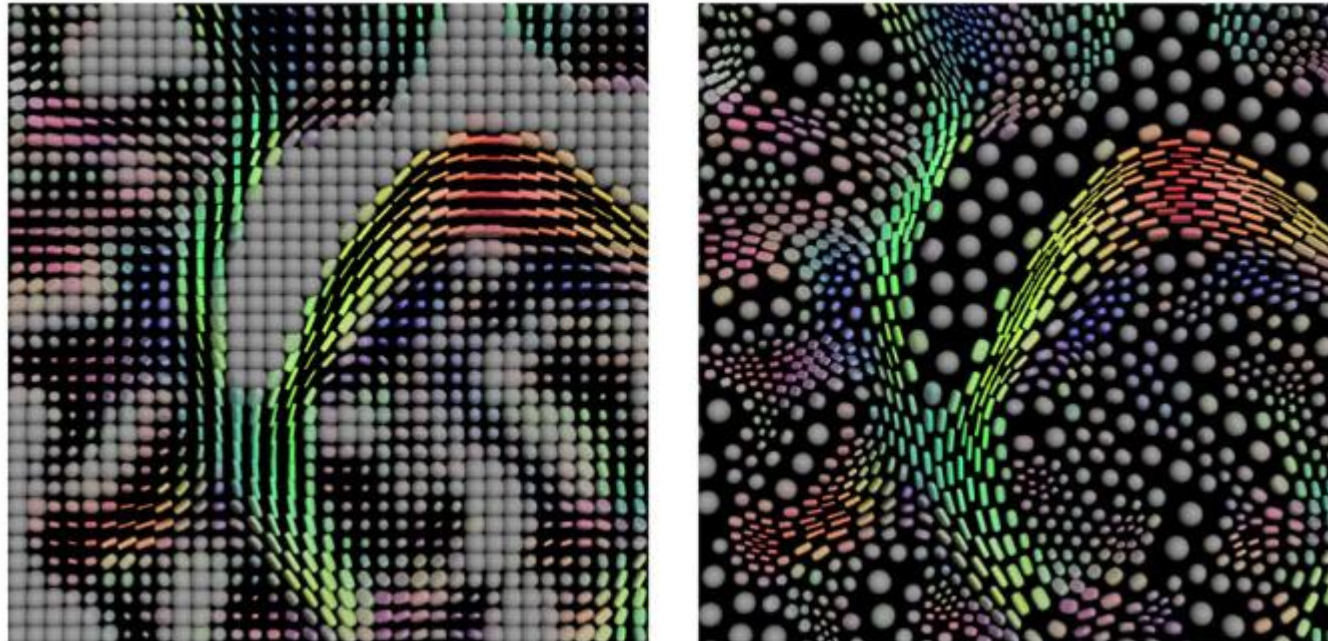
[Borkin et al., 2011]



[Angelelli & Hauser, 2011]

Brain Connectivity

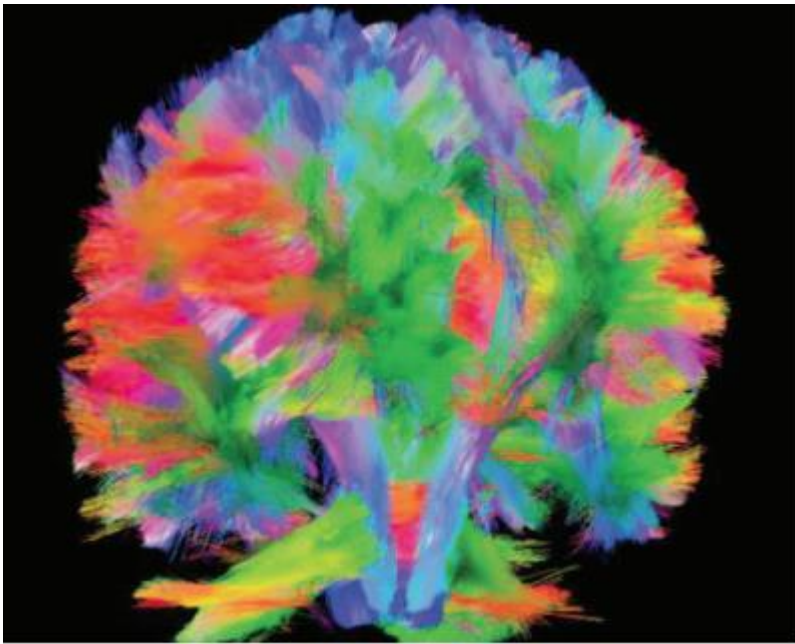
- Based on diffusion MRI
- Glyph based representations vs. fibers tracking



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

Brain Connectivity – Fiber Tracking

- Streamlines/stream tubes



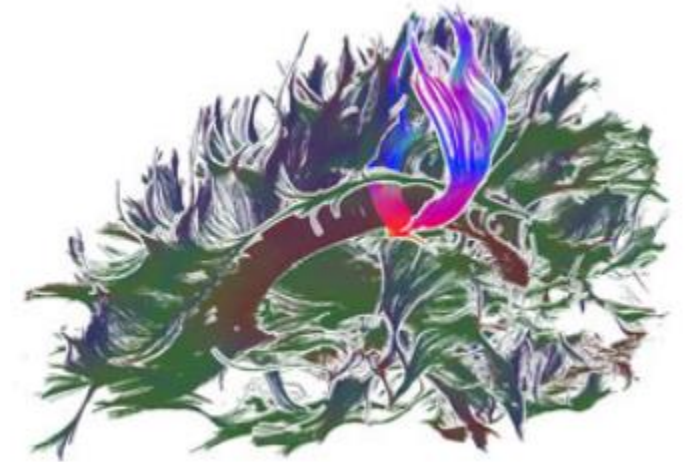
Illuminated lines

Line rendering colored according to local tangent direction

[Eichelbaum et al., 2013]



Ambient Occlusion

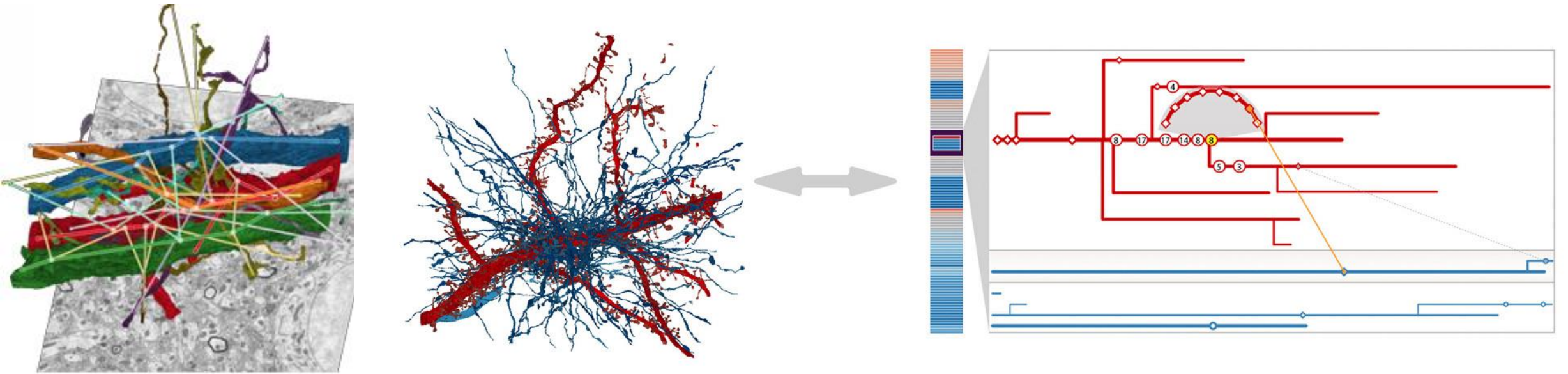


Fiber tract contraction
+ white halos

[Everts et al., 2013]

Neuronal Connectivity

- Abstraction

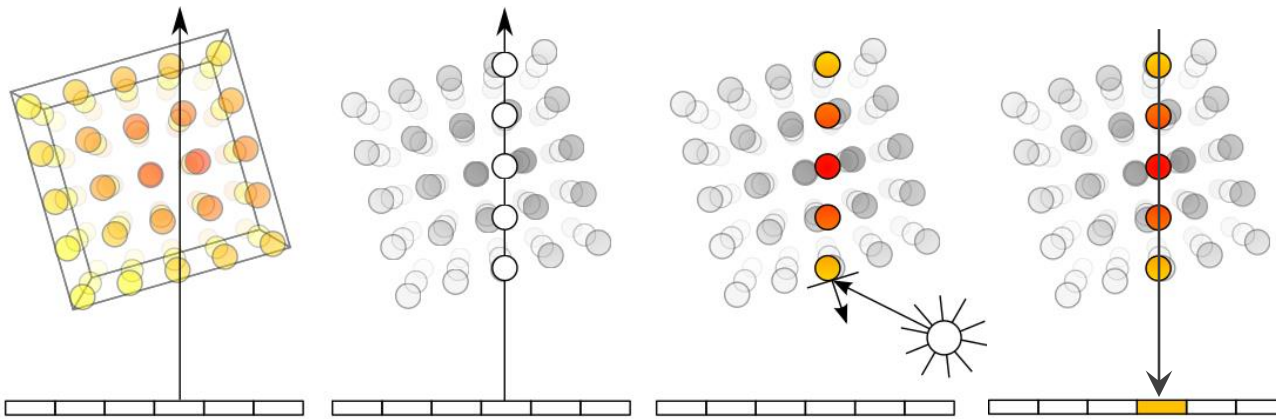


Subway map metaphor for neuronal connectivity

[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”



[Thetawave via Wikimedia Commons](#) CC-BY-SA-3.0



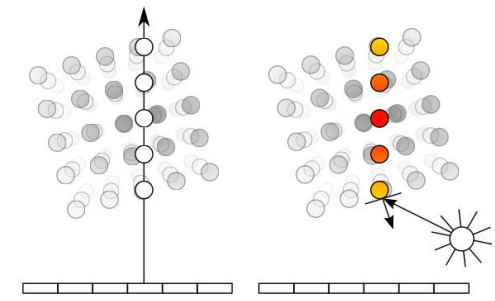
Average intensity projection



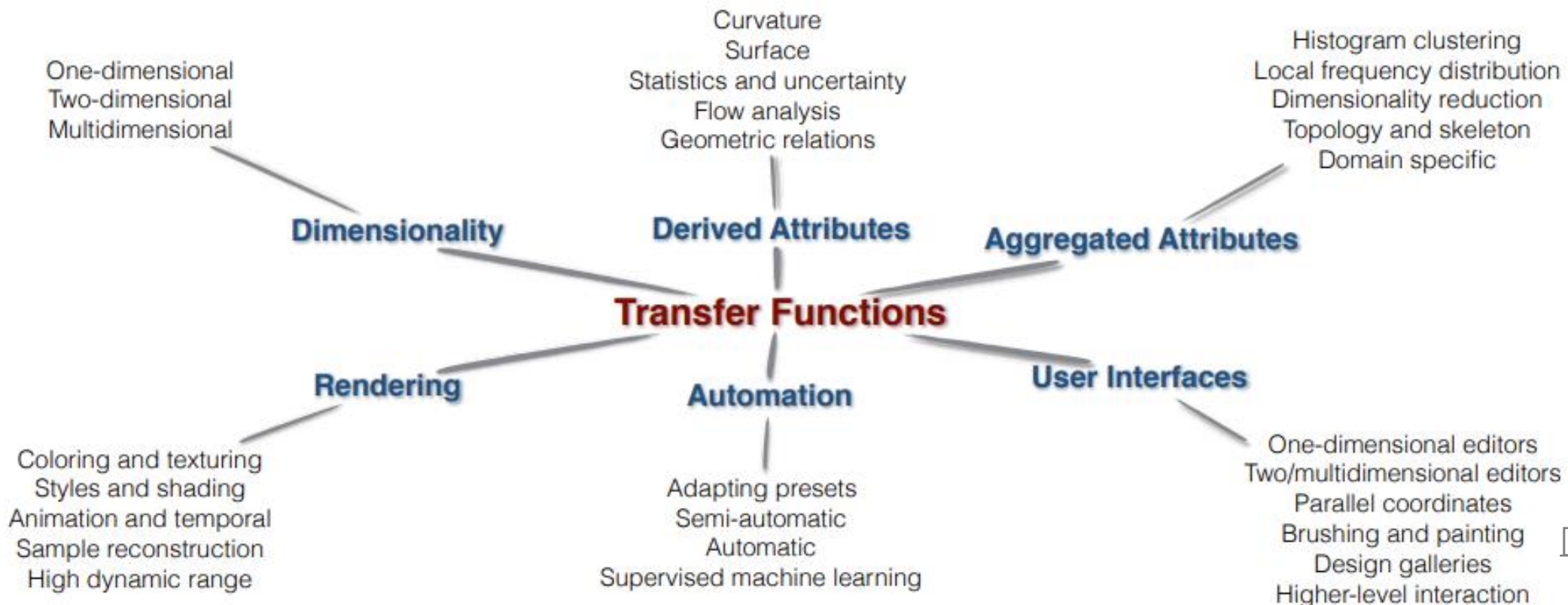
Maximum intensity projection

[Mikael Häggström via Wikimedia Commons](#) CC-BY-SA-2.1

Transfer Functions



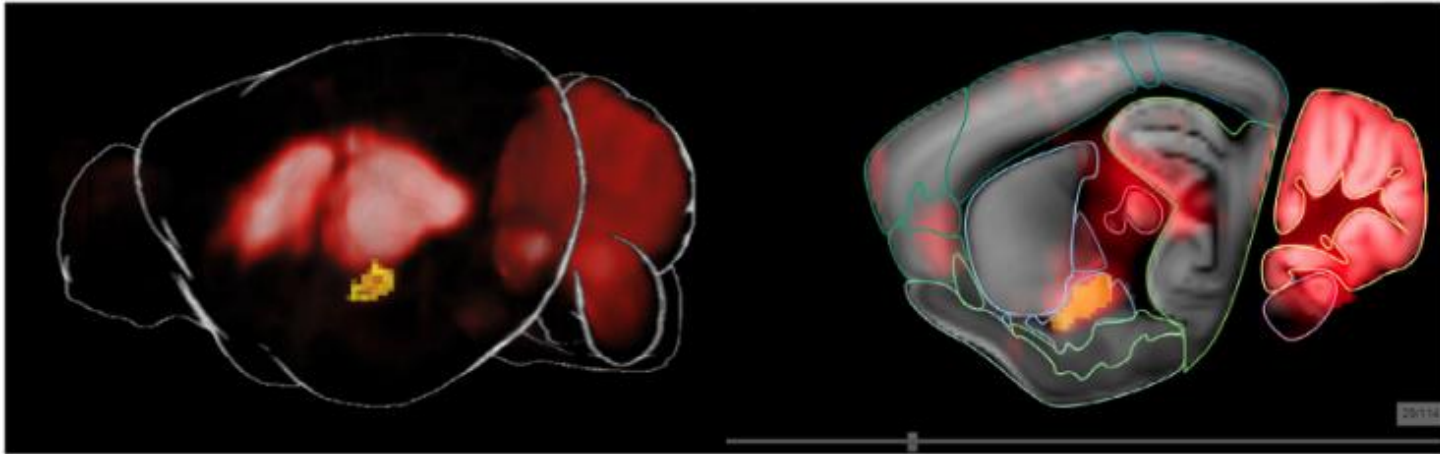
- Define opacity and color of each voxel
- 1D – classification based on material density (intensity) of the voxel
- Multidimensional – additional attributes, e.g., gradient or curvature



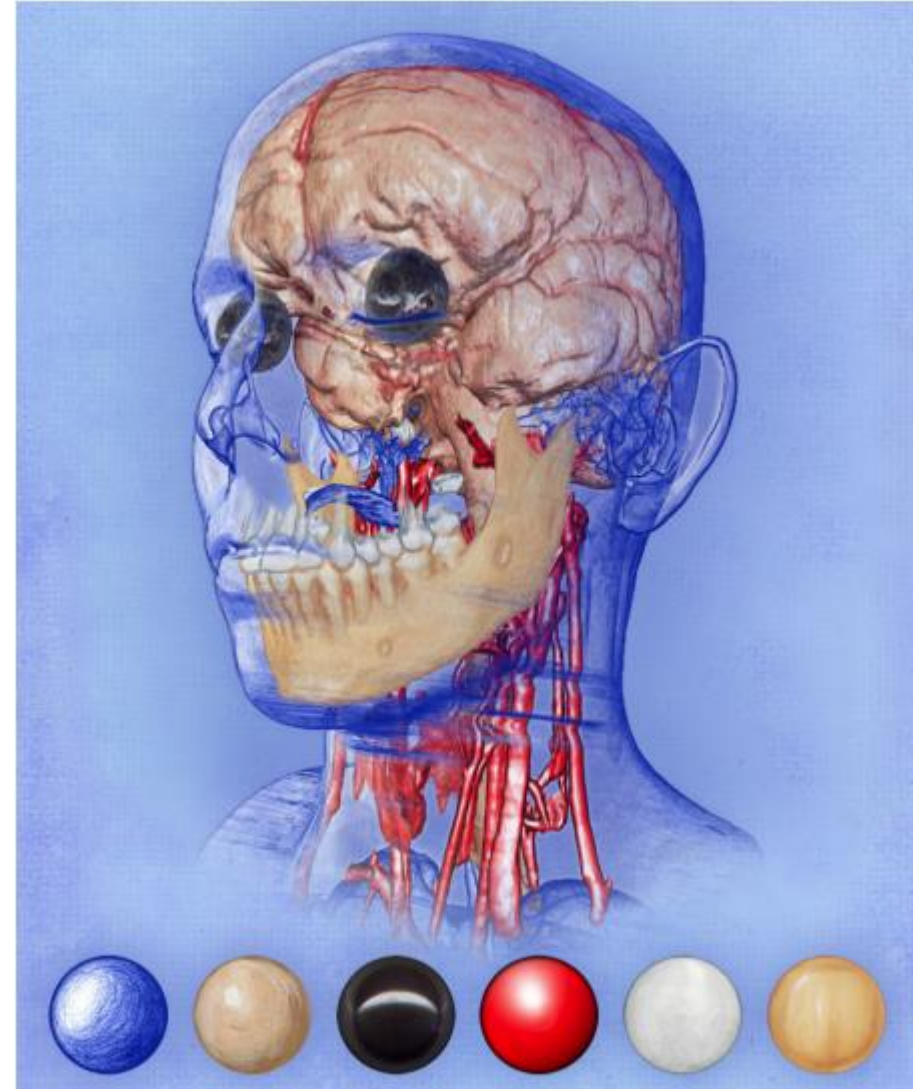
[Ljung et al., 2016]

Illustrative Techniques

- Silhouettes, hatching , style transfer

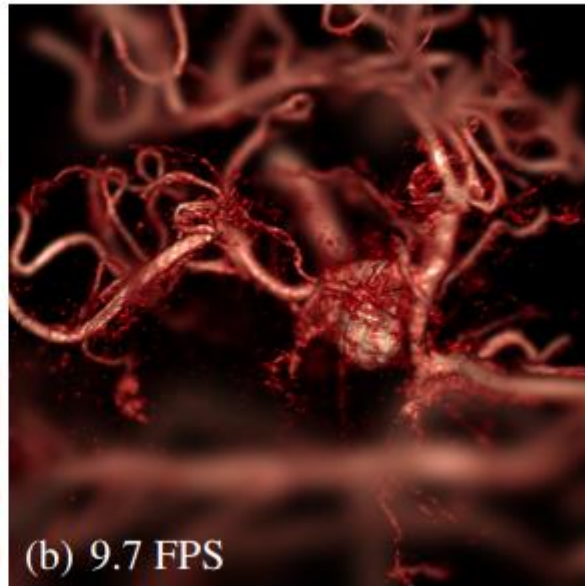
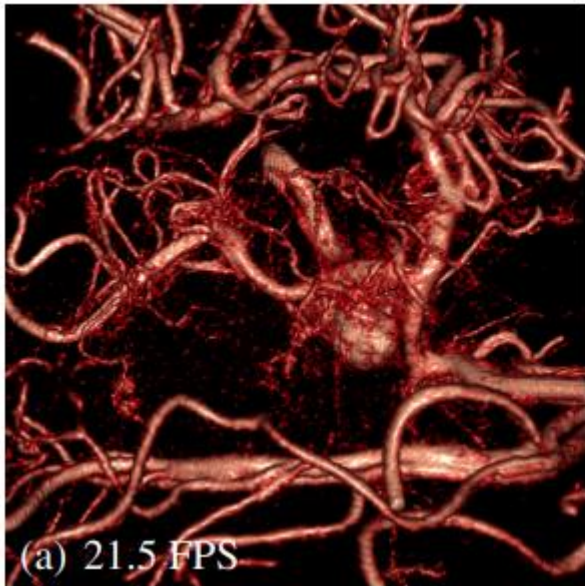


[Ganglberger et al., 2019]



[Bruckner & Gröller, 2007]

Depth Perception

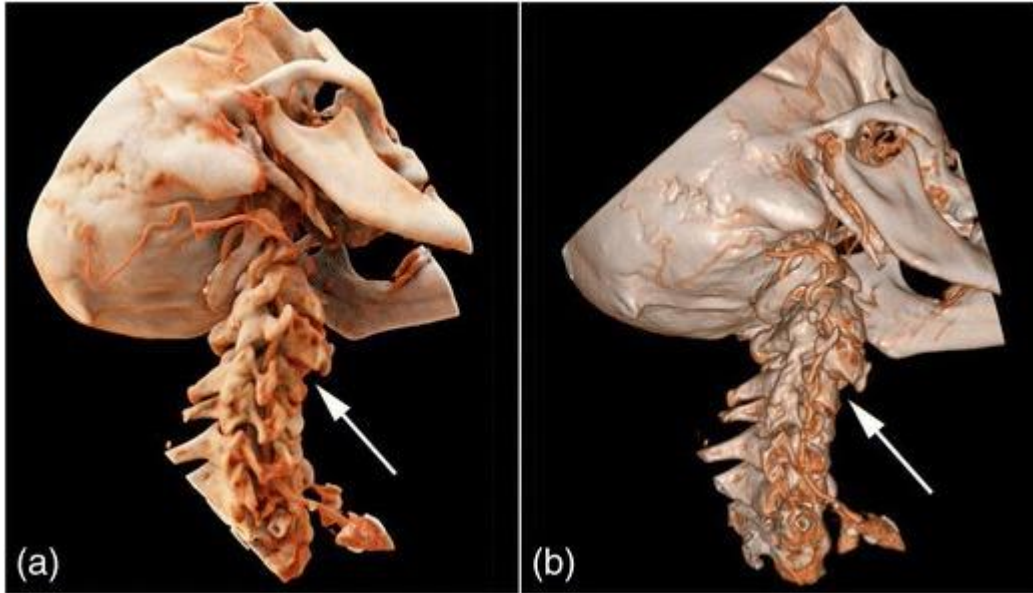


Depth of field simulation
[Schott et al., 2011]

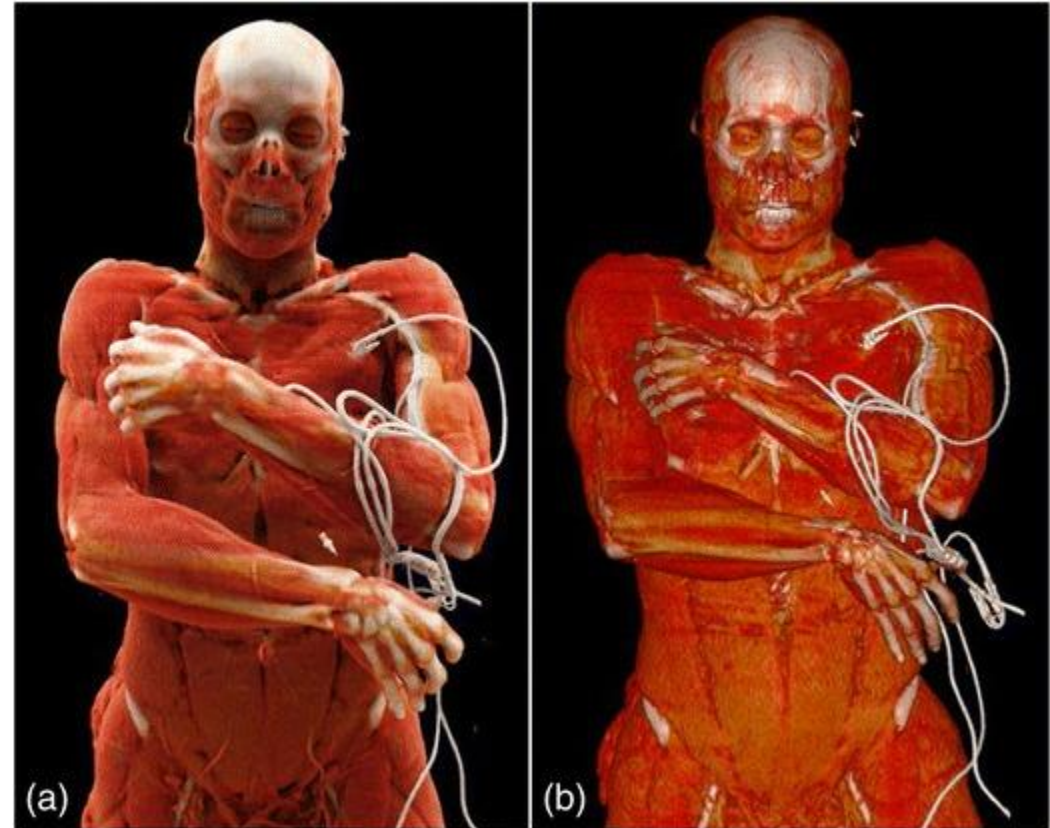
Depth dependant silhouettes and blurring
[Svakhine et al., 2009]



Lighting – Cinematic Rendering



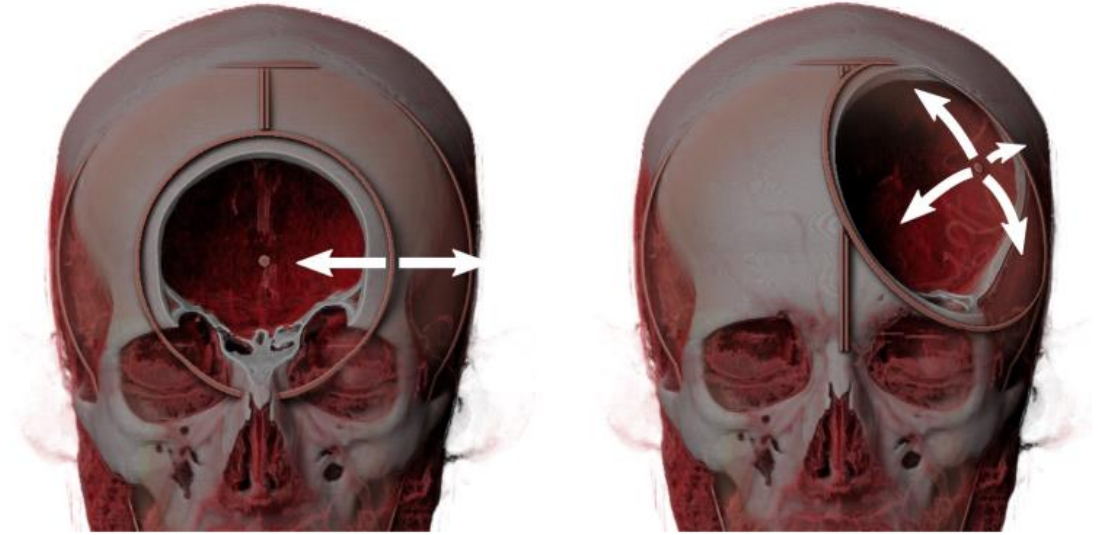
- Conventional VR – local illumination
- Cinematic rendering – simulates physical light scattering



[Dappa et al., 2016]

Smart Visibility

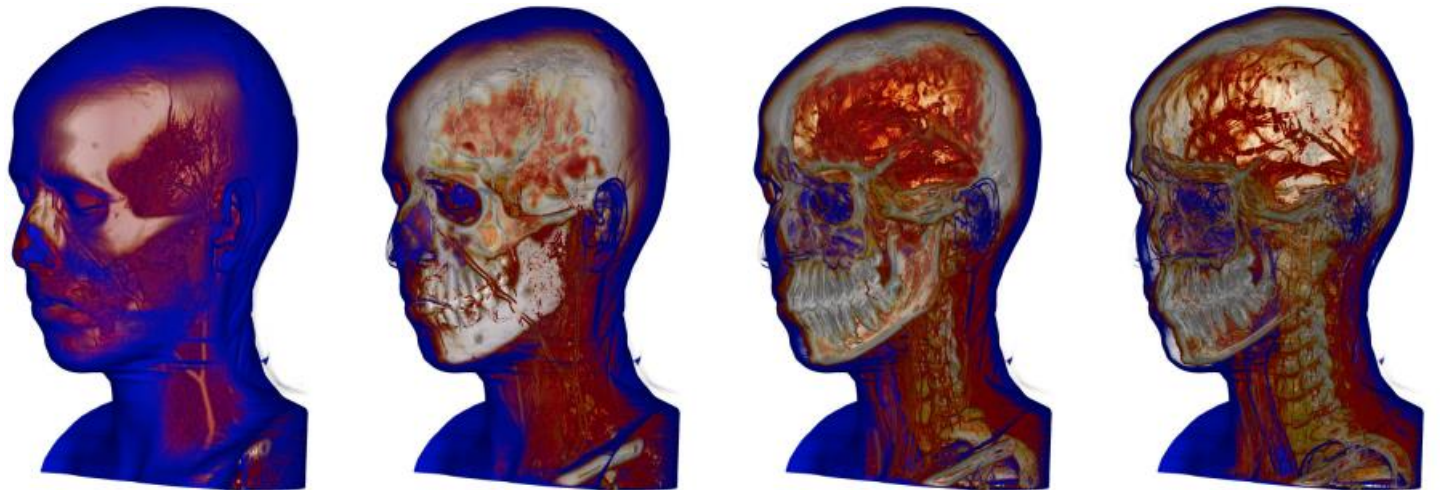
- Peel aways
- Exploded views
- Importance driven TFs
- Lenses



[Stoppel & Bruckner, 2018]



[Bruckner & Gröller, 2006]



[Bruckner et al., 2005]

Visualization Approaches for Non-Spatial Data

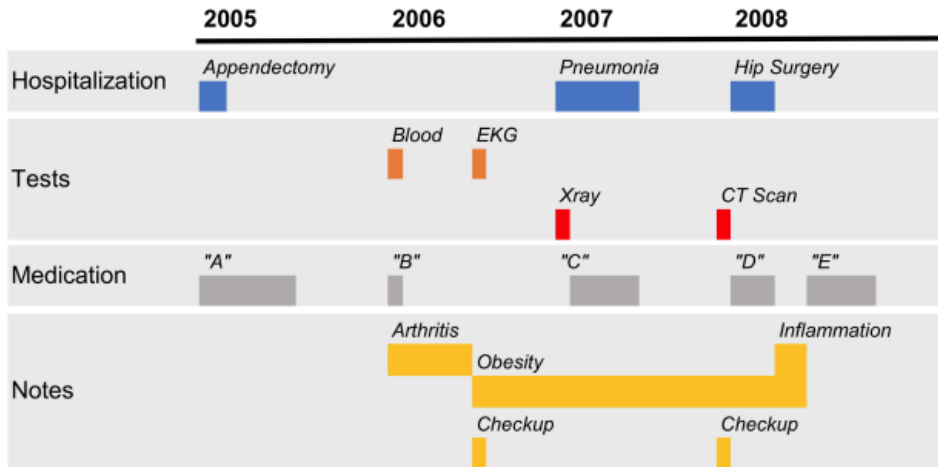


Visualization Challenges

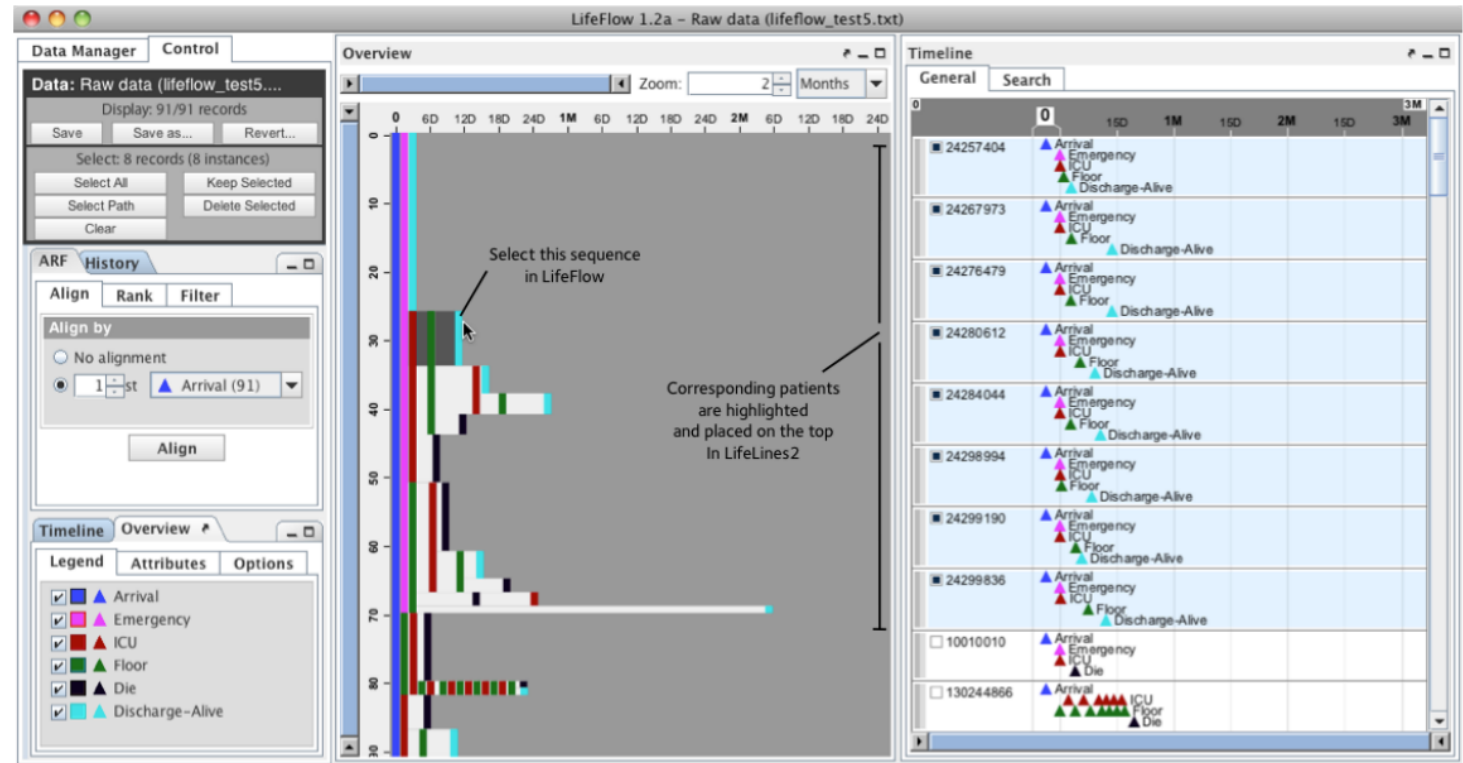
- Datasets too large for visual inspection of all individuals/data points
- Combination with statistical and/or machine-learning based analysis
- Data quality: missing values, standardization, ...

Electronic Health Records

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



LifeLines



[Wongsuphasawat et al., 2011]

Electronic Health Records

- Visualizing medical texts

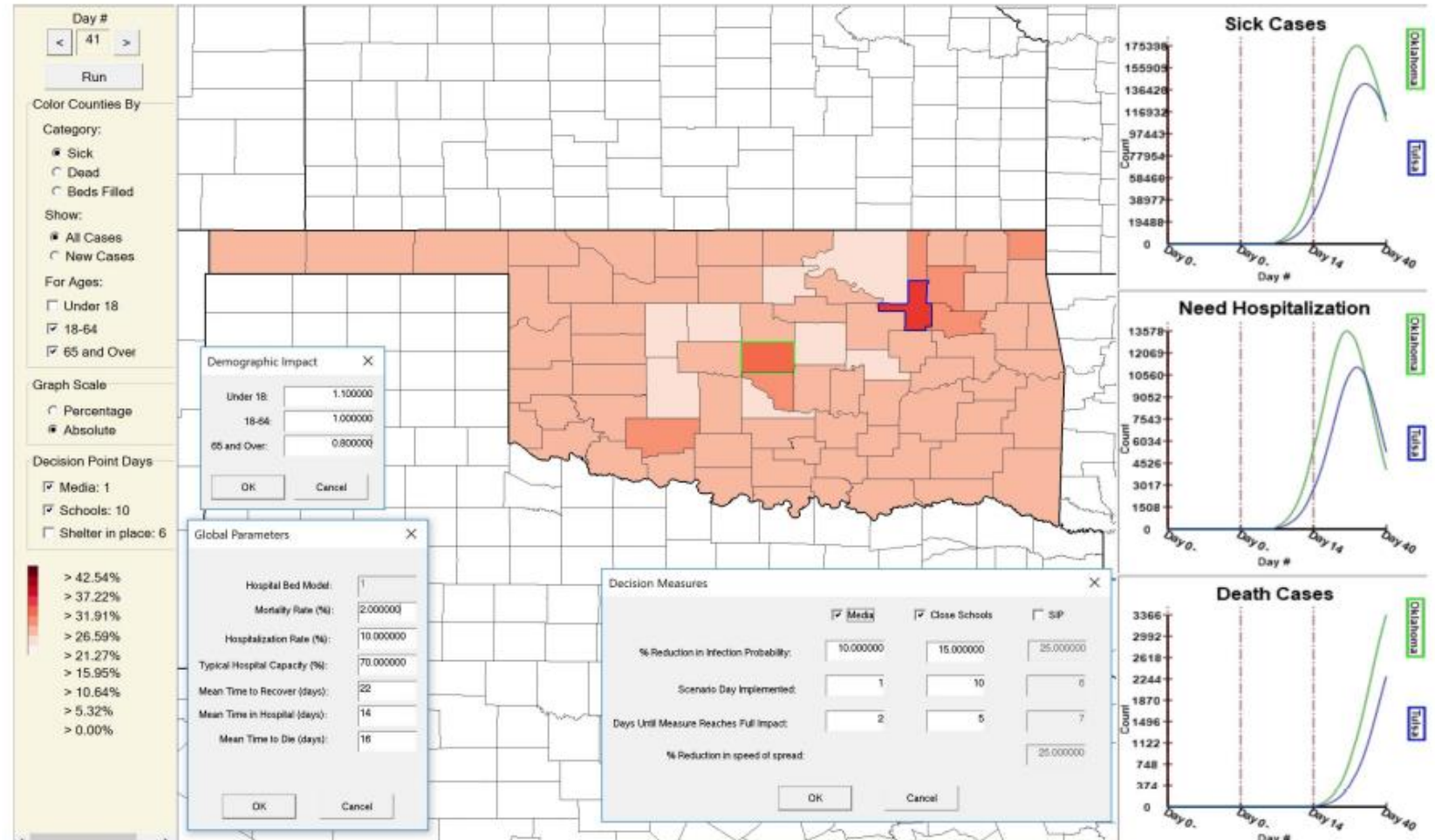
Doccurate
[Sultanum et al. 2018]

The screenshot displays a comprehensive EHR interface with the following components:

- A.1 Patient Information:**
 - Current date: 20 Jun 2206
 - Name: Macy Gauthier
 - Birth (Age): 6 Oct 2168 (37)
 - Sex: F
- A.2 Binning Document Type:**
 - 3d: Nur/O.
 - 1w: ECG
 - 2w: Disch.
 - 3w: Echo
 - 1m: (empty)
 - 3m: (empty)
- A.3 Filter Collections:**
 - Other
 - Cardiovascular
 - Gastroenterology**
 - Endocrinology
 - Orthopaedics
 - Respiratory
 - Dermatology
 - Neurology
 - Nephrology
 - Section Headers
 - General Medicine
 - Mental Health
 - Medications
 - Psychosocial
 - Gyn/Ob/Breast
- B. Timeline (B.1-B.5):** A vertical timeline from 2201 to 2205 showing symptoms like nausea, vomiting, emesis, renal, abdominal, and gastroparensis. Key events include 'FINDING OF NAUSEA', 'VOMITING', 'KIDNEY STRUCTURE', 'DIARRHEA SYMPTOM', 'PERITONEAL DIALYSIS', 'ABDOMINAL', 'GASTROPARENSIS', and 'END STAGE RENAL FAILURE'.
- C.1 Clinical Notes:**
 - Admission Date: 2202-3-31** Discharge Date: 2202-4-6**
 - Date of Birth: 2168-10-6** Sex: F
 - Service: Company 191** MEDICINE
 - HISTORY OF PRESENT ILLNESS:** The patient is a 33-year-old female, with type 2 diabetes mellitus, poorly controlled diabetes, who was admitted to the Fenard Intensive Care Unit on 2202-3-31** with diabetic ketoacidosis. The patient had been vomiting for several days with chronic diarrhea, and on admission had an initial blood pressure of 70/palp, and in the Emergency Department was found to have a blood glucose level of 1,400, an anion gap of 55, and a serum bicarbonate of 6. She received 7 liters of normal saline, potassium repletion, 55 units of insulin, and then was put on insulin GTT in the ED. The patient had coffee ground emesis, melena on admission. Coffee ground emesis was cleared after a 350 cc NG lavage. Her course was also notable for T wave inversions in the inferolateral leads, and a troponin of 2.5. The patient also grew out Clostridium perfringens, lactobacillus and coag-negative staph aureus from her initial blood cultures. She also was found to have acute on chronic prerenal failure. The patient was initially given 1 gm of vancomycin for her bacteremia before speciation in the Hospital Unit Name 153**, and was later started on clindamycin. Her lytes were repleted and free water was repleted for her hypernatremia on admission in the Hospital Unit Name 153**, and she was then called out to the floor. Upon call-out, the patient was complaining of tender left upper chest pain at her central line site, but no fevers, chills, nausea, vomiting or abdominal pain.
 - PAST MEDICAL HISTORY:** 1) Type 1 diabetes since age 6, multiple admissions for DKA, 2) Hypertension, 3) Asthma, 7) Hypercholesterolemia, 8) Chronic renal insufficiency with a baseline of 1.5.
 - MEDICATIONS AT HOME:** 1) reglan, 2) insulin, schedule of Lantus 32 U at night and 18 Location at the morning, and then Humalog sliding scale for lunch and dinner.
 - ALLERGIES:** Pork and beef insulin, erythromycin, compazine, codeine, aspirin, barium contrast dye.
 - SOCIAL HISTORY:** Married, currently homeless but expecting to move into a new home on the 6. No alcohol or tobacco use.
 - MEDICATIONS ON TRANSFER TO THE FLOOR FROM THE ICU:** 1) clindamycin 600 mg IV q 8 h day 1 on 2202-4-3**, 2) metoprolol 12.5 tid, 3) Reglan 10 IV qid, 4) famotidine 20 IV qd, 5) Zofran 2 mg q 6 h prn, 6) albuterol/ipratropium nebs, 7) nystatin swish and swallow, 8) viscous lidocaine, 9) subcu heparin, 10) sublingual Nitroglycerin prn, 11) glargine insulin 20 U q hs and regular insulin sliding scale.
 - EXAM ON TRANSFER TO FLOOR:** T-max 100.6, T-current 99.1, pulse 97, respirations 12, blood pressure 117/68 with a range of 86-175/32-104, pulse ox 98% on 2 liters. General - the patient was lethargic but
- C.2 Keywords:** pylori x
- D.1 Medical Taxonomy Codes (UMLS/SNOMED):**
 - (386617003) Digestive system finding X
 - (106098005) Urinary system finding X
 - (128606002) Disorder of the urinary system X
 - (122489005) Urinary system structure X
- D.2-D.4 Interface Elements:** Search bars, 'Add' buttons, 'Save Filter Collection' button, and 'Save' button.

Public Health

[Afzal et al., 2020]

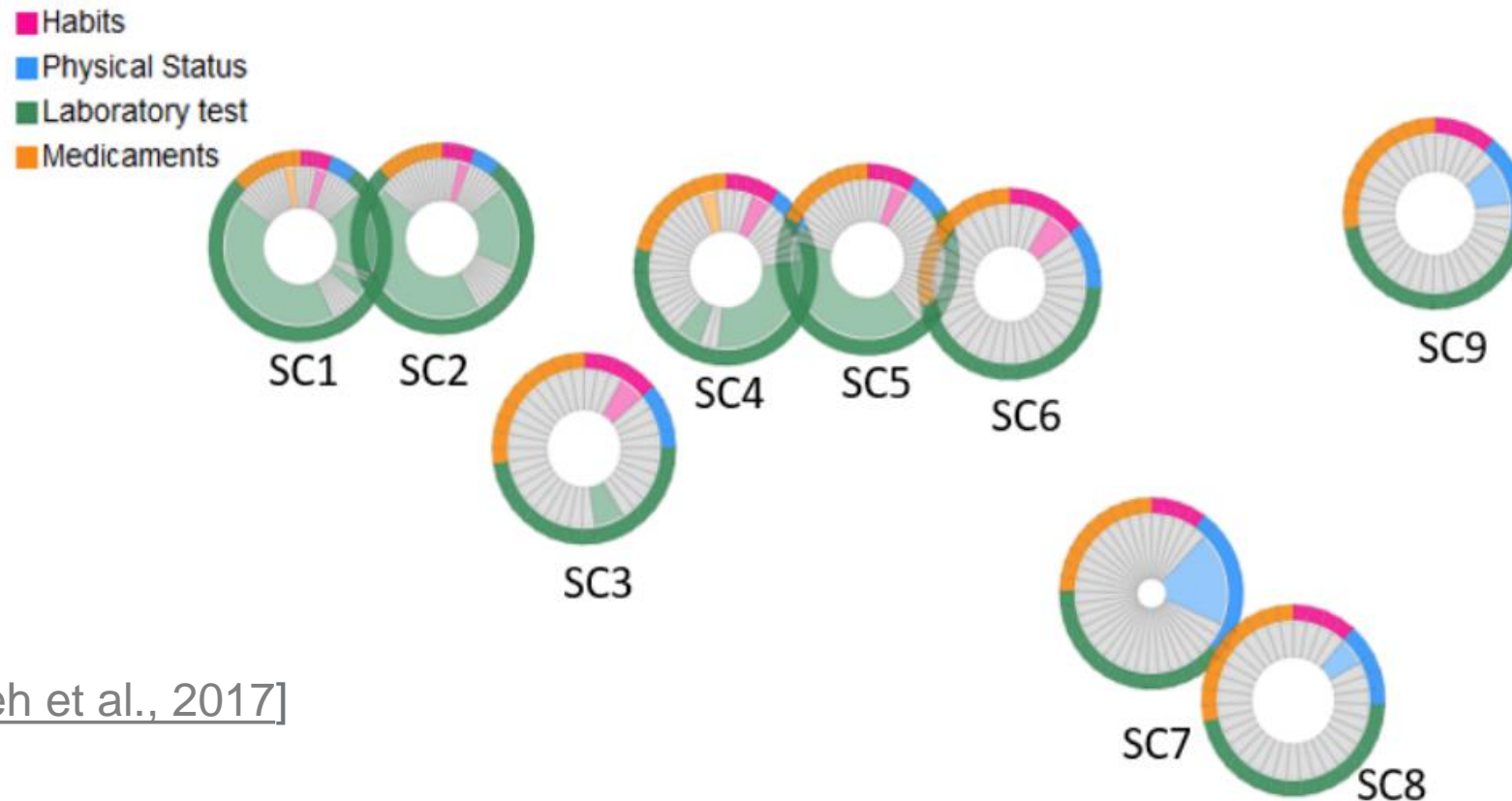


Martin Krzywinski: A pandemic of bad charts

https://www.youtube.com/watch?v=_YGmfsKL8N8&ab_channel=HelenaKlaraJambor

Cohort Studies

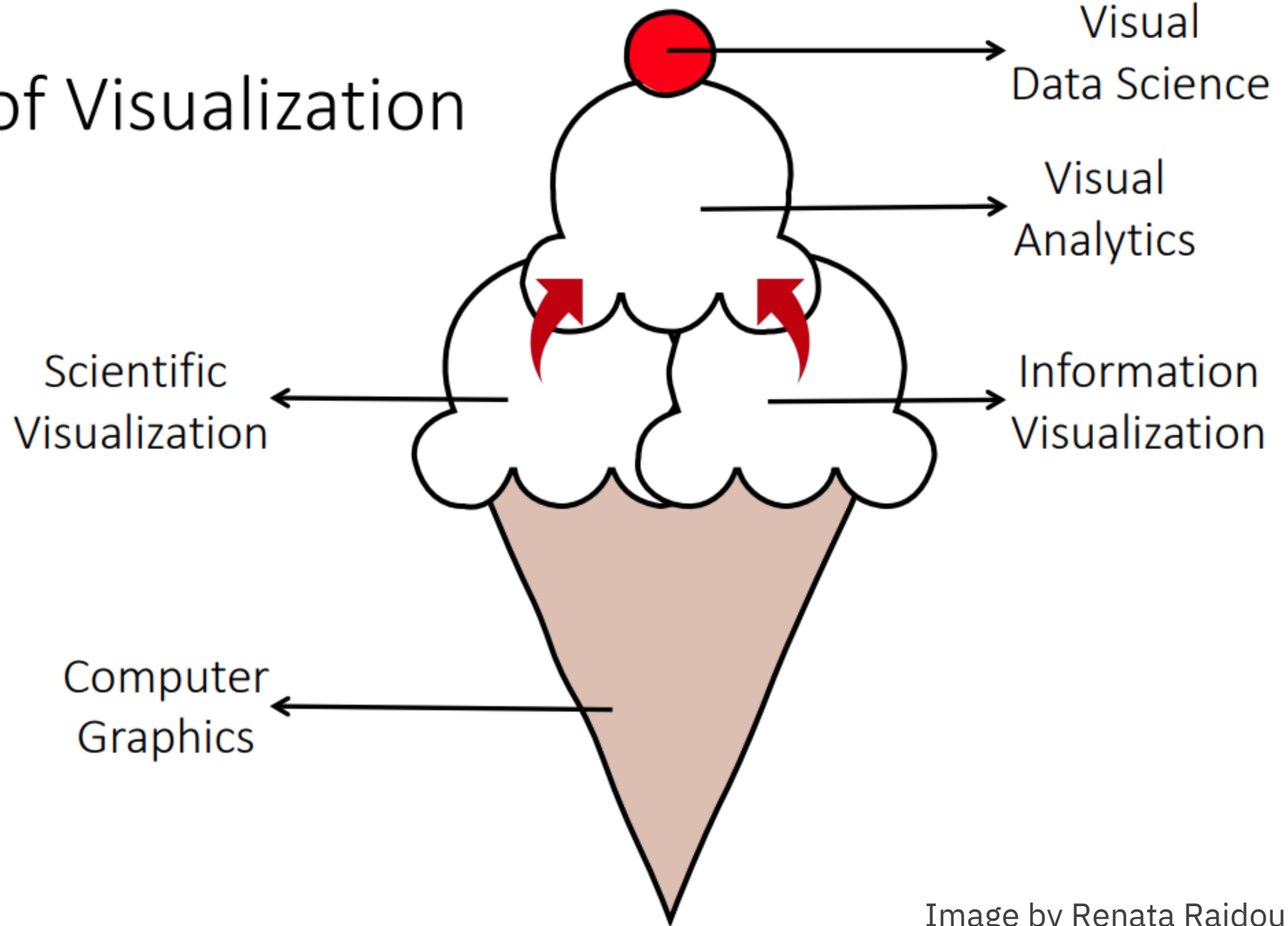
- Feature extraction, dimensionality reduction, clustering, ...



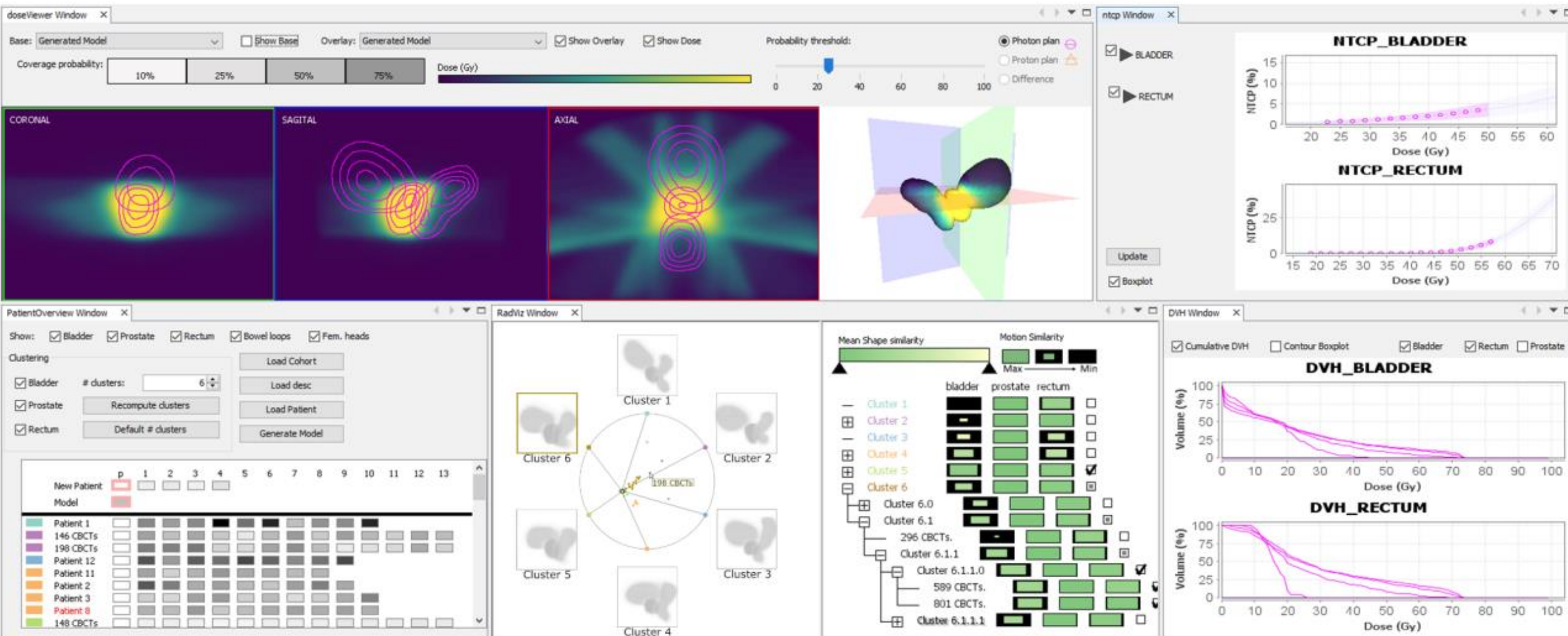
[Alemzadeh et al., 2017]

Visual Analytics – Bringing It All Together

“Flavors” of Visualization



Visual Analytistics



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

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

Acknowledgement

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