Imperial College London

AI in Medicine I

Introduction

Daniel Rueckert, Julia Schnabel and Veronika Zimmer

Team

Lecturers

Professor
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Professor
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Dr. Georgios
Kaissis

Professor
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Coordinator

Dr. Veronika
Zimmer

Tutors

- Chen
- Cosmin
- Dima
- Felix
- Haifa
- Ivan
- Moritz
- Paul
- Sophia

Lab for AI in Medicine @ TUM

BioMedIA @ Imperial College London

Klinikum rechts der Isar
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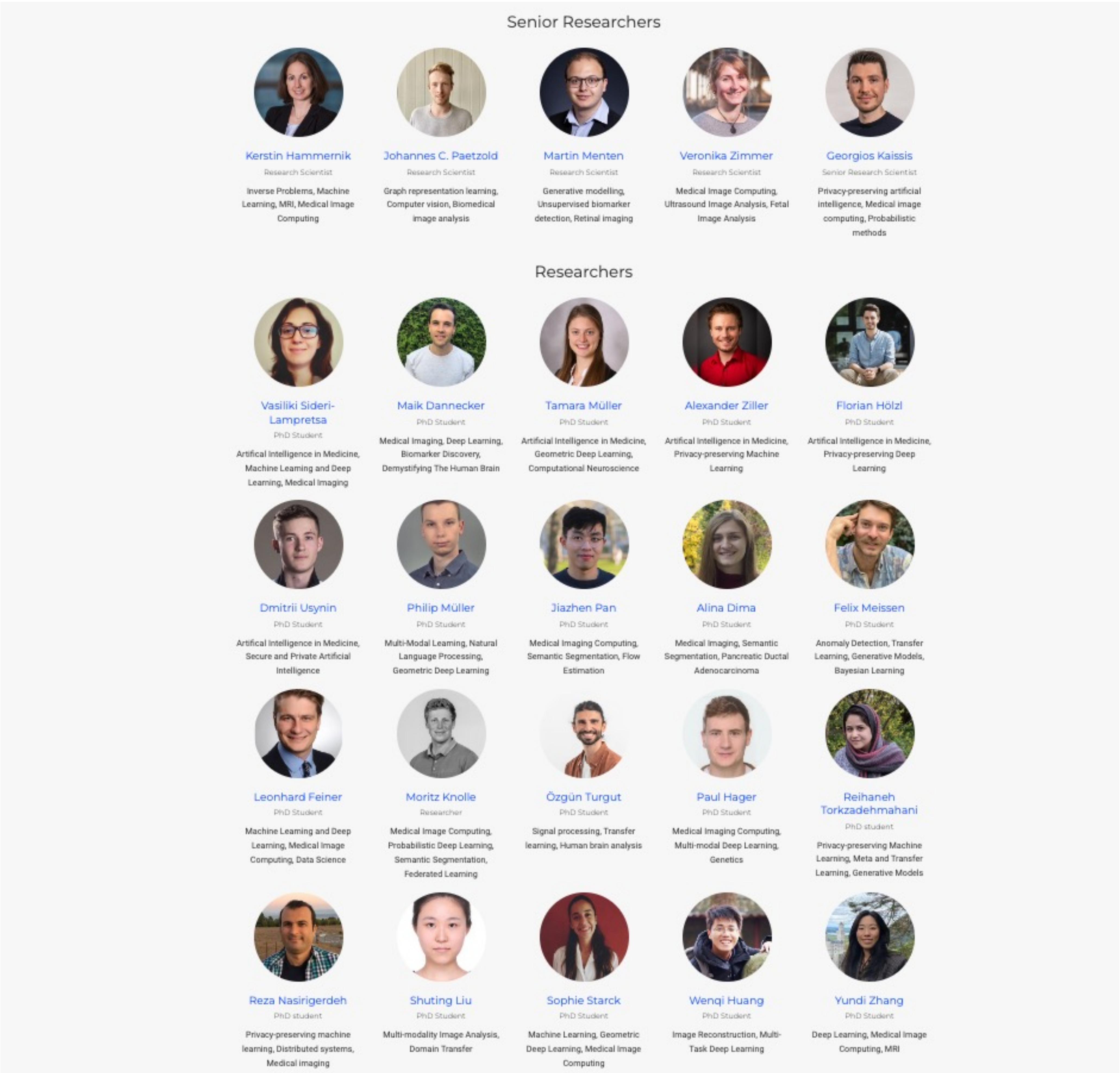
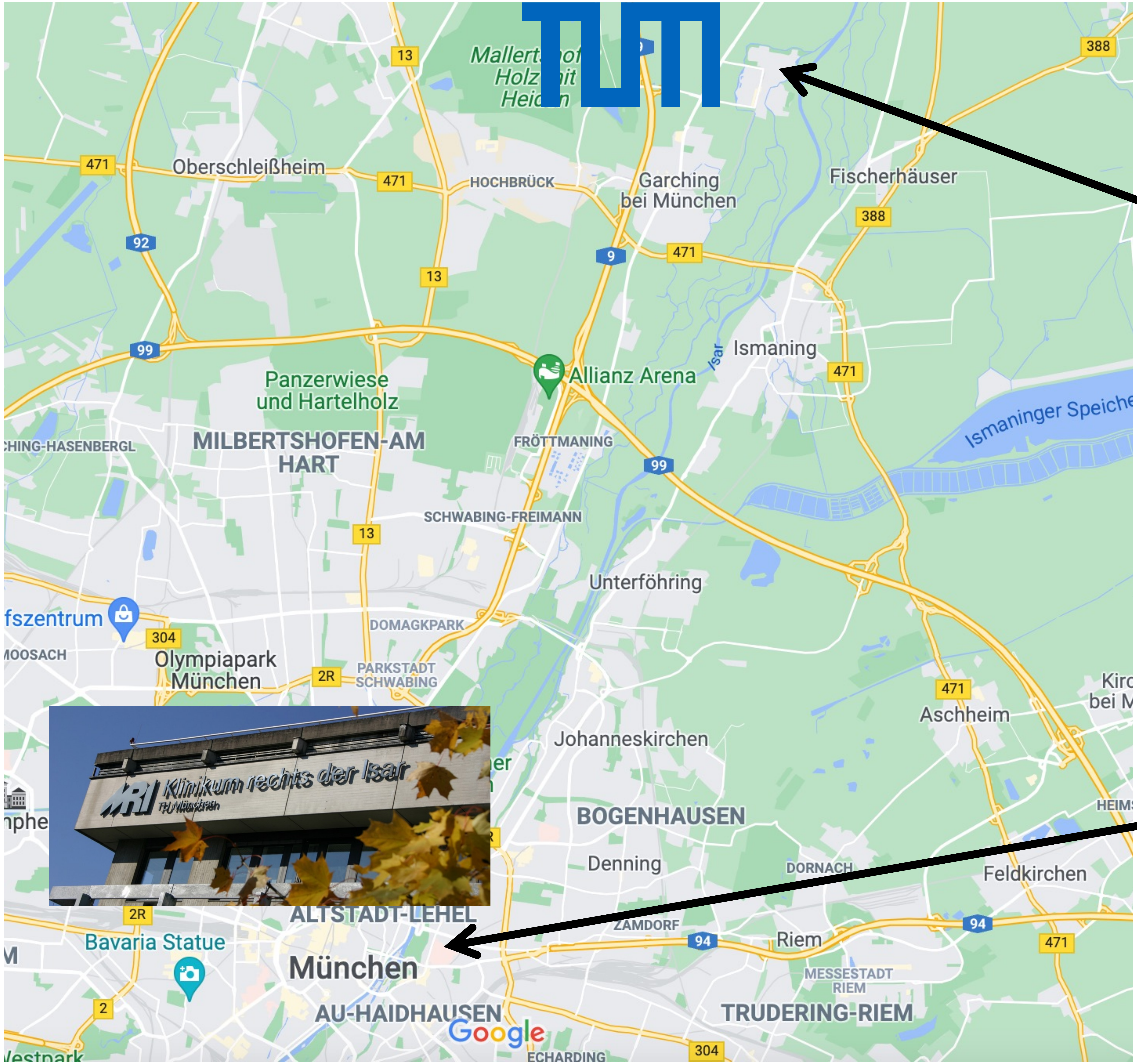
Lab for AI in Medicine @ TUM



https://aim-lab.io/

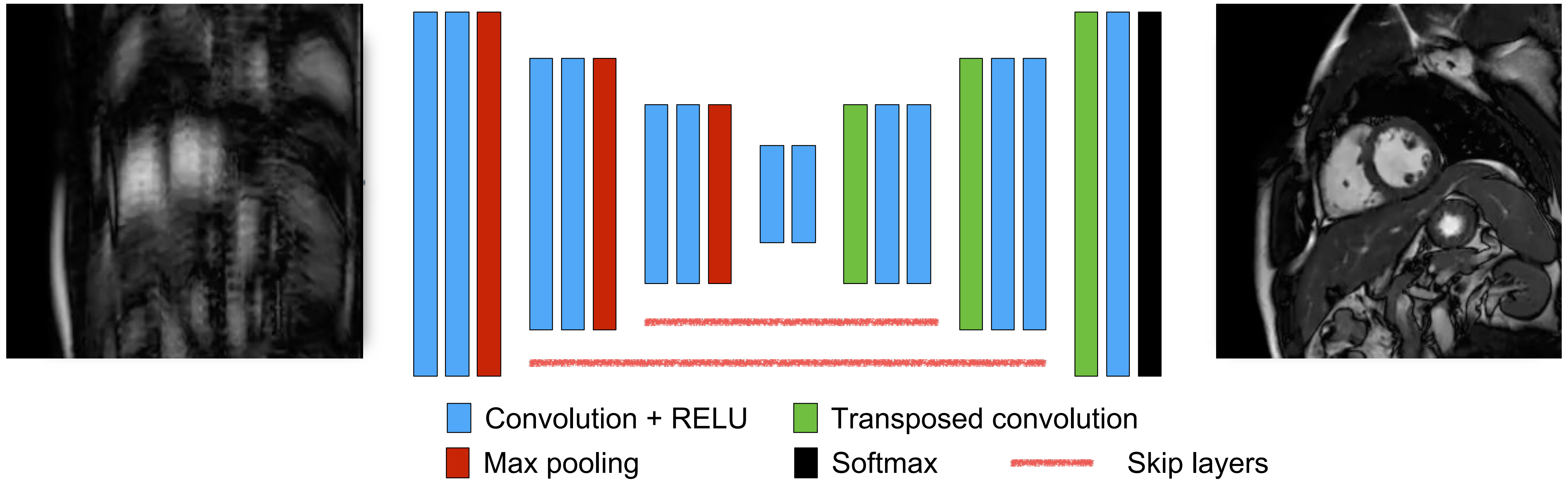
BioMedIA @ Imperial College London



Lab @ Campus Garching
GALILEO
Walther-von-Dyck-Str. 4
85748 Garching/München

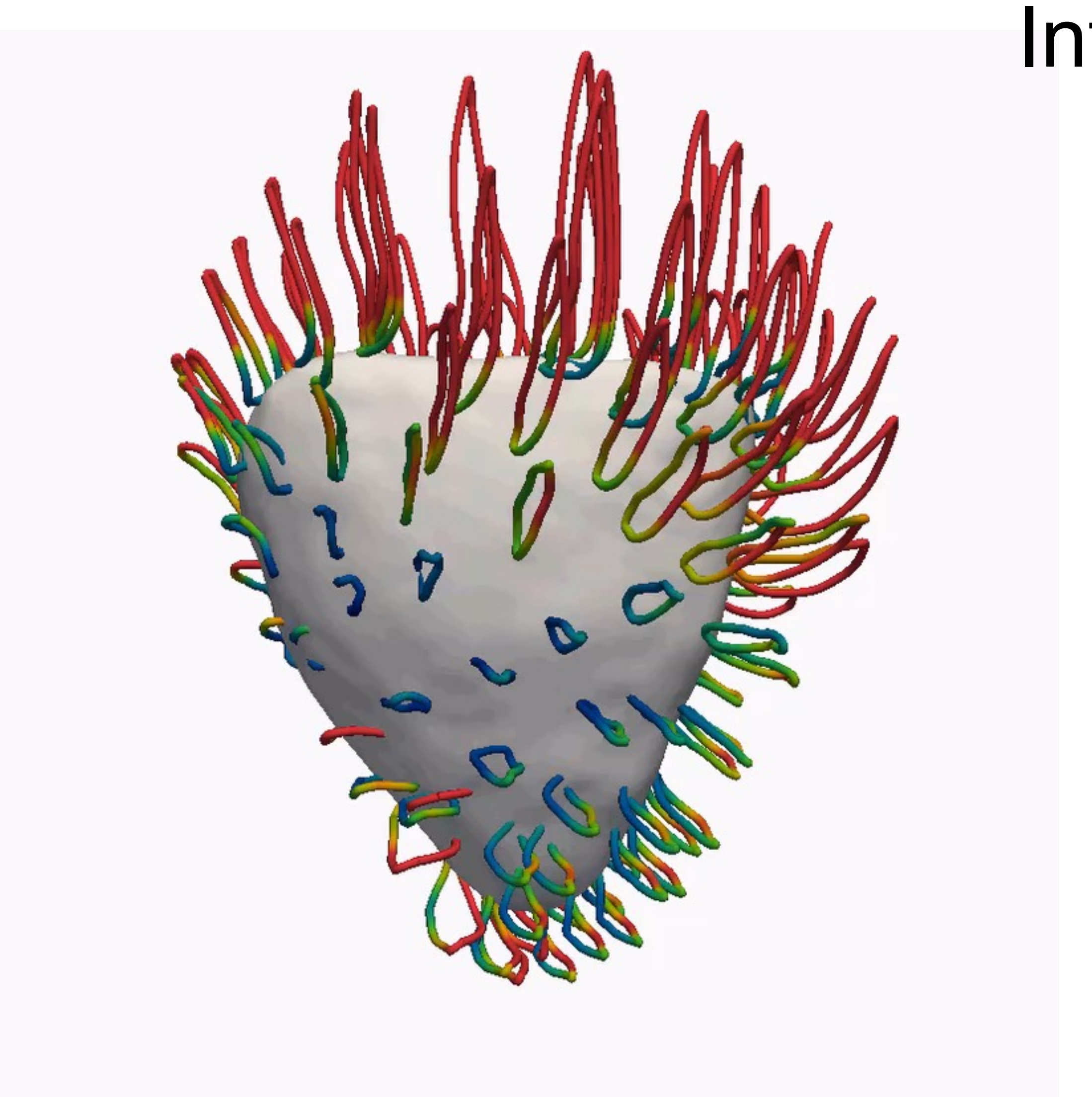
Lab @ Campus Klinikum RdI
TranslaTUM (Building 522)
Einsteinstraße 25
81675 München

Examples of our research

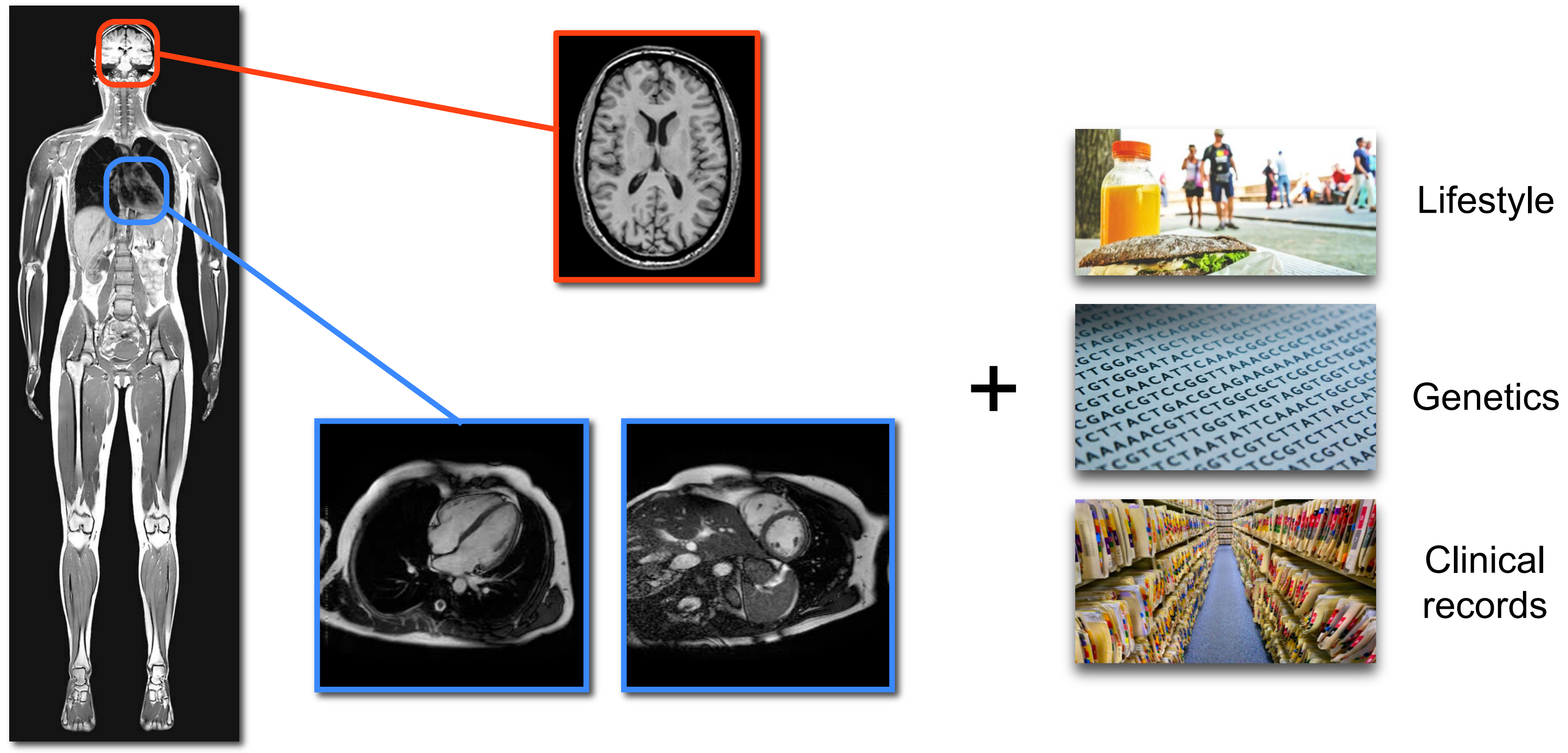


Intelligent Imaging

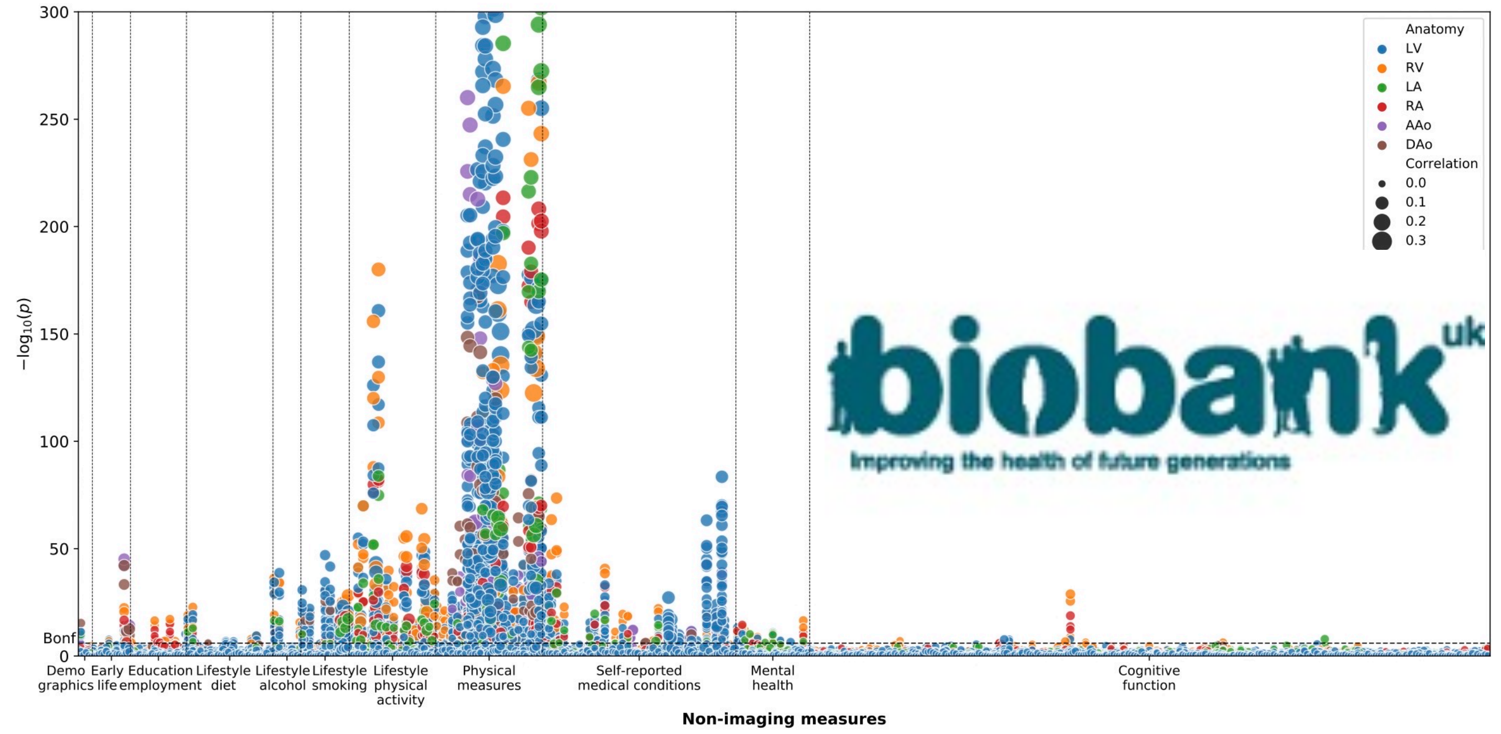
Medical Image Computing



Biomedical Computing and Modelling

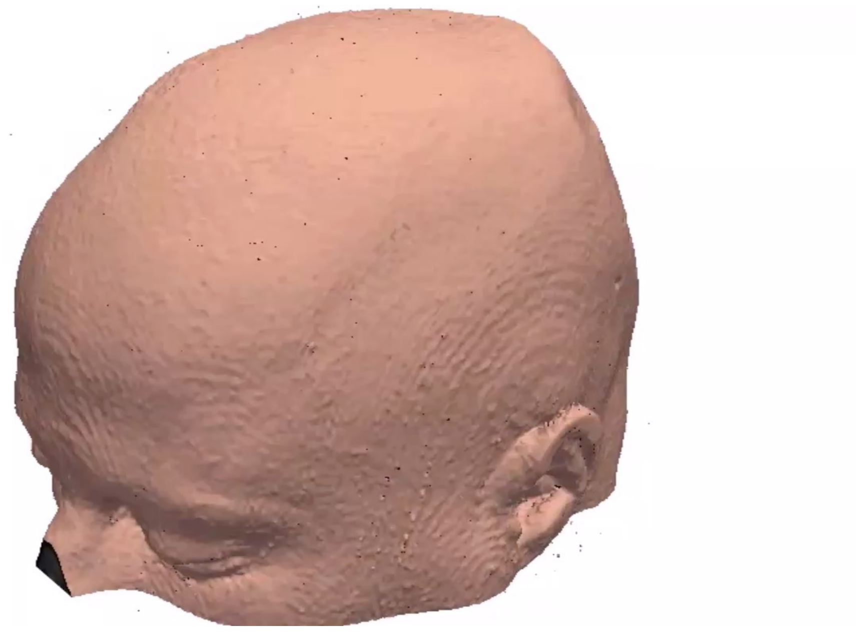


Multi-modal learning

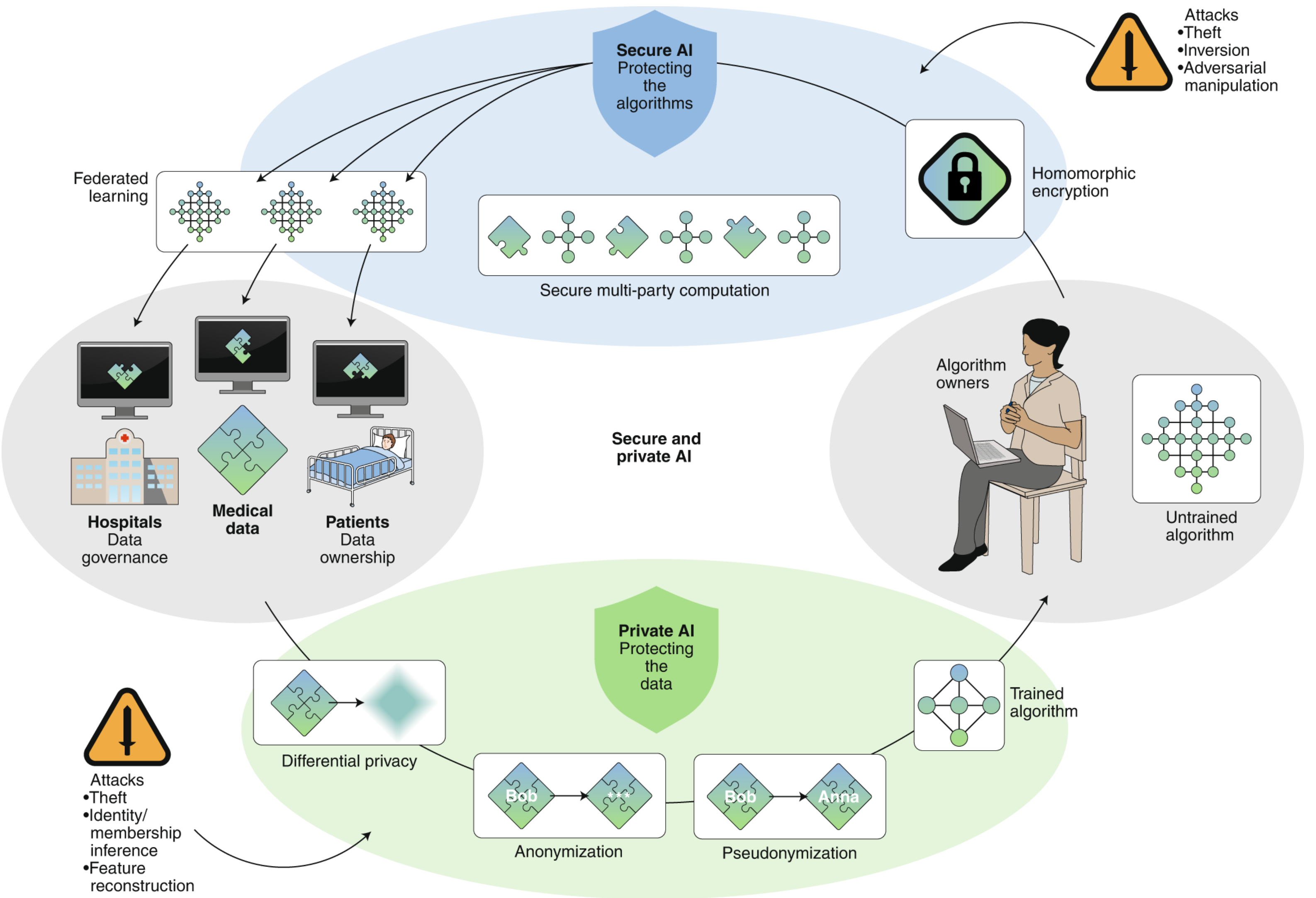


Population studies

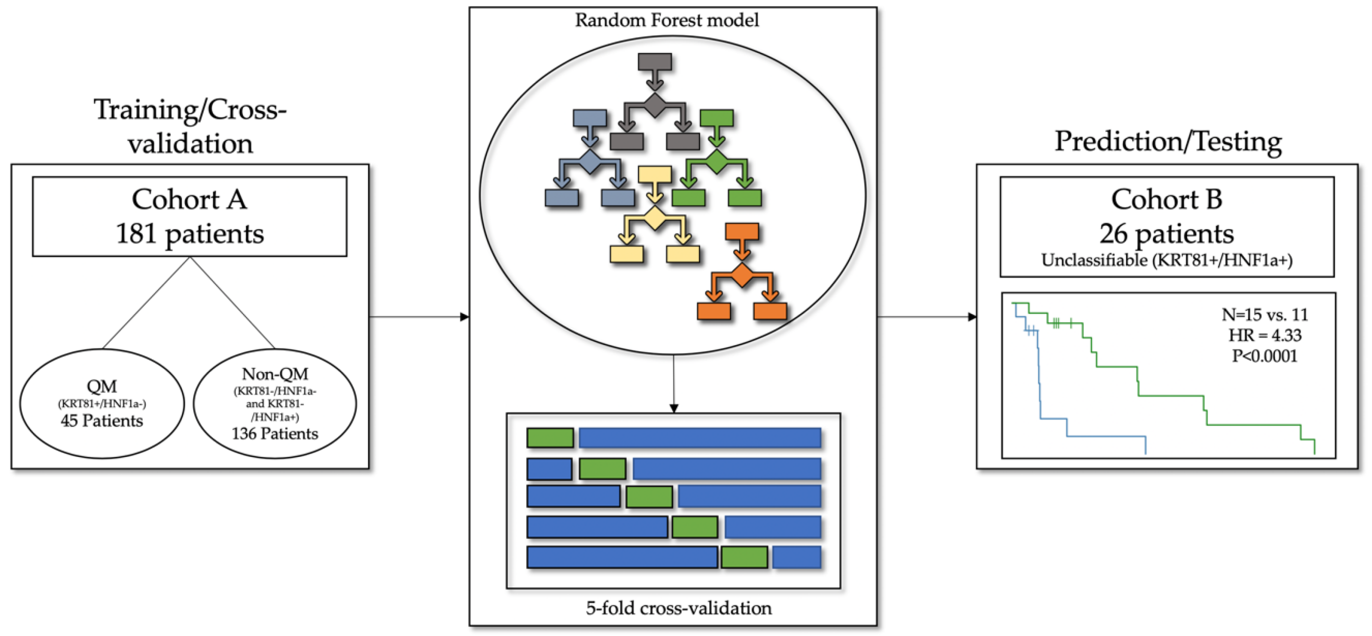
Examples of our research

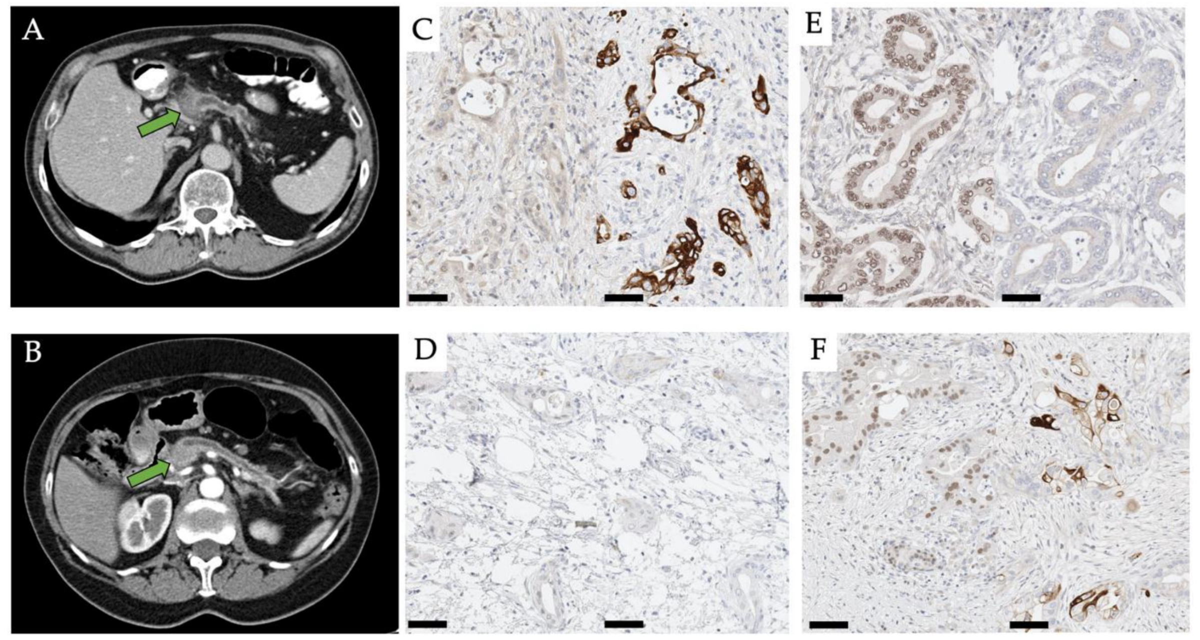


Neuro: Stroke, MS and Dementia

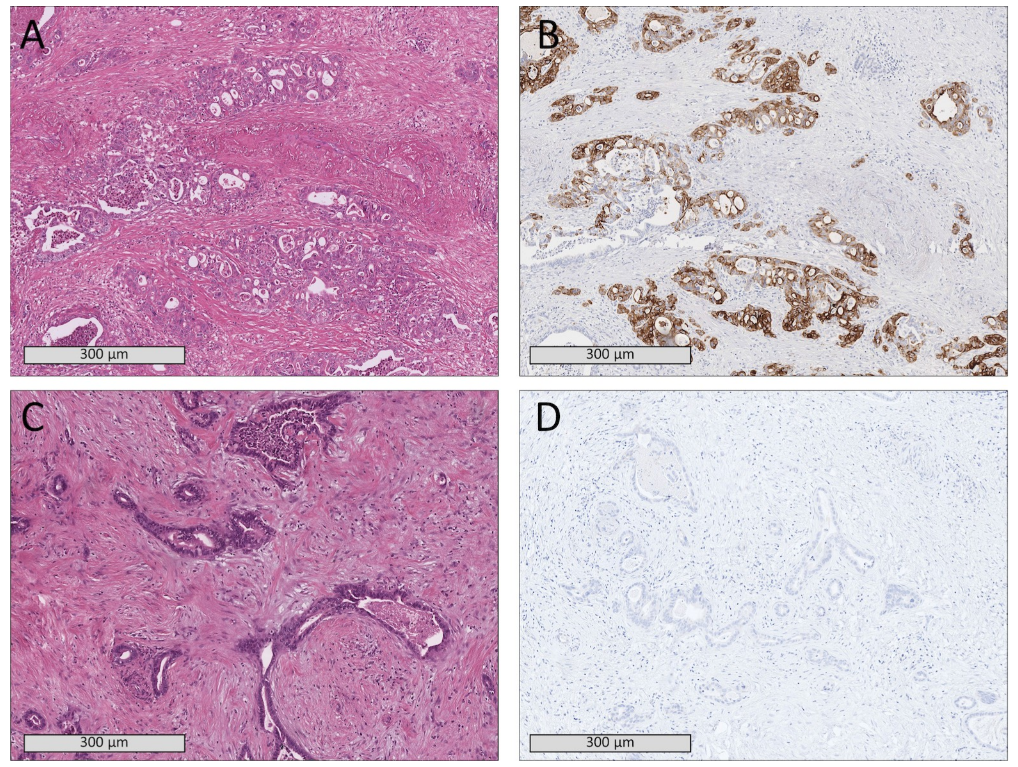


Differential privacy, federated learning





Oncology: Lung, Pancreas, Prostata



Computational pathology

Julia Schnabel, Ph.D.

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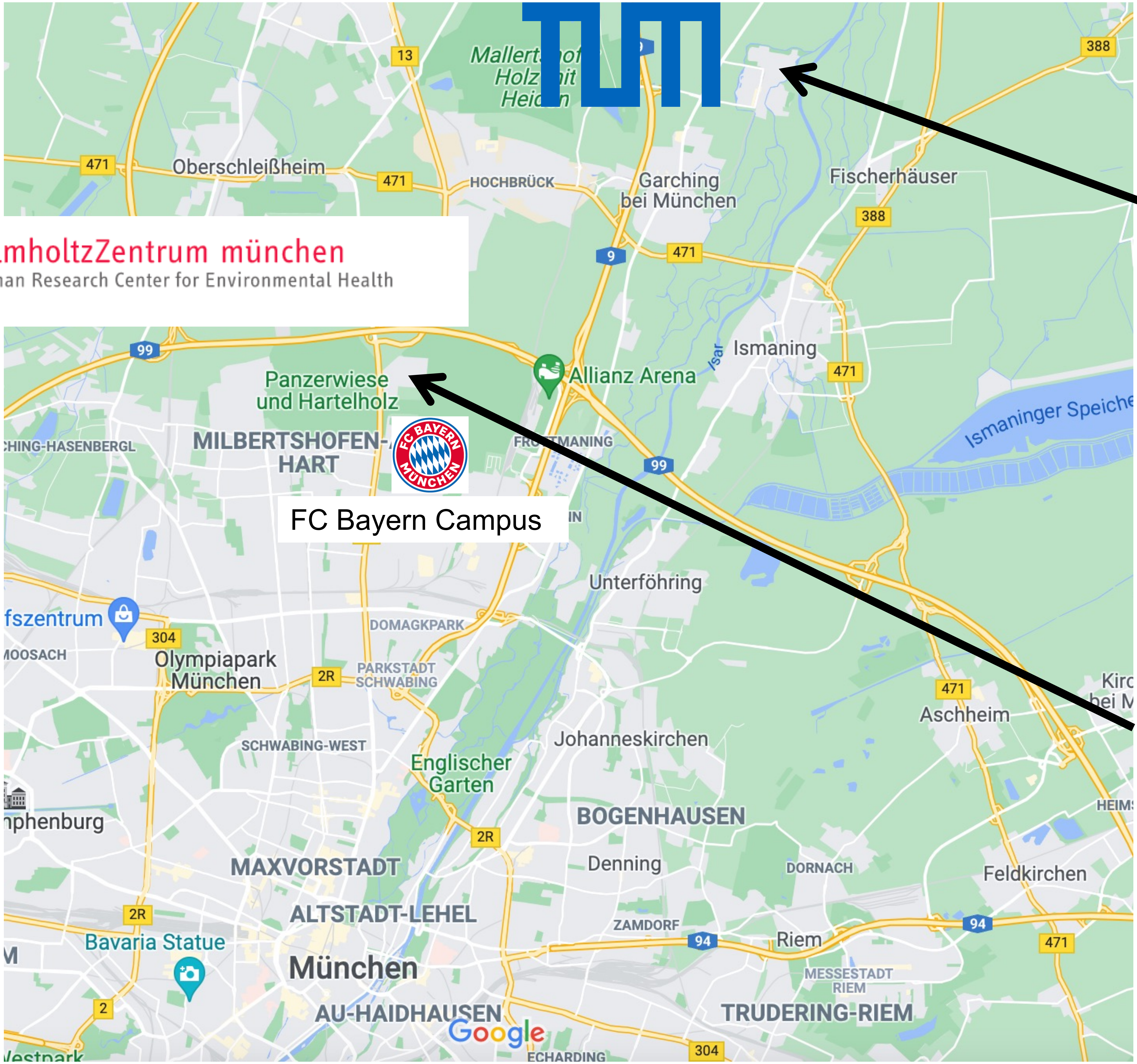
Computational Imaging Lab @ King's

Institute for Machine Learning in Biomedical Imaging @ Helmholtz Munich and CompAI Lab @TUM

https://compai-lab.io/

HelmholtzZentrum münchen
German Research Center for Environmental Health



IAS TUM Institute for Advanced Study

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85748 Garching/München

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IML – Building 35.33
Ingolstädter Landstr. 1
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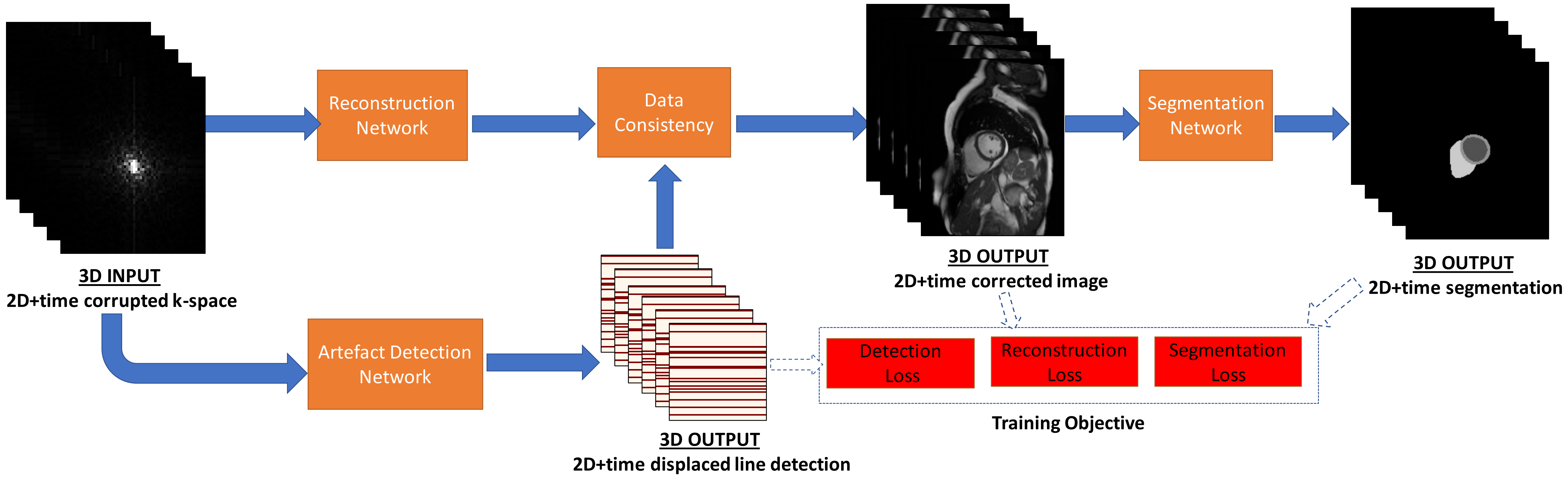
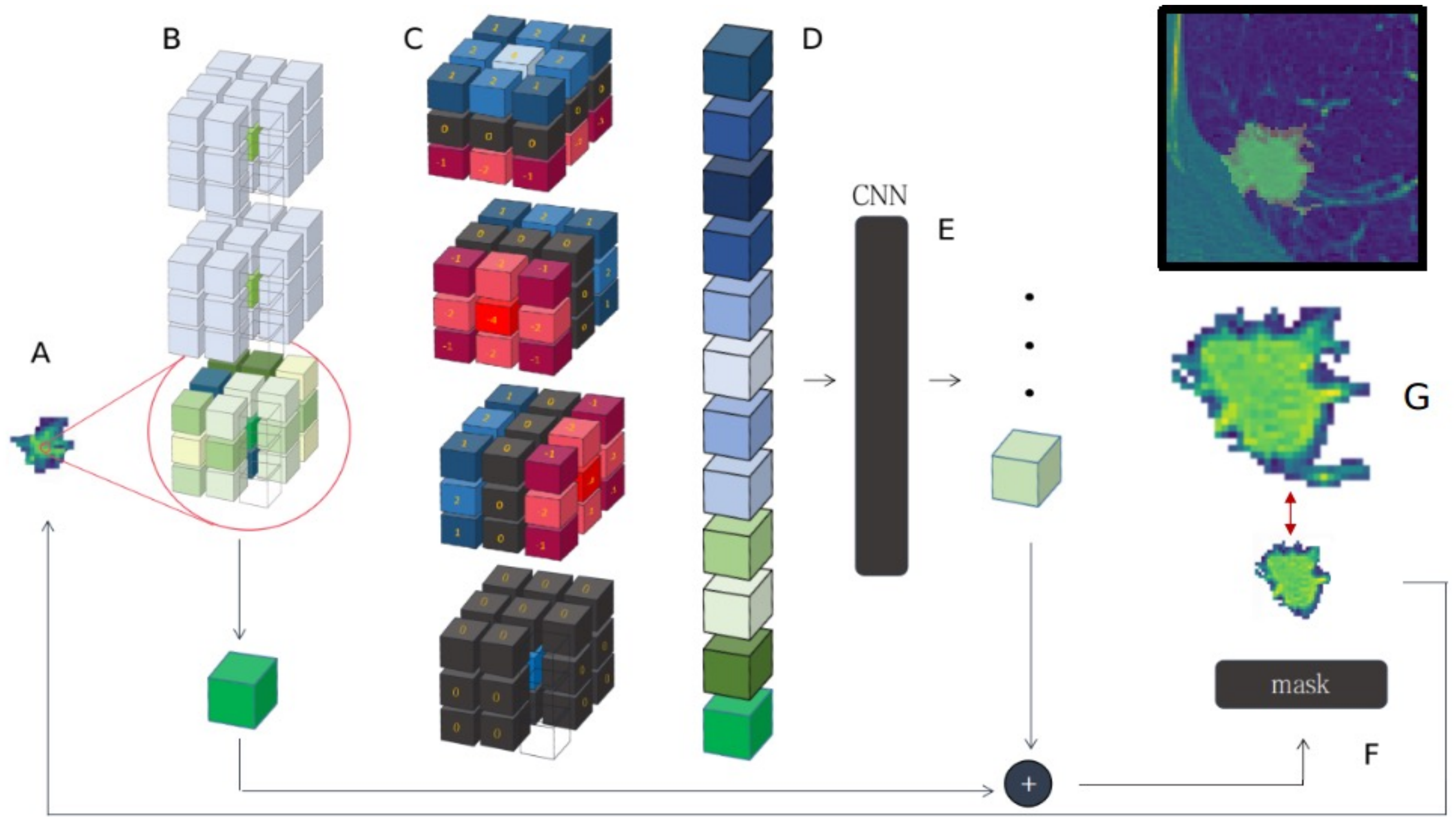
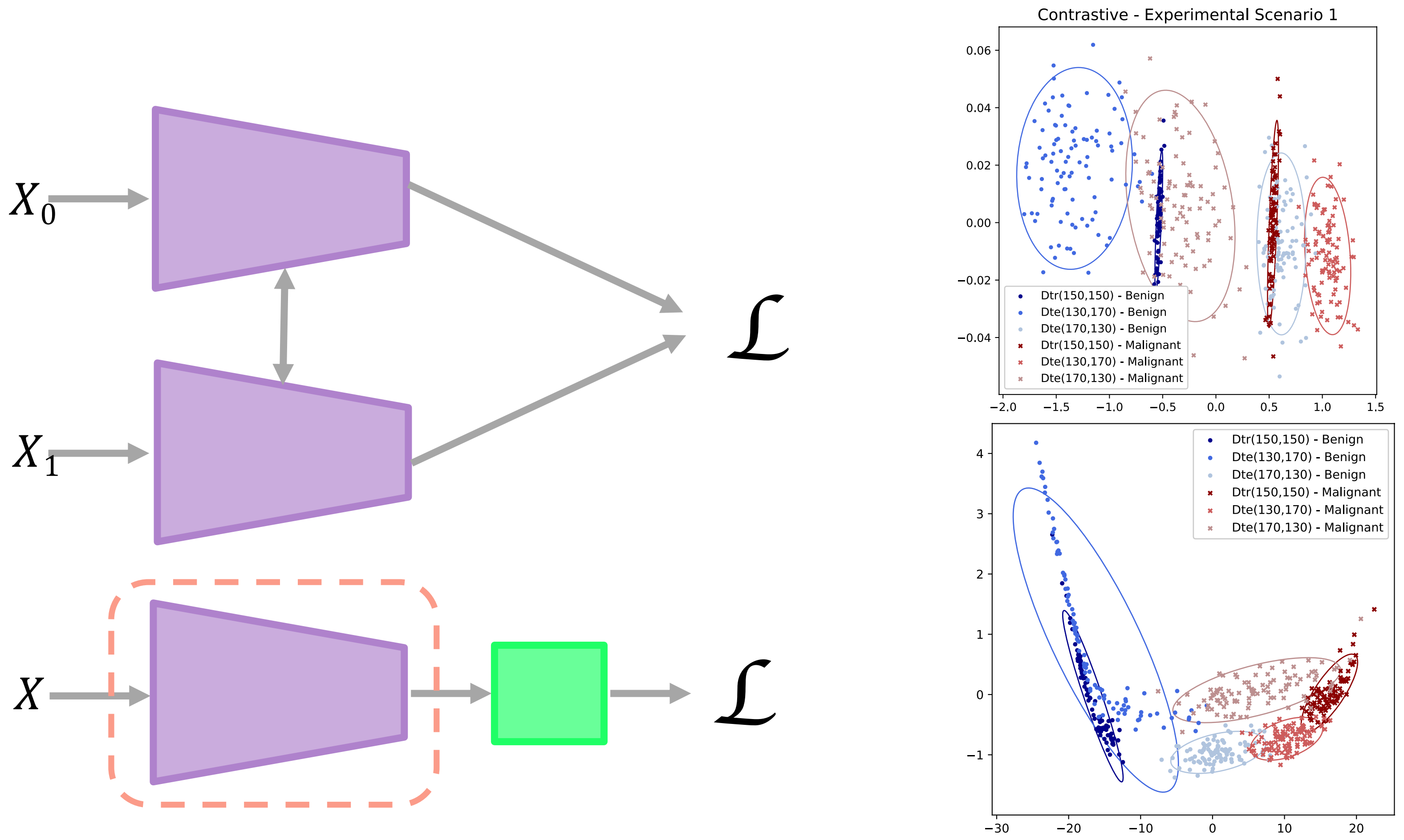
Examples of our research



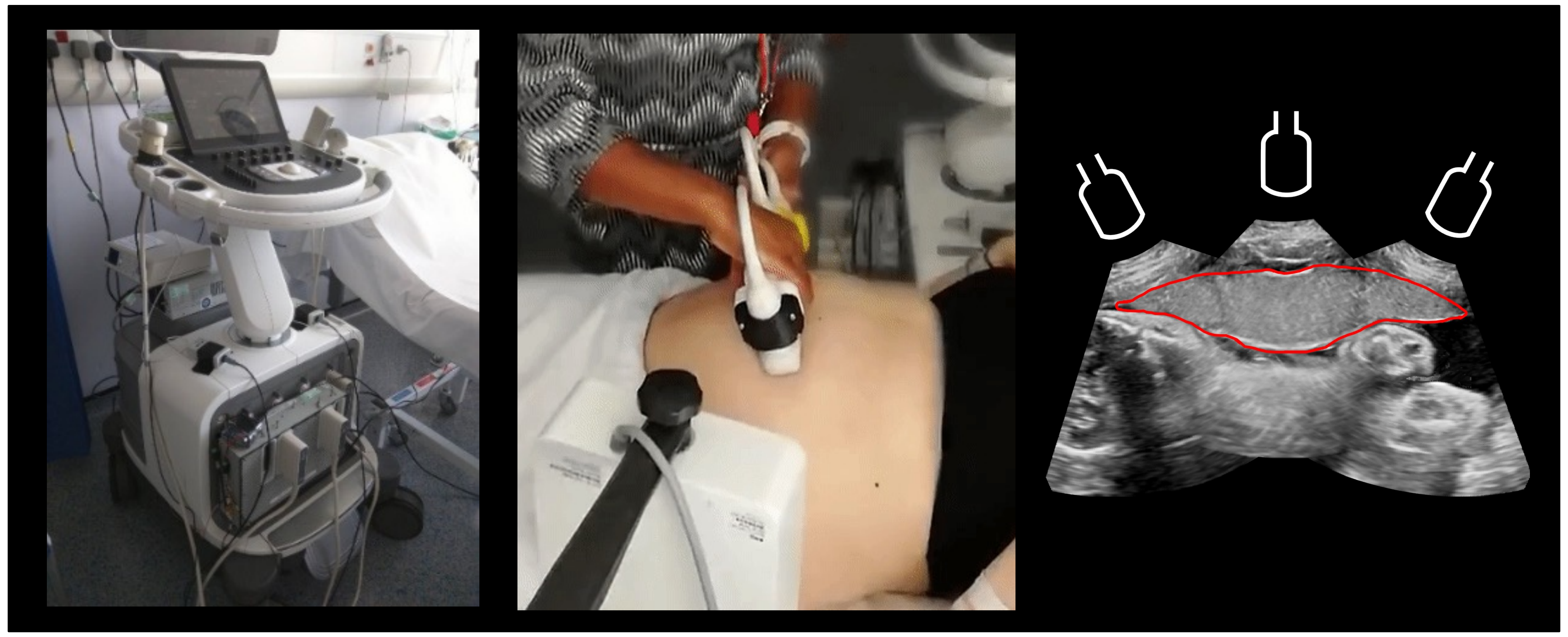
End-to-end learning



Data augmentation, domain generalisation and quality control

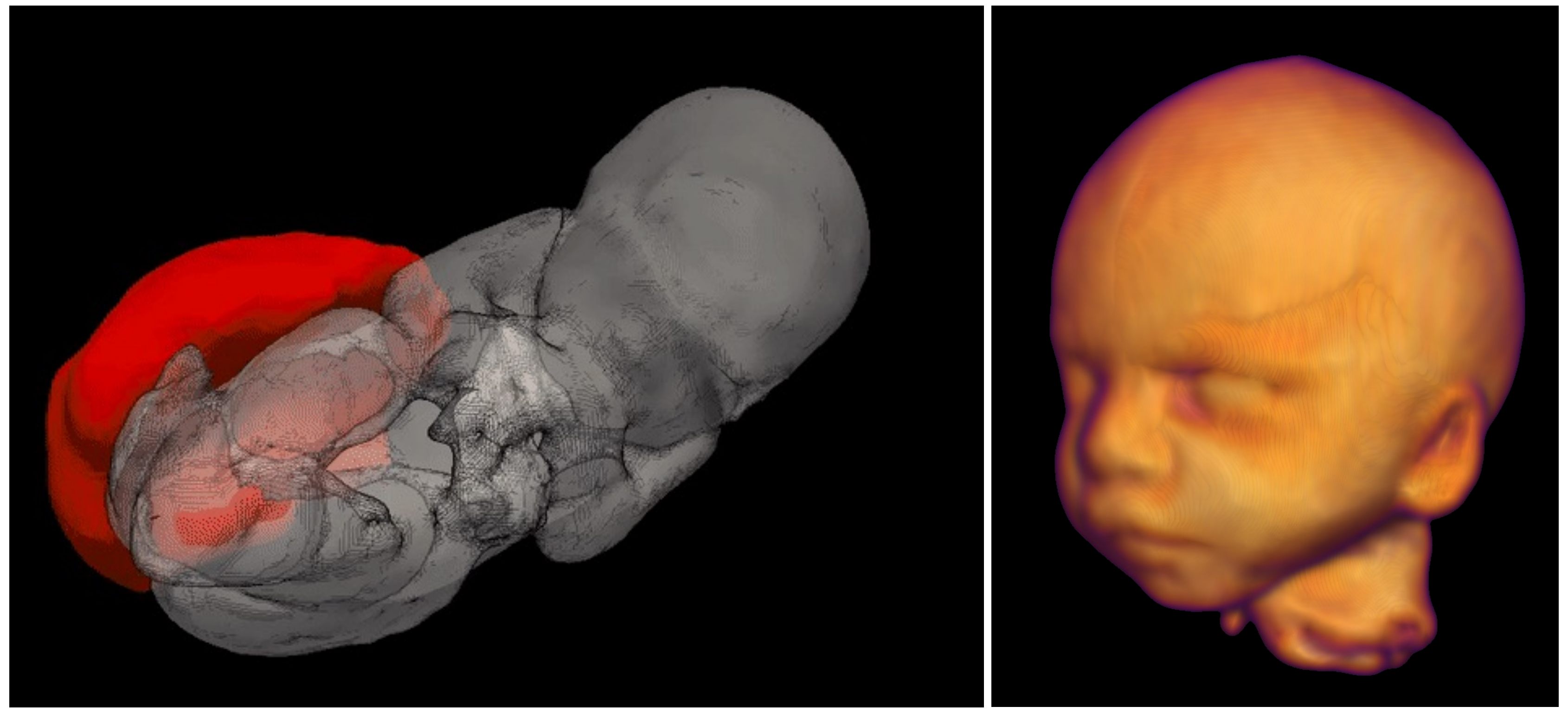


Explainable AI

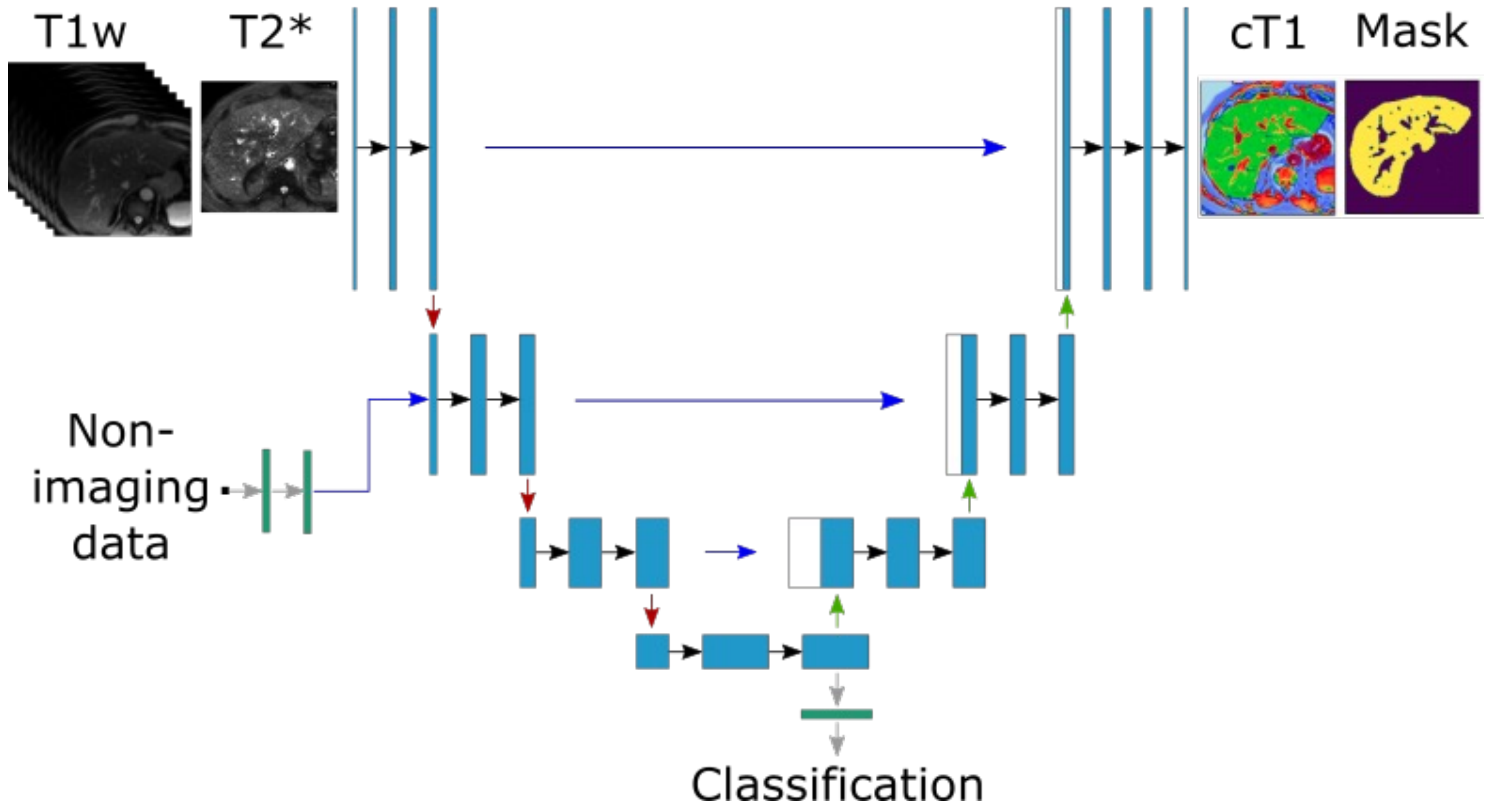


Advanced medical imaging

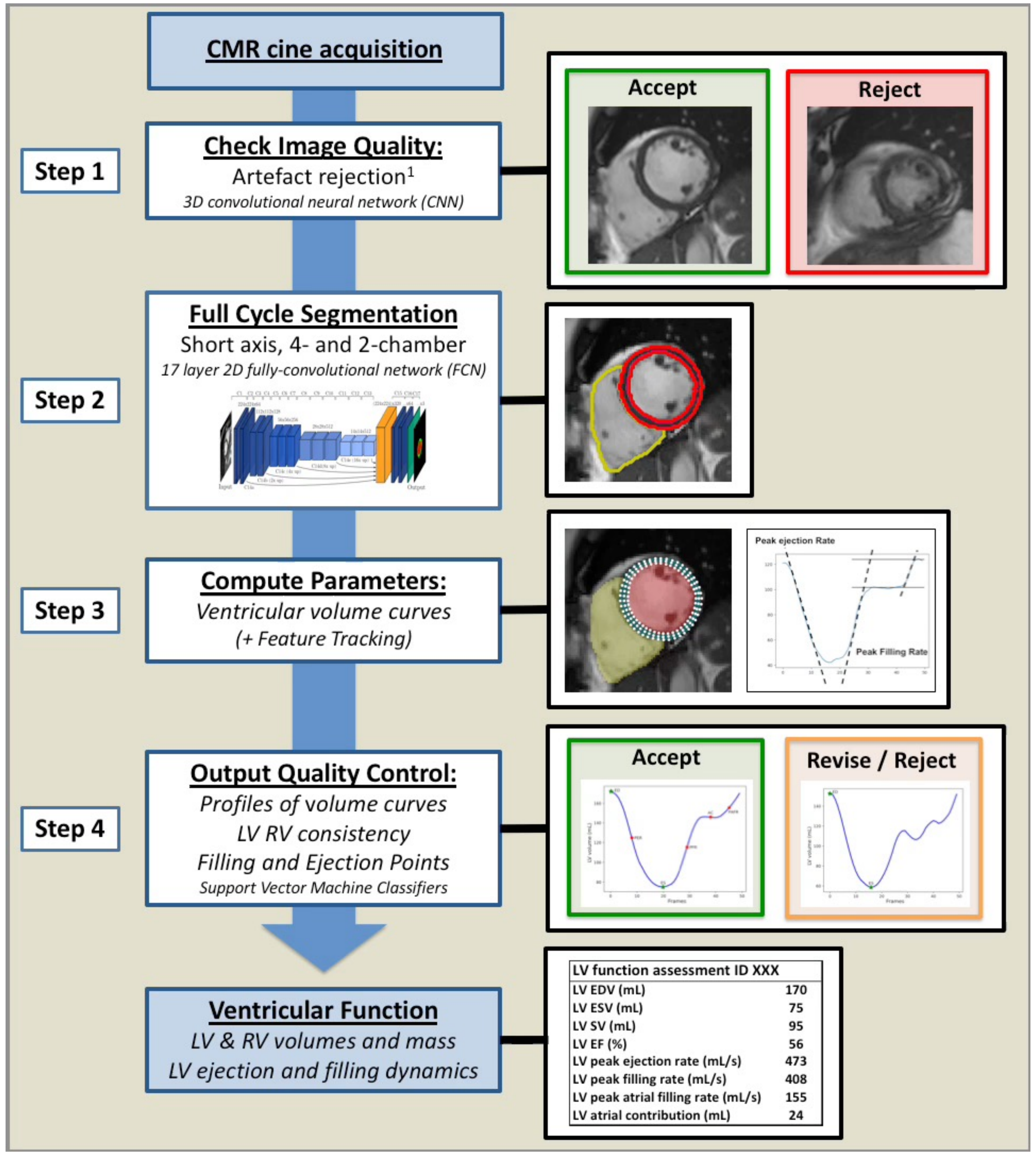
Examples of our research



Fetal imaging and maternal health



Cancer imaging: lung and liver



Cardiac imaging

Logistics –Dates & Material

- Lecture hall: 5901.EG.051
- Dates:
  – Monday, 16:15 – 17:45 (lecture)
  – Thursday, 16:15 – 17:45 (lecture or tutorial/practical)
  – 15 weeks (guest lecture and revision in the last week)
- Format
  – Lectures in presence
  – Tutorials/practicals in presence – **please bring your laptop**
- Course material:
  – Moodle for slides, videos (introduction/revision only), forum and exercises
  – https://www.moodle.tum.de/course/view.php?id=79915
- Contact in important cases
  – course.aim-lab@med.tum.de

Logistics - Assessment

- **Tutorials**
  - Practical exercises
    - 3 assessed practicals
    - **20% of overall grade**
    - You have a choice from 4 practicals
    - **Please join groups of max 5 people**
  - Theoretical exercises
    - Preparation for exam

- **Written exam:**
    - **80% of overall grade**
    - Date TBA

Logistics - Tutorials

- Publication of exercise sheet on Mondays (via Moodle)
- **Practical sessions**
  - Submission after 2 weeks (Monday) via Moodle
  - Group work: Please join groups of 5 (via Moodle)
    - Group selection open until 27. October (Tutorial session)
    - Smaller groups (<4 members) will be merged on 28. October!
    - Always put your group name and group members on the submissions!
  - Thu session to answer question and start working on the assignment
  - **Please bring your laptop!**
- **Theoretical sessions**
  - Solutions will be given and discussed on Thursdays
  - Preparation for exam!

Syllabus

- Week 1: Introduction into AI for Healthcare and Course Logistics
  - *Also recorded on Moodle: Revision of ML/NNs*
- Week 2: AI / Machine Learning for Medical Imaging: Classification
  - Practical 1
- Week 3: Machine Learning for Medical Imaging: Segmentation
- Week 4: Machine Learning for Medical Imaging: Registration
  - Practical 2
- Week 5: Transfer learning, data augmentation techniques
- Week 6: Unsupervised learning and self-supervised learning
  - Practical 3
- Week 7: Few shot learning, meta-learning

Syllabus (cont.)

- Week 8: Trustworthy AI: Explainability, Interpretability and Uncertainty
  - Practical 4
- Week 9: Probabilistic ML
- Week 10: Differential Diagnosis

(Xmas break)

- Week 11: Risk Stratification, Population studies
- Week 12: Reinforcement Learning
- Week 13: Trustworthy AI: Federated ML, Privacy-preserving ML
- Week 14: Trustworthy AI: Bias and Fairness
- Week 15: Reproducibility and MICCAI Challenges (Guest Lecture tbc)

Prerequisites

Recommended:

- Introduction to Deep Learning (IN2346)
- Computer Aided Medical Procedures I (IN2021)

- **Moodle Prerecorded Revision on ML and NN**
  - **If you haven’t watched this yet, please do by the next lecture!**

Recommended Reading

Books:

1. Deep Learning
   I. Goodfellow, Y. Bengio and A. Courville. MIT Press, 2016. Available at http://www.deeplearningbook.org
2. Hands-on Machine Learning with Scikit-Learn & TensorFlow
   Aurelien Geron, O'Reily, 2017
3. Mathematics for Machine Learning
   M. Deisenroth, A. Faisal, C. Ong. Cambridge University Press, 2019
4. Deep Medicine - How Artificial Intelligence Can Make Healthcare Human Again. E. Topol, 2019.

Recommended Reading

Articles:

1. E. J. Topol. High-performance medicine: the convergence of human and artificial intelligence. Nat Med 25, 44–56, 2019. https://doi.org/10.1038/s41591-018-0300-7
2. A. Esteva, K. Chou, S. Yeung, et al. Deep learning-enabled medical computer vision. npj Digit. Med. 4, 5, 2021. https://doi.org/10.1038/s41746-020-00376-2
3. B. Norgeot, G. Quer, B.K. Beaulieu-Jones et al. Minimum information about clinical artificial intelligence modeling: the MI-CLAIM checklist. Nat Med 26, 1320–1324 (2020). https://doi.org/10.1038/s41591-020-1041-y
4. V. Sounderajah, H. Ashrafian, R. Aggarwal et al. Developing specific reporting guidelines for diagnostic accuracy studies assessing AI interventions: The STARD-AI Steering Group. Nat Med 26, 807–808 (2020). https://doi.org/10.1038/s41591-020-0941-1

AI/ML in Medicine

23,216 views | Apr 30, 2017, 12:10pm

AI In Medicine: Rise Of The Machines

Paul Hsieh Contributor

I cover health care and economics from a free-market perspective.

THE NEW YORKER

APRIL 3, 2017 ISSUE

A.I. VERSUS M.D.

What happens when diagnosis is automated?

By Siddhartha Mukherjee

AI/ML in Medicine: There is a lot of hype

MIT Technology Review

Artificial intelligence / Machine learning

Hundreds of AI tools have been built to catch covid. None of them helped.

Some have been used in hospitals, despite not being properly tested. But the pandemic could help make medical AI better.

by **Will Douglas Heaven** July 30, 2021

1970's: MYCIN expert system

- MYCIN expert system that used artificial intelligence to identify bacteria causing severe infections and to recommend antibiotics, with the dosage adjusted for patient's body weight
- Proposed a good therapy in ~69% of cases. Better than infectious disease experts

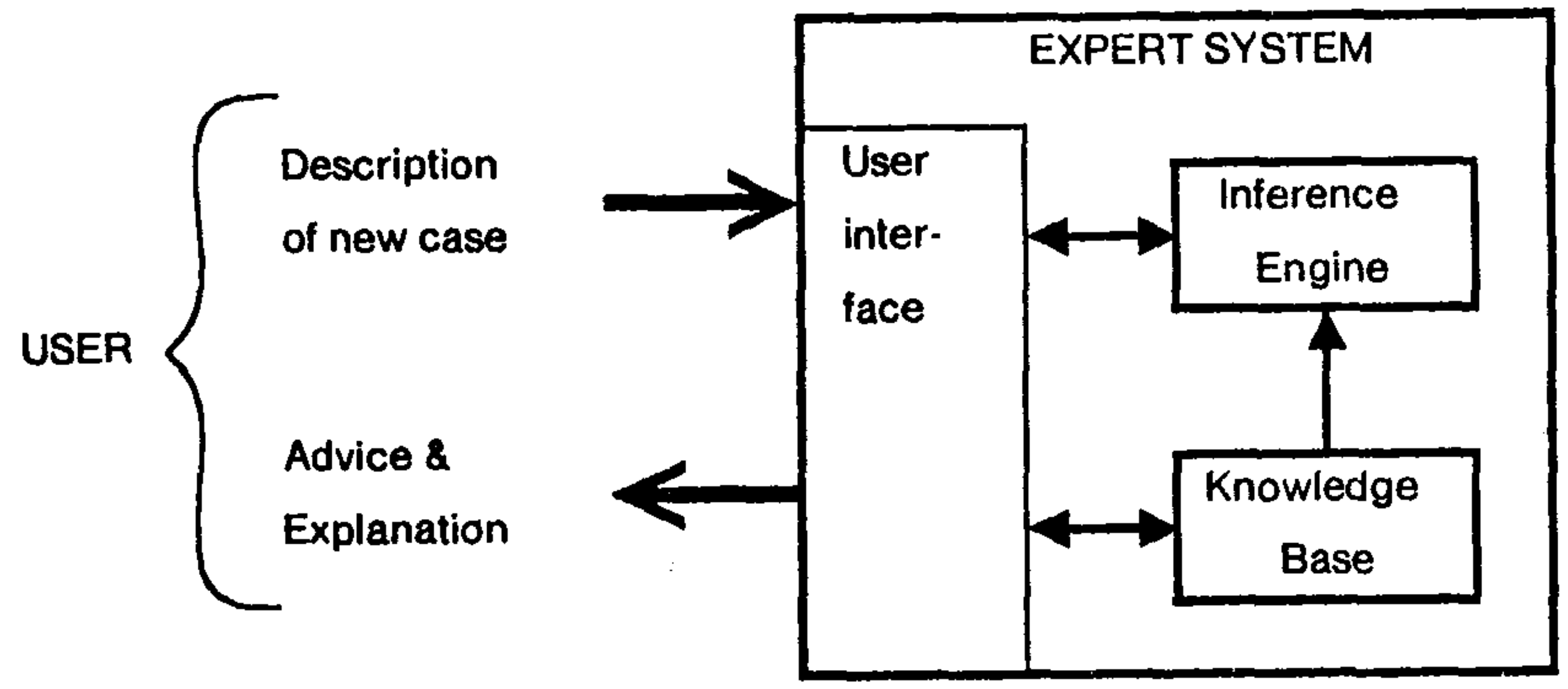


FIGURE 1-1 Major parts of an expert system. Arrows indicate information flow.

I am ready

** THIS IS A 26 YEAR OLD MALE PATIENT

My understanding is:
The age of the patient is 26
The sex of the patient is male

** FIVE DAYS AGO, HE HAD RESPIRATORY-TRACT SYMPTOMS

What is his name?

** JO

My understanding is:
The name of the patient is Jo
Respiratory-tract is one of the symptoms that the patient had

** A COUPLE OF DAYS BEFORE THE ADMISSION, HE HAD A MALAISE

Please give me the date of admission

** MARCH 12, 1979

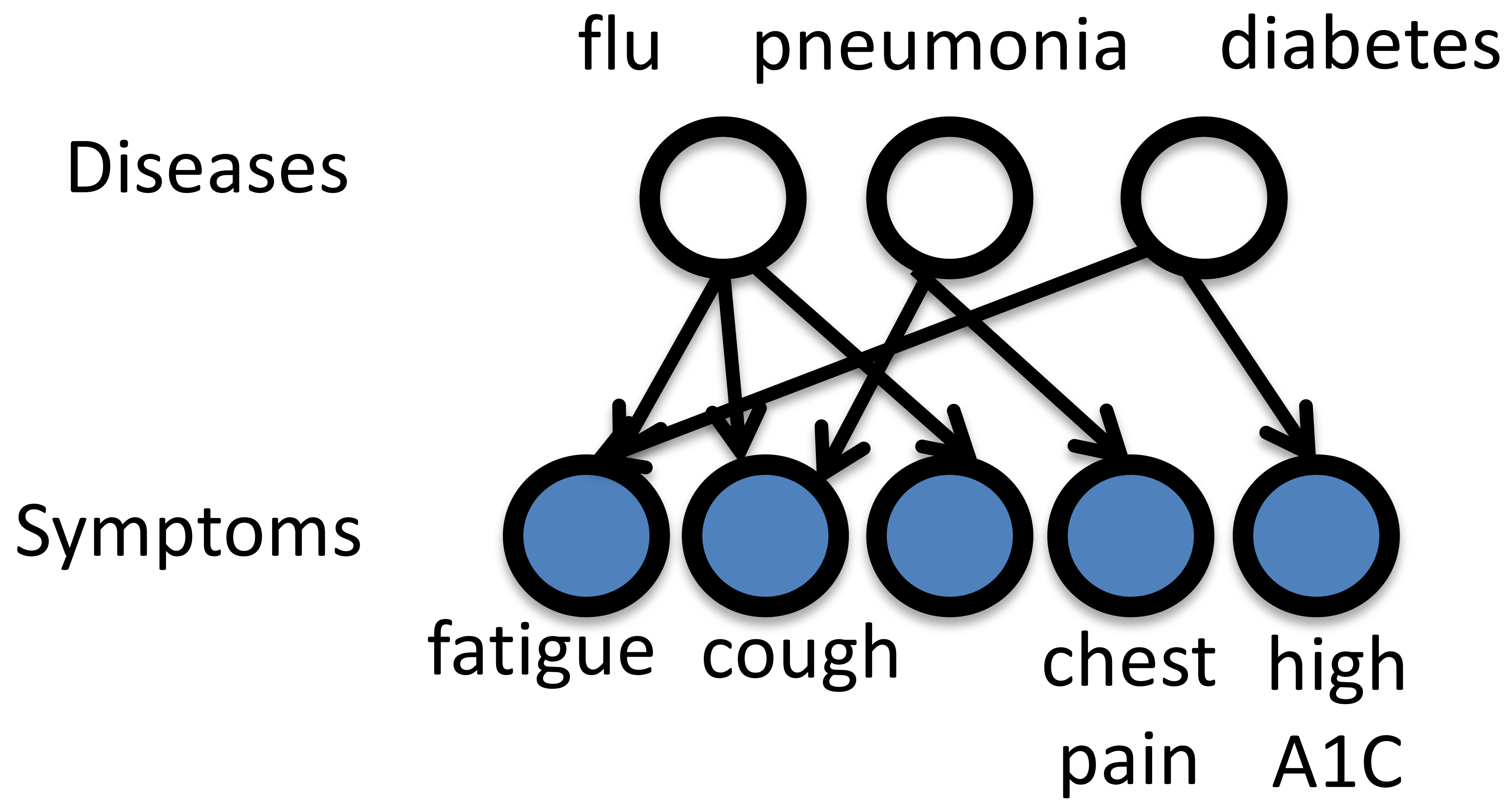
My understanding is:
The patient was admitted at the hospital 3 days ago
Malaise is one of the symptoms that the patient had 5 days ago

FIGURE 33-1 Short sample dialogue. The physician's inputs appear in capital letters after the double asterisks.

https://en.wikipedia.org/wiki/Mycin

1980's: INTERNIST-1/QMR model

- Diagnosis for internal medicine



- Challenges:
  1. Clinicians must enter symptoms manually
  2. Difficult to maintain, difficult to generalize

Probabilistic model relating:

570 binary disease variables
4,075 binary symptom variables
45,470 directed edges

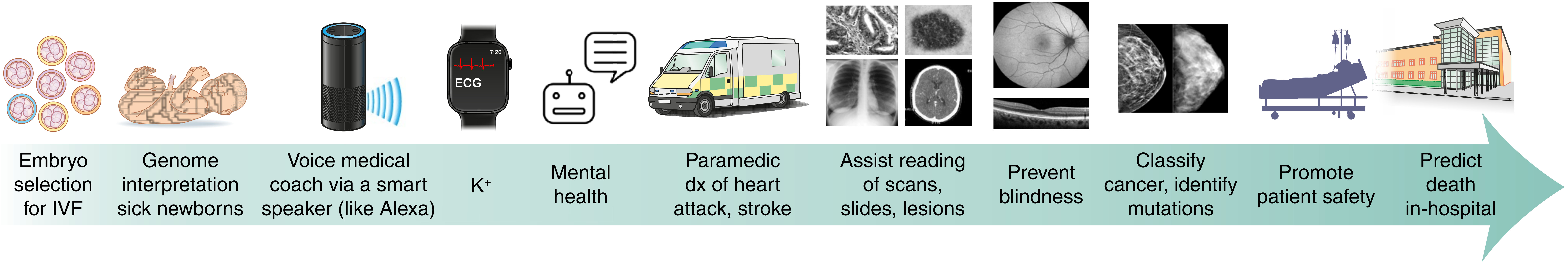
Elicited from doctors:
15 person-years of work

Led to advances in ML & AI (Bayesian networks, approximate inference)

https://en.wikipedia.org/wiki/Internist-I

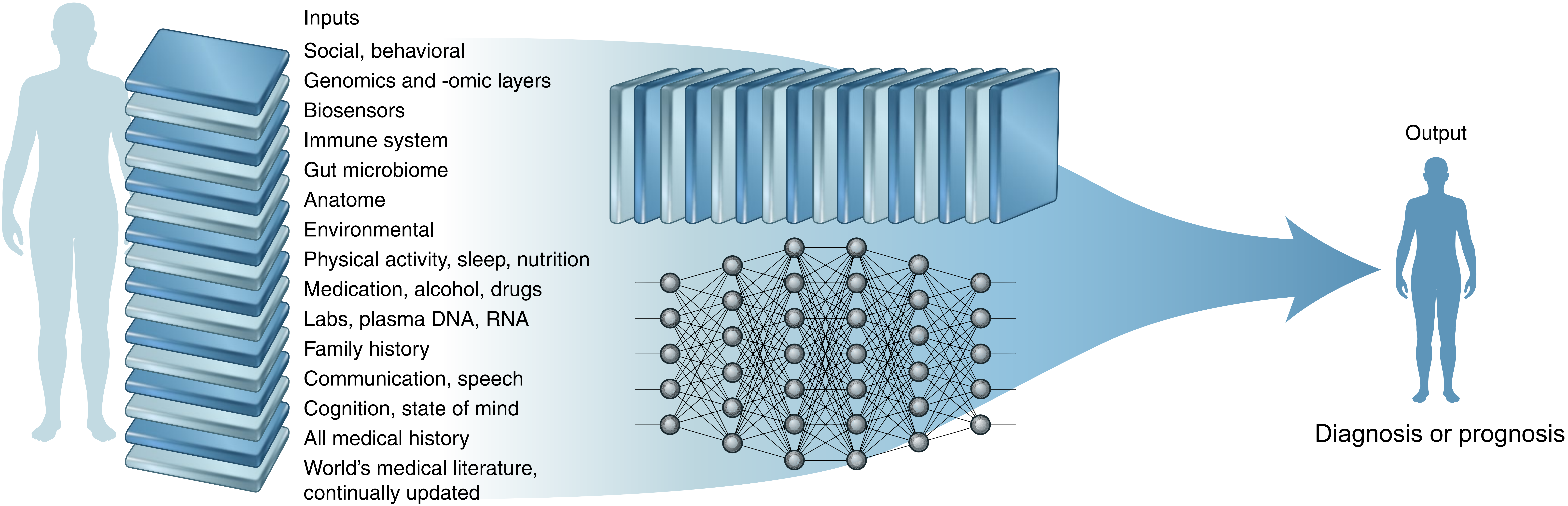
AI/ML in Medicine – Applications

– Diagnosis of diseases
– Prognosis of outcome
– Machine learning for perceptual tasks (e.g. radiology or pathology)
– Robotic surgery
– Automating administrative or workflow tasks
– Reducing operational costs
– Precision medicine
– Drug discovery



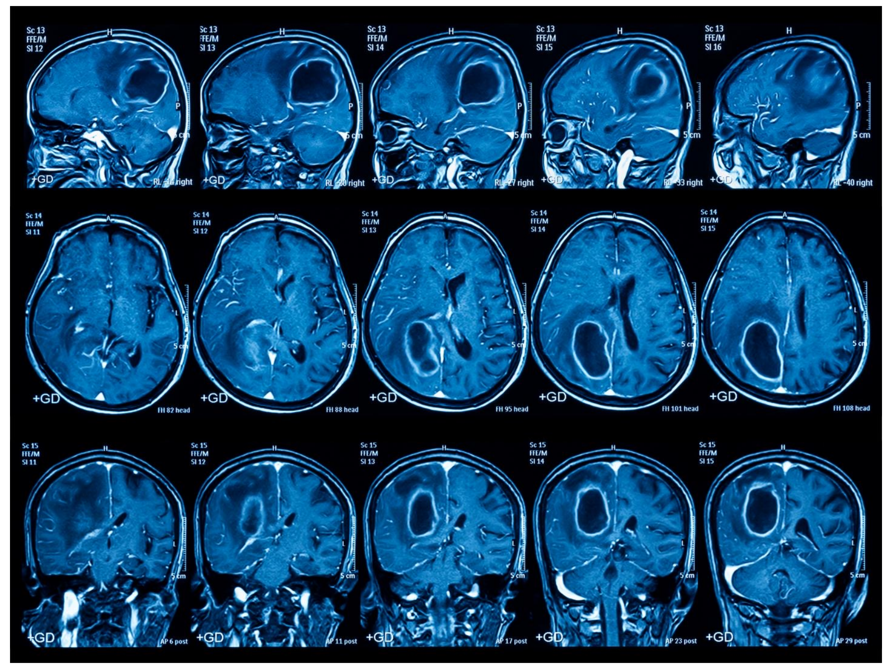
E. Topol, 2017

AI/ML in Medicine – Applications



E. Topol, 2017

Healthcare: The data

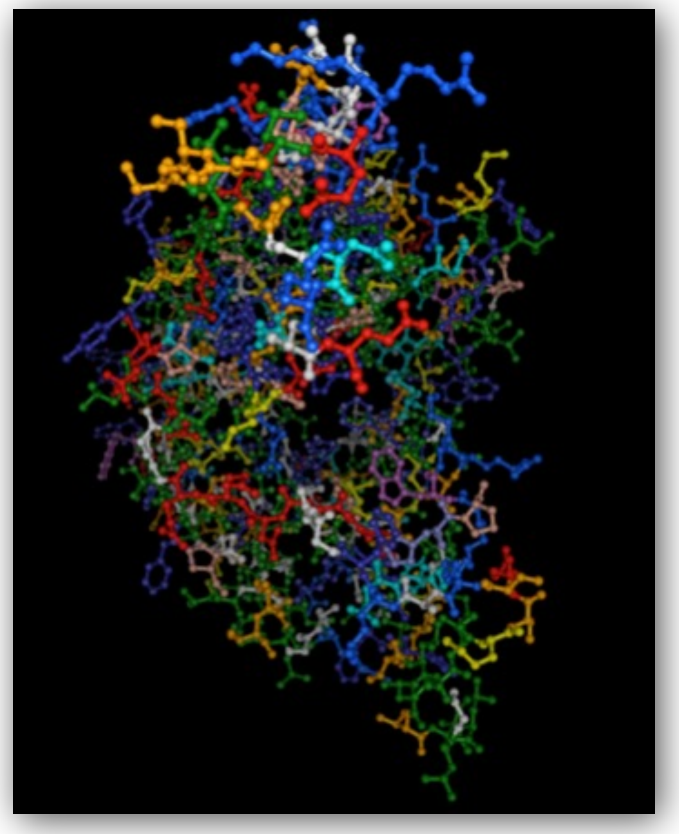


Medical imaging

Vital measures

Lifestyle

Wearables



Proteomics

Genomics

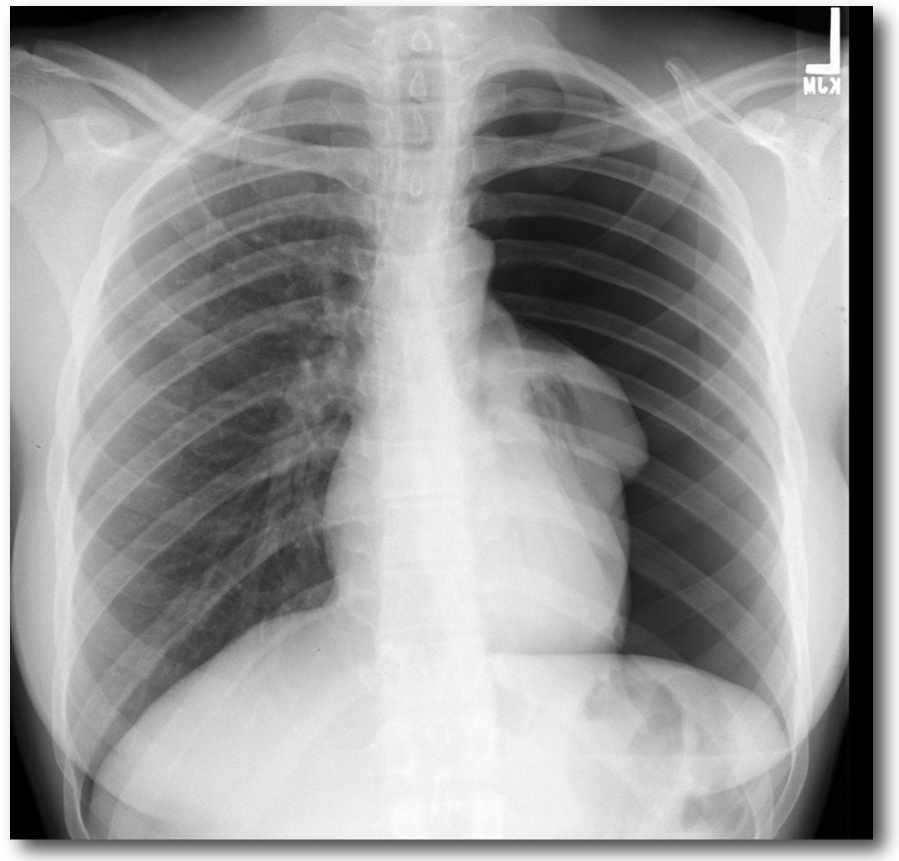
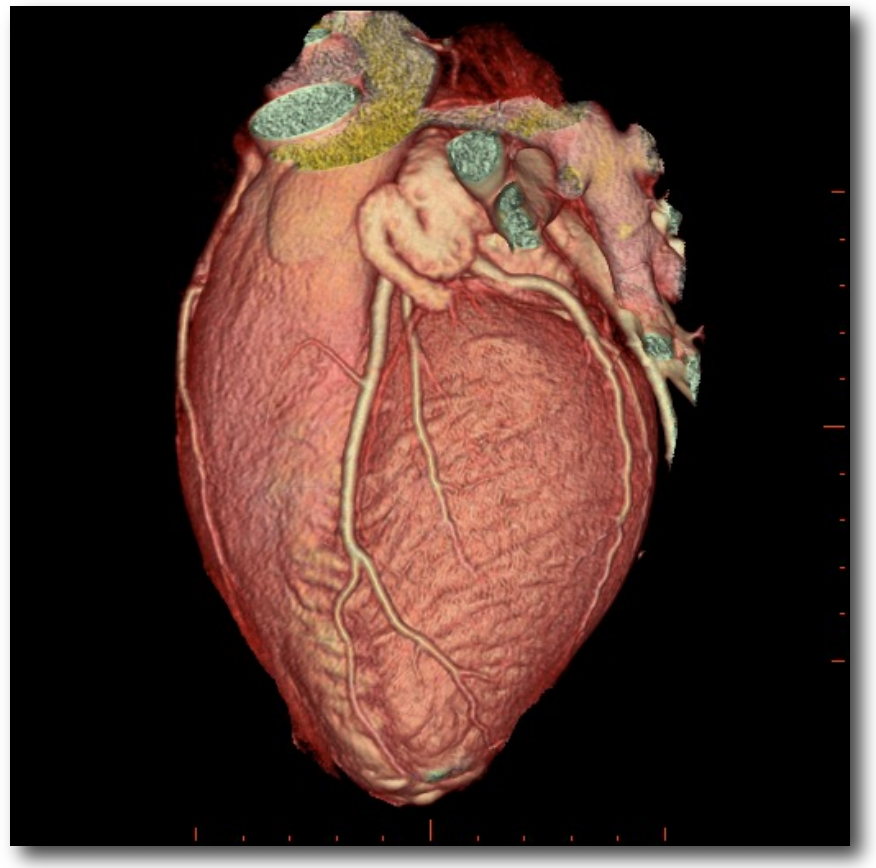
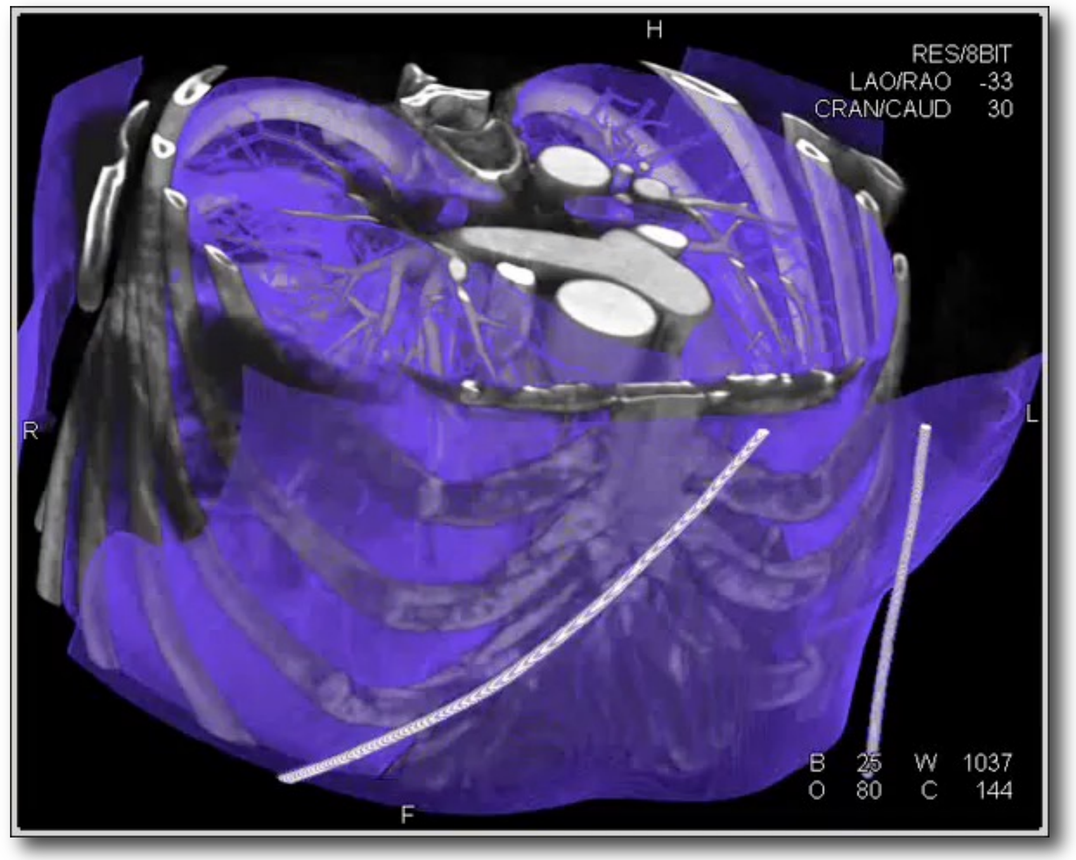
Lab tests

Social media

Clinical records

Healthcare data: Medical imaging

- Medical imaging allows non-invasive visualization of internal organs, tissue, etc.
  - Imaging modalities produce a map or ***image*** of some physical properties of the organs, tissues, etc.
- Images:
  - 2D measurements $f(x,y)$, 3D $f(x,y,z)$ or 4D $f(x,y,z,t)$
  - Measurements $f\,(...)$ can be
    - scalars (often visualized as intensity or brightness)
    - vector-valued (more difficult to visualize)

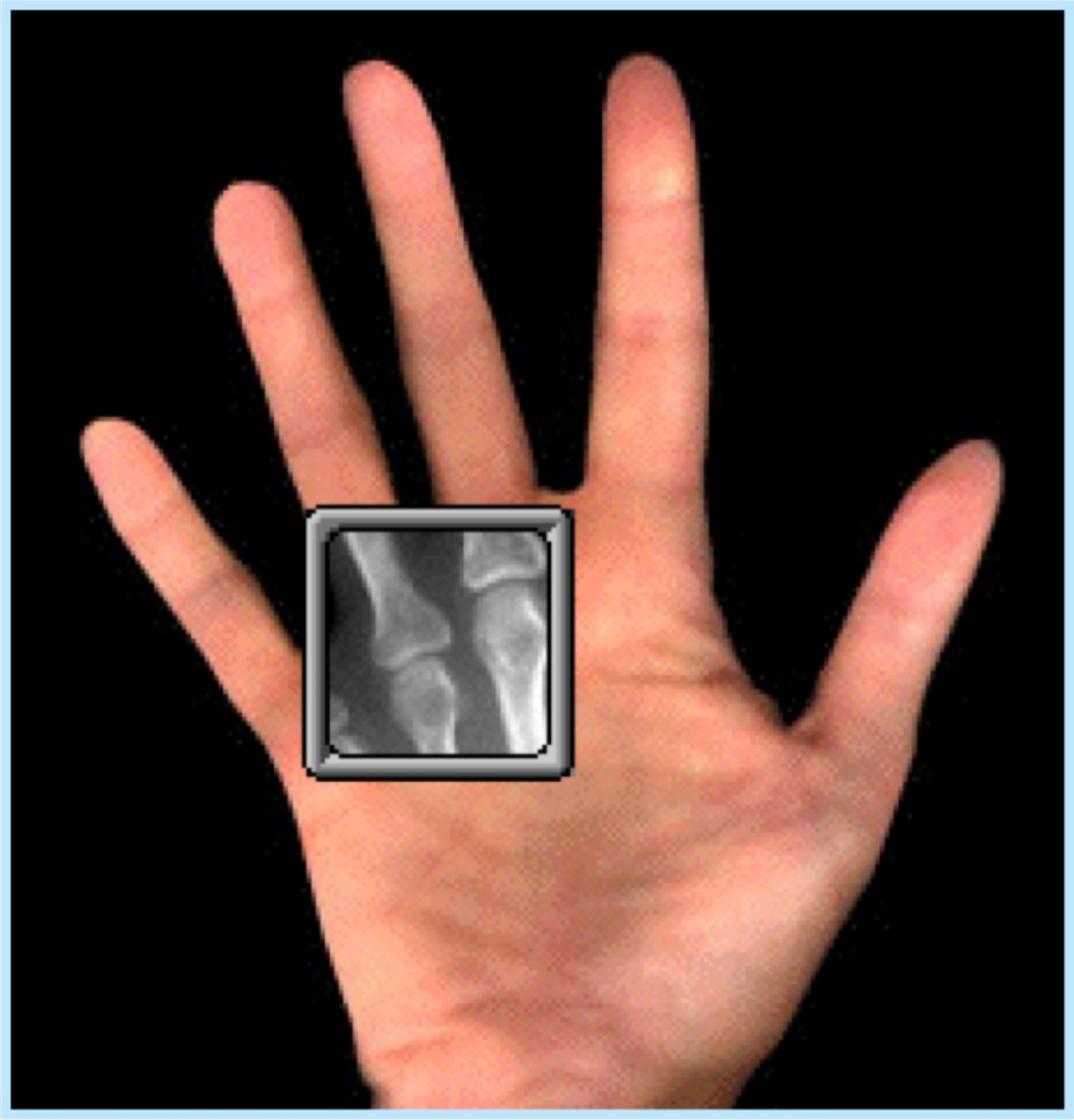




Healthcare data: Medical imaging

- Different modalities
  - x-ray, ultrasound, CT, MR, SPECT, PET
- Different physics-based mechanisms for generating contrast
  - radiation
  - magnetization
  - sound
  - light
- Different characteristics
  - some harmful to the patients (using ionizing radiation)
  - some invasive (require injection of contrast agents or insertion of imaging device into the body)
  - many are harmless and non-invasive

Imaging Modalities: X-Ray

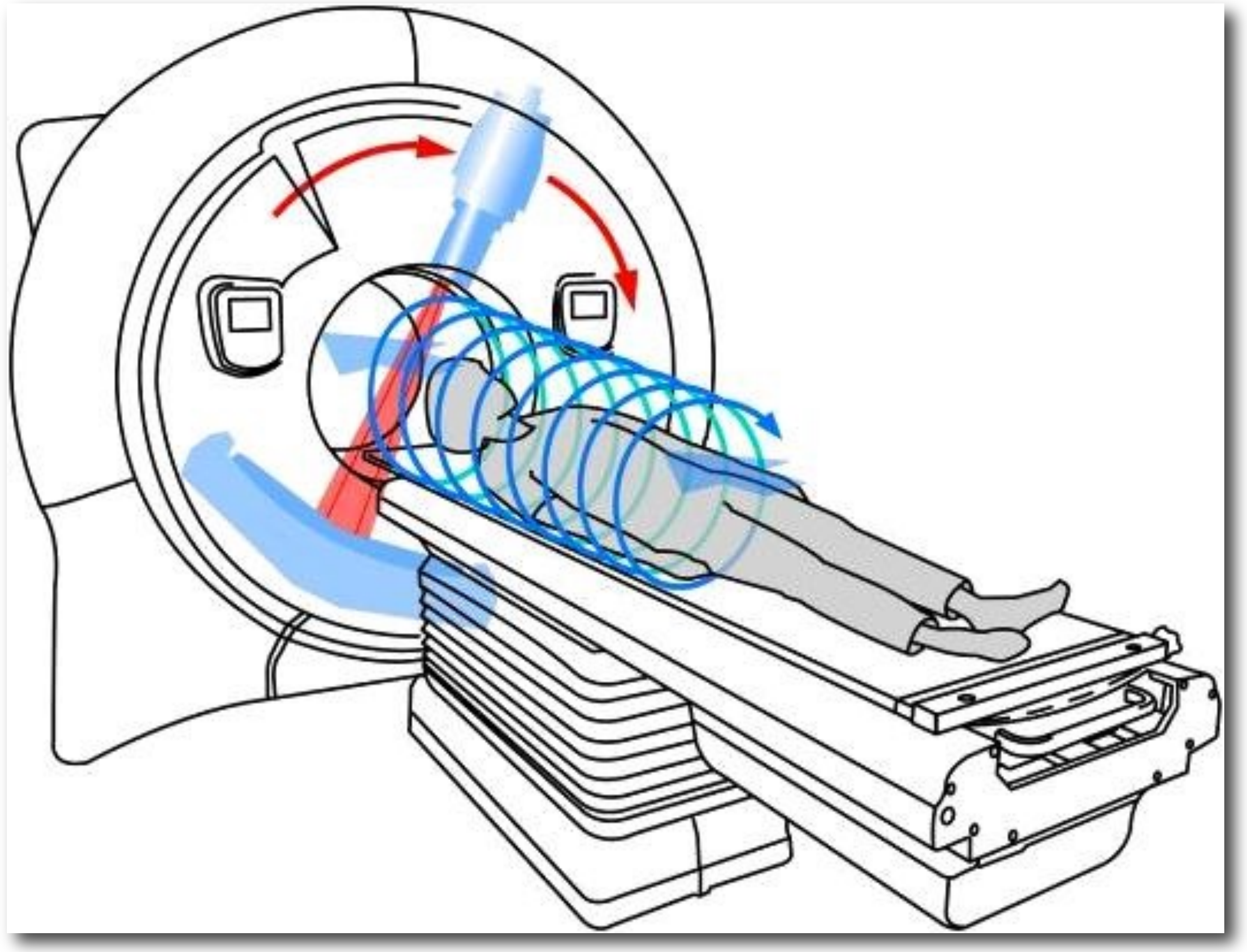
- X-rays (Radiography)
  - Uses x-rays or ionizing radiation
  - Produces 2D images which are projections of 3D objects

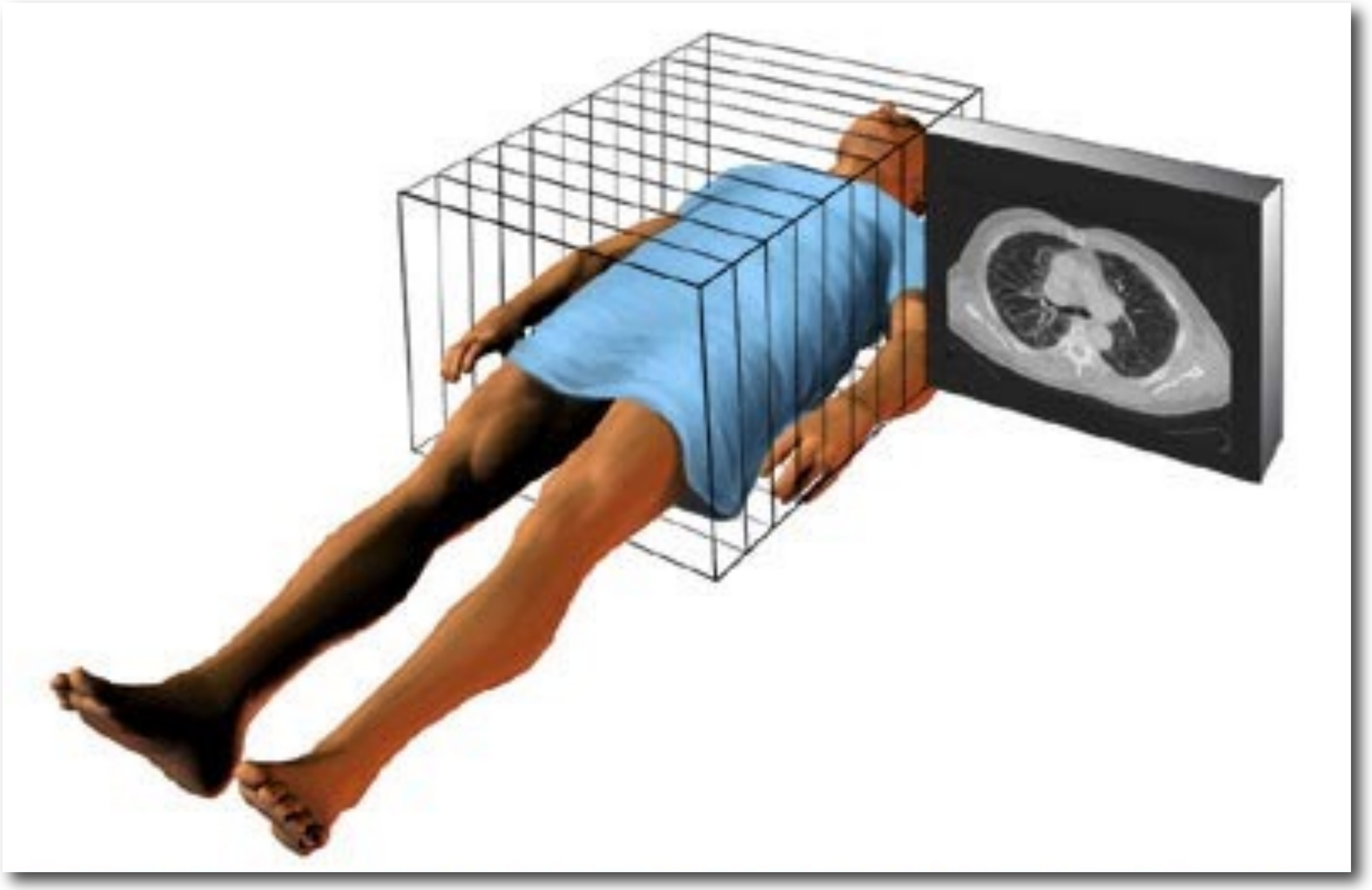


radiograph

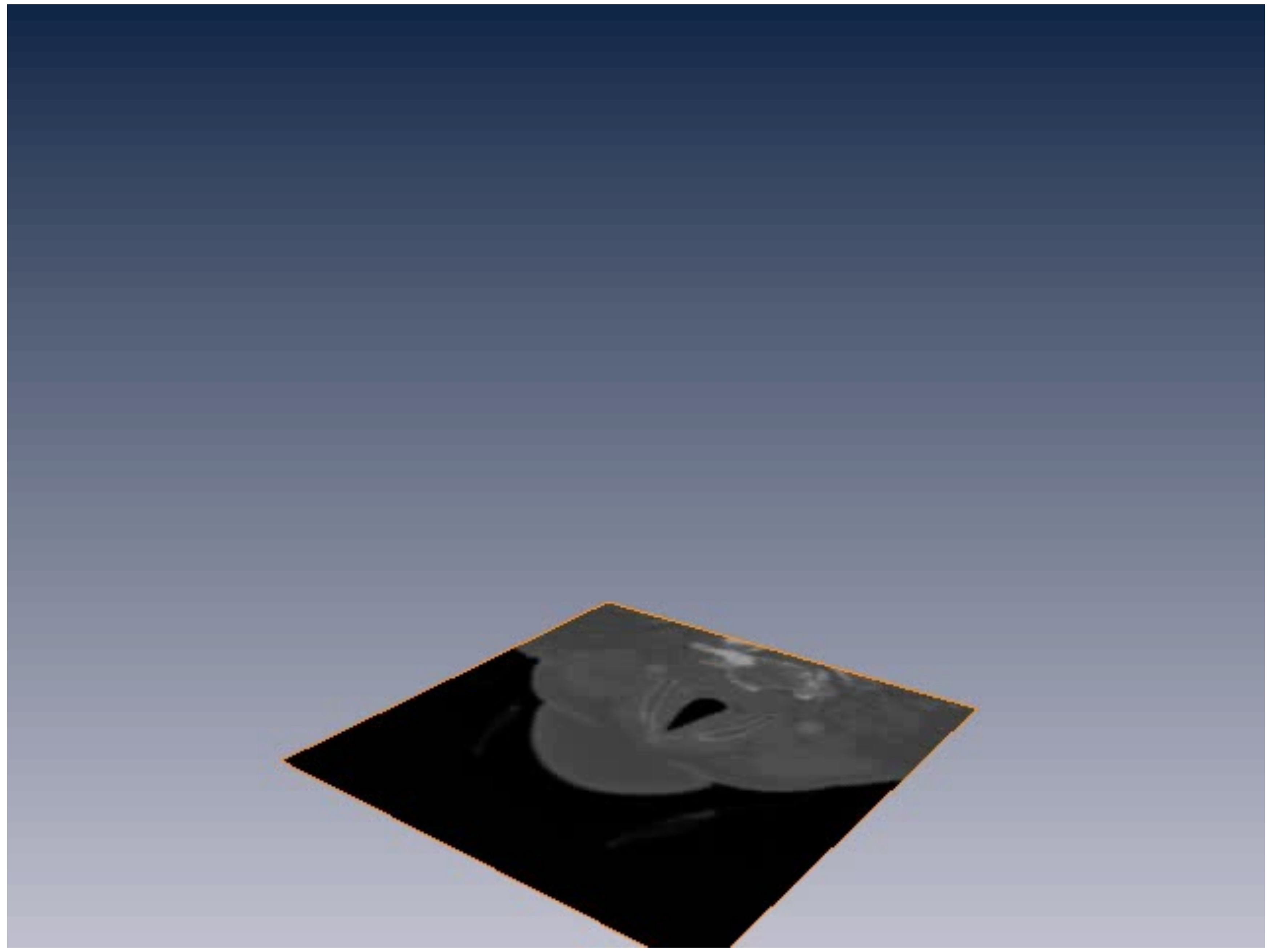
Imaging Modalities: X-ray Computed Tomography

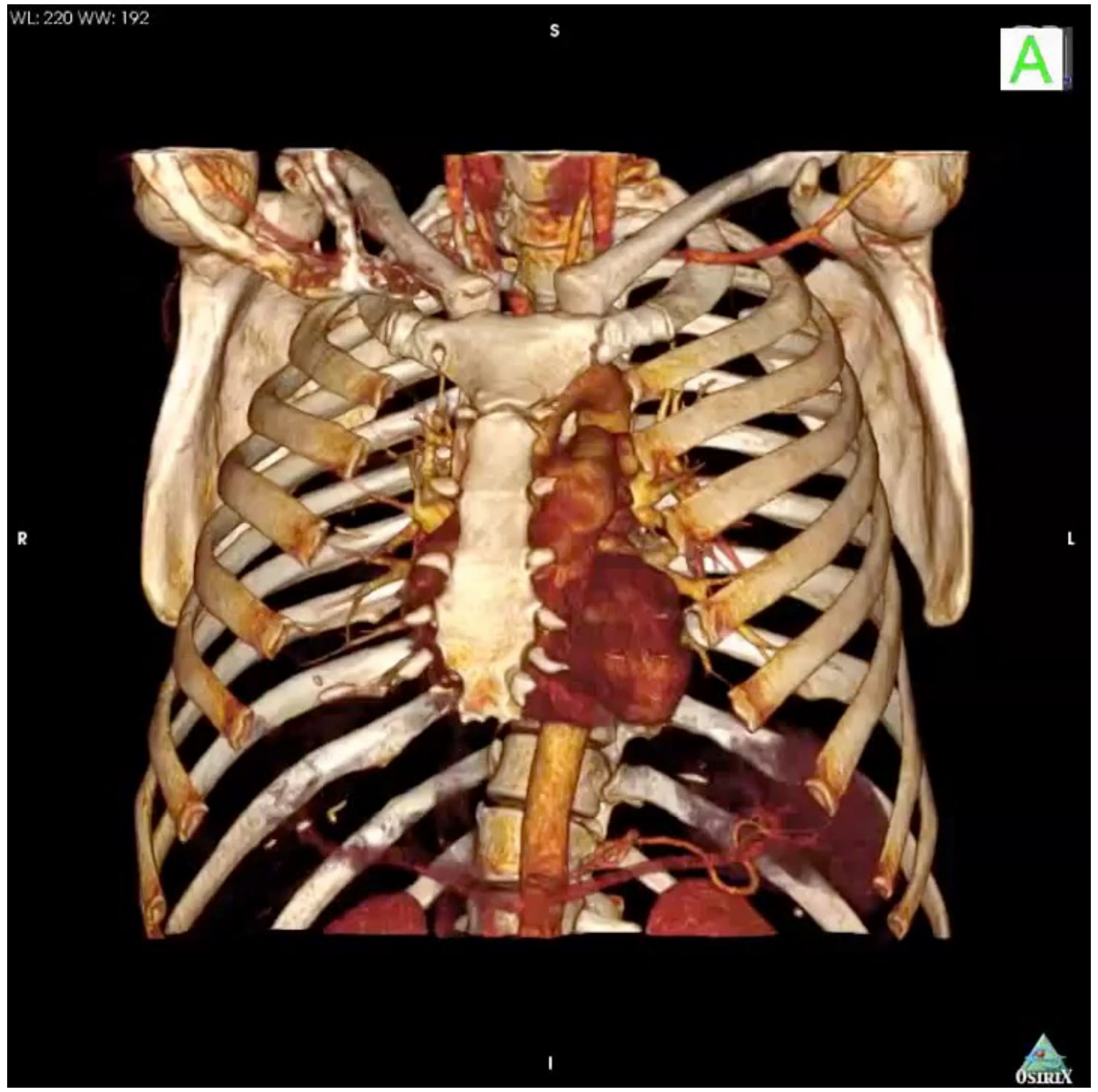
- Uses x-rays, but exposure is limited to a slice (or “a couple of” slices) by a collimator
- Source and detector rotate around object – projections from many angles
- The desired image, $I(x,y) = \mu(x,y,z_0)$, is computed from the projections



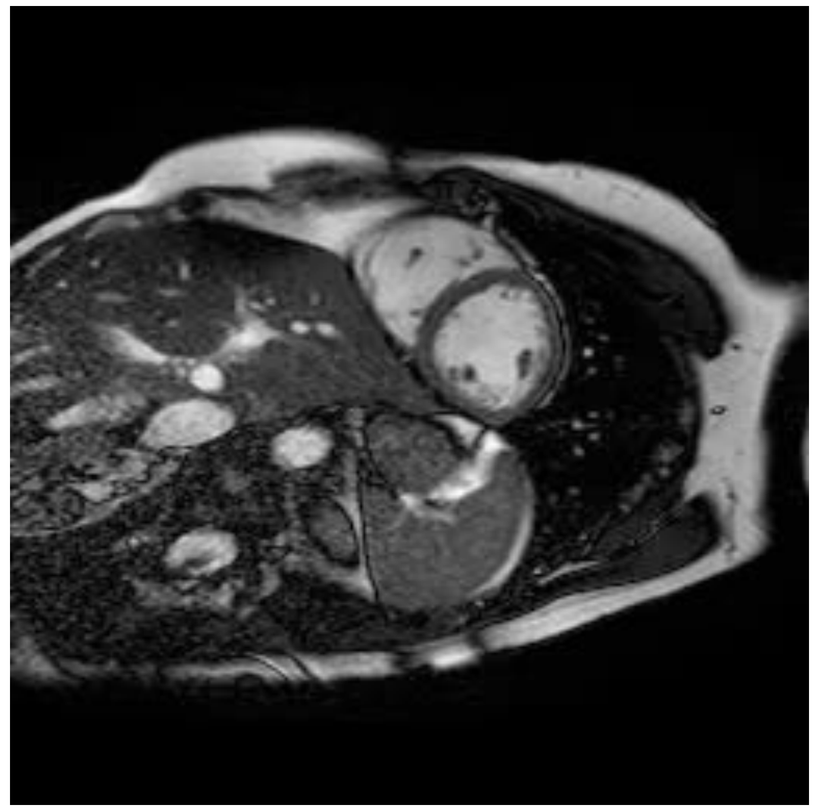


Imaging Modalities: X-ray Computed Tomography

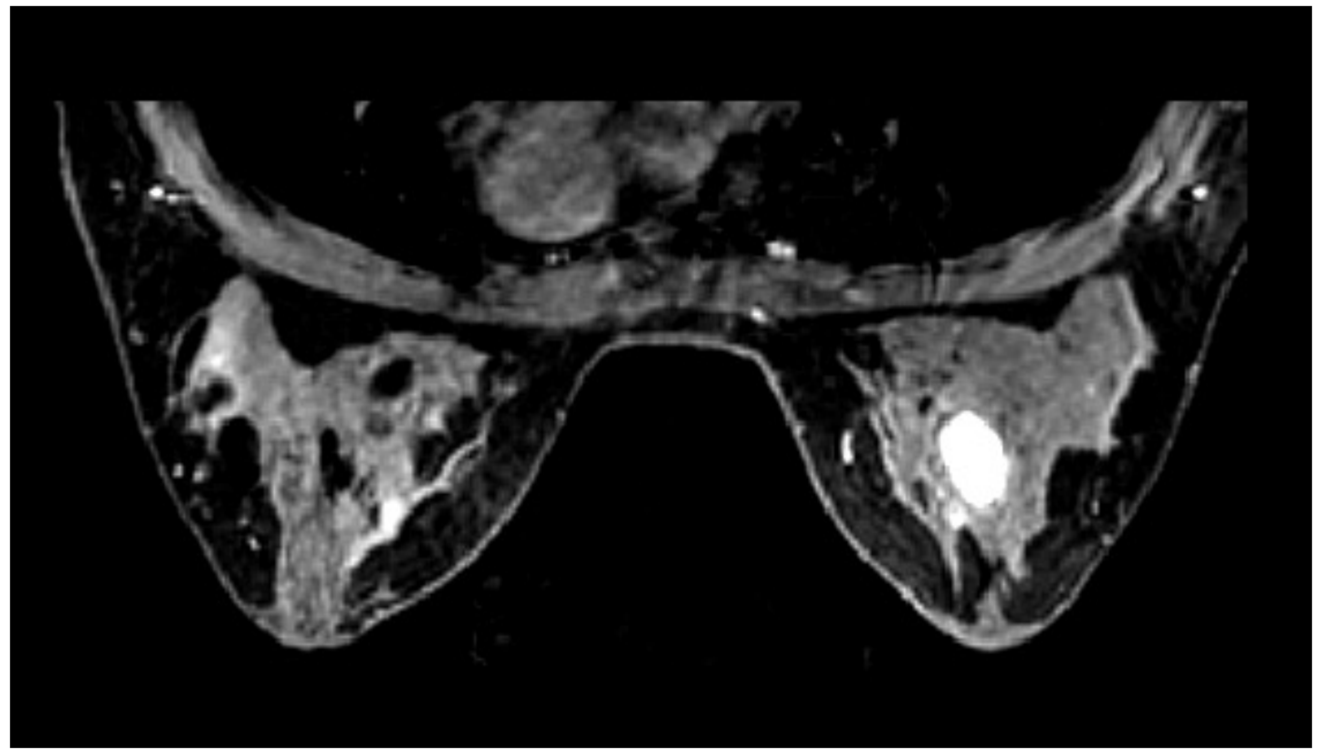




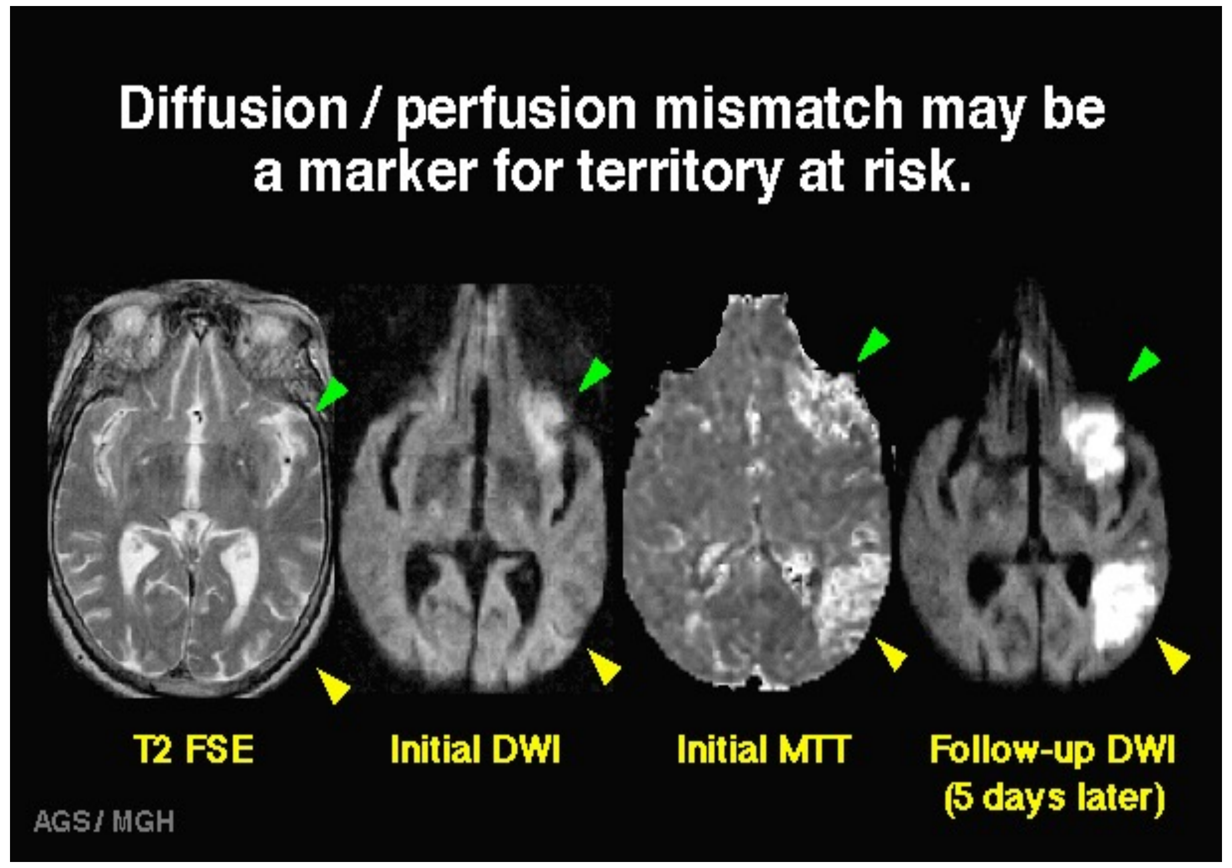
Imaging Modalities: Magnetic Resonance Imaging



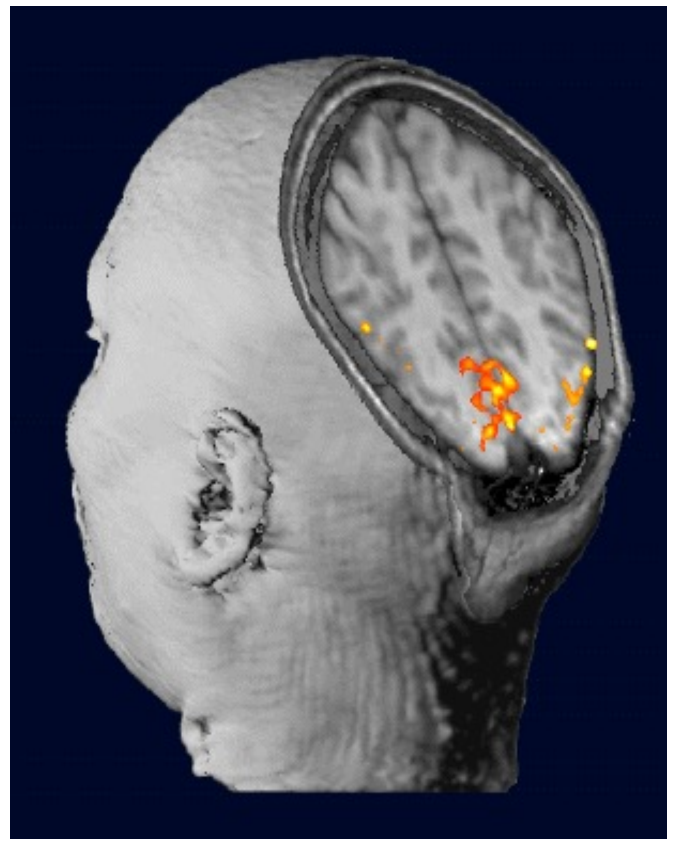
cardiac



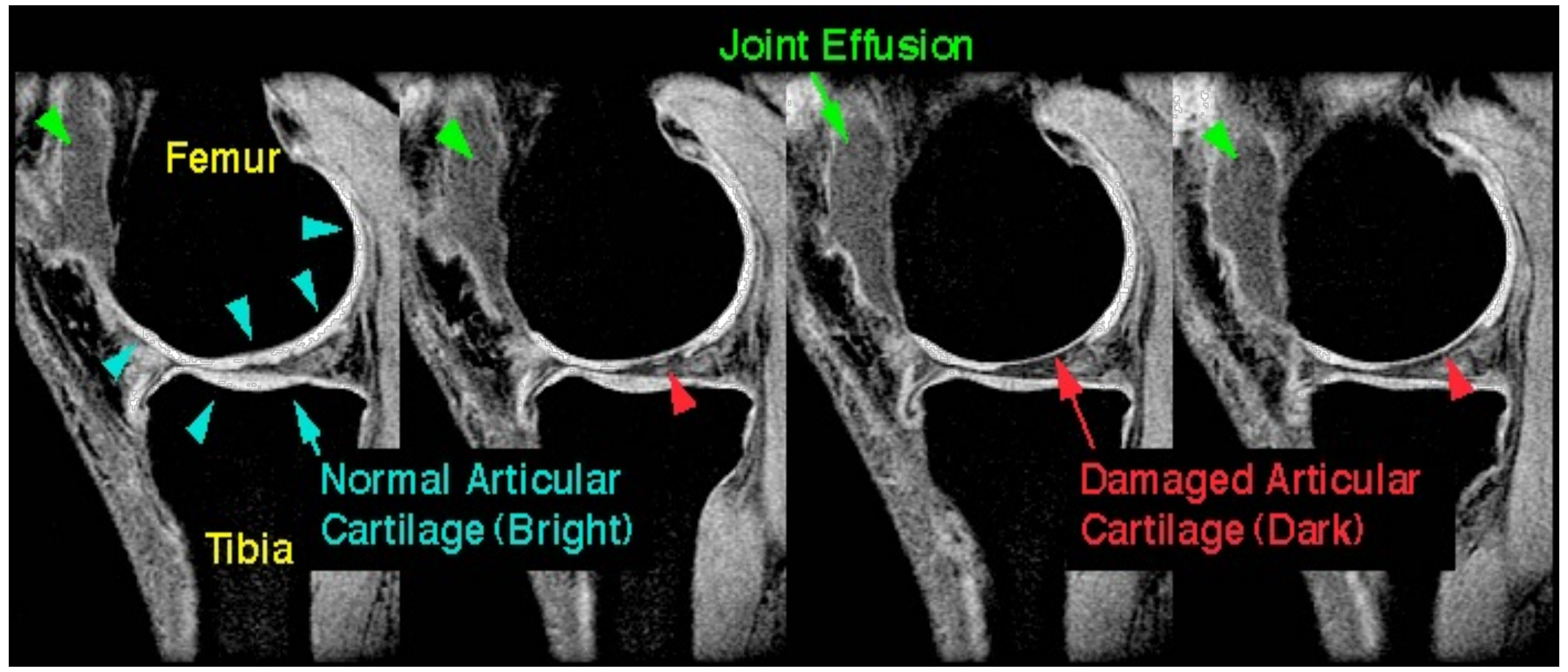
cancer



stroke



brain

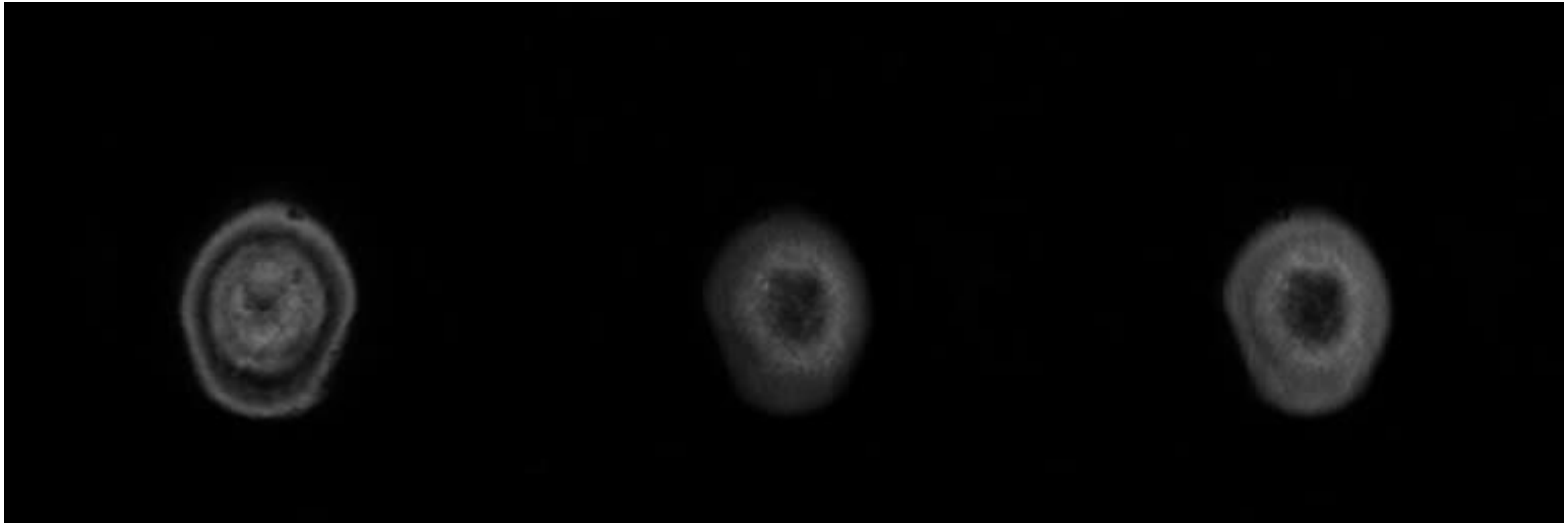


joints

lung

Imaging Modalities: Magnetic Resonance Imaging

- Can produce maps of different tissue properties

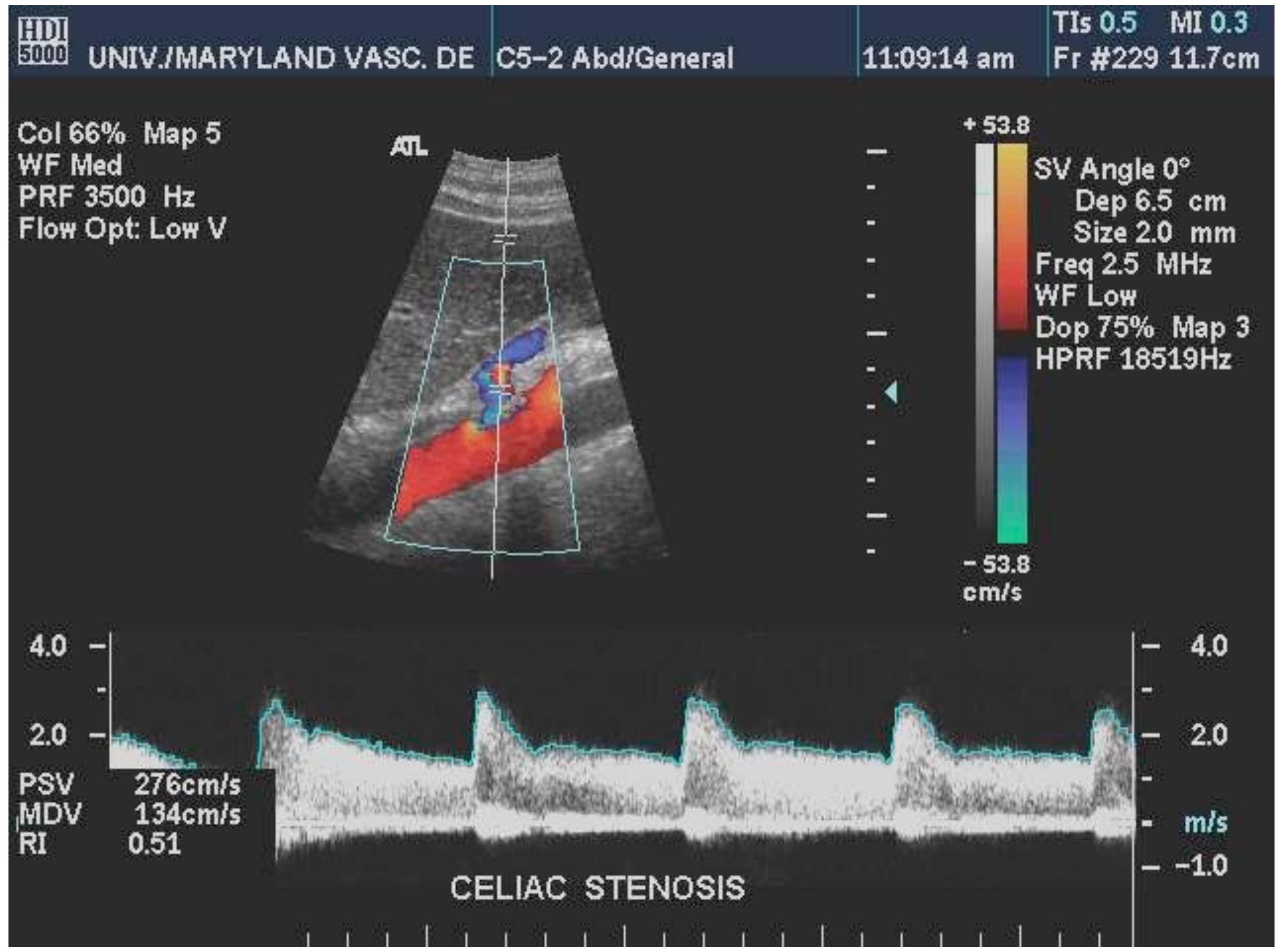


T1-weighted T2-weighted Proton density

Imaging Modalities: Ultrasound

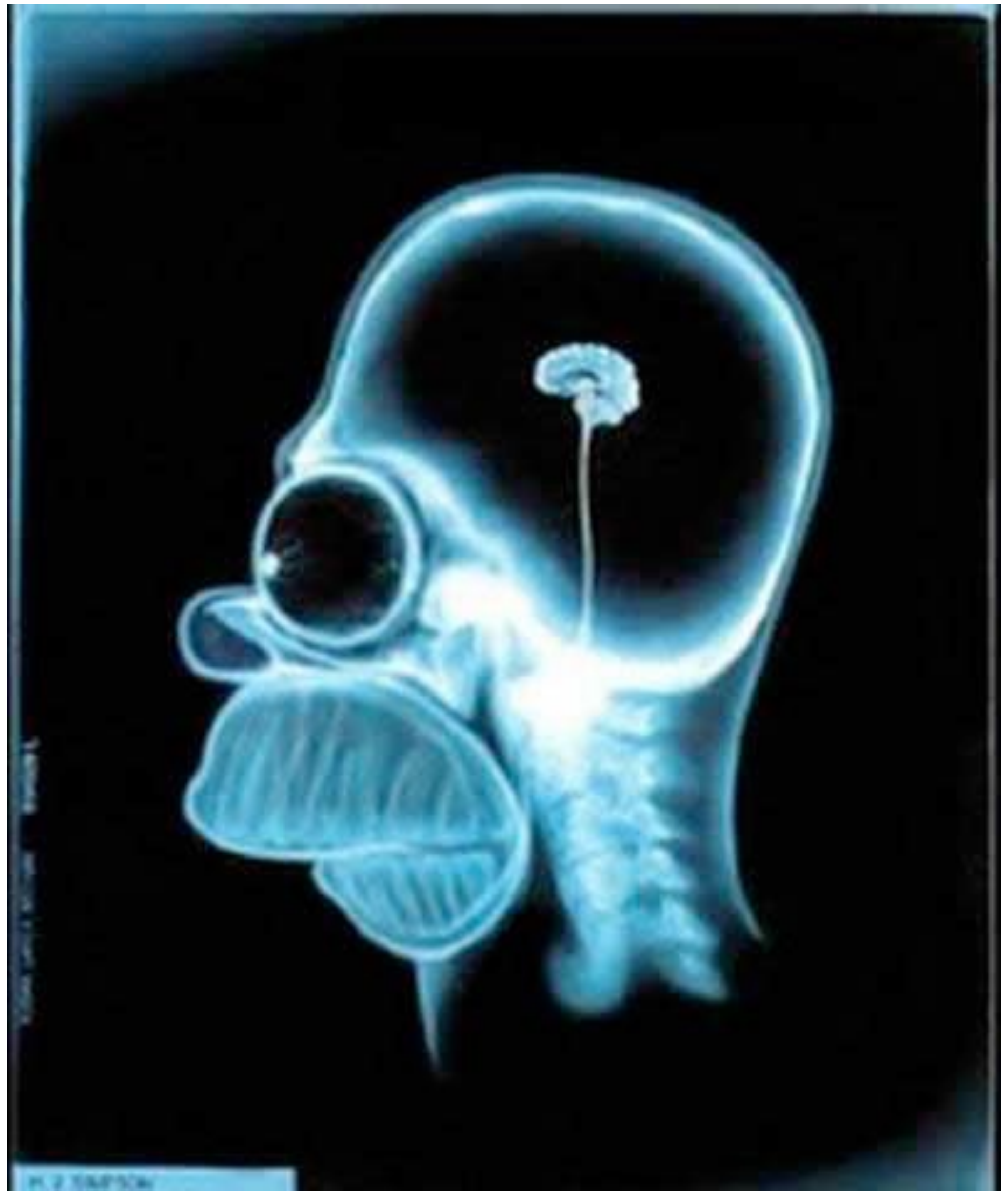
- Issue: Flow
  - Can use Doppler effect to image flow
- Issue: Speckle
  - Most noise in US is speckle (signal dependent)

High-Resolution

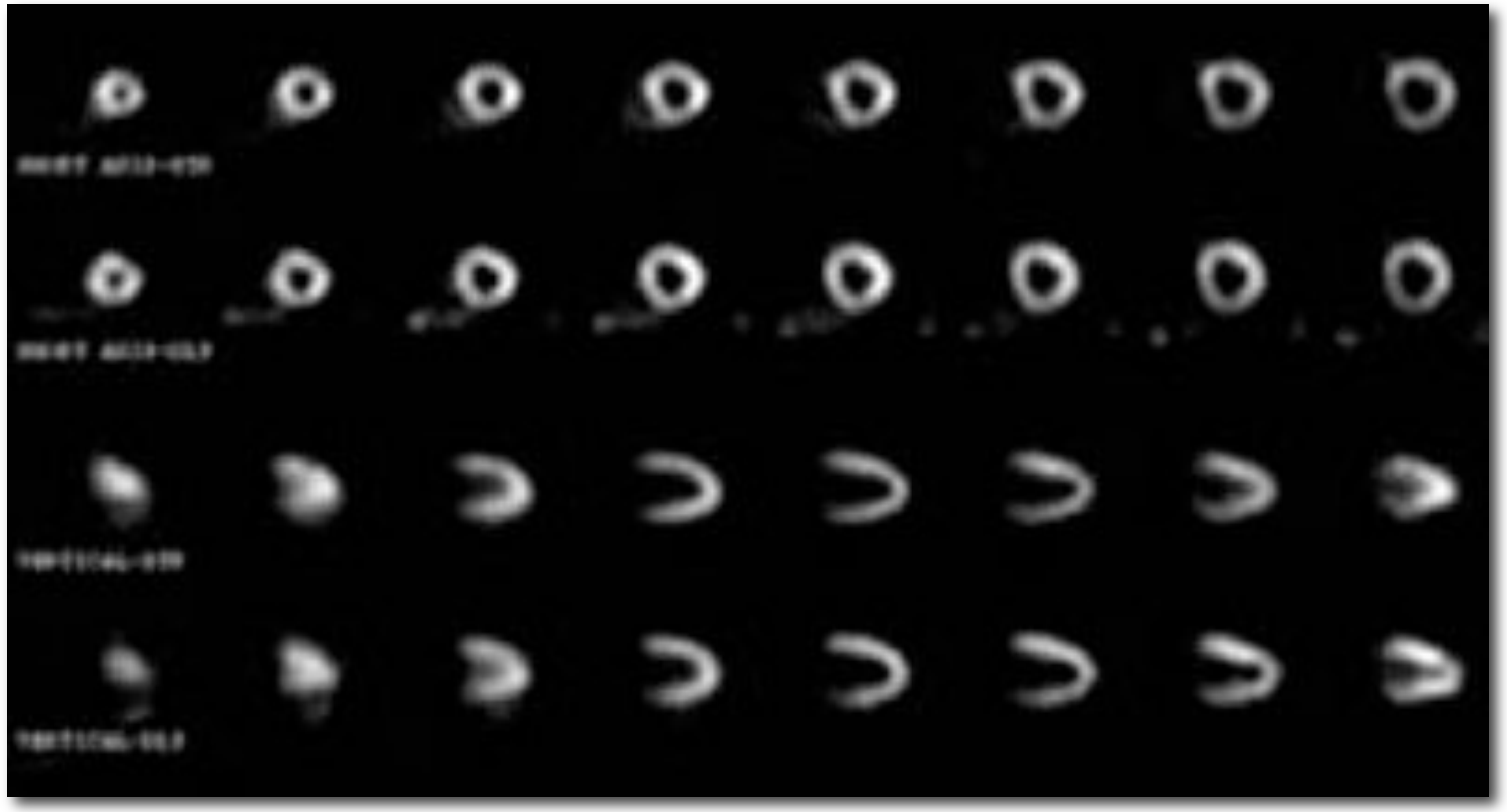


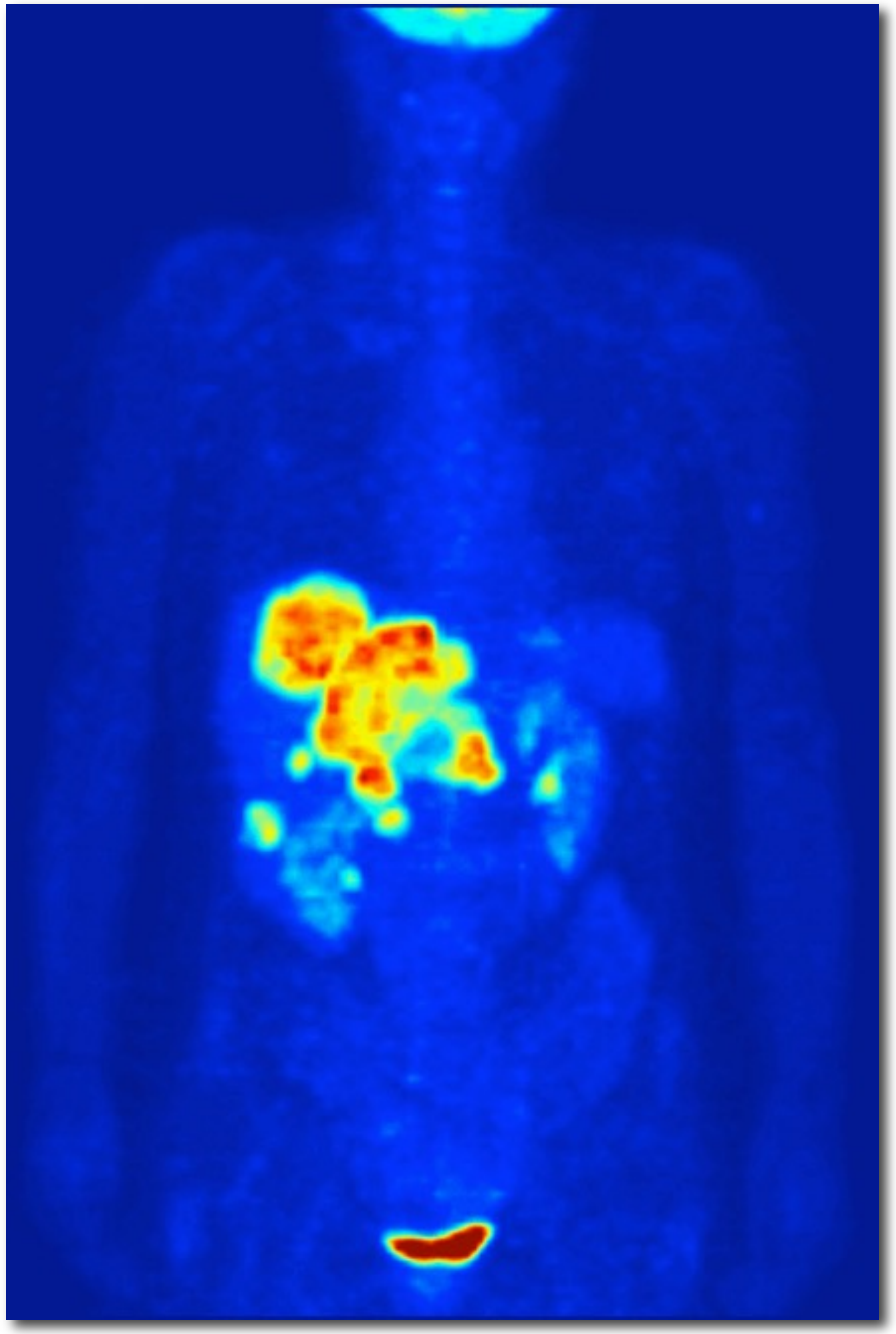
Color Doppler

Anatomical vs Functional Imaging

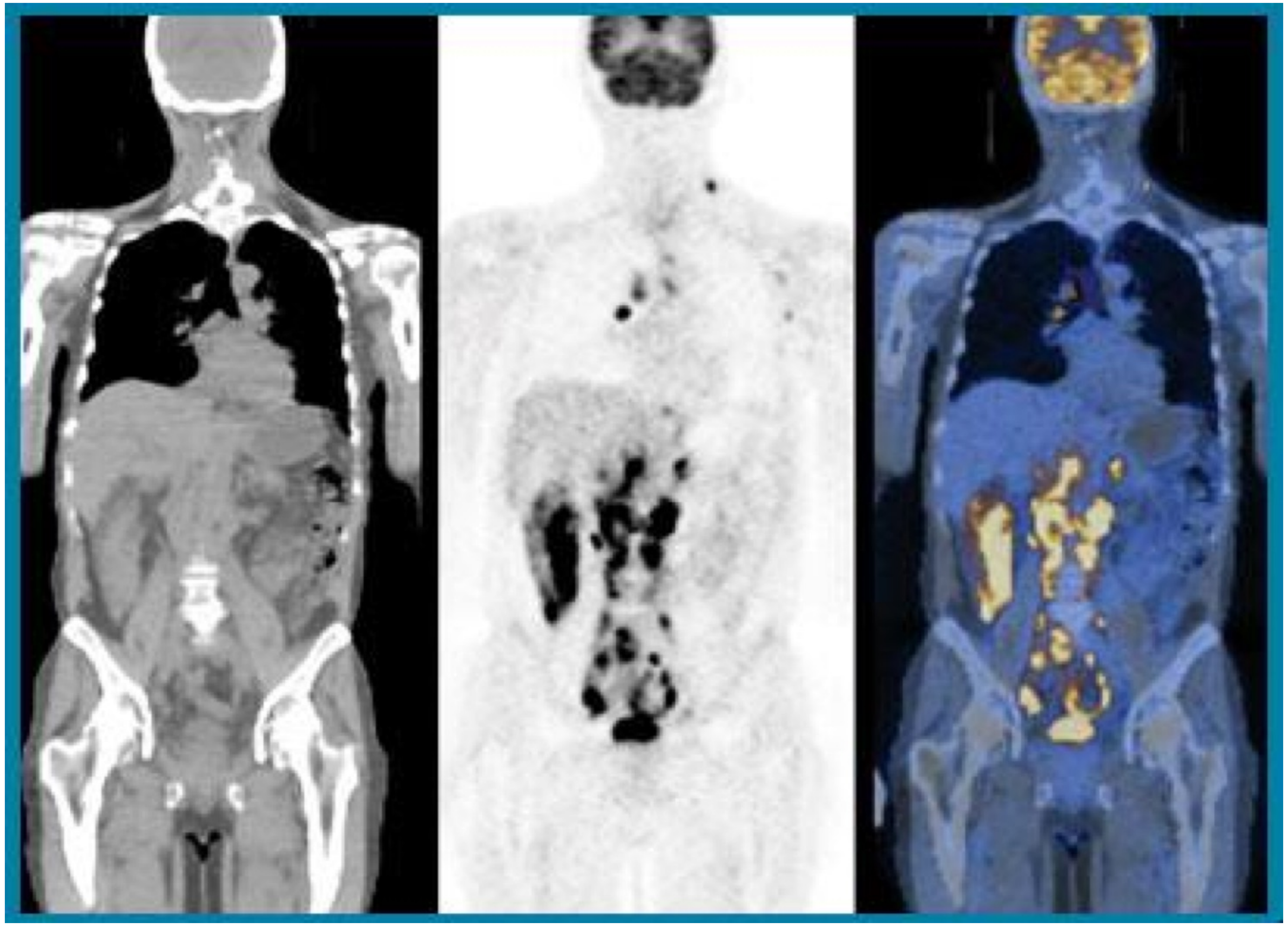


Imaging Modalities: SPECT & PET





Hybrid modalities: PET/CT



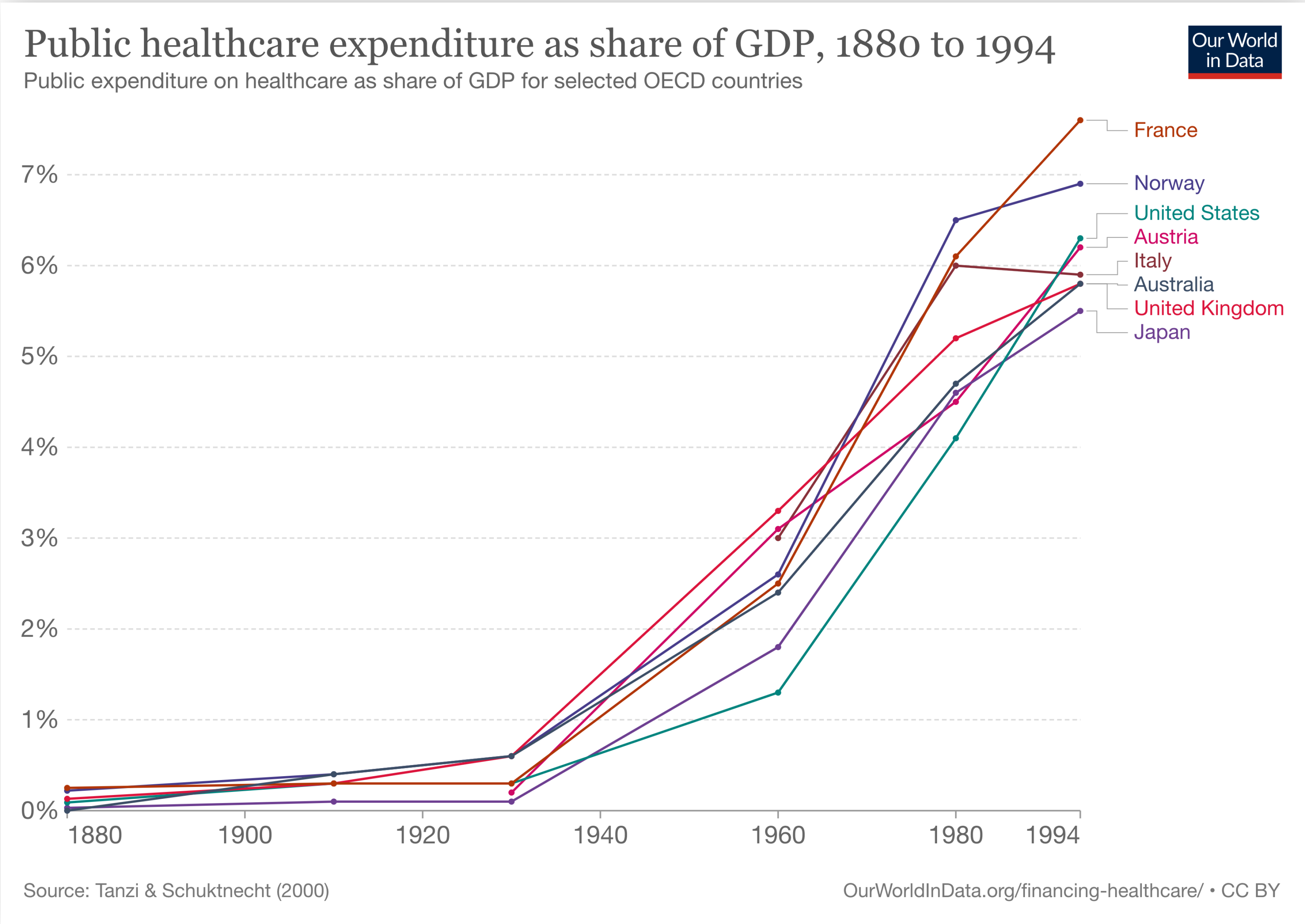
Anatomy Function Both

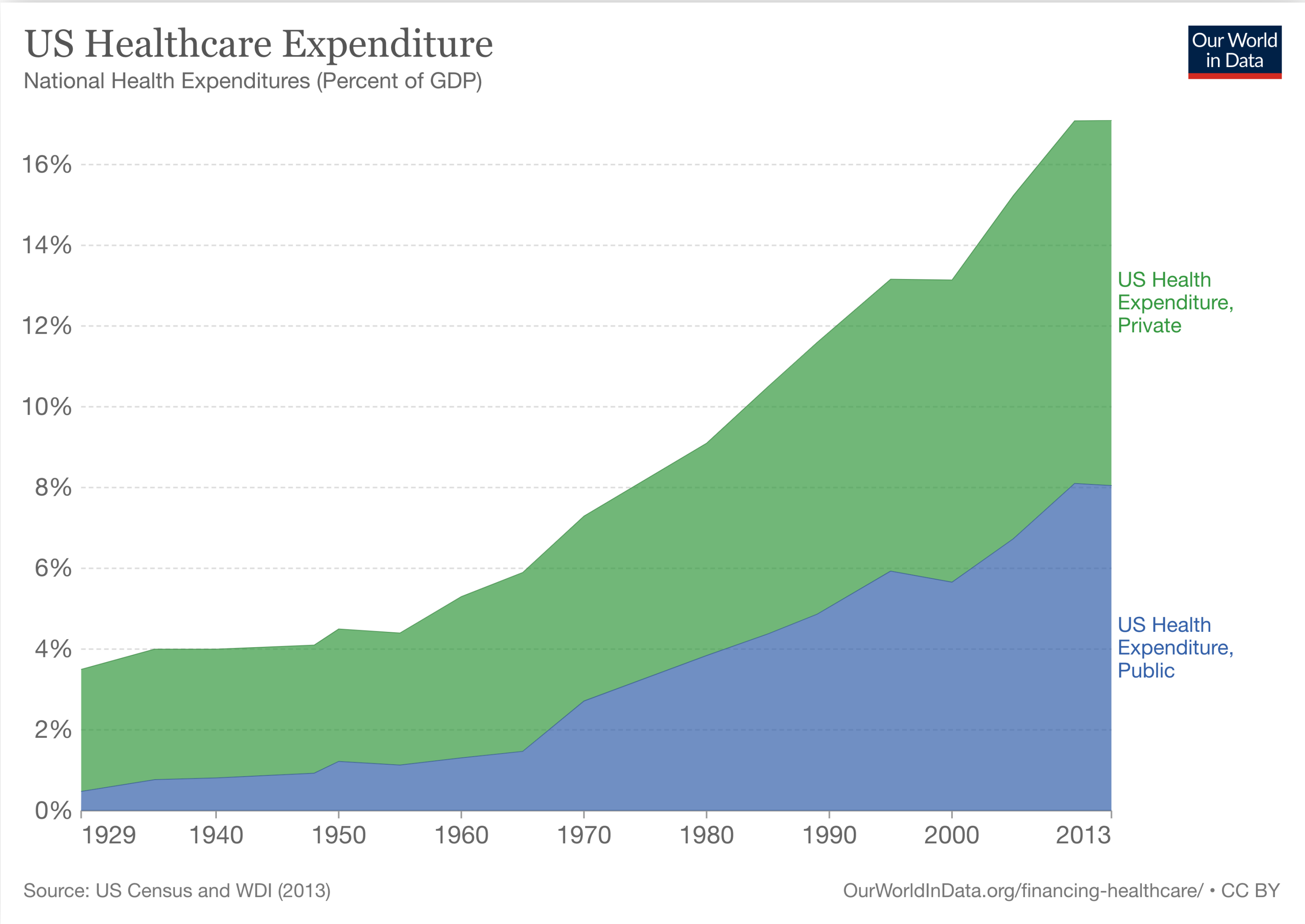
Comparison of imaging modalities

	2D	3D	4D	Ionizing radiation?	Invasive?	Anatomical imaging	Functional imaging	High-resolution
X-ray (radiography)	✓	✗	✗	✓	✗	✓	✗	✓
Ultrasound	✓	✓	✓	✗	✗	✓	✓	✓
CT	n/a	✓	✓	✓	✗	✓	✗	✓
MRI	✓	✓	✓	✗	✗	✓	✓	✓
SPECT	n/a	✓	✗	✓	✓	✗	✓	✗
PET	n/a	✓	✓	✓	✓	✗	✓	✗

Healthcare: The problem

- Cost of healthcare is rising



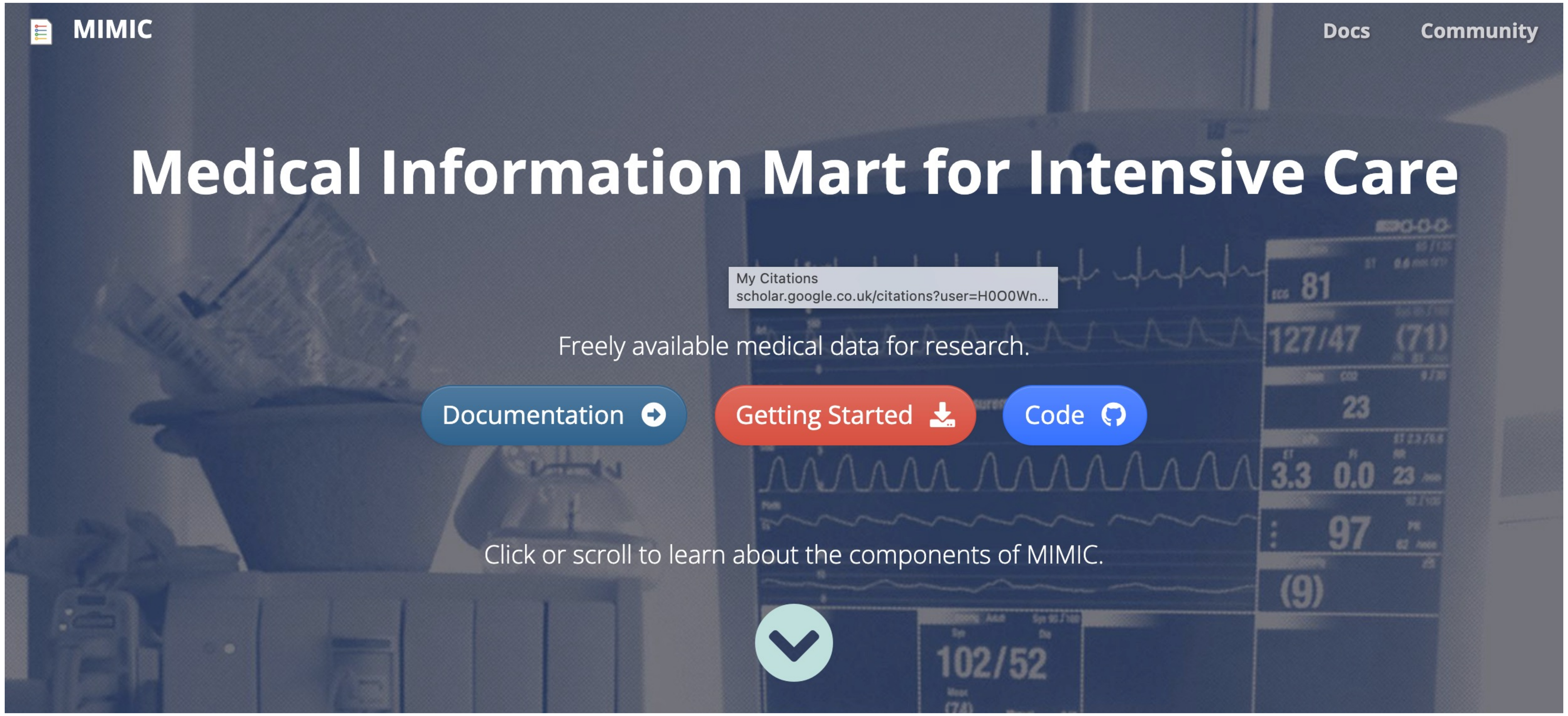


- Despite medical advances, chronic conditions are
  - often diagnosed late
  - often inappropriately managed
- Medical errors are pervasive

Healthcare: The opportunity

- Availability of large data sets
- Increasing digitalisation
- Increasing standardisation
- Advances in machine learning
- Advances in hardware and software
- Opportunities for commercialisation

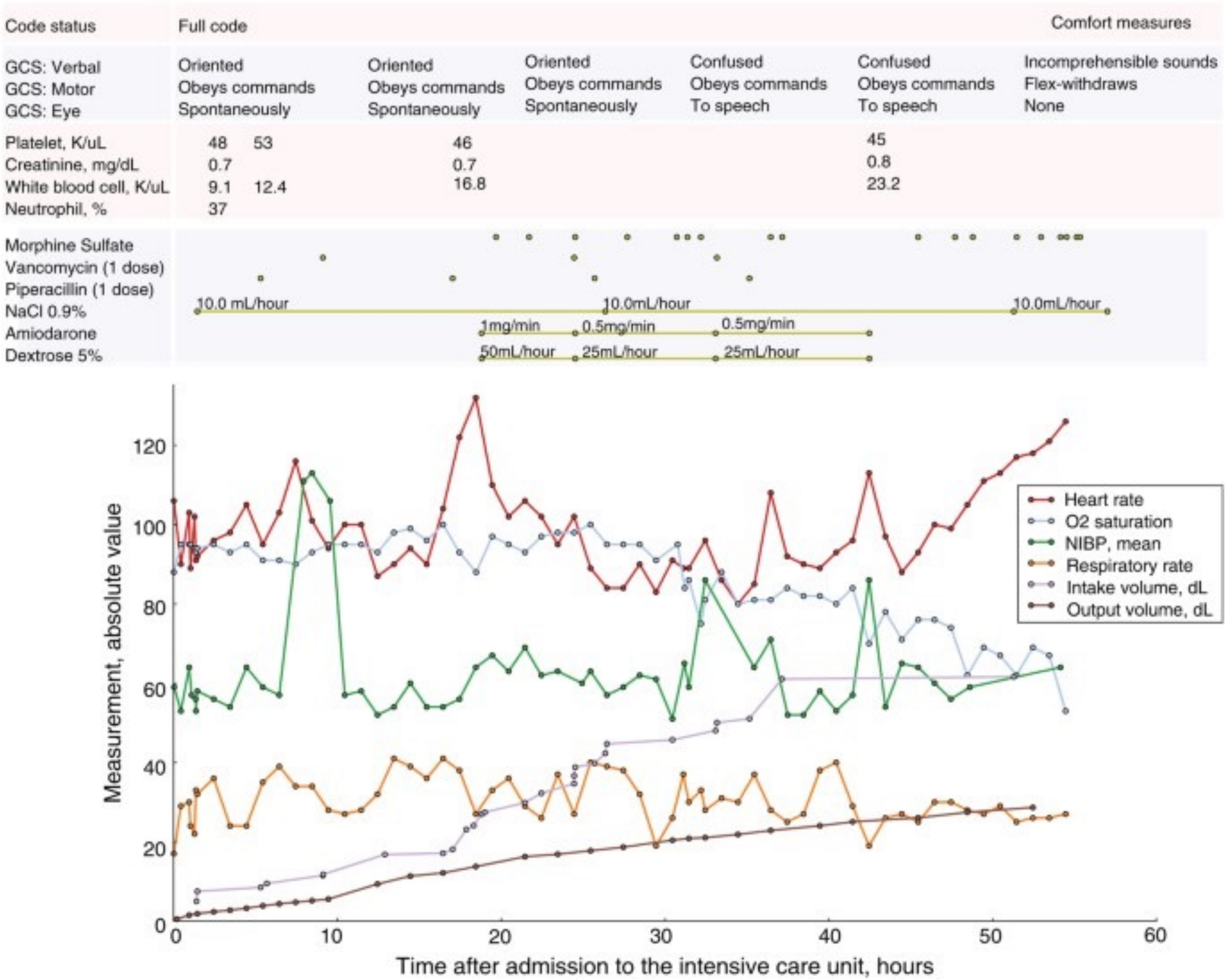
Availability of large data sets: Example – MIMIC



MIMIC-III contains data associated with 53,423 distinct hospital admissions for patients admitted to critical care units plus data for 7870 neonates.

MIMIC (Medical Information Mart for Intensive Care) is a large, freely-available database comprising deidentified health-related data from patients who were admitted to the critical care units of the Beth Israel Deaconess Medical Center.

Availability of large data sets: Example – MIMIC



EXAMINATION: CHEST (PA AND LAT)

INDICATION: ___ year old woman with ?pleural effusion // ?pleural effusion

TECHNIQUE: Chest PA and lateral

COMPARISON: ___

FINDINGS:

Cardiac size cannot be evaluated. Large left pleural effusion is new. Small right effusion is new. The upper lungs are clear. Right lower lobe opacities are better seen in prior CT. There is no pneumothorax. There are mild degenerative changes in the thoracic spine

IMPRESSION:

Large left pleural effusion

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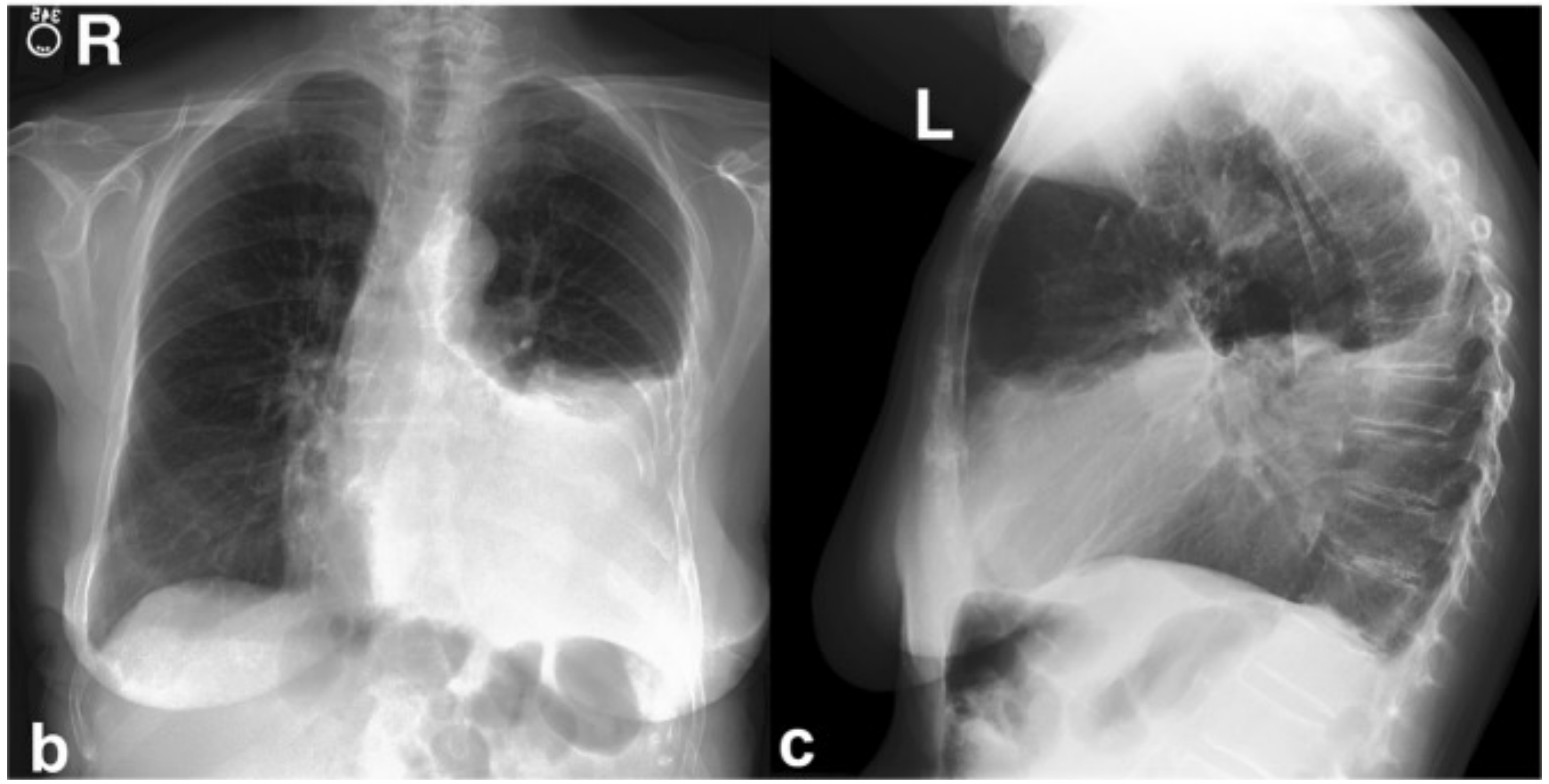


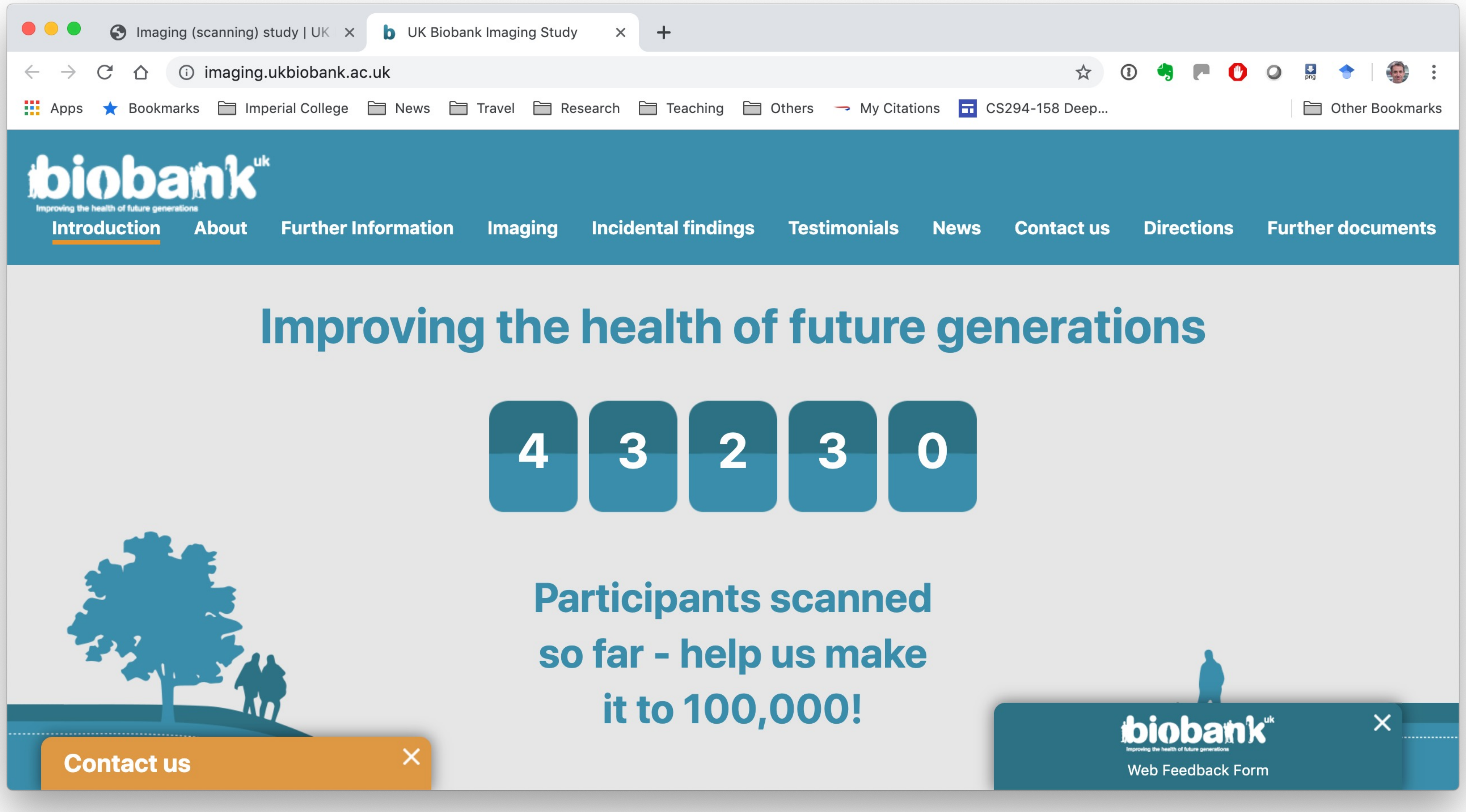
Availability of large data sets: Example – UK Biobank

- Prospective cohort study of over 500,000 individuals from across the UK
- Participants are volunteers:
  - Aged between 40 and 69 when recruited in 2006–2010
  - Assessed in one of 22 centres across the UK
  - Blood, urine and saliva samples were collected, samples for genetic analysis and physical measurements were taken, and each individual answered an extensive questionnaire focused on aspects of health and lifestyle.
- Aims:
  - To provide insight into how the health of the UK population develops over many years
  - To improve the diagnosis and treatment of common diseases which will inevitably occur in sub-groups of the population
- Data available to researchers worldwide

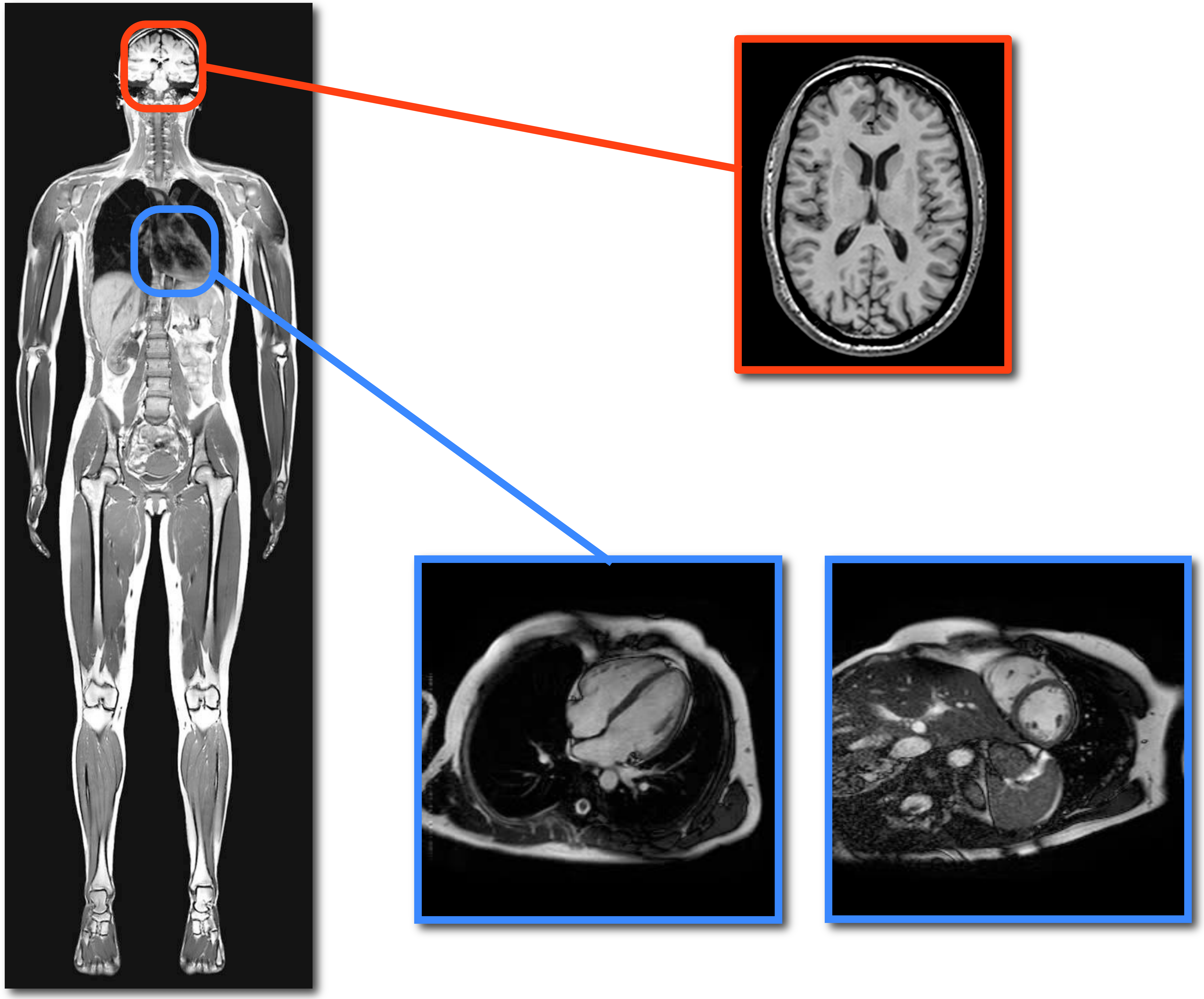
biobank uk
Improving the health of future generations

Availability of large data sets: Example – UK Biobank

- In 2014, UK Biobank began the process of inviting back 100,000 of the original volunteers for brain, heart and body imaging.
- Imaging is done across several dedicated centres in the UK



Availability of large data sets: Example – UK Biobank



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Lifestyle

Genetics

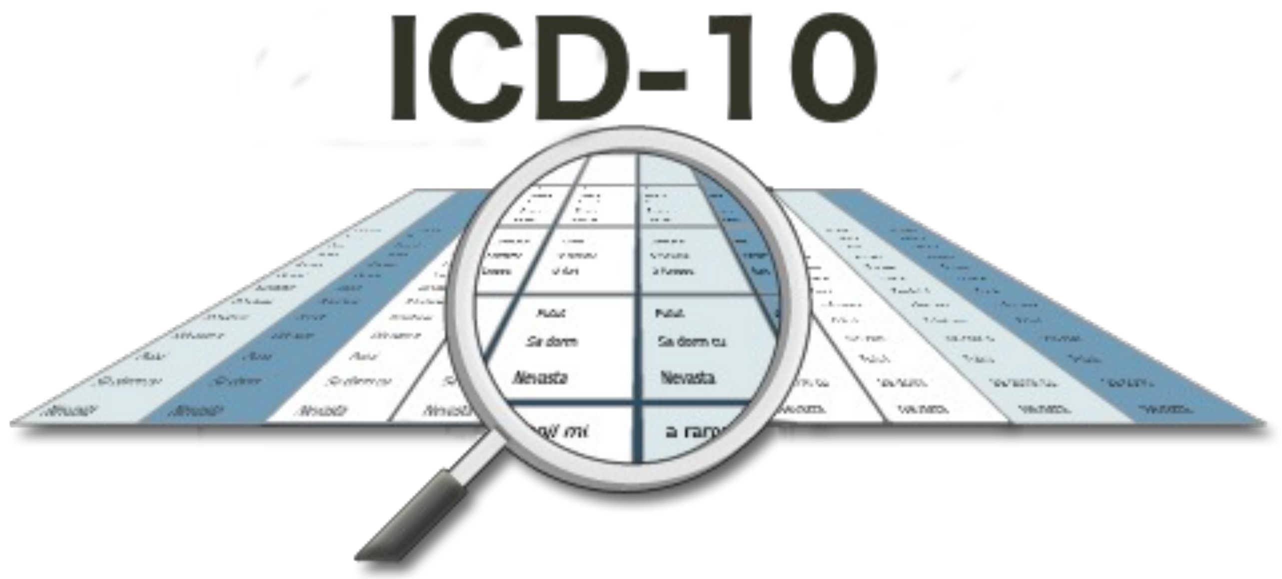
Clinical records

biobank uk

Improving the health of future generations

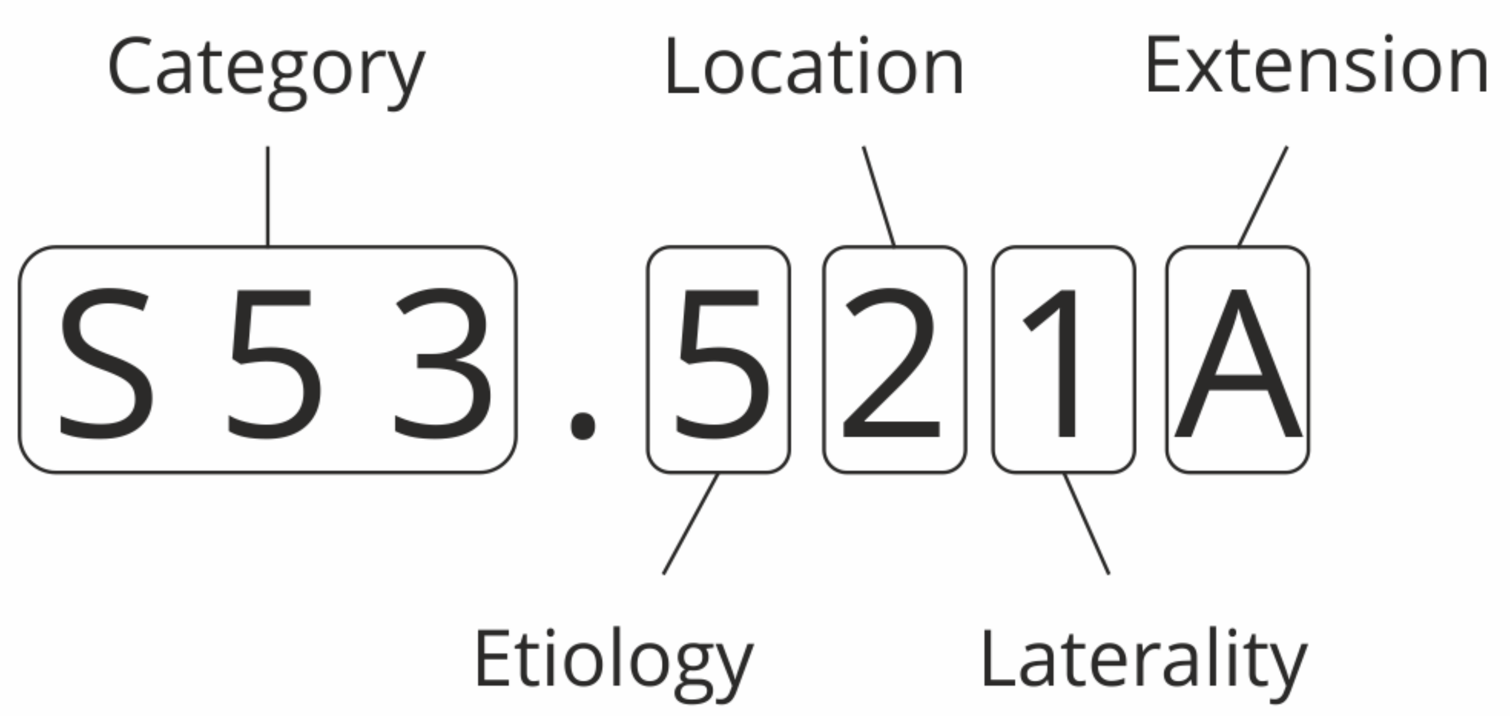
Increasing digitalisation

Increasing standardization



- International Classification of Diseases Version 10

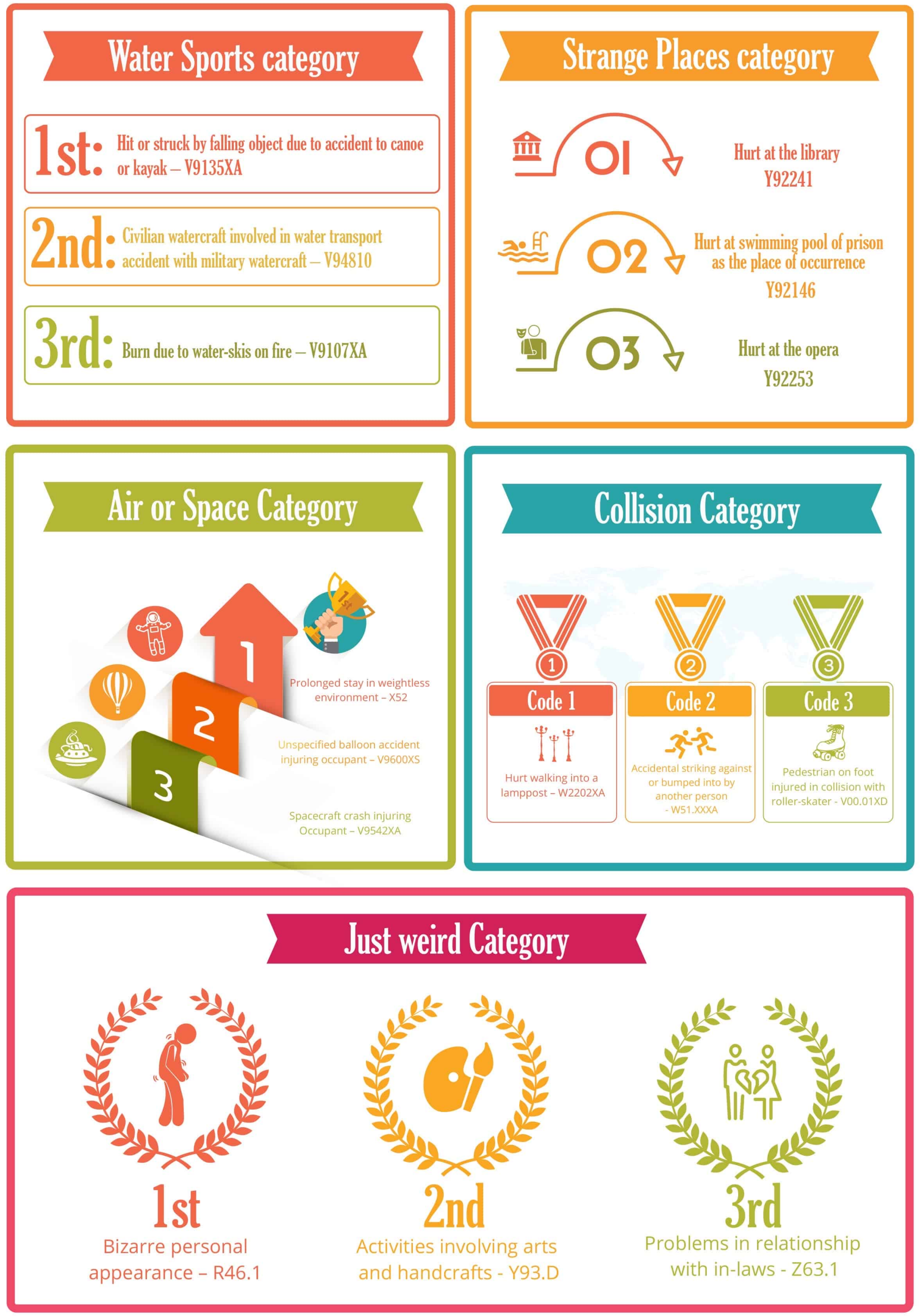
ANATOMY OF AN ICD-10 CODE



ICD-10 code for torus fracture of lower right end of right radius, initial encounter for closed fracture

Code	Disease
A00–B99	Certain infectious and parasitic diseases
C00–D48	Neoplasms
D50–D89	Diseases of the blood and blood-forming organs and certain disorders involving the immune mechanism
E00–E90	Endocrine, nutritional and metabolic diseases
F00–F99	Mental and behavioural disorders
G00–G99	Diseases of the nervous system
H00–H59	Diseases of the eye and adnexa
H60–H95	Diseases of the ear and mastoid process
I00–I99	Diseases of the circulatory system
J00–J99	Diseases of the respiratory system
K00–K93	Diseases of the digestive system
L00–L99	Diseases of the skin and subcutaneous tissue
M00–M99	Diseases of the musculoskeletal system and connective tissue
N00–N99	Diseases of the genitourinary system
O00–O99	Pregnancy, childbirth and the puerperium
P00–P96	Certain conditions originating in the perinatal period
Q00–Q99	Congenital malformations, deformations and chromosomal abnormalities
R00–R99	Symptoms, signs and abnormal clinical and laboratory findings, not elsewhere classified
S00–T98	Injury, poisoning and certain other consequences of external causes
V01–Y98	External causes of morbidity and mortality
Z00–Z99	Factors influencing health status and contact with health services
U00–U99	Codes for special purposes

Increasing standardization

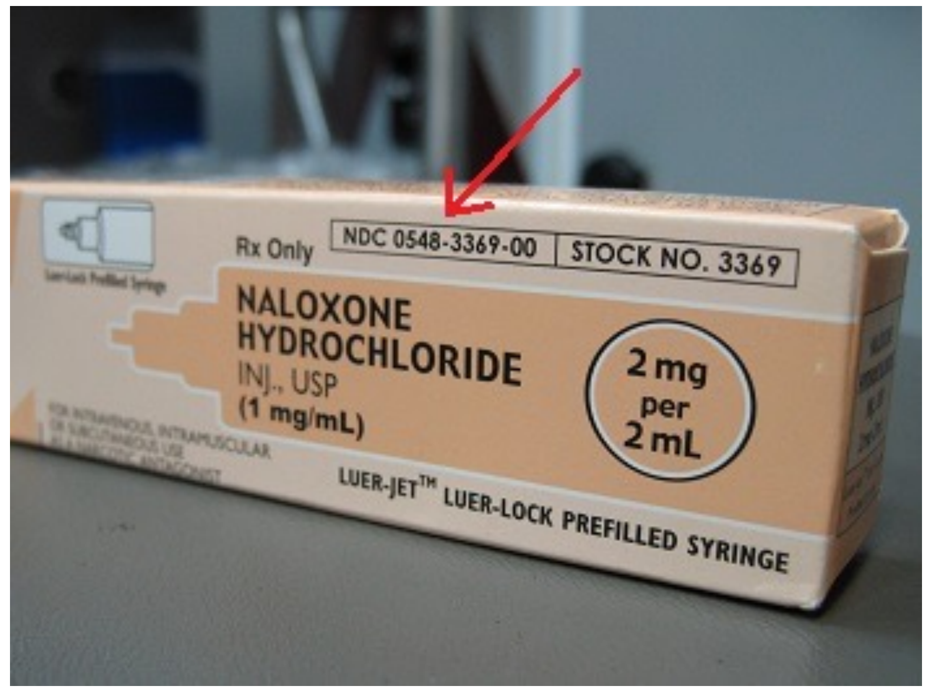


https://www.healthcarebusinesstoday.com/the-most-bizarre-icd-10-codes/

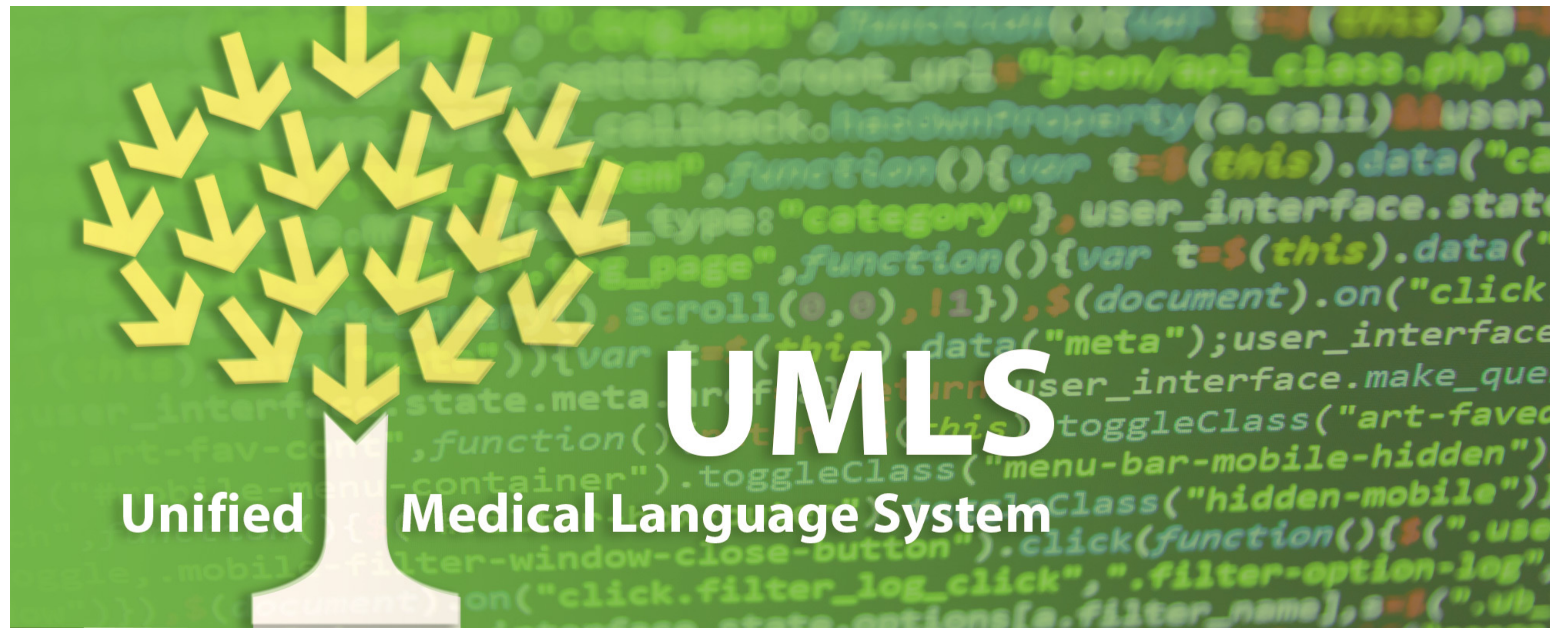
Increasing standardization

- Laboratory codes (LOINC)
  - database and universal standard for identifying medical laboratory observations

- National Drug Codes (NDC)
  - unique product identifier used for drugs intended for human use



- Unified Medical Language System (UMLS)
  - mapping structure among medical vocabularies
  - comprehensive thesaurus and ontology of biomedical concepts
  - Allows natural language processing



Advances in machine learning

Image recognition
(deep CNNs)

Generative adversarial
networks (GANs)

DALL.E / Diffusion models

AlphaGo
(reinforcement learning)

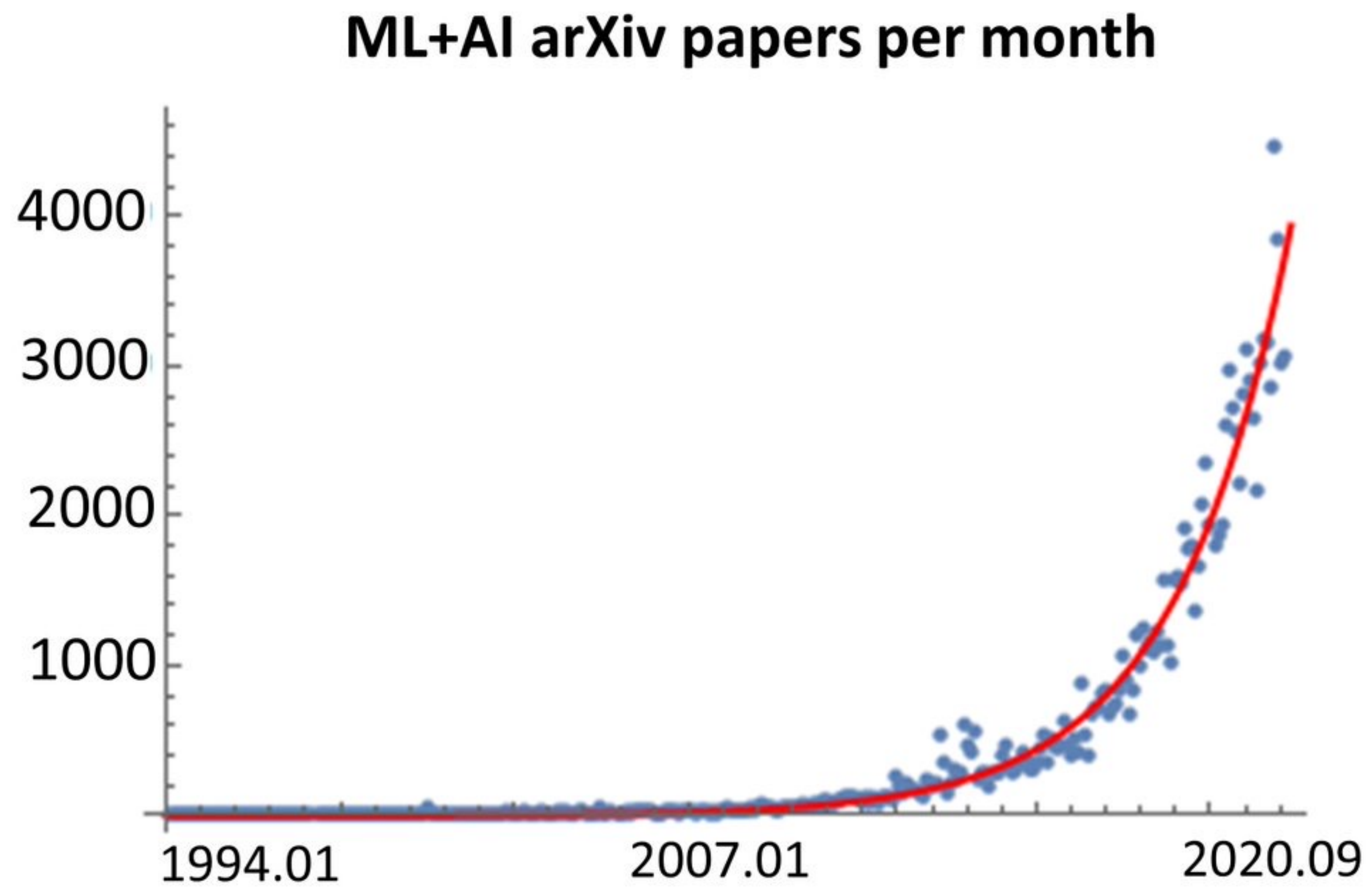
Language understanding
(transformers)

Advances in hardware and software

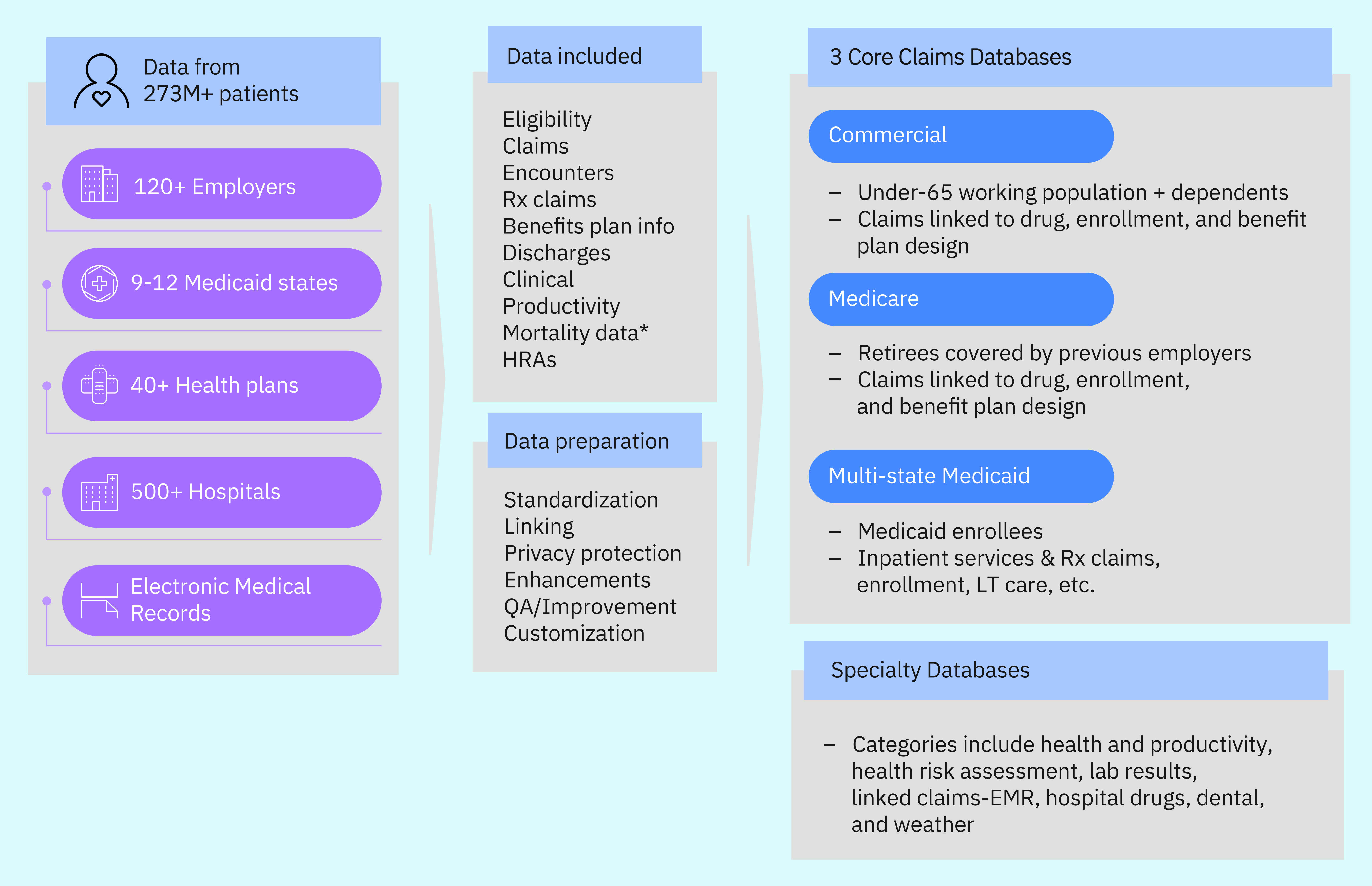
- Hardware
  - faster
  - cheaper

- Software
  - scikit-learn, PyTorch, Tensorflow

- Active research community



Opportunities for commercialisation: €€€



90+ Healthcare AI Startups To Watch

Imaging & Diagnostics

ablacon, aidence, aidoc, Healthy.io, PathAI, RadiomicsAI, Aillis, EXO, deepwise, 推想科技 infervision, sight, enlitic, EXAWIZARDS, freenome, JLK INSPECTION, zebra MEDICAL VISION, BUTTERFLY Network, Inc., IBEX, IDx, SIGTUPLE, 数坤科技, ULTROMICS, PAIGE, VUNO, VoxelCloud, Lunit, VIZ

Drug Discovery

Accutar Biotech, BenevolentAI, DIP 深度智耀, FINCH THERAPEUTICS, APEIRON, BlackThorn THERAPEUTICS, Frontier MEDICINES, insitro, Atomwise Better medicines faster., Exscientia DRIVEN BY KNOWLEDGE, engine BIOSCIENCES, JUVENESCENCE, Notable Labs, OWKIN, RECURSION pharmaceuticals, 药研社, Standigm, XtalPi, twoXAR, SPRING DISCOVERY

Predictive Analytics & Risk Scoring

BenchSci, lu, 森亿智能 SYNYI·AI, saama, GNS HEALTHCARE, Medial EarlySign, TEMPUS, ikioo, medopad, Welltok, nference

Genomics

DECIPHER BIOSCIENCES, SOPHIA GENETICS, Syntekabio, WuXiNextCODE

Fitness

FiNC, VI

Virtual Assistant

babylon, Curai, mfine, notable, buoy, K, Suki

Hospital Decision Support

binaryfountain, Cardinal Analytx Solutions, Qventus, gauss, Olive, OM1, KenSci, NextHealth TECHNOLOGIES, LeanTaaS, Medical INFORMATICS

Clinical Trials

deep lens, HEALTH[at]SCALE TECHNOLOGIES, teckro.

Nutrition

NURITAS LIFE-CHANGING INGREDIENTS, WHOLE BIOME

Remote Monitoring

biofourmis, ContinUse Biometrics, DENTAL MONITORING Connected orthodontics

Compliance

DATAVANT, PROTENUS

Mental Health

mindstrong

Created by You. Powered by CBINSIGHTS

Open Master Projects for Artificial Intelligence in Healthcare and Medicine

- https://aim-lab.io
  - Loss functions for MRI reconstruction
  - Motion-Compensated MRI Reconstruction
  - Combining longitudinal volumetric imaging and tabular data for depression prediction
  - Federated, privacy preserving deep learning for fetal MRI brain segmentation
  - Vertebrae detection and labelling in MR images
  - Attention mechanisms for end-to-end therapy response prediction on PDAC CTs
  - Non-invasive and accurate prediction of prostate cancer aggressiveness
  - Adversarial attacks in collaborative machine learning
  - Defending collaborative machine learning through interpretability methods
  - ...
- Contact us via: office.aim-lab@med.tum.de

Open Master Projects for Computational Imaging and AI in Medicine

- https://compai-lab.io
  - Unsupervised Anomaly Detection for Medical Imaging
  - Multi-object and multi-modal image segmentation in dental MRI and CT using limited data
  - Segmentation of sparse annotated data: application to cardiac imaging
  - Uncertainty-Guided Registration of Normal Variability for Unsupervised Anomaly Detection
  - Motion reconstruction for abdominal imaging
  - AI-enabled medical imaging
  - …

- Contact us via: iml.office@helmholtz-munich.de