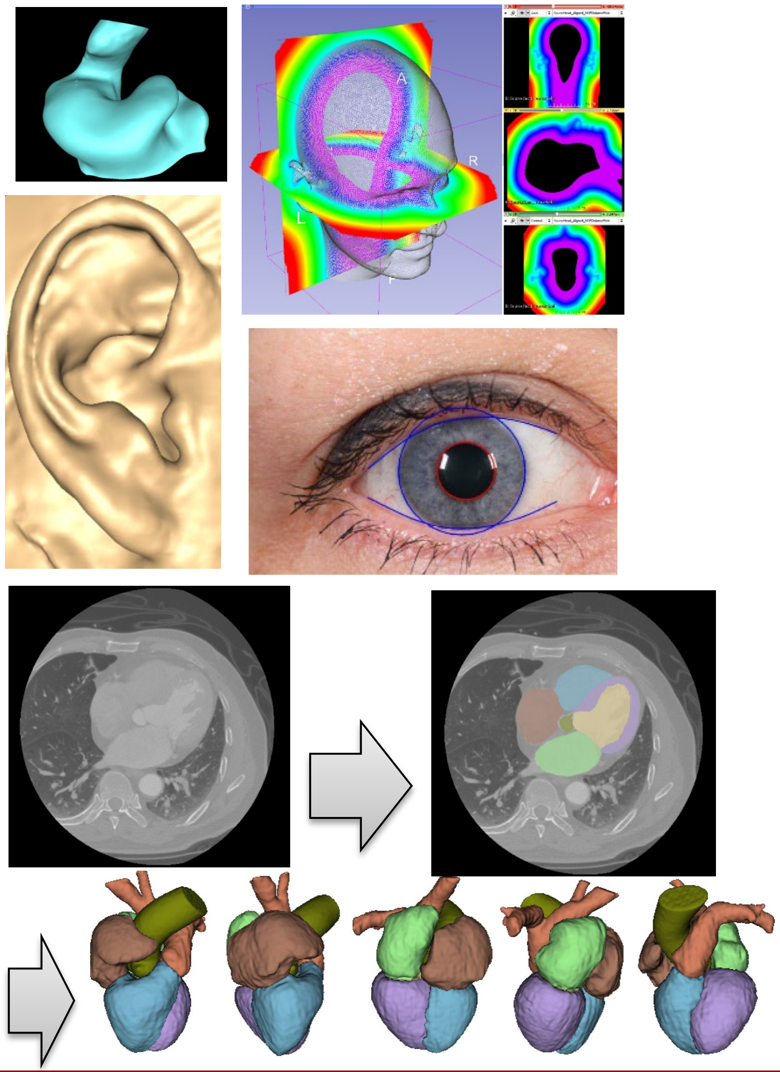
DTU

Rasmus R. Paulsen

AI Driven Medical Image Analysis

- for the society, the science and the students

The professional Rasmus



- **Education**
  - **2001-2004:** Industrial Ph. D.
    - DTU IMM
    - Oticon Research Centre Eriksholm
    - INRIA Sophia-Antipolis, France
  - **1998:** Master of science, DTU

- **Employment**
  - **2023-Present** Professor, DTU Compute
  - **2009-2023** Associate Professor, DTU Compute
  - **2008-2009** Assistant Professor, DTU IMM
  - **2004-2008** R&D Oticon A/S
  - **1998-2001** R&D Startup Pronosco

Ph. D. supervisors

DTU’s mission og vision 2020-2025

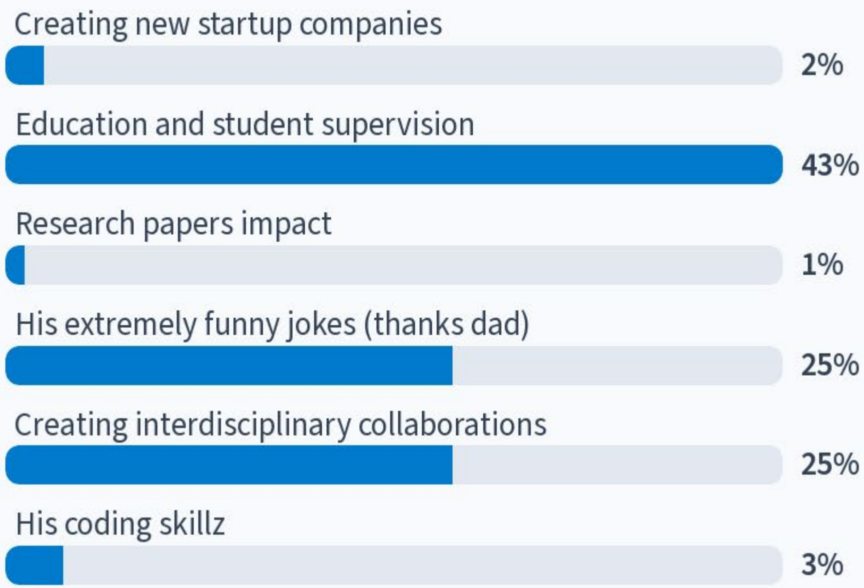
Mission
DTU skal udvikle og nyttiggøre naturvidenskab og teknisk videnskab til gavn for samfundet.

Vision
DTU er et af Europas fem førende tekniske universiteter og har Europas bedste ingeniøruddannelse.

DTU er internationalt anerkendt for sin polytekniske eliteforskning og uddannelse af innovative ingeniører med dyb faglighed, der er en drivkraft for bæredygtig forandring i en global verden.

I krydsfeltet mellem forskning, uddannelse, innovation og forskningsbaseret rådgivning, og i tæt interaktion med omverdenen, udvikler DTU værdiskabende teknologi for mennesker.

What is Rasmus' biggest contribution to society?



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Education
- for the society, the industry and the future

- **Research based education**
- **AI driven image analysis**
  - Not only for biomedical applications
  - Material science and sustainable energy
    - Wind turbines – inspection and material analysis
    - Sustainable buildings and materials
    - High energy tomography
  - Food science and quality control
  - Self-driving vehicles
  - Sports, entertainment and edutainment
  - Intelligent farming systems
  - Building inspection and construction planning

Companies presenting in the DTU Course 02502 Image Analysis in 2022 and 2023

Education – DTU course in Image Analysis

600 students per year

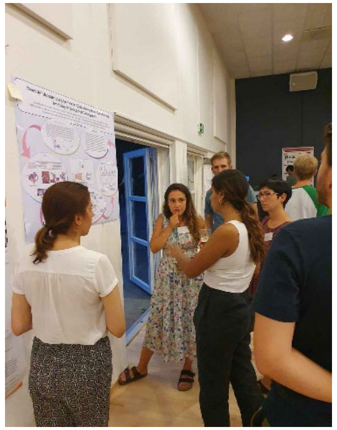
Ph. D. summer schools and student supervision

Summer school on missing data, augmentation and generative models

14. – 18. August 2023

WELCOME SPEAKERS PROGRAM TALKS, MATERIALS AND CHALLENGE POSTERS PRACTICALITIES ABOUT

Welcome



Rasmus' B. Sc and M. Sc students 2023

- **Main DTU organizer of yearly Ph. D. summer school**
  - – DTU Compute
  - – Department of Computer Science, KU
  - – Aalborg University
  - – 100 Participants in 2022 and 2023

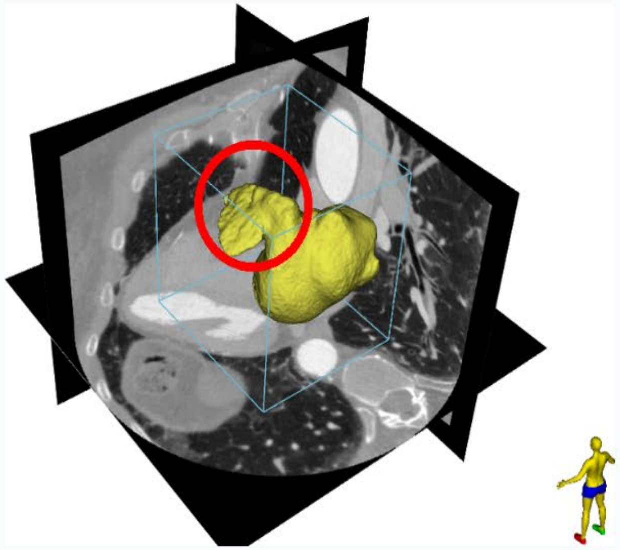
- **Group based student supervision**
  - – Tradition in the visual computing group
  - – 4 – 6 groups of student co-supervised
  - – Part of the DTU Learning lab curriculum

Research based education

ARTICHOKE biweekly meeting

What is the most similar shape to this left atrial appendage (LAA)

89



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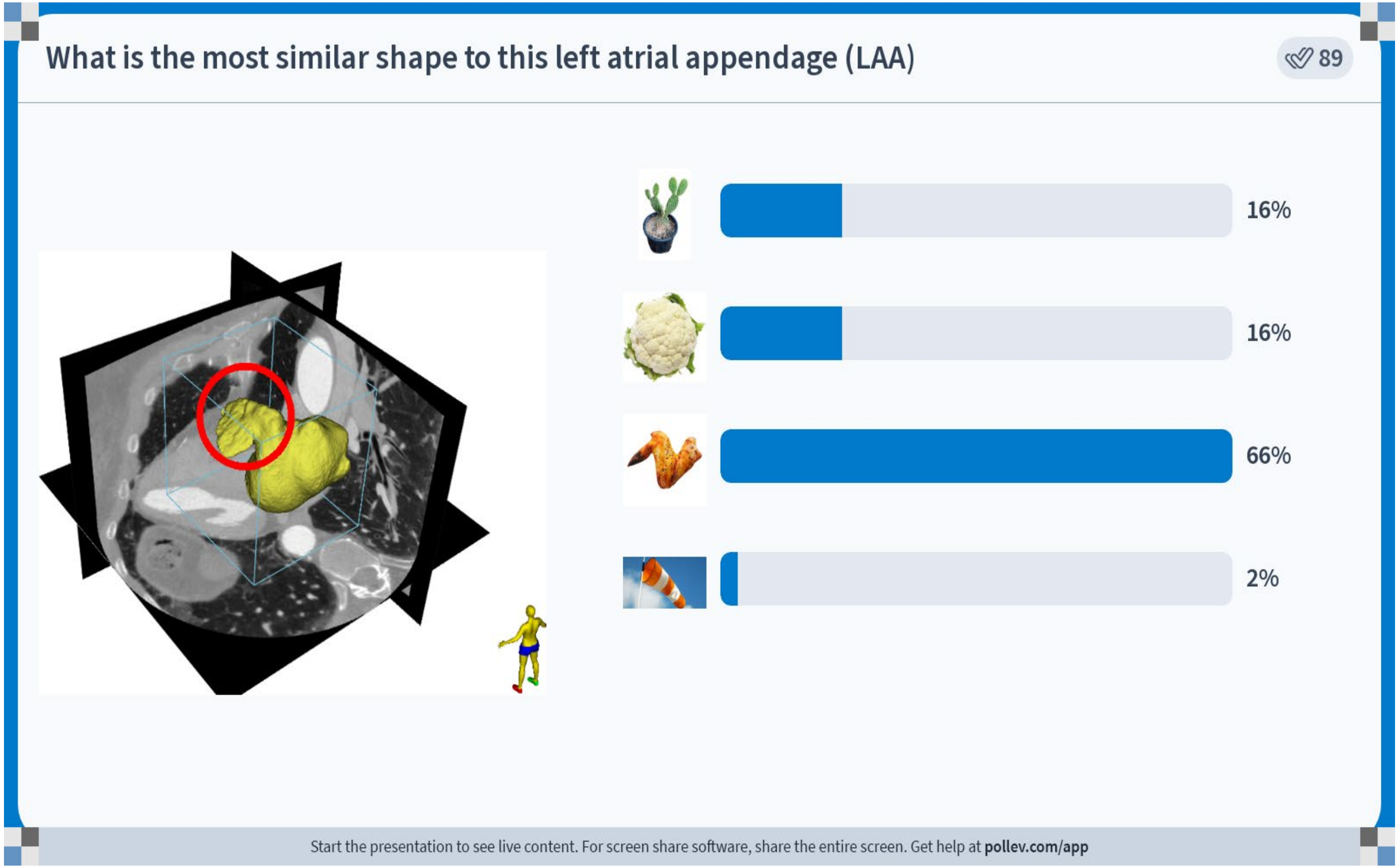
What is the most similar shape to this left atrial appendage (LAA)
89
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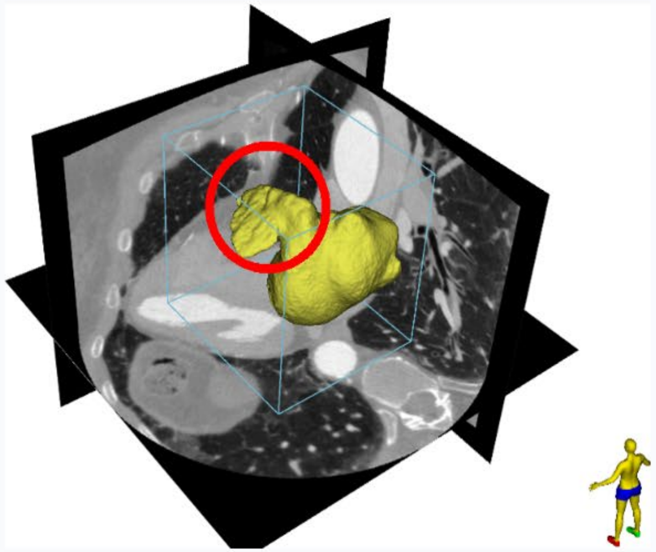
What is the most similar shape to this left atrial appendage (LAA)

89

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16%


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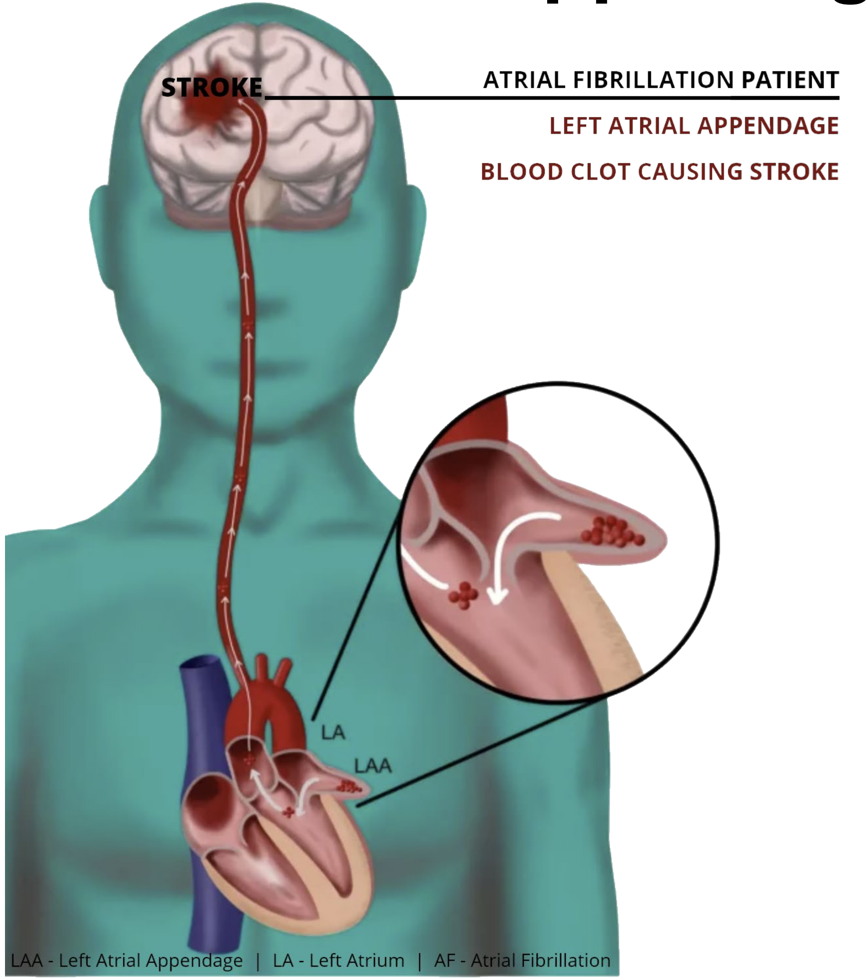
The shape of the left atrial appendage and stroke risk

Higher stroke risk



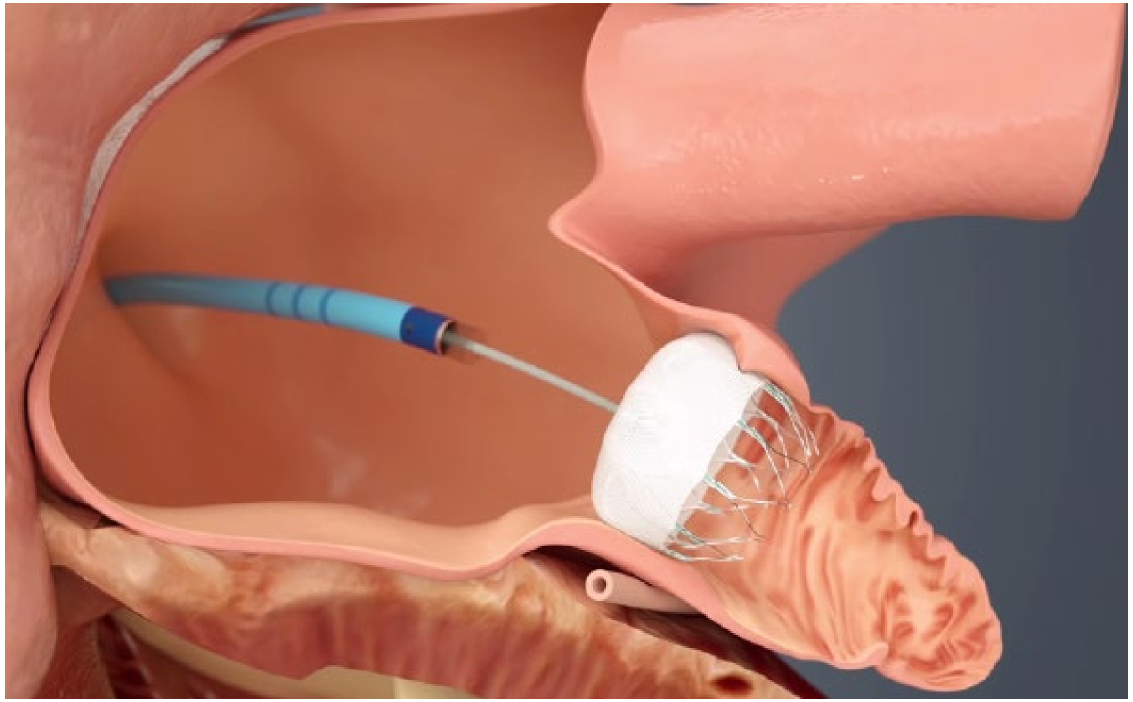
Lower stroke risk

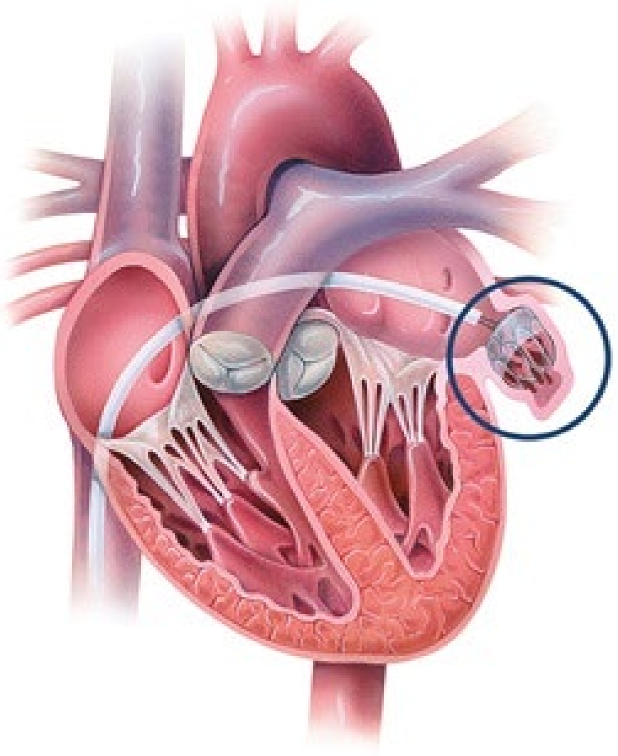
More than 90% of thrombus accumulation occurs in the left atrial appendage (LAA) (for atrial fibrillation related strokes)

Stroke prevention

- It is possible to reduce the stroke risk
  – medicine (anticoagulants) or surgery (left atrial appendage closure)

- **Is it possible to identify patients at risk?**
- **Is it possible to optimise the surgical intervention?**





Cross disciplinary solutions are needed

Team ARTICHOKE

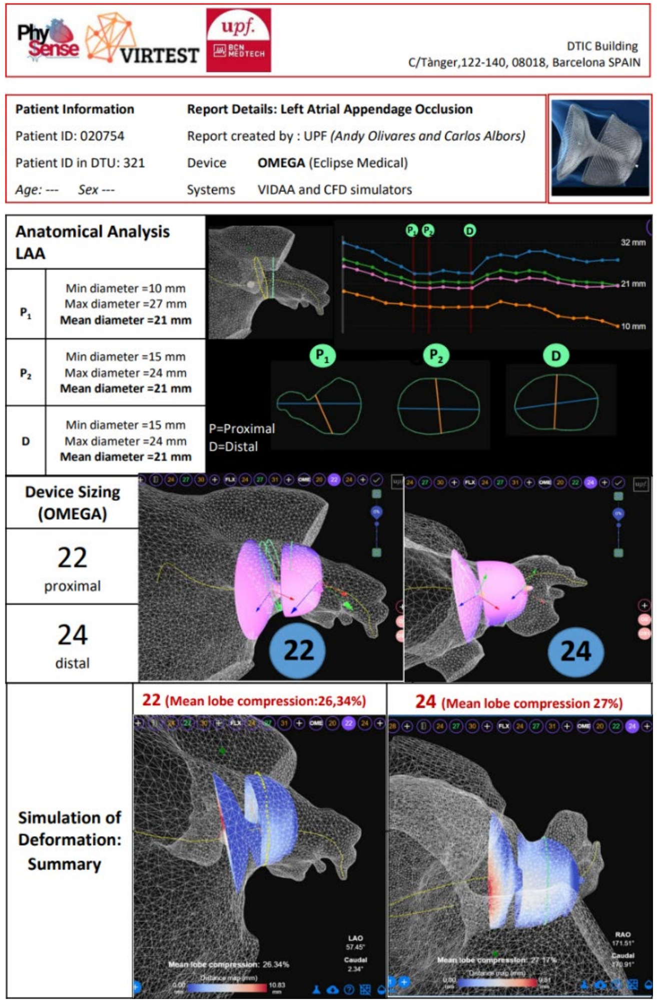
Cross disciplinary solutions are needed

Team ARTICHOKE

- Rigshospitalet VIP   Students
  - Cardiology / Radiology
- DTU Compute VIP   Students
  - AI Driven Image Analysis
- INRIA Sophia-Antipolis, France VIP
  - Electrophysiological cardiac modelling
- Universitat Pompeu Fabra, Spain VIP
  - Computational Cardiac Fluid Modelling

- Novo Nordisk Tandem Grant
- 4 years: 2023 – 2027
- Artificial intelligence-driven 3D image analysis and radiomics for high quality personalized cardiovascular risk assessment (ARTICHOKE)
- Principal investigators:
  - Klaus Kofoed Fuglsang, Rigshospitalet
  - Rasmus R. Paulsen, DTU Compute
- 4 Ph. D. students :
  - 2 Rigshospitalet, 2 DTU Compute
- Data:
  - 12.000+ CT scans with patient outcome
  - Herlev-Østerbro population study

Team ARTICHOKE in action at Rigshospitalet

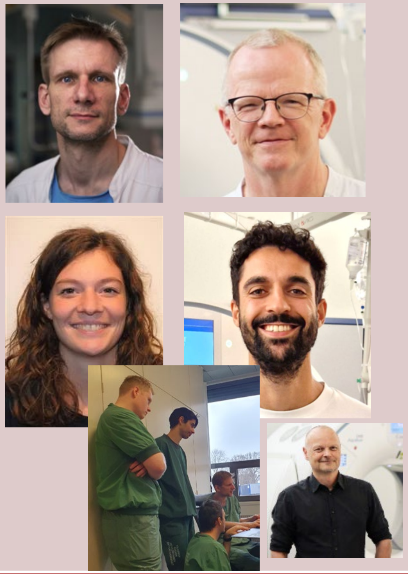
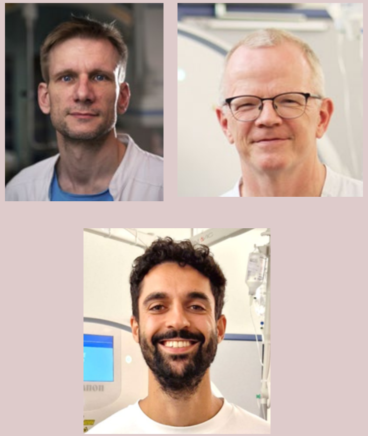


AI driven intervention planning of
Left atrial appendage closure

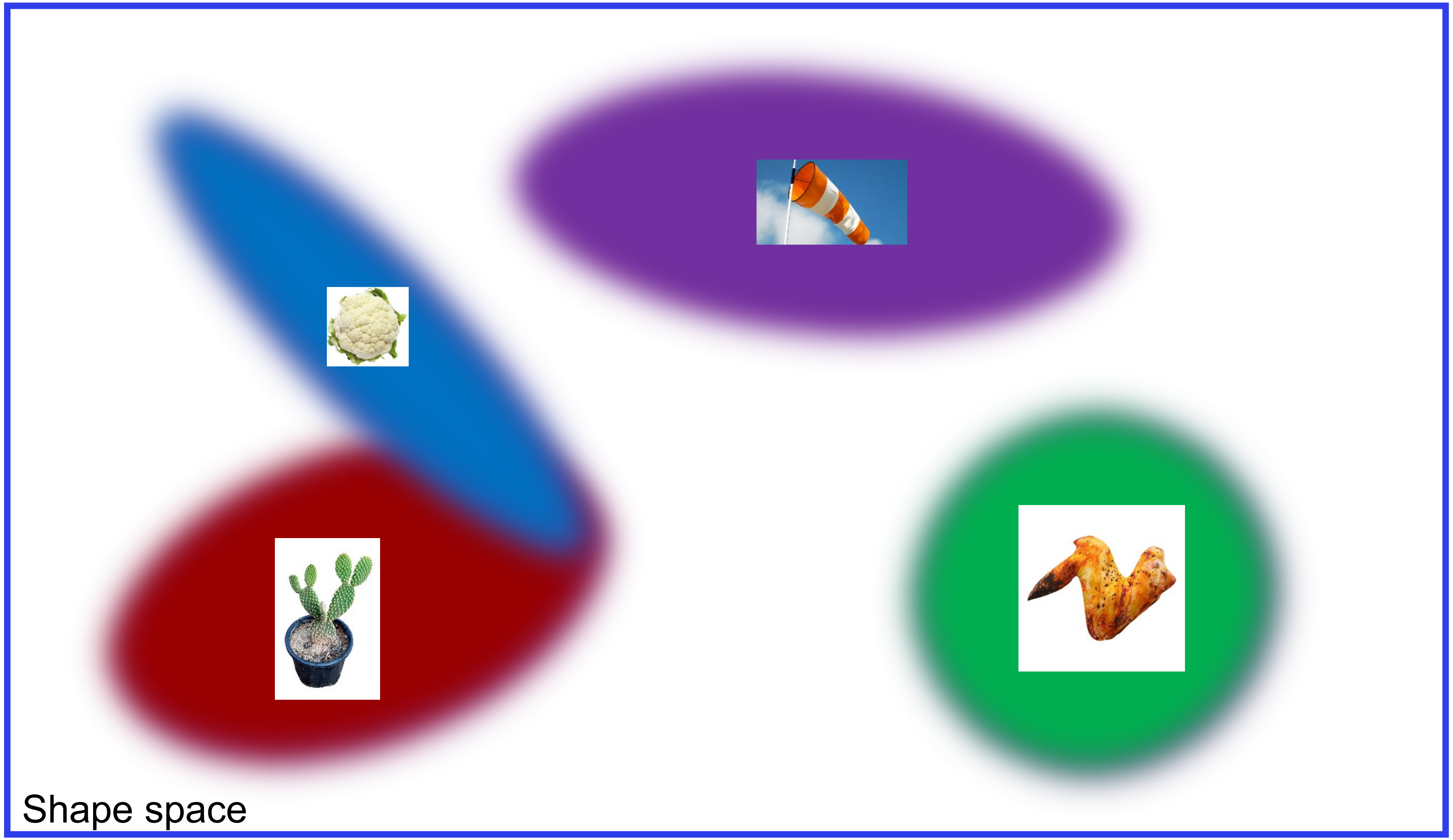
- DTU – AI Image Analysis
- Rigshospitalet, Interventional cardiology (surgery)
- Rigshospitalet, Cardiology and imaging
- Universitat Pompeu Fabra – Surgical simulation and planning
- Eclipse medical – device manufacturer

What is my role in this?

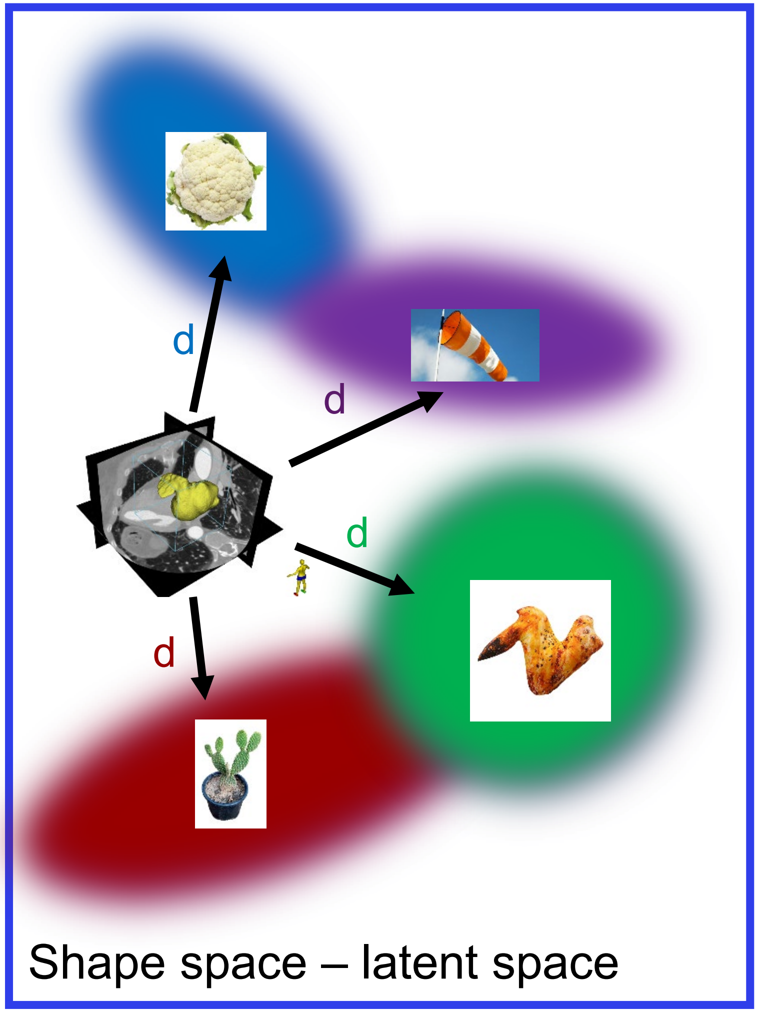
Example: Left atrial appendage closure

Patient specific risk prediction	Patient treatment strategy	Pre-procedural planning	Interprocedural guidance	Post-procedural evaluation and follow up
Risk of stroke based on patient history, biomarkers and CT analysis 	Anticoagulants vs. procedure 	Device selection: size and shape Deployment strategy 	Image overlays Warning systems 	Device position Leaks Device influence on cardiovascular system ?

Statistics on complex biological shapes

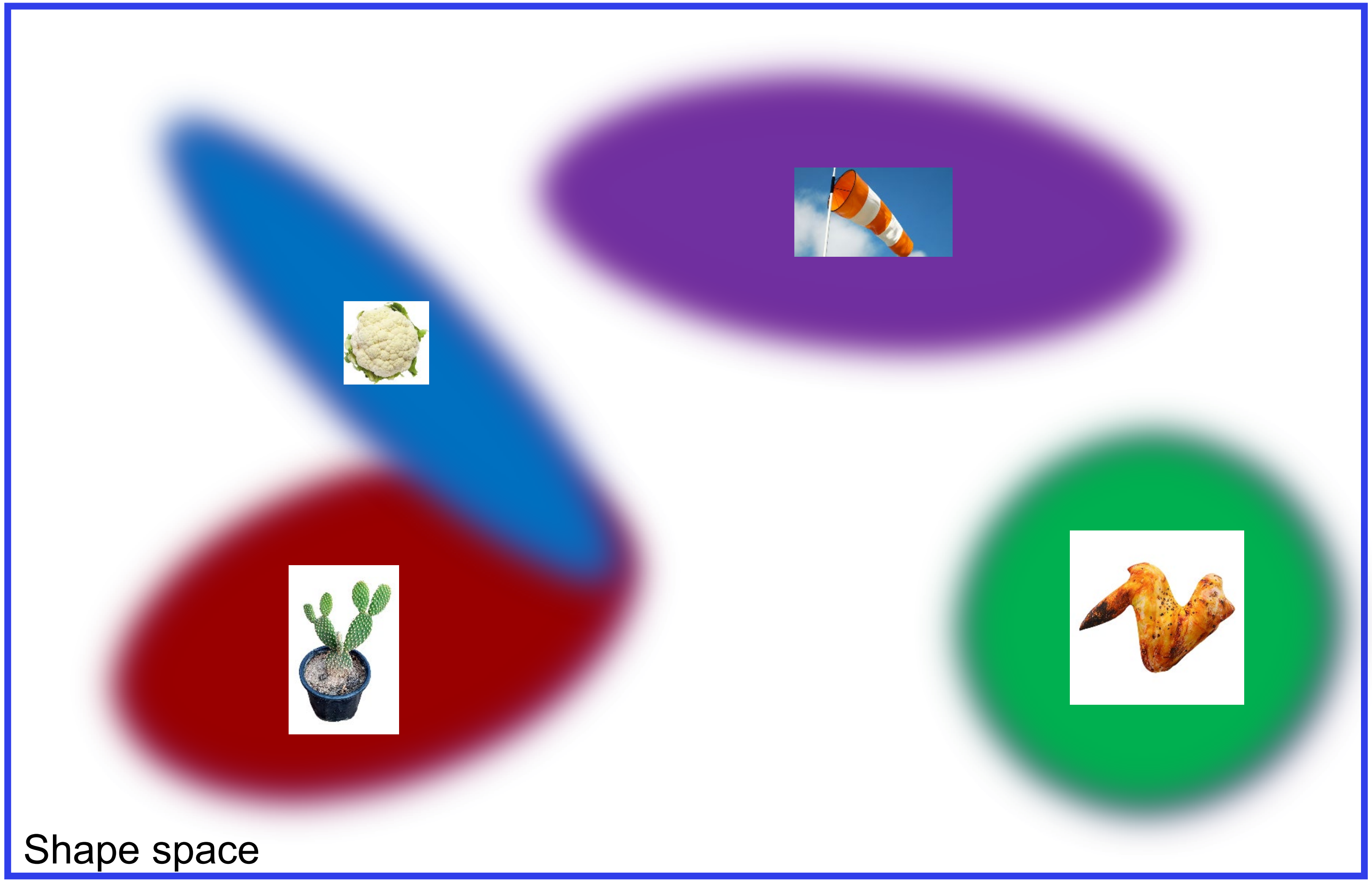


Statistics on complex biological shapes



- **Research questions**
  - How to parameterise complex 3D shapes to be able to do machine learning?
  - How to map complex 3D shapes to low-dimensional spaces (latent spaces)
  - How to compute meaningful distances in latent spaces
  - Supervised and unsupervised clustering and classification of complex 3D shapes
  - Prediction based on 3D shapes:
    - Risk scores
      - Risk of stroke based on your LAA shape
    - Device selection and deployment strategies
    - Procedural outcome prediction

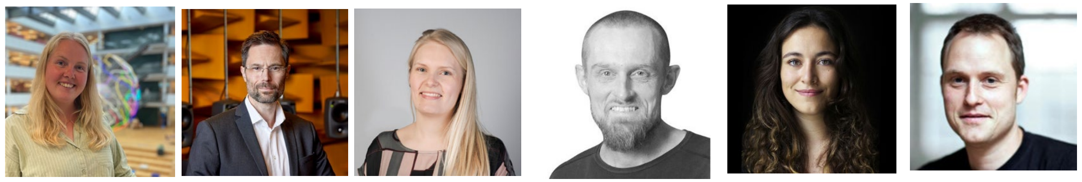
Research questions: Left atrial appendage shape

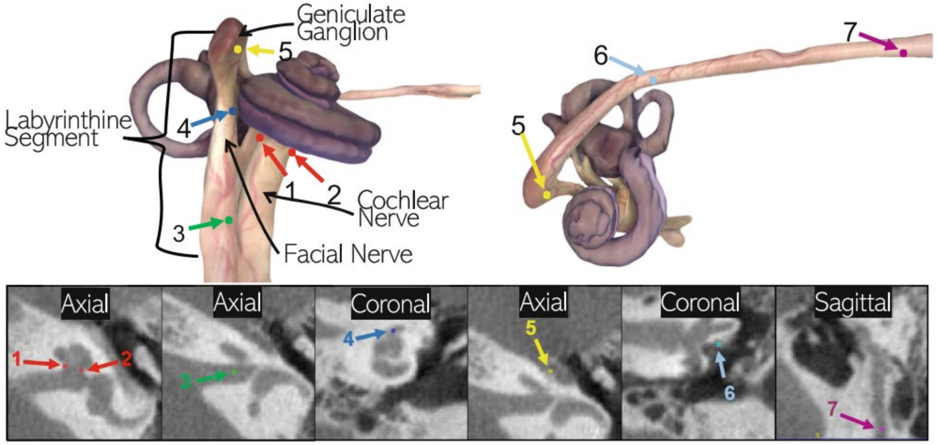


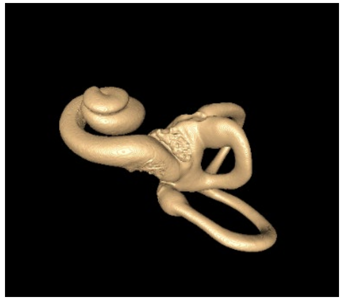
- We extract the shape of the LAA from 10.000+ patient CT scans
- Transform the shapes to a lower dimensional space
- Do these shape cluster in separate groups?
- Is there are connection between the shape clusters and the risk of stroke?

Previous work: Shape driven hearing aid design

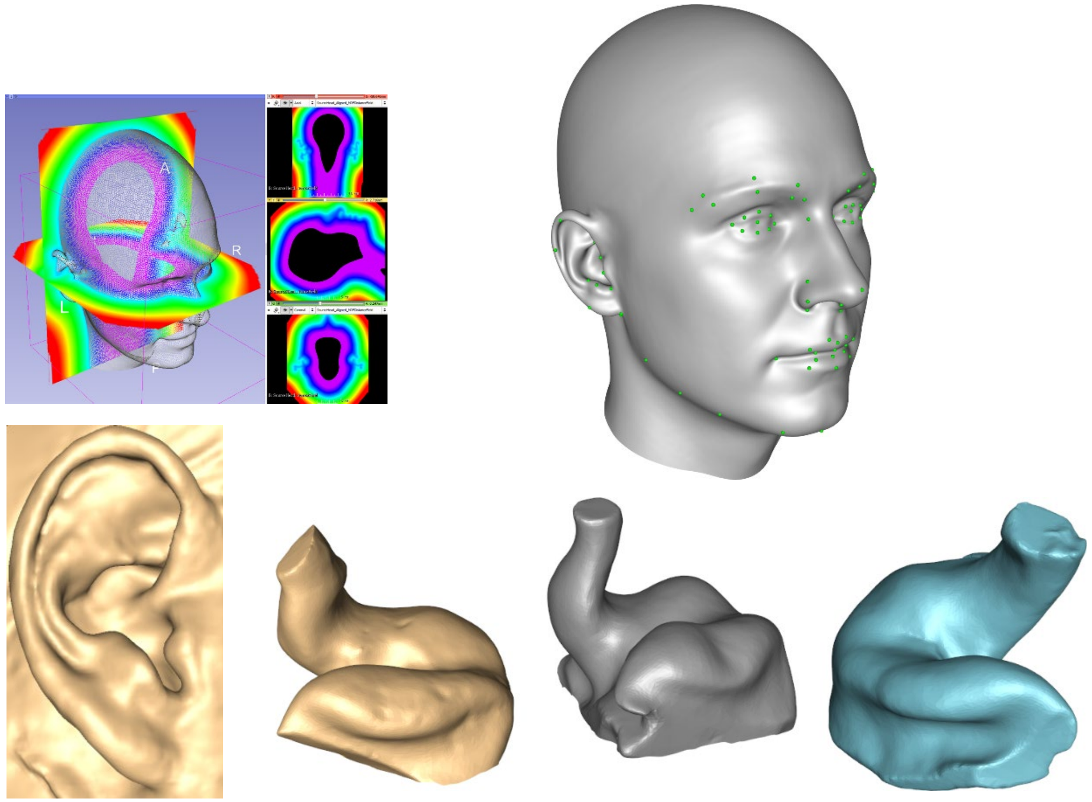
- Extensive collaboration with Oticon, Oticon Medical and Interacoustics





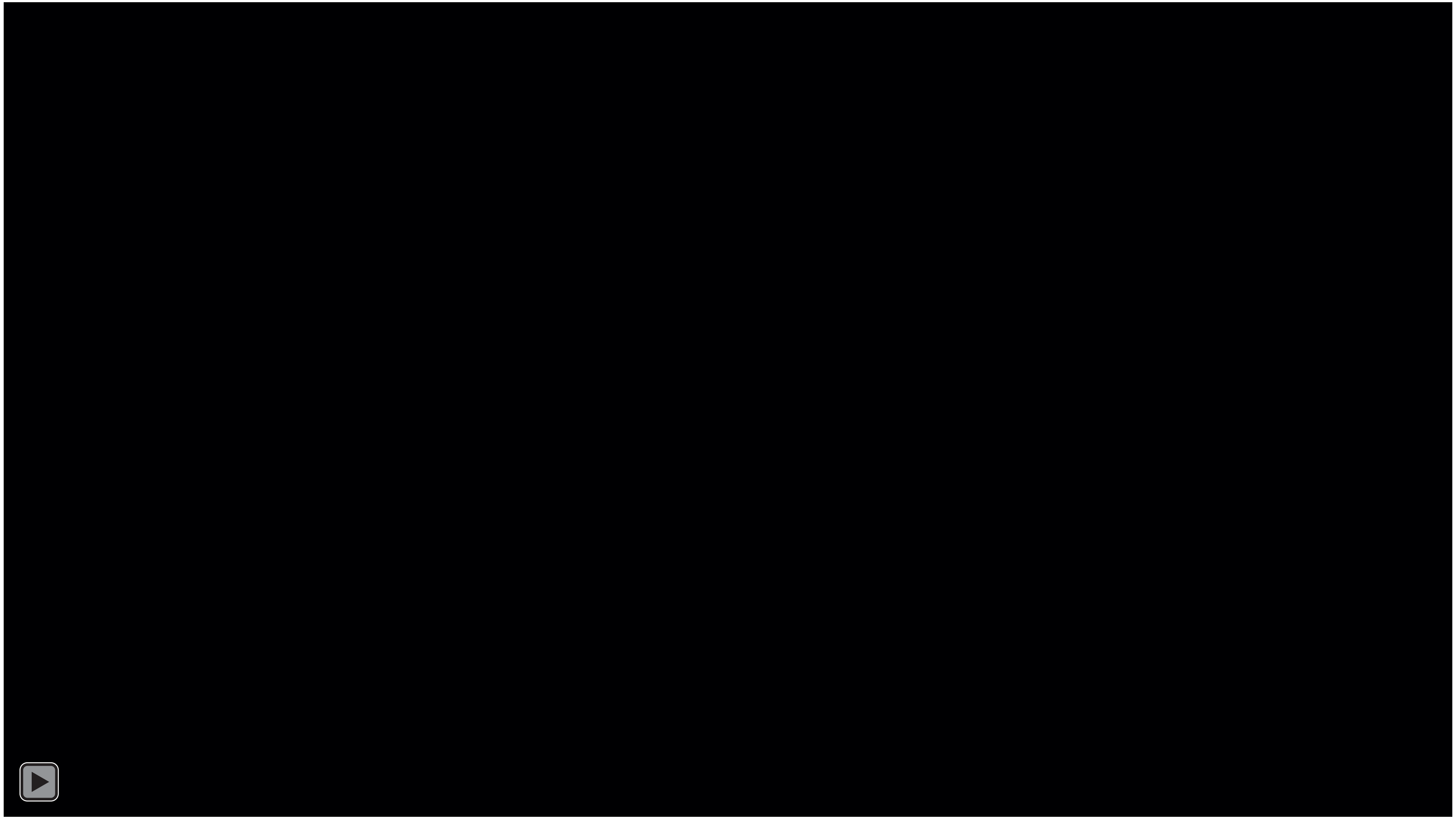


- Image guided cochlear implant surgery planning
- AI based congenital abnormality detection

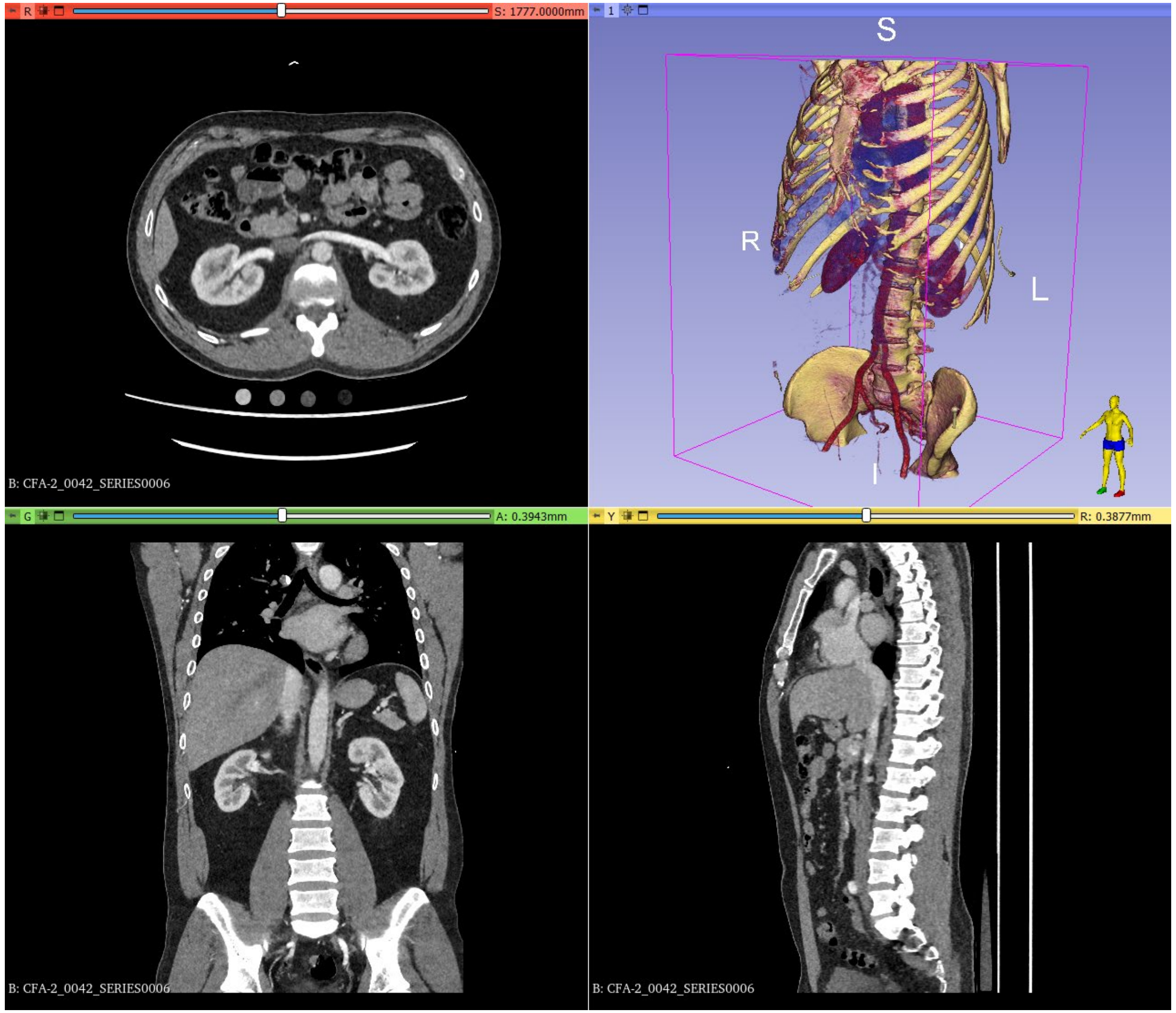


- Statistical shape models for hearing aid design and acoustical simulations

What is a computed tomography (CT) scanner?



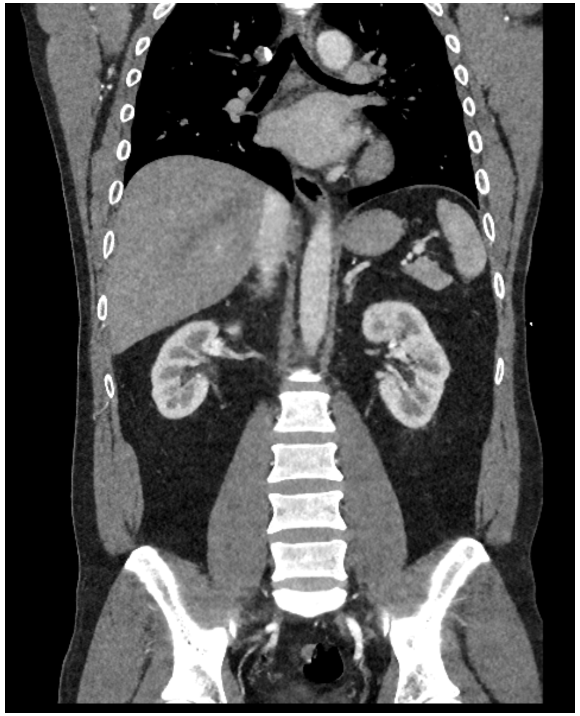
How does a CT scan look like?



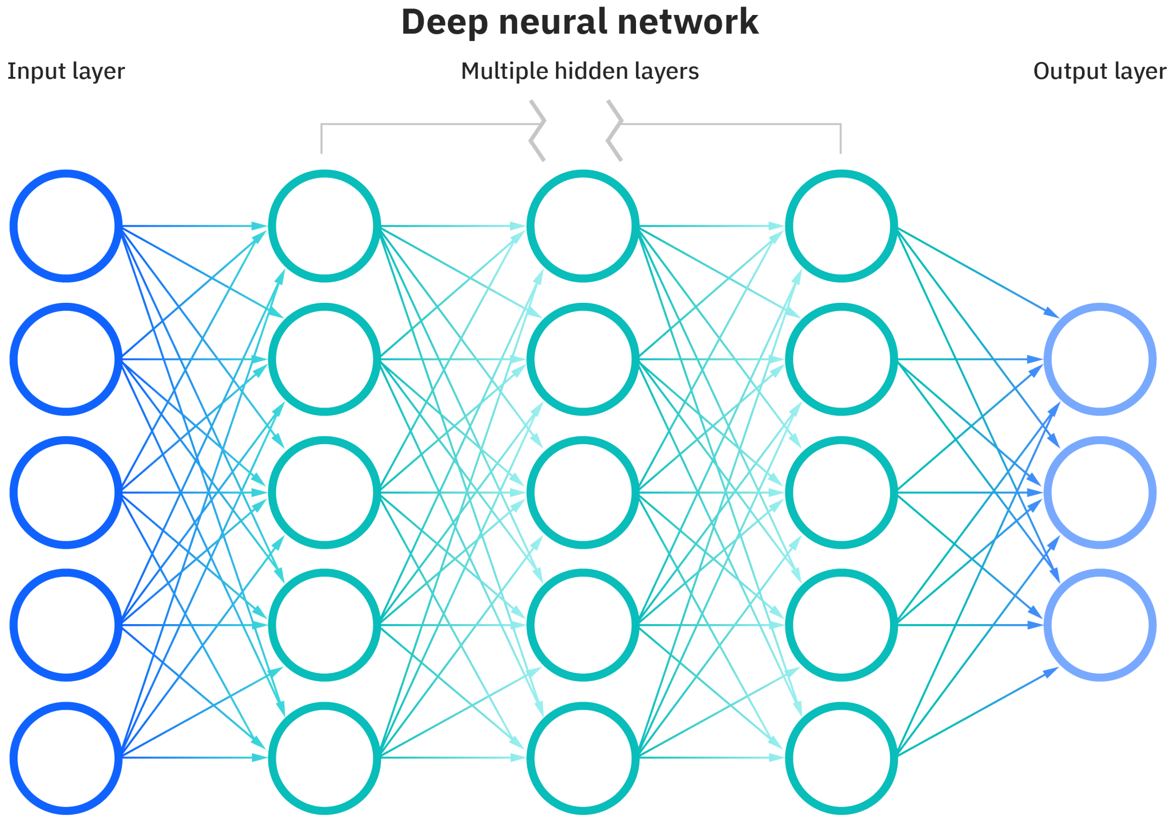
- A 3D volume consisting of small cubes (voxels)
- The value in each voxel reflects the amount of X-ray radiation that is absorbed
  - Bone: A lot of absorption (bright voxels)
  - Soft-tissue: Medium absorption (grey voxels)
  - Air: Low absorption (dark voxels)

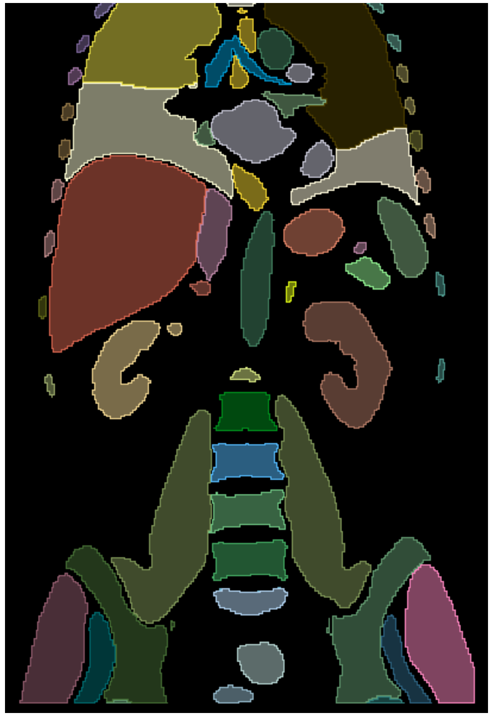
- Contrast enhanced CT-scan
  - A liquid is injected just before the CT scan
  - The liquid makes blood light up on the CT scan
  - Blood pools, arteries and veins become clearly visible

What is a deep neural net?
- Connected neurons



Input scan

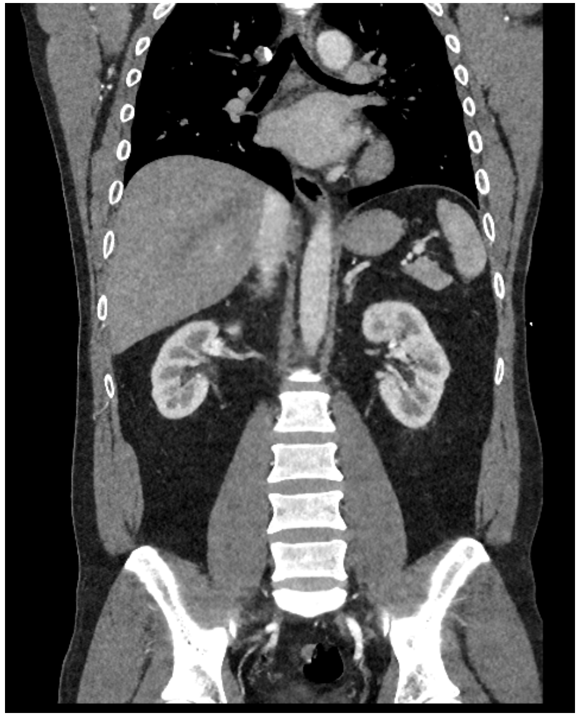




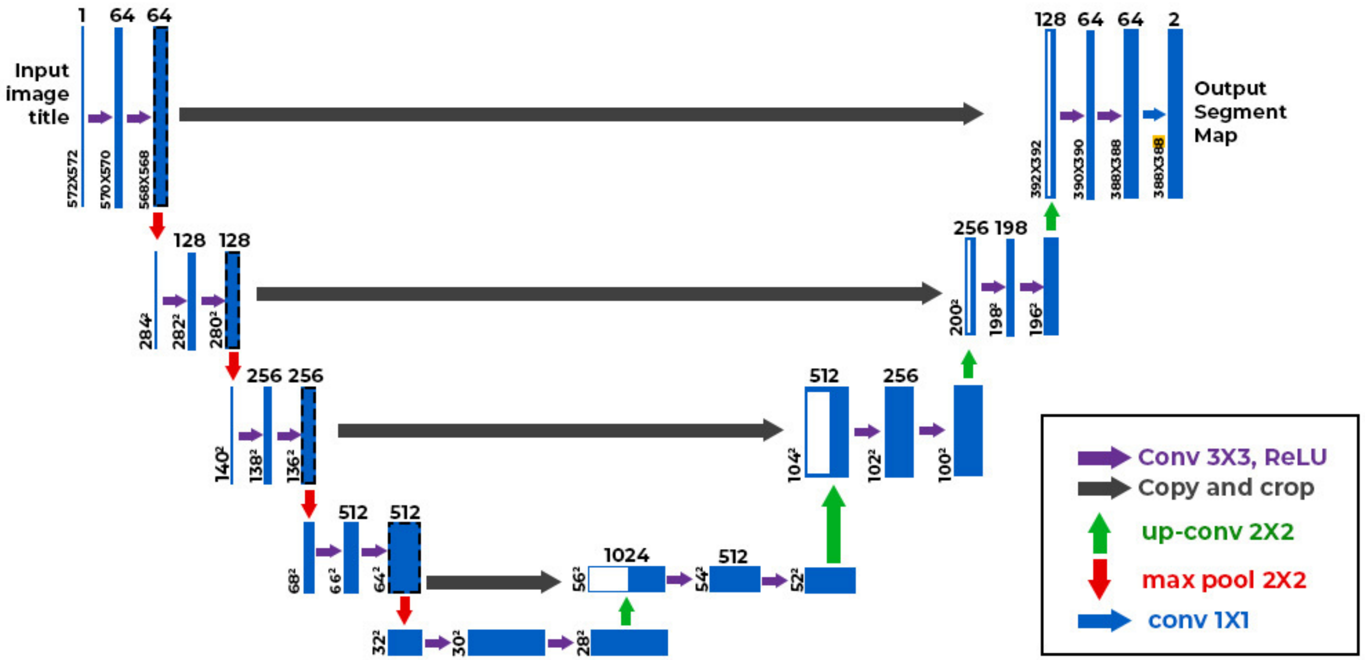
Predicted anatomy

https://www.ibm.com/topics/neural-networks

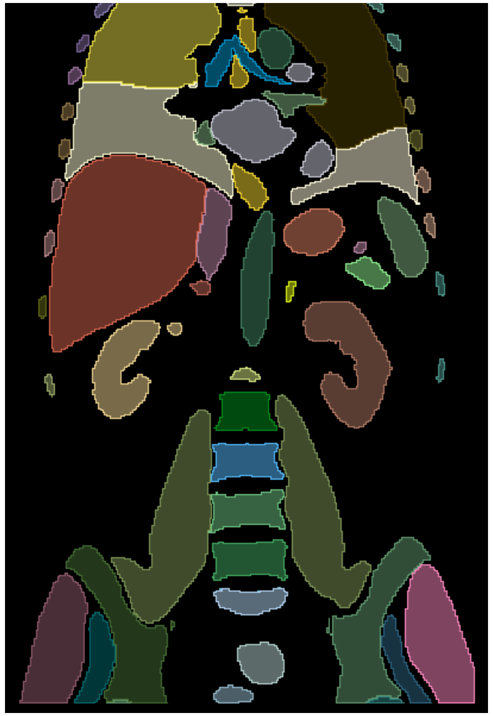
What is this latent space?



Input scan

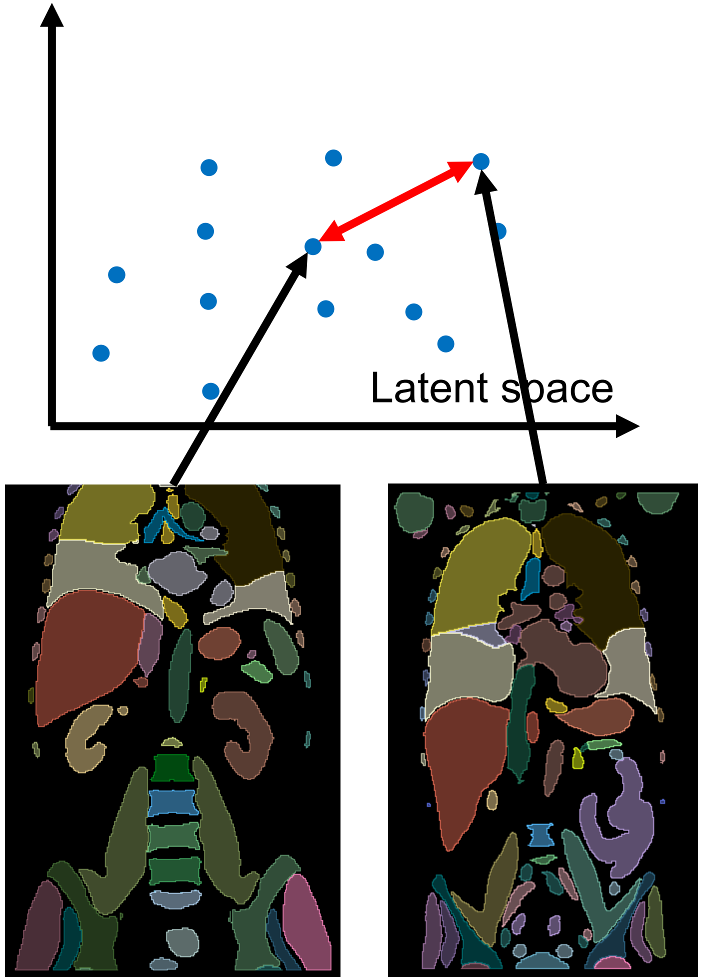


Lower dimensional description of the anatomy



Predicted anatomy

Latent space - embeddings



- Lower dimensional space (only around 64ish dimensional)
- A sample / patient / scan is a point in this space
- The relation between the positions in this space can be used in a variety of ways
  - Supervised and unsupervised clustering and classification
  - Optimising networks to improve class separation
    - Deep metric learning

Research question: How do we get complex 3D shapes into this latent space?

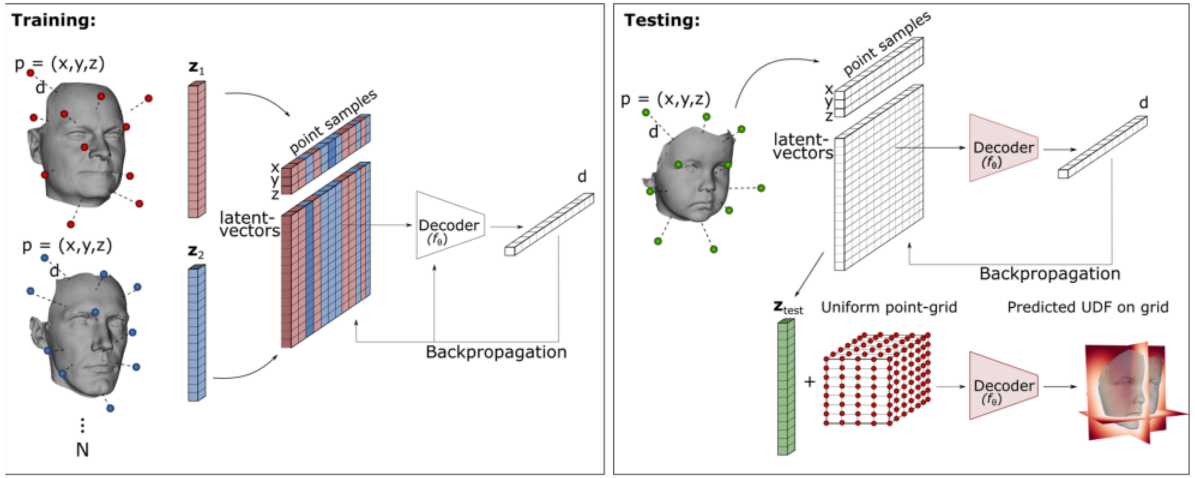
Representing complex 3D shapes and their appearance – Geometric Deep Learning

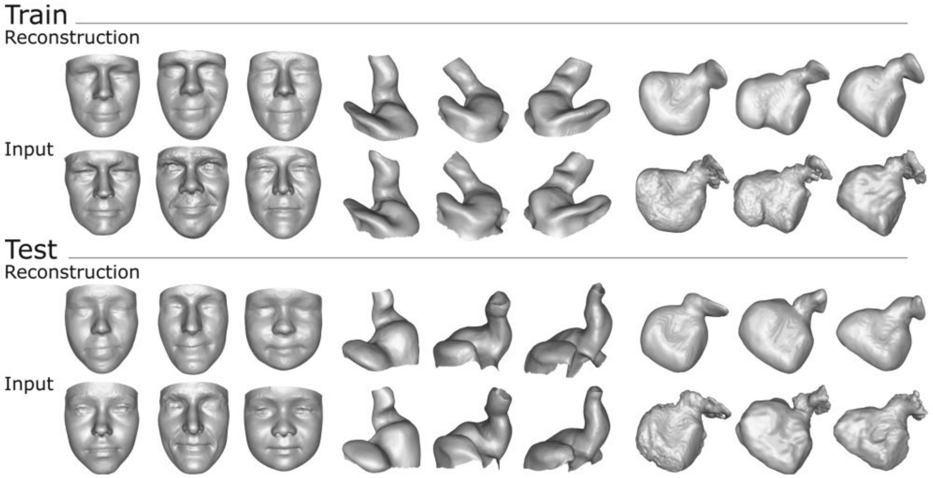
MICCAI 2021

Implicit Neural Distance Representation for Unsupervised and Supervised Classification of Complex Anatomies

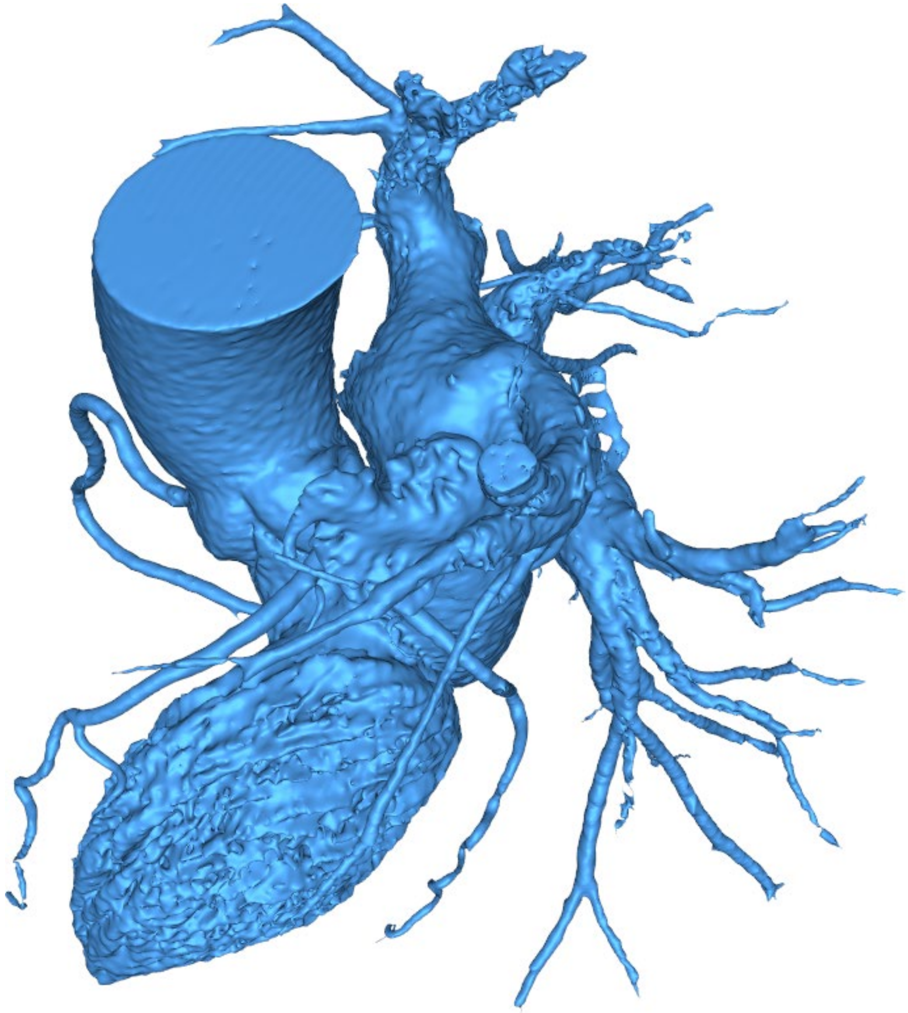
Kristine Aavild Juhl[1(✉)], Xabier Morales[2], Ole de Backer[3], Oscar Camara[2], and Rasmus Reinhold Paulsen[1]

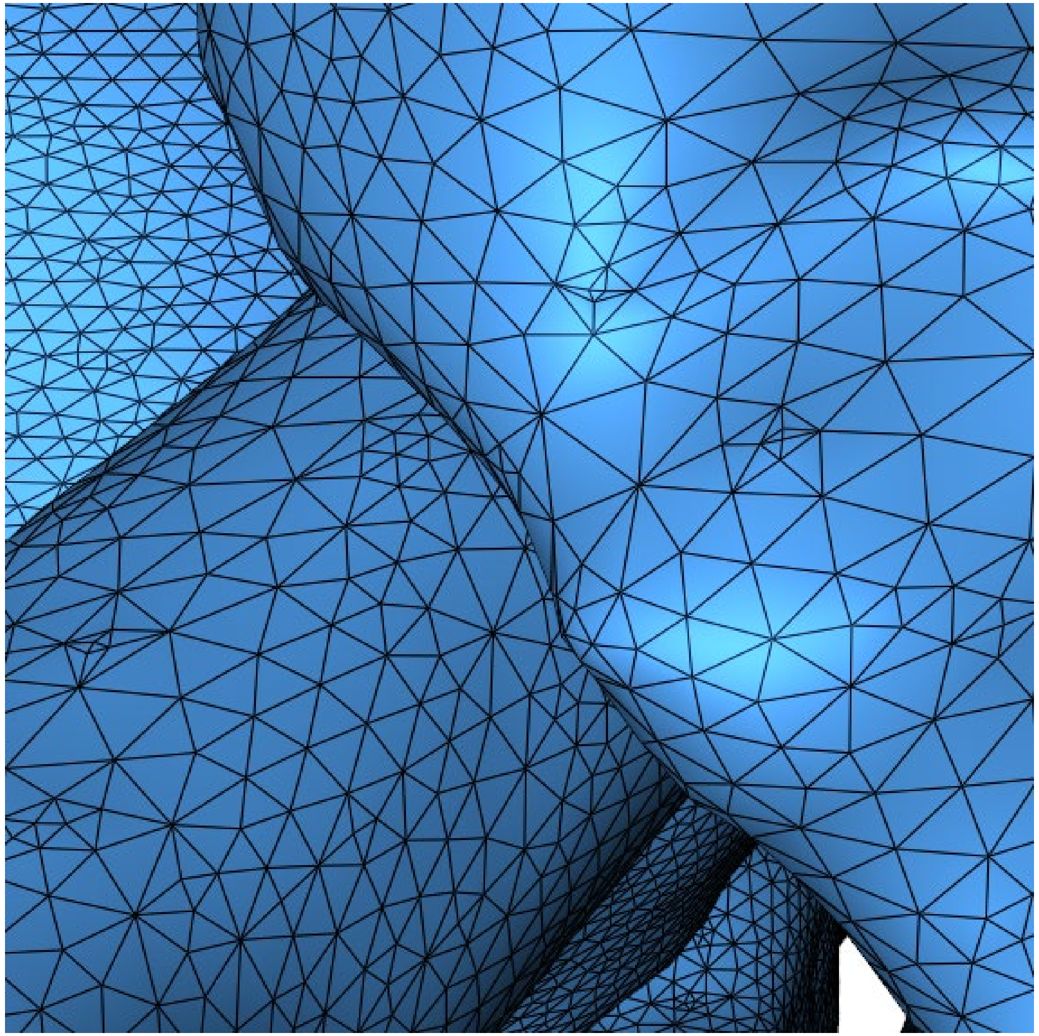
- Novel ways of representing 3D shapes is a very hot research topic
- Facilitates the use of deep learning on complex geometries
- Enabling statistics with and on shapes





3D shapes – points and triangles (mesh)



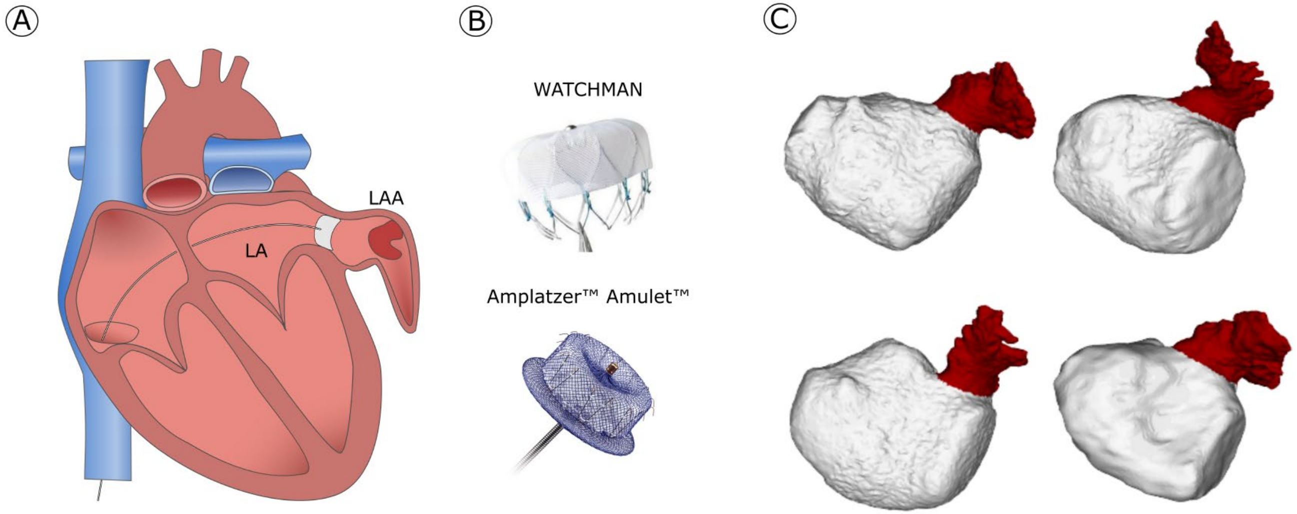


Deep learning directly on 3D meshes

SparseMeshCNN with Self-Attention for Segmentation of Large Meshes

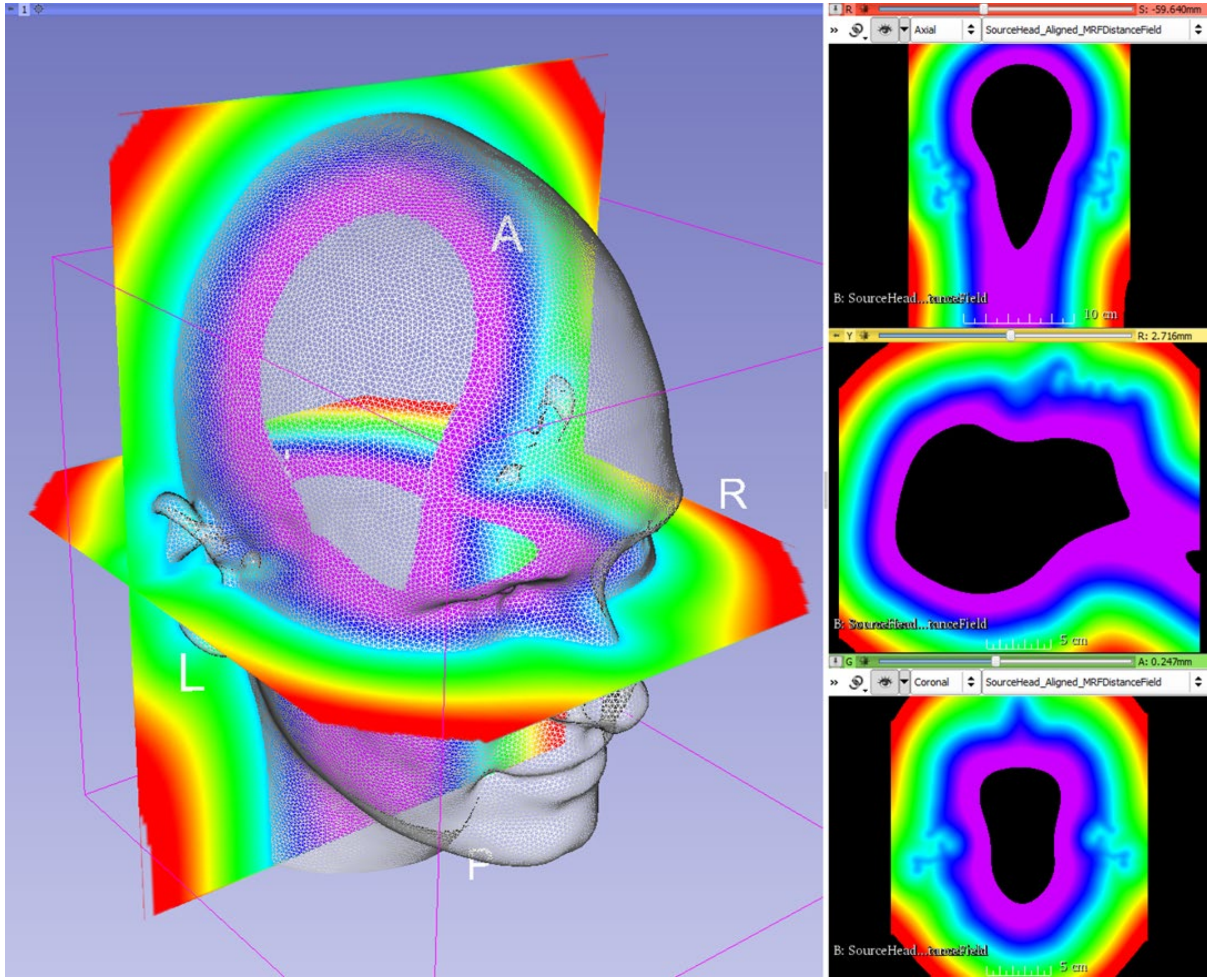
Bjørn Hansen*[1], Mathias Lowes*[1], Thomas Ørkild[1], Anders Dahl[1], Vedrana Dahl[1], Ole de Backer[2], Oscar Camara[3], Rasmus Paulsen[1], Christian Ingwersen†[1,4], and Kristine Sørensen†[1]

[1]Department of Applied Mathematics and Computer Science, Technical University of Denmark, Kgs. Lyngby, Denmark
[2]The Heart Center, Rigshospitalet, University of Copenhagen, Copenhagen, Denmark
[3]BCN MedTech, Universitat Pompeu Fabra, Barcelona, Spain
[4]Trackman A/S, Vedbæk, Denmark



Prediction of intersection between the left atrium and the left atrial appendage in the human heart. For simulation of surgical device insertion.

Implicit shape descriptions



- Implicit shape description
- Carries information about the shape in the entire field
- In the simplest version it is just a 3D voxel grid
  – A distance field



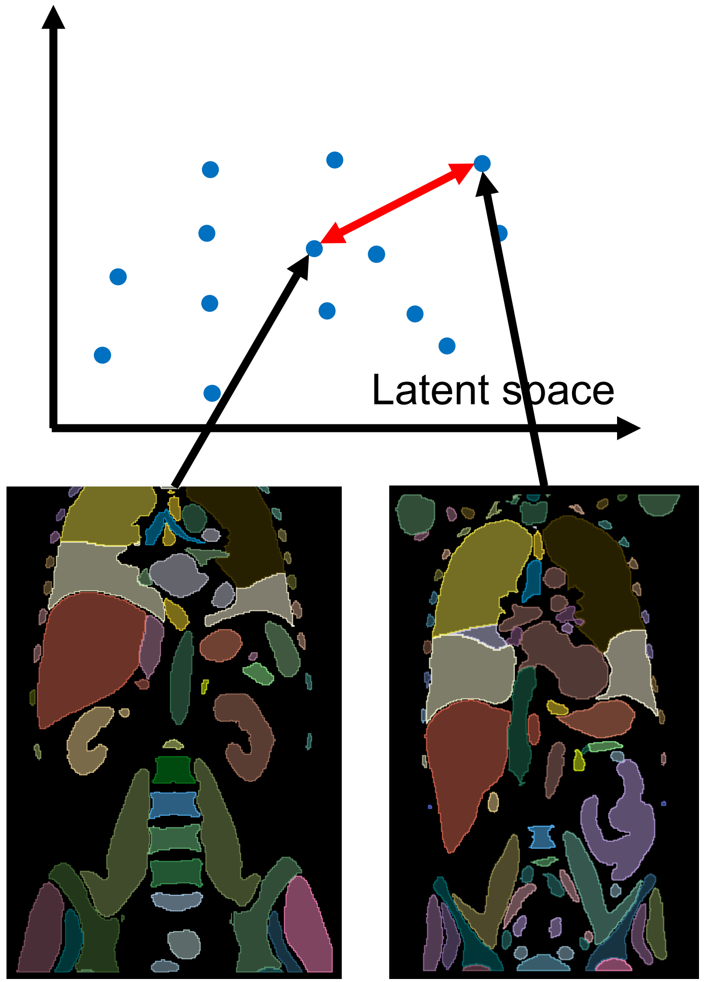
Intersection between image analysis and computer graphics



Neural Representation of Open Surfaces

Christiansen, T. V., Bærentzen, J. A., Paulsen, R. R. & Hannemose, M. R., 2023, (Accepted/In press) In: Computer Graphics Forum. 13 p., e14916.

Latent space



- Lower dimensional space (only around 64ish dimensional)
- A sample / patient / scan is a point in this space
- The relation between the positions in this space can be used in a variety of ways
  - Supervised and unsupervised clustering and classification
  - Optimising networks to improve class separation
    - Deep metric learning
  - Research question: How do we use and manipulate the latent space?

Latent space manipulations – deep metric learning

Contents lists available at ScienceDirect

Medical Image Analysis

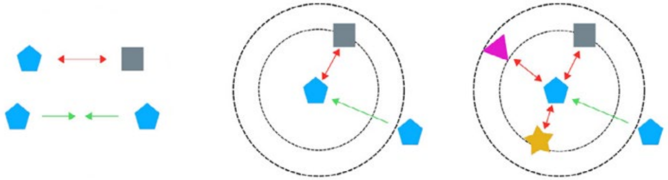
journal homepage: www.elsevier.com/locate/media

Deep metric learning for otitis media classification

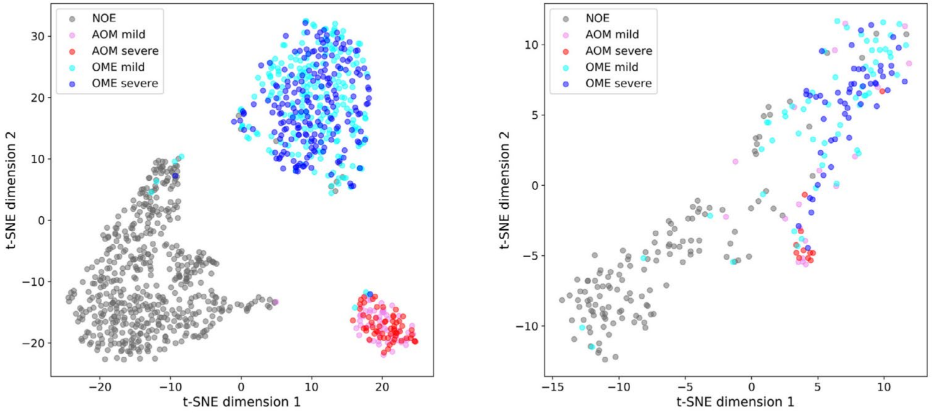
Josefine Vilsbøll Sundgaard[a,*], James Harte[b], Peter Bray[c], Søren Laugesen[b], Yosuke Kamide[d], Chiemi Tanaka[e], Rasmus R. Paulsen[a,1], Anders Nymark Christensen[a,1]

- Deep metric learning is an approach to cluster samples in the low-dimensional latent space
- We have shown its strengths in complex classification tasks

(a) AOM (b) OME (c) NOE



(a) Contrastive loss (b) Triplet loss (c) Multi-class N-pair loss



(a) Train embeddings (b) Test embeddings

AI Driven Medical Image Analysis for cardiovascular risk assessment (Project ARTICHOKE)



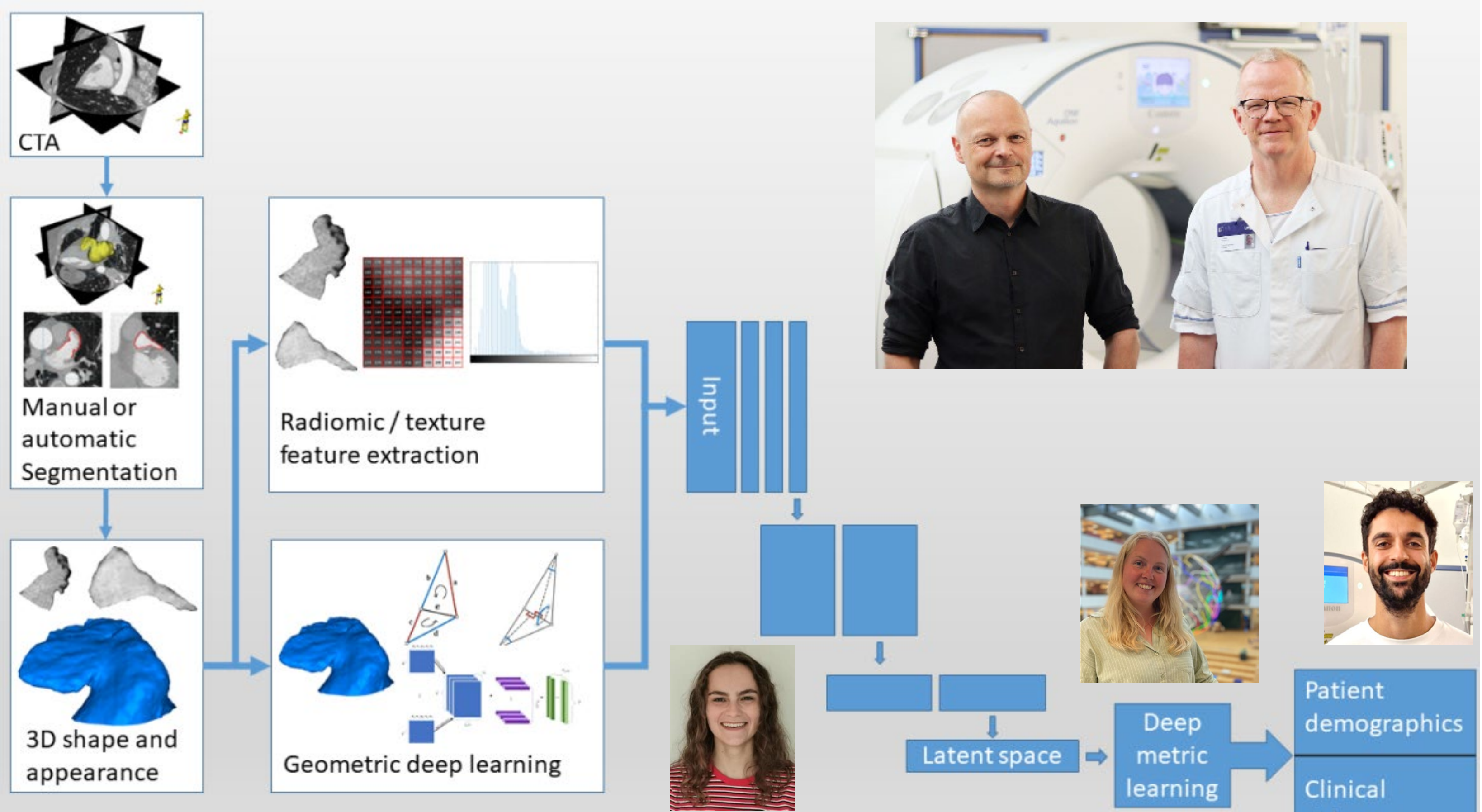
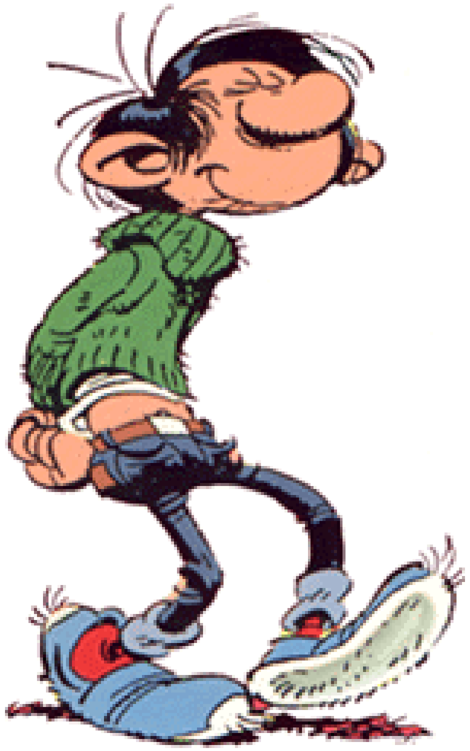


Figure 3: Artificial intelligence-driven 3D image analysis and Radiomics system. The AI system combines input features from a CT scan including morphologic and Radiomic features and predicts a clinical risk or patient specific demographics

Data driven generative models



Disclaimer: This is a real Rytz

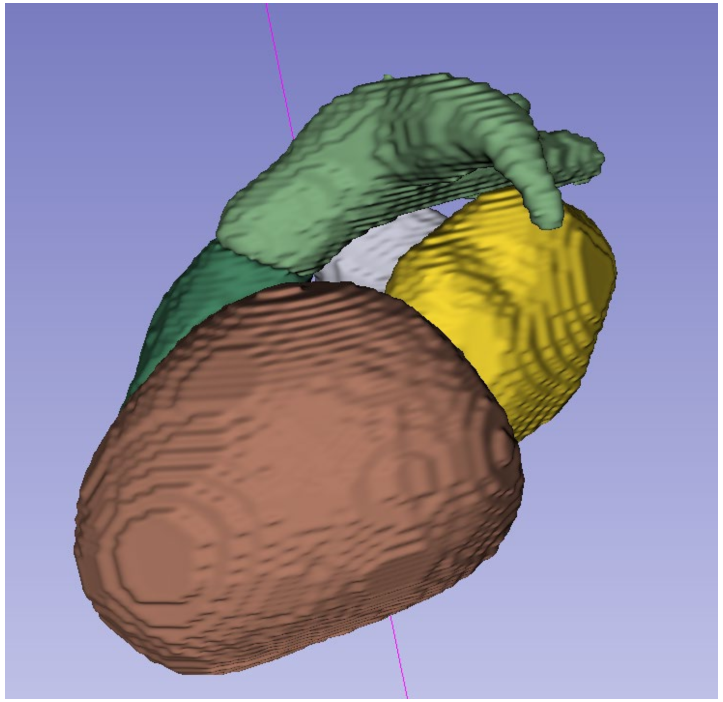
Generate a drawing of Gaston Lagaffe (Vakse Viggo) **in the style of Michael Rytz**

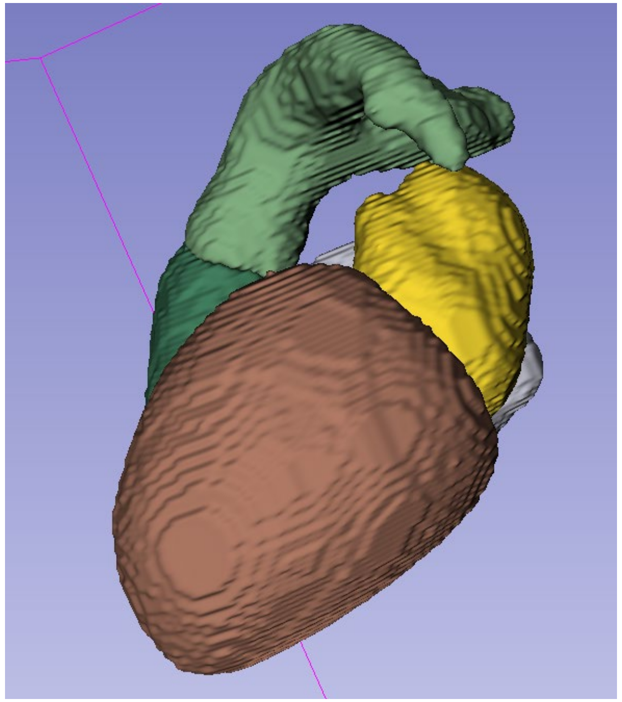
- Large neural networks trained on extremely large collections of images
- Can synthesize plausible images
- Do style transfer
- Issues with using creative property without crediting the original creator

Data driven generative models for risk factor exploration

Generate the geometry and Hounsfield unit distribution of two hearts:

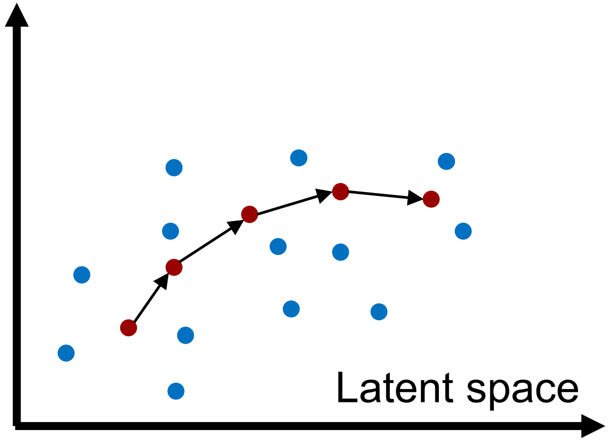
- 60 year, male, heavy smoker
- 60 year, male, not smoking



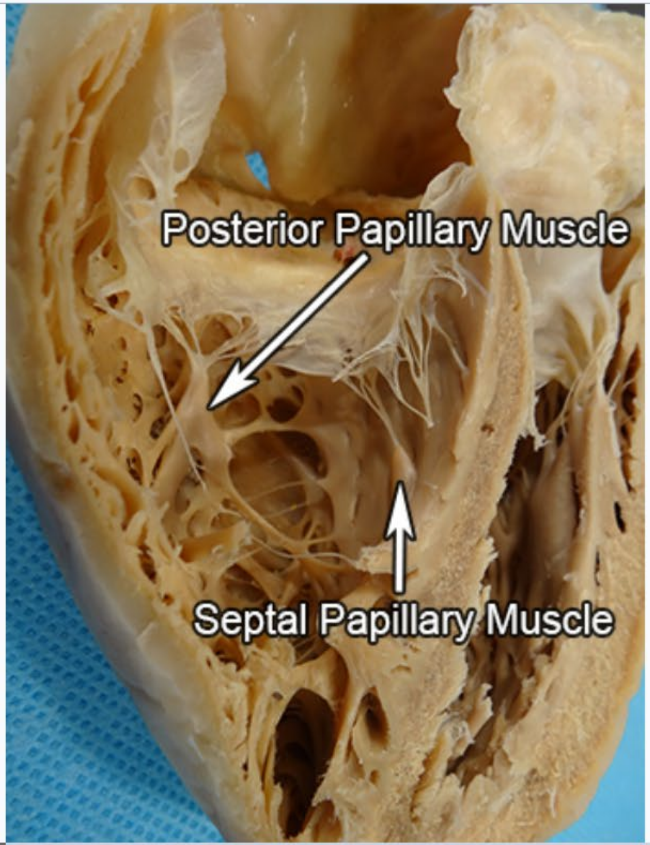


- Trained on large CT cardiac image databases
- Known patient demographics, biochemistry, morbidity and mortality

- Research Questions:
  - Finding life-style / risk factor trajectories in latent space
  - Latent space disentanglement



What do we see in this photo?



- Left atrial appendage and its muscles?
- The lower part of the stomach?
- The left ventricle with trabeculation?
- The aortic arch?
- The left kidney?

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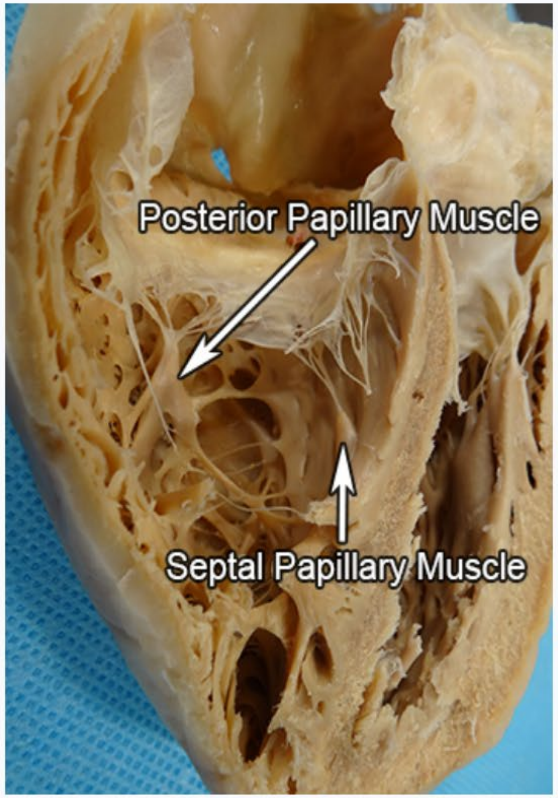
What do we see in this photo?



Left atrial appendage and its muscles?	31%
The lower part of the stomach?	6%
The left ventricle with trabeculation?	52%
The aortic arch?	6%
The left kidney?	6%

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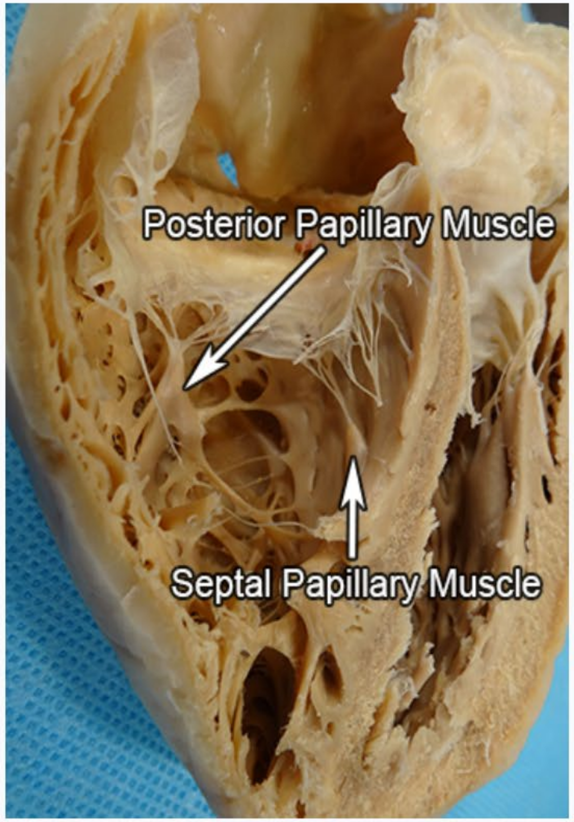
What do we see in this photo?



Left atrial appendage and its muscles?	31%
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The left ventricle with trabeculation?	52%
The aortic arch?	6%
The left kidney?	6%

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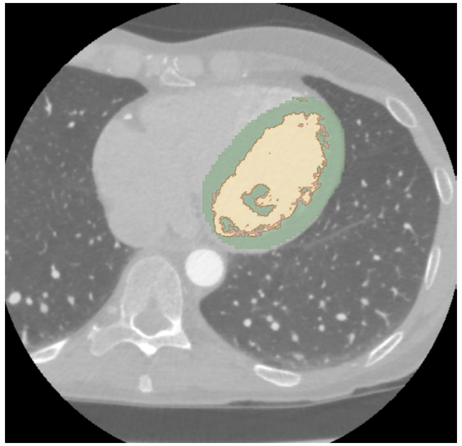
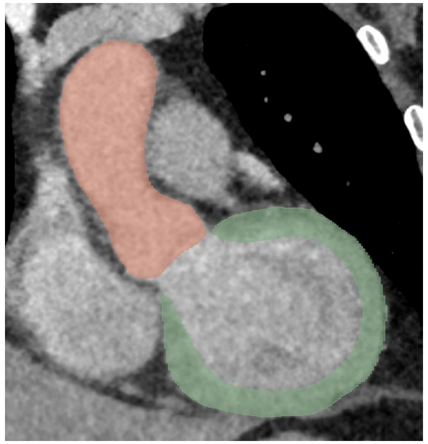
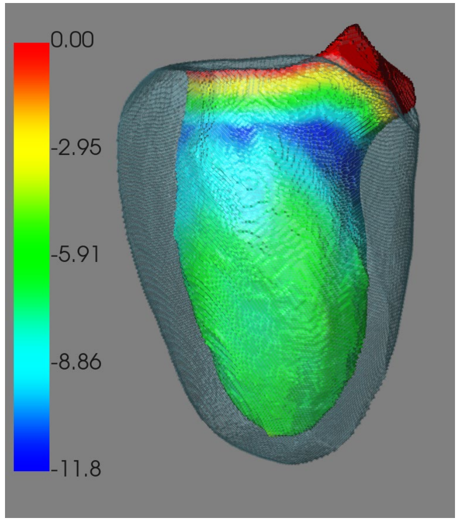
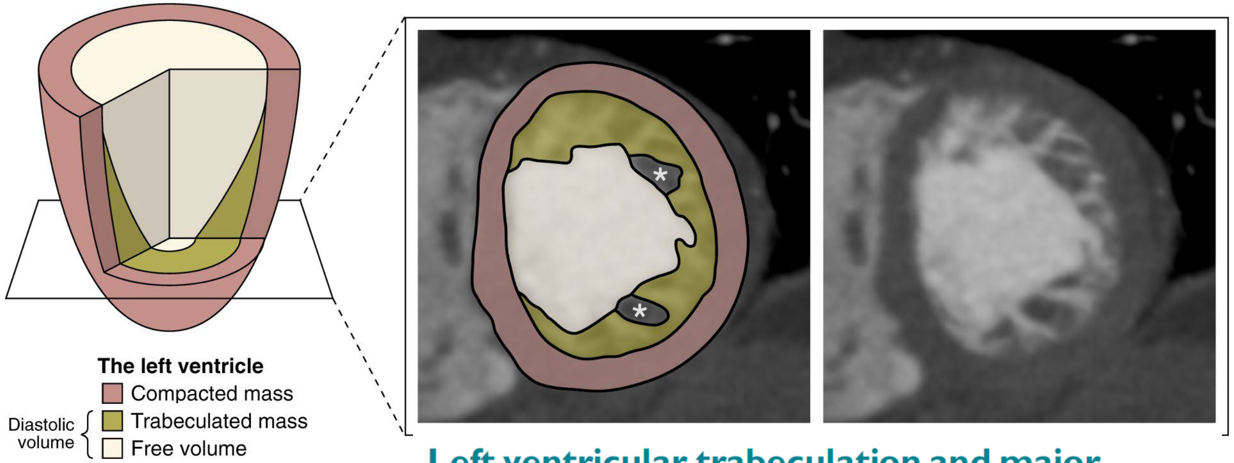
Artichoke part 2: Myocardium and left ventricle





- The shape and appearance of the heart muscle (myocardium) is a known predictor for cardiac death
- Not trivial to define the borders between
  - Heart muscle
  - Left ventricular blood volume
  - Trabeculation

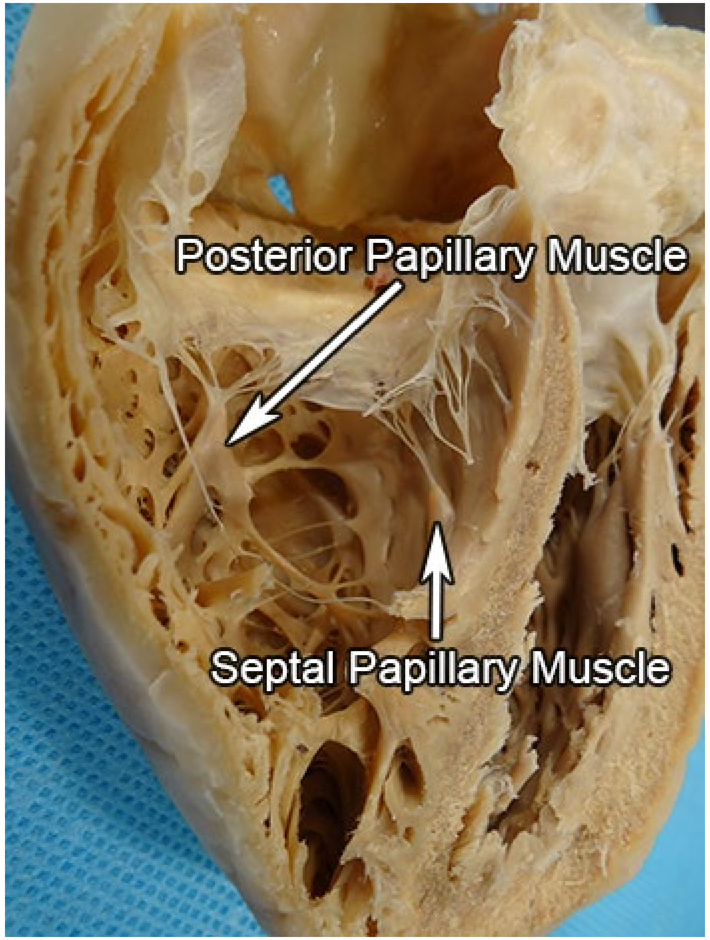




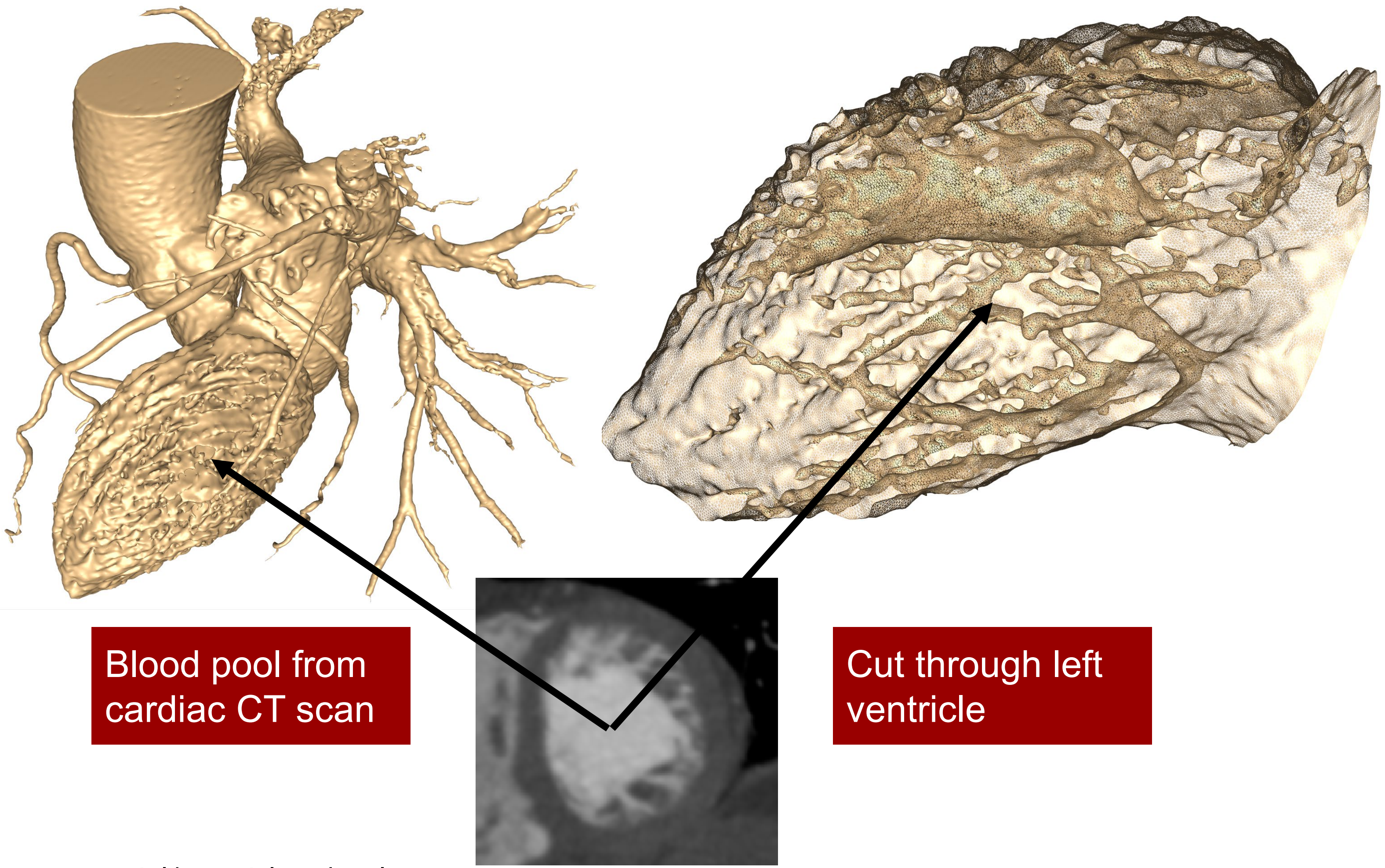
Left ventricular trabeculation and major adverse cardiovascular events: the Copenhagen General Population Study

Per E. Sigvardsen [1,2], Andreas Fuchs[1], Jørgen T. Kühl[1], Shoaib Afzal[2,3], Lars Køber[1,2], Børge G. Nordestgaard [2,3], and Klaus F. Kofoed [1,2,4]*

Complex geometries – left ventricular blood pool



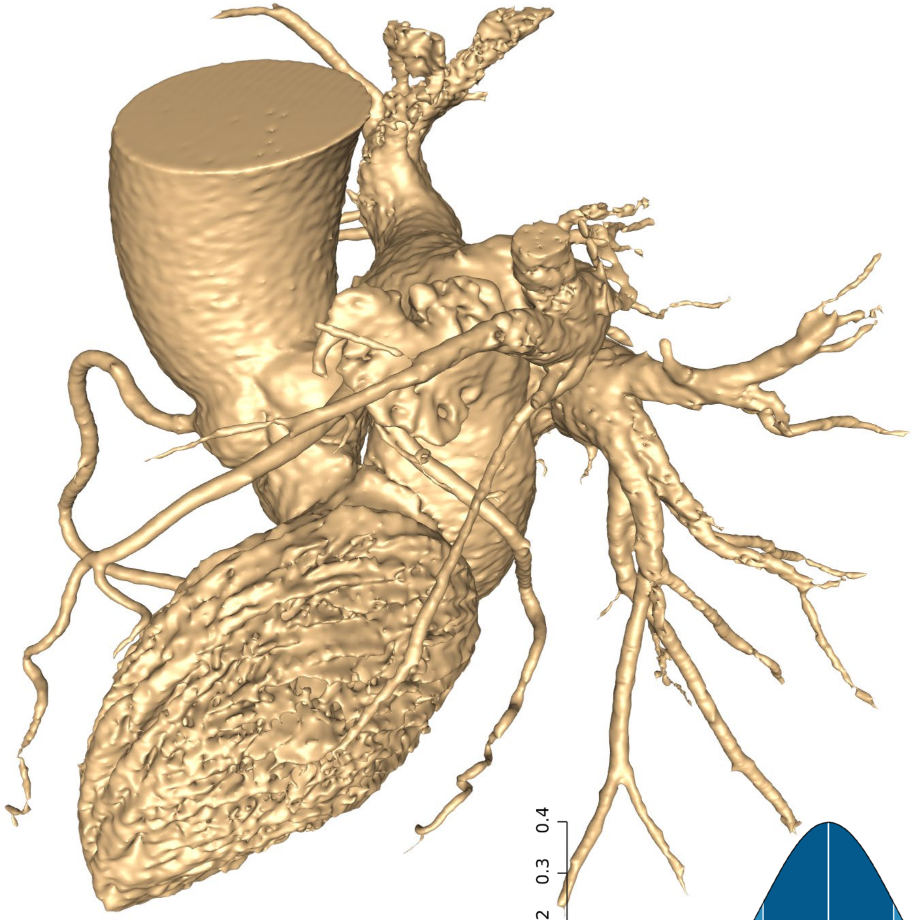
http://www.vhlab.umn.edu/atlas/comparative-anatomy-tutorial/ventricles.shtml

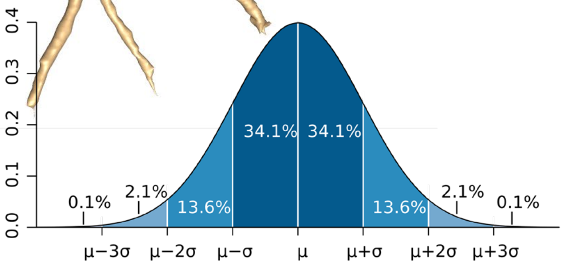


Blood pool from cardiac CT scan

Cut through left ventricle

Statistics on complex shapes





- Research questions:
  - How to parameterize complex geometries
  - How do we make meaningful statistical distributions of these shapes?
  - How do we test if a given patient is closer to one distribution or another?
  - How to compute risk scores using shapes?



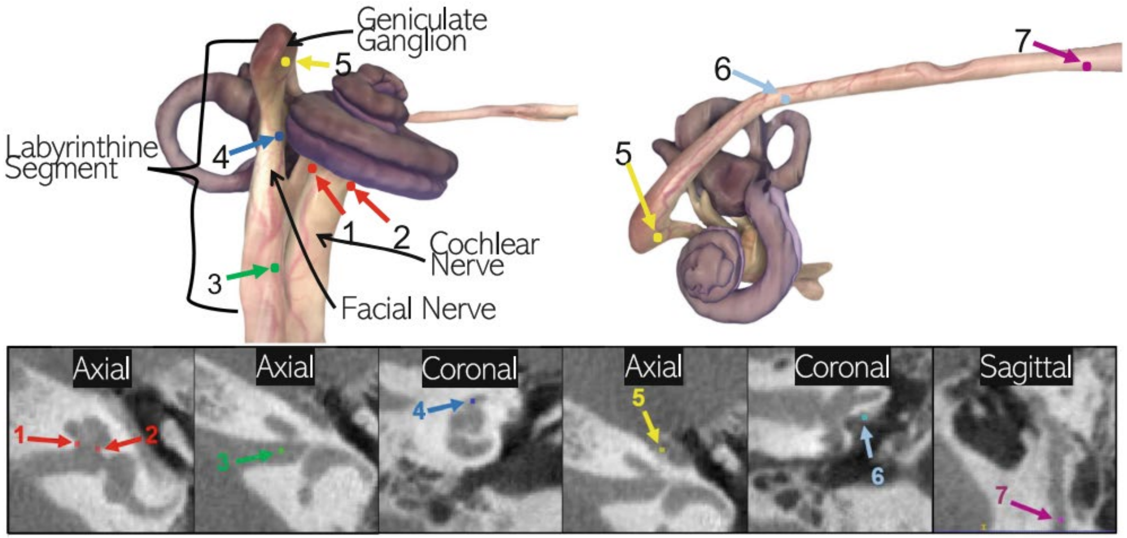
Deep Reinforcement Learning

Deep Reinforcement Learning for Detection of Inner Ear Abnormal Anatomy in Computed Tomography

Paula López Diez[1], Kristine Sørensen[1], Josefine Vilsbøll Sundgaard[1], Khassan Diab[4], Jan Margeta[3], François Patou[2], and Rasmus Paulsen[1]

[1] DTU Compute, Technical University of Denmark, Kongens Lyngby, Denmark
[2] Oticon Medical, Research & Technology group, Smørum, Denmark
[3] KardioMe, Research & Development, Nova Dubnica, Slovakia
[4] Tashkent International Clinic, Tashkent, Uzbekistan
plodi@dtu.dk

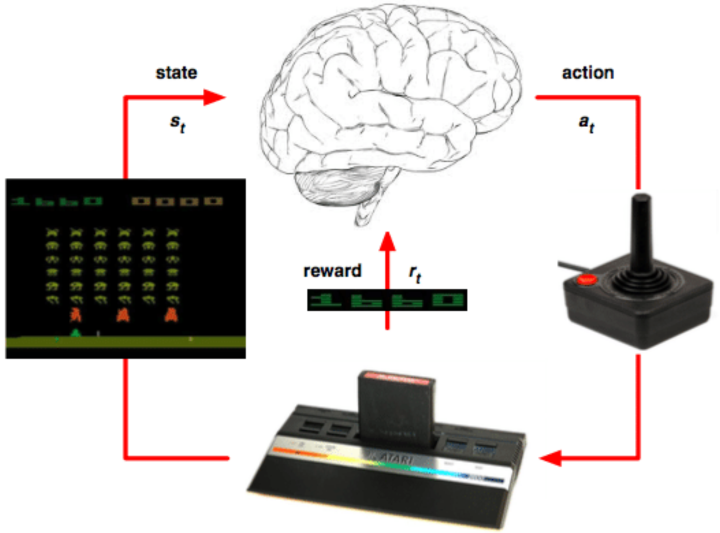
MICCAI 2022








- Deep reinforcement learning has shown to have super human performance in solving complex tasks
- We use it to trace and characterize complex patterns in medical images



DTU and Rigshospitalet collaboration

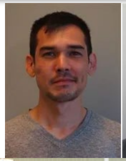
Matematik og teknologi

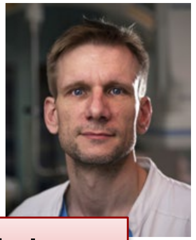
DTU Compute

Medicin og Teknologi

DTU Health Tech

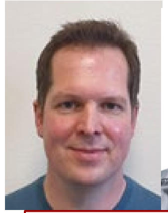
Kunstig intelligens og data





Cardiology

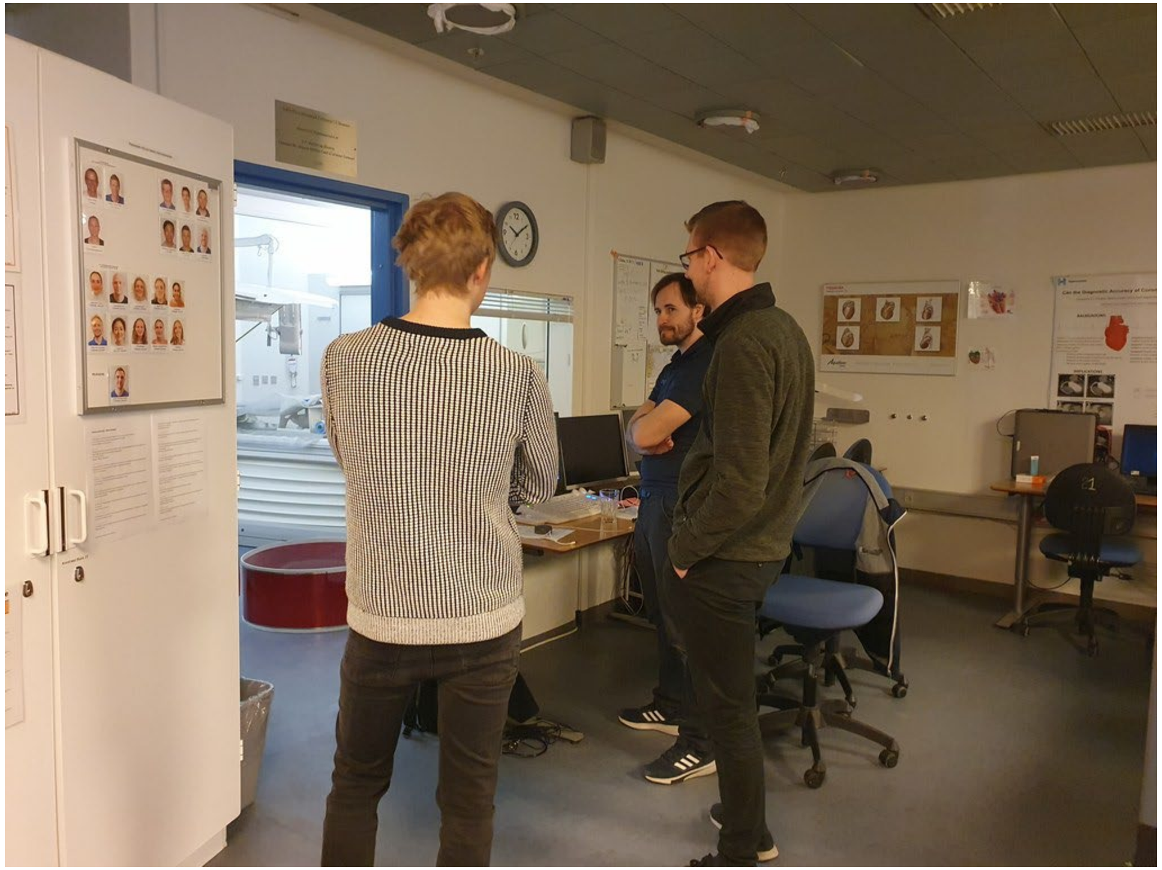
CIMT PACS



Diagnostic Radiology

Nuclear medicine

Daily DTU life at Rigshospitalet

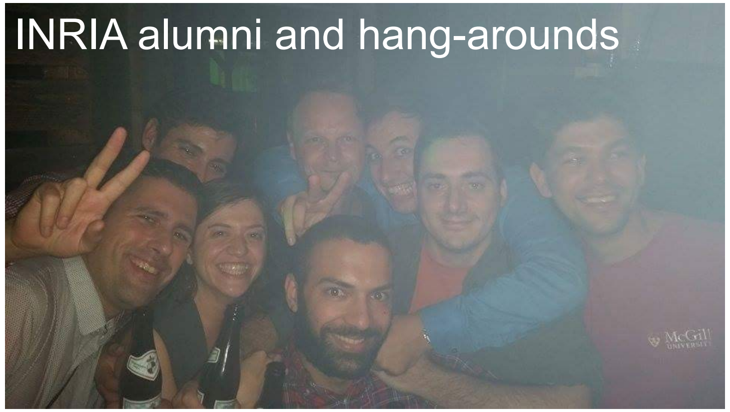


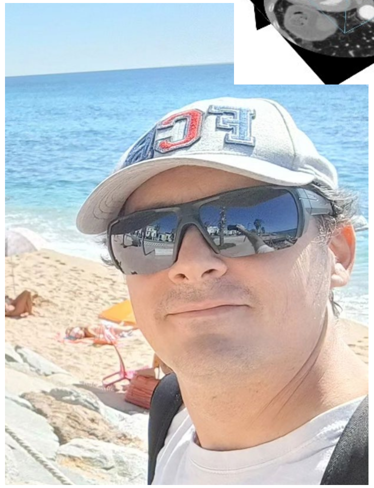
DTU GPU Setup and Rigshospitalet Ph. D. office → Just beside the clinical and research CT Scanner

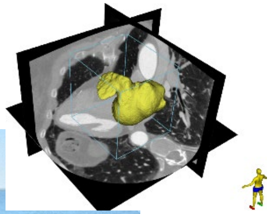
How can we establish cross disciplinary collaborations

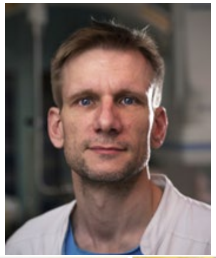
- Take a deep look inside yourself
- What makes you go to work every morning
- Find someone who share this passion

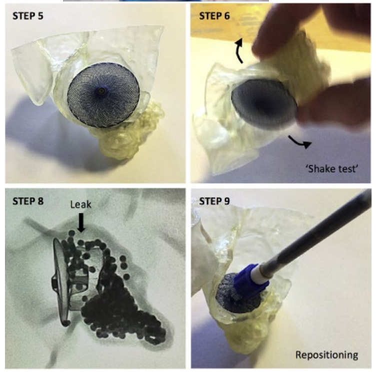
And a degree of chance – from Barcelona and back

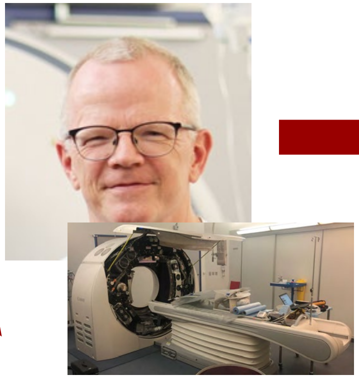













Michael Huy Cuong Pham

rh-ct.org

DTU's mission og vision 2020-2025

Mission

DTU skal udvikle og nyttiggøre naturvidenskab og teknisk videnskab til gavn for samfundet.

Vision

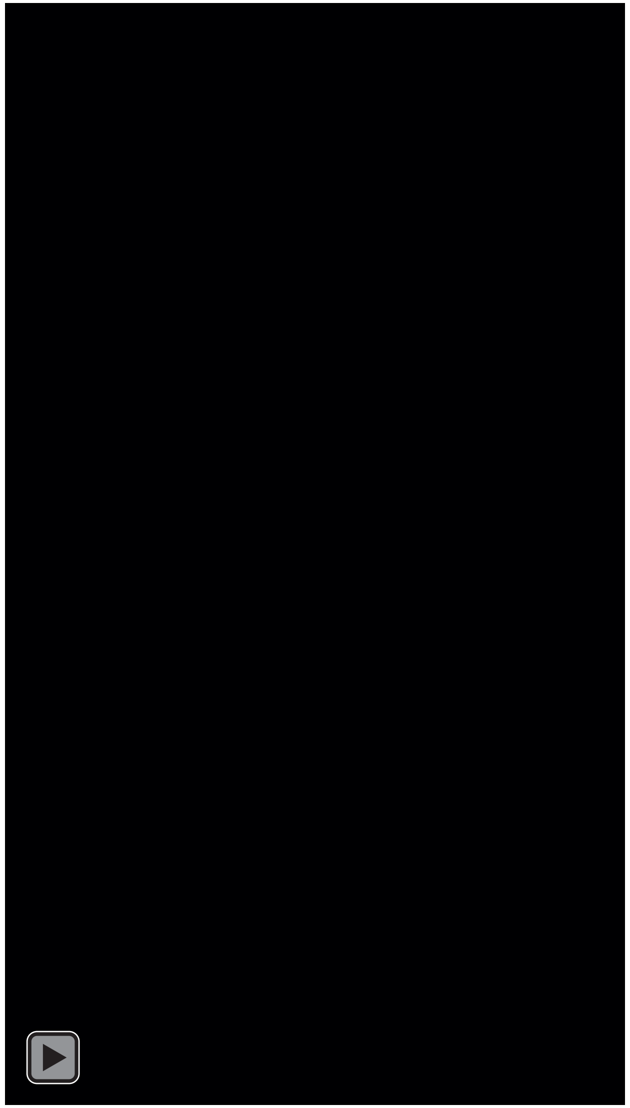
DTU er et af Europas fem førende tekniske universiteter og har Europas bedste ingeniøruddannelse.

DTU er internationalt anerkendt for sin polytekniske eliteforskning og uddannelse af innovative ingeniører med dyb faglighed, der er en drivkraft for bæredygtig forandring i en global verden.

I krydsfeltet mellem forskning, uddannelse, innovation og forskningsbaseret rådgivning, og i tæt interaktion med omverdenen, udvikler DTU værdiskabende teknologi for mennesker.

A little detour - my brothers' laboratory

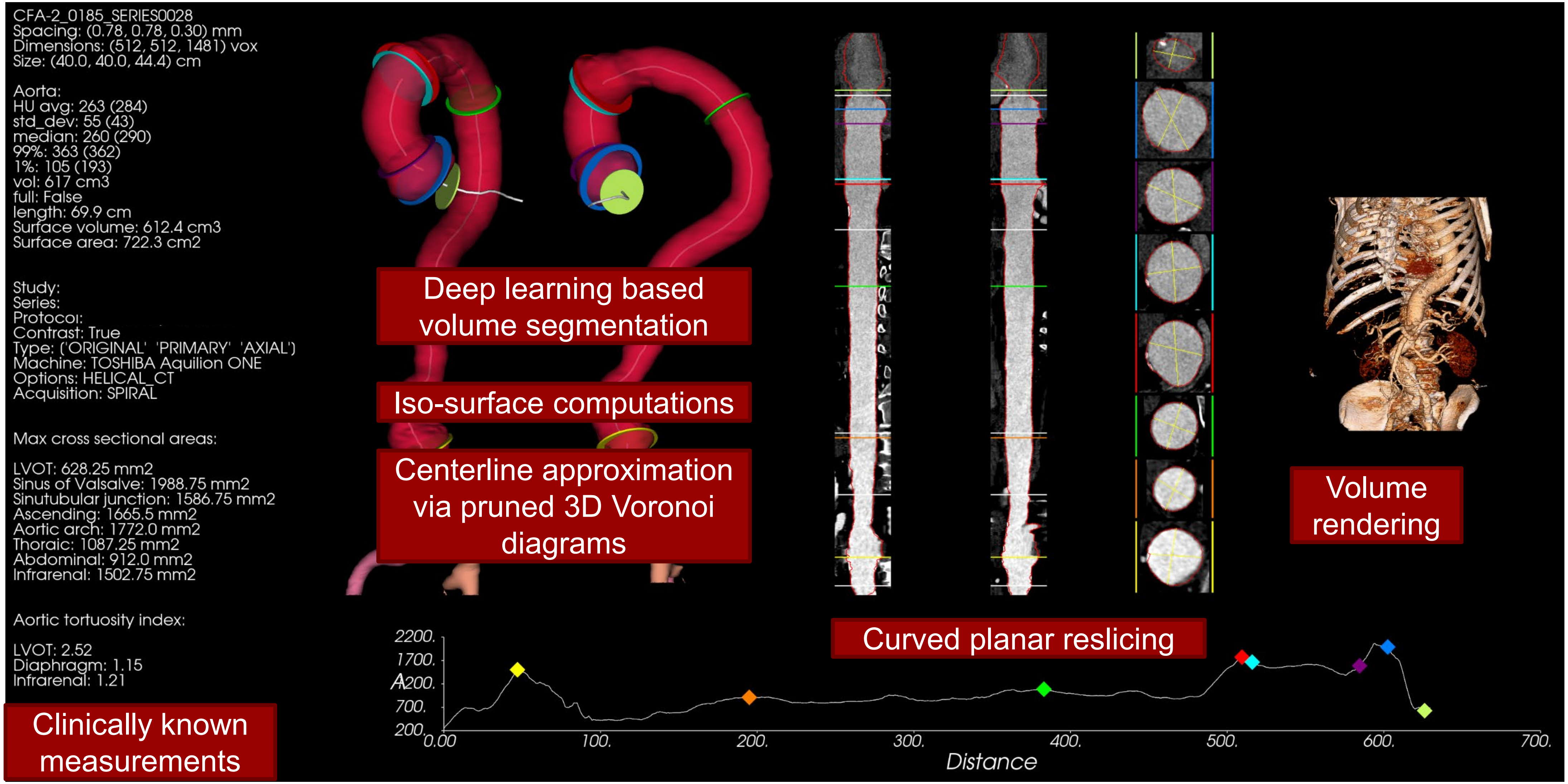
Turning apple pulp into leather



https://www.explore-leap.com/

My Laboratory – The Aorta Explorer

Testing new algorithms on relevant data



From image biomarkers to improved patient outcome

ESC European Society of Cardiology

European Heart Journal - Cardiovascular Imaging (2019) 0, 1–10
doi:10.1093/ehjci/jez012

Normal values of aortic dimensions assessed by multidetector computed tomography in the Copenhagen General Population Study

Michael H.C. Pham[1], Christian ...llegaard[1], Martina C. de Knegt[1], Per E. Sigvardsen[1], Mathias H. Sørg...rd[1], Andreas Fuchs[1], Jørgen T. Kühl[1], Mikkel Taudorf[2], Børge G. Nordestgaard[3], Lars V. Køber[1], and Klaus F. Kofoed[1,2]*

Left ventricular trabecul... adverse cardiovascular e... General Population Stu...

Per E. Sigvardsen [1,2], Andreas Fuchs[1], J... Lars Køber[1,2], Børge G. Nordestgaard [2...

Annals of Internal Medicine ORIGINAL RESEARCH

Subclinical Coronary Atherosclerosis and Risk for Myocardial Infarction in a Danish Cohort

A Prospective Observational Cohort Study

Andreas Fuchs, MD, PhD; Jørgen Tobias Kühl, MD, PhD, DMSc; Per Ejlstrup Sigvardsen, MD, PhD; Shoaib Afzal, MD, PhD; Andreas ...hlbæk Knudsen, MD, PhD; Mathias Bech Møller, MD, PhD; Martina Chantal de Knegt, MD, PhD; Mathias Holm Sørgaard, MD, PhD; Børge Grønne Nordestgaard, MD, DMSc; Lars Valeur Køber, MD, DMSc; and Klaus Fuglsang Kofoed, MD, PhD, DMSc

Assessment of left atrial volume and function: a comparative ...aphy, magnetic resonance ...puted tomography

...uchs ·
...g Kelbæk ·
...F. Kofoed

From image biomarkers to improved patient outcome

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Updated national and international clinical guidelines for risk estimation

Local implementation of new guidelines

Improved patient outcome.

Decrease in morbidity and mortality

Normal and high risk left atrial appendage morphologies estimated in the Copenhagen General Population Study

(Using an AI driven image analysis framework)

And now to something completely

Different

And after that some questions from the audience!

Friends, inspiration, education and creativity

- the best ideas come when you least expect it!

Alexander Shirinyan Rohde
Marianna Shirinyan

mariannashirinyan.com www.dkdm.dk/da/employee/marianna-shirinyan