

Medical image analysis

Medical images?



Medical images?

- 2D or 3D images



Medical images?

- 2D or 3D images
- Interior living (human) body



Medical images?

- 2D or 3D images
- Interior living (human) body
- Non-invasive medical imaging scanners



Medical images?

- 2D or 3D images
- Interior living (human) body
- Non-invasive medical imaging scanners
- Anatomy and/or physiology

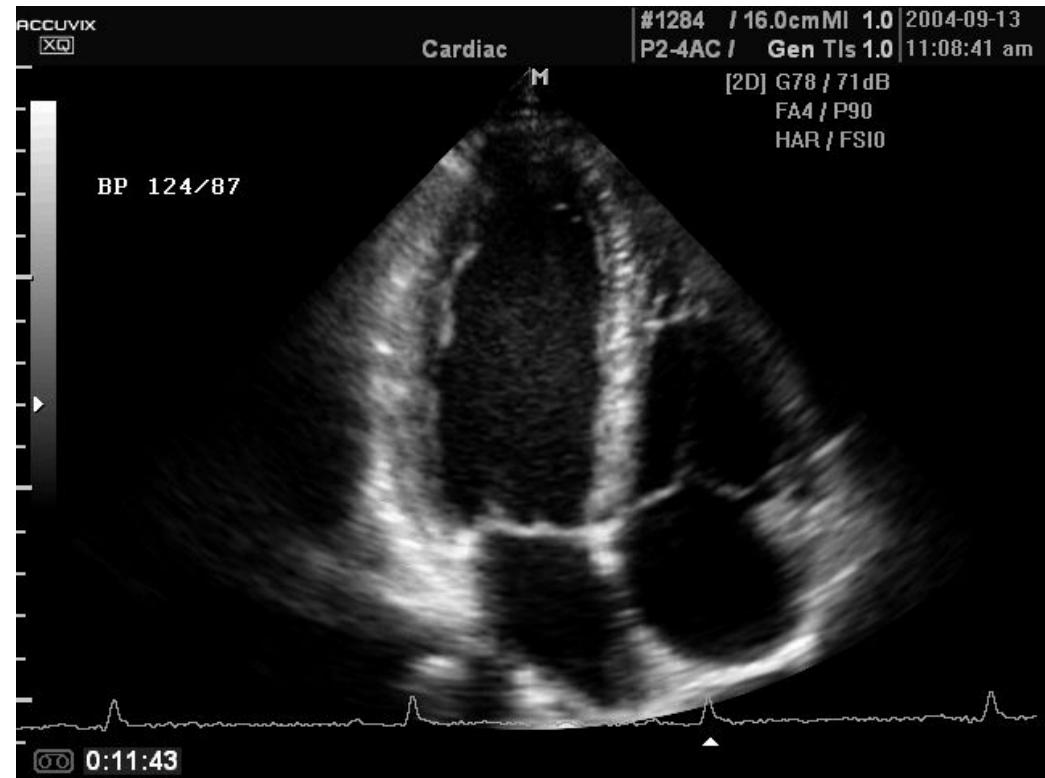


Medical images?

- 2D or 3D images
- Interior living (human) body
- Non-invasive medical imaging scanners
- Anatomy and/or physiology
- Examine, diagnos, treat

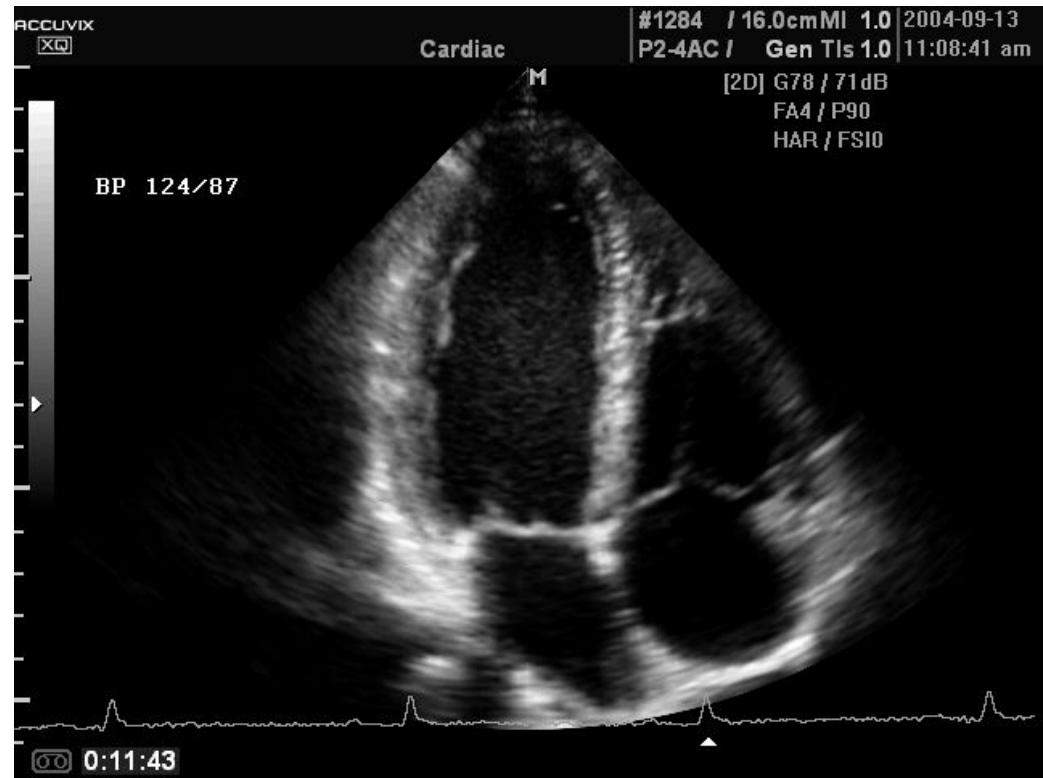


Medical ultrasound



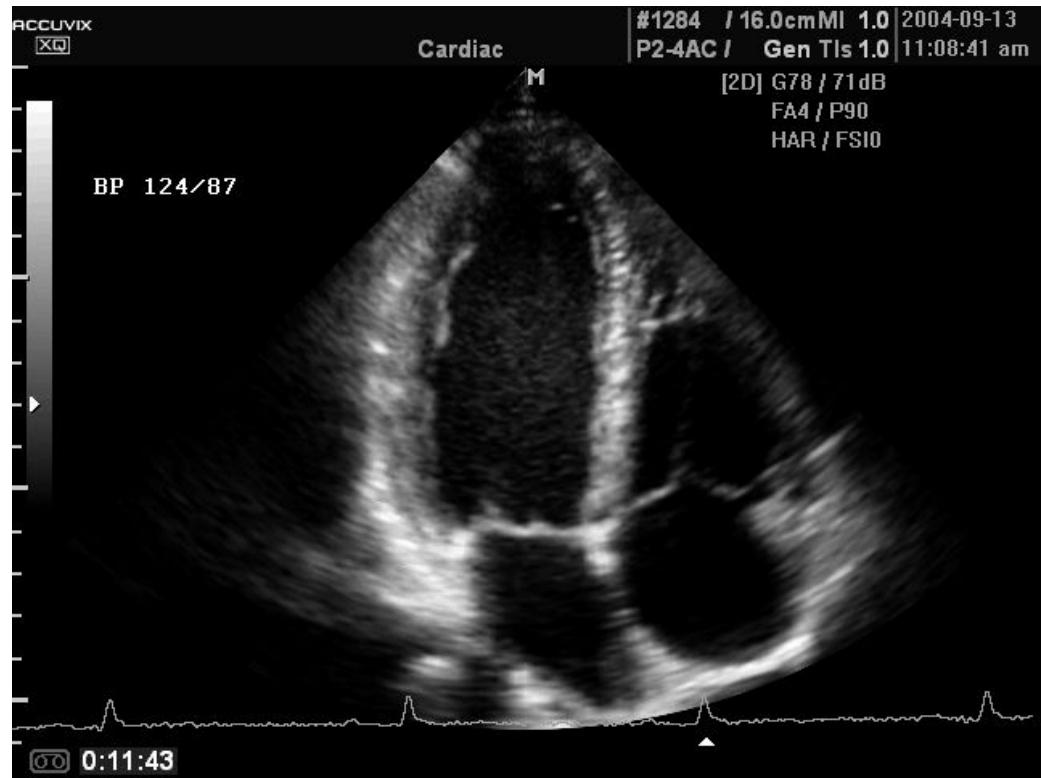
Medical ultrasound

- 2D or 3D (+ time)



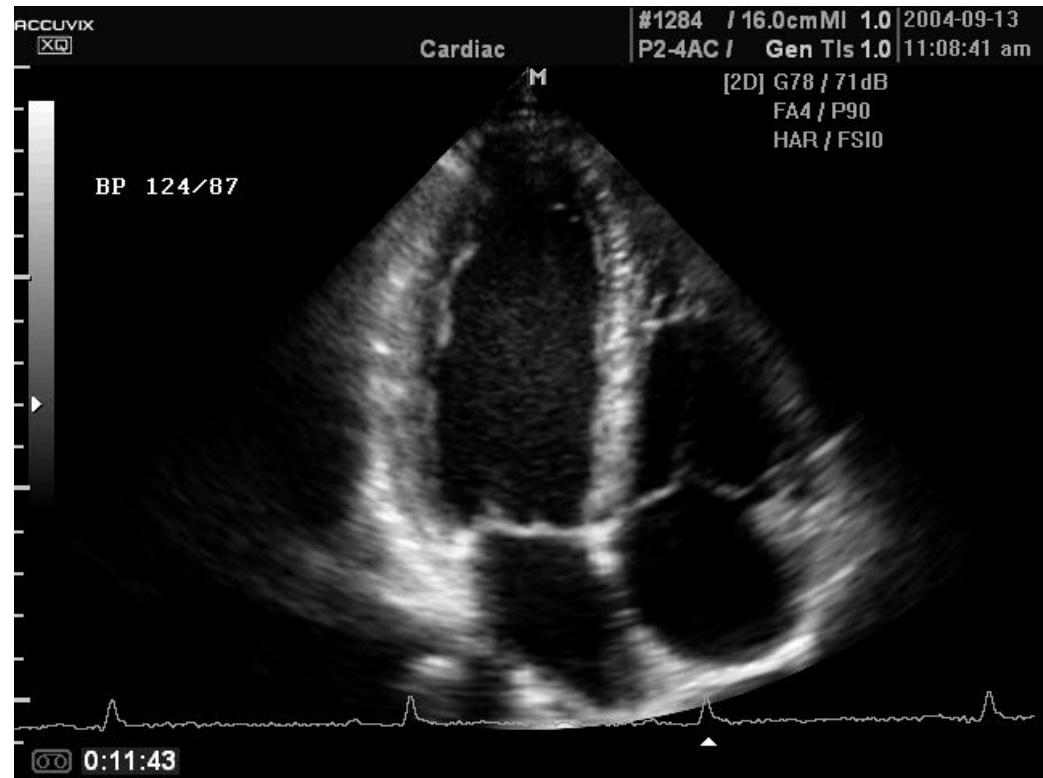
Medical ultrasound

- 2D or 3D (+ time)
- Shows anatomy and physiology

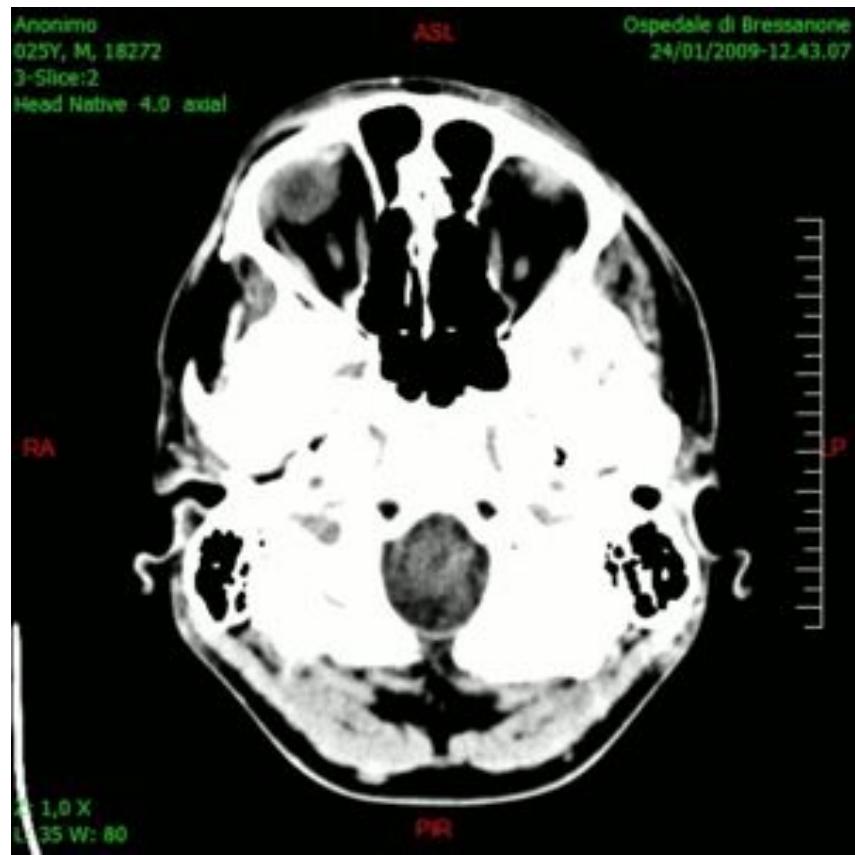


Medical ultrasound

- 2D or 3D (+ time)
- Shows anatomy and physiology
- Gynecology/obstetrics,
heart, ...

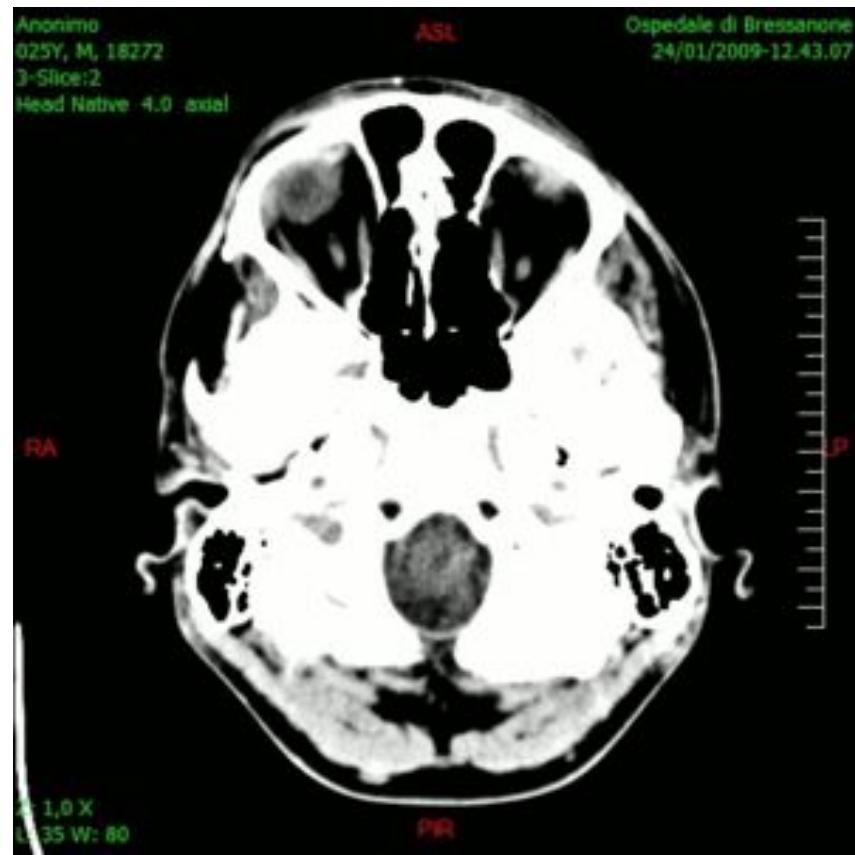


CT and CTA



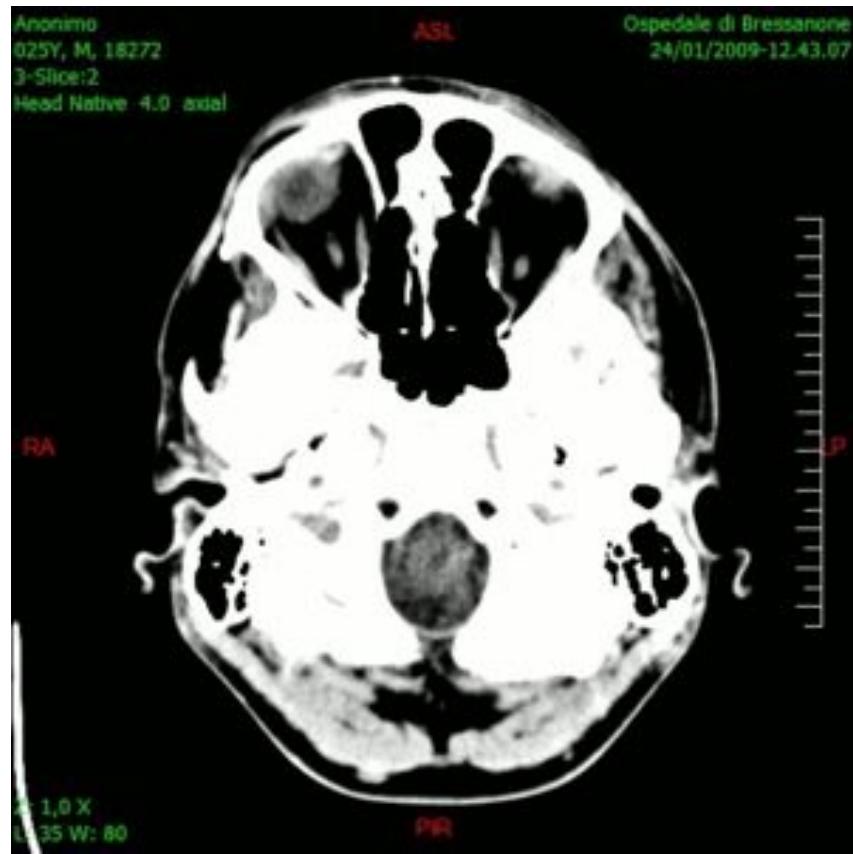
CT and CTA

- Computed tomography



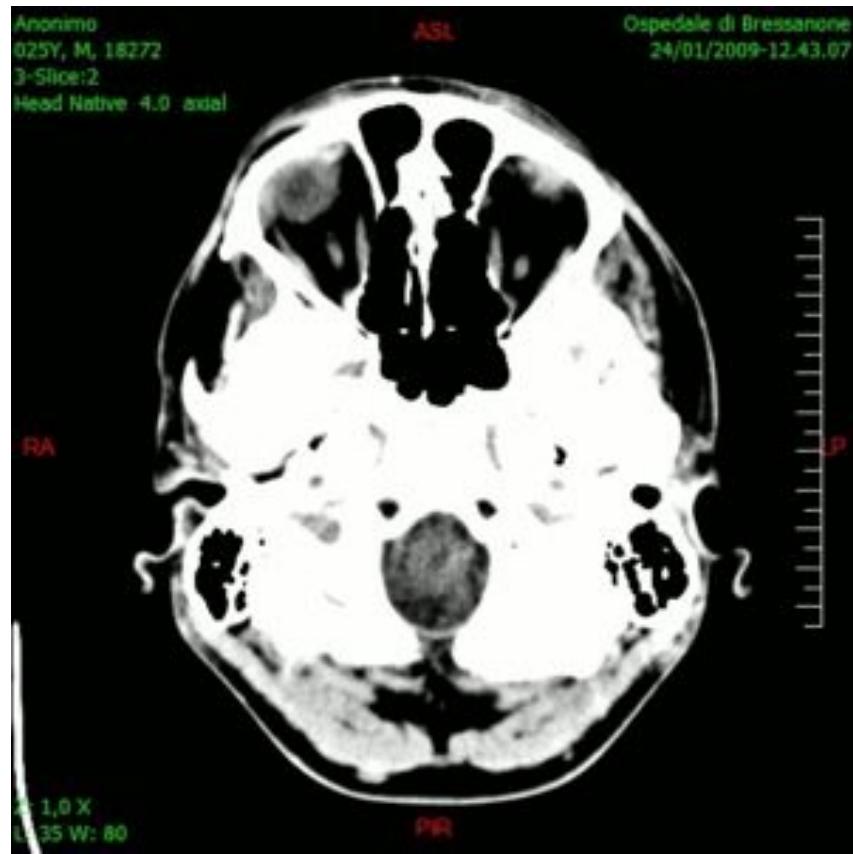
CT and CTA

- Computed tomography
- 3D X-ray



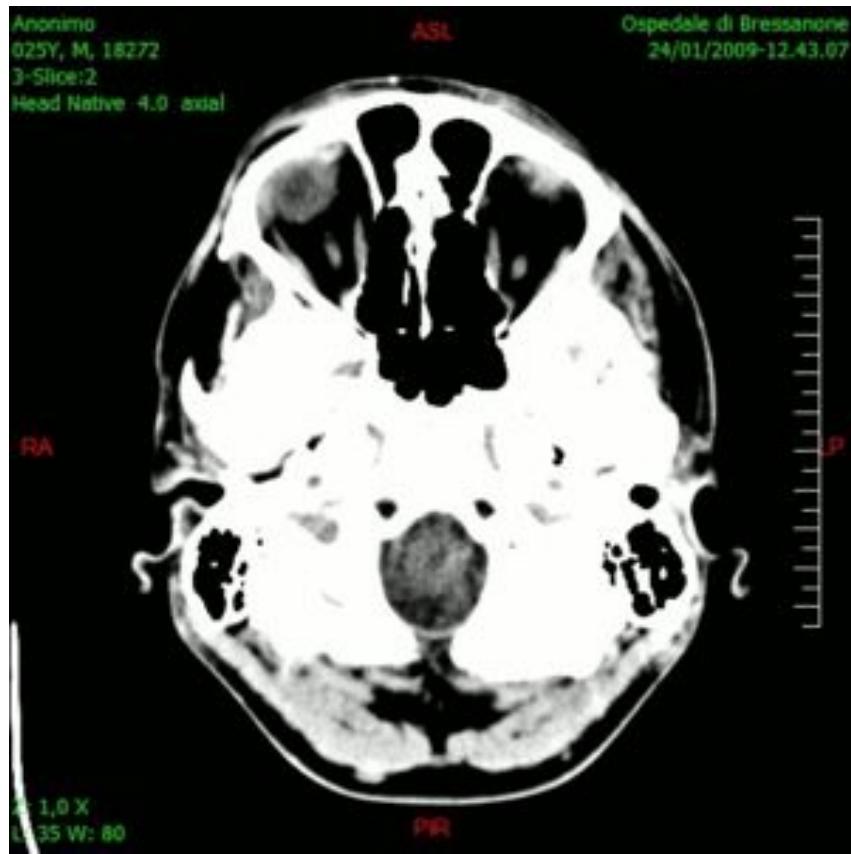
CT and CTA

- Computed tomography
- 3D X-ray
- Shows anatomy
- Head/brain, lungs, heart, vessels, abdomen (=belly), skeleton, ...

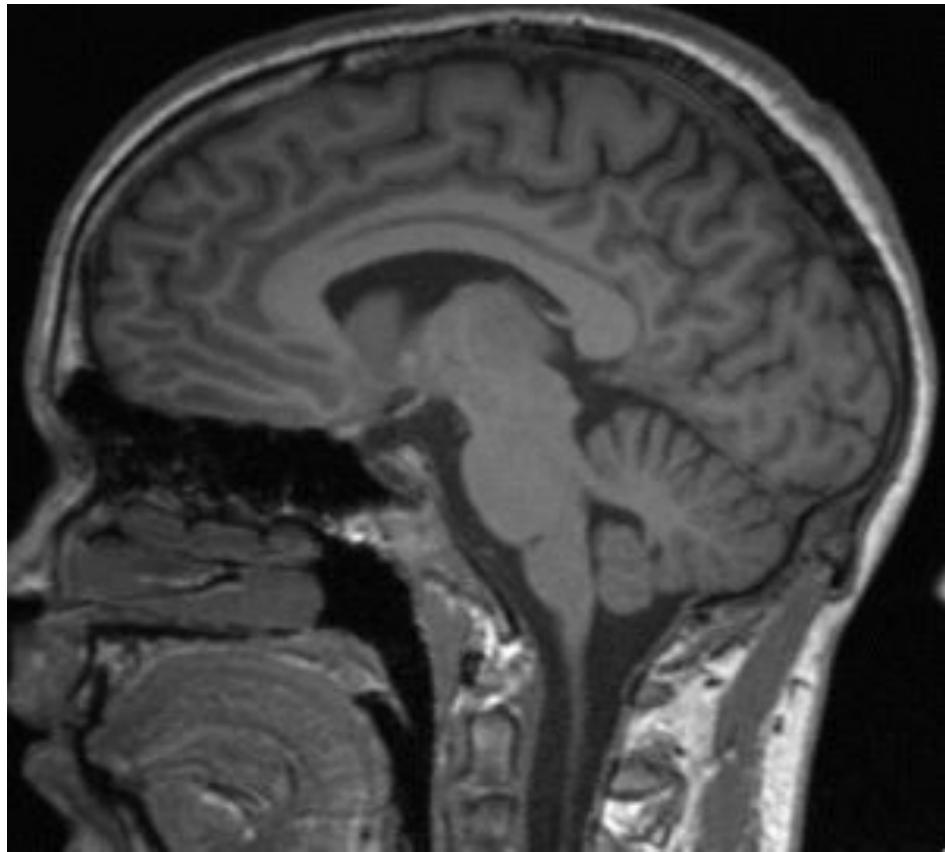


CT and CTA

- Computed tomography
- 3D X-ray
- Shows anatomy
- Head/brain, lungs, heart, vessels, abdomen (=belly), skeleton, ...
- Contrast-enhanced = CTA

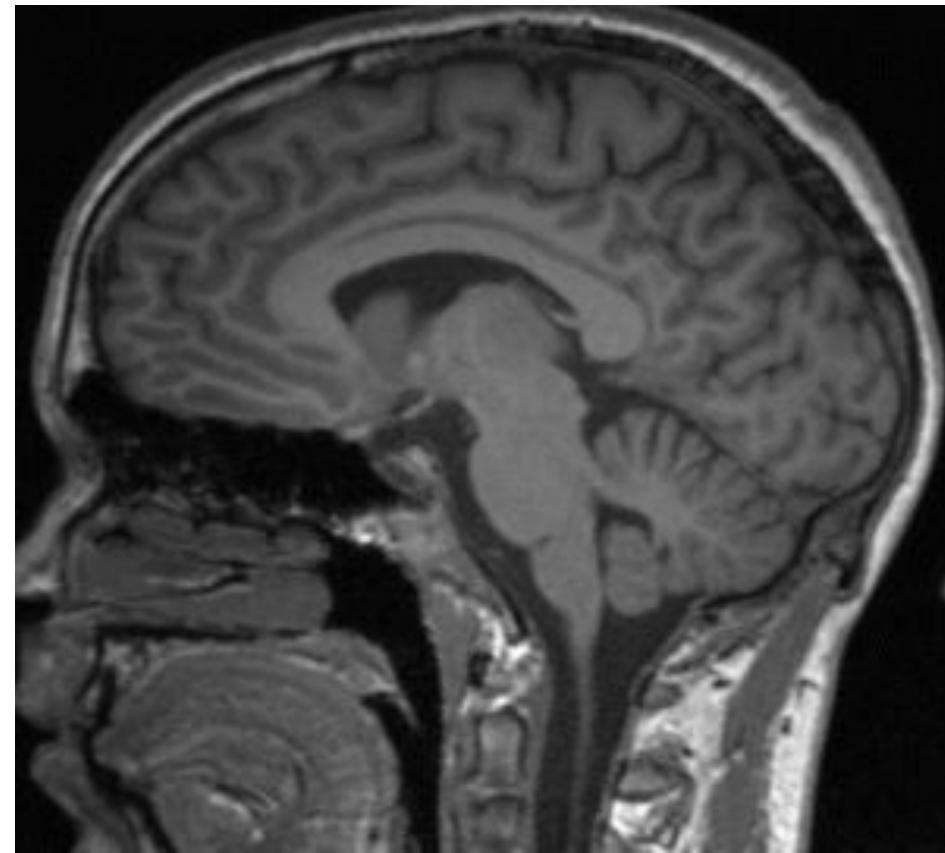


MR(I)



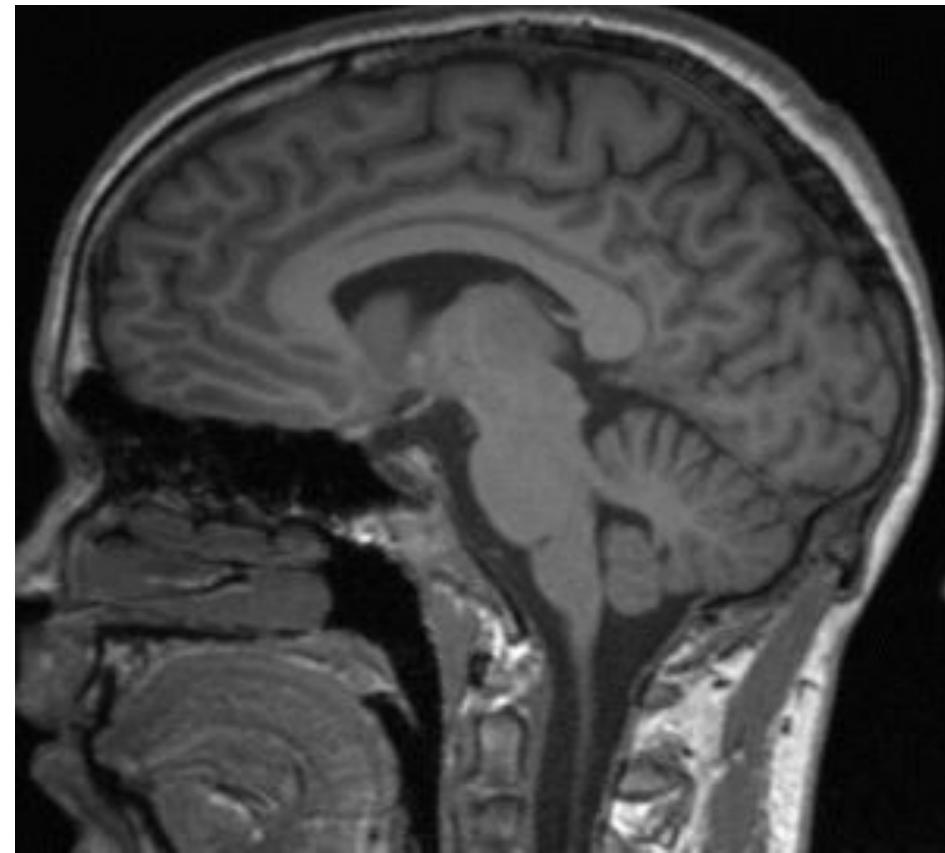
MR(I)

- Magnetic resonance imaging



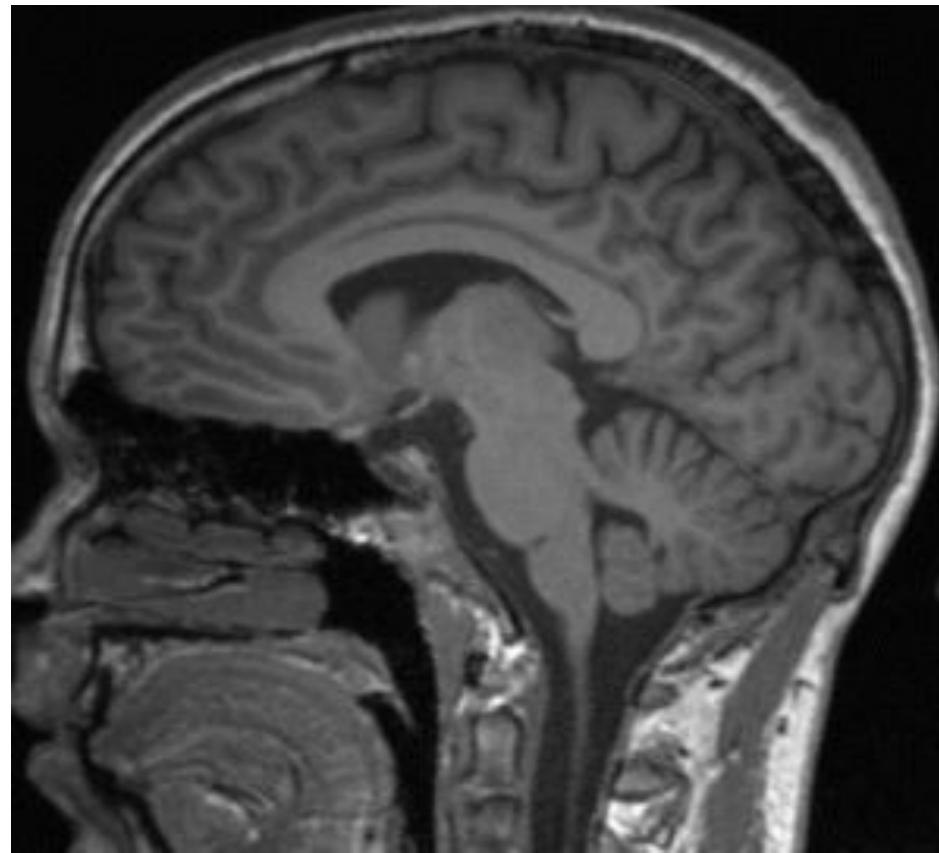
MR(I)

- Magnetic resonance imaging
- 3D



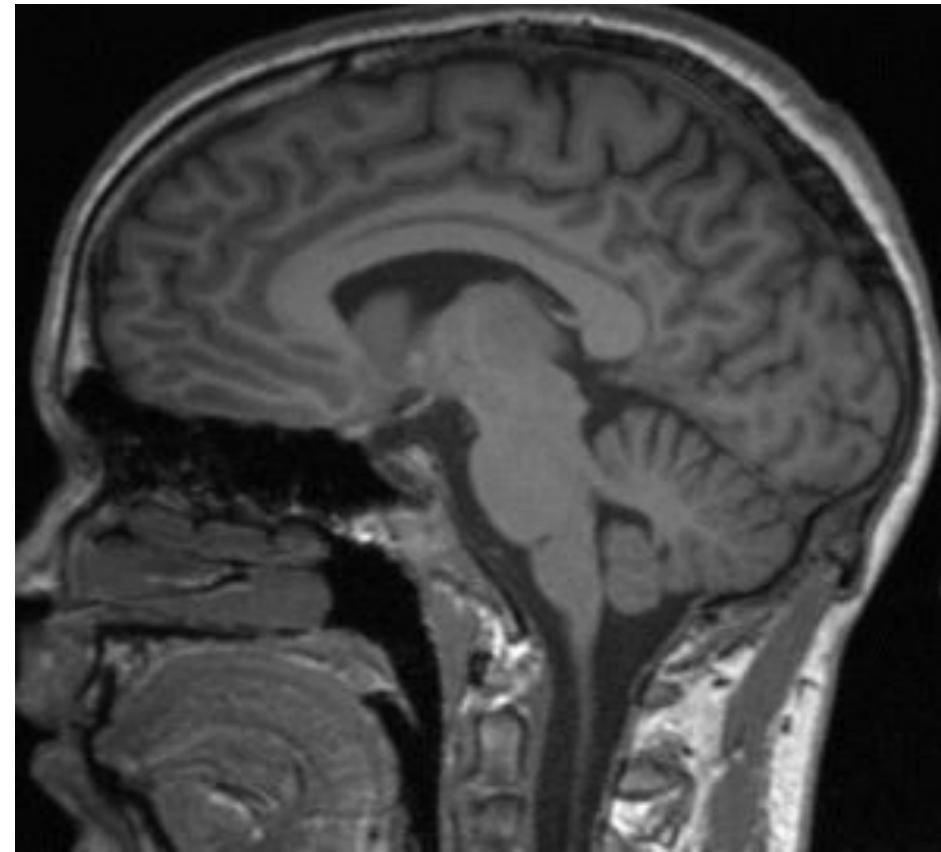
MR(I)

- Magnetic resonance imaging
- 3D
- Shows anatomy & physiology



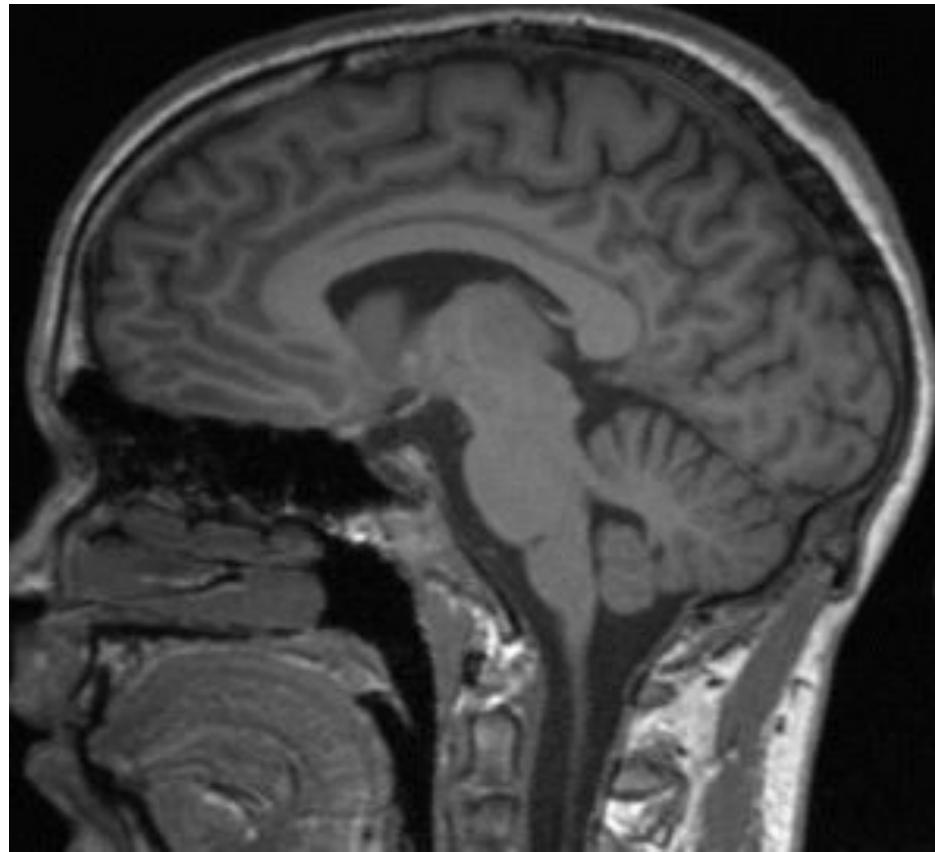
MR(I)

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- 3D
- Shows anatomy & physiology
- Head/brain, lungs, heart, vessels, abdomen (=belly), skeleton, ...



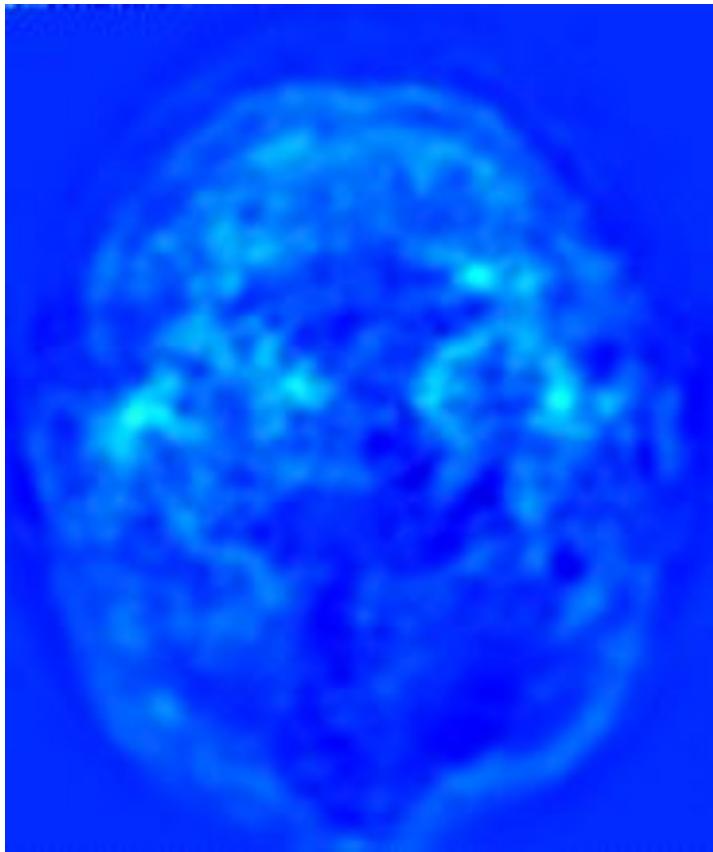
MR(I)

- Magnetic resonance imaging
- 3D
- Shows anatomy & physiology
- Head/brain, lungs, heart, vessels, abdomen (=belly), skeleton, ...
- Contrast-enhanced = MRA



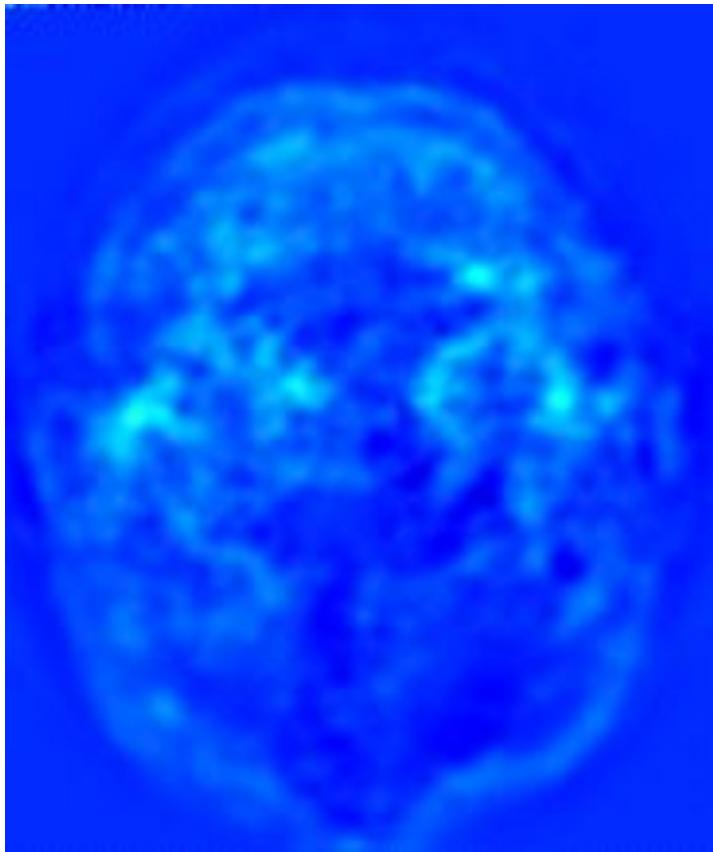
PET

— — —



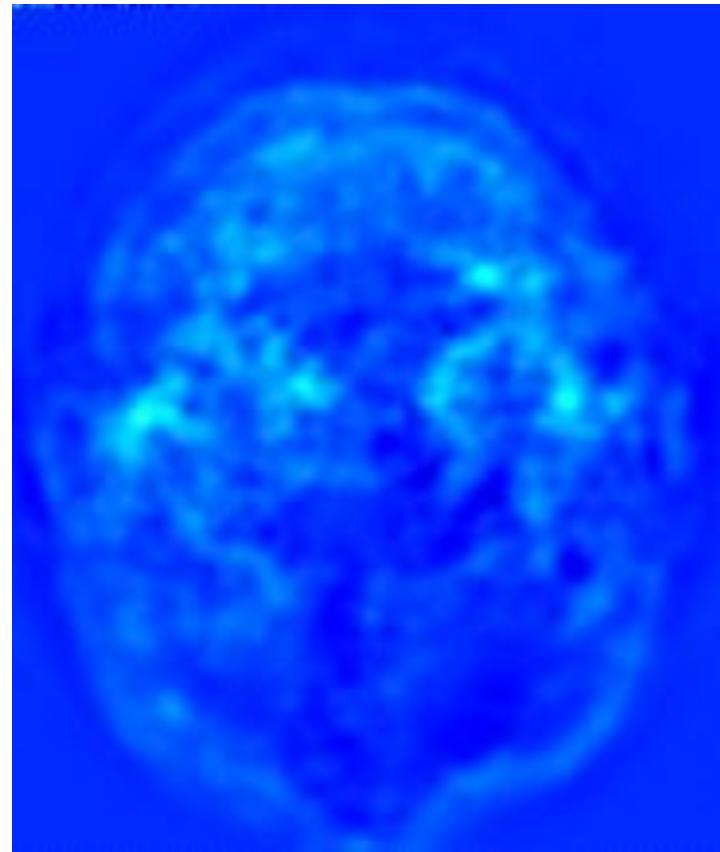
PET

- Positron emission tomography



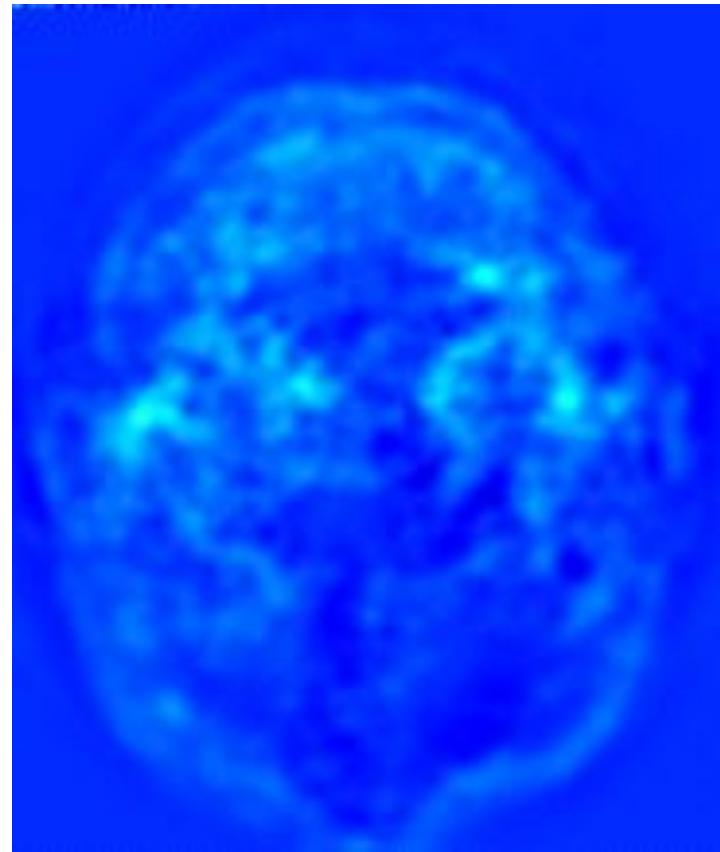
PET

- Positron emission tomography
- 3D



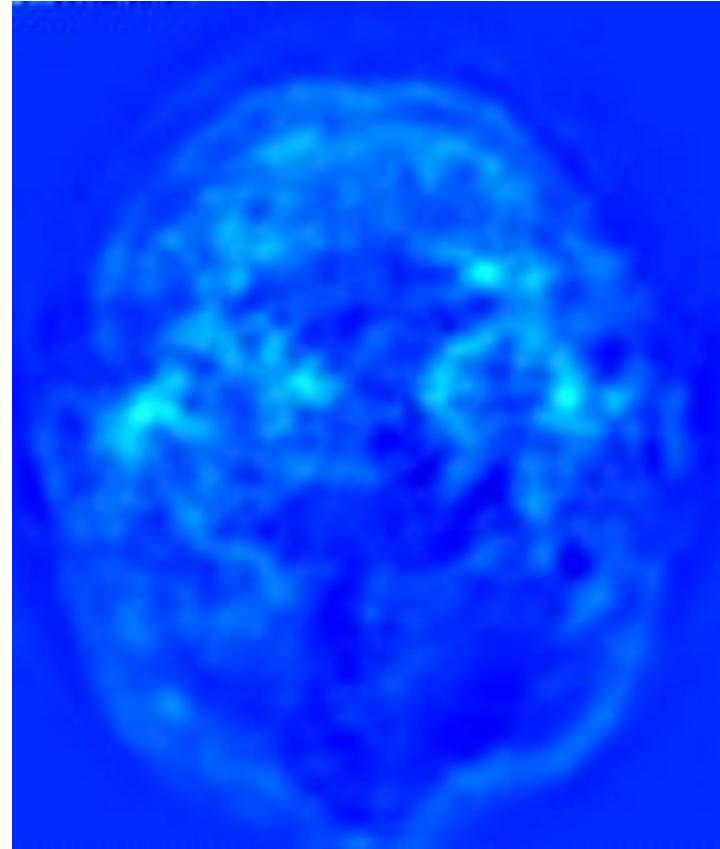
PET

- Positron emission tomography
- 3D
- Shows physiology, e.g.
 - metabolism
 - proteins
 - neurotransmitters



PET

- Positron emission tomography
- 3D
- Shows physiology, e.g.
 - metabolism
 - proteins
 - neurotransmitters
- Oncology (=cancer), heart & vessel, head/brain



Other modalities

Other modalities

- fMRI
- SPECT

Other modalities

- fMRI
- SPECT
- Mammography

Other modalities

- fMRI
- SPECT
- Mammography
- ...

Other modalities

- fMRI
- SPECT
- Mammography
- ...

Hot research topic: Convert one modality to another. Ideas?

Problems/topics in medical image analysis

Problems/topics in medical image analysis

- Detection
- Segmentation
- Registration
- Classification

Problems/topics in medical image analysis

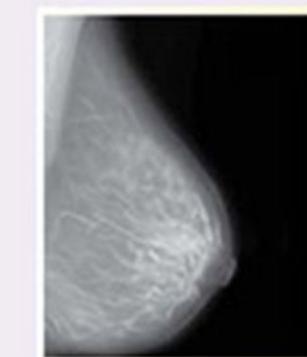
- **Detection**
- Segmentation
- Registration
- Classification

Detection



Detection

- Detect e.g.
 - tumours
 - lesions
 - hemorrhage
 - other pathologies



Detection

- Detect e.g.
 - tumours
 - lesions
 - hemorrhage
 - other pathologies
- Used in e.g. CAS = computer-aided diagnosis



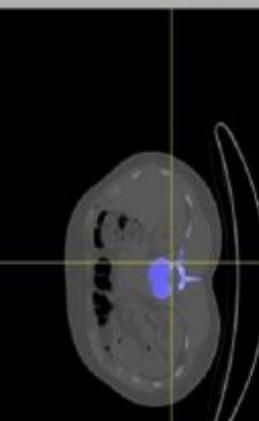
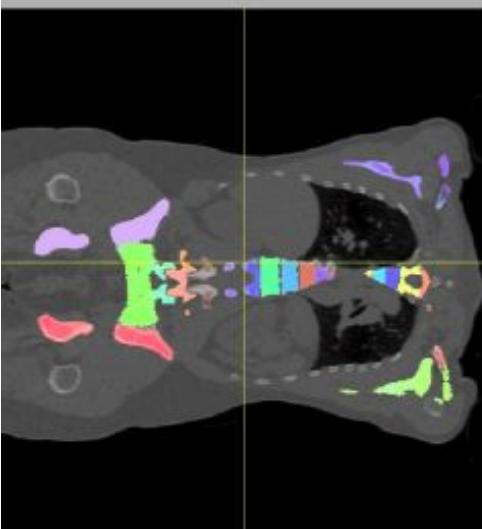
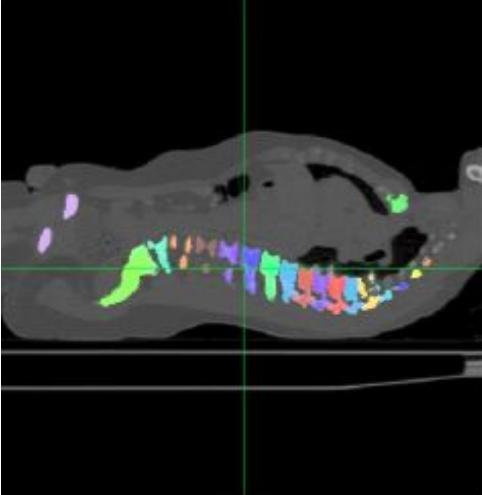
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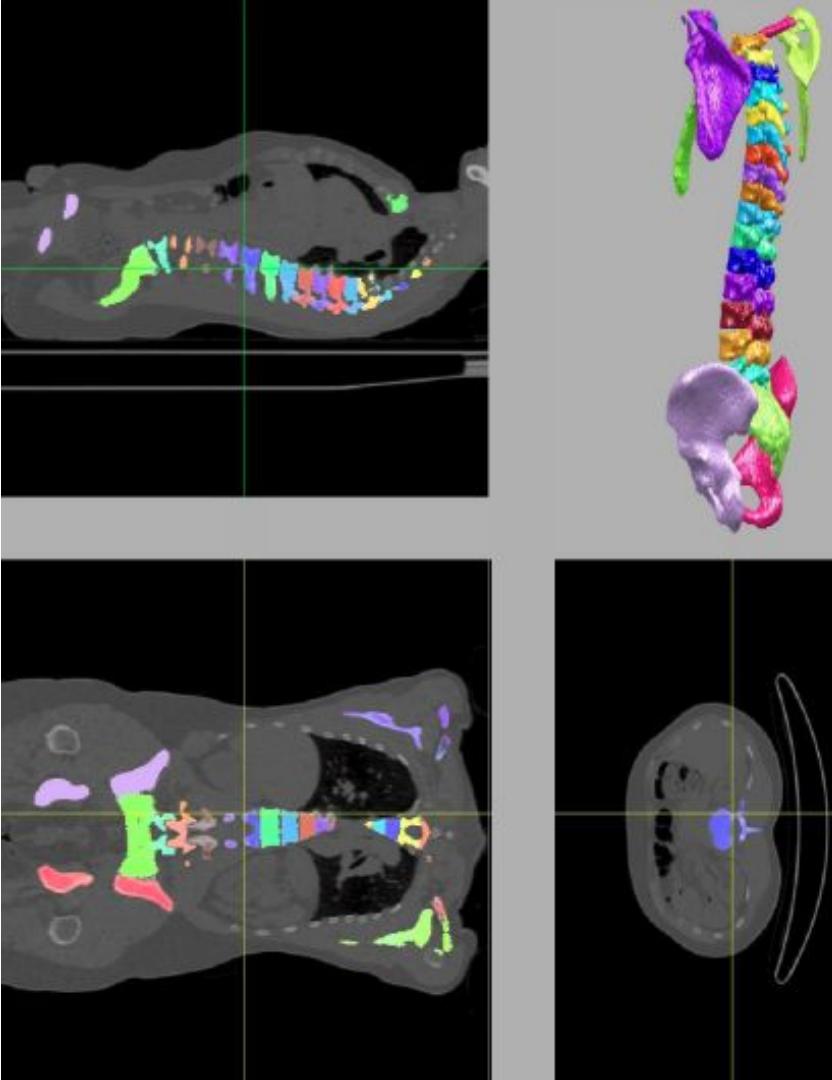
- Detection
- **Segmentation**
- Registration
- Classification

Segmentation



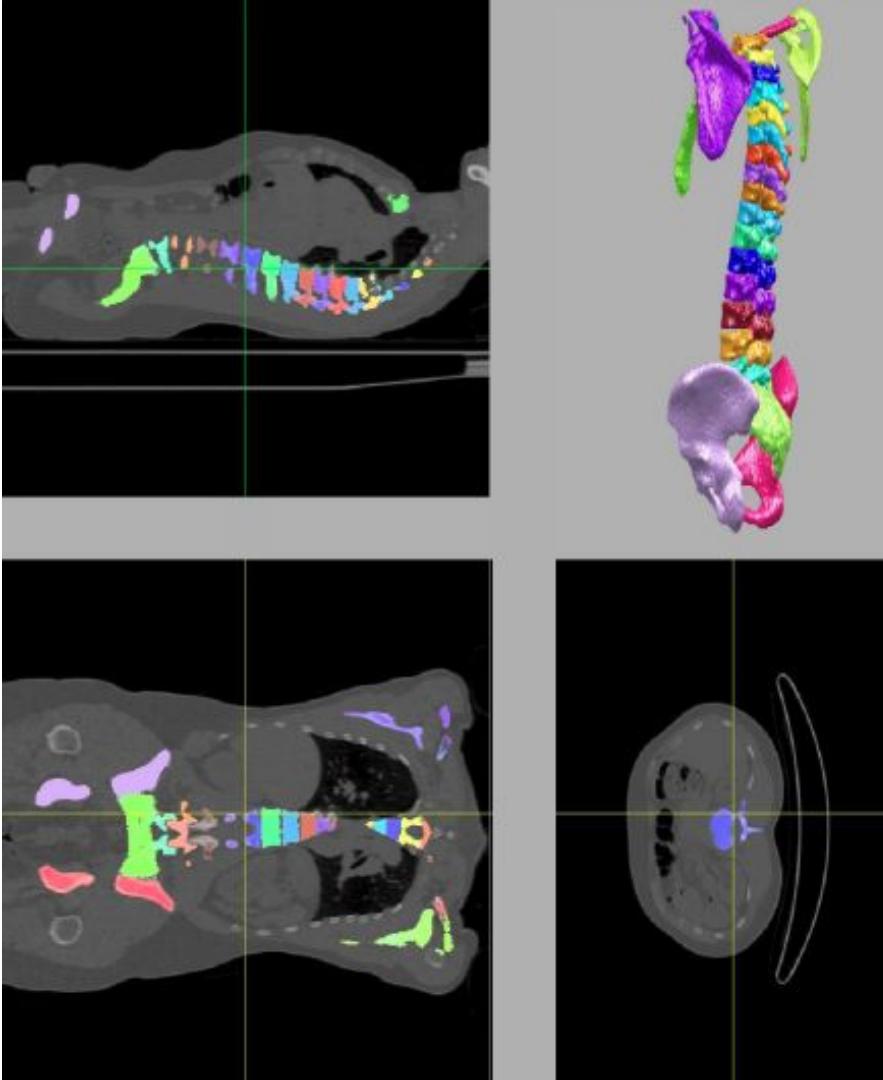
Segmentation

- Segment e.g.
 - organs
 - tumours
 - tissues



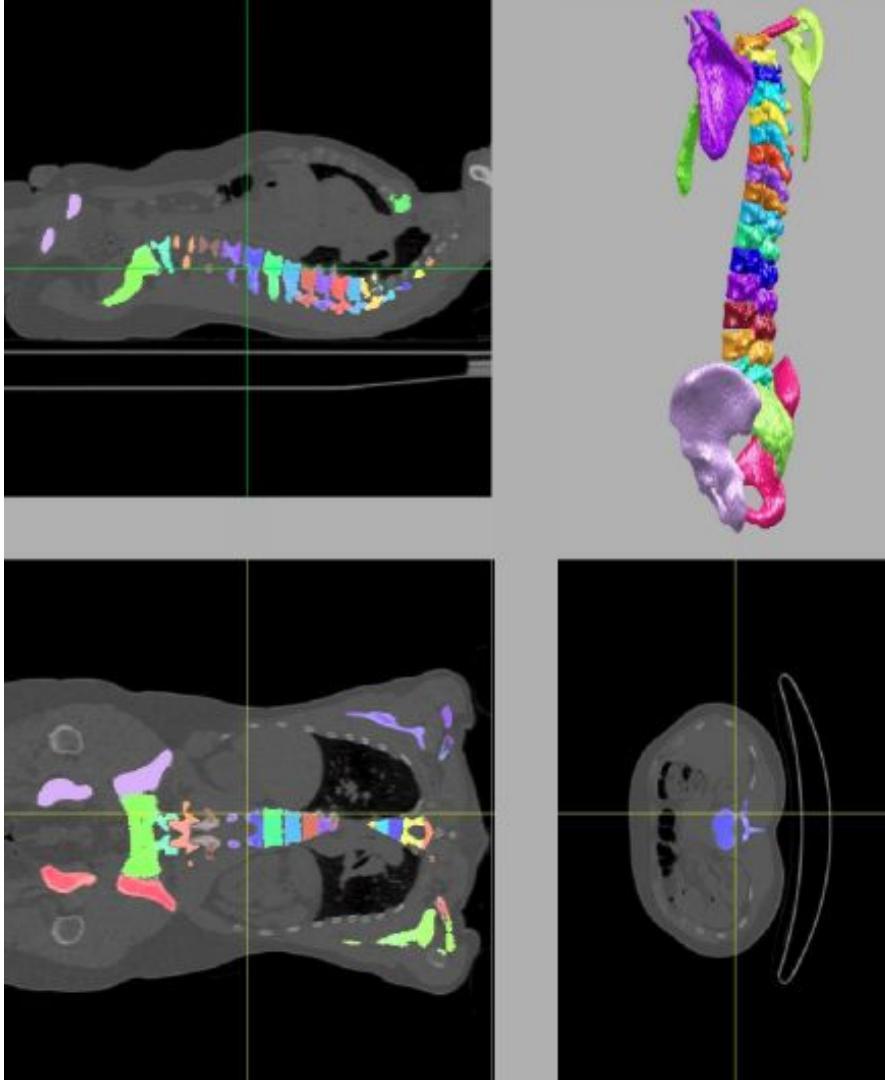
Segmentation

- Segment e.g.
 - organs
 - tumours
 - tissues
- Used in e.g.
 - CAD



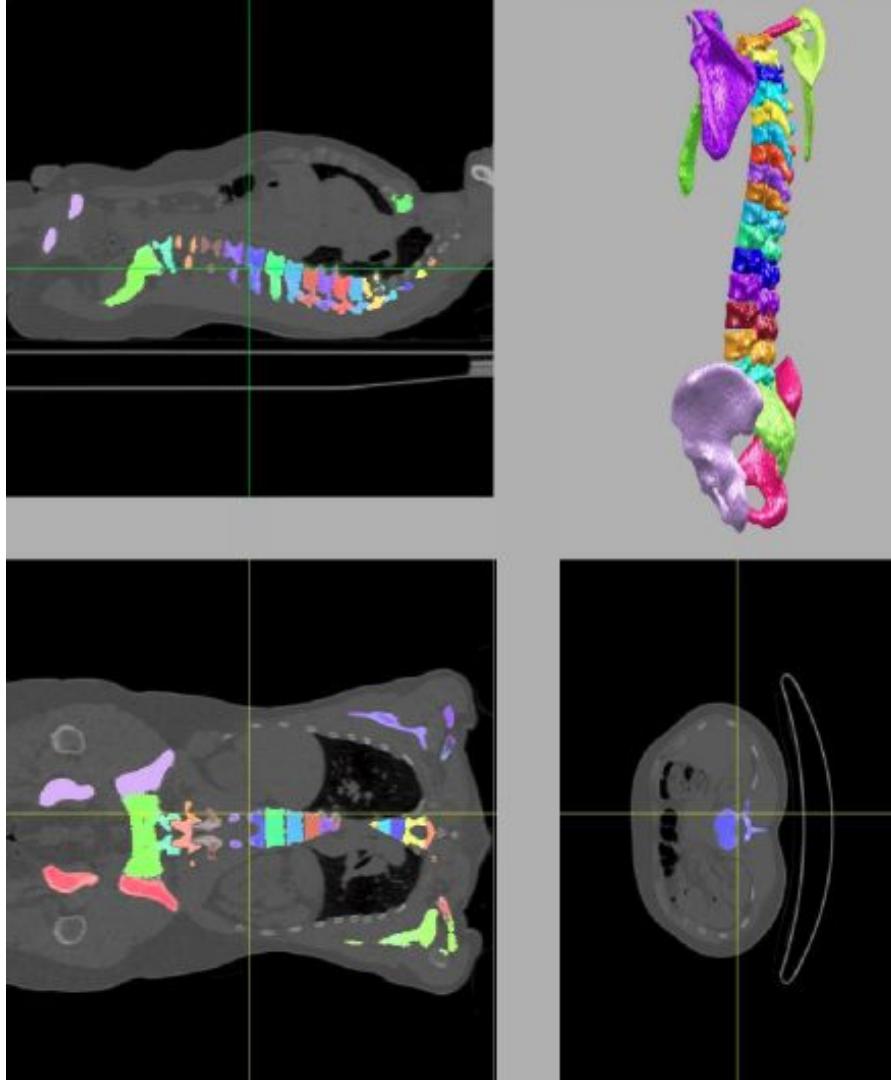
Segmentation

- Segment e.g.
 - organs
 - tumours
 - tissues
- Used in e.g.
 - CAD
 - radiotherapy planning



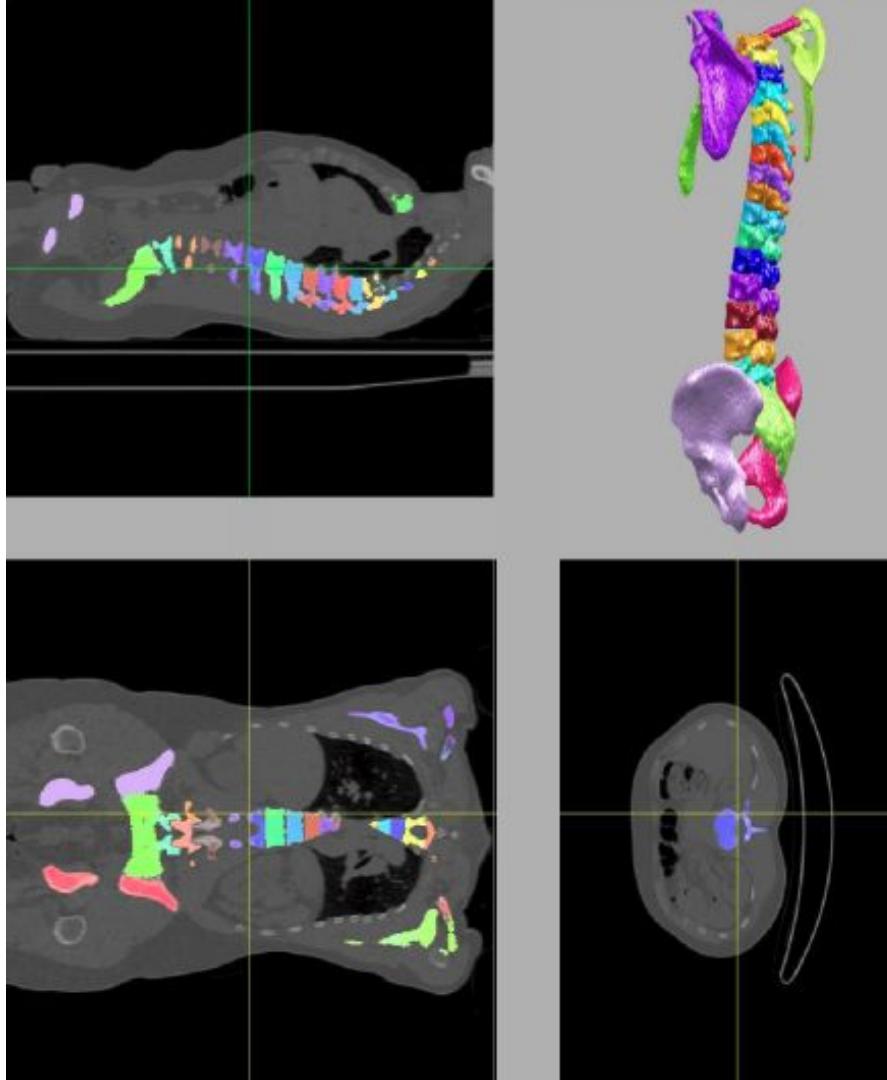
Segmentation

- Segment e.g.
 - organs
 - tumours
 - tissues
- Used in e.g.
 - CAD
 - radiotherapy planning
 - CAS = computer-aided surgery



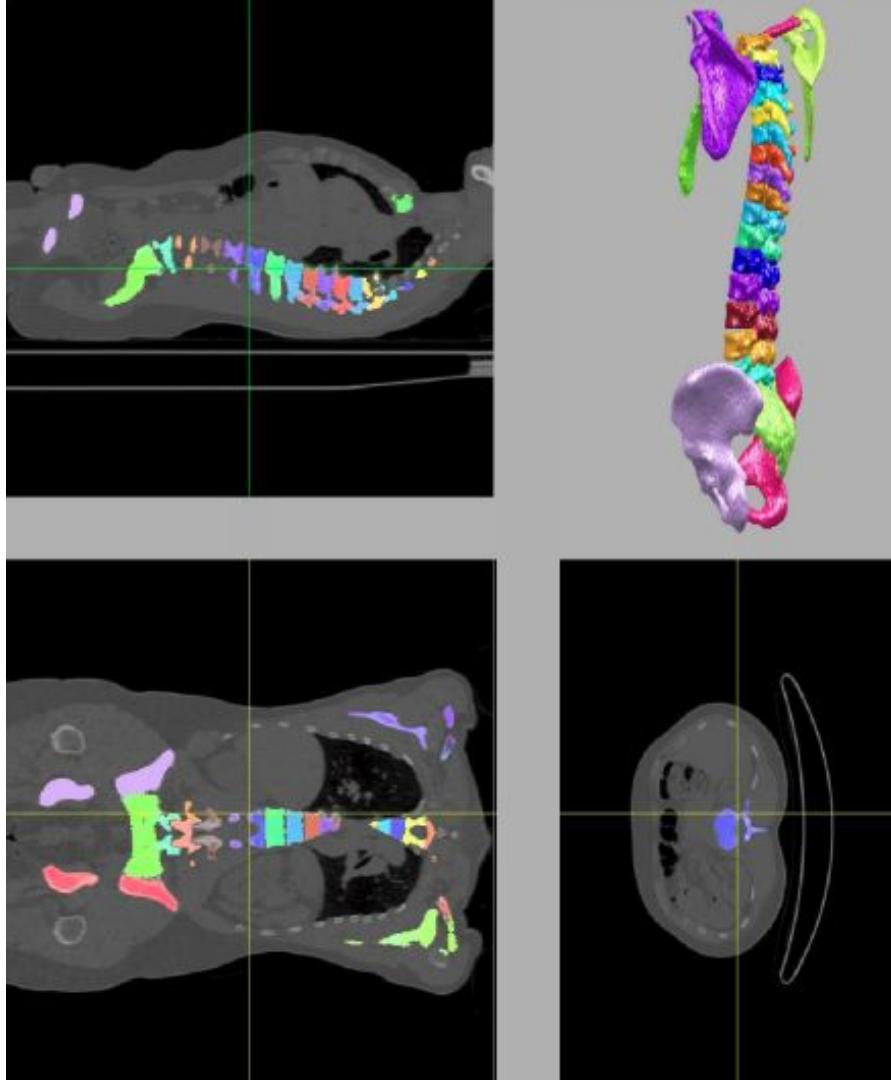
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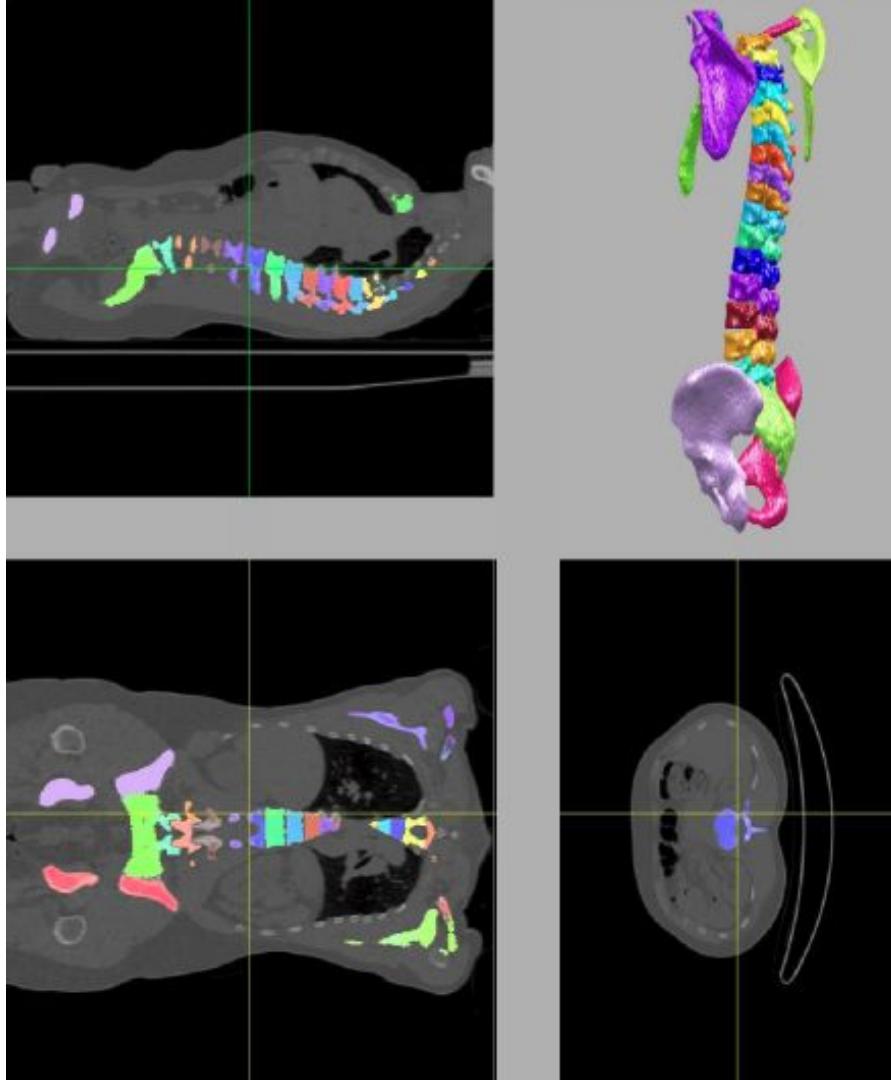
Segmentation

- Segment e.g.
 - organs
 - tumours
 - tissues
- Used in e.g.
 - CAD
 - radiotherapy planning
 - CAS = computer-aided surgery
 - surgery planning
 - virtual surgery simulation



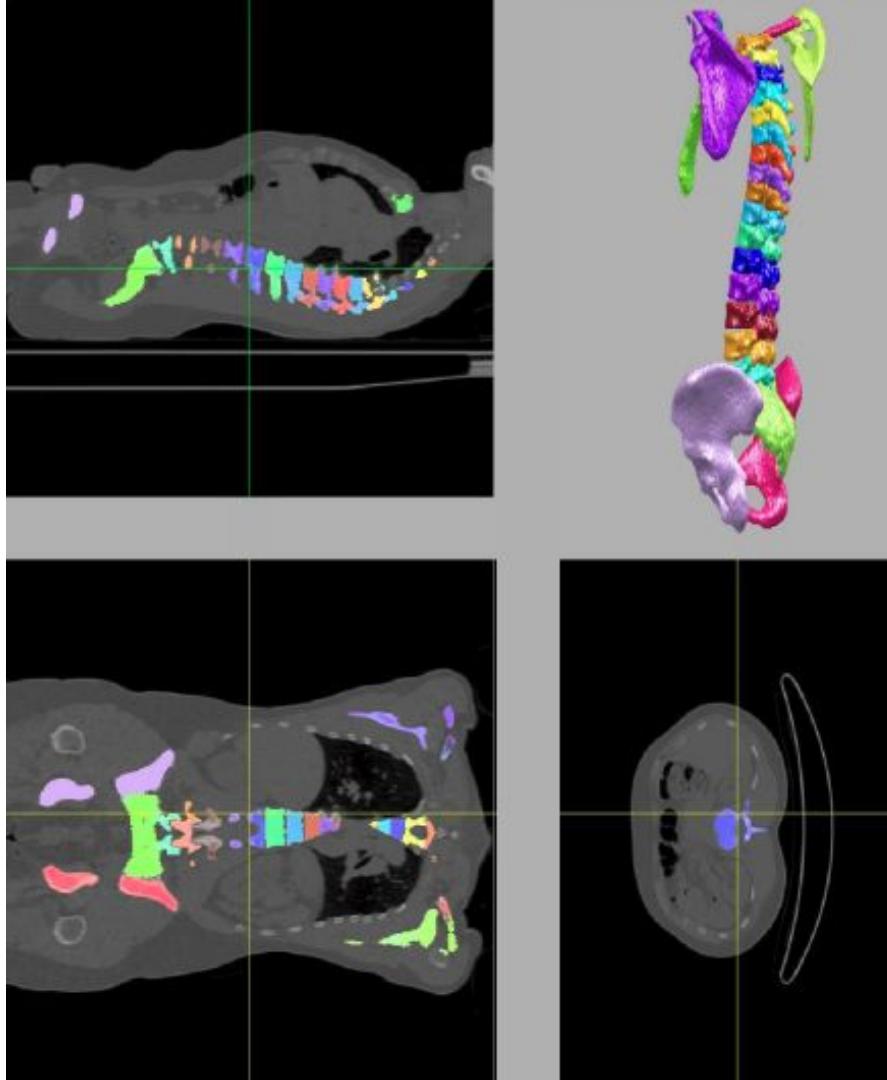
Segmentation

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 - organs
 - tumours
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- Used in e.g.
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 - radiotherapy planning
 - CAS = computer-aided surgery
 - surgery planning
 - virtual surgery simulation
 - intra-surgery navigation



Segmentation

- Segment e.g.
 - organs
 - tumours
 - tissues
- Used in e.g.
 - CAD
 - radiotherapy planning
 - CAS = computer-aided surgery
 - surgery planning
 - virtual surgery simulation
 - intra-surgery navigation
 - robotic surgery



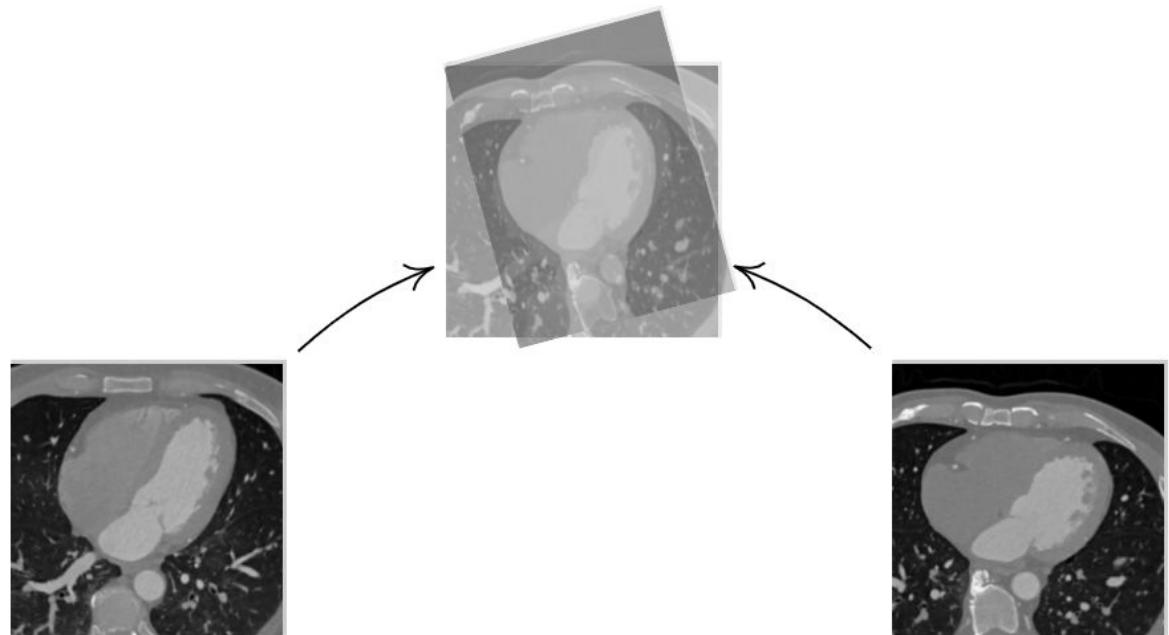
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- Detection
- **Segmentation**
- Registration
- Classification

Problems/topics in medical image analysis

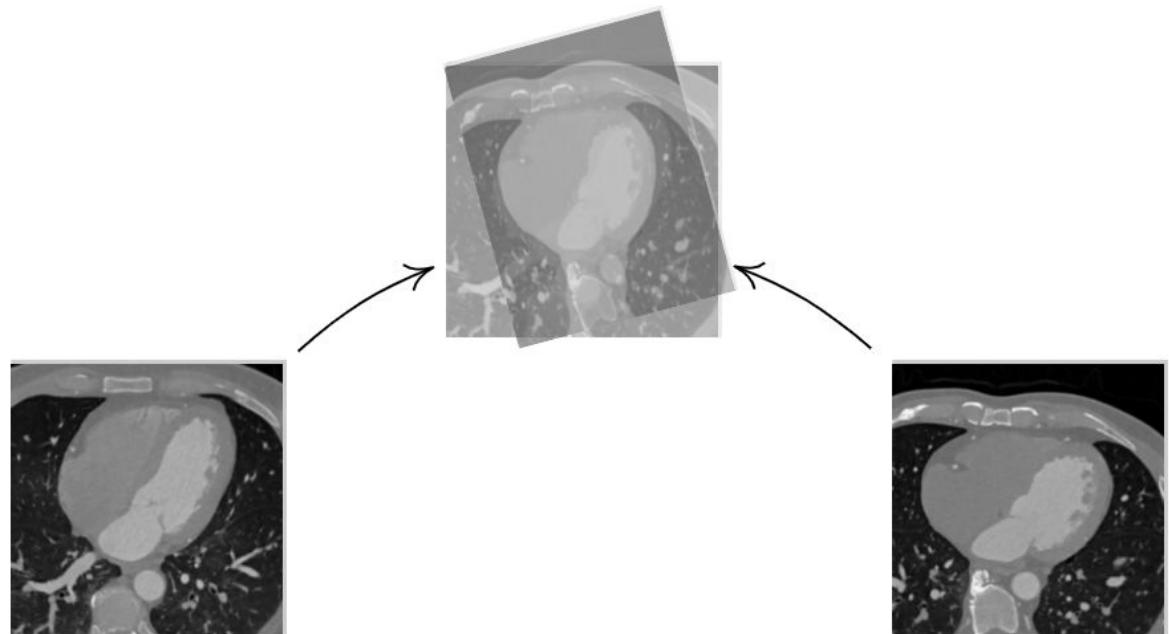
- Detection
- Segmentation
- **Registration**
- Classification

Registration



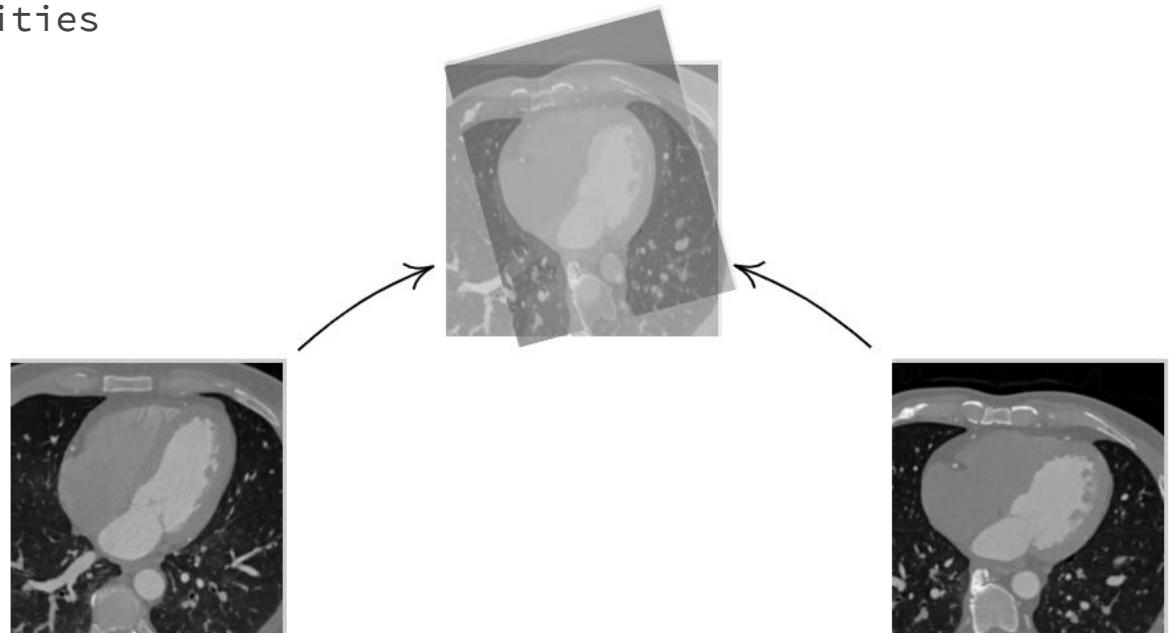
Registration

- Intra-patient, e.g.



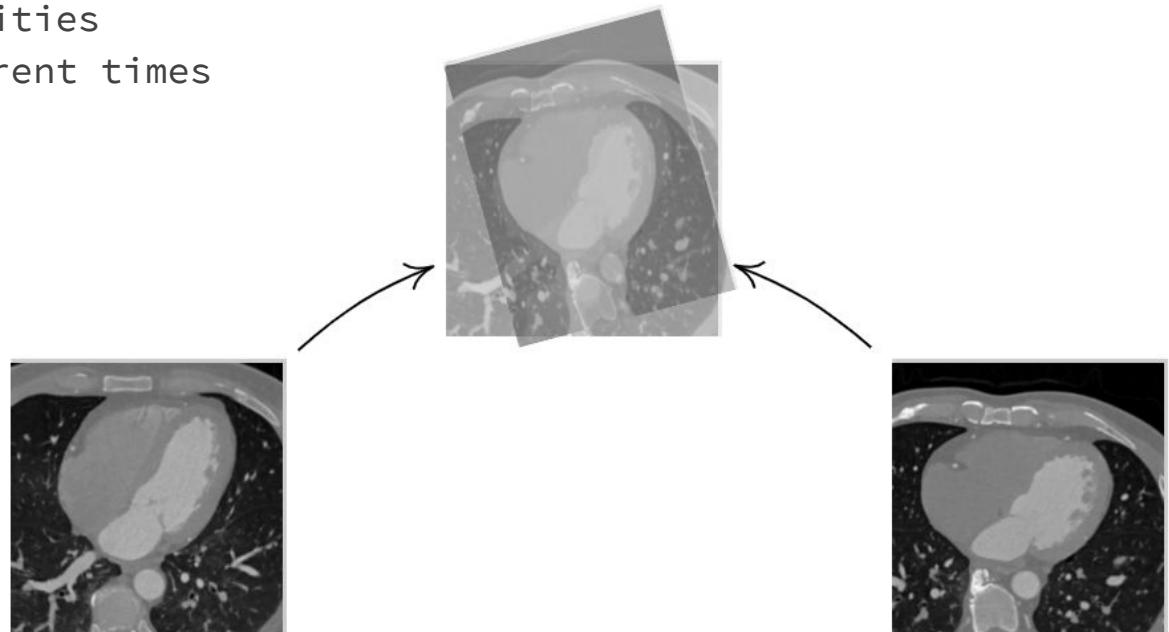
Registration

- Intra-patient, e.g.
 - map between modalities



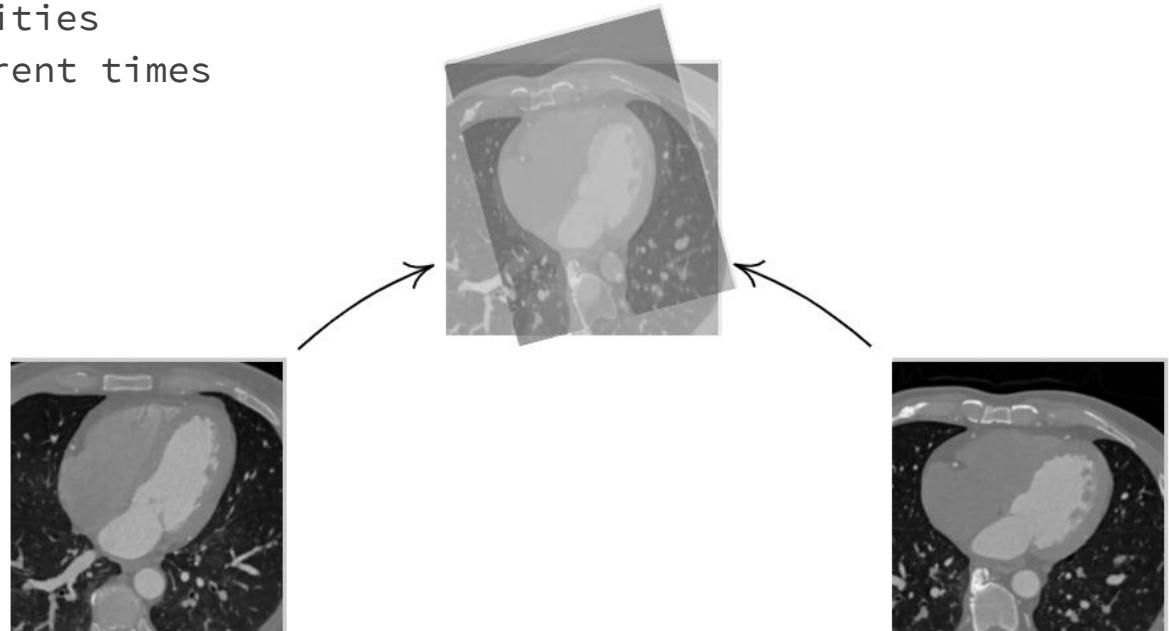
Registration

- Intra-patient, e.g.
 - map between modalities
 - map between different times



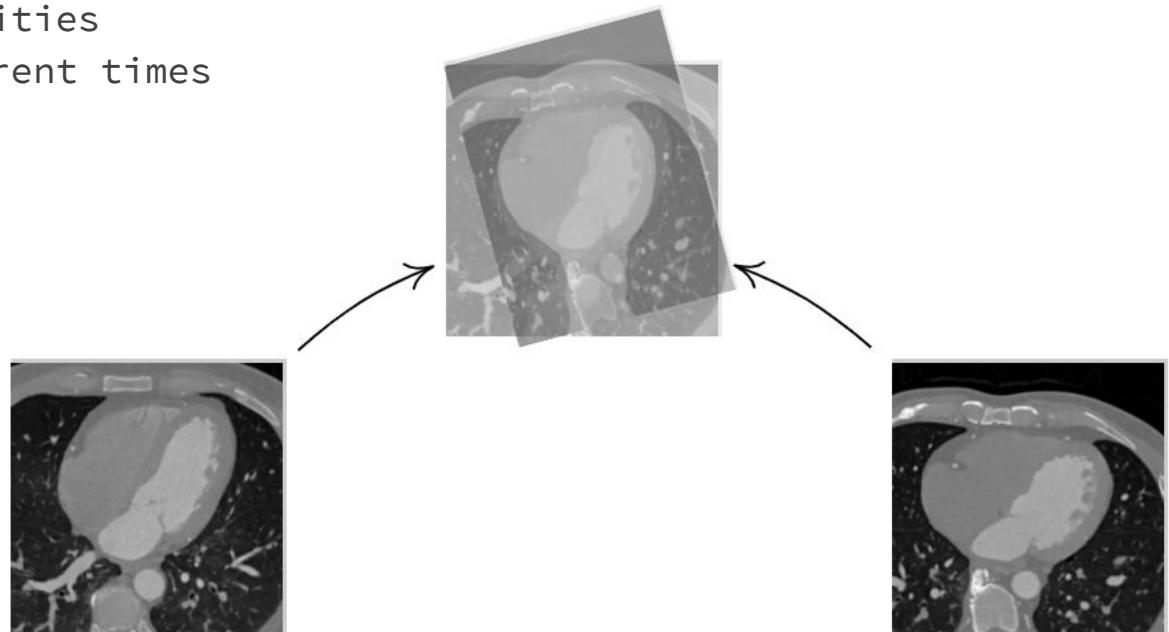
Registration

- Intra-patient, e.g.
 - map between modalities
 - map between different times
 - used in CAD & CAS



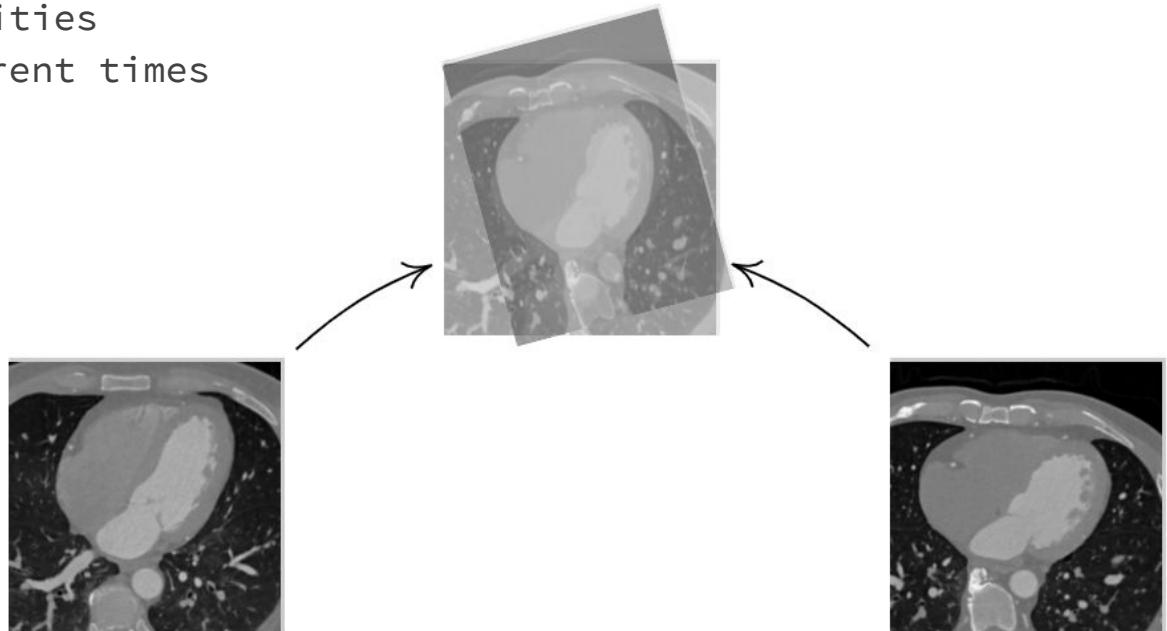
Registration

- Intra-patient, e.g.
 - map between modalities
 - map between different times
 - used in CAD & CAS
- Inter-patient, e.g.



Registration

- Intra-patient, e.g.
 - map between modalities
 - map between different times
 - used in CAD & CAS
- Inter-patient, e.g.
 - medical research



Problems/topics in medical image analysis

- Detection
- Segmentation
- **Registration**
- Classification

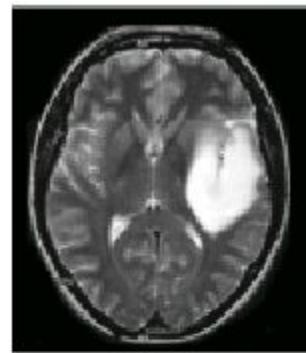
Problems/topics in medical image analysis

- Detection
- Segmentation
- Registration
- **Classification**

Classification



(a) Normal



(b) Benign



(c) Malignant



Normal: 0.9
True: Normal



Normal: 1.0
True: Normal



Normal: 1.0
True: Normal



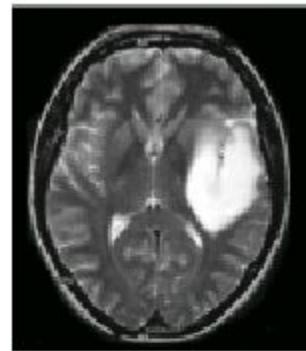
Abnormal: 1.0
True: Abnormal

Classification

- Image-wise, e.g.
 - is the patient sick?



(a) Normal



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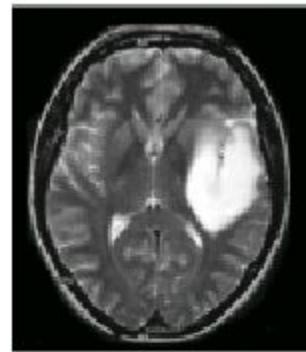
Abnormal: 1.0
True: Abnormal

Classification

- Image-wise, e.g.
 - is the patient sick?
- Pixel-wise, e.g.
 - what tissue class?
 - what organ?
 - healthy or pathological?



(a) Normal



(b) Benign



(c) Malignant



Normal: 0.9
True: Normal



Normal: 1.0
True: Normal



Normal: 1.0
True: Normal



Abnormal: 1.0
True: Abnormal

Problems/topics in medical image analysis

- Detection
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- **Classification**

Problems/topics in medical image analysis

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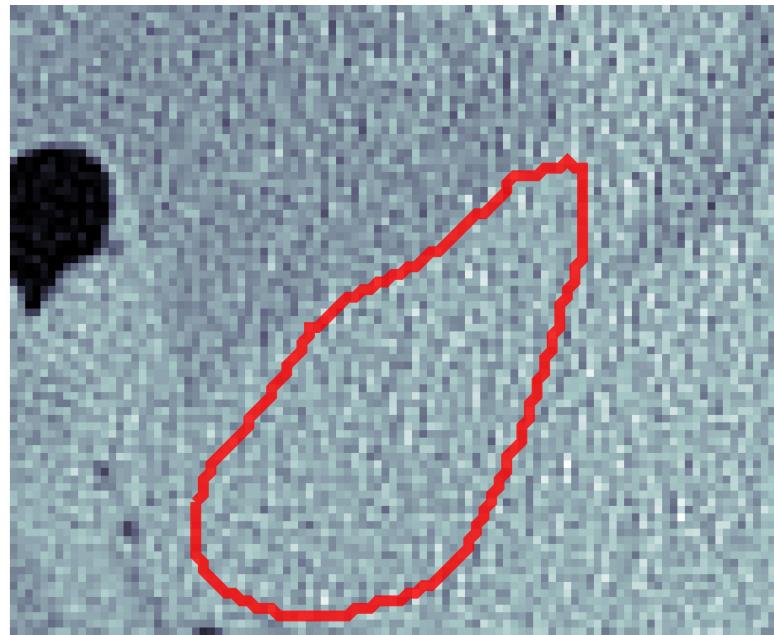
What makes medical image analysis hard?

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- 3D = needs more computational power:
 - more memory
 - longer running times

What makes medical image analysis hard?

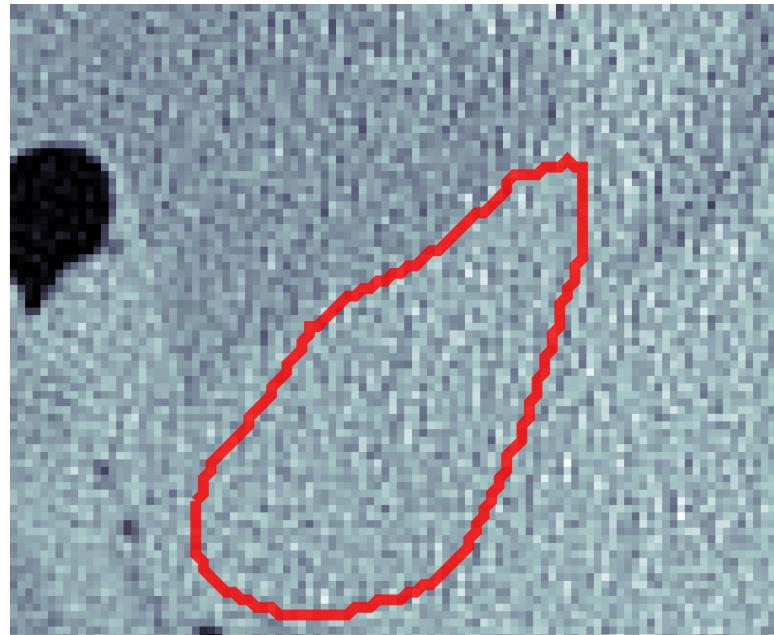
- 3D = needs more computational power:
 - more memory
 - longer running times
- Low contrast details
- Moderate to high-level of noise
- Inter- and intra-patient variability



— Gallbladder

What makes medical image analysis hard?

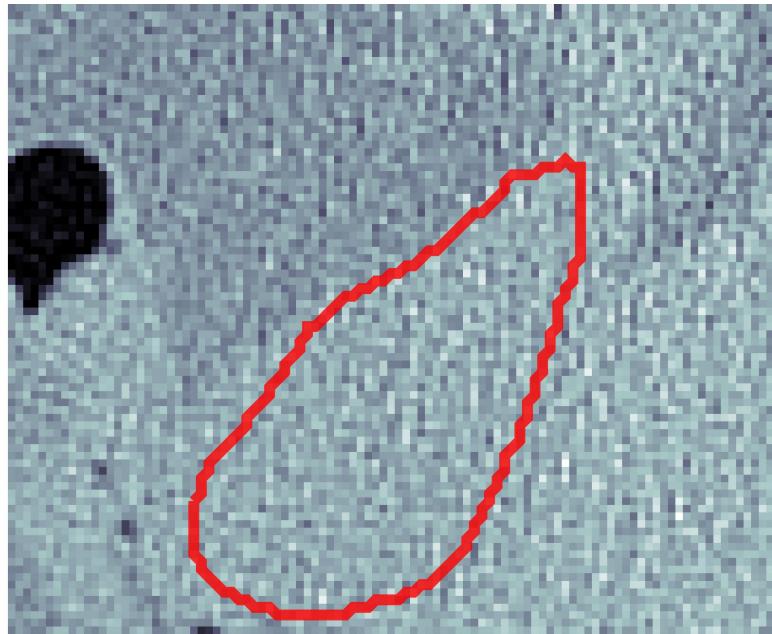
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- Low contrast details
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- Inter- and intra-patient variability
- Motion artifacts
- Partial volume effects



— Gallbladder

What makes medical image analysis hard?

- 3D = needs more computational power:
 - more memory
 - longer running times
- Low contrast details
- Moderate to high-level of noise
- Inter- and intra-patient variability
- Motion artifacts
- Partial volume effects
- **Lack of data**



— Gallbladder

Deep learning in medical image analysis

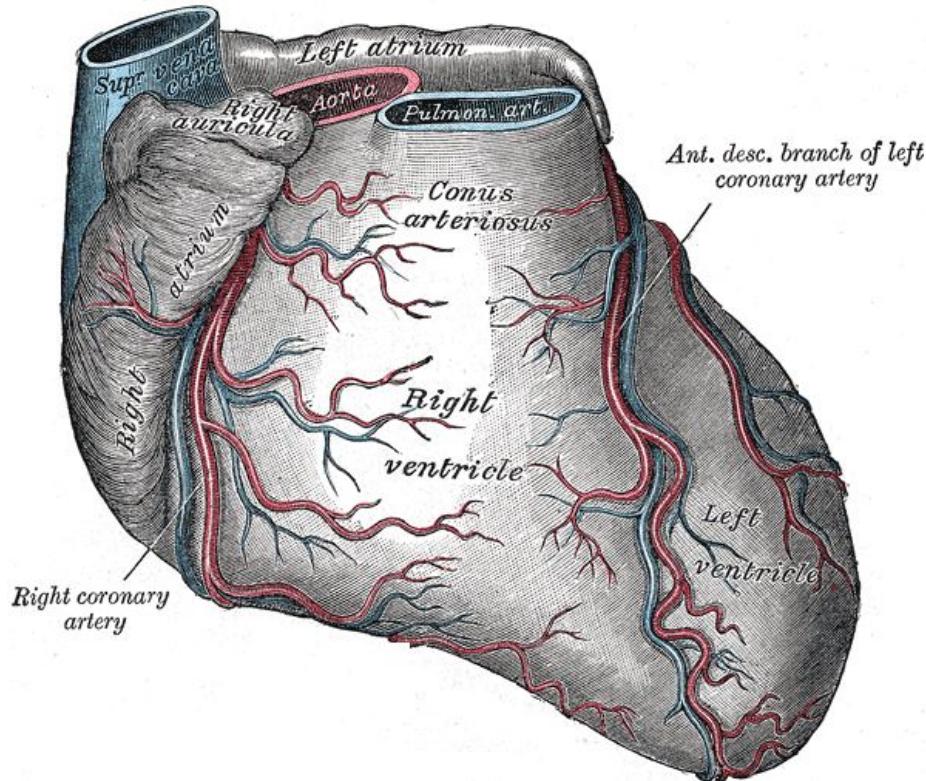
Problems/topics in medical image analysis

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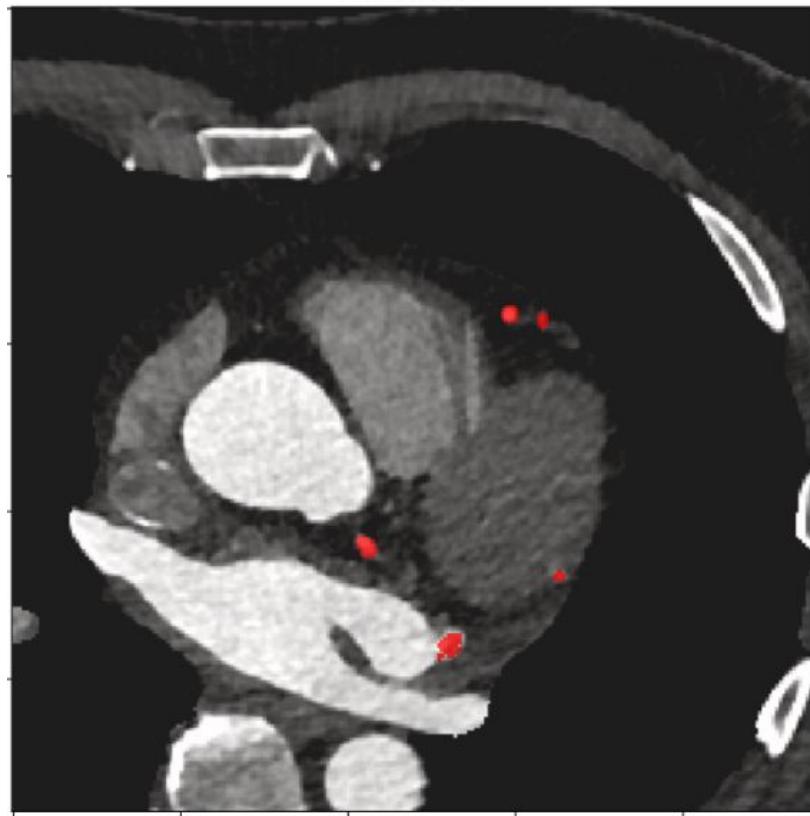
Problems/topics in medical image analysis

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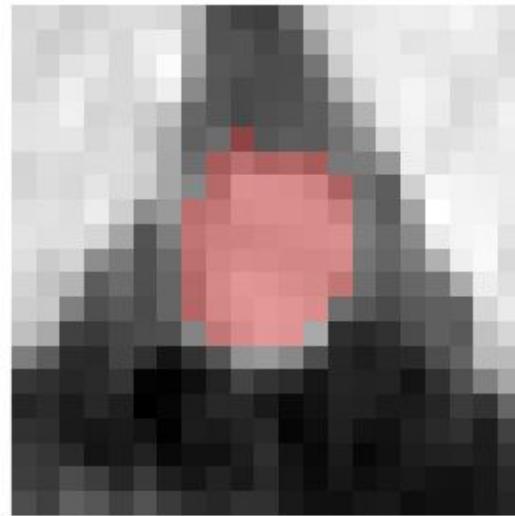
Coronary artery segmentation (+ stenosis detection?)



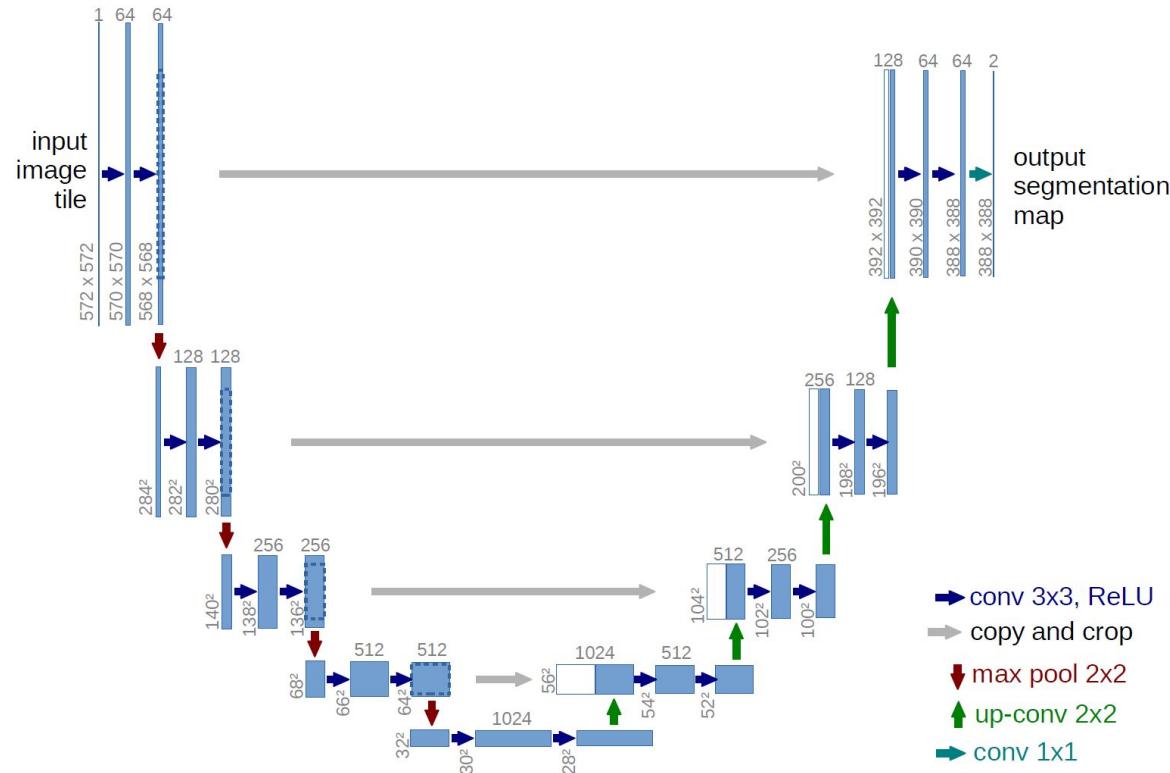
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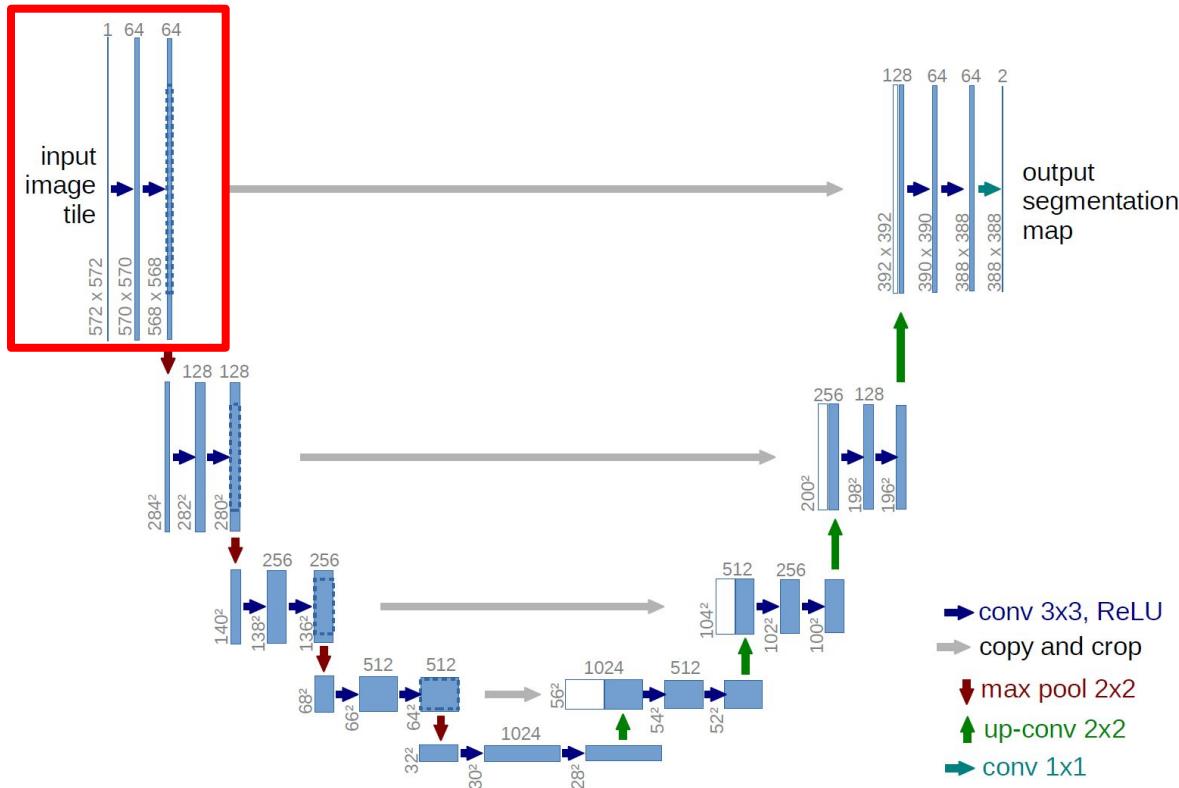
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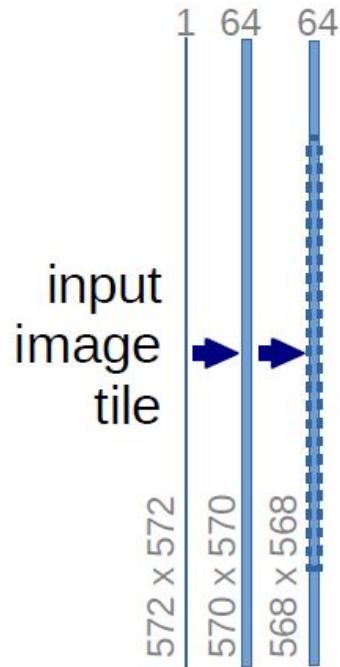
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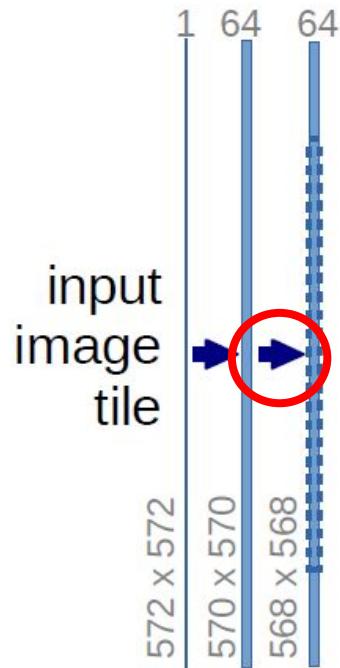
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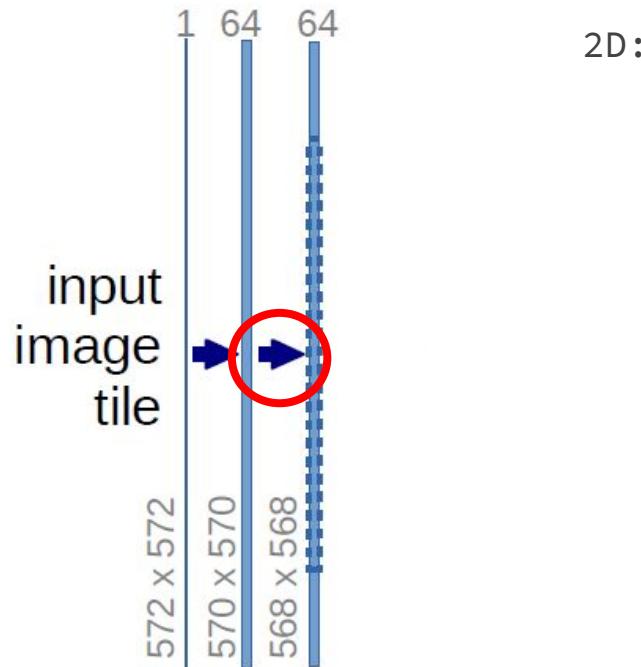
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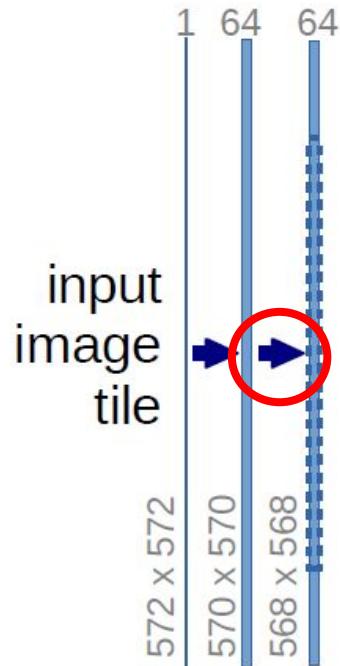
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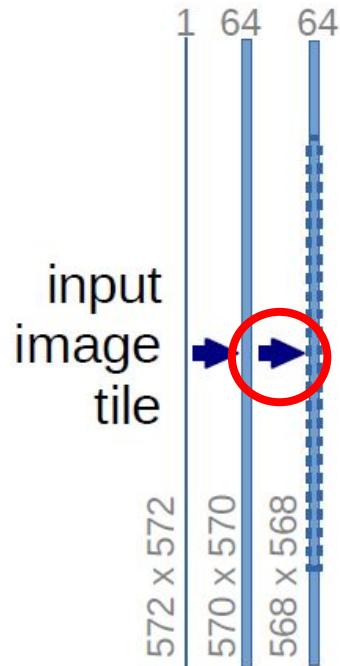
Coronary artery segmentation (+ stenosis detection?)



2D:

- Filter size: $3 \times 3 \times 64$ = 576

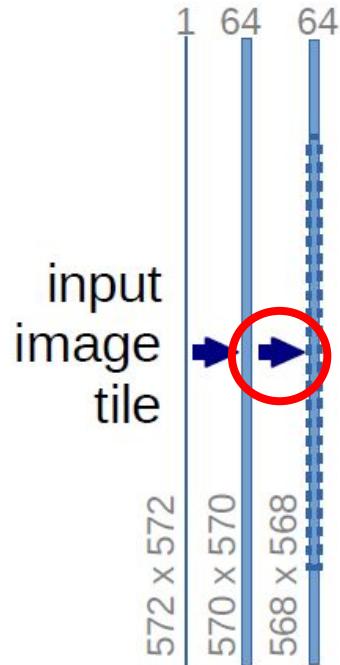
Coronary artery segmentation (+ stenosis detection?)



2D:

- Filter size: $3 \times 3 \times 64$ = 576
- # Parameters: 576×64 = 36864

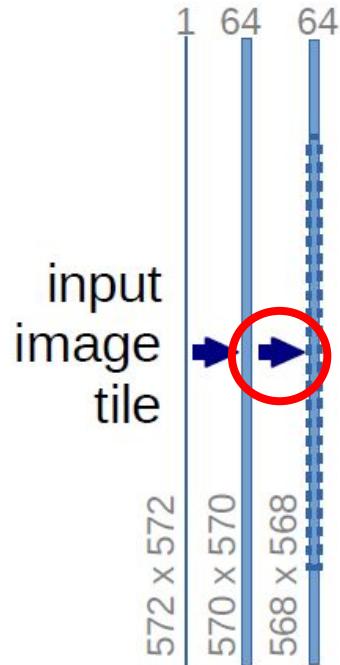
Coronary artery segmentation (+ stenosis detection?)



2D:

- Filter size: $3 \times 3 \times 64$ = 576
- # Parameters: 576×64 = 36864
- Image size: 572×572 = 327184

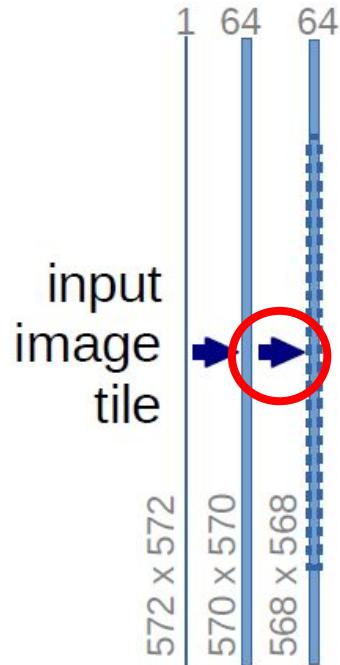
Coronary artery segmentation (+ stenosis detection?)



2D:

- Filter size: $3 \times 3 \times 64 = 576$
- # Parameters: $576 \times 64 = 36864$
- Image size: $572 \times 572 = 327184$
- # Computations: $327184 \times 36864 \approx 12 \times 10^9$

Coronary artery segmentation (+ stenosis detection?)

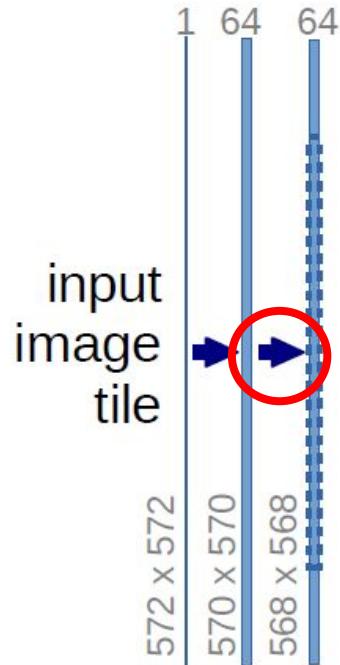


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3D:

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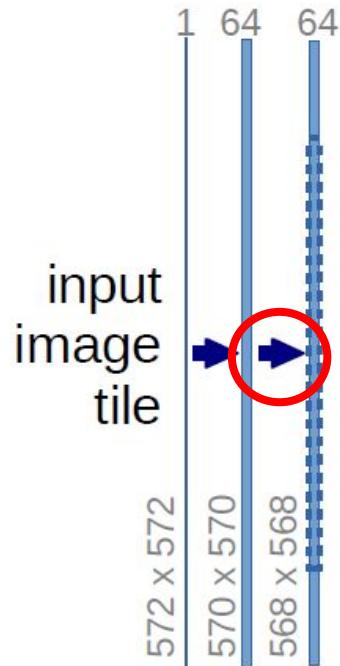
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- # Parameters: 576×64 = 36864
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3D:

- Filter size: $3 \times 3 \times 3 \times 64$ = 1728

Coronary artery segmentation (+ stenosis detection?)



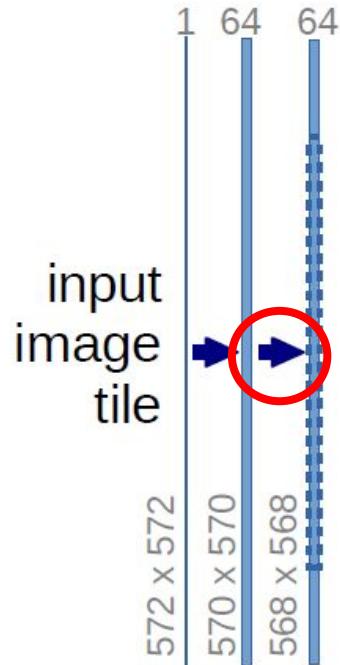
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- # Computations: $327184 \times 36864 \approx 12 \times 10^9$

3D:

- Filter size: $3 \times 3 \times 3 \times 64$ = 1728
- # Parameters: 1728×64 = 110592

Coronary artery segmentation (+ stenosis detection?)



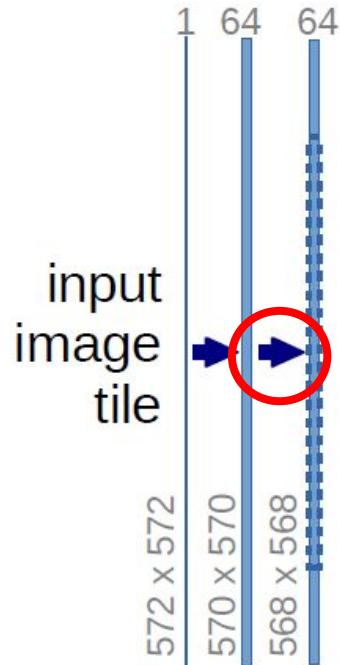
2D:

- Filter size: $3 \times 3 \times 64$ = 576
- # Parameters: 576×64 = 36864
- Image size: 572×572 = 327184
- # Computations: $327184 \times 36864 \approx 12 \times 10^9$

3D:

- Filter size: $3 \times 3 \times 3 \times 64$ = 1728
- # Parameters: 1728×64 = 110592
- Image size: $572 \times 572 \times 572 \approx 187 \times 10^6$

Coronary artery segmentation (+ stenosis detection?)



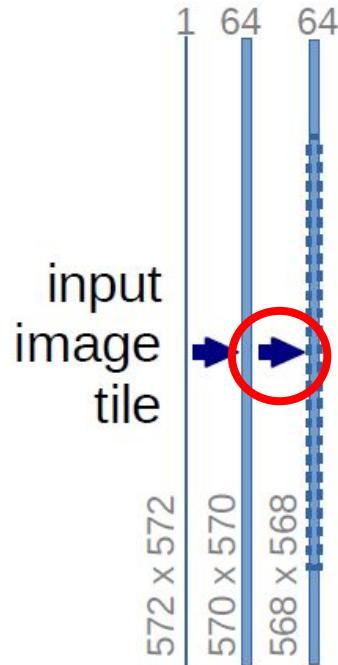
2D:

- Filter size: $3 \times 3 \times 64$ = 576
- # Parameters: 576×64 = 36864
- Image size: 572×572 = 327184
- # Computations: $327184 \times 36864 \approx 12 \times 10^9$

3D:

- Filter size: $3 \times 3 \times 3 \times 64$ = 1728
- # Parameters: 1728×64 = 110592
- Image size: $572 \times 572 \times 572 \approx 187 \times 10^6$
- # Computations: $12 \times 10^6 \times 110592 \approx 20 \times 10^{12} \dots$

Coronary artery segmentation (+ stenosis detection?)



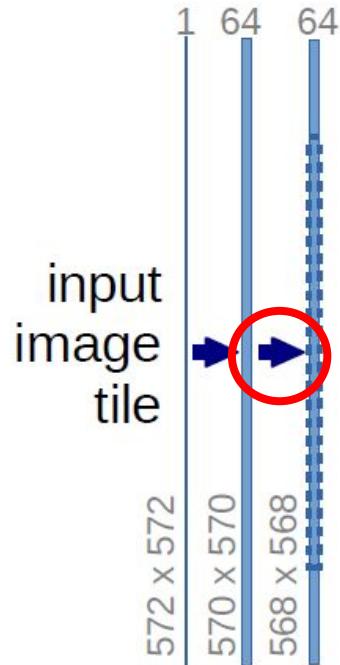
2D:

- Filter size: $3 \times 3 \times 64$ = 576
- # Parameters: 576×64 = 36864
- Image size: 572×572 = 327184
- # Computations: $327184 \times 36864 \approx 12 \times 10^9$

3D:

- Filter size: $3 \times 3 \times 3 \times 64$ = 1728
- # Parameters: 1728×64 = 110592
- Image size: $572 \times 572 \times 572$ $\approx 187 \times 10^6$
- **# Computations:** $12 \times 10^9 \times 110592 \approx 20 \times 10^{12} \dots$

Coronary artery segmentation (+ stenosis detection?)



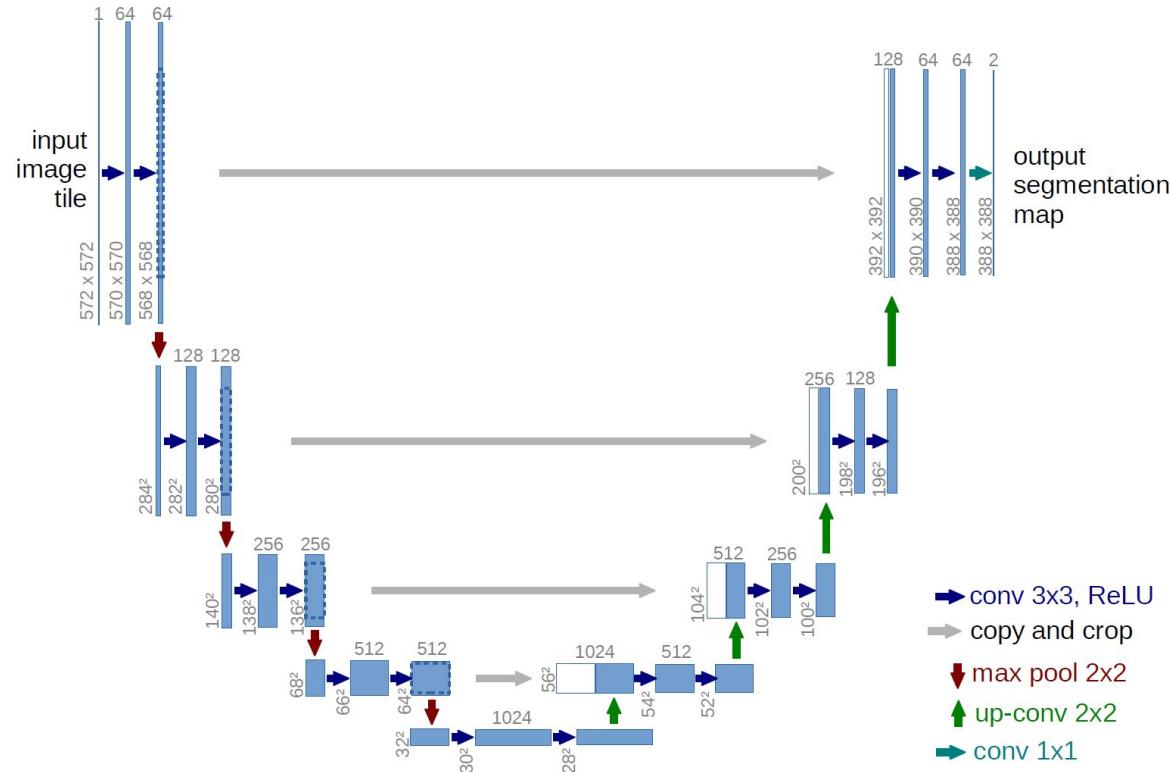
2D:

- Filter size: $3 \times 3 \times 64$ = 576
- # Parameters: 576×64 = 36864
- Image size: 572×572 = 327184
- # Computations: $327184 \times 36864 \approx 12 \times 10^9$

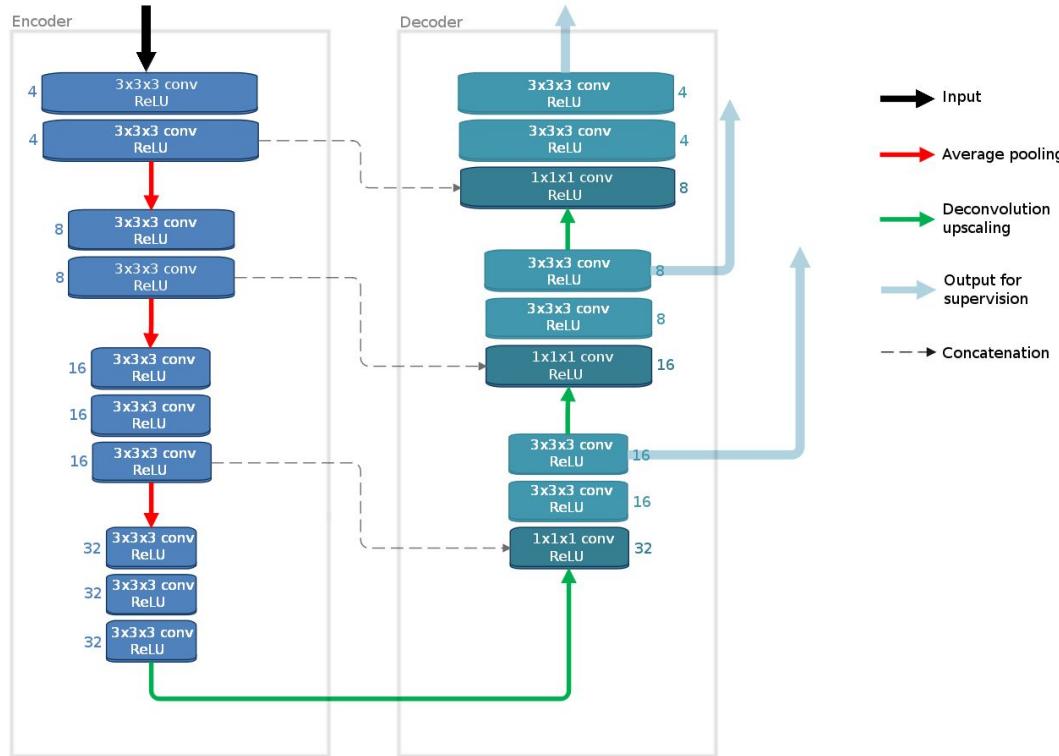
3D:

- Filter size: $3 \times 3 \times 3 \times 64$ = 1728
- **# Parameters:** 1728×64 = **110592**
- Image size: $572 \times 572 \times 572 \approx 187 \times 10^6$
- # Computations: $12 \times 10^6 \times 110592 \approx 20 \times 10^{12} \dots$

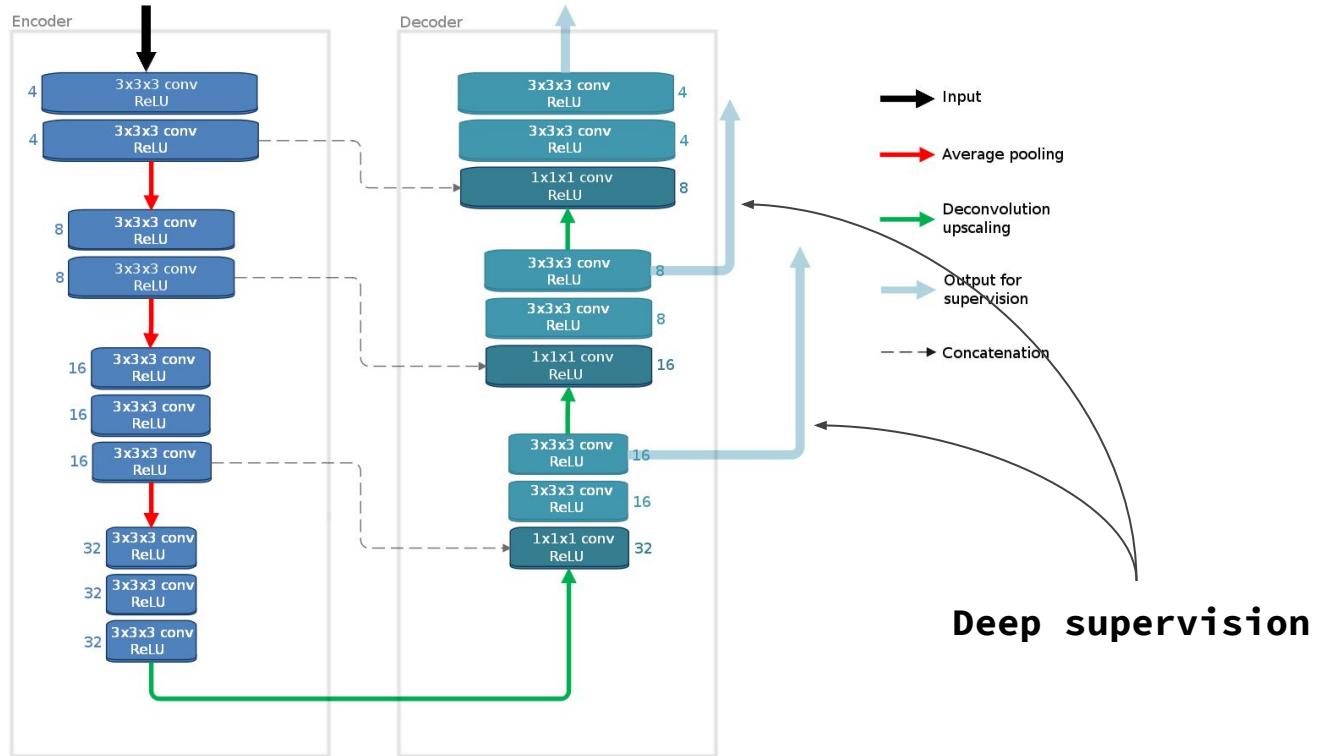
Coronary artery segmentation (+ stenosis detection?)



Coronary artery segmentation (+ stenosis detection?)



Coronary artery segmentation (+ stenosis detection?)



Coronary artery segmentation (+ stenosis detection?)

Deep supervision:

Coronary artery segmentation (+ stenosis detection?)

Deep supervision:

- Improves accuracy

Coronary artery segmentation (+ stenosis detection?)

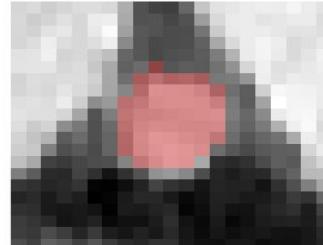
Deep supervision:

- Improves accuracy
- Speeds-up training (i.e. convergence)

Coronary artery segmentation (+ stenosis detection?)

Deep supervision:

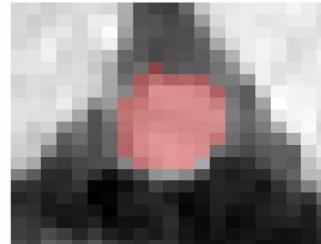
- Improves accuracy
- Speeds-up training (i.e. convergence)
- Beneficial for small-scale structures



Coronary artery segmentation (+ stenosis detection?)

Deep supervision:

- Improves accuracy
- Speeds-up training (i.e. convergence)
- Beneficial for small-scale structures
- Helps enforcing tree-structure



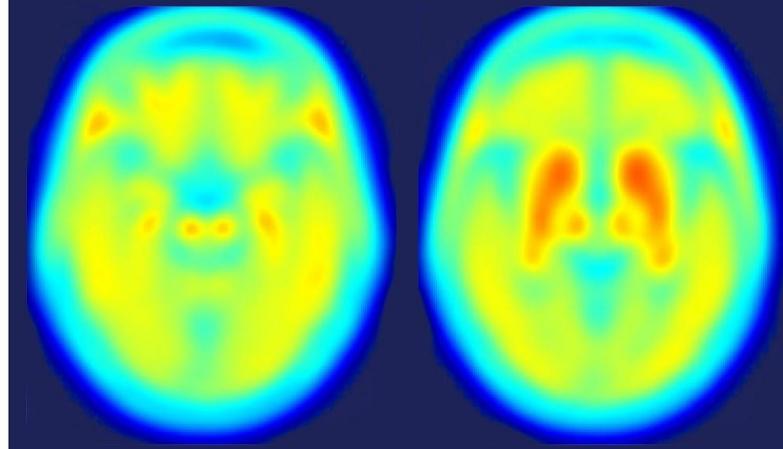
Problems/topics in medical image analysis

- **Detection**
- **Segmentation**
- Registration
- Classification

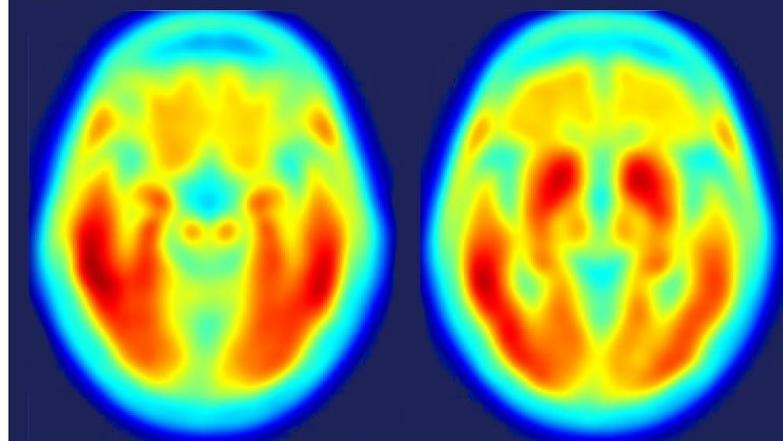
Problems/topics in medical image analysis

- Detection
- Segmentation
- **Registration**
- Classification

Tau PET registration

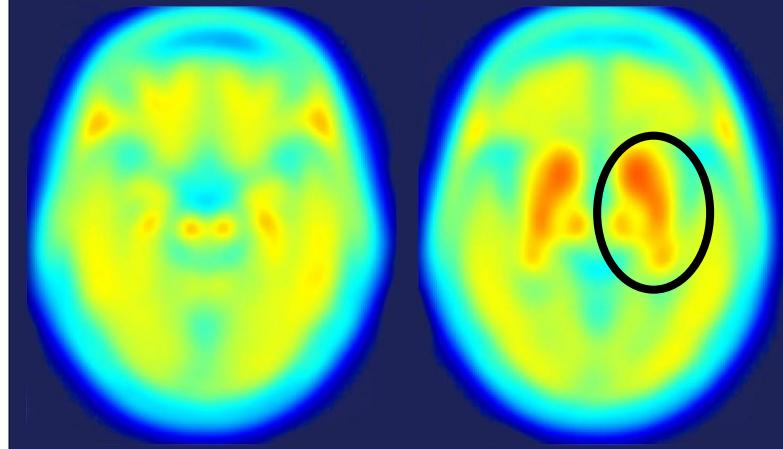


HEALTHY TAU

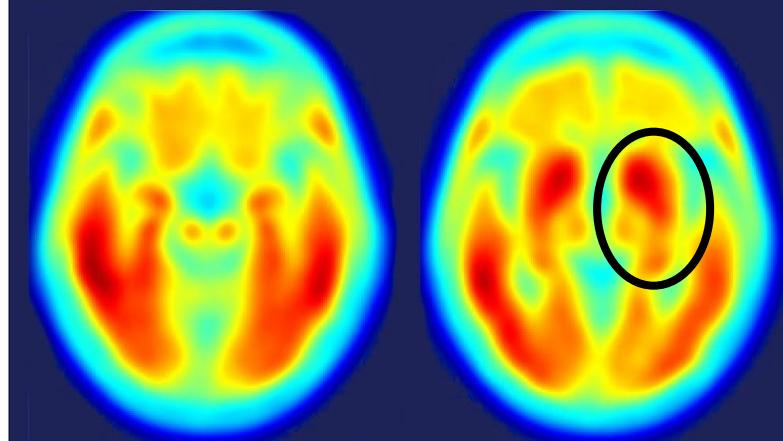


ALZHEIMER'S TAU

Tau PET registration

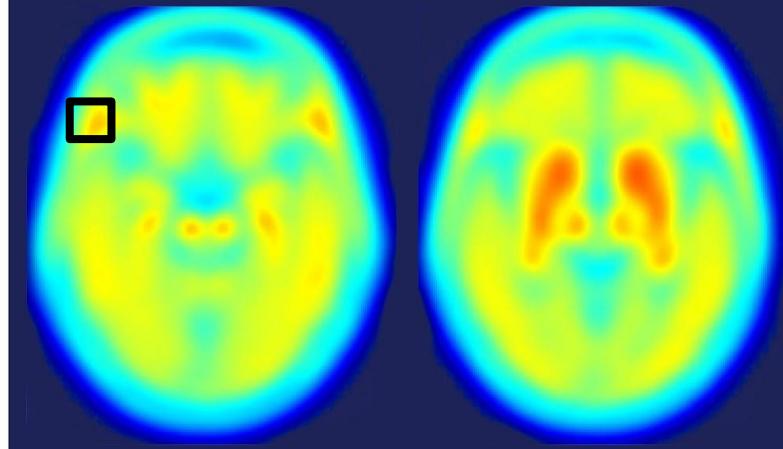


HEALTHY TAU

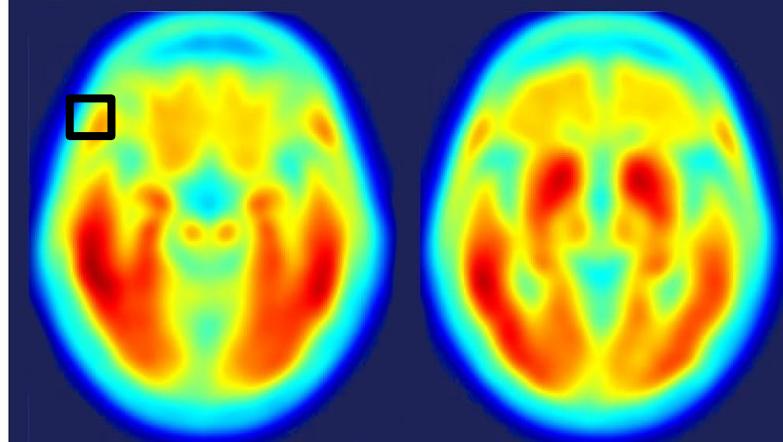


ALZHEIMER'S TAU

Tau PET registration

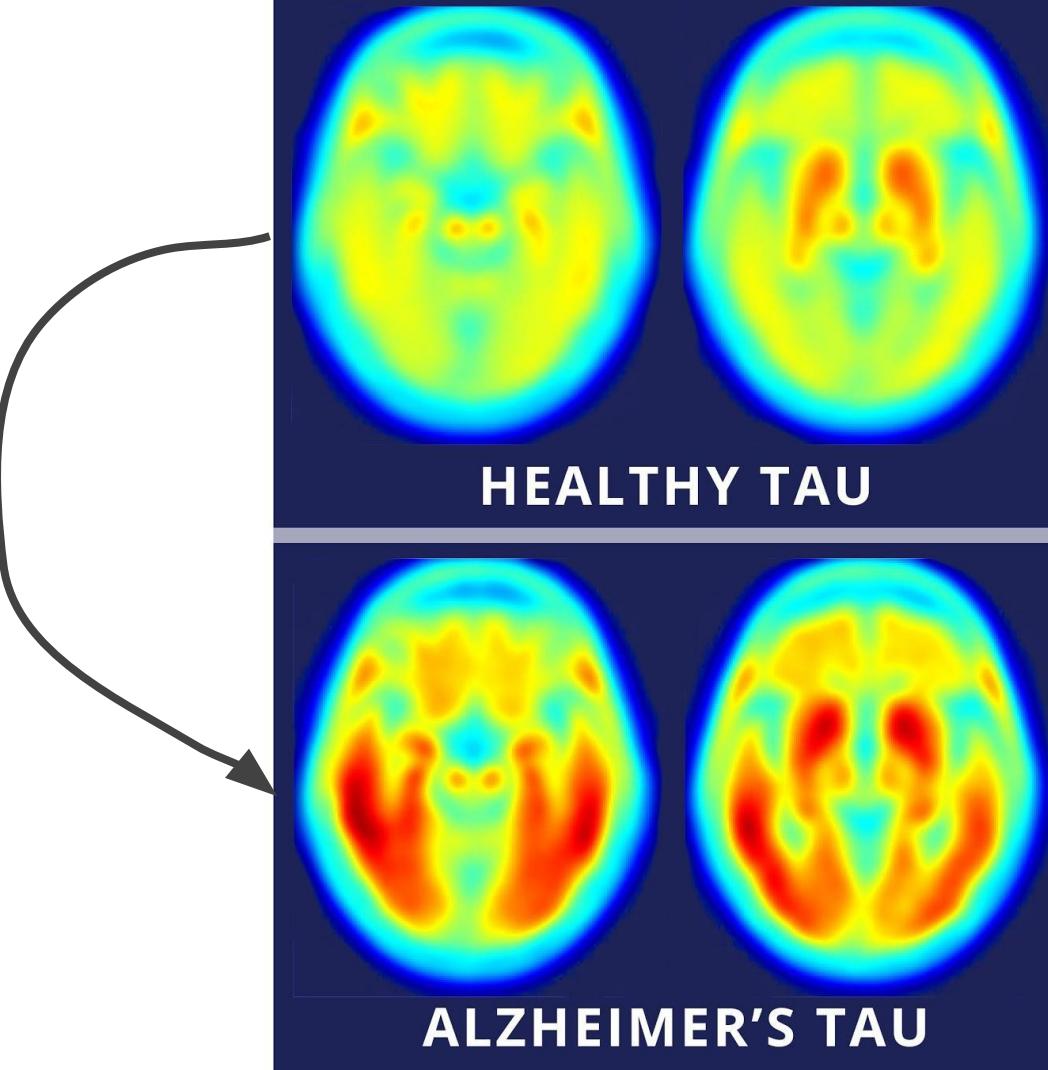


HEALTHY TAU



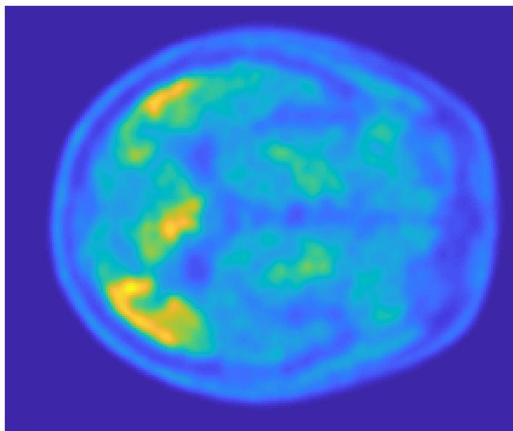
ALZHEIMER'S TAU

Tau PET registration

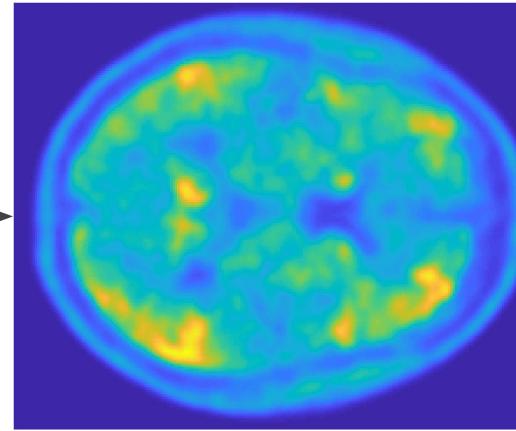


Tau PET registration

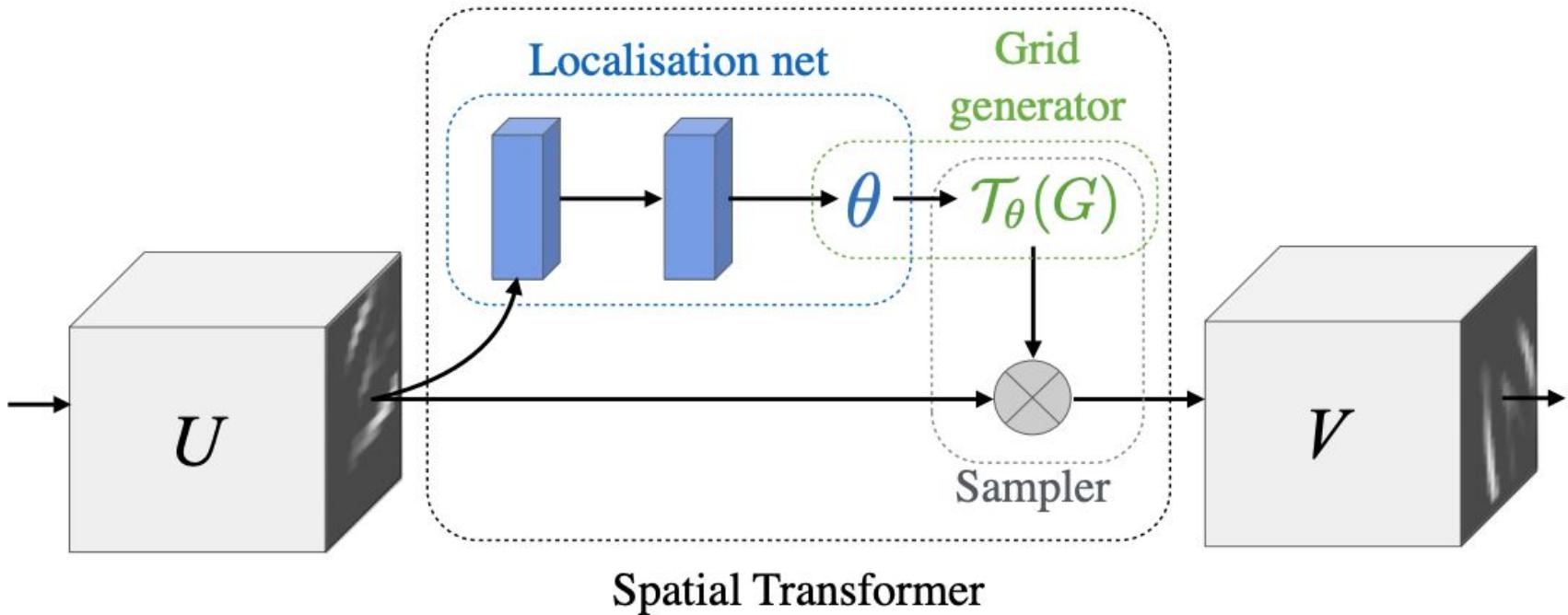
source



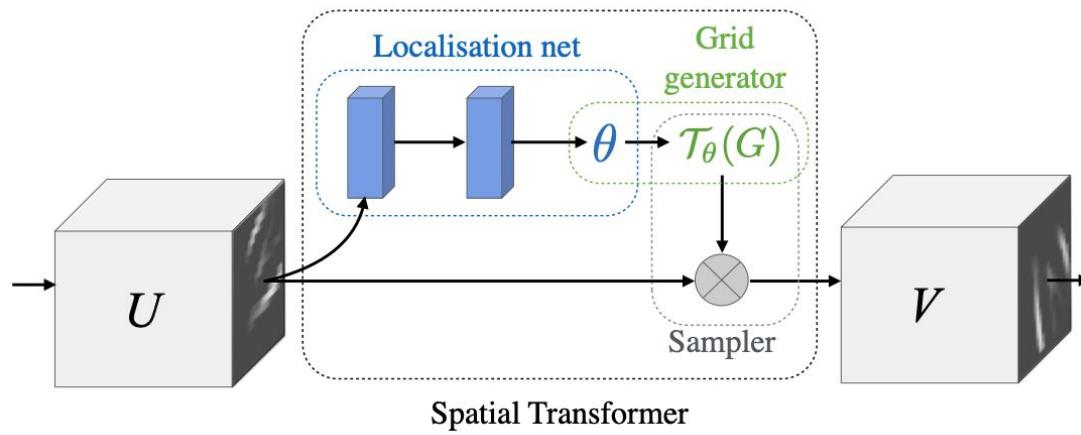
target



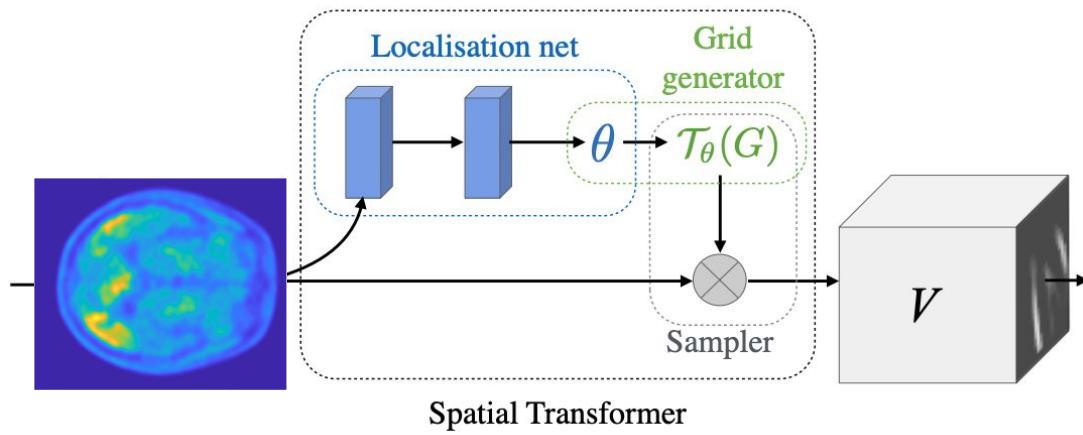
Tau PET registration



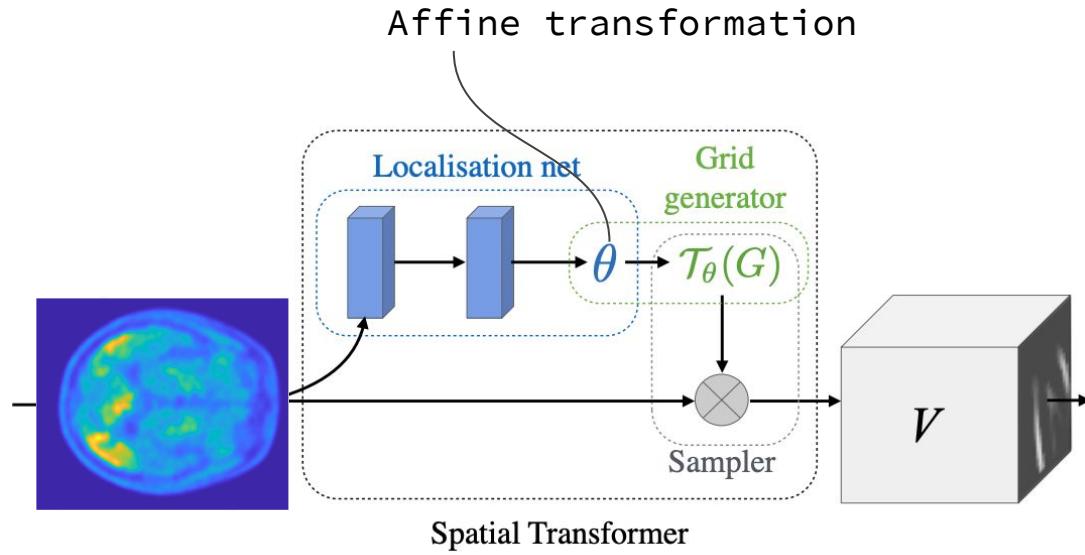
Tau PET registration



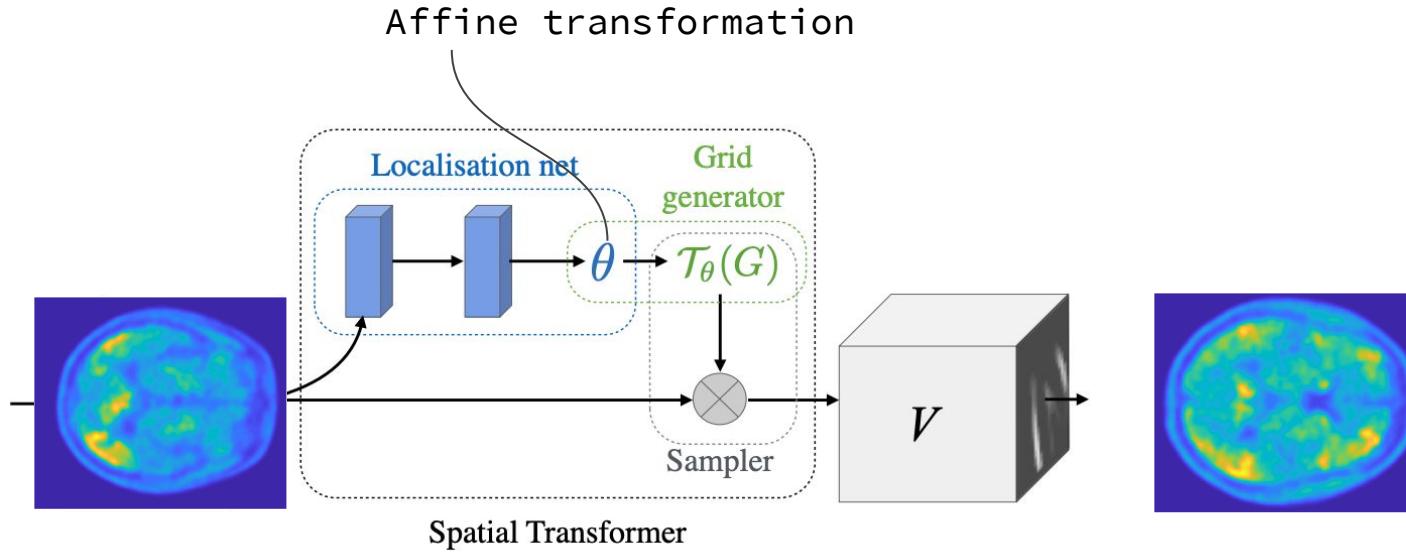
Tau PET registration



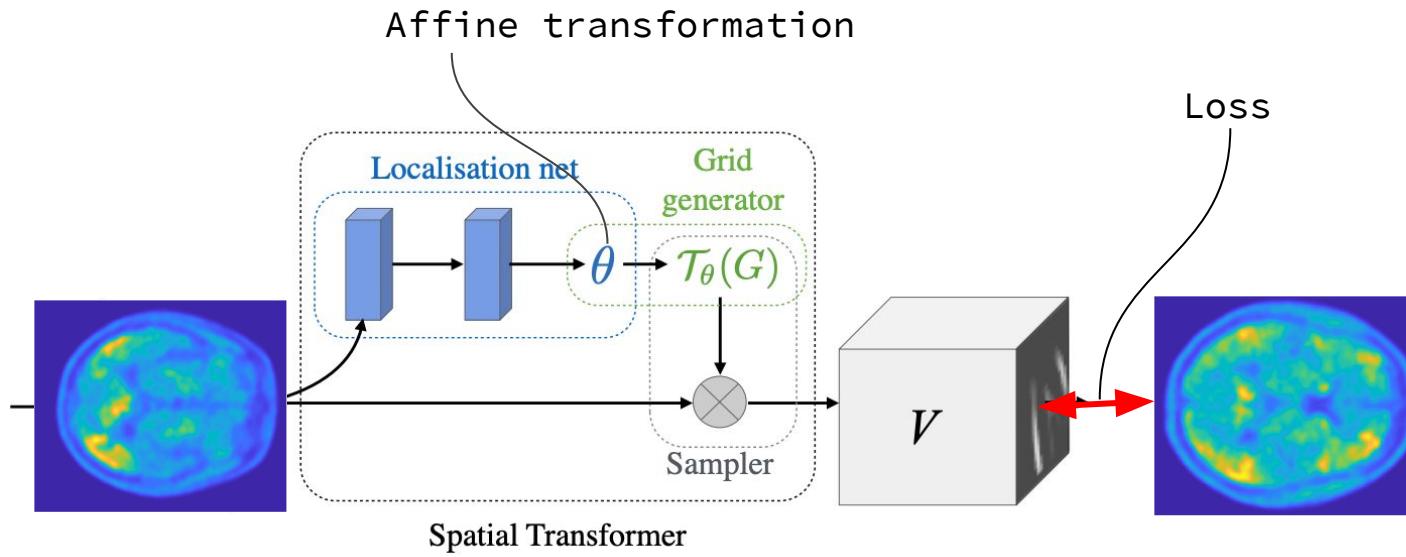
Tau PET registration



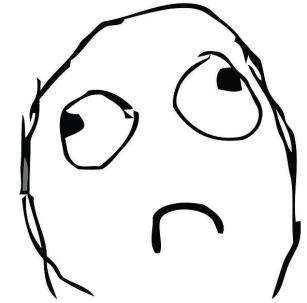
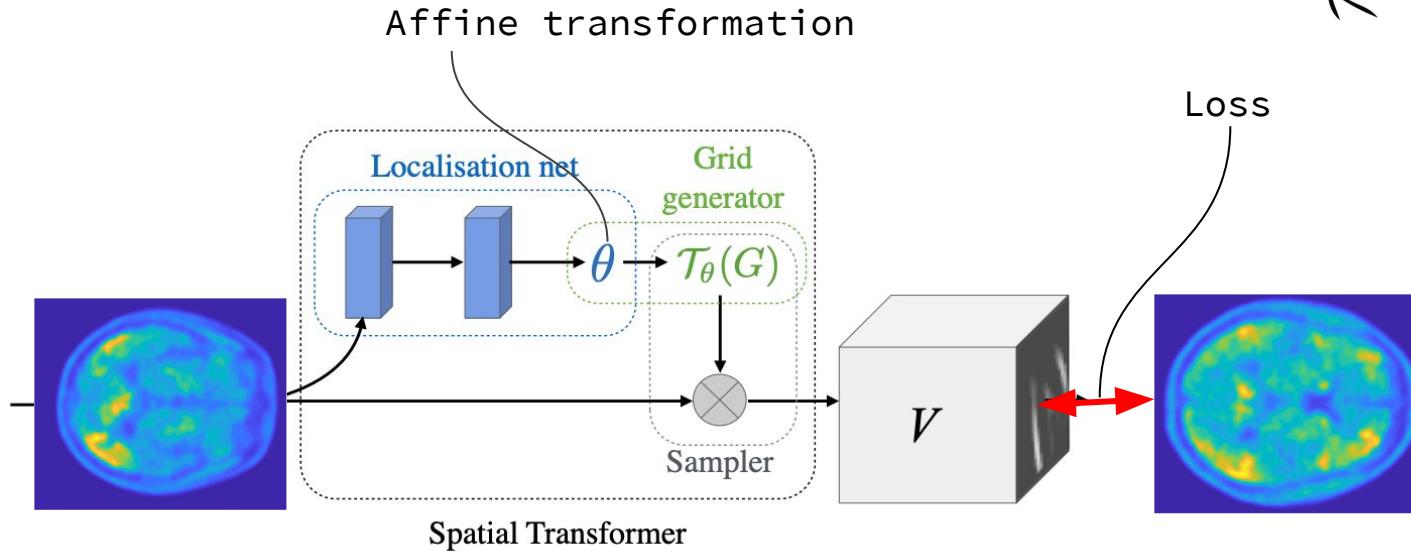
Tau PET registration



Tau PET registration



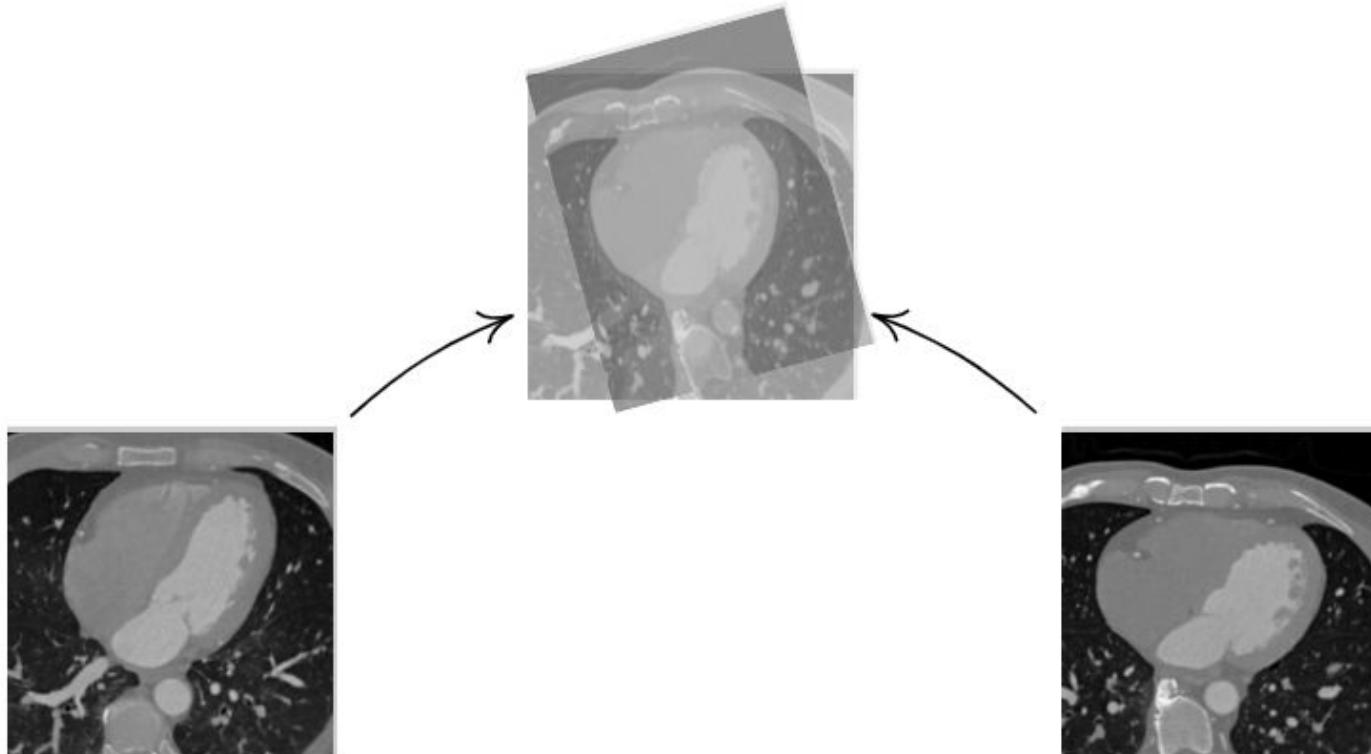
Tau PET registration



Tau PET registration



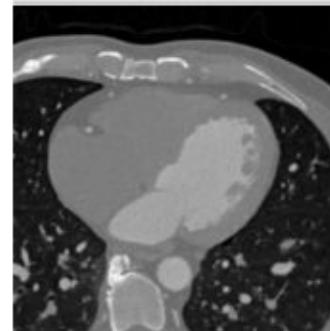
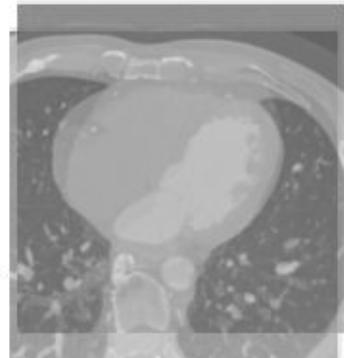
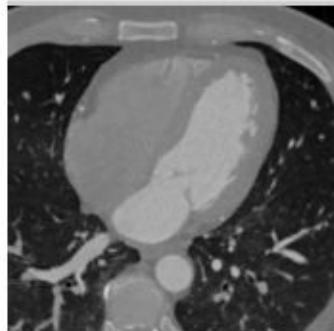
Tau PET registration



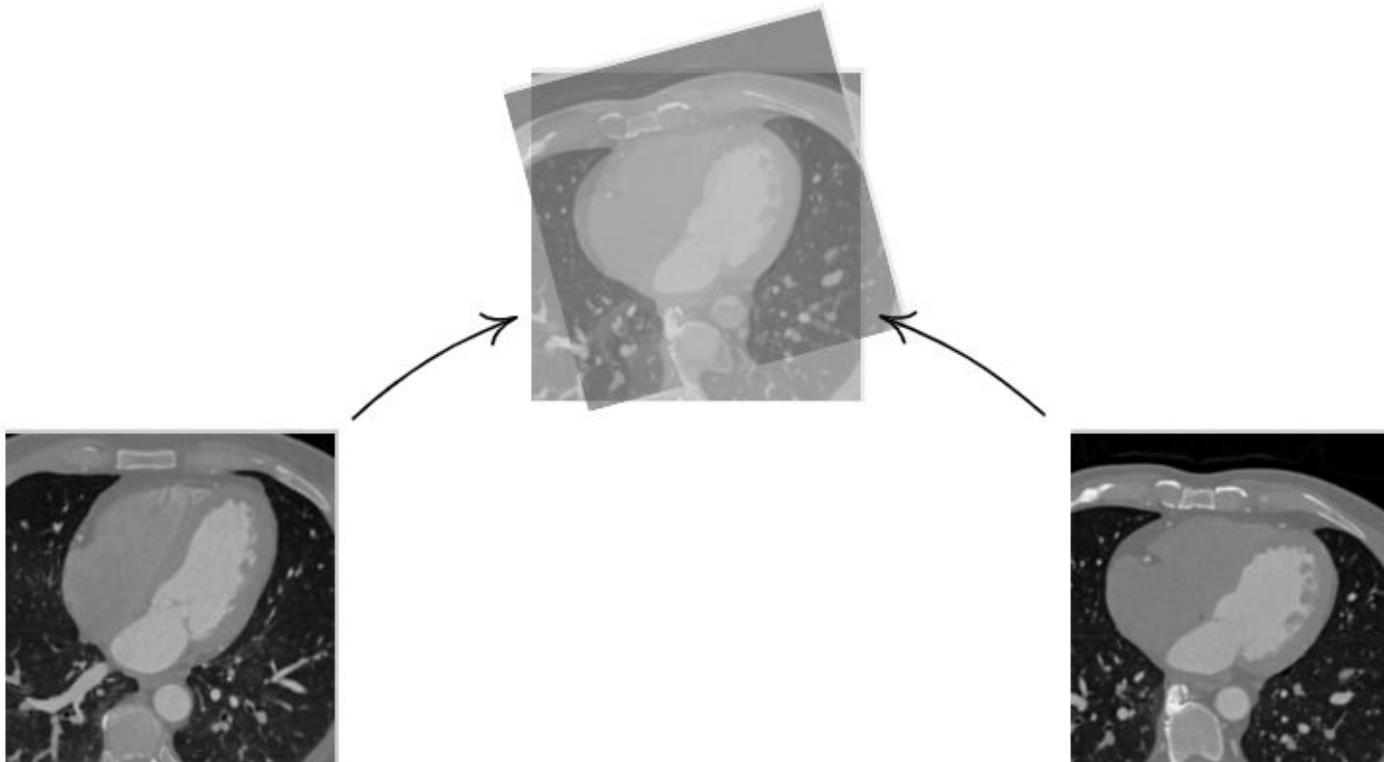
Tau PET registration



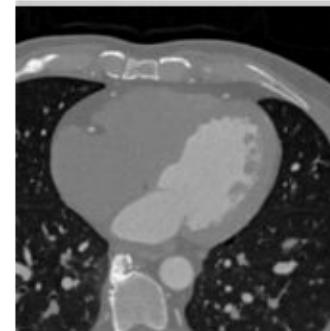
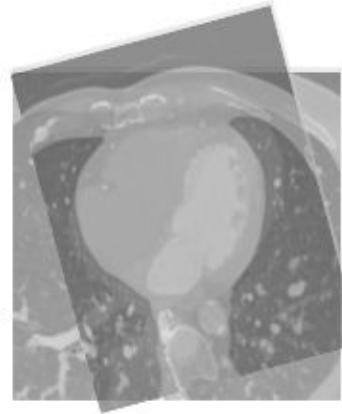
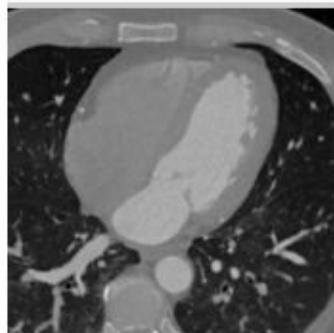
Tau PET registration



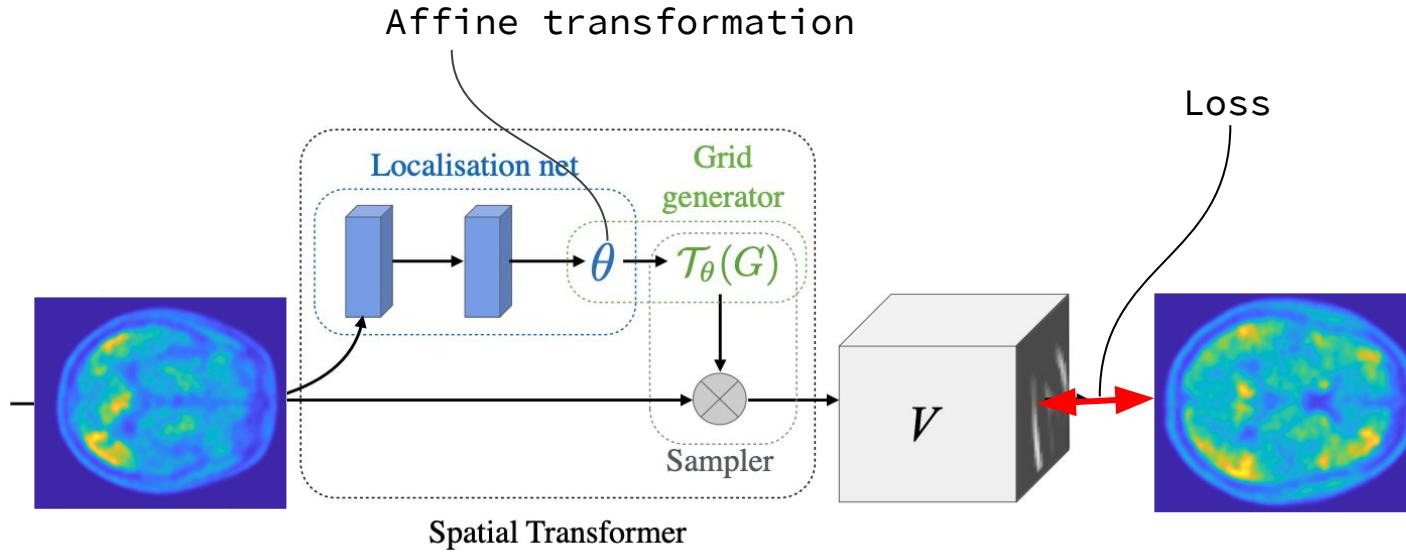
Tau PET registration



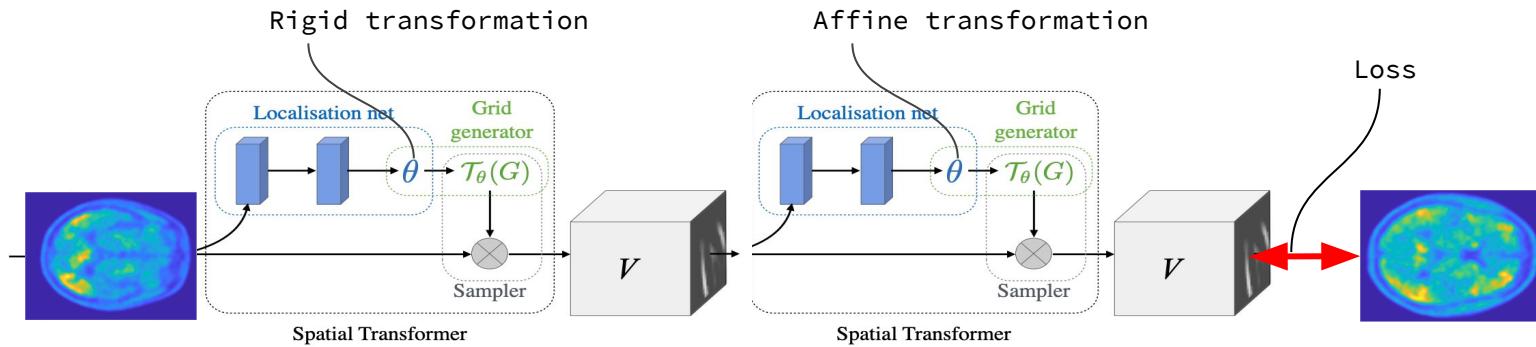
Tau PET registration



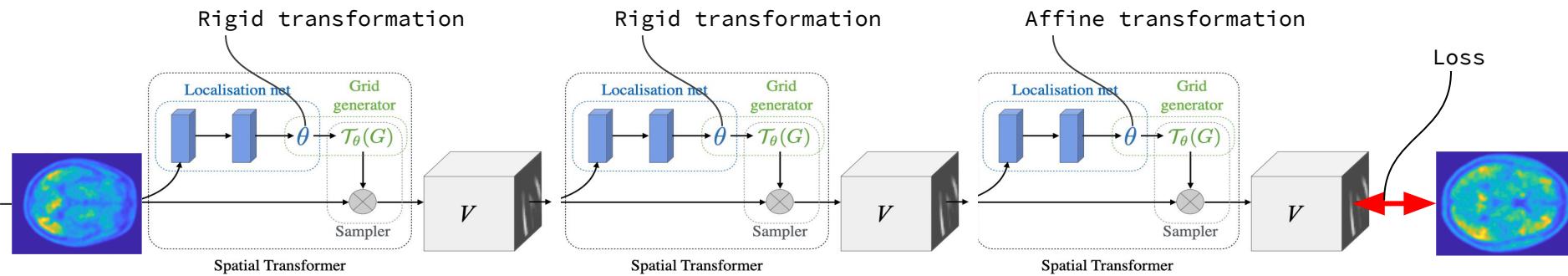
Tau PET registration



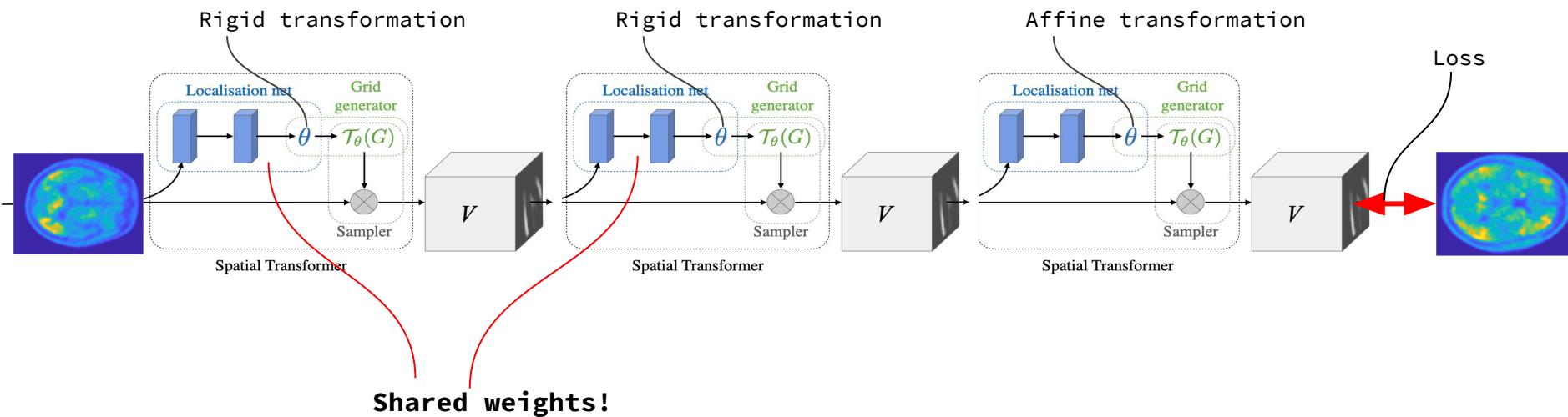
Tau PET registration



Tau PET registration



Tau PET registration

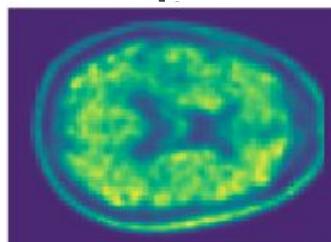


Tau PET registration

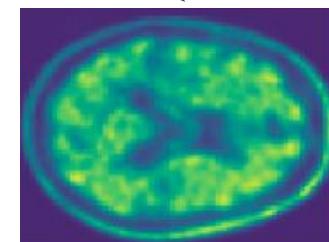
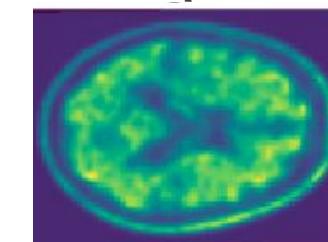
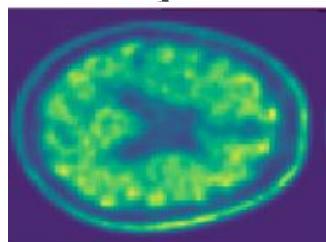
Rigid

rigid

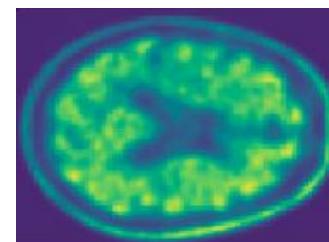
affine



input (source)



output (warped)



target

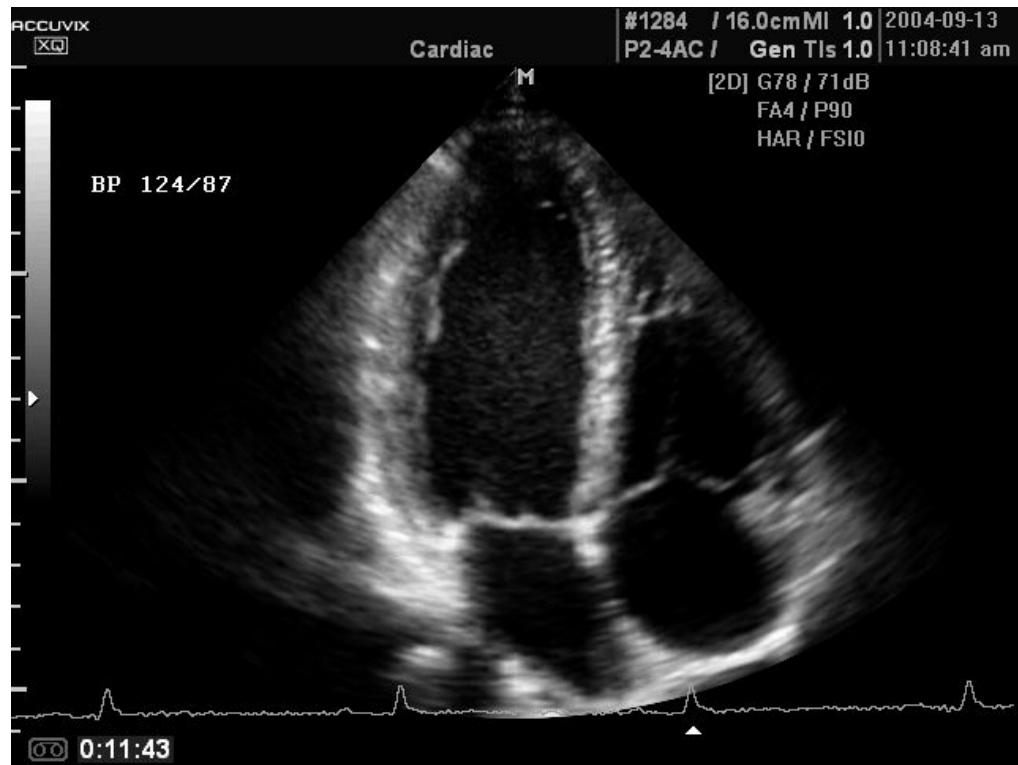
Problems/topics in medical image analysis

- Detection
- Segmentation
- **Registration**
- Classification

Problems/topics in medical image analysis

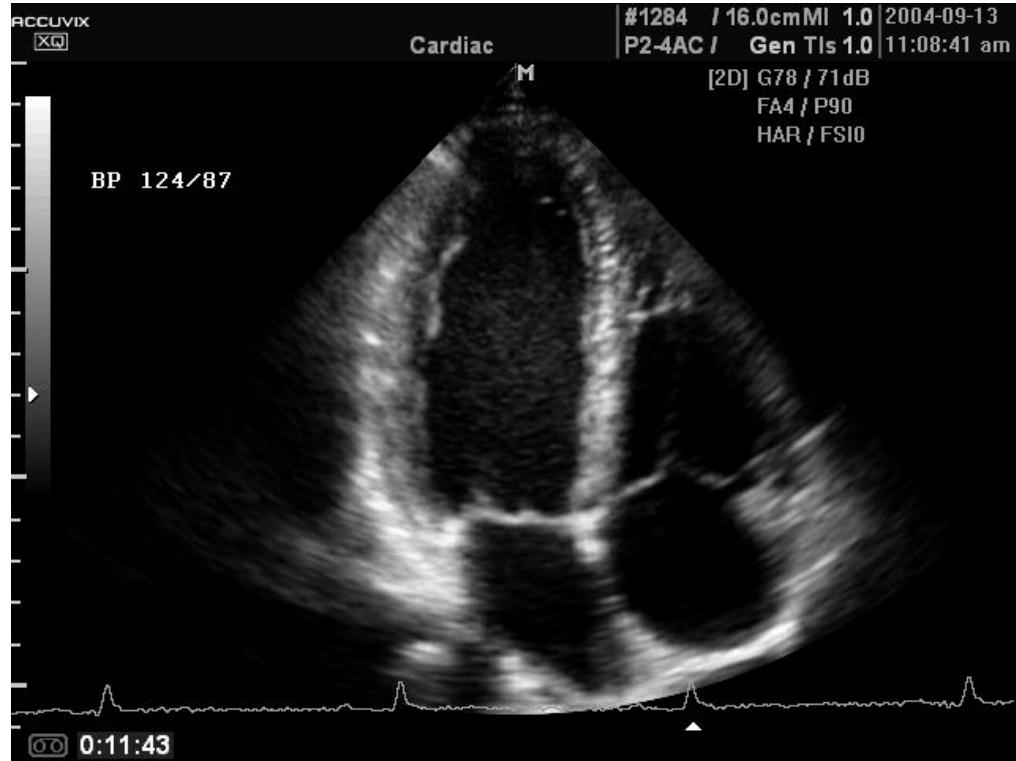
- Detection
- Segmentation
- Registration
- **Classification**

Echocardiography classification



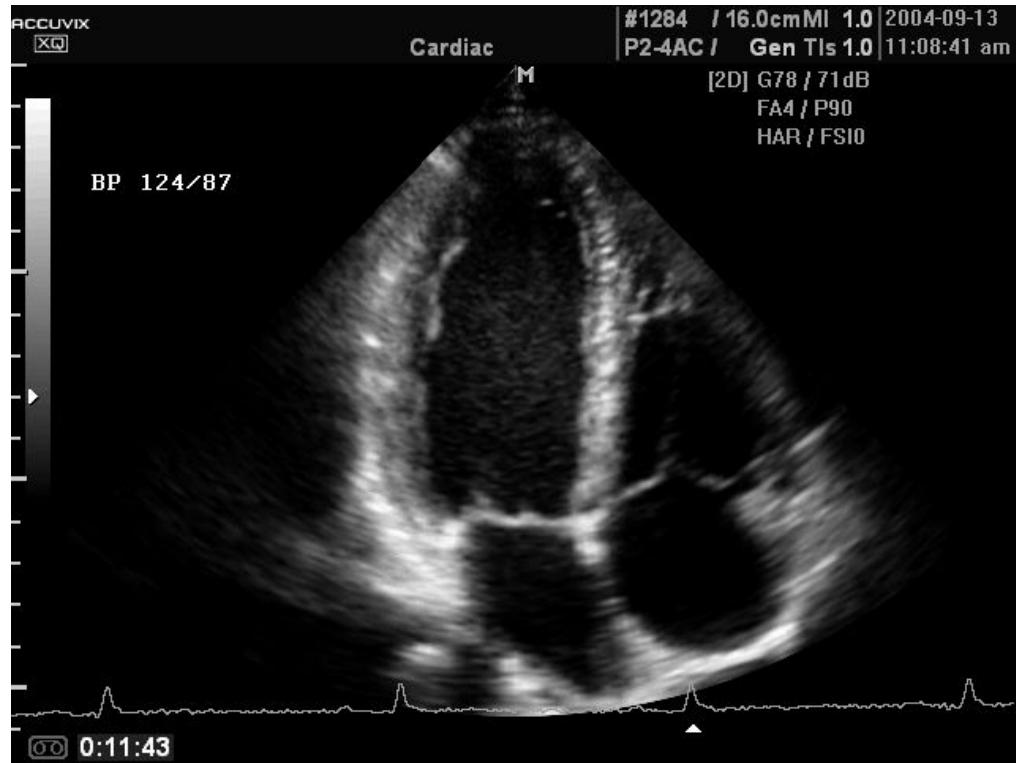
Echocardiography classification

- Ejection fraction?



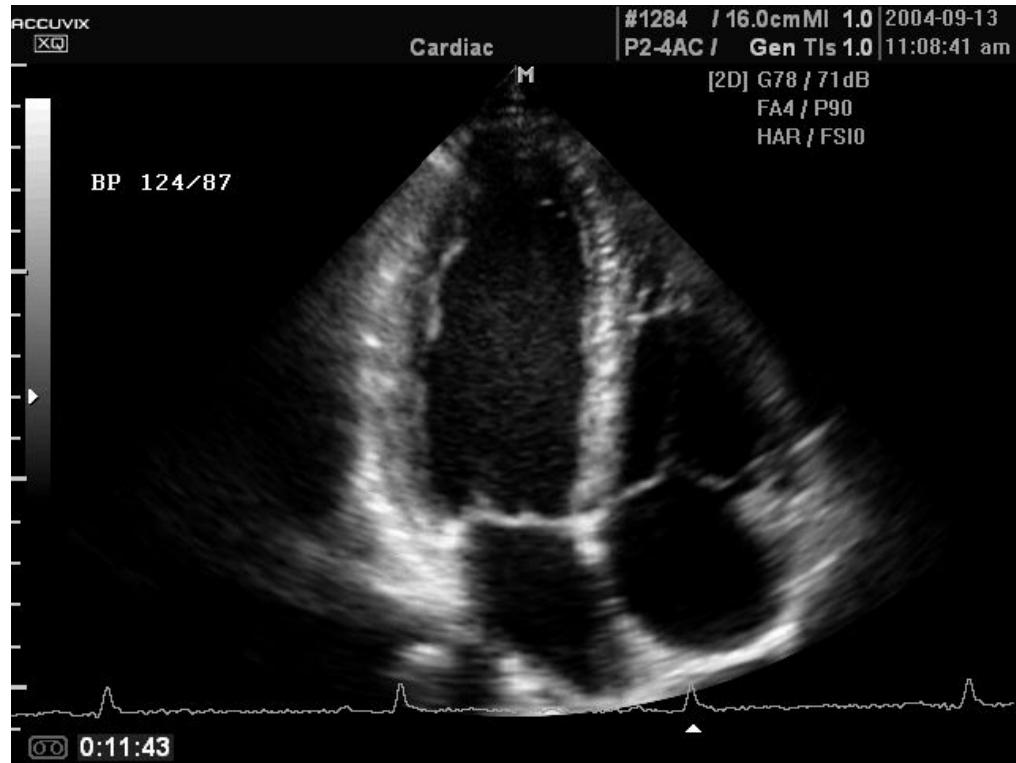
Echocardiography classification

- Ejection fraction?
- Ventricle size?



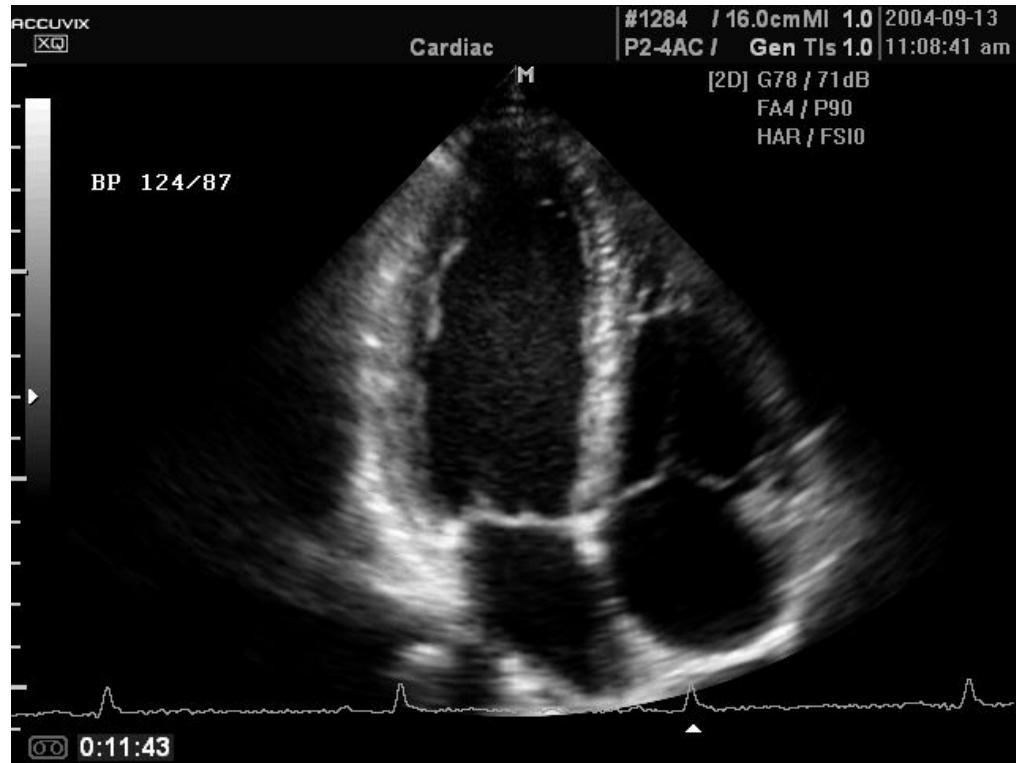
Echocardiography classification

- Ejection fraction?
- Ventricle size?
- Valve function?

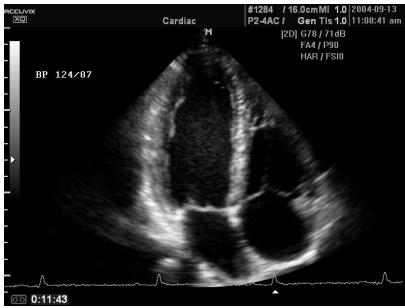


Echocardiography classification

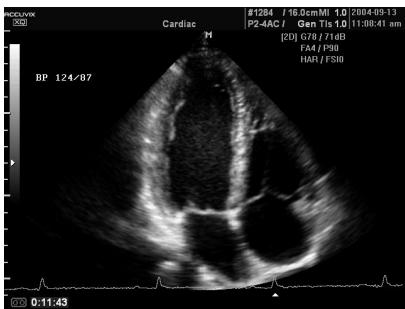
- Ejection fraction?
- Ventricle size?
- Valve function?
- View point?



Echocardiography classification



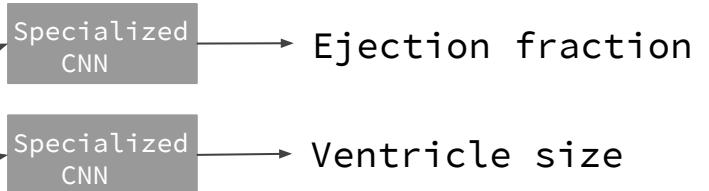
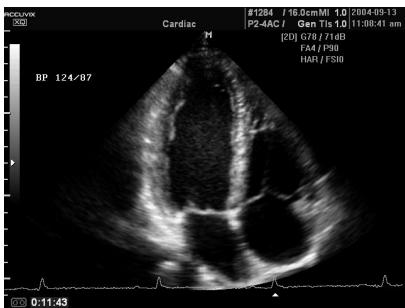
Echocardiography classification



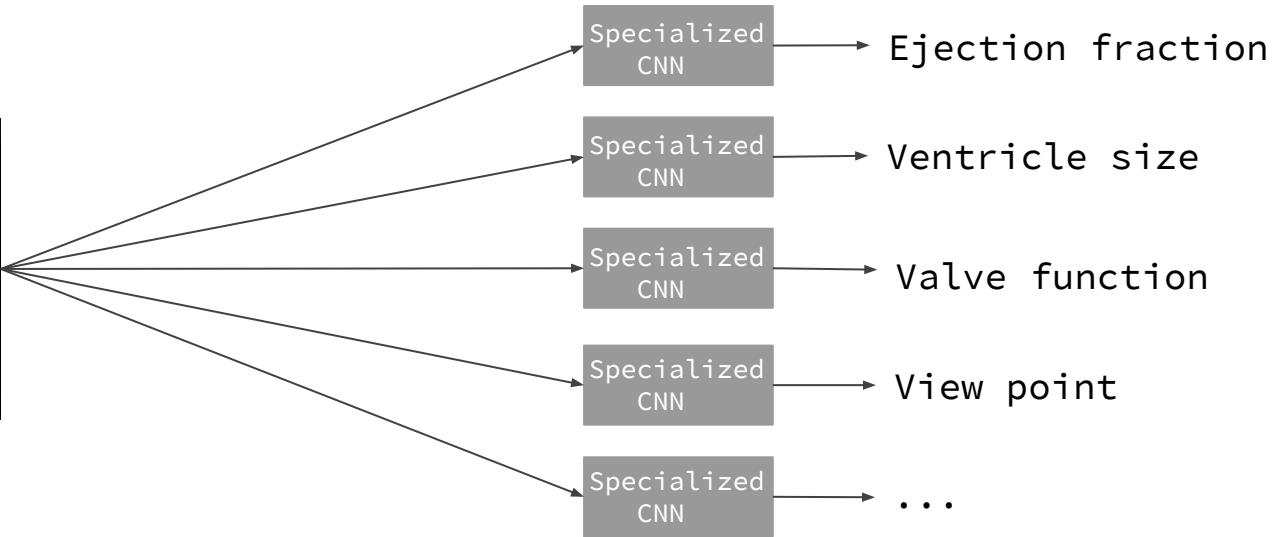
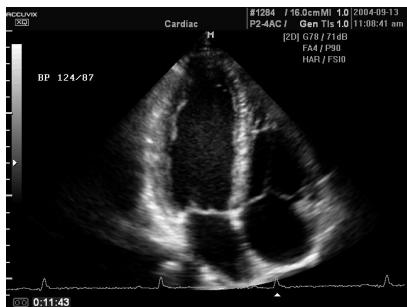
Specialized
CNN

→ Ejection fraction

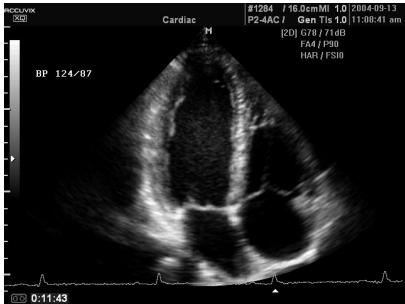
Echocardiography classification



Echocardiography classification

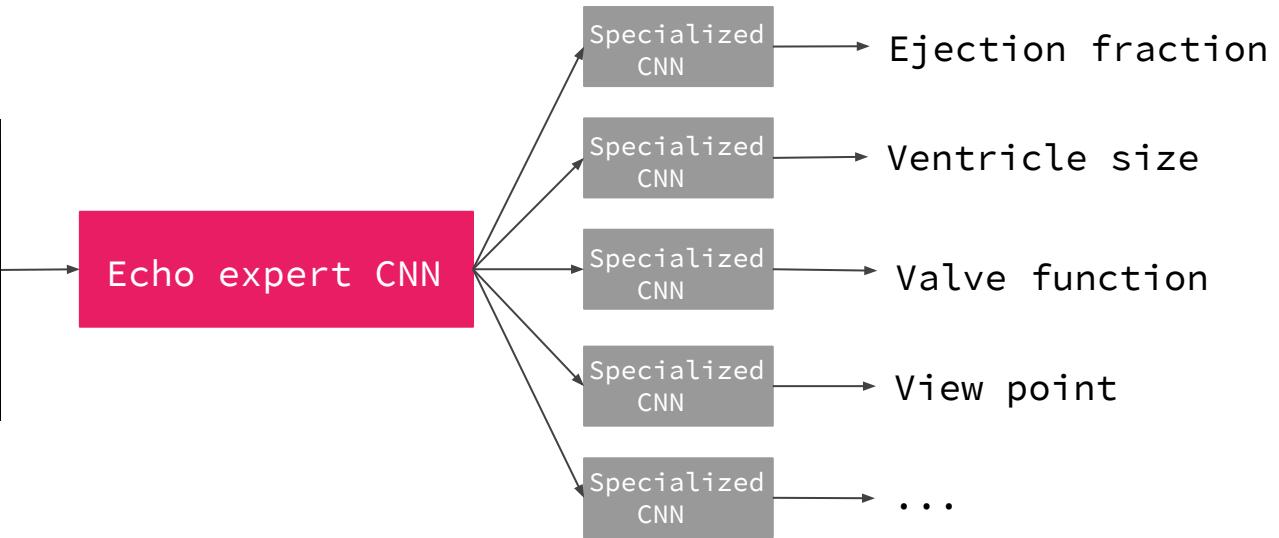
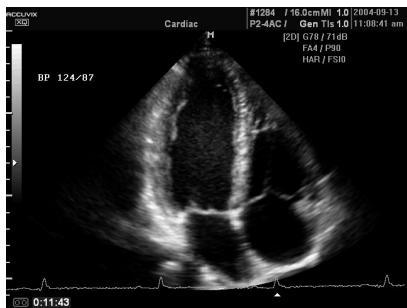


Echocardiography classification

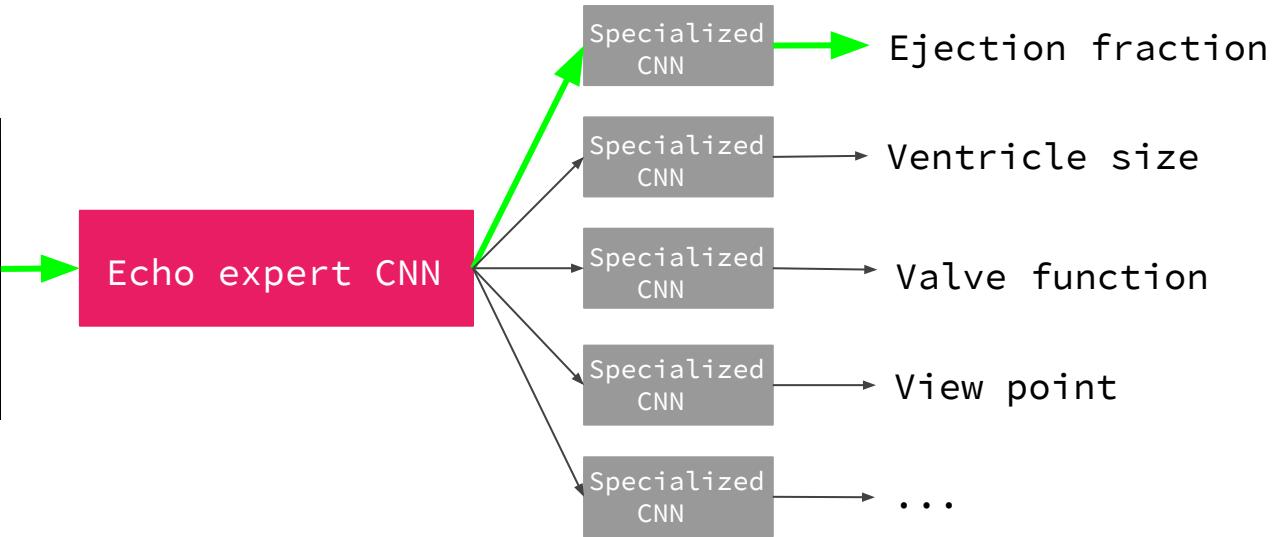
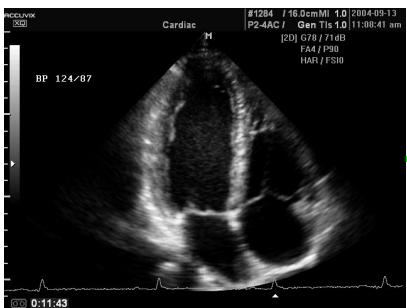


Echo expert CNN

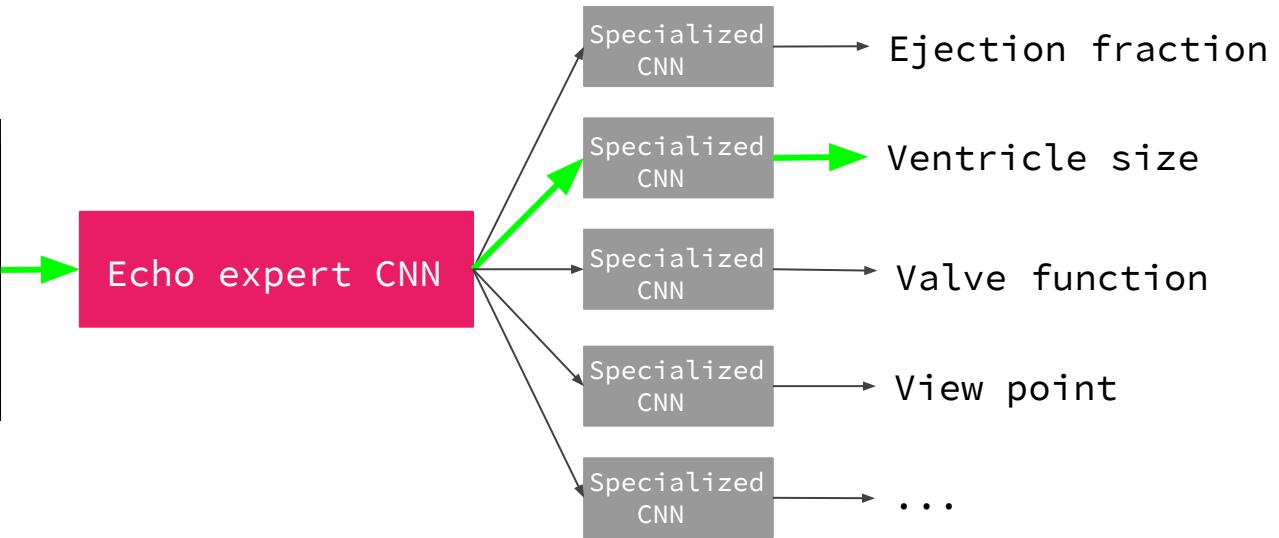
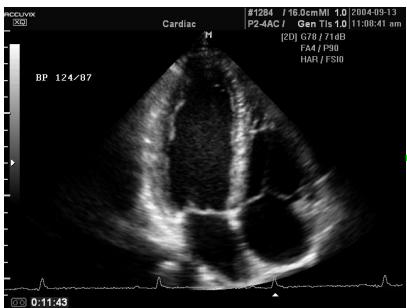
Echocardiography classification



Echocardiography classification

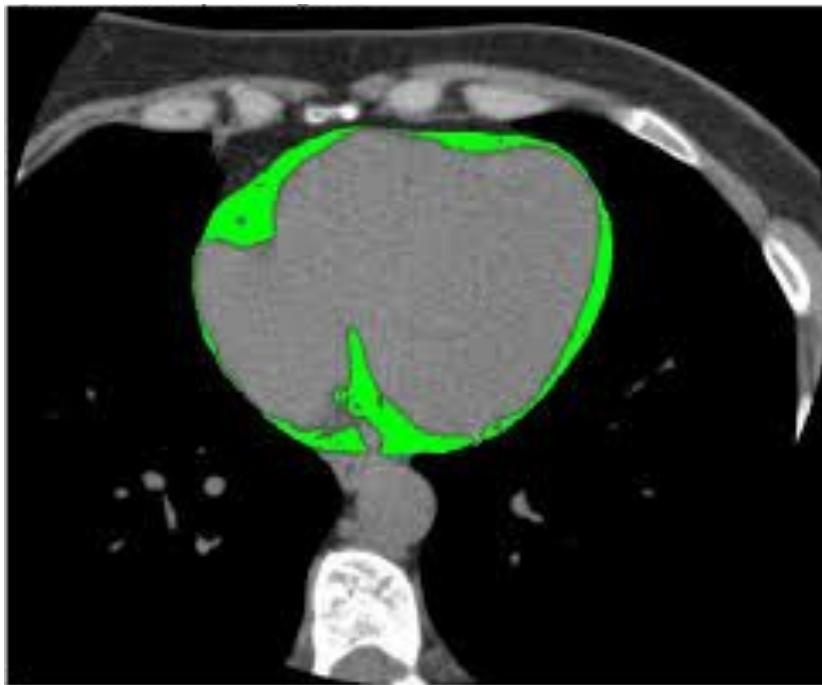


Echocardiography classification

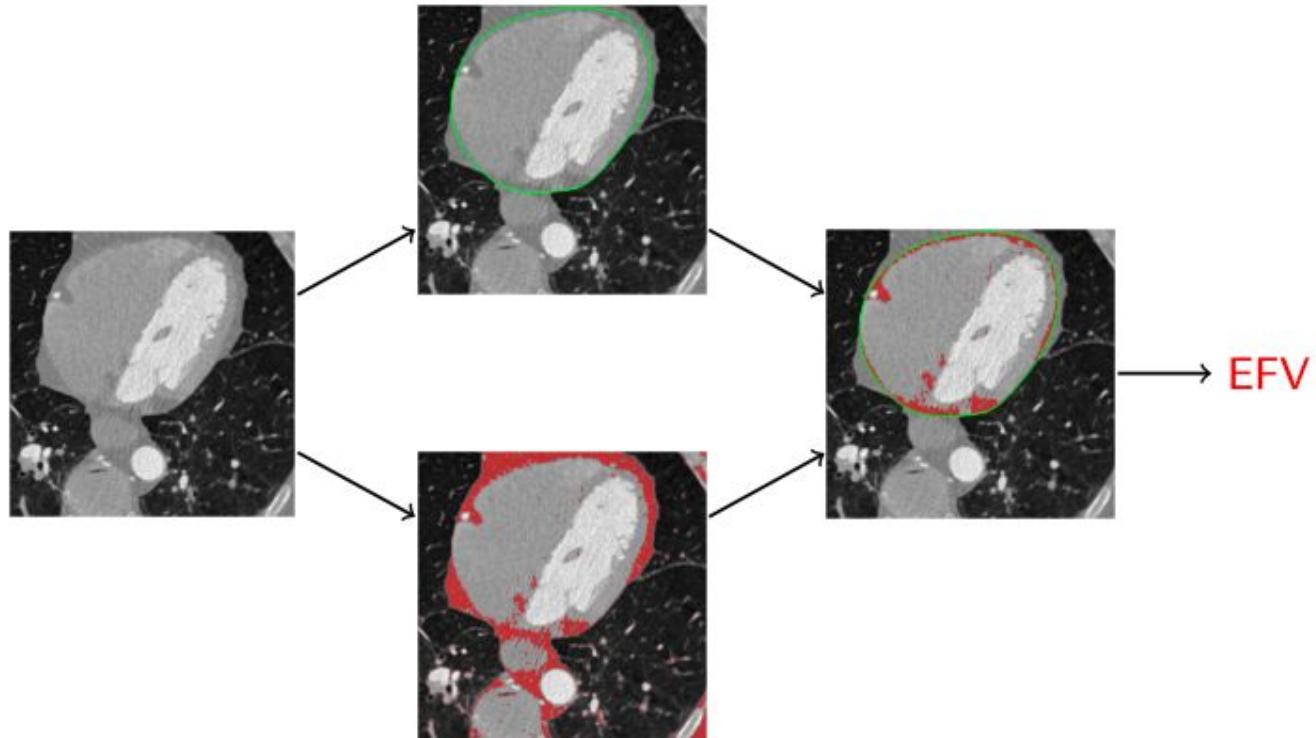


Multi-atlas segmentation

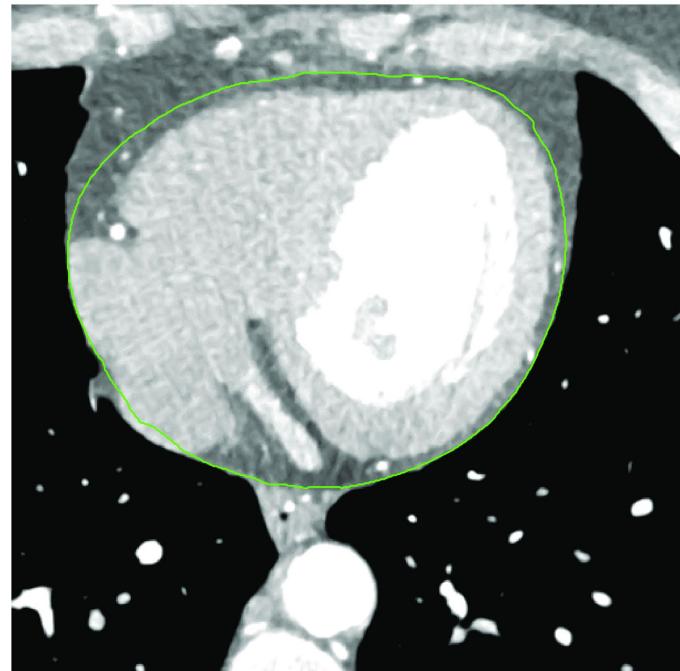
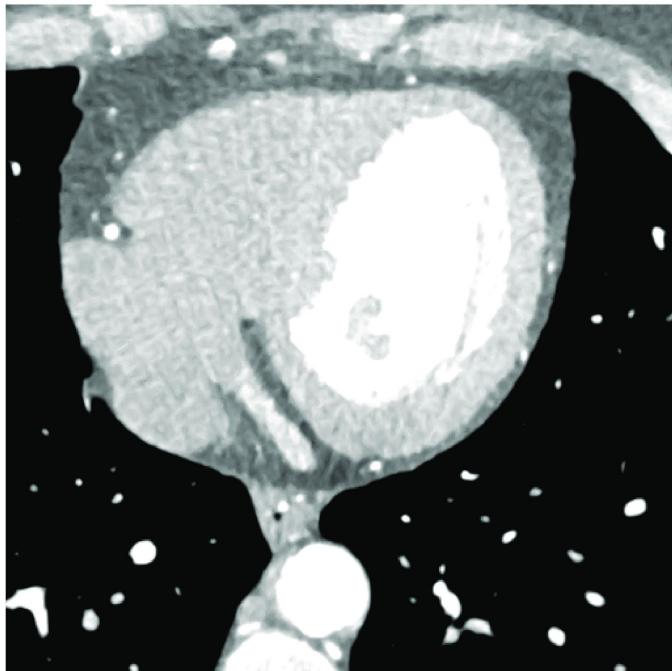
Pericardium ('heart sac') segmentation



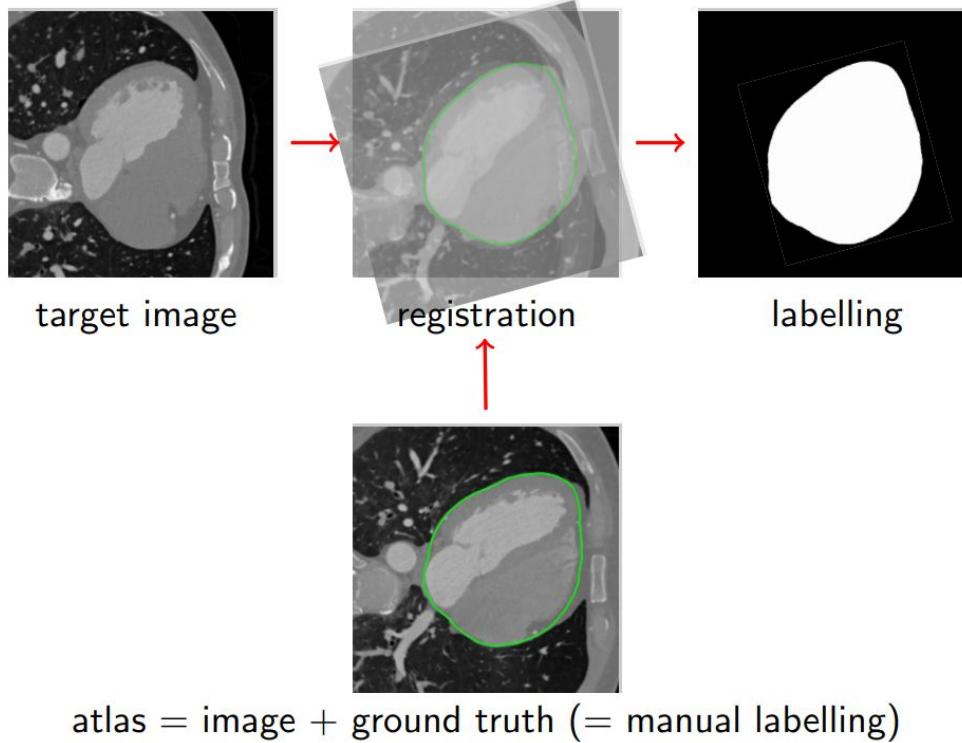
Pericardium ('heart sac') segmentation



Pericardium ('heart sac') segmentation



Atlas segmentation

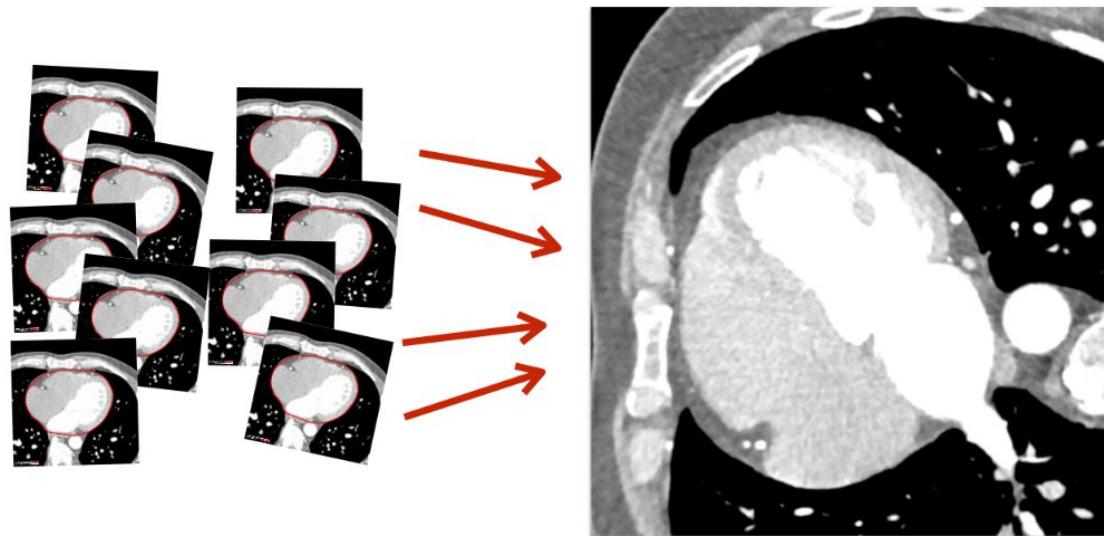


Multi-atlas segmentation

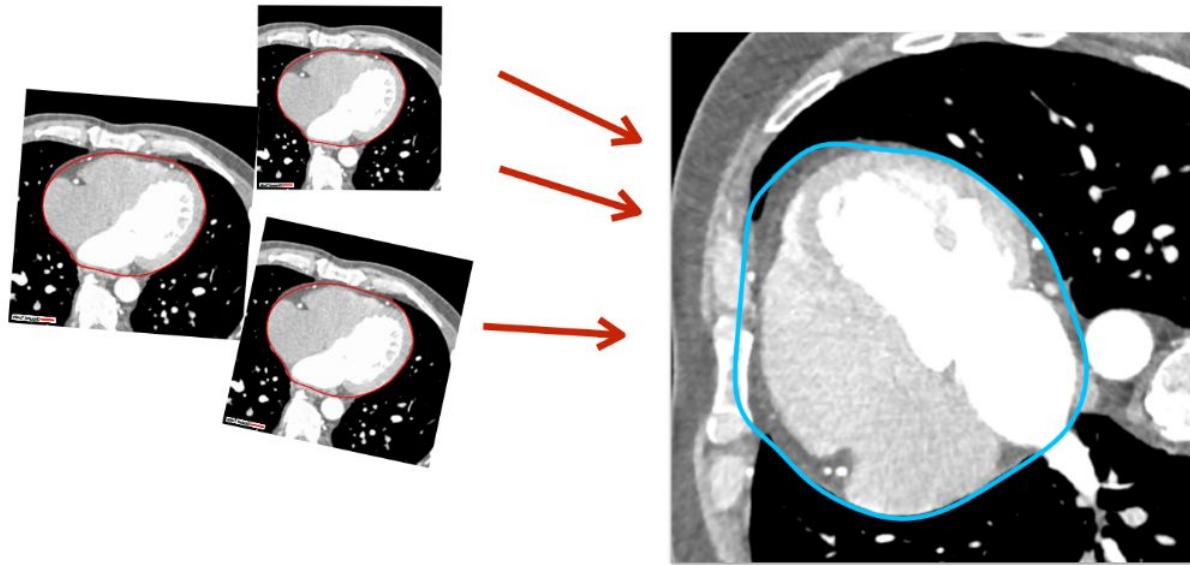
Multi-atlas = several atlases



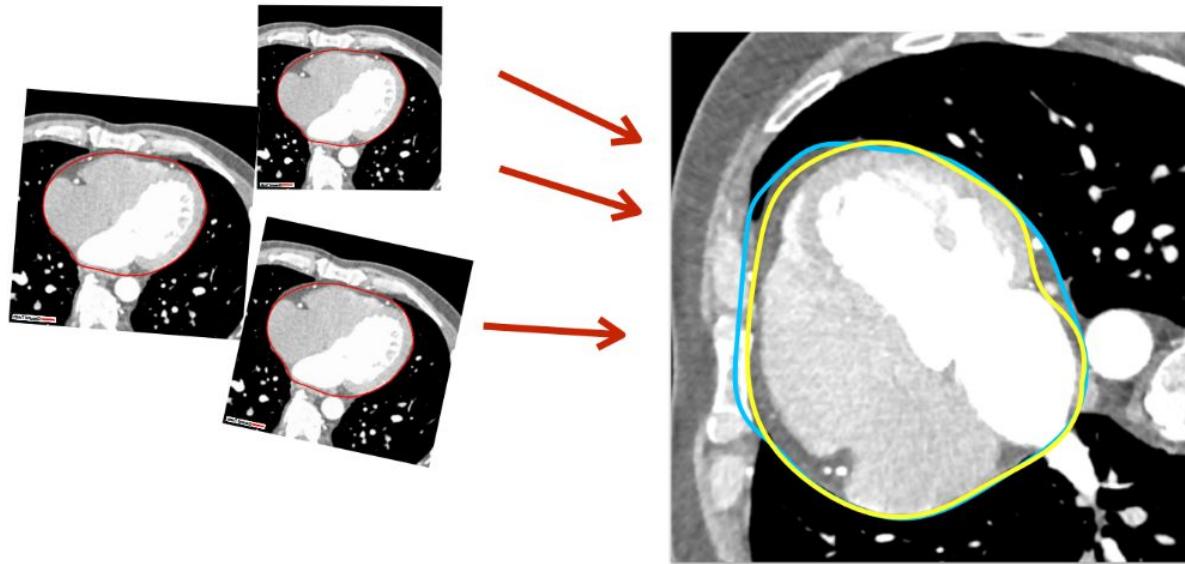
Multi-atlas segmentation



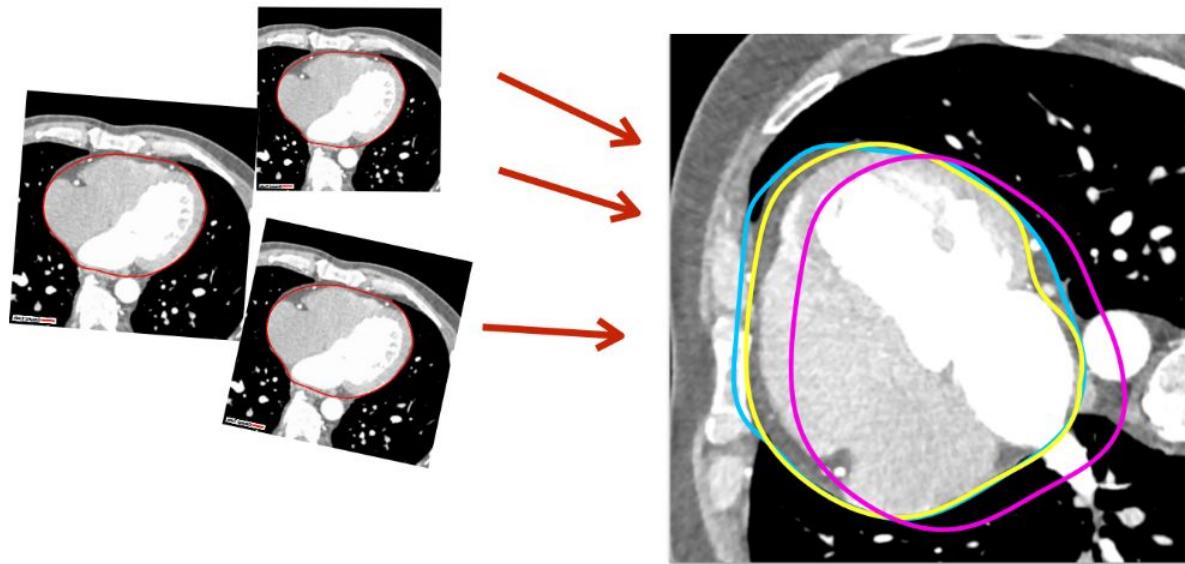
Multi-atlas segmentation



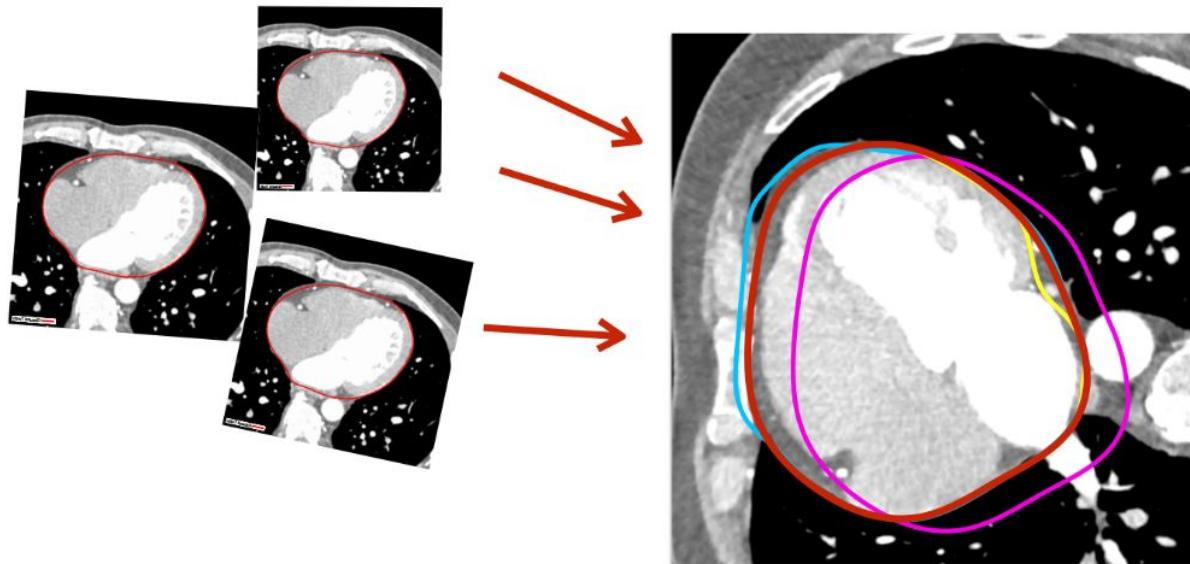
Multi-atlas segmentation



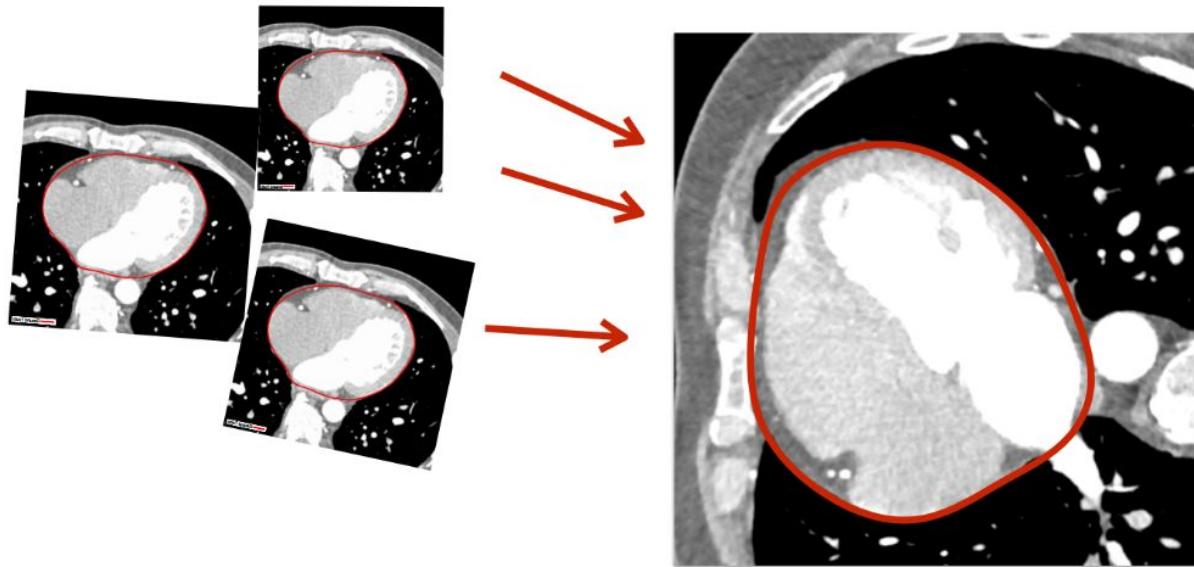
Multi-atlas segmentation



Multi-atlas segmentation



Multi-atlas segmentation



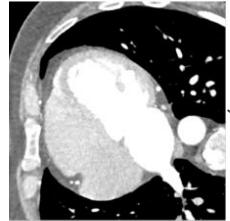
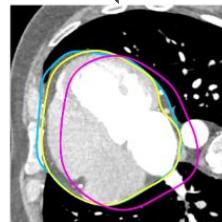


image registration



label fusion

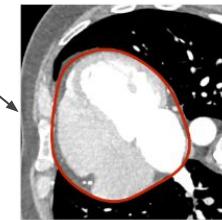
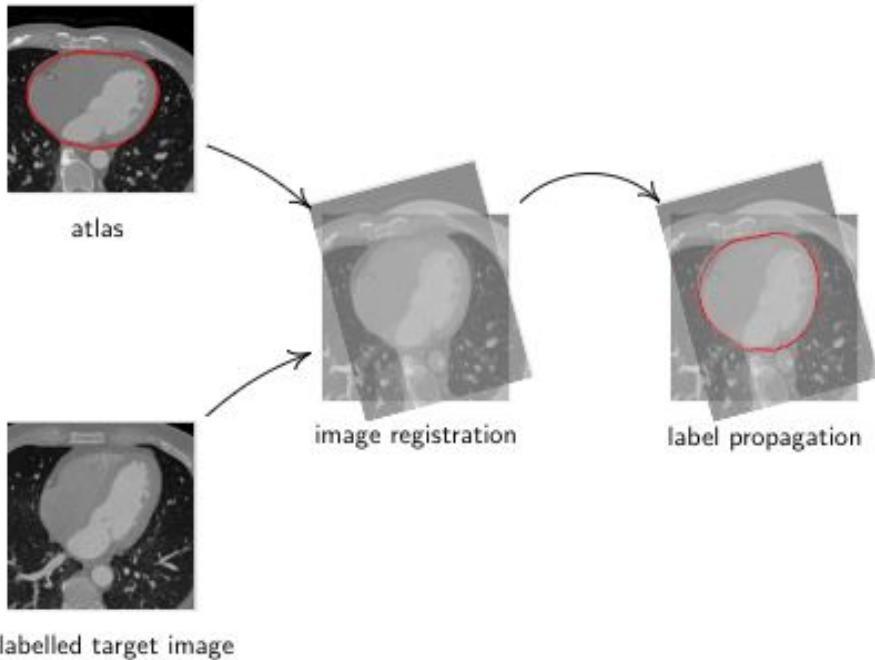
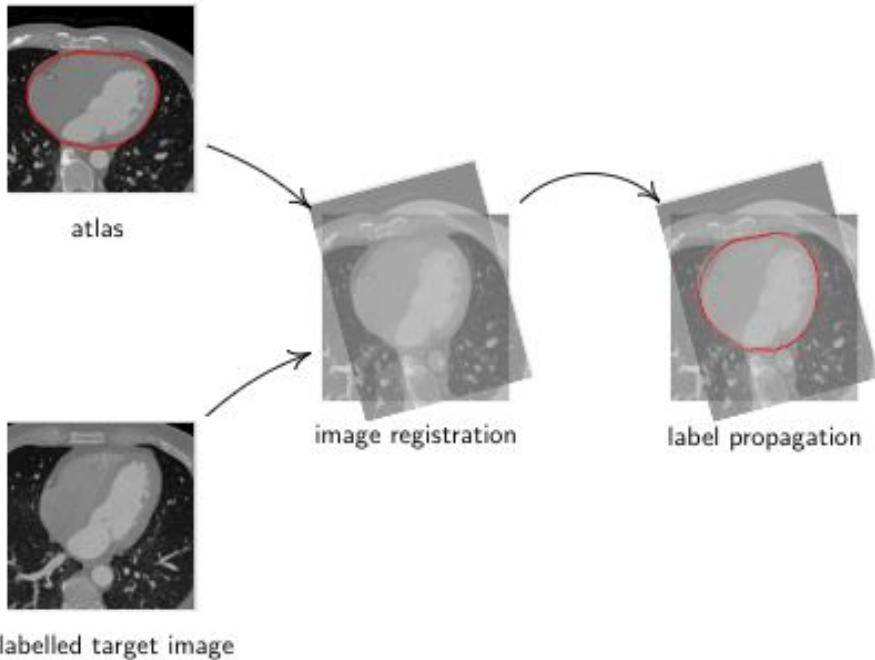


Image registration



1. Compute feature points + descriptors
2. Match descriptors
3. Compute transformation from correspondences
4. Warp atlas segmentation and done!

Image registration



Problems:

- Few distinctive feature points:
 - Few correct correspondences
 - High outlier rate
- Many atlases = registration takes time...

Image registration

Problem: Few distinctive feature points,
i.e. few correct correspondences, and a high outlier rate.

Proposed solutions:

- Only use feature points found in several atlas images
- Only use atlas feature points close to the organ (boundary)
- Only use atlas feature points that are known to produce good matches

Image registration

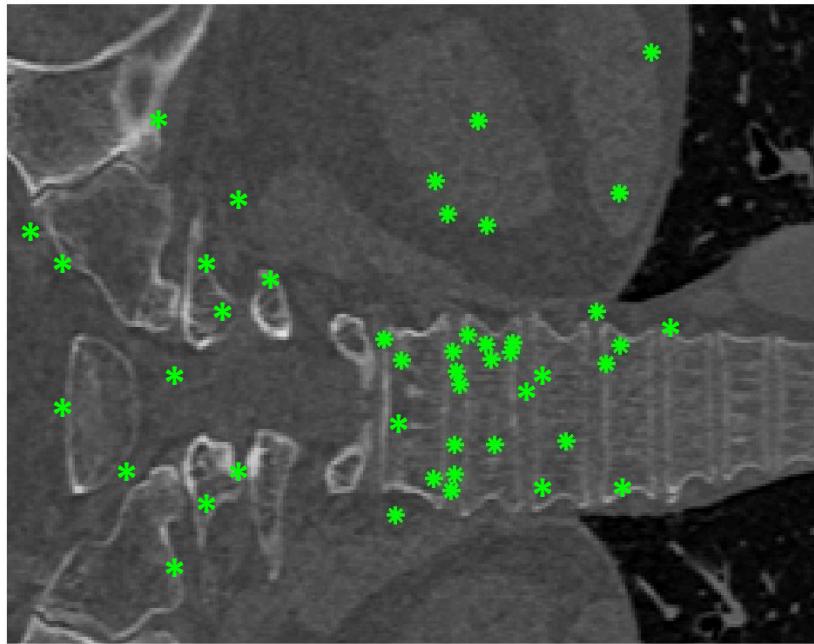


Image registration

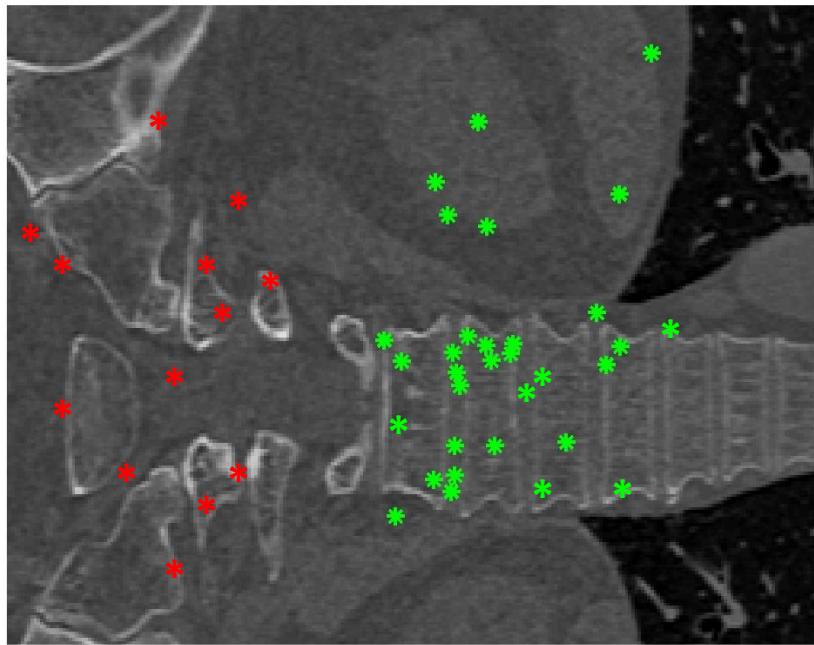


Image registration

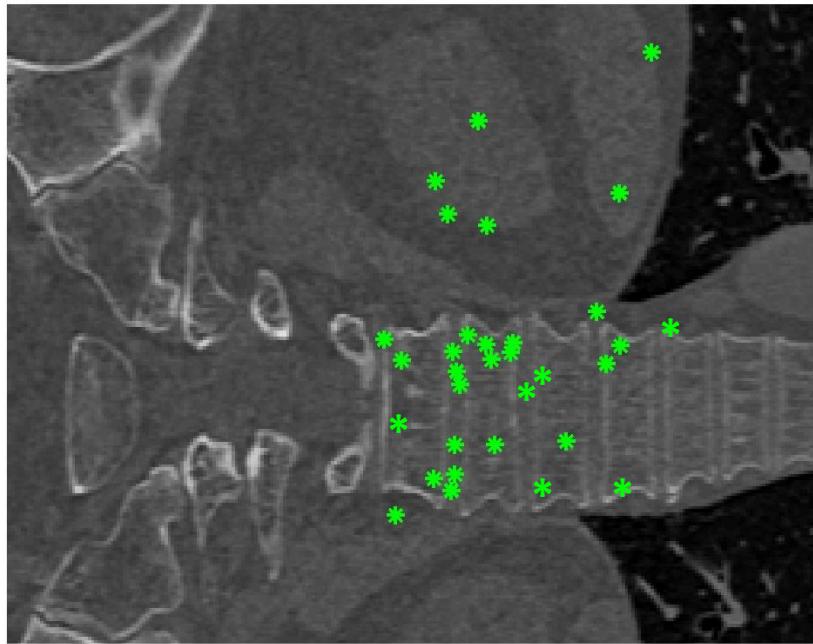


Image registration

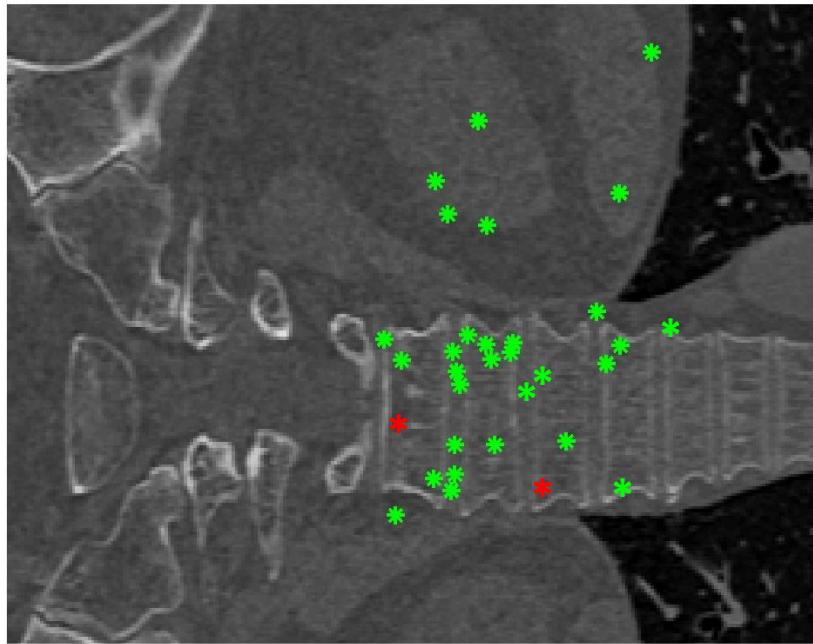


Image registration

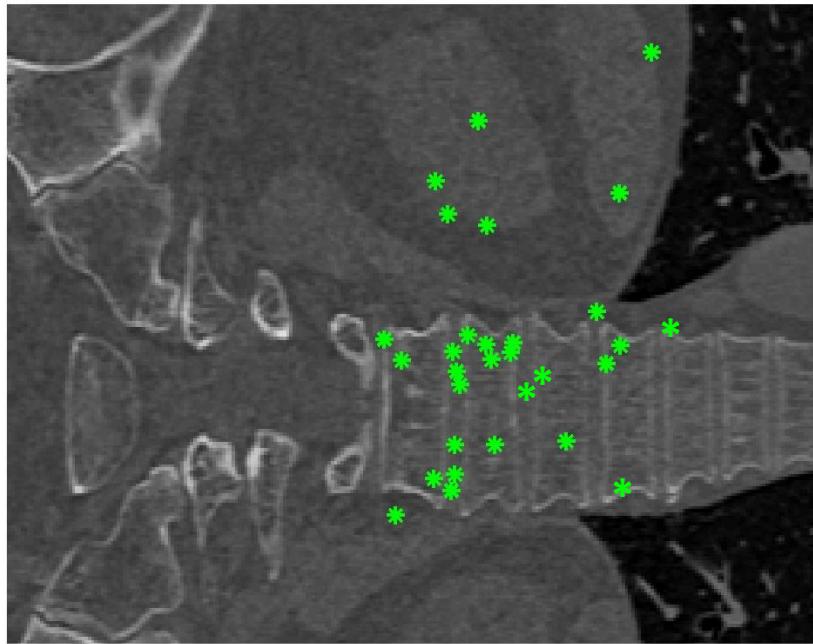


Image registration

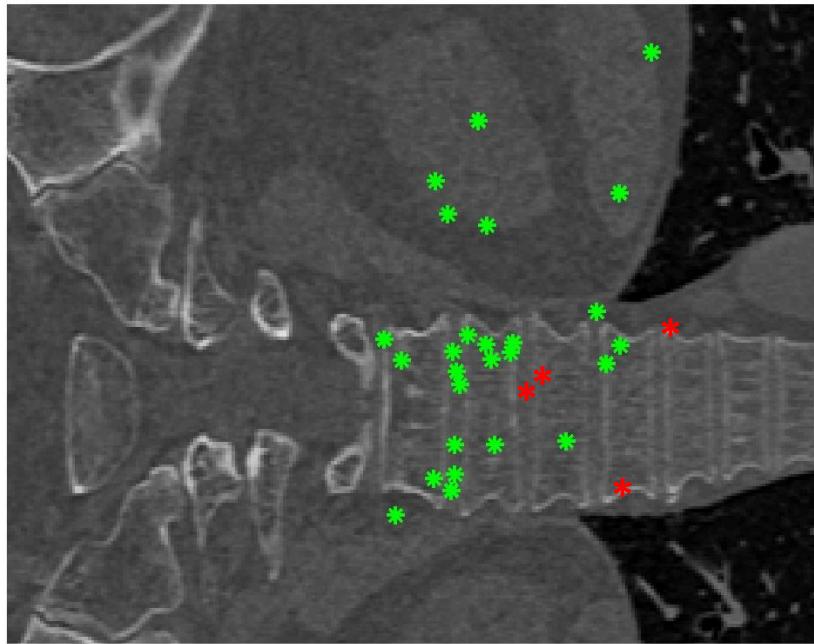


Image registration

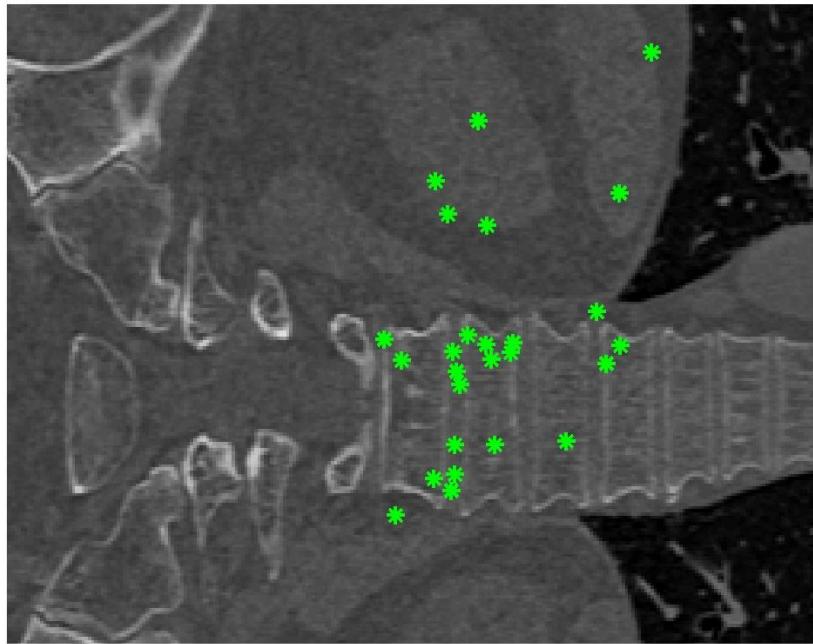


Image registration

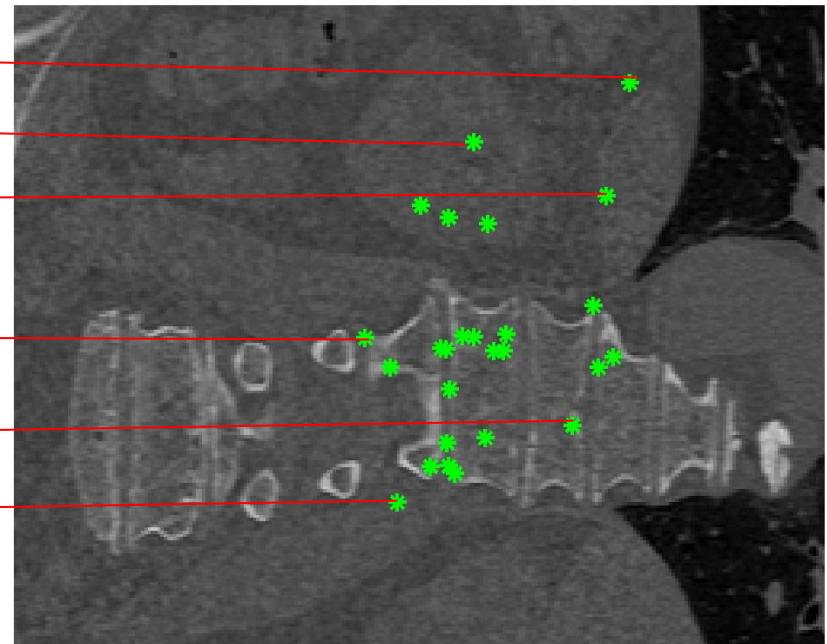
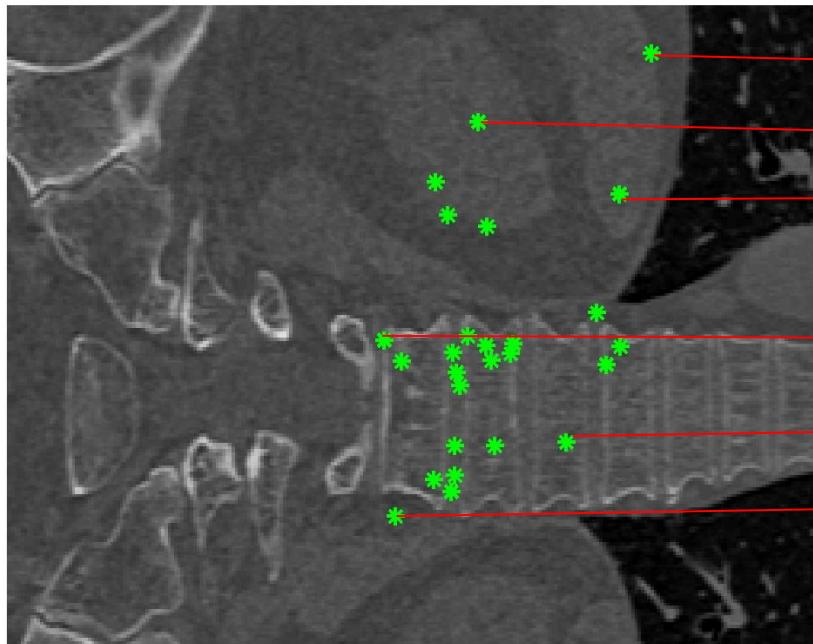


Image registration

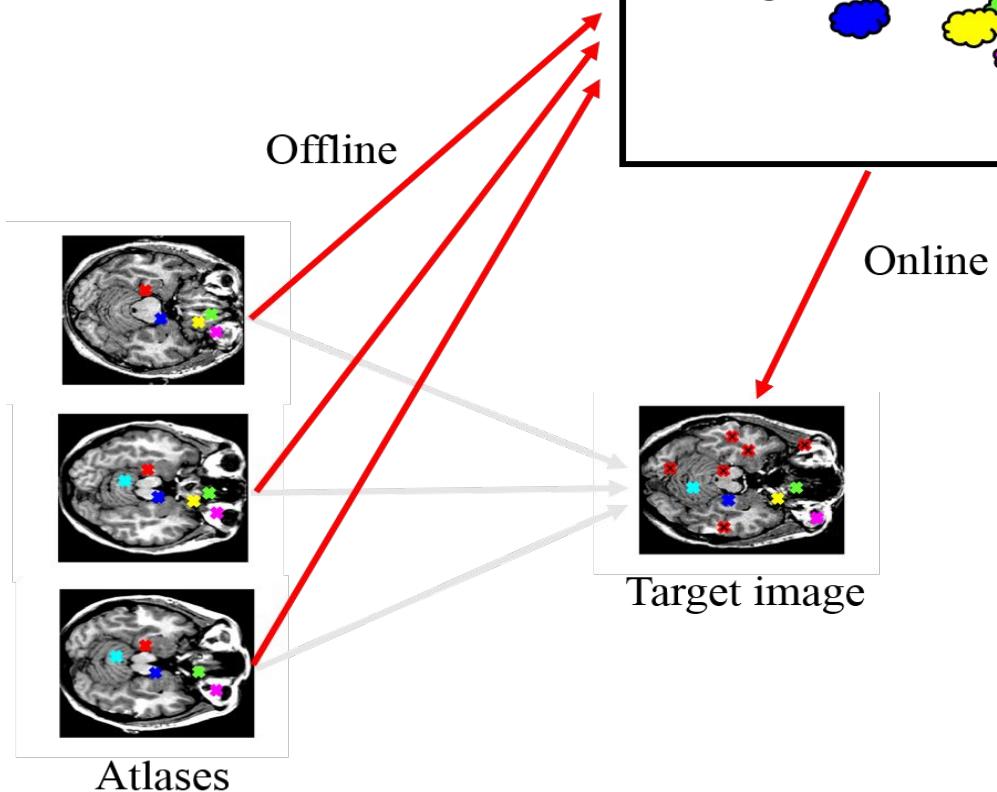
Problem: Many atlases = registration takes time...

Proposed solutions:

- Cluster (=group) atlas features offline based on e.g.
 - descriptor similarity
 - spatial distance
- Compute “mean features”
- Match target features to these mean features

Überatlas

Image registration



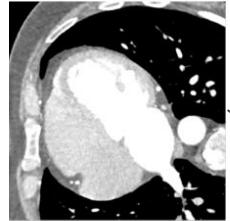
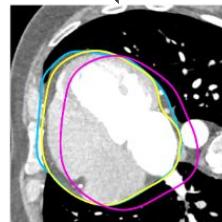
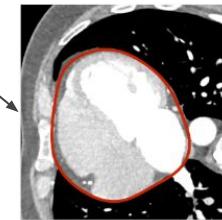


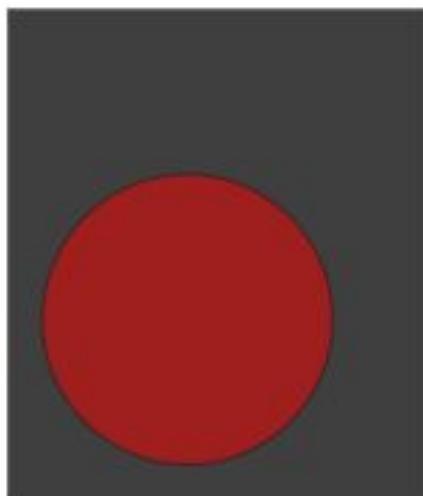
image registration



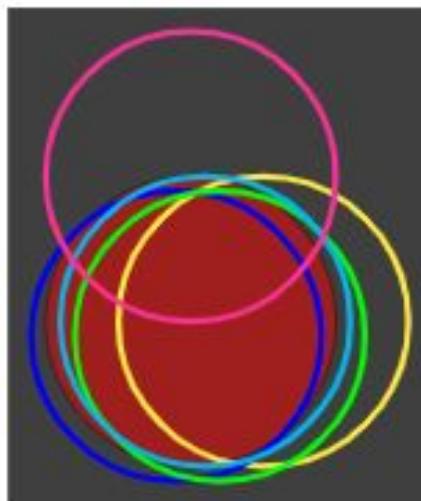
label fusion



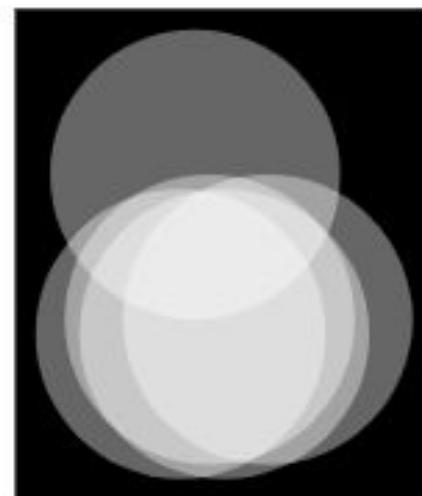
Label fusion



Unlabelled target image

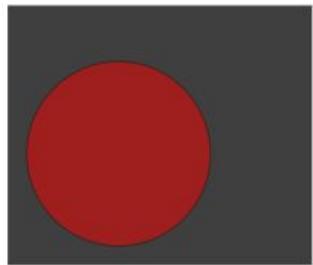


Propagated labels

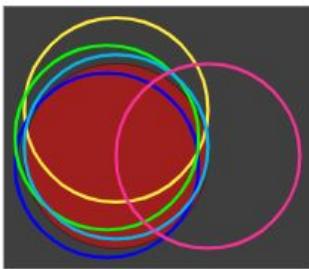


Voting map

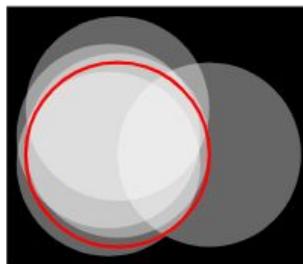
Label fusion



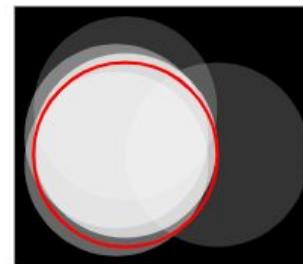
(a) Unlabelled target image



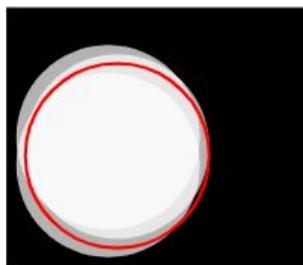
(b) Propagated labellings



(c) Unweighted voting map



(d) Weighted voting map



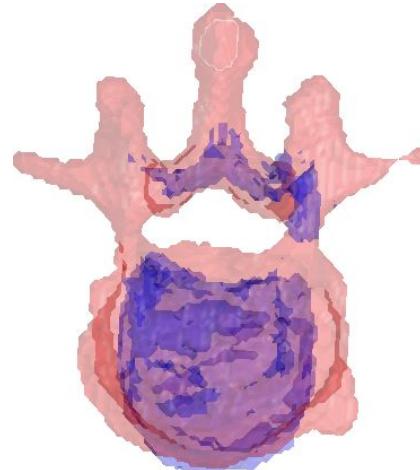
(e) Atlas selection



(f) Best atlas selection

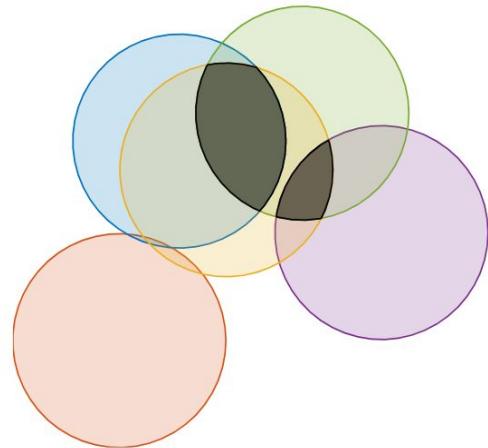
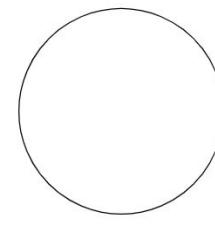
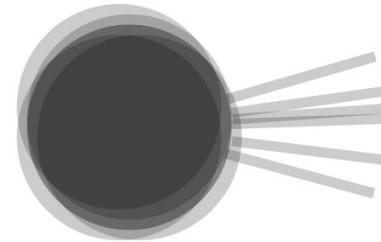
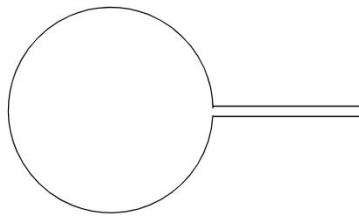
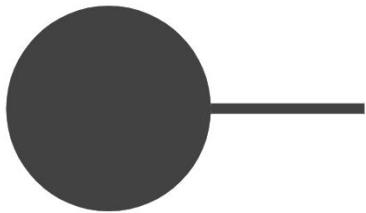
Label fusion

Problem: Lost structures and implausible shapes



Label fusion

Problem: Lost structures and disjoint shapes



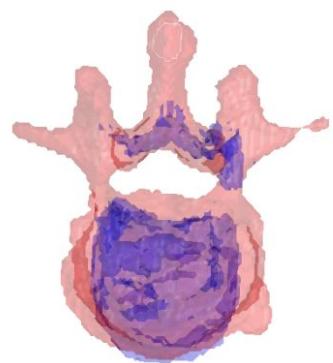
Label fusion

Problem: Lost structures and disjoint shapes

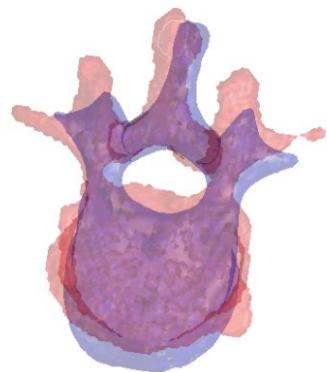
Solution: Add shape model, e.g.

- statistical shape model (point distribution model)
- conditional random fields (CRFs)

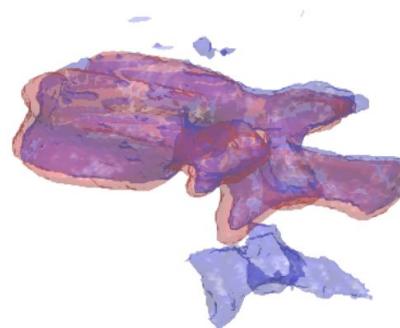
Label fusion



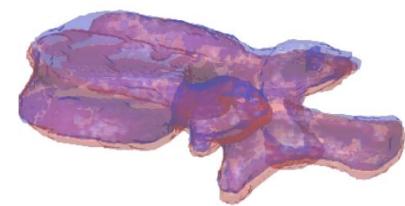
(a) Multi-atlas



(b) Multi-atlas + shape model



(a) Multi-atlas



(b) Multi-atlas + shape model

Summary

- Medical images
 - CT(A), MR, ultrasound, PET
 - CAS, CAD, ...
 - 3D – computationally expensive
 - Noise, low contrast, small-scale structures, large variability, ...
- Deep learning in medical image analysis
 - Hot!
 - GANs, U-net, spatial transformer networks, transfer learning
 - Access to annotated data is limited
- Multi-atlas segmentation
 - Application of feature-based image registration
 - Alternative segmentation technique when data is scarce