Learn2Reg:

Opportunities and Challenges for Data Fusion

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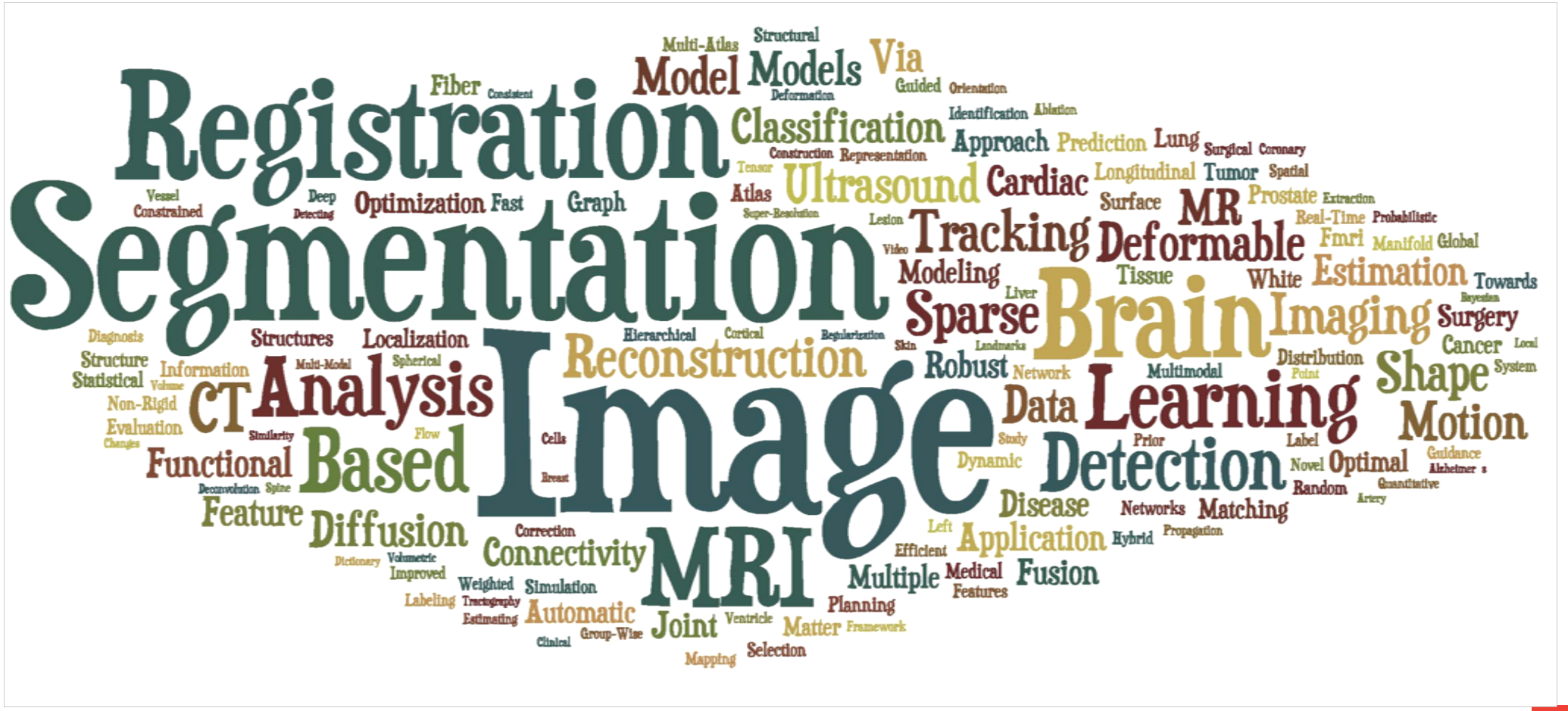
Image registration – a brief MICCAI history (2013)



MICCAI 2013, Nagoya, Japan
– courtesy of Kensaku Mori

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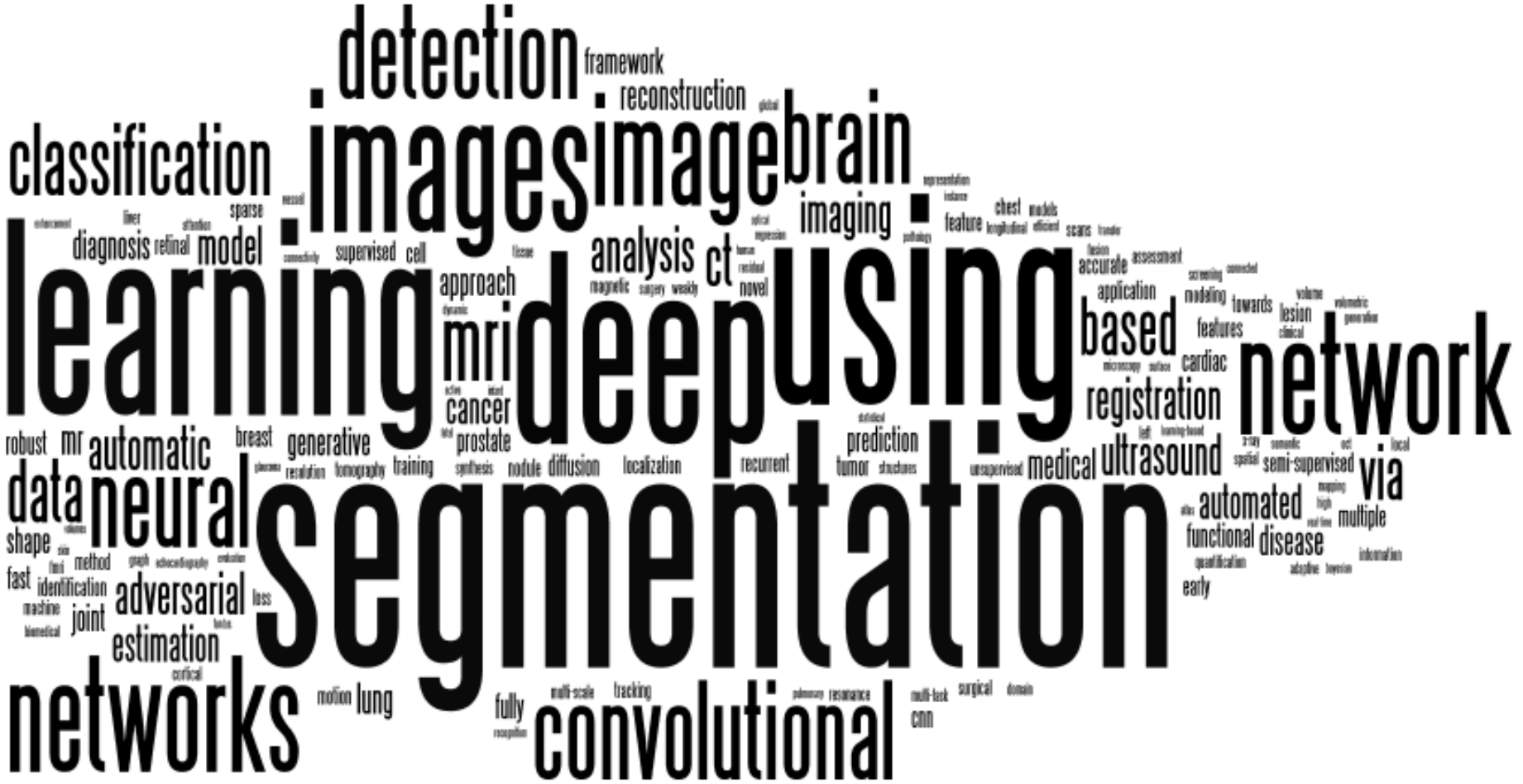
Image registration – a brief MICCAI history (2018)



MICCAI 2018, Granada, Spain

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Image registration – a brief MICCAI history (2018)

- Medical Image Analysis - MICCAI 2018 special issue had 2/9 published papers worked on deep learning for registration:

Unsupervised learning of probabilistic diffeomorphic registration for images and surfaces

Adrian V. Dalca, Guha Balakrishnan, John Guttag, Mert R. Sabuncu

October 2019

Pages 226-236

Adversarial learning for mono- or multi-modal registration

Jingfan Fan, Xiaohuan Cao, Qian Wang, Pew-Thian Yap, Dinggang Shen

December 2019

Page 101545

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Image registration – a brief MICCAI history (2019)

- **MICCAI 2019** – registration papers:
  - 24 papers with the word “registration” in title
  - 17 papers with the word “motion” in title
  - 3 papers with the word “deformation” in title
  - *(did not check for tracking, image guidance, fusion….)*
  - That makes ~44 / 538 accepted papers (~8%)

- Satellite events – 3 registration tutorials but no workshops:
  - **Learn2Reg**
  - AirLab: Autograd Image Registration Laboratory
  - Image Registration during Minimally Invasive Catheter-based Interventions

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Image registration – a brief MICCAI history (2019)

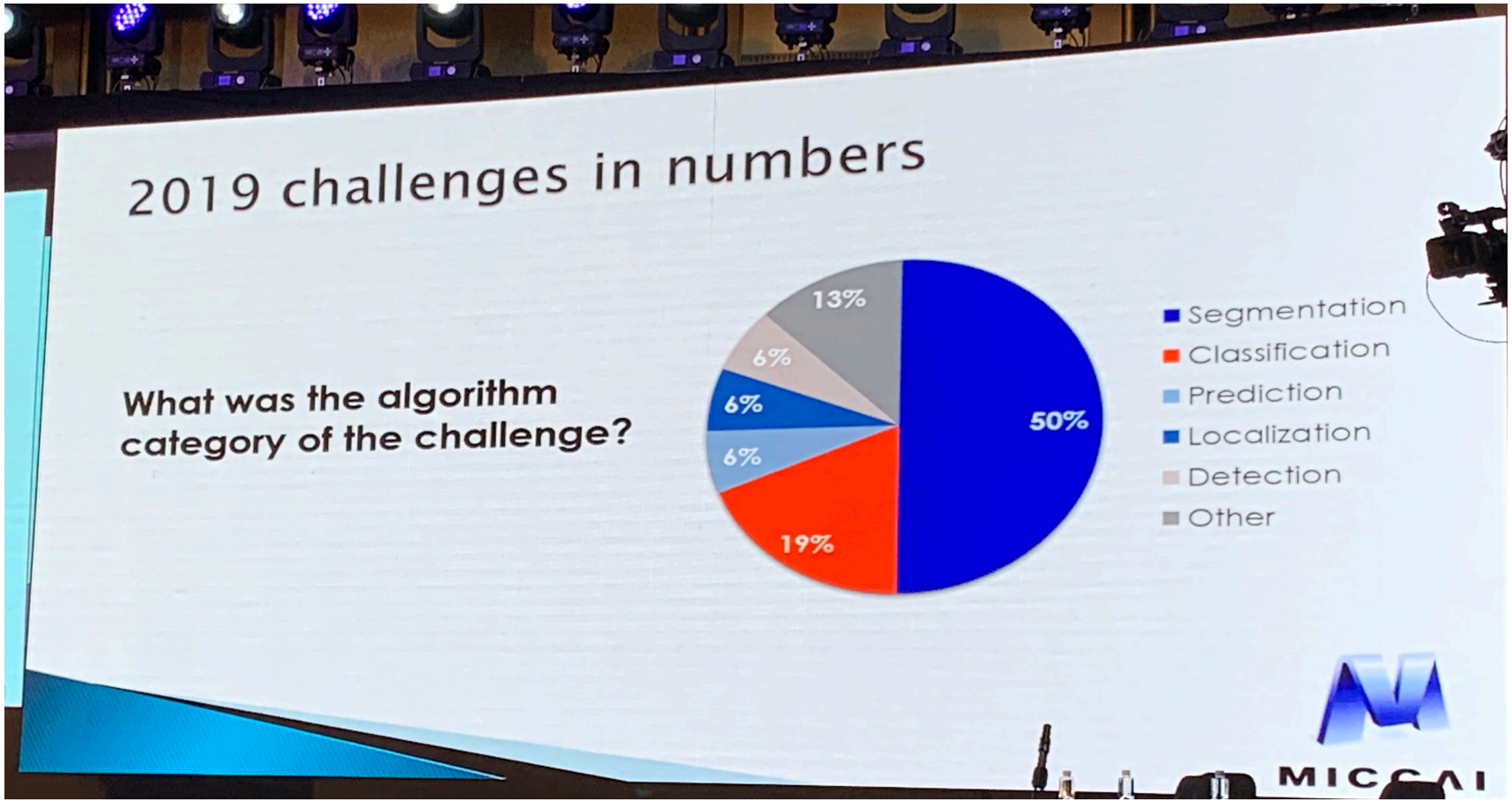

Image registration – a brief WBIR history

- 8th International Workshop on Biomedical Registration 2018:
  - Invited lecture: *"Is image registration a solved problem?"*

WBIR 2018

WBIR 2018 in Leiden, NL
Marius Staring and Stefan Klein

- *Apparently not!*

https://wbir2020.org/

WBIR 2020 in Portorož, Slovenia
Žiga Špiclin, Jamie McClelland, Jan Kybic, and Orcun Goksel

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Opportunities and Challenges

- Deep Learning has made huge advances predominantly in image/disease classification, detection, prediction and segmentation
  - Due to availability of large, annotated/labelled data sets
  - Generally now considered to outperform previous, more traditional methods
  - Still challenges related to domain changes, presence of abnormalities etc

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Opportunities and Challenges

- Image registration still somewhat “limping behind”
  - Due to lack of ground truth annotations, true deformation field etc
  - In deep learning methods, registration often used for data augmentation, preprocessing etc.
- **New deep learning approaches for registration are emerging***

***Introductions to unsupervised, self-supervised, semi- and weakly supervised methods have been given this morning!**

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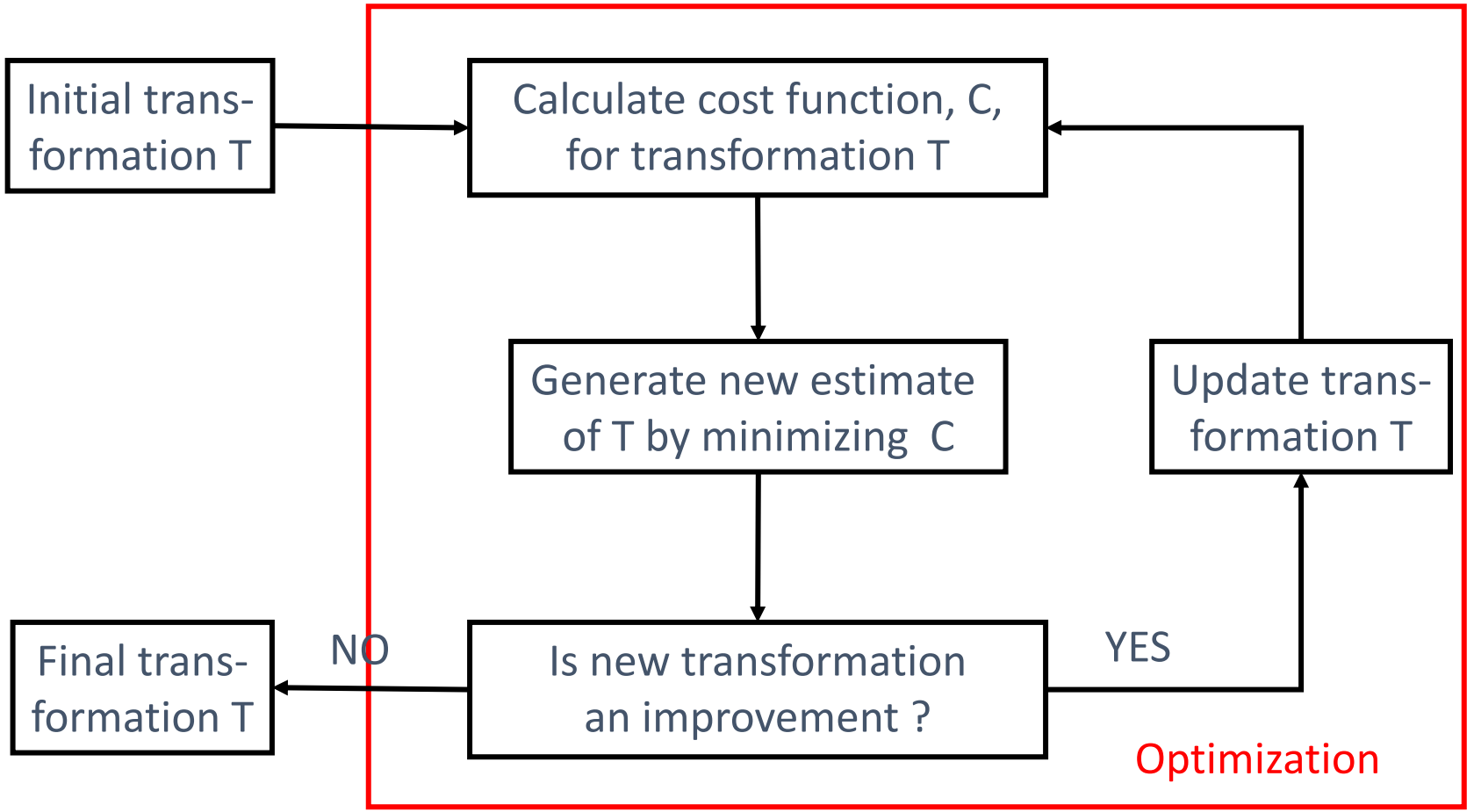
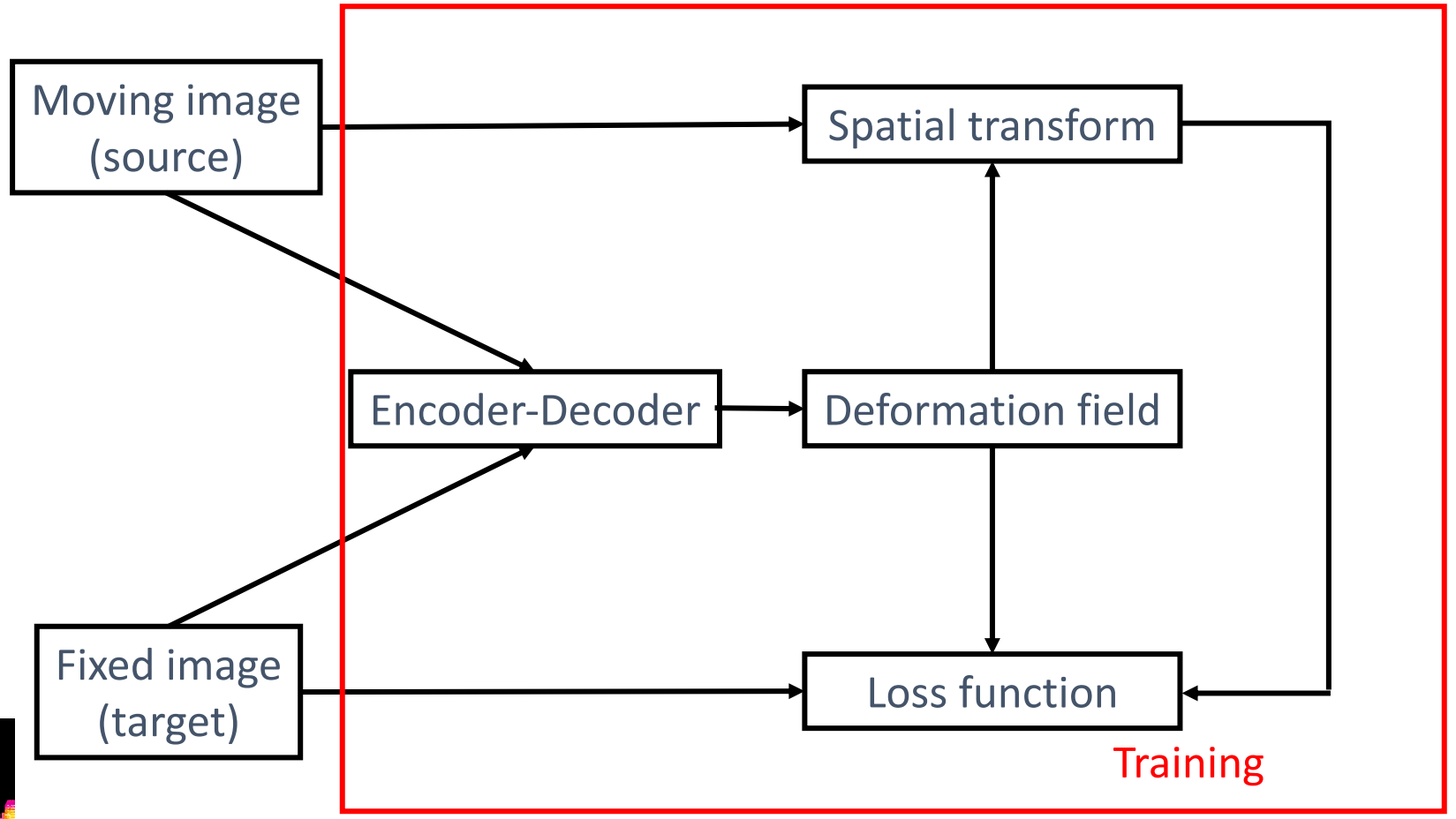
Opportunities and Challenges

- Recall conventional registration:



Opportunities and Challenges

- Model for deep learning registration:



Opportunities and Challenges

- Conventional registration:
  - Requires domain knowledge
    - Single/multi-modal image registration, image protocol used, which organ…
  - Requires robust parameter tuning and setting
    - Weighted cost function, number of resolution levels, …
  - Requires prior information on expected types of deformation:
    - Rigid, affine, deformable, composite, sliding, volume preserving, …

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Opportunities and Challenges

- Deep learning registration:
  - Conventional cost function, transformation, optimisation methods have counterparts in loss function, transformer network, training
  - Training on many image pairs replaces optimisation on single image pair
  - Network architecture design and associated hyperparameters still remain important
  - Super-fast at inference time – but requires training data and training time!
    - And some conventional image registration methods have also near real-time performance and do not require training data – in many cases they now work “out of the box”

Opportunities and Challenges

- Loss function has direct relation to conventional registration cost function!
  - Ie here one can play with almost all existing image similarity and regularization methods **as long as they are differentiable** (as required for backpropagation)
- But this handcrafted loss function also has drawbacks
  - We fall into the same trap as before, as we do not directly learn the image similarity measure (nor the transformation model)
  - Instead, we indirectly tune the weightings in regard to the loss function, by using many representative data pairs
  - We also still face the issue of weighted terms in the loss function

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Opportunities and Challenges

- Same **challenges** as for conventional image registration!
- Lack of sufficient validation criteria:
  - Dice coefficient, target registration error, intensity based measures: *these are all surrogate measures*
  - A lot of focus on inter-subject brain registration (due to availability of labelled data)
  - How good is good enough?
- Clinical value is unclear:
  - Perhaps more clear in image guidance and tracking applications
  - But does image registration – and subsequent image fusion – help in clinical decision making?

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Opportunities and Challenges

- Danger of standing still! We are currently re-creating of what we had before:
  - Rigid and deformable registration
  - Multi-modal registration
  - Diffeomorphic registration
  - *With often superior results on standard datasets* (LBP40 etc)
- Yet researchers are shying away from some of the hard, clinically more relevant problems:
  - Anatomical and disease variability, normal vs abnormal growth patterns, complex physiological motion, new emerging imaging protocols, motion during image acquisition…

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Opportunities and Challenges

- Treating deep learning as a black box in registration *(or anywhere else)* would be a mistake:
  - Need to incorporate prior knowledge:
    - anatomy, physiology, imaging physics
  - Need to discover and study new knowledge obtained but hidden:
    - motion models, weightings and losses
  - Need to find generic solutions that can transfer between domains
    - E.g. low-dose vs high-dose CT, different MR protocols, different radiotracers…
    - *Within reason!*
  - Need to cater for patient-specific vs population-generic problems*
    - Multi-modal, dynamic or longitudinal registration is patient specific
    - Atlases and cross-sectional registration need to work for a population

*We could make that same argument for disease-specific or organ-specific registration

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Some opportunities – and challenges – illustrated:

- Case study 1: Fetal head compounding
  - We are following a moving target …
  - … with a manually held ultrasound probe …
  - … making this highly operator dependent …
  - … and don't even mention the artefacts (shadows due to attenuation)!

Robert Wright et al. "Complete Fetal Head Compounding from Multi-View 3D Ultrasound", *MICCAI 2019*

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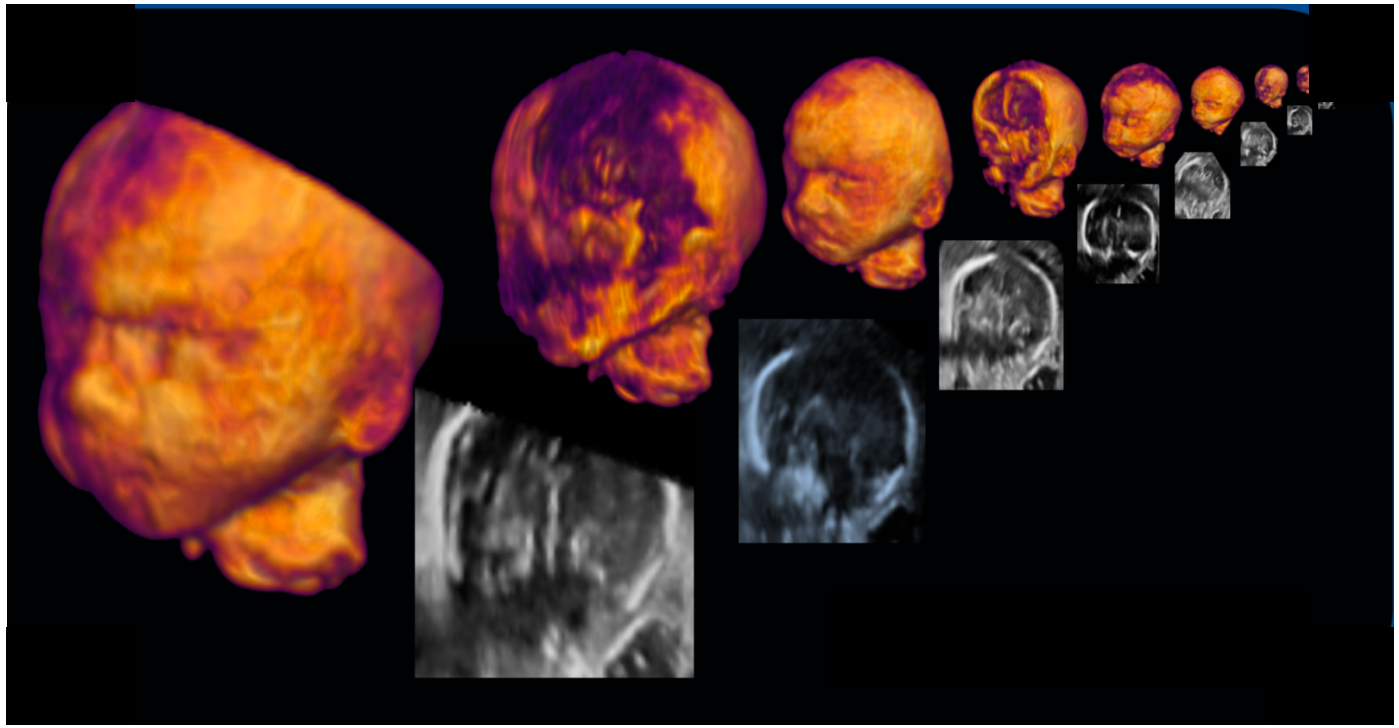
Some opportunities – and challenges – illustrated:

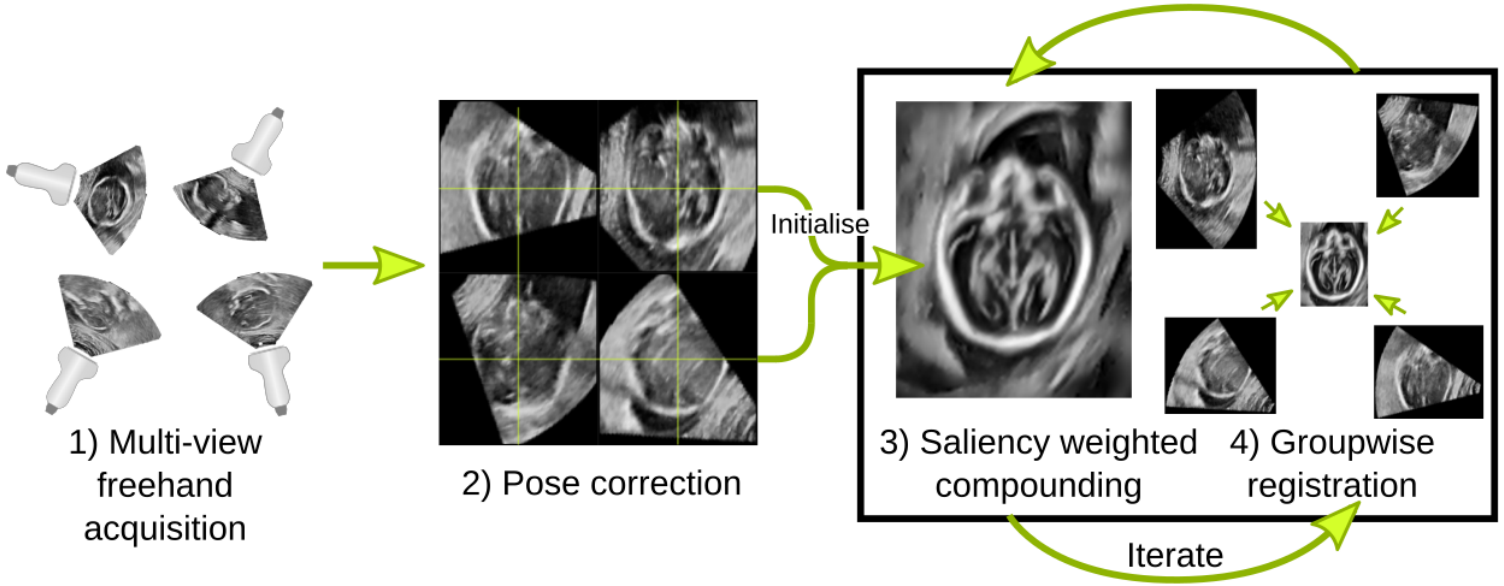
- Case study 1: Fetal head compounding
  - Register the moving head (we can stay rigid)



Robert Wright et al. "Complete Fetal Head Compounding from Multi-View 3D Ultrasound", *MICCAI 2019*

Some opportunities – and challenges – illustrated:

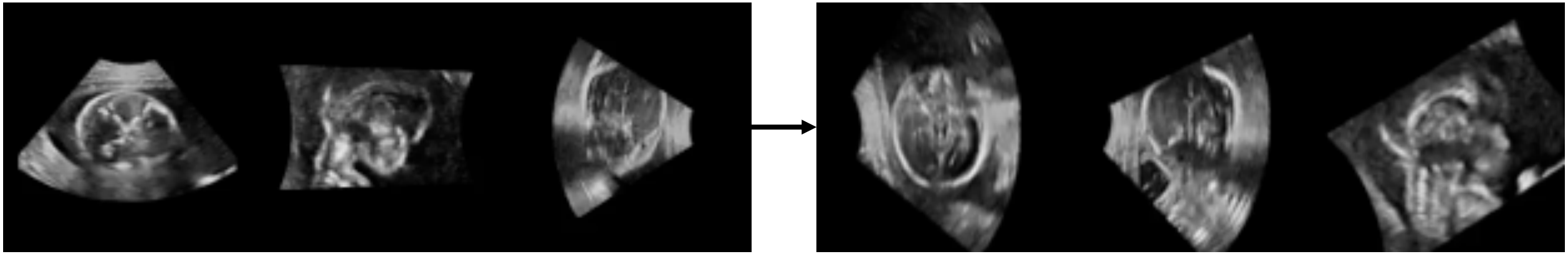
- Case study 1: Fetal head compounding
  - Iterative spatial transformer network gives a precise alignment given any initial orientation.
  - Robust to fast fetal / probe movement where previous methods fail.



Robert Wright et al. "Complete Fetal Head Compounding from Multi-View 3D Ultrasound", *MICCAI 2019*

Some opportunities – and challenges – illustrated:

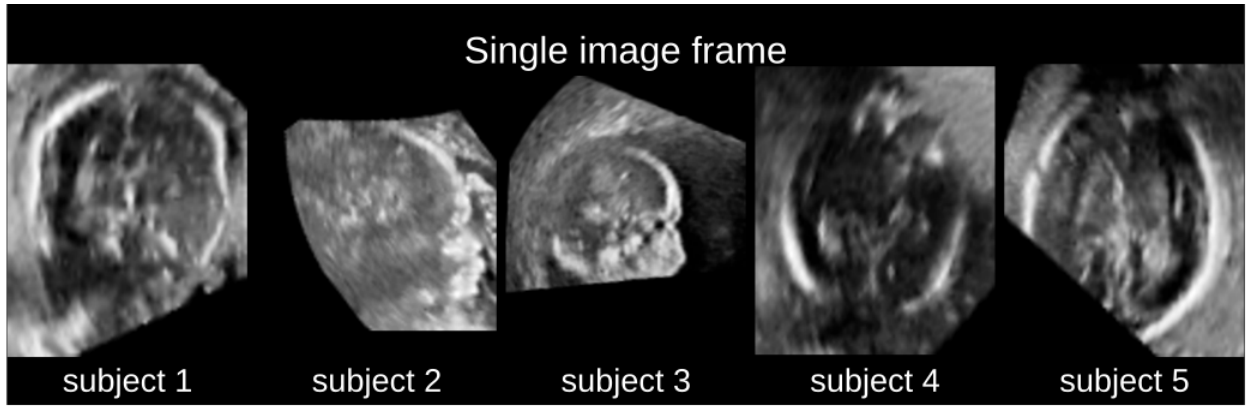
- Case study 1: Fetal head compounding
  - Pose correction of multi-view images:

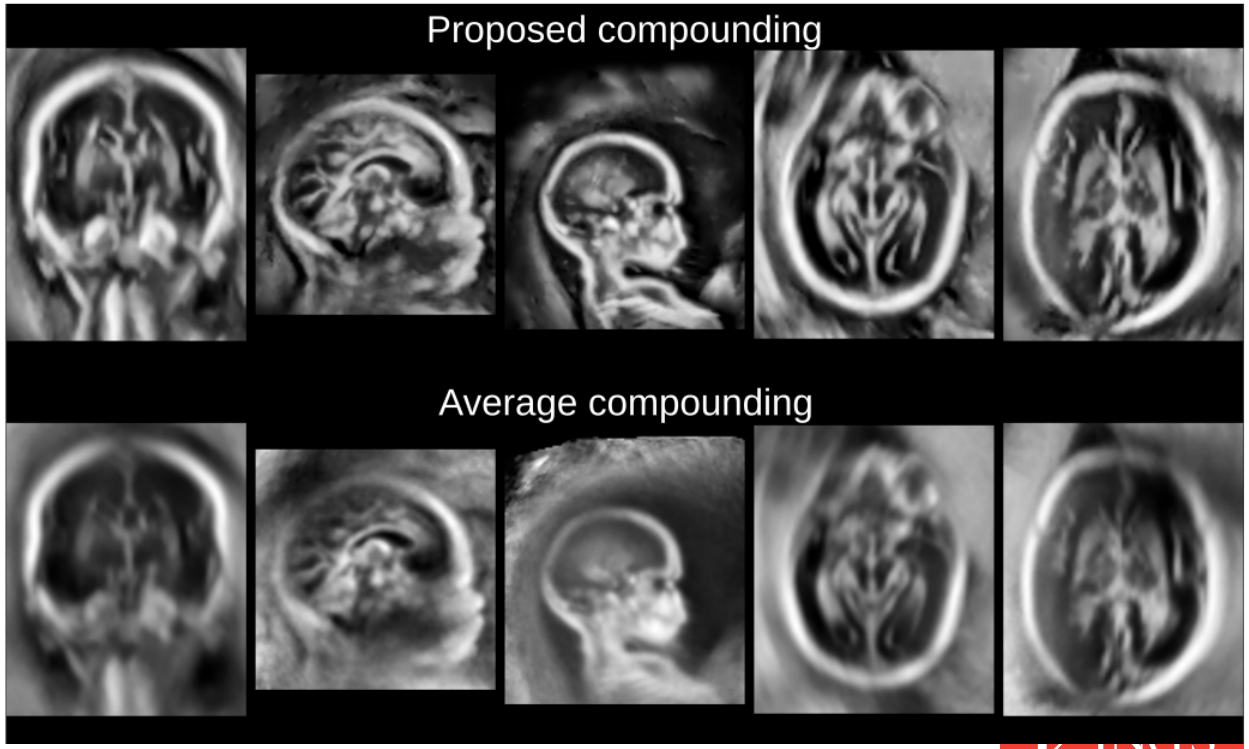


Robert Wright et al. "Complete Fetal Head Compounding from Multi-View 3D Ultrasound", *MICCAI 2019*

Some opportunities – and challenges – illustrated:

- Case study 1: Fetal head compounding
  - Iterative compounding with saliency weighting:

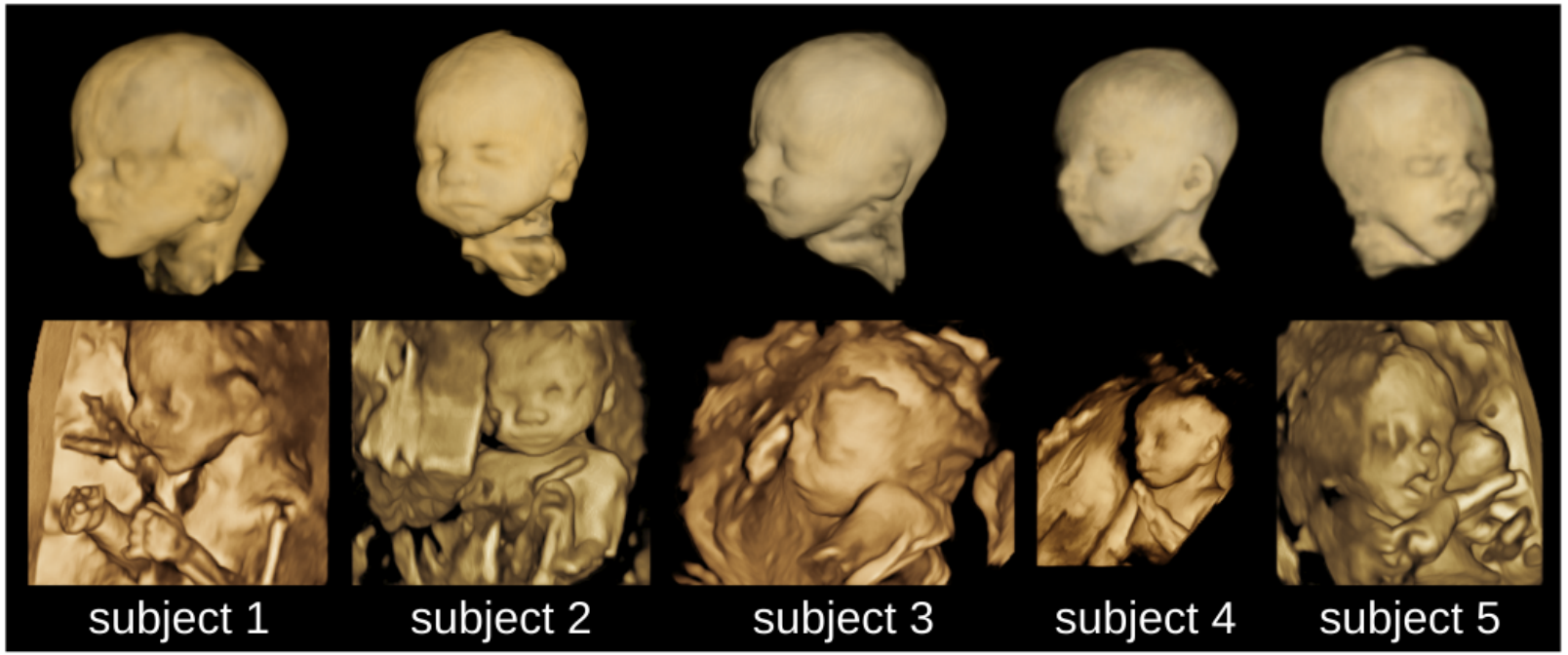




Robert Wright et al. "Complete Fetal Head Compounding from Multi-View 3D Ultrasound", *MICCAI 2019*

Some opportunities – and challenges – illustrated:

- Case study 1: Fetal head compounding
  - Rendering result for visualization:



Robert Wright et al. "Complete Fetal Head Compounding from Multi-View 3D Ultrasound", *MICCAI 2019*

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Some opportunities – and challenges – illustrated:

- Case study 2: Fetal head compounding
  - Remaining challenges:
    - Ultrasound frame rate – ultimately we want to do this real-time
    - Ultrasound distortion – currently solved with conventional, low-parameter B-spline registration
    - Pose correction still requires initial registration to an atlas – which has been formed by conventional registration
    - Small deformations of fetus – swallowing fluid, opening/closing lips, …
    - Large deformations of fetus – moving limbs near face, sucking thumb, …

Robert Wright et al. "Complete Fetal Head Compounding from Multi-View 3D Ultrasound", *MICCAI 2019*

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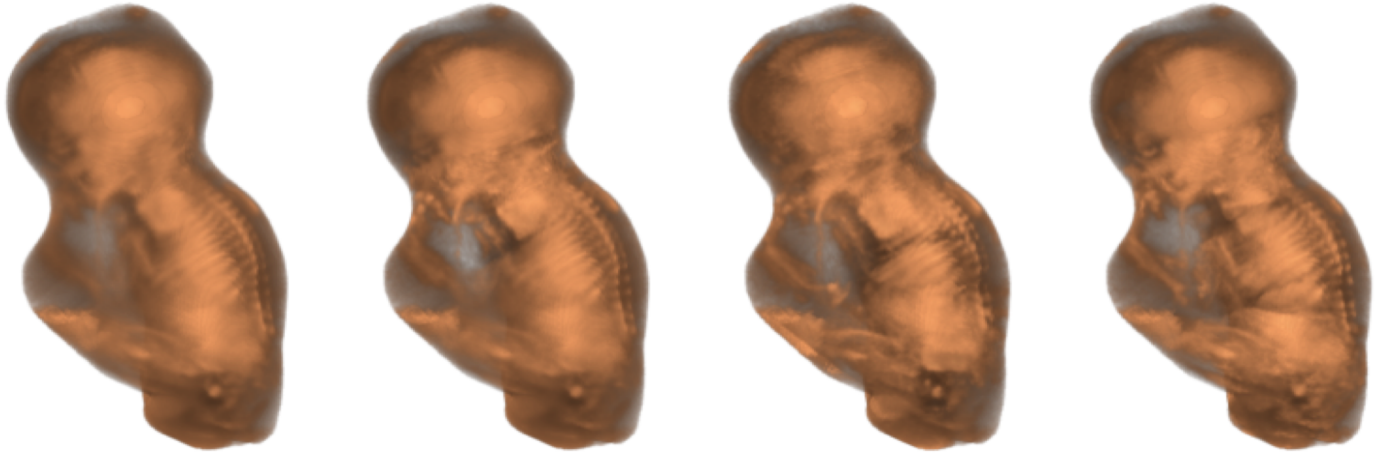
Some opportunities – and challenges – illustrated:

- Case study 2: Whole fetal body compounding
  - We are still following a moving target with ultrasound …
  - … which is way too big to image in one go …
  - … and now also moving limbs and doing summersaults!



Alberto Gomez et al.. "Image Reconstruction in a Manifold of Image Patches: Application to Whole-fetus Ultrasound Imaging"

MICCAI 2019 workshop MLMIR – machine Learning for Medical Image Reconstruction. ***Today at 16:30***

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Thank you!

<- Today at 16:30

MLMIR El Chino 4

wellcome EPSRC centre medical engineering

iFIND

Contact me (julia.schnabel@kcl.ac.uk) on:

- **PhD places available in Smart Medical Imaging**
- **PostDoc positions available in AI for early detection of disease and prognosis of outcome**

(Some even require novel registration!)

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