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# Deep Learning for Advanced Image Segmentation and Registration: Applications in Placenta Contraction Detection and 4D MRI Movement Tracking

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**leap**<sup>w</sup>

leap

NEW \$50M PROGRAM

**In Utero**

MEASUREMENT AND MODELLING  
DURING GESTATIONAL DEVELOPMENT



**SWiRL**

Stillbirth: When is Risk Low?



# Background

- Every 16 seconds one baby is stillborn, this amounts to more than two million stillborn babies globally every year.
- Stillbirths have long-lasting personal and psychological consequences for parents, as well as substantial costs for wider society.

**“Experiencing a stillbirth during pregnancy or childbirth is a tragedy insufficiently addressed in global agendas, policies and funded programmes.**

**There are psychological costs to women, especially women, and their families, such as maternal depression, financial consequences and economic repercussions, as well as stigma and taboo.”**

– World Health Organization

<https://wellcomeleap.org/inutero/>



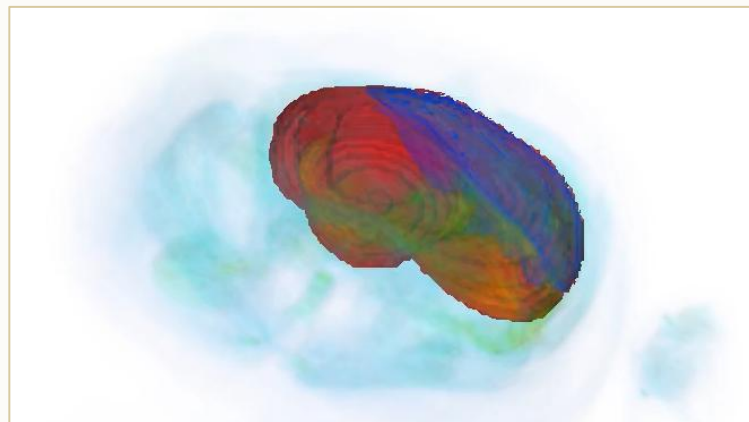
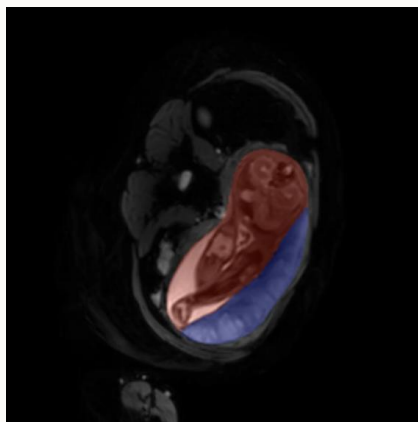
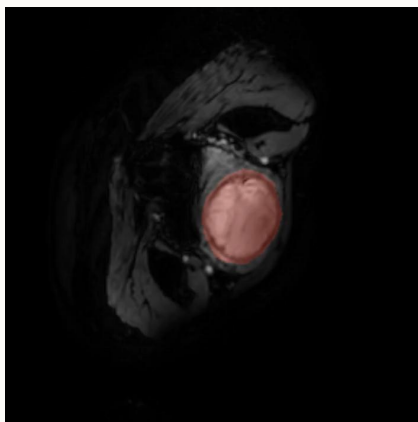
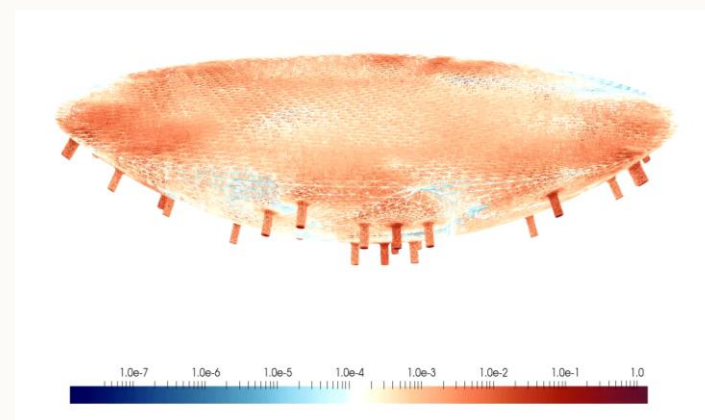
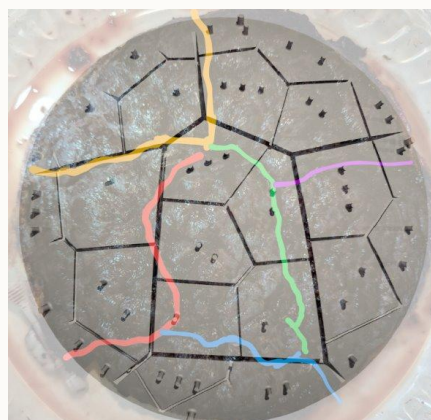
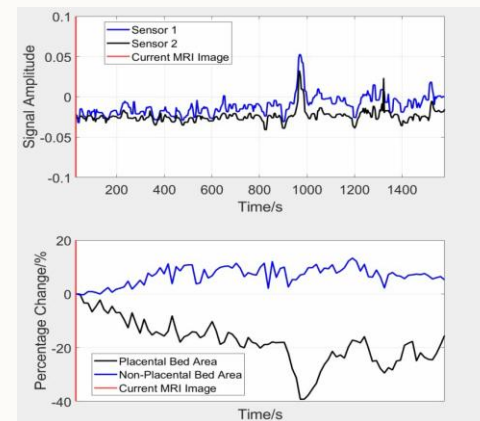
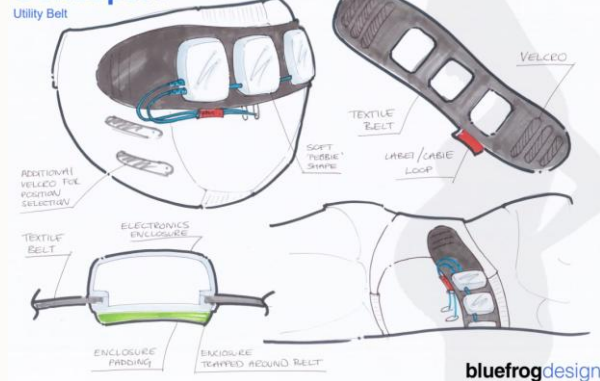


# Background

## Data

- Placental Contraction Monitor (PCM) data
- Biophysical data & Mathematical model from placenta (Oxygen levels and transport, ...)
- Clinical data (Age, blood pressure, ...)
- **4D dynamic MRI uterus data**

### Concept A



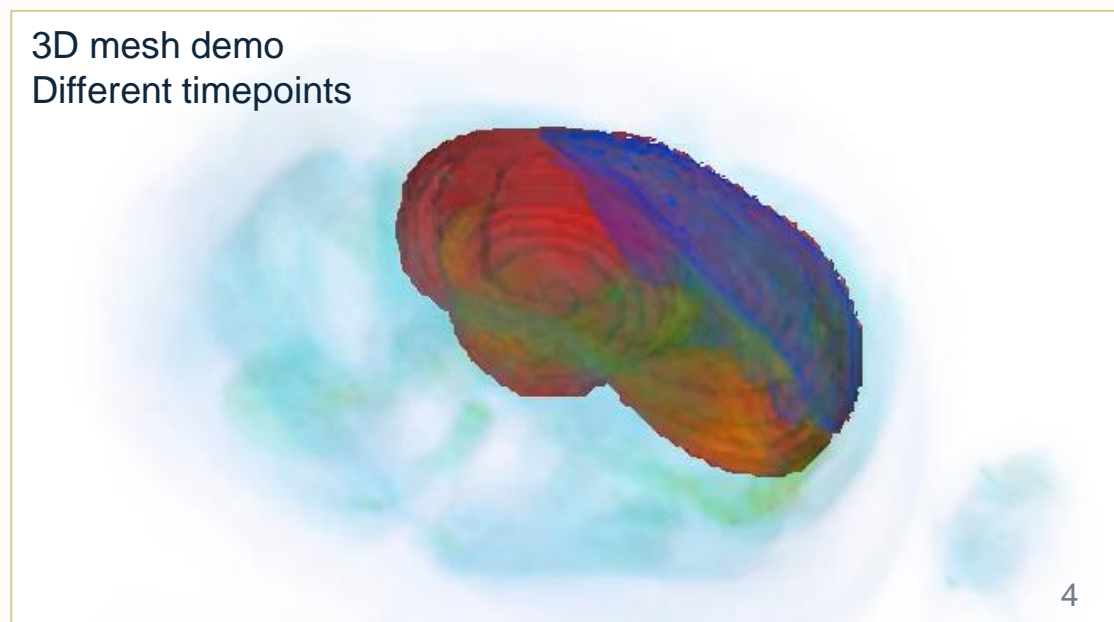
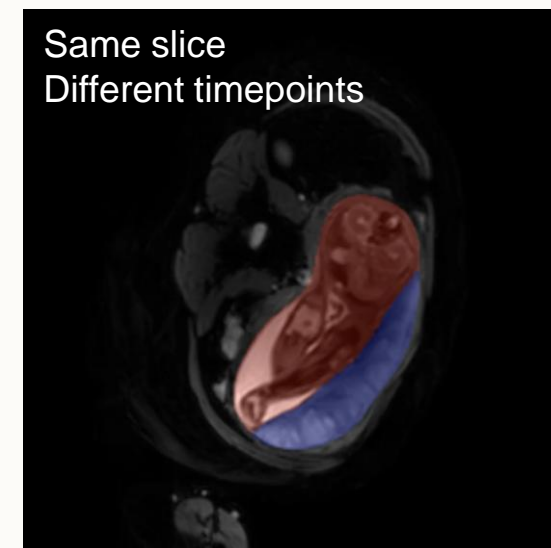
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30	11			



# Background

## 4D dynamic MRI in Prenatal Imaging

- Usage:
  - **Still birth prediction** (through placenta contraction)
  - Placenta health
  - Fetal development
  - etc.
- Challenges:
  - Large data volumes (3D volume with multiple timepoints)
  - Complex movements (baby kick, heartbeat, placenta contraction, ...)
  - Manual segmentation workload for regions of interest (ROI)





# Activities

## Automatic Utero & Placenta **Segmentation** and Placenta **Contraction** Detection

- **Aims:** build a model that can automatically segment the image and detect placenta contractions.
- **Objectives:**
  - **Fully automatic:** after model trained, fully automatic segmentation without additional annotations.
  - **Accurate segmentation:** identify the uterus and placenta regions.
  - **Contraction detection:** Detect and track placenta contractions.

## Track Movement in 4D Dynamic MRI through Image **Registration**

- **Aim:** create a pipeline to track movement in 4D MRI with minimal human input.
- **Objectives:**
  - **Minimize human work:** Automate tracking as much as possible.
  - **Flexible region tracking:** Allow easy editing and customization of target regions (e.g., placenta, fetal).
  - **Flexible with timepoints:** Adaptable to varying numbers of timepoints.
  - **Fast inference:** Use a faster model architecture to speed up inference time.



# Activities

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# Activity 1 – Segmentation & Contraction

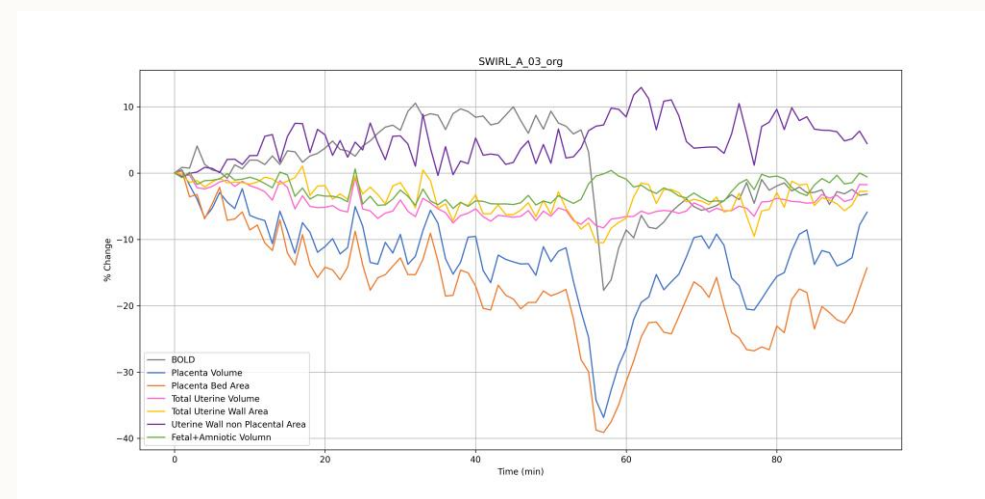
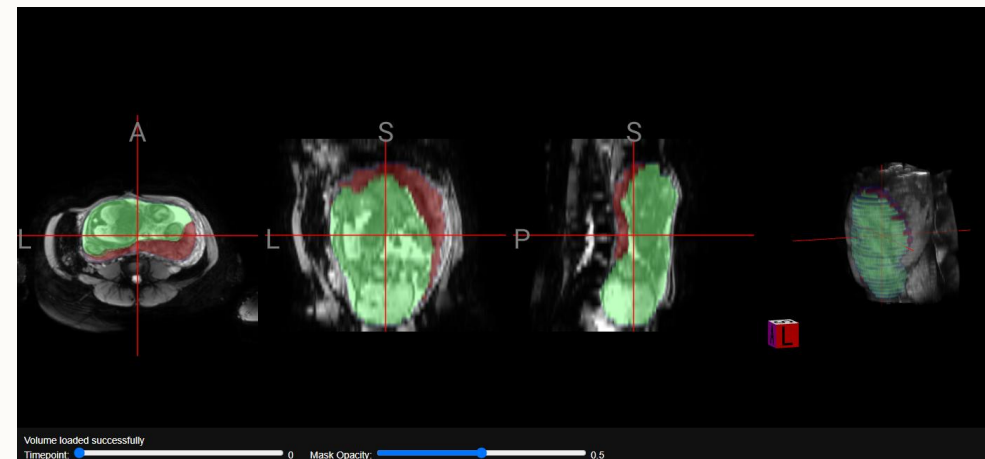
## Segmentation:

- Model: nn-UNet v2<sup>[1]</sup>
- Data:
  - Training: **169** manually segmented volumes from **39** individuals.
  - Validation: **4616** 2D slices.
- Results:

➤ 4D masks (uterus & placenta) for 4D MRI image. Dice coefficient (mean  $\pm$  std), larger is better:

Whole Uterus	Placenta
$0.9350 \pm 0.0256$	$0.8333 \pm 0.1234$

➤ Segmentation curves (e.g. % changes of volumes / wall lengths).



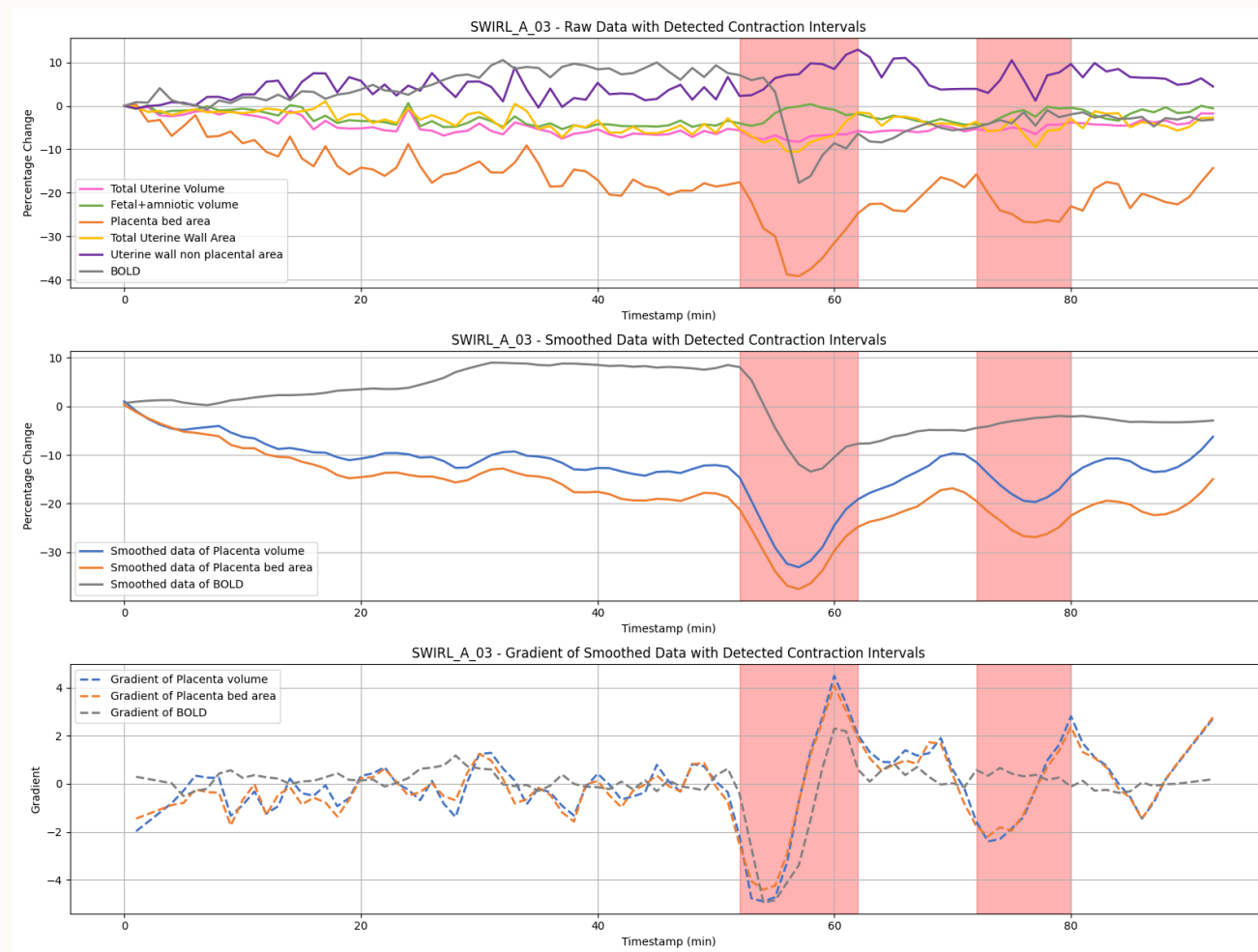


# Activity 1 – Segmentation & Contraction

## Contraction Detection:

- Draw curves based on the Utero & Placenta segmentations from the segmentation model.
- Gradient based contraction detection:
  - 1) Smooth the original line.
  - 2) Calculate local gradient.
  - 3) Detect  $\text{value} < -\text{std} * [\text{factor}]$
  - 4) Agreement ( $\geq 2$ ) of **Placenta volume**, **Total Uterine Volume** and **BOLD**.
- Code hosted on GitHub:

<https://github.com/InUtero-SWIRL/PCx-detection>

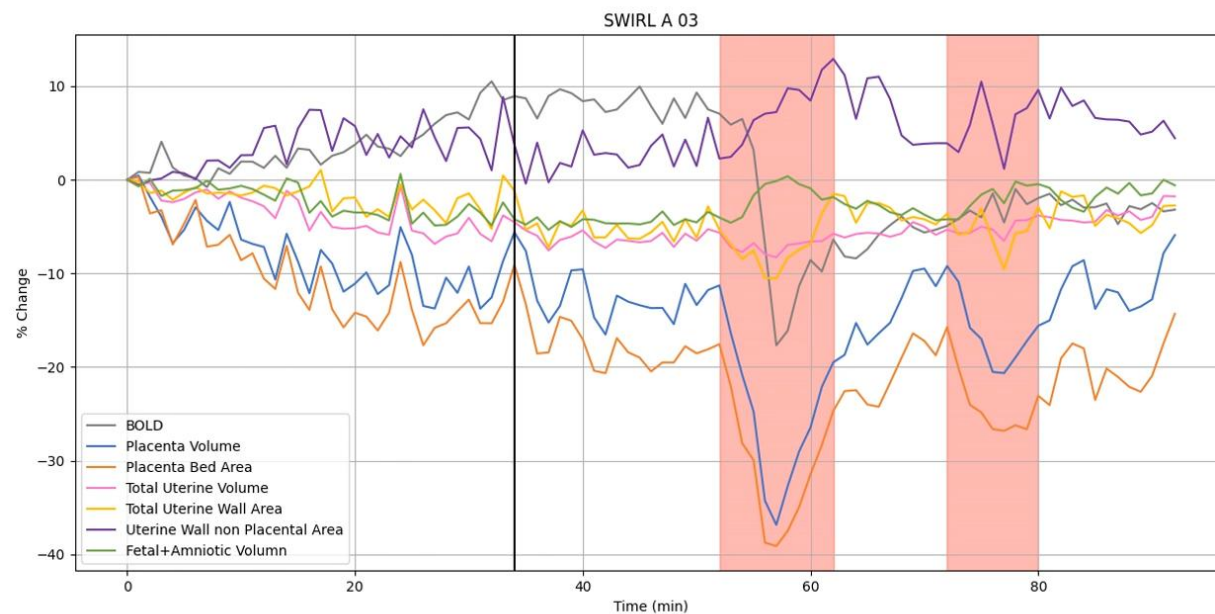
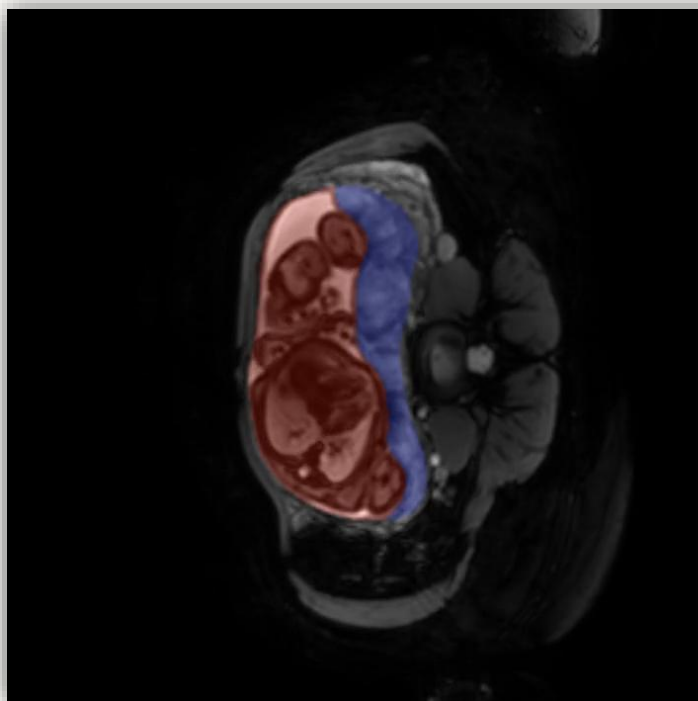


Example (SWIRL A 03): The three rows of graphs represent: 1) original curve, 2) smoothed curve, 3) local gradient curve. The **vertical red region** indicates the detected contractions.



# Activity 1 – Segmentation & Contraction

Example: 4D dynamic MRI with Contractions





# Activities

## Automatic Utero & Placenta **Segmentation** and Placenta **Contraction** Detection

- **Aims:** build a model that can automatically segment the image and detect placenta contractions.
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  - **Contraction detection:** Detect and track placenta contractions.

## Track Movement in 4D Dynamic MRI through Image **Registration**

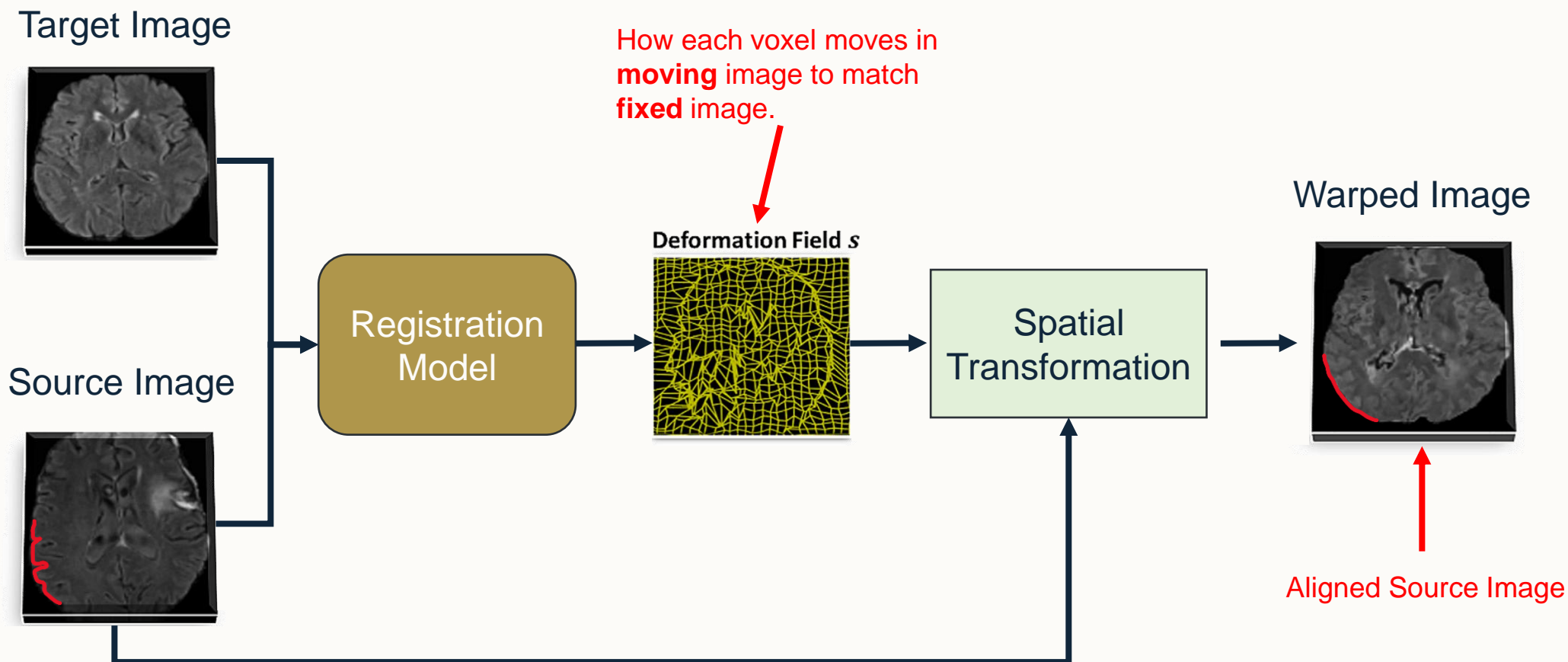
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# Activity 2 – Registration & Movement

## Deep learning-based Deformable Image Registration:

Align one image (source) to another image (target)





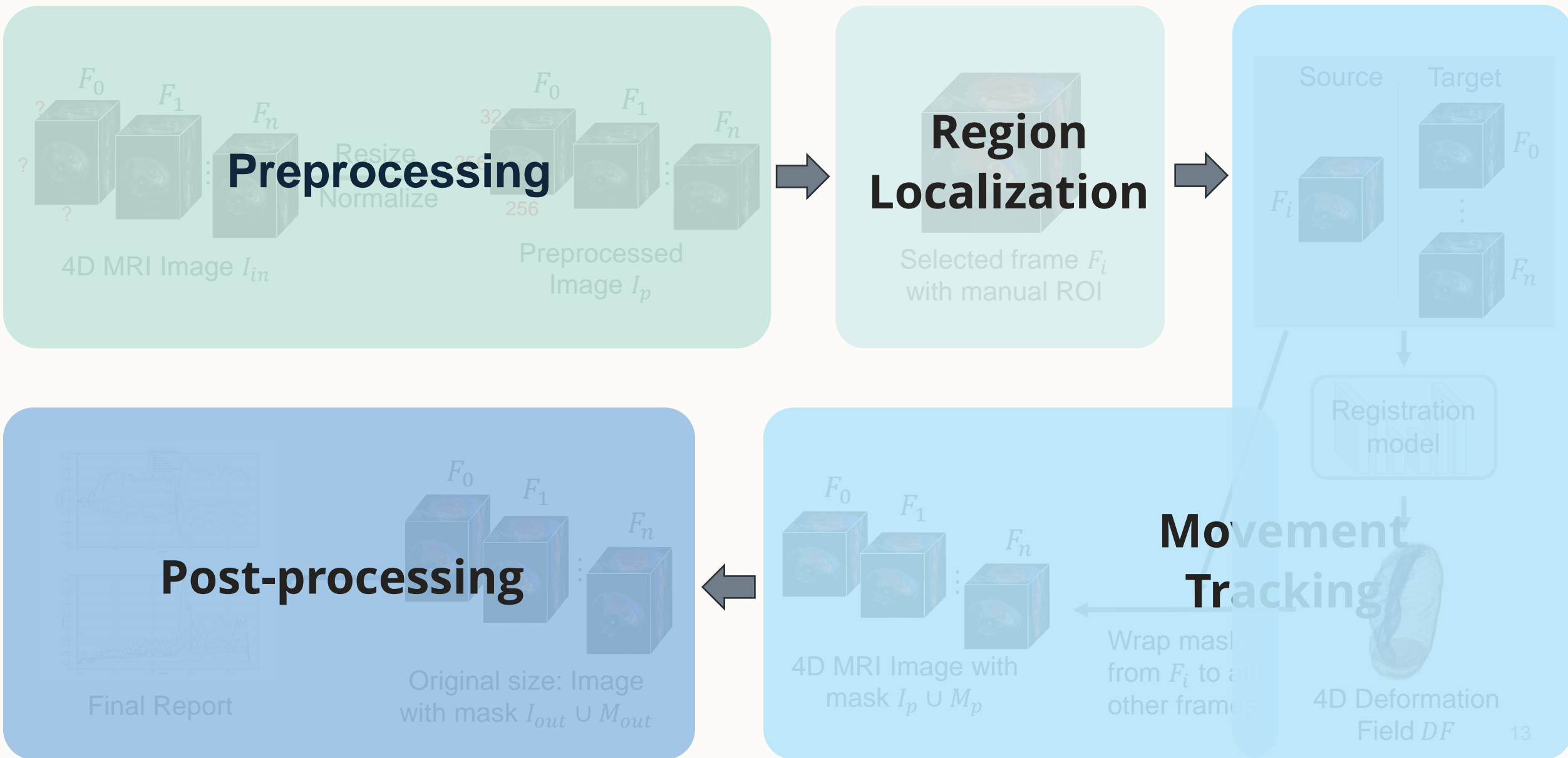
# Activity 2 – Registration & Movement

## Pipeline

- Input: 4D image with ROIs (masks) for one frame (3D Volume)
- Outputs:
  - Deformation field
  - ROIs (masks) for all frames (whole 4D image)
  - Curves indicate the movement of each ROI (mask)
- Method:
  - Model: MrRegNet<sup>[4]</sup> -- a deep learning based deformable image registration network
  - Training data: Unannotated paired 3D MRI images



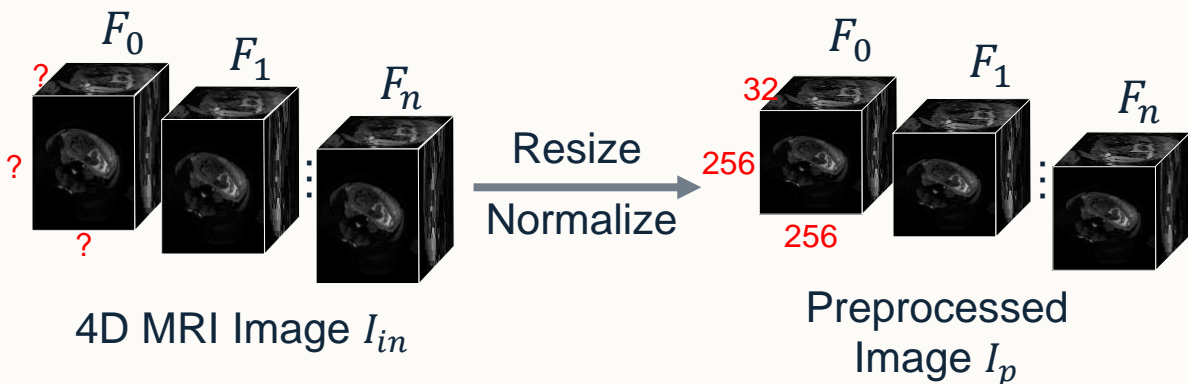
# Activity 2 – Registration & Movement





# Activity 2 – Registration & Movement

## Preprocessing



## Region Localization

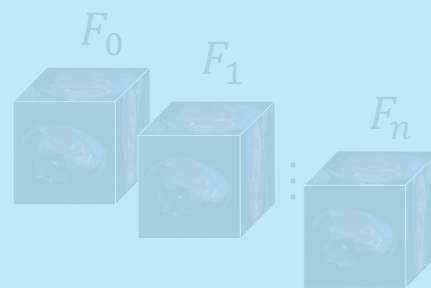
Selected frame  $F_i$   
with manual ROI

Source Target



Registration  
model

## Movement Tracking



Wrap mask  
from  $F_i$  to all  
other frames

4D Deformation  
Field  $DF$

## Post-processing

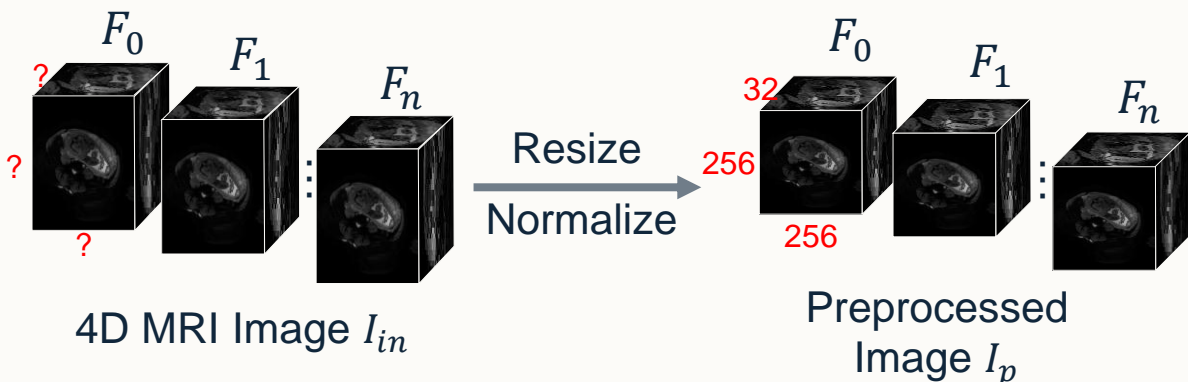
Final Report

Original size: Image  
with mask  $I_{out} \cup M_{out}$

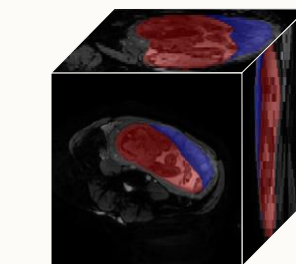


# Activity 2 – Registration & Movement

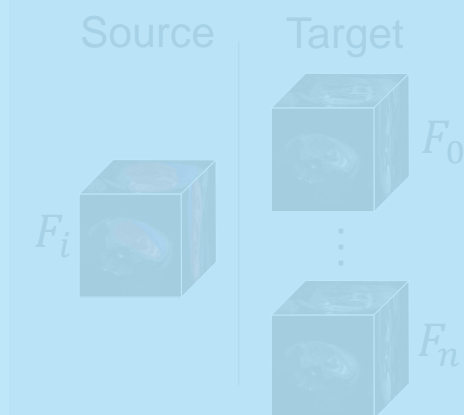
## Preprocessing



## Region Localization

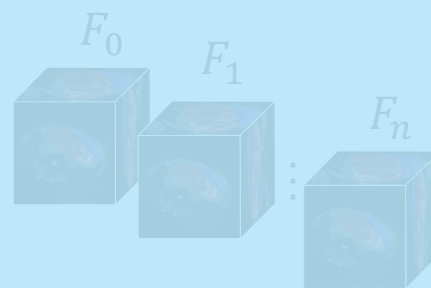


Selected frame  $F_i$   
with manual ROI



Registration  
model

## Movement Tracking



4D MRI Image with  
mask  $I_p \cup M_p$

Wrap mask  
from  $F_i$  to all  
other frames

4D Deformation  
Field  $DF$

## Post-processing



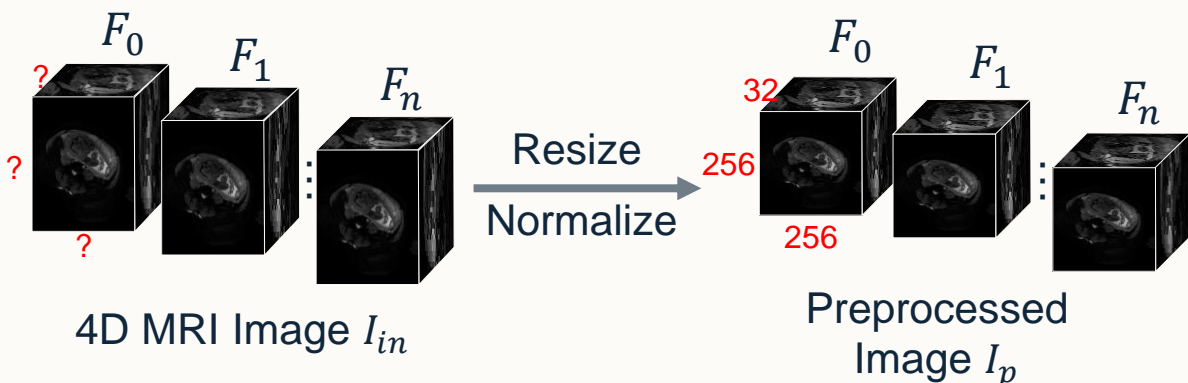
Original size: Image  
with mask  $I_{out} \cup M_{out}$

Final Report

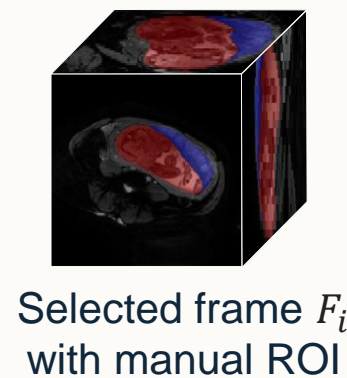


# Activity 2 – Registration & Movement

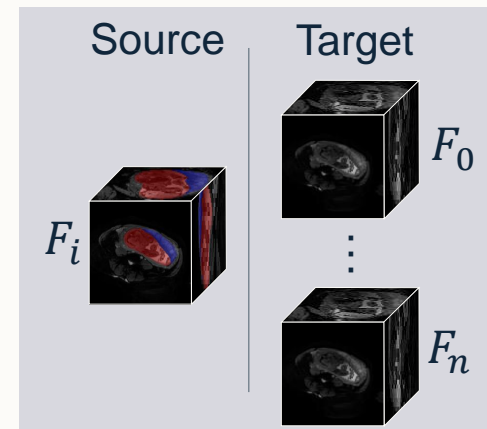
## Preprocessing



## Region Localization



## Movement Tracking

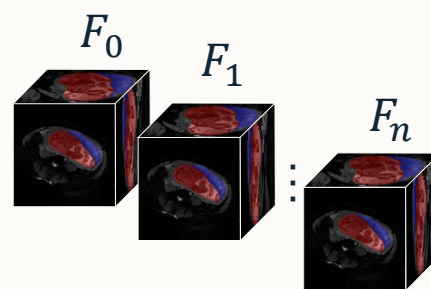


Registration  
model



4D Deformation  
Field  $DF$

Wrap mask  
from  $F_i$  to all  
other frames



4D MRI Image with  
mask  $I_p \cup M_p$

## Post-processing

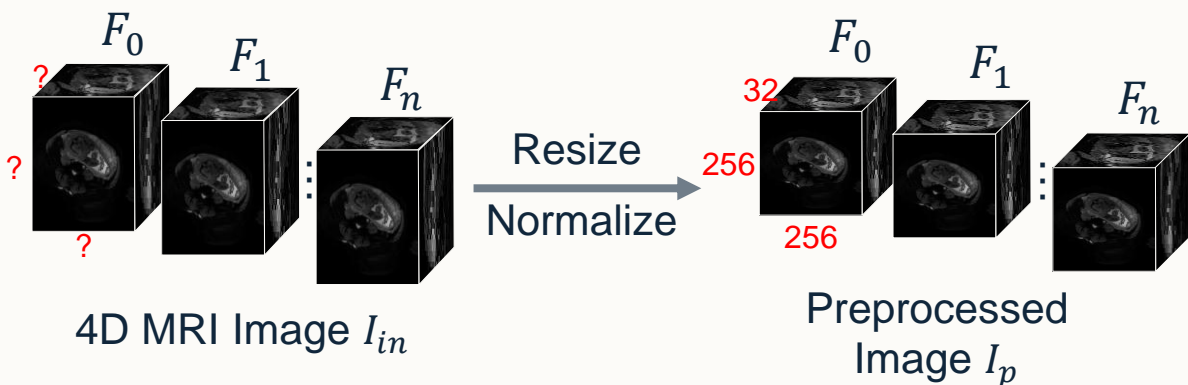
Final Report

Original size: Image  
with mask  $I_{out} \cup M_{out}$

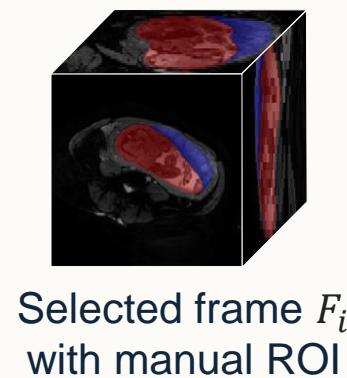


# Activity 2 – Registration & Movement

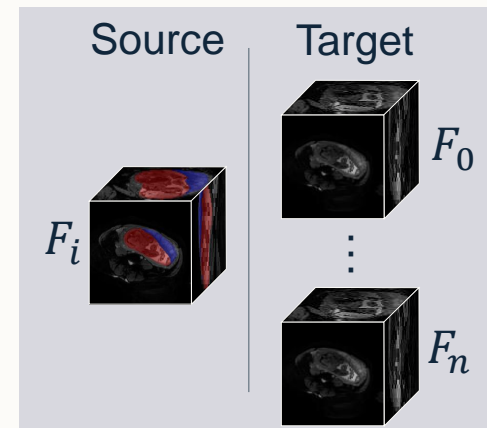
## Preprocessing



## Region Localization



## Movement Tracking

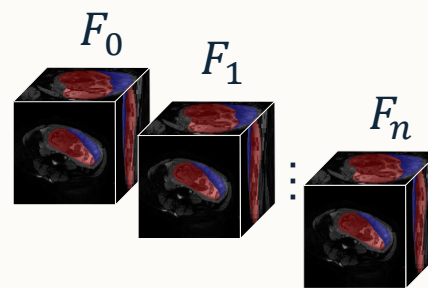


Registration  
model



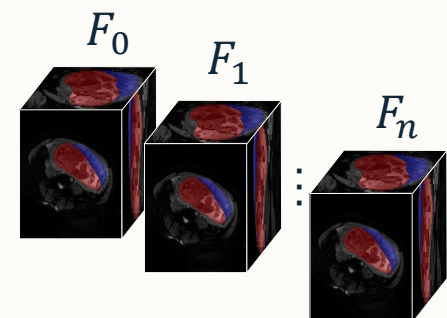
4D Deformation  
Field  $DF$

Wrap mask  
from  $F_i$  to all  
other frames

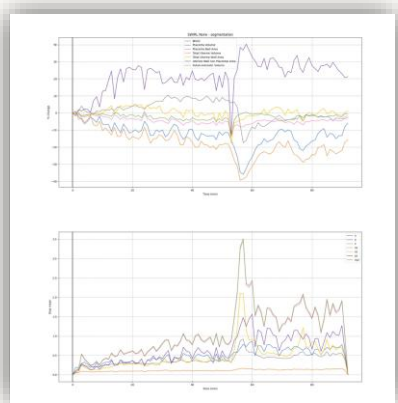


4D MRI Image with  
mask  $I_p \cup M_p$

## Post-processing



Original size: Image  
with mask  $I_{out} \cup M_{out}$



Final Report



# Activity 2 – Registration & Movement

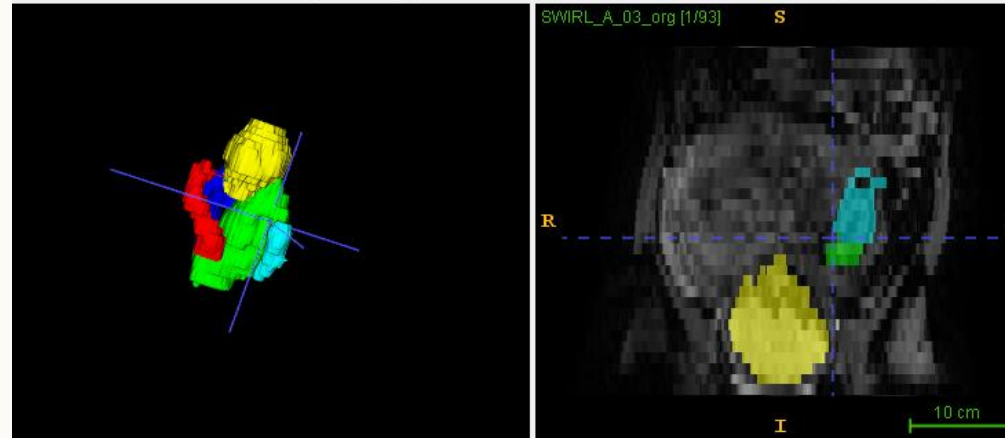
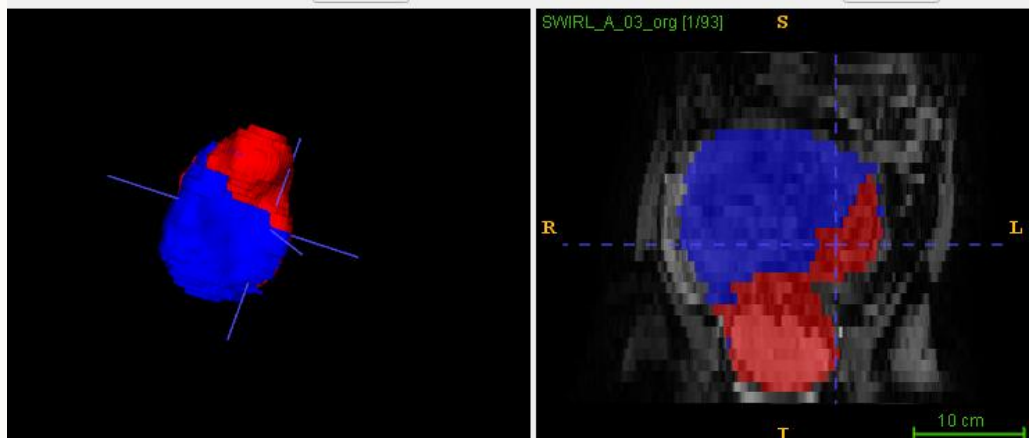
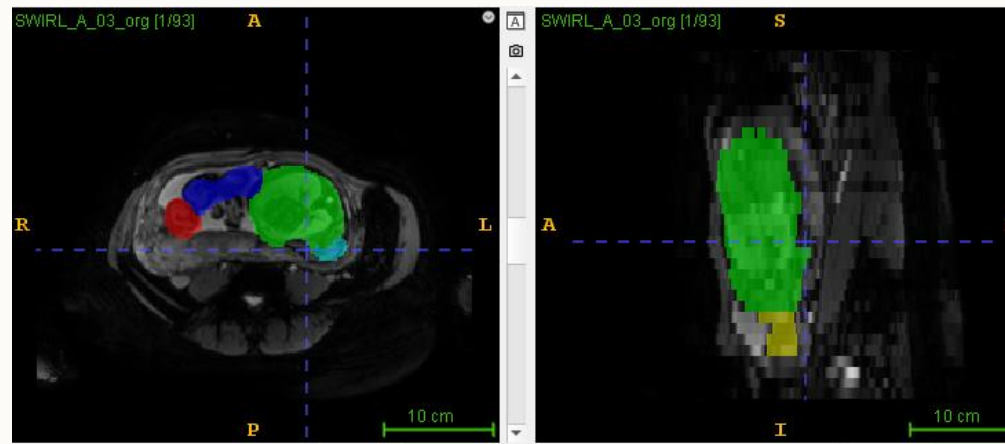
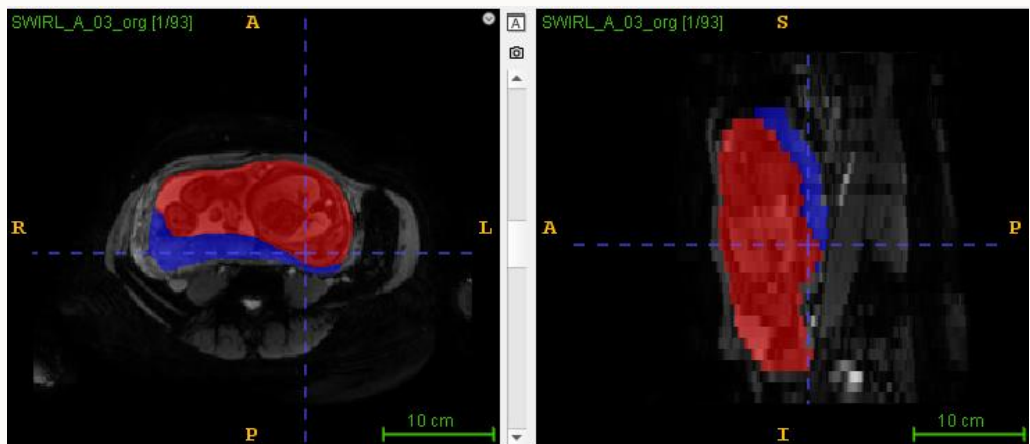
## Pipeline

- Input: 4D image with ROIs (masks) for one frame (3D Volume)
- Outputs:
  - Deformation field
  - ROIs (masks) for all frames (whole 4D image)
  - Curves indicate the movement of each ROI (mask)
- Input: 4D image only
- Outputs:
  - Deformation field
  - Curve indicate the global movement of 3D volume



# Activity 2 – Registration & Movement

## Examples:



Red: utero  
Blue: placenta

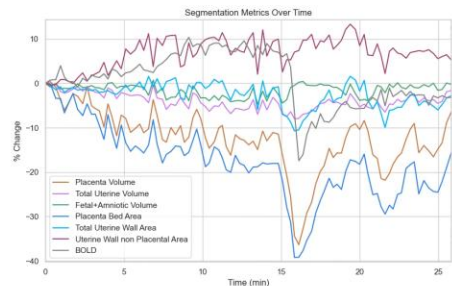
Yellow: head  
Green: body  
Others: arms + legs



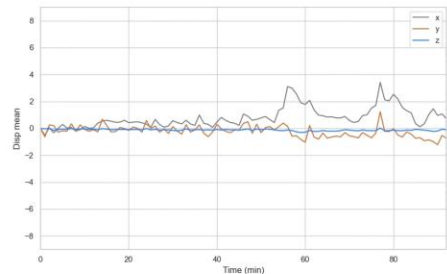
# Activity 2 – Registration & Movement

Whole utero vs. Whole baby

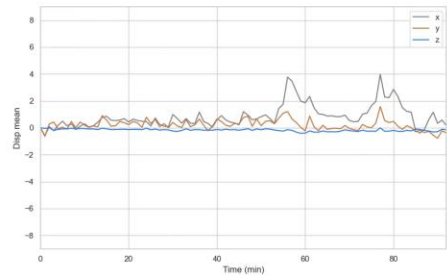
Segmentation curve for Utero & Placenta



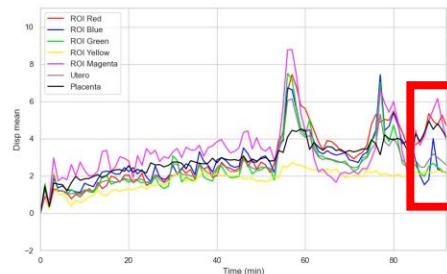
Utero & Placenta



Whole baby



All ROIs



Utero & Placenta

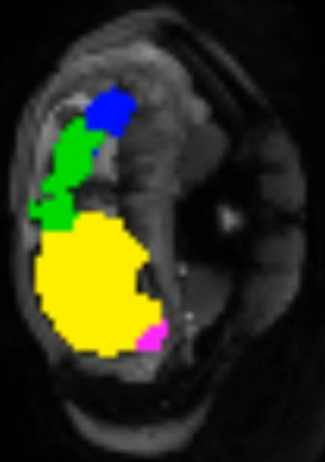


Whole Mask Mesh



Red: utero  
Blue: placenta

Baby



Baby Mask Mesh



Yellow: head  
Green: body  
Others: arms + legs



# Website page

## Website:

1. Segmentation
  - Input: 3D/4D image
  - Output: 3D/4D masks, Volume change curves
2. Registration
  - Input: 4D image with/without 3D ROI
  - Output: 4D masks, Deformation fields, Curves for all ROIs.
3. Contraction Detection
  - Input: 4D image
  - Output: Curves with detected contractions

Code hosted on GitHub:

<https://github.com/InUtero-SWIRL/SWIRL-AI>

The screenshot shows the InUteroAI web interface. On the left is a sidebar with 'Analysis Controls' containing a 'Select Analysis Task' dropdown set to 'Segmentation', a 'Data Input' section with a file upload area (drag and drop, limit 10GB per file), and 'Segmentation Options' with a dropdown set to 'nnUNet', checkboxes for 'Use GPU acceleration', 'Remove small regions', and 'Draw segmentation curves', and a green box indicating 'GPU: NVIDIA RTX 6000 Ada Generation'. The main content area has a 'Deploy' button in the top right, a title 'InUteroAI: Fetal MRI Analysis', a subtitle 'Upload and analyze 3D and 4D fetal MRI data using deep learning techniques', a 'Getting Started' section with a 4-step list, and two example visualizations: 'Example Segmentation' showing fetal MRI slices with colored masks and 'Example Plot' showing a line graph of volume change over time.



# Summary & Takeaways

- Developed an automated segmentation model for precise **Utero & Placenta segmentation**.
- Implemented **placenta contraction detection** through analysis of volumetric and wall structure changes.
- Built a **registration model** for accurate ROI tracing in **4D dynamic MRI imaging**.
  - Currently optimized for fetal MRI, with adaptability to other 4D MRI types.
- Designed a fully functional **web platform**, with plans for public release upon project completion.

**Thank you!**

**Any questions?**