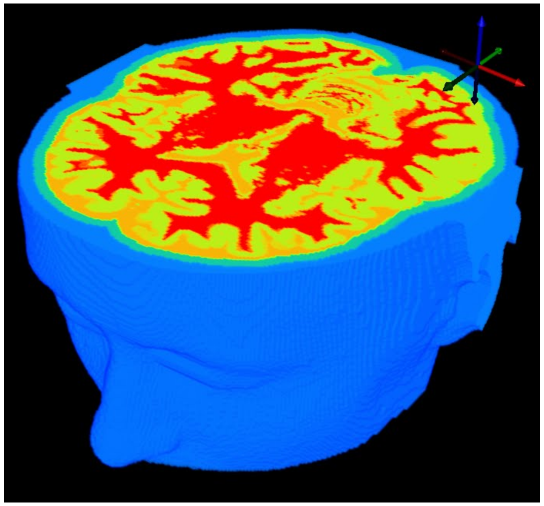
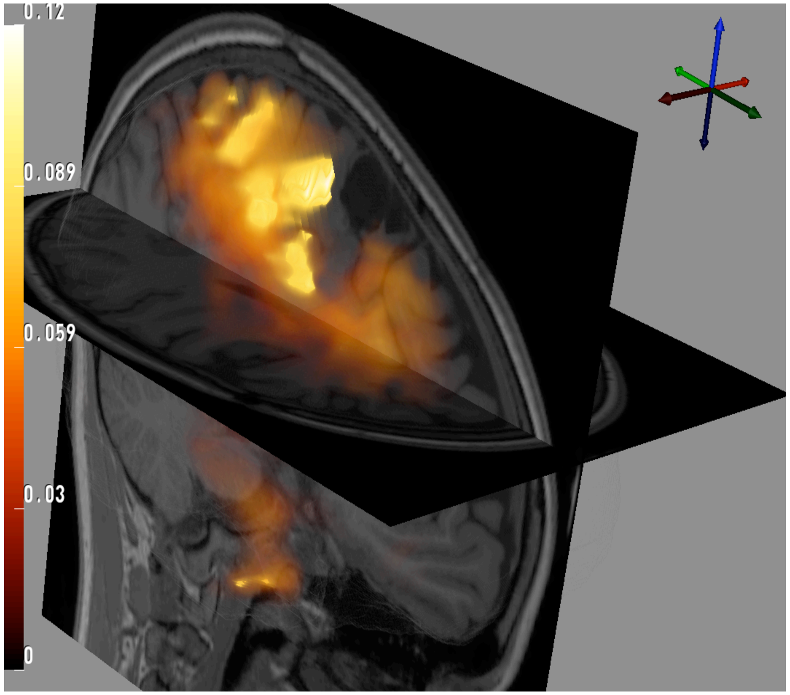
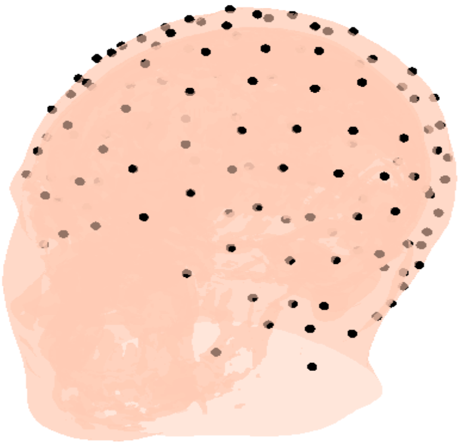
EEG Source Imaging Solution



Patient-Specific Segmentation





Electrode to MRI
Registration

Imaging Enables Guidance in Surgery

- Patient specific modeling with:
  - Advanced image acquisition.
  - Automated image analysis.
    - Segmentation.
    - Registration.
  - Increased computational capacity and efficient algorithms to simulate electromagnetic propagation.
- Expanding accuracy and robustness.

Fetal Brain Volumetry through MRI Volumetric Reconstruction and Segmentation

Ali Gholipour, Judy A. Estroff, Carol E. Barnewolt, Susan A Connolly, Simon K. Warfield

Computational Radiology Laboratory (CRL) and

Advanced Fetal Care Center (AFCC)

Department of Radiology, Children's Hospital Boston

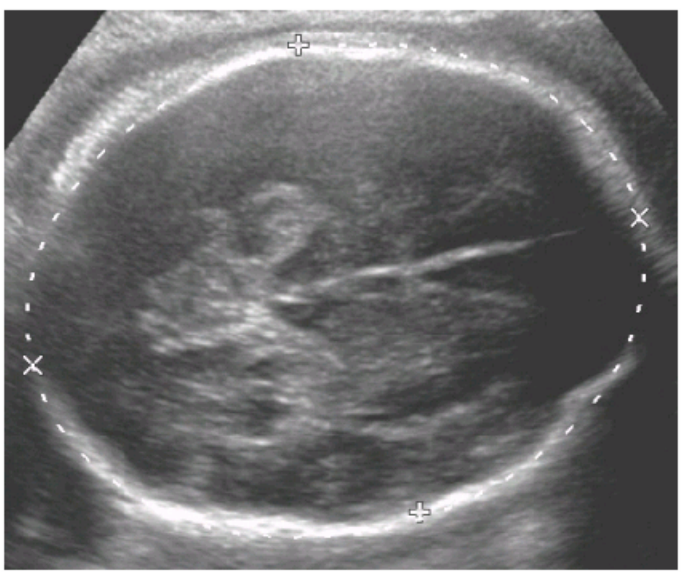
and Harvard Medical School

CARS 2010 June 26, 2010

Computational
Radiology
Laboratory

How is fetal imaging performed?

- Ultrasonography
- Magnetic Resonance Imaging (MRI)
- Biometry based on 2D measurements
- Volumetry based on several 2D sections



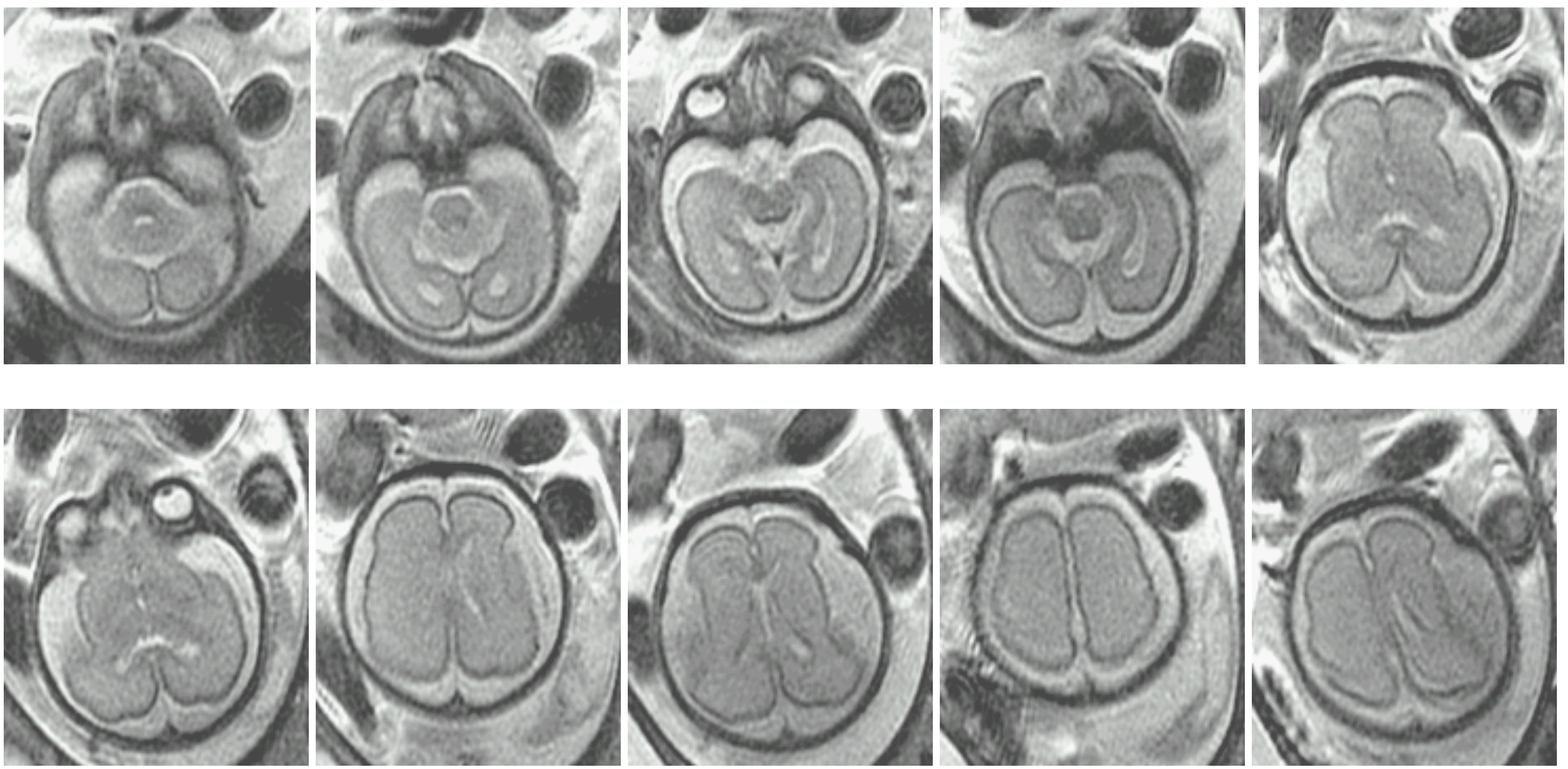
Fetal Brain Volumetry

- Fetal brain volumetry is crucial for the quantitative evaluation of fetal development.
- But it is limited by
  - dependency on motion-free scans,
  - tedious manual segmentation, and
  - spatial inaccuracy due to thick-slice acquisitions.

- We present an image processing pipeline to address these limitations. This involves fetal brain MRI volumetric reconstruction and segmentation.

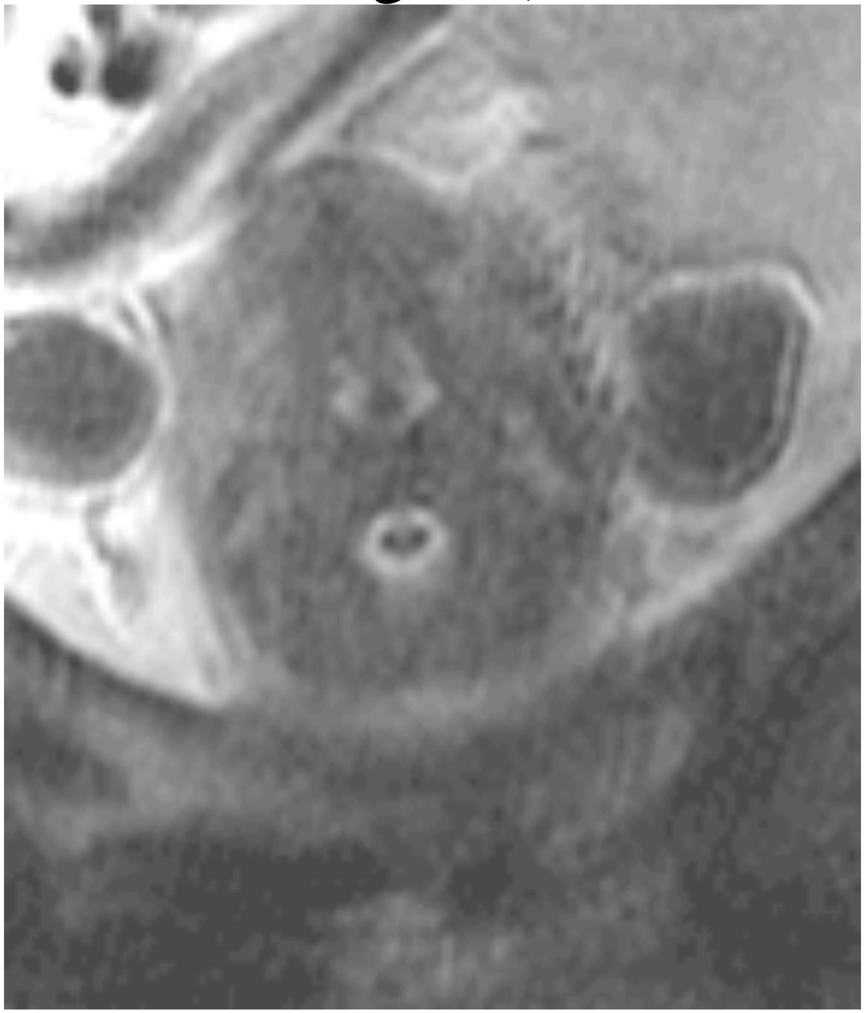
What is current fetal MRI practice?

- Single-shot fast spin echo (SSFSE) MRI for fast snapshot imaging in the presence of intermittent fetal motion.



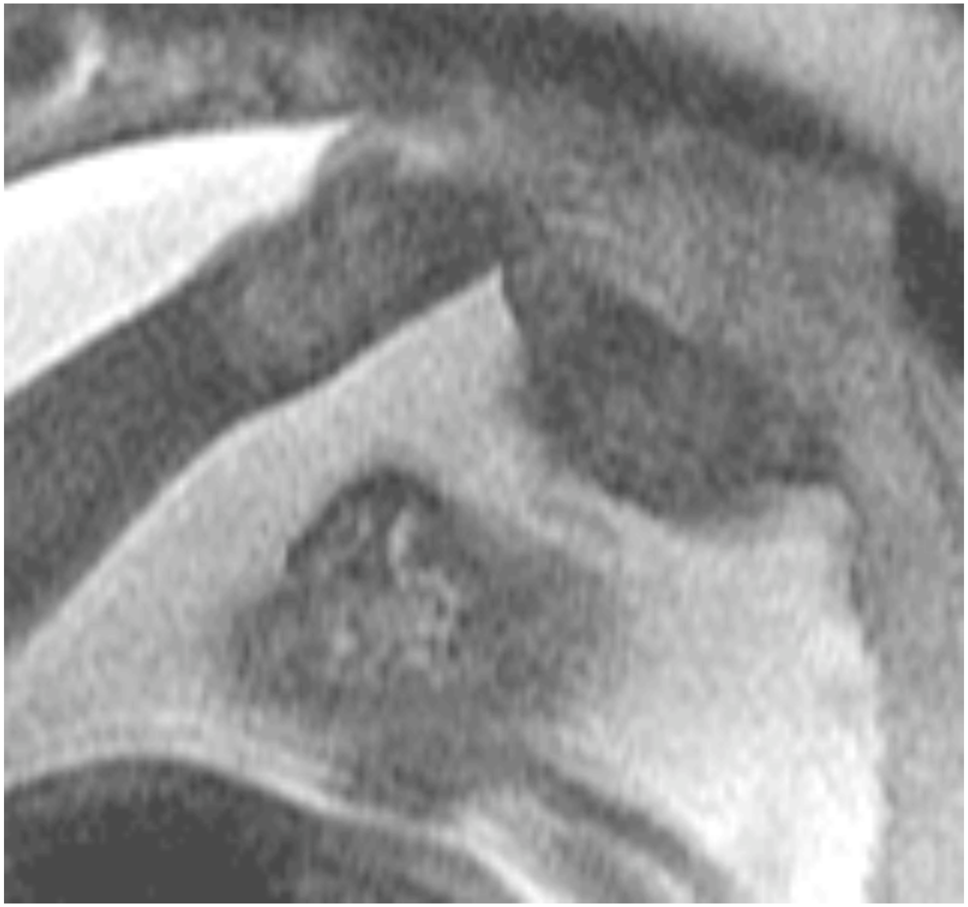
What do the images look like?

Multiple ssFSE images are acquired in fetal orthogonal planes (**axial**, coronal, sagittal).



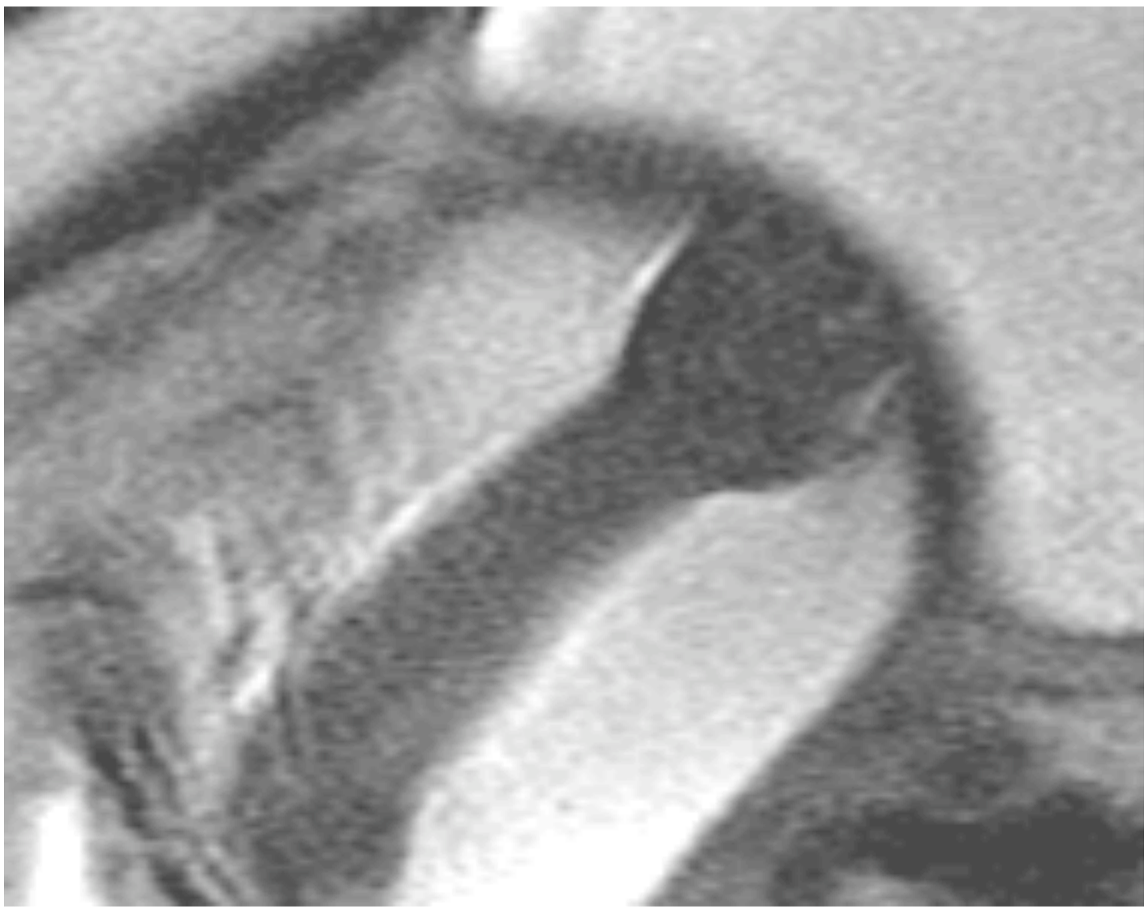
What do the images look like?

Multiple ssFSE images are acquired in fetal orthogonal planes (axial, **coronal**, sagittal).



What do the images look like?

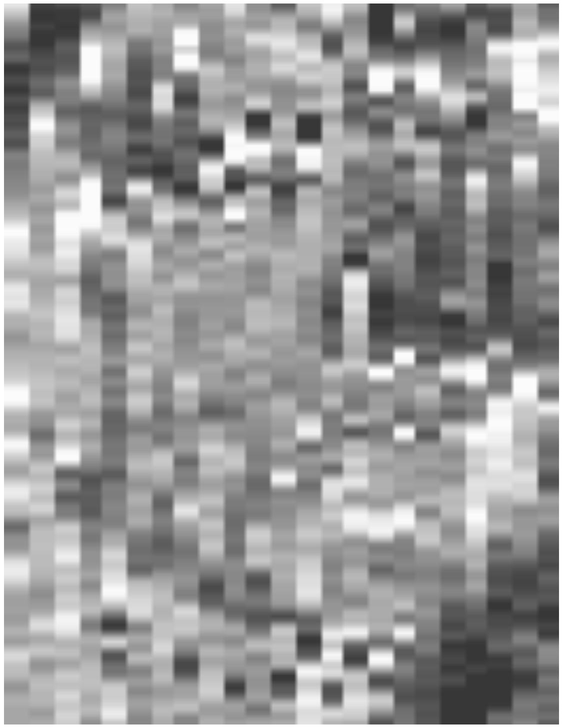
Multiple ssFSE images are acquired in fetal orthogonal planes (axial, coronal, **sagittal**).



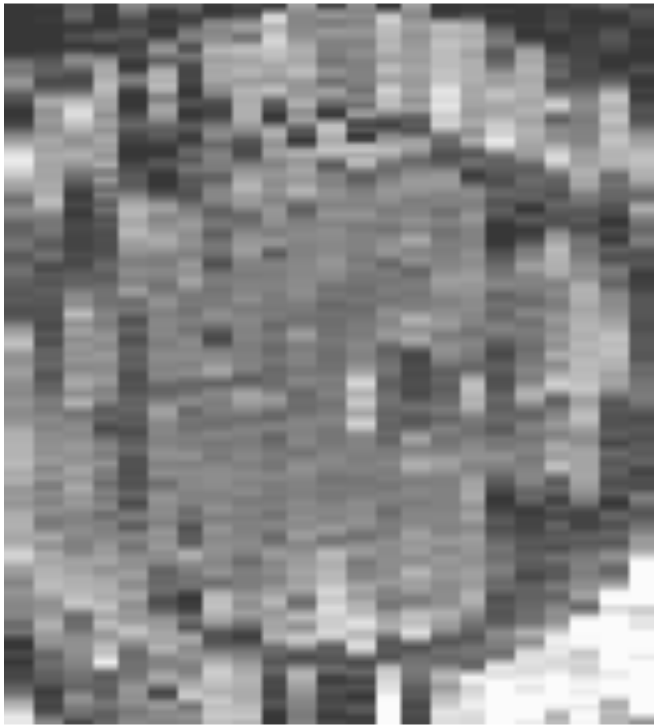
What do the images look like?

- Due to motion and thick slice acquisitions the out-of-plane views do not reflect the 3D anatomy and coherent tissue boundaries.

Axial view



Sagittal view



Coronal view

Limitations and objective

- Thick slice acquisitions are necessary to maintain high signal-to-noise ratio.
- Inter-slice motion artifacts are typically observed.
- 3D fetal brain MRI is desired for improved evaluation and automated segmentation and analysis.

How to reconstruct 3D fetal MRI?

- A first simple idea: define the high-resolution 3D image space, resample the SSFSE scans, and average the resampled scans.

Axial view

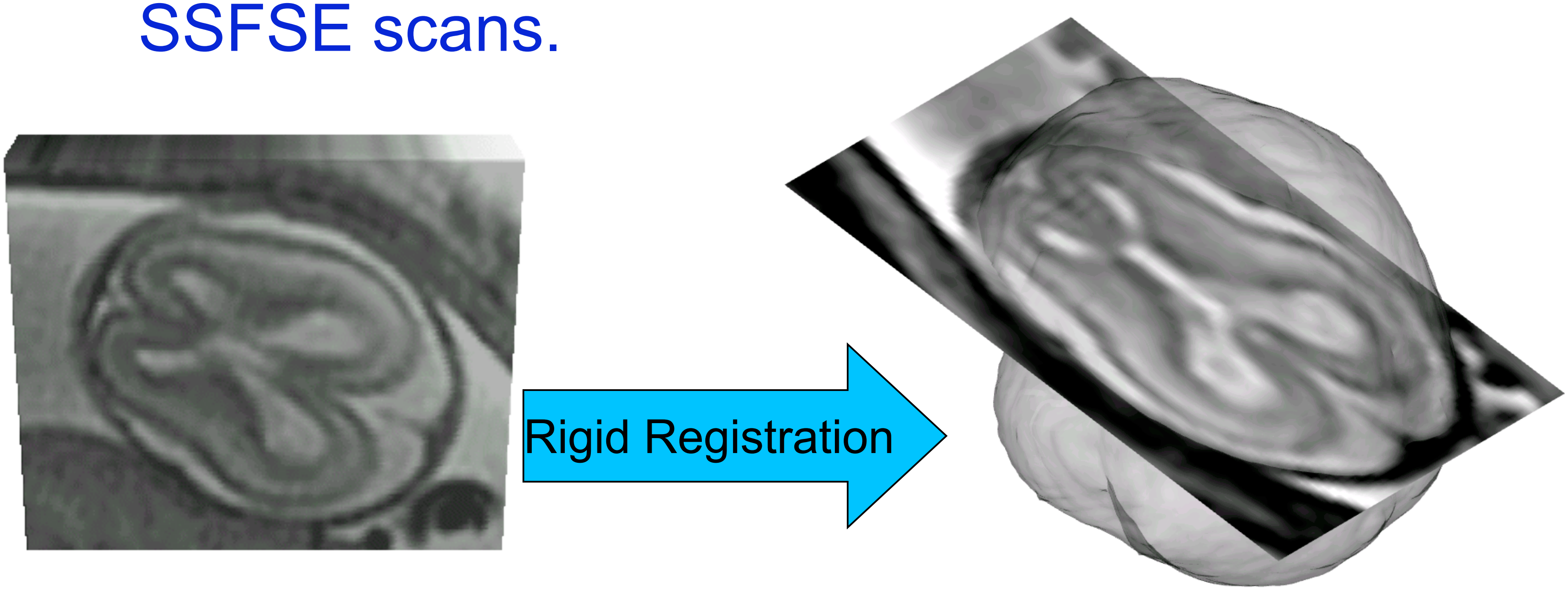
Coronal view

Sagittal view

Not effective! Motion correction is needed.

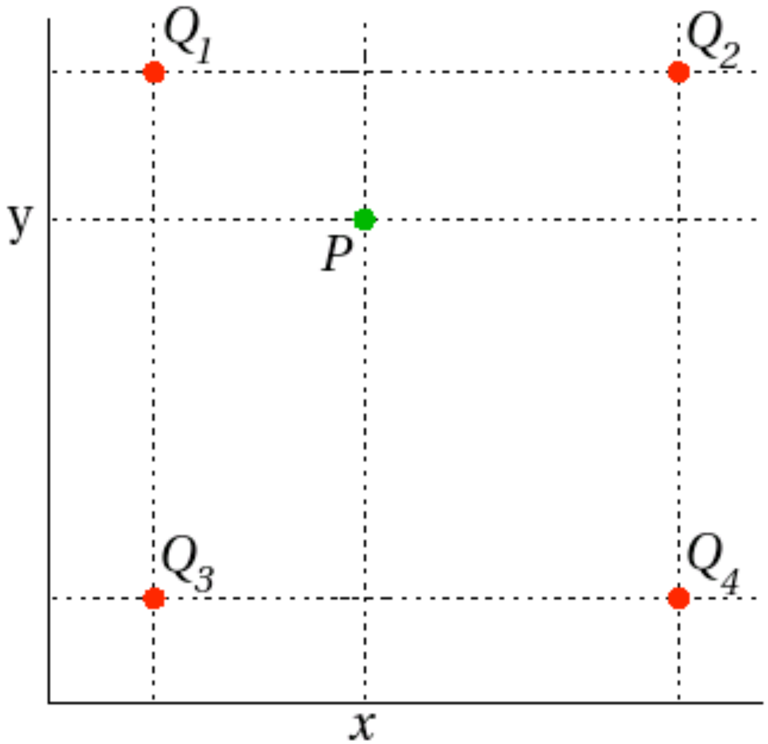
Correction for Motion

- Slice-to-volume registration
  - 3D Rigid registration to an estimated reconstructed volume.
  - The first estimation is obtained by averaging the SSFSE scans.

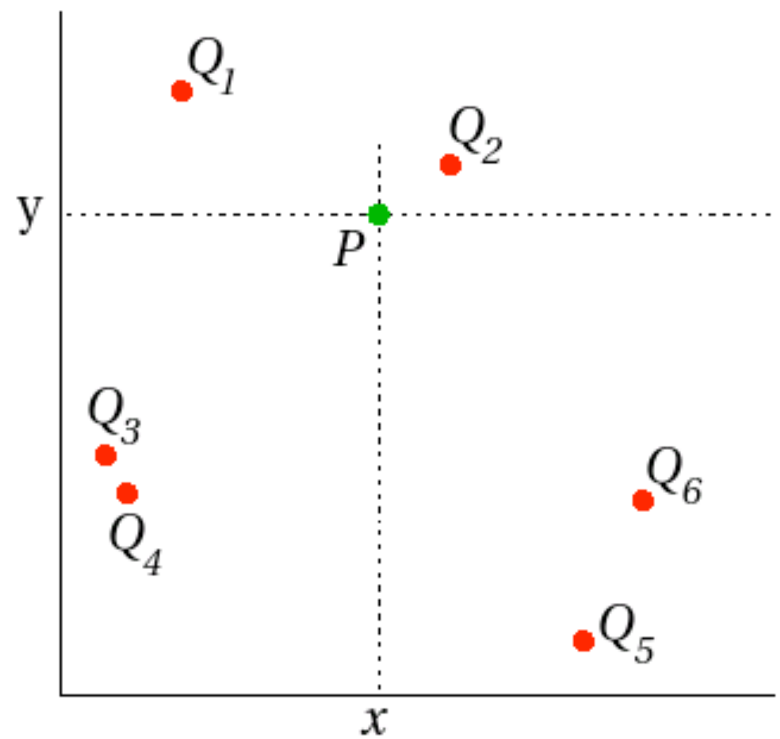


Scattered data interpolation (SDI)

- After motion correction, the voxels from slices will be scattered data in the 3D volumetric image space.



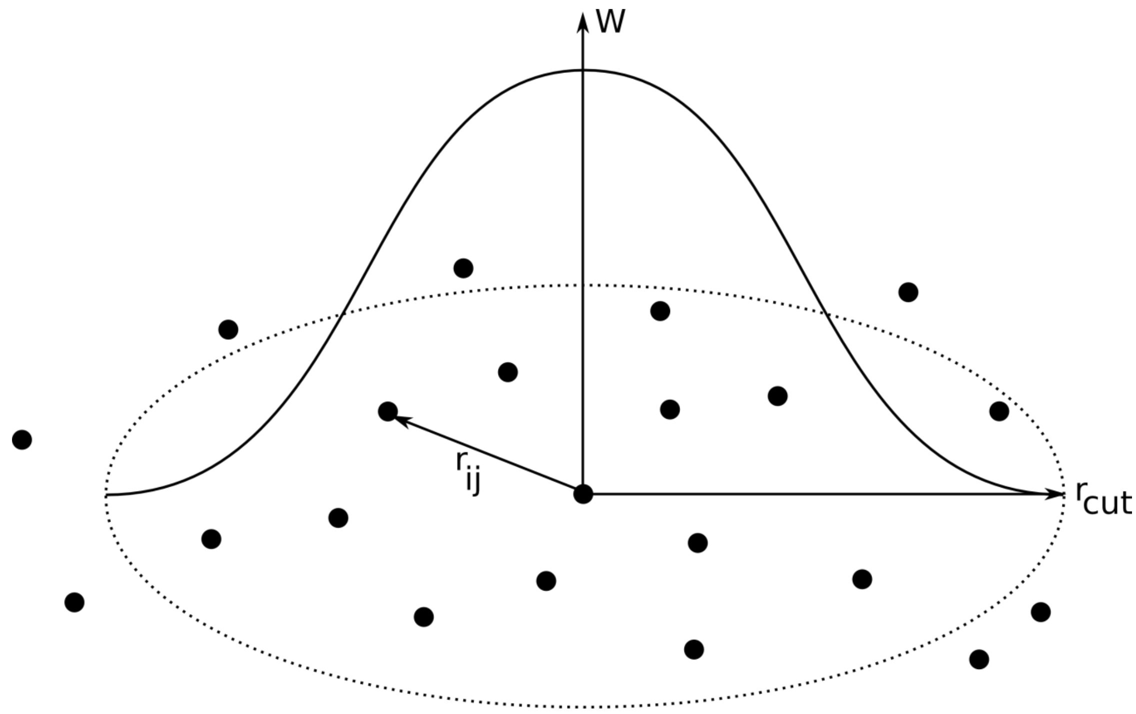
Regular grid interpolation



Scattered data interpolation

Scattered data interpolation (SDI)

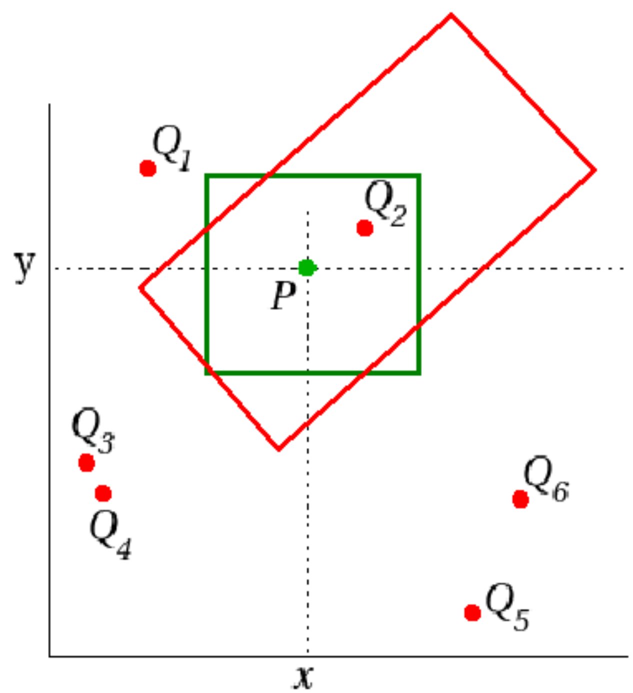
- Scattered data interpolation is performed using sample weighting through kernels.



[1] Rousseau et al. Acad. Radiol. 2006; [2] Jiang et al. IEEE Tran Med. Imag. 2007

Limitations of SDI

- SDI result depends on the choice of the interpolation kernel and the kernel size.
- Thick-slice voxels are heterogeneous and involve signal averaging in the slice select direction, thus they should not be approximated as points.



1mm x 1mm x 4mm

Our approach: Slice acquisition model

Imaged object

noise

k^{th} 2D slice

number of slices

$$\underline{Y}_k = \mathbf{D}_k \mathbf{B}_k \mathbf{S}_k \mathbf{M}_k \underline{X} + \underline{V}_k \quad , \quad k = 1,\ldots,n$$

Down-sampling

PSF blur

Motion (3D)

Slice selection profile (3D)

$$\left| \vec{\mu}_{sk} . \vec{r} - s_{0k} \right| < \Delta s_k / 2$$

[4] Gholipour & Warfield MICCAI'09; [5] Gholipour et al. IEEE Tran Med. Imag. 2010

Image reconstruction

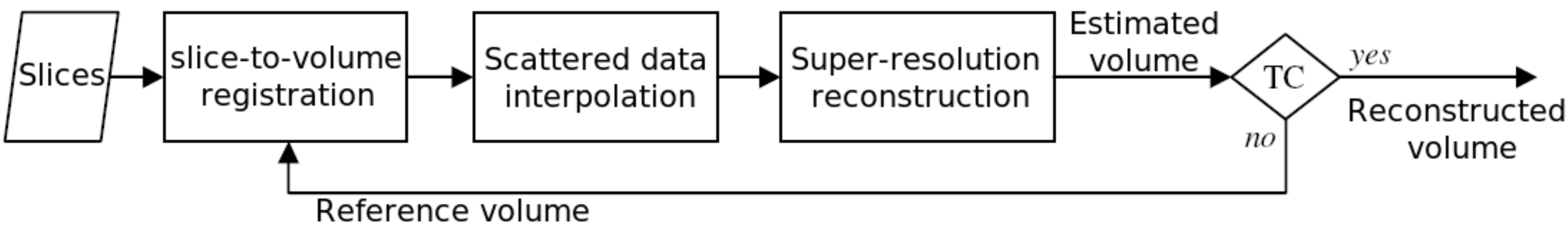
- Find the high-resolution image (*X*)
  - Maximum likelihood estimation to minimize an error function between the reconstructed volume and the acquired slices.

$$\hat{\underline{X}} = \underset{\underline{X}}{ArgMin}\left[\sum_{k=1}^{N} d\left(\underline{Y}_k, \mathbf{D}_k\mathbf{B}_k\mathbf{S}_k\mathbf{M}_k\underline{X}\right)\right]$$

$$\hat{\underline{X}} = \underset{\underline{X}}{ArgMin}\left[\sum_{k=1}^{N} \left\|\mathbf{D}_k\mathbf{B}_k\mathbf{S}_k\mathbf{M}_k\underline{X} - \underline{Y}_k\right\|_2^2 + \lambda\left\|\mathbf{C}\underline{X}\right\|_2^2\right]$$

Super-resolution reconstruction

- Iterations of slice-to-volume registration, scattered data interpolation, and maximum likelihood super-resolution reconstruction.



Super-resolution reconstruction through iterative maximum likelihood error minimization:

$$\underline{\hat{X}}^{n+1} = \underline{\hat{X}}^{n} + \alpha \left[\sum_{k=1}^{N} \mathbf{M}_k^{\mathbf{T}} \mathbf{S}_k^{\mathbf{T}} \mathbf{B}_k^{\mathbf{T}} \mathbf{D}_k^{\mathbf{T}} \left(\underline{Y}_k - \mathbf{D}_k \mathbf{B}_k \mathbf{S}_k \mathbf{M}_k \underline{\hat{X}}^{n} \right) - \lambda \mathbf{C}^{\mathbf{T}} \mathbf{C} \underline{\hat{X}}^{n} \right]$$