Integrative and Multiscale Image Registration: Application to Fetal and Neonatal Brain Development Analysis

Veronika A. Zimmer, Miguel Ángel González Ballester and Gemma Piella

Simulation, Imaging and Modelling in Biomedical Systems (SIMBioSys),
Department of Information and Communication Technologies,
Universitat Pompeu Fabra, Barcelona, Spain

Abstract

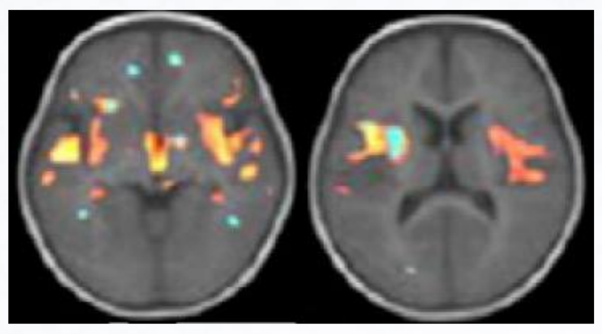
The quantification of abnormal brain development is important for the study of diseases such as **Intrauterine Growth Restriction (IUGR)** or **Ventriculomegaly**, where already in utero changes in brain structure and function can be noticed and where the neurodevelopmental outcome is unknown. To be able to characterize early the severness of the disease, **quantification of the abnormal fetal brain development** and comparison to normality are necessary. To achieve this, image registration is an important preprocessing step for spatial normalization of subjects and/or populations. To obtain good registration results, which is crucial for the quantification, we adress two different issues of image registration, the **integration of additional sources of information** and the **multiscale nature of medical image data**. For the former, we propose a spatially weighted multichannel similarity measure to distiguish between useful and redundant additional information. For the latter, we present an adaptive multiscale similarity measure which combines image statistics at multiple scales for a multiscale representation of regional image similarities. In addition, we present the idea of simultaneously optimization of transformation parameters to capture better the different scales in the datasets. Both approaches show improvements over common registration methods. Preliminary results are presented on synthetic and clinical data.

Application

Development of an integrative and multiscale registration framework to model and quantify fetal and neonatal abnormal brain development and to estimate their variability within and across populations.

Intrauterine Growth Restriction:

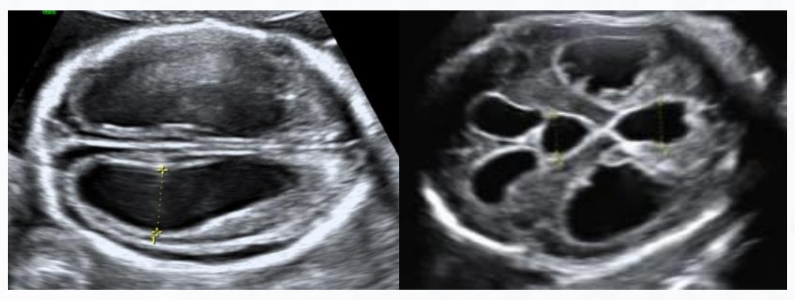
- occurs 5 – 10 % of pregnancies
- due to placental insufficiency
- preterm birth
- associated with neurostructural and neurodevelopmental anomalies



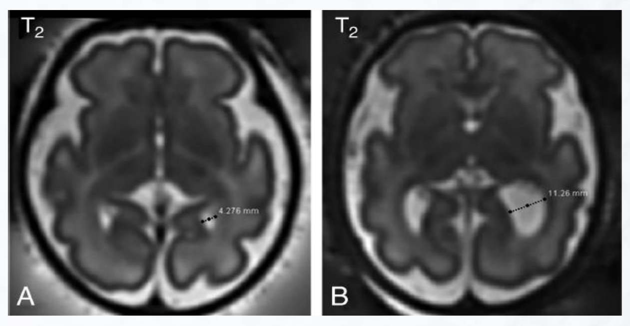
Gray and white matter volume changes between IUGR and term infants [1].

Ventriculomegaly:

- occurs in 0.15 – 0.7 % of pregnancies
- ventricular enlargement
- Association with schizophrenia, autism and ADHD



US of fetus with ventriculomegaly.



MRI of normal control fetus (A) and fetus with ventriculomegaly (B) [2].

Methods

Image Registration:

Images:

$F, M \; : \; \mathbb{R}^d \rightarrow \mathbb{R}$

Transformation:

$T : \mathbb{R}^d \rightarrow \mathbb{R}^d$

Find a transformation T such that a transformed moving image M is most similar to a fixed image F.

$$\mathcal{J}(T) = \mathcal{S}(F, M \circ T_\mu) + \alpha \mathcal{R}(T)$$

$$T^* = \min(\mathcal{J}(T))$$

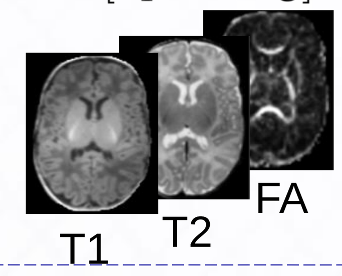
$\mathcal{R}$: Regularization term,
$\mathcal{S}$: Similarity measure

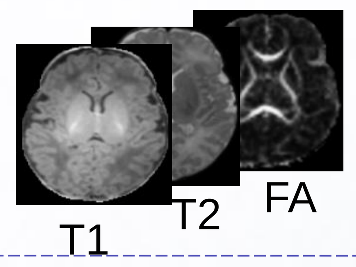
Integration of information

Multichannel similarity measure [3]:

$$\mathcal{S}(\mathbf{F}, \mathbf{M}; T) = \sum_{c=1}^{C} \lambda_c \cdot \mathcal{S}_c(F_c, M_c; T)$$

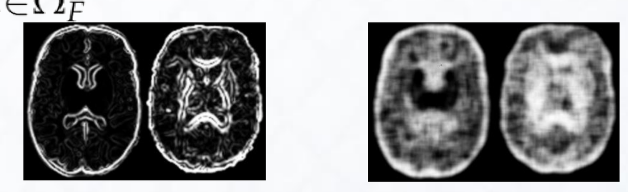
$\mathbf{F} = [F_1, \dots, F_C]$ $\quad$ $\mathbf{M} = [M_1, \dots, M_C]$





Voxel- or patch-based spatial weighting:

$$\mathcal{S}_c(F_c, M_c; T) = \sum_{x \in \Omega_F} w_c(x) (F_c(x) - M_c(T(x)))^2$$

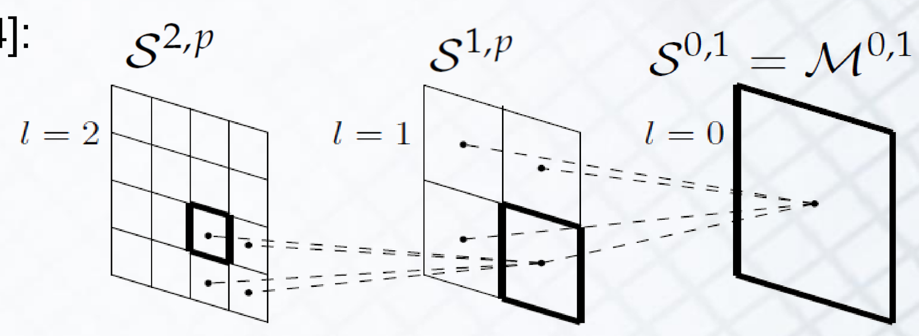


Gradient Magnitude $\quad$ Local Entropy

Multiscale Image Registration:

Adaptive Multiscale Similarity Measure [4]:

- Measuring image similarity on multiple levels at spatially varying locations
- Combination of regional similarities through adaptive weights: low regional similarity → higher weight
- Patchwise matching measure:



$$\mathcal{M}^{l,p} = (1 - \lambda_l)\mathcal{S}^{l,p} + \lambda_l \sum_{p'=1}^{2^{d(l-1)}} \alpha_{p'} \mathcal{M}^{l-1,p'}$$

Weights:

$$\lambda_l(p) = \mathcal{S}^{l,p} - 1 \in [0, 1]$$

$$\alpha_{p'} = \begin{cases} \frac{1}{d_{p'}} / \sum_{p'' \in P} \frac{1}{d_{p''}} & \text{if } p' \in P \\ 0 & \text{otherwise} \end{cases}$$

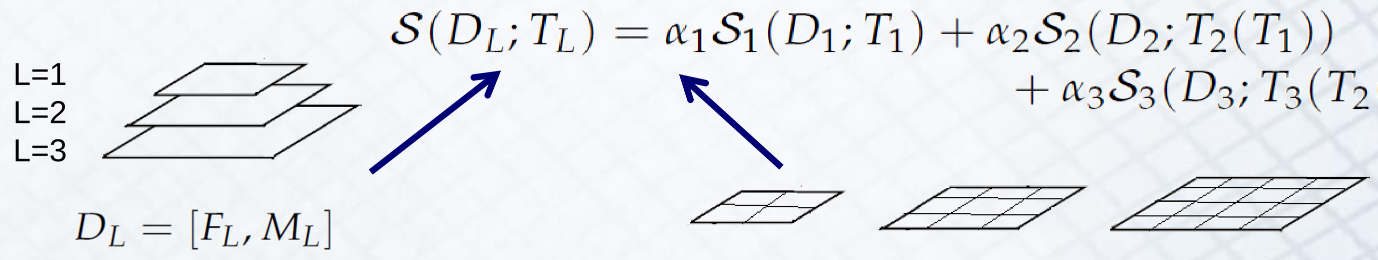
- Final measure:

$$\mathcal{M}^{(L)} = \frac{1}{2^{dL}} \sum_{p=1}^{2^{dL}} \mathcal{M}^{L,p}$$

Simultaneously multiscale transform optimization:

$$\mathcal{S}(D_L; T_L) = \alpha_1 \mathcal{S}_1(D_1; T_1) + \alpha_2 \mathcal{S}_2(D_2; T_2(T_1)) + \alpha_3 \mathcal{S}_3(D_3; T_3(T_2(T_1)))$$

Fixed and moving image pyramids



Multiscale transform reperesentation

Results and Future Work

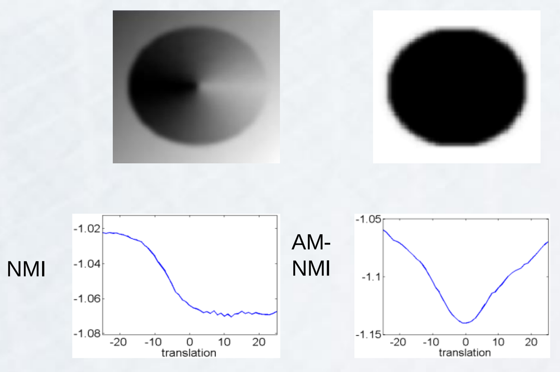
Multichannel Image Registration with spatial weighting:

	no weighting	GM	LE
T2	-2.170		
T2-FA	-2.196	-2.023	$\mathbf{-2.241}$
T2-ADC	-2.248	-2.023	$\mathbf{-2.303}$
T2-FA-ADC	-2.295	-2.300	$\mathbf{-2.319}$

- Data: neonatal MRI and DTI (T1,T2,FA,ADC)
- Registration results assessed with MI
- Spatial weighting with Gradient Magnitude and Local Entropy

→ Including DTI info through spatially weighted multichannel can improve results.

Multiscale Image Registration:



Mod.	INU	NMI	AM-NMI
T1-T1	0 %	0.459 ± 0.012	0.419 ± 0.013
T1-T2		0.965 ± 0.012	$\mathbf{0.929 \pm 0.012}$
T1-PD		0.821 ± 0.009	0.806 ± 0.010
T1-T1	20 %	0.465 ± 0.011	0.420 ± 0.020
T1-T2		1.164 ± 0.011	$\mathbf{0.940 \pm 0.026}$
T1-PD		1.237 ± 0.031	$\mathbf{0.913 \pm 0.025}$
T1-T1	40 %	0.468 ± 0.010	0.421 ± 0.007
T1-T2		1.329 ± 0.016	$\mathbf{1.007 \pm 0.046}$
T1-PD		1.485 ± 0.050	$\mathbf{0.972 \pm 0.025}$

- synthetic ex: AM-NMI is, in contrast to NMI, able to detect the minimum for translation
- BrainWeb data with random deformation: AM-NMI is robust to increasing INU fields

Future Work:

- Investigate the power of simultaneously multiscale transform optimization:
- Adaptation of transformation model to anatomy, e.g. including growth models
- Population analysis with respect to abnormal brain development for fetuses affected by IUGR and/or by Ventriculomegaly.

References: [1] N. Padilla et al: Differential effects of intrauterine growth restriction on brain structure and development in preterm infants: A magnetic resonance imaging study. Brain Research 1382, pp. 98–108, 2011. [2] V. Kyriakopoulou et al: Cortical Overgrowth in Fetuses With Isolated Ventriculomegaly. Cerebral Cortex, March 2013. [3] H.-J. Park et al: Spatial normalization of diffusion tensor mri using multiple channels. NeuroImage 20, pp. 1995–2009, 2003. [4] V.A. Zimmer and G. Piella: An adaptive multiscale similarity measure for non-rigid registration. WBIR 2014.

Acknowledgements: The work of V.A. Zimmer is supported by the grant FI-DGR 2013 (2013 FI_B00159) from the Generalitat de Catalunya. This research was partially founded by the Spanish Ministry of Economy and Competiveness (TIN2012-35874) and by the European Union FP7 grant agreement no. HEAR-EU 304857.
It will be in close collaboration with the Fetal and Perinatal Medicine Research Center from Hospital Clínic, Barcelona, Spain.