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LONGITUDINAL DIFFEOMORPHIC FETAL BRAIN ATLAS LEARNING FOR TISSUE LABELING USING GEODESIC REGRESSION AND GRAPH CUTS

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Abstract

The human brain undergoes fundamental structural changes between the second and the third trimester of pregnancy [1]. The most accurate non-invasive method for observing these events to date is the **(ultra) fast magnetic resonance (MR) imaging** technique. It allows to image a fetus at a satisfying resolution, despite its small size or varying position [2]. A problem of MR imaging is the **lack of comparability and constancy of gray-values,** which are mapped according to the proton (hydrogen) concentration. It differs among patients and results in varying gray-values for varying proton density [3]. This **motivates** to build a fetal brain atlas to use it as a standard space. Brain structures can be mapped according to marked anatomical locations, to make fetal brains comparable for studying brain development, fetal pathology locations, fetal abnormalities or anatomy.

The **aim of the work** is to provide an atlas of the developing fetal brain, consisting of a **continuous, quantifiable model of brain development** derived by geodesic shooting regression [4,5] and an **automated labeling procedure** using a graph cut based segmentation approach [7].

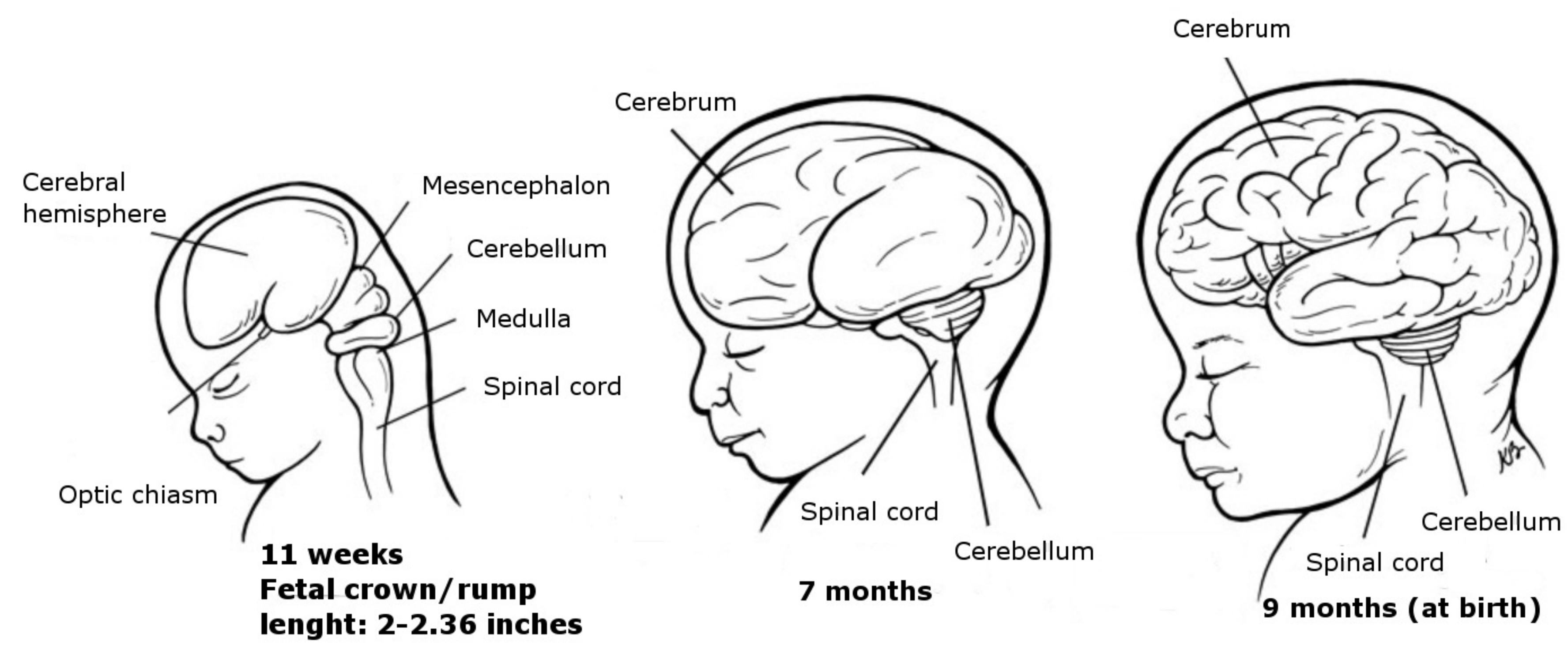
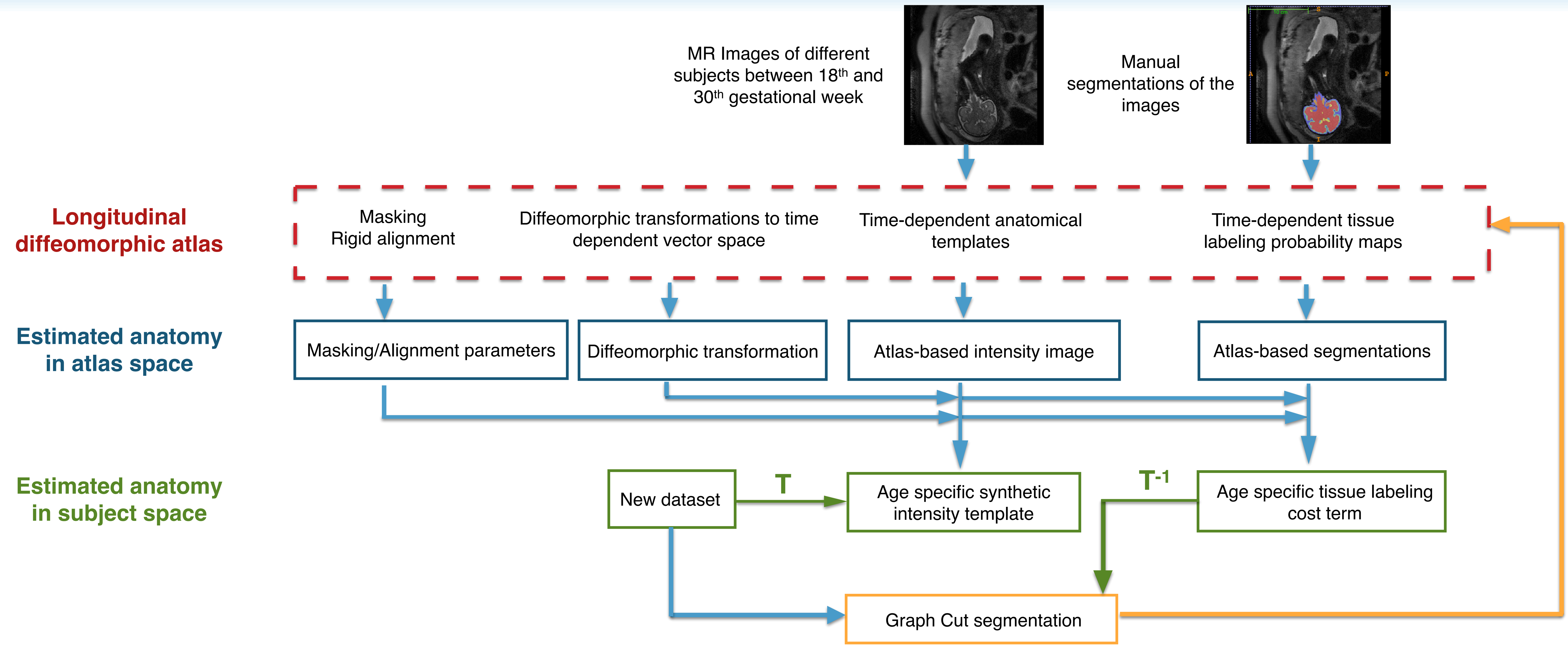


Illustration of the fetal brain development. Figure from Dana Guide to Brain Health (2006) [6]

Atlas of the Developing Brain - Tissue Labeling Framework



Geodesic Shooting

- Non-rigid, fluid model based registration approach
- Restricted to diffeomorphic matching, physically valid
- Large Deformation Diffeomorphic Metric Mapping (LDDMM) based [8]
  Calculates a series of velocity fields to find the optimal diffeomorphic mapping function from template to target image

$$\hat{v} = \underset{v:\dot{\phi}_t = v_t(\phi_t)}{\arg\min} \left(\int_0^1 \|v_t\|_V^2 \, dt + \frac{1}{\sigma^2} \left\| I_0 \circ \phi_t^{-1} - I_1 \right\|_{L^2}^2 \right)$$

LDDMM cost function

$$\frac{d\phi_t}{dt} = v_t(\phi_t)$$

ODE: flow of time dependent velocity vector field

$$v_t = K\left(\left|D\phi_t^{-1}\right| (D\phi_t^{-1})^T (u_0 \circ \phi_t^{-1})\right)$$

ϕ_t … Diffeomorphic transformation represented as flow
v_t … Time dependent velocity fields
V … Space of allowable velocity vector fields
L^2 … Standard L^2 norm for square integrable functions
L … Differential operator $\|f\|_V = \|L f\|_{L^2}$
A = L^*L^{inv} … Inertia of the system
K … Inverse (Green's function) of operator A
D … Jacobian tensor
μ … Template image

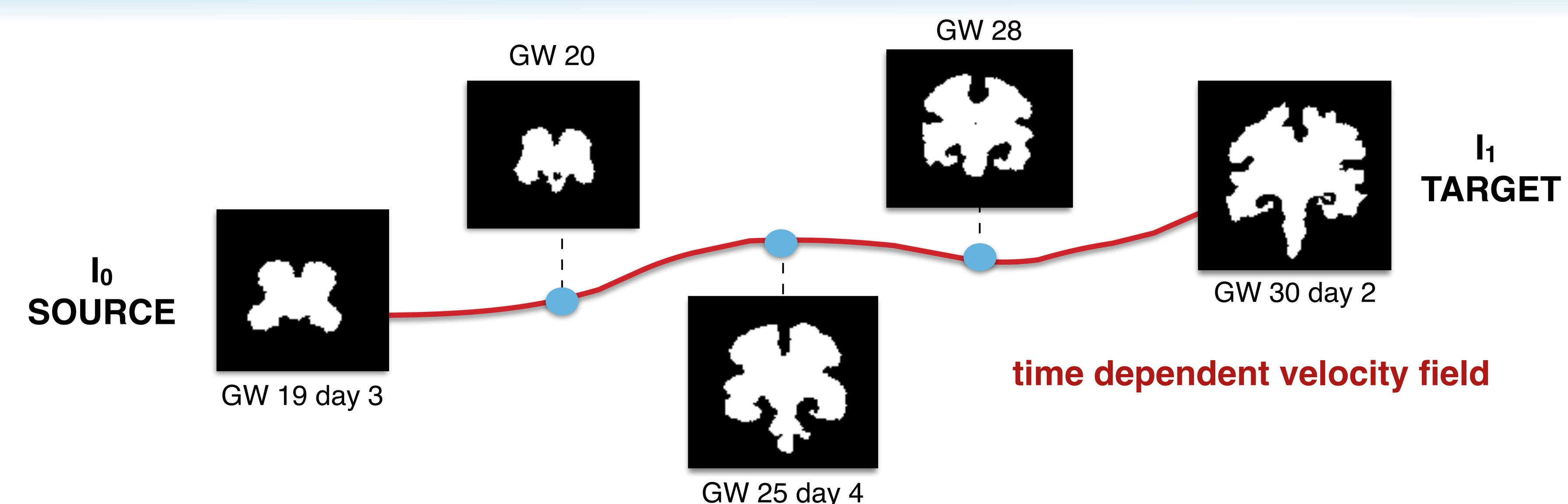
- Velocity is given at any time by initial velocity (momentum) $u_0 = A * v_0$

$$E = \frac{1}{2} \|v_0\|_V^2 \, dt + \frac{1}{2\sigma^2} \left\| I_0 \circ \phi_t^{-1} - I_1 \right\|_{L^2}^2$$

- Conservation of momentum: formulation of each iteration of the registration as an initial value problem [4].

Longitudinal Registration

GW… Gestational Week



$$E = \sum_{n=1}^{N} \left(\frac{\lambda_n}{2} \left\| I_n - \mu \circ \phi_{v_n}^{-1} \right\| \right)^2 + \frac{1}{2} \left\| L_{v_n} v_n \right\|^2$$

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