Alignment strategy of datasets from TPFM, 3D-PLI, and dMRI (D2.3.1 – SGA2)

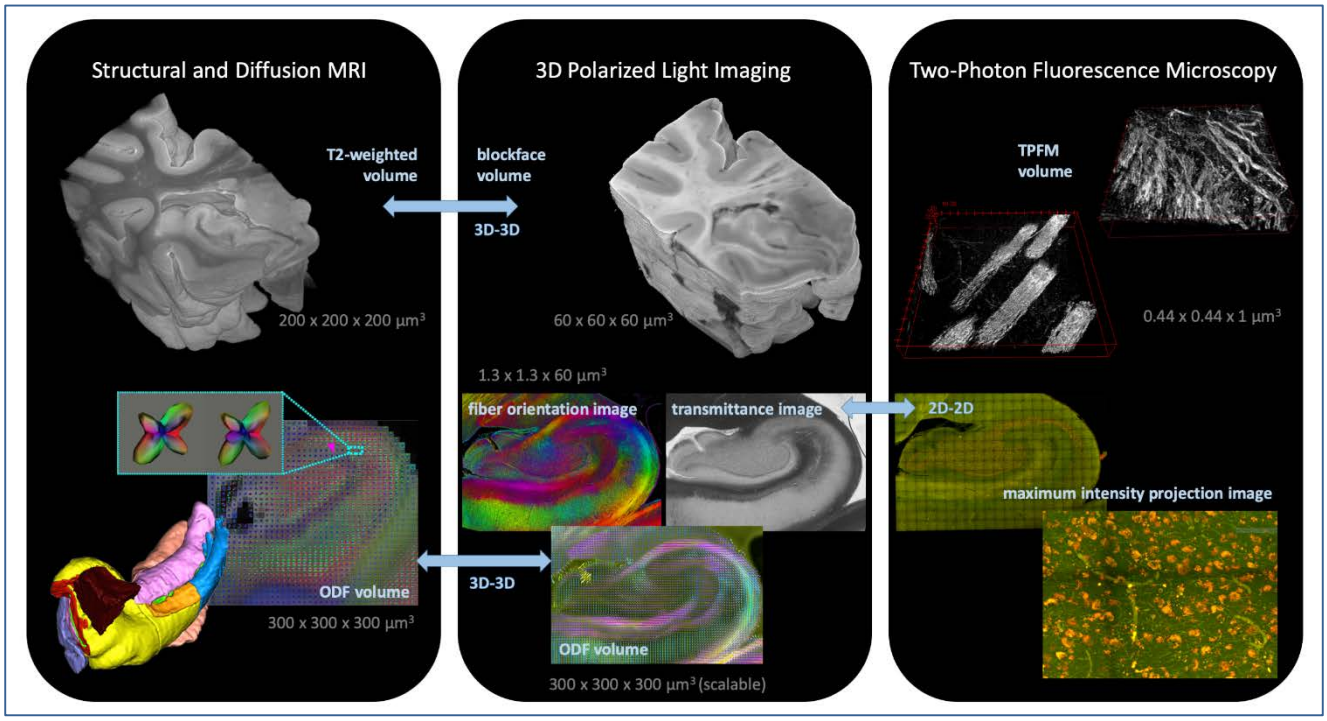

Figure 1: Image modalities from dMRI, 3D-PLI, and TPFM used for co-registration.

The employed alignment algorithms have to deal with 2D-2D and 3D-3D alignments across scales.

Project Number:	785907	Project Title:	Human Brain Project SGA2

Document Title:	Alignment strategy of datasets from TPFM, 3D-PLI, and dMRI
Document Filename:	D2.3.1 (D10.1 D59) SGA2 M18 ACCEPTED 201005.docx
Deliverable Number:	SGA2 D2.3.1 (D10.1 D59)
Deliverable Type:	Other
Work Packages:	WP2.3
Dissemination Level:	PU
Planned Delivery Date:	SGA2 M18 / 30 Sep 2019
Actual Delivery Date:	SGA2 M19 / 25 Oct 2019; resubmitted 31 Aug 2020; accepted 5 Oct 2020
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Editorial Review:	Annemieke MICHELS, EPFL (P1)
Description in GA:	Alignment strategy of datasets from TPFM, 3D-PLI, and dMRI (T2.3.4); Datasets made available in the HBP human brain atlas
Abstract:	The combination of brain imaging data from complementary modalities requires dedicated approaches to get aligned (i.e. registered) amongst each other. Here, we present a strategy to register adequate modalities obtained from the same brain tissue using MRI, 3D-PLI and TPFM techniques into a common space, the blockface volume.
Keywords:	Image registration, multi-modality, multi-scale, dMRI, 3D-PLI, TPFM
Target Users/Readers:	Neuroscientific community, neuroimaging community, histologists

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History of Changes made to this Deliverable (post Submission)

Date	Change Requested / Change Made / Other Action
25 Sep 2020	Deliverable submitted to EC
29 Jul 2020	Resubmission with specified changes requested in Review Report Main changes requested: • Change 1: Before publication, this public deliverable should be editorially adjusted as the data links bring the reader in a non-informed manner to a CSCS web page with an authorisation failure.
31 Aug 2020	Revised draft sent by SP/CDP to PCO. Main changes made, with indication where each change was made: • Change 1: see Section 2. Validation and impact
31 Aug 2020	Revised version resubmitted to EC by PCO via SyGMa

1. Output

1.1 Introduction

One of the key datasets for multiscale structural connectivity analysis in HBP (to be delivered at M24, SGA2) will be composed of complementary data acquired from the same brain tissue using three different imaging techniques applied sequentially: diffusion magnetic resonance imaging (dMRI), 3D polarized light imaging (3D-PLI), and two-photon fluorescence microscopy (TPFM). Tasks T2.2.4 in SGA1 as well as T2.1.3, T2.3.3 and T2.3.4 in SGA2 provide the common basis for assembling the multi-modal data. This includes the establishment of joint brain tissue treatment, scanning protocols and measurements.

Deliverable D2.3.1 reports on the strategy developed to align (i.e. to register) the datasets across scales and across imaging modalities. 3D-PLI appeared to be an ideal bridging technology between the (intrinsically) 3D imaging techniques, MRI and TPFM. Although the datasets were acquired from the same specimen, tissue handling between the different imaging techniques inevitably introduces artefacts like shrinkage, non-linear deformations, even local destructions.

Furthermore, some of the datasets used for implementing and testing the alignment strategy are available via the links below (Section 2 Validation and Impact). They are parts of the hippocampus project that will be delivered at M24.

1.2 Alignment of multimodal data

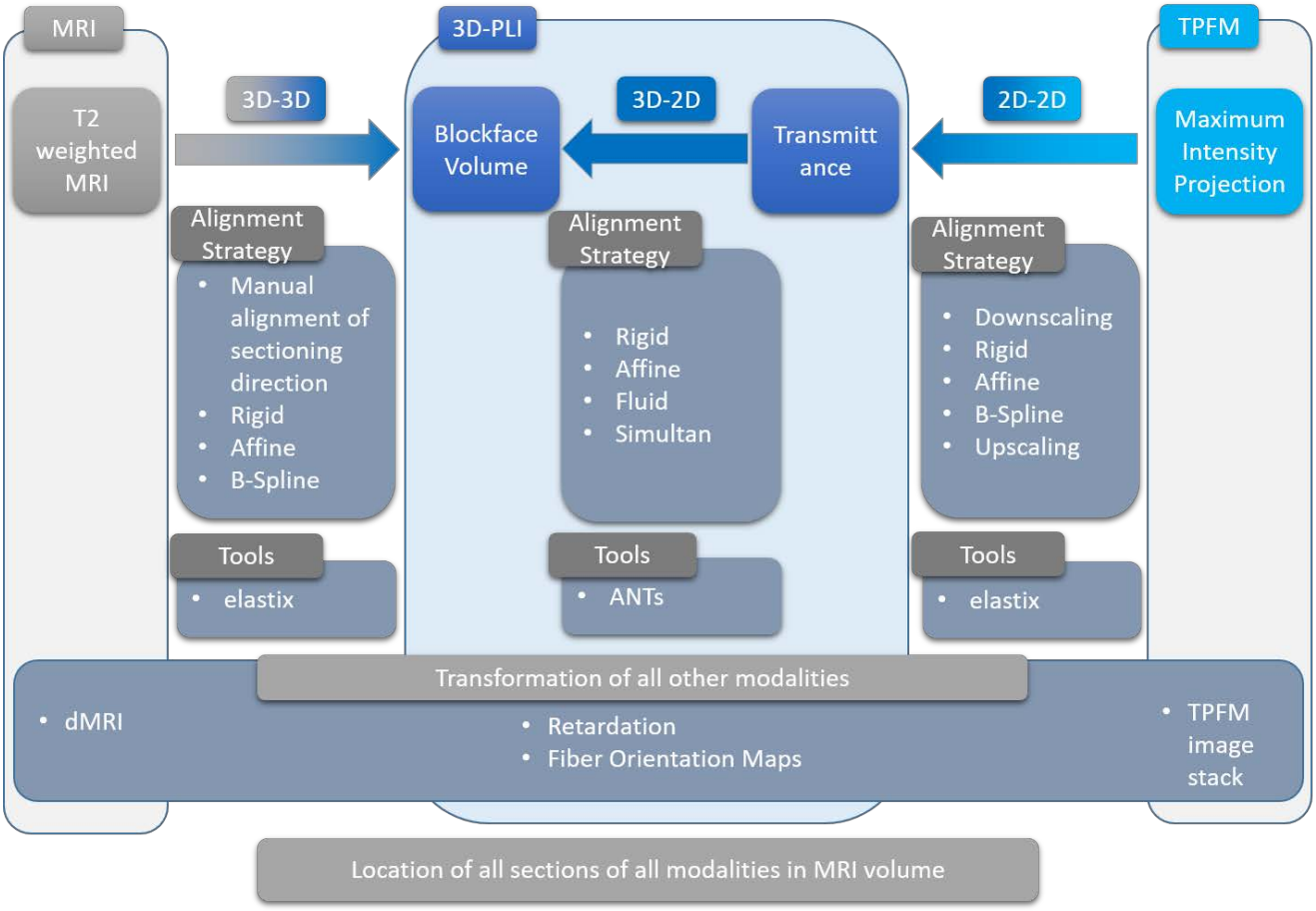

Figure 2: Overview schematic of the developed multimodal co-alignment concept.

1.2.1 Volumes, sections, and scales

The alignment strategy has to provide solutions for 3D-3D, 2D-2D, and 3D-2D registration tasks across spatial scales and modalities. While structural and diffusion MRI (resolutions: 200 and 300 μm, resp.) as well as TPFM (resolution: <1 μm) generate 3D datasets, 3D-PLI is at a first glance restricted to 2D section-wise measurements. However, the 3D-PLI methodology includes the possibility to derive spatial (3D) information from 2D scans (using blockface images and fibre orientation maps) at the mesoscale (resolutions: 1 to 60 μm depending on the used polarimetric device) [1,2]. This marks 3D-PLI as a perfect bridging/reference technology. Therefore, the general strategy is to transfer MRI-based data into blockface/3D-PLI space, which also holds true for the TPFM measurements.

1.2.2 Data types, methods, and tools

Figure 2 gives an overview of the data types, methods, and tools we identified to be well suited for co-alignment. The central reference dataset is the **blockface (image) volume** reconstructed from serial *en-face* images acquired during the cryo-sectioning process of the brain tissue after MRI scanning and prior to 3D-PLI measurements. The used rigid method to reconstruct the blockface volume has been described in [3] and a follow-up manuscript is currently in preparation. In order to determine the exact positioning and orientation of each histological brain section within the MRI volume, rigid, affine, and non-linear (B-spline) 3D-3D registration of the MRI-based **T2-weighted volume** has to be performed by employing the elastix toolkit [4]. Each blockface image has its corresponding 3D-PLI image. Complementary registration tools were identified and/or developed to align the 3D-PLI based 2D **transmittance images** to the blockface images enabling different non-linear transformations (based on B-spline, Gaussian elastic body spline or fluidal deformation models) [5-7] after a rigid registration with elastix. Furthermore, we found the 2D **maximum intensity projection images** (MIP) derived from 3D TPFM measurements to be most similar to the transmittance images. The alignment of the images was achieved with the strategy of consecutive rigid, affine, and B-spline registration using the elastix toolkit.

The derived transformations are applied to all available modalities to take care of the individual tissue displacements. Since tissue displacement is always accompanied with (fibre) orientation displacements, the (rotational parts of the) transformations have to be used to correct the measured orientations. After aligning these datasets, a diffeomorphic registration approach [8] makes a fine alignment of **orientation distribution functions** (**ODF**s) derived from dMRI and 3D-PLI possible.

References

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2. Validation and impact

Implementation and validation were done on selected datasets of a human hippocampus by comparing mutual local features detected in the different modalities (as indicated in Figure 1).

Final results can be accessed via the following link: https://doi.org/10.25493%2FJQ30-E08 .

Description of the data can be found in the data descriptor on the same EBRAINS page: https://object.cscs.ch/v1/AUTH_227176556f3c4bb38df9feea4b91200c/hbp-d000030_hippocampus_DMRI_3D-PLI_TPFM_pub/DataDescriptor.pdf

The delivered alignment strategy of three complementary imaging methods is a proof of concept and fundamental to unprecedented joint connectivity analysis. It is a key element to render cross-scale, cross-modality comparison possible for the first time. In the context of T2.3.3 and T2.3.4 in SGA2, the defined strategy will allow to assemble an entire human hippocampus based on dMRI, 3D-PLI and (in selected regions) TPFM, due at M24.

The addressed user communities are (1) computer scientists working on registration algorithms, which are important in any cohort MRI study or histological atlasing/mapping project, and (2) neuroscientists particularly interested in histology-based MRI analysis and fibre pathway tractography. Understanding the underlying (real) microstructure of the water diffusion signal measured with Diffusion MRI opens up new ways to identify and characterise pathology-induced changes in the brain, for example. Furthermore, the data generated by means of the alignment strategy are perfectly suitable for large-scale simulation of the water diffusion process or optical effects enabling new artificial intelligence approaches to go beyond the current biophysical models (which is addressed in T2.6.5).

3. Dissemination

The work described here has been presented at the following conferences, seminars, exhibitions, journals:

“Quantitative whole-brain multi-modal fiber and cell mapping”, seminar talk by M. AXER, Netherlands Institute for Neuroscience, Amsterdam, Netherlands, September 2019.

“Polarized Light Imaging of the brain’s fiber architecture”, talk by M. AXER, Workshop: Generative Connectomics and Plasticity, Organization for Computational Neuroscience OCNS 2019, Barcelona, Spain, July 2019.

“Night of Science”, booth exhibition, Düsseldorf, September 2019.

Amunts K, Knoll AC, Lippert T, Pennartz CMA, Ryvlin P, Destexhe A, Jirsa VK, D'Angelo E, *et al*. (2019), The Human Brain Project-Synergy between neuroscience, computing, informatics, and brain-inspired technologies. PLoS Biol 17:e3000344.