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Towards a high-density packing white matter substrate generator **CACTUS: C**omputational **A**xonal **C**onfigurations for **T**ailored and **U**tradense **S**imulations

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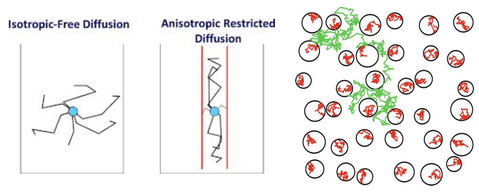
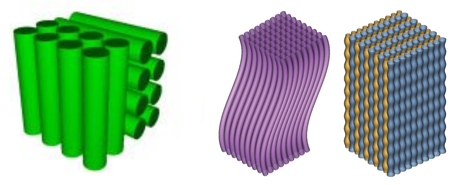
MOTIVACIÓN

How to model synthetic DW-MRI signals?

1. Monte Carlo Diffusion Simulations
   - MC/CD is an engine built to simulate particle diffusion dynamics in complex obstacle environments.[1]
2. They require an geometrical representation of the diffusion media Called ***substrate***
3. This works present an enhanced framework for ***substrate*** design.



1) Simulation of water particles motion for DW-Montecarlo Simulations

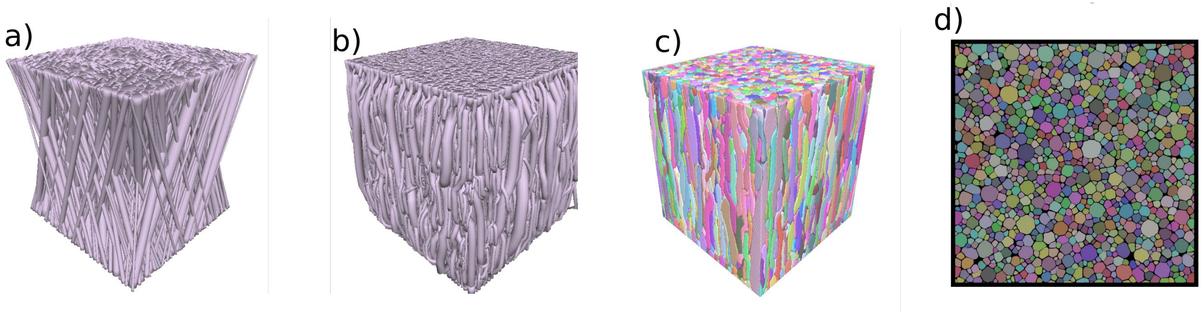


2) Simple substrates representations used in simulations

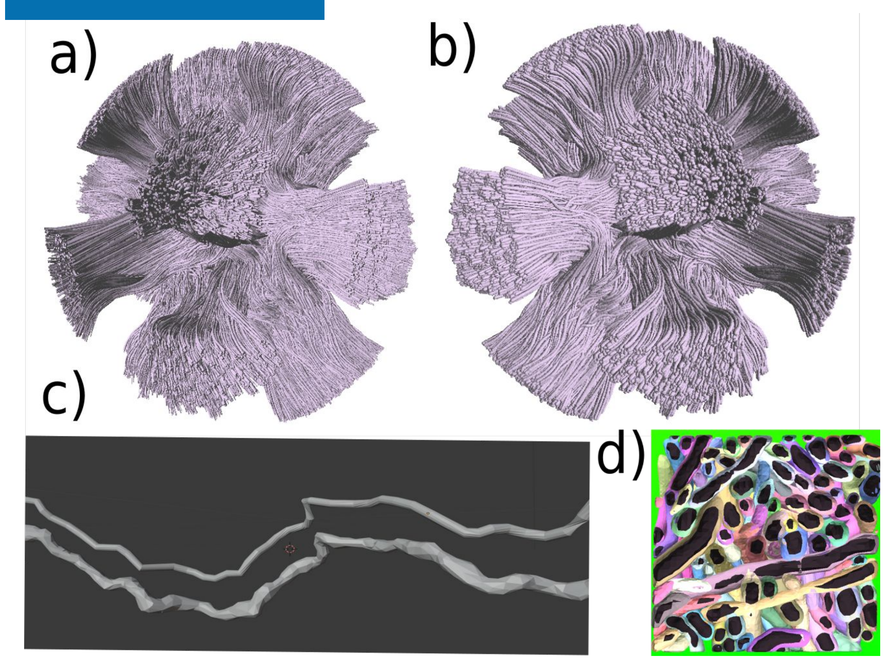
METHODS

In house substrate generator: **CACTUS** (Computational Axonal Configurations for Tailored and Ultradense Substrates), a novel framework with multiple parameters to create substrates mimicking various white matter features.

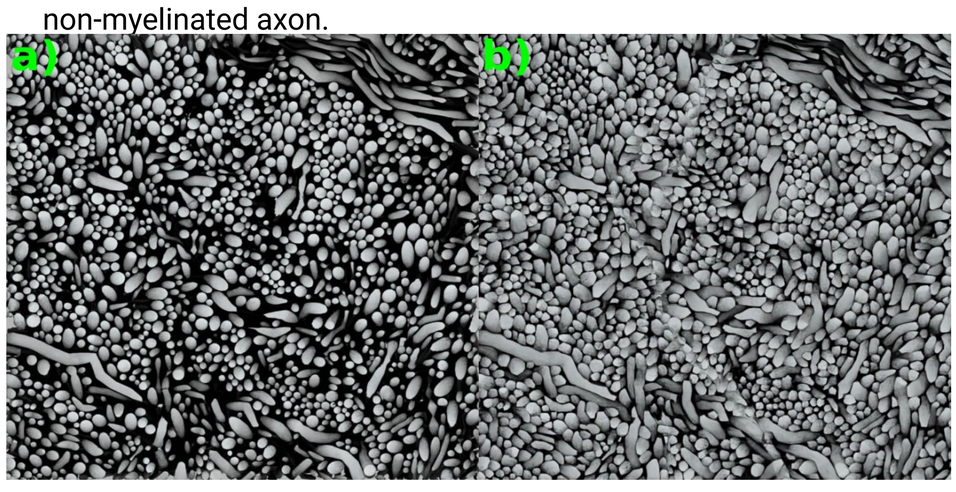
a) **Firstly, the *fibre initialisation step***, where we select the prior distributions of the fibre trajectories and radii used in the substrates
b) ***Global optimisation step***, the fibres are divided into a set of control connected through truncated cones along their trajectories, which are then optimised concerning a global cost function
c) ***Meshing-growth*** *step* transforms the tubular-shaped fibres into more complex shapes, using a post-processing framework based on BFS growth



RESULTS



- DiSCo-inspired phantoms with substrate size of 1 mm^3 a) Substrate built with cylindrical fibres. b) Substrate optimised and meshed with CACTUS. c) Comparison of the cylindrical and the CACTUS-optimised fibre. d) Packing substrate zoom-in showing the substrate compartments in b); the myelin wraps are coloured individually for each axon, and the dark inner mesh is the non-myelinated axon.



- **Figure 4**. The Cross-sectional cut of the substrates is shown in Figure 3a,b. The black area represents the extracellular space. a) Cylindrical fibre substrate with 64% ICVF. b) CACTUS-optimised substrate with 88% ICVF.

CONCLUSIONS

Numerical substrates have an increasingly higher role in microstructure modelling. Simulating the complexity of the white matter axons structure in substrates is challenging. **The improvement in substrate features will lead to improved realism of Monte-Carlo simulations in DW-MRI.**

Substrates' properties:

- **Parameterizable Features:** changes in radii, curvature and ICVF.
- **Improved axonal shapes,** avoiding cylindrical regular shapes and building tortuous axons.
- **A denser axonal packing: 95%** ICVF, compared with the **65**% found in CONFIG.
- **Larger voxel size simulations**: **(500µm)^3**, against **(35µm)^3** in CONFIG.

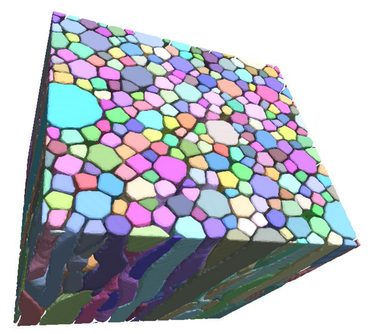


Fig 1: (50 um)^3 voxel size

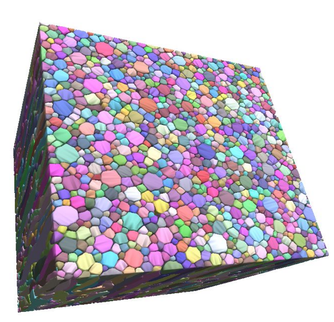


Fig 2: (100 um)^3 voxel size

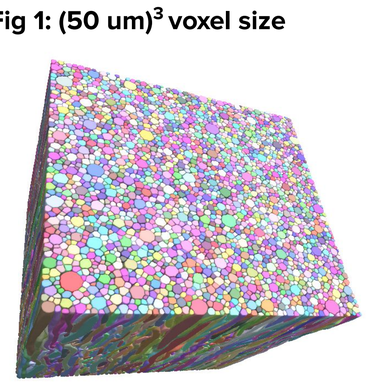


Fig 3: (200 um)^3 voxel size

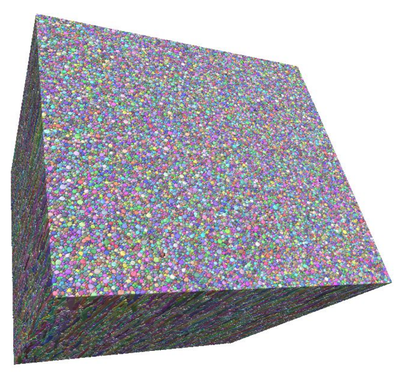


Fig 4: (500 um)^3 voxel size

[1]Rafael-Patino, Jonathan, et al. "Robust Monte-Carlo simulations in diffusion-MRI: Effect of the substrate complexity and parameter choice on the reproducibility of results." *Frontiers in neuroinformatics* 14 (2020): 8.