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P16

Astrocyte Integration: Enhancing White Matter Numerical Substrates for diffusion MRI simulations

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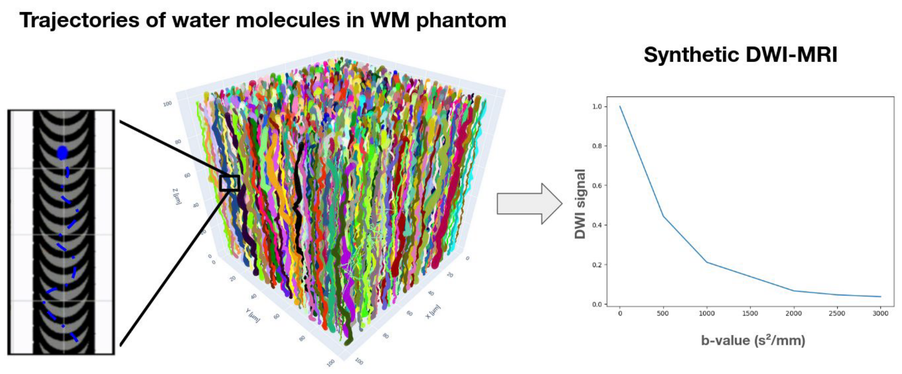
AIM

This study introduces **CATERPillar** (Computational Axonal Threading Engine for Realistic Proliferation), a method simulating natural axonal growth by using overlapping spheres as elementary units. It allows parallel axon growth while preventing collisions and offers user flexibility, enabling control over parameters like density, tortuosity, and beading. Many different compartments can be created within the phantom, such as axons, myelin and astrocytes.

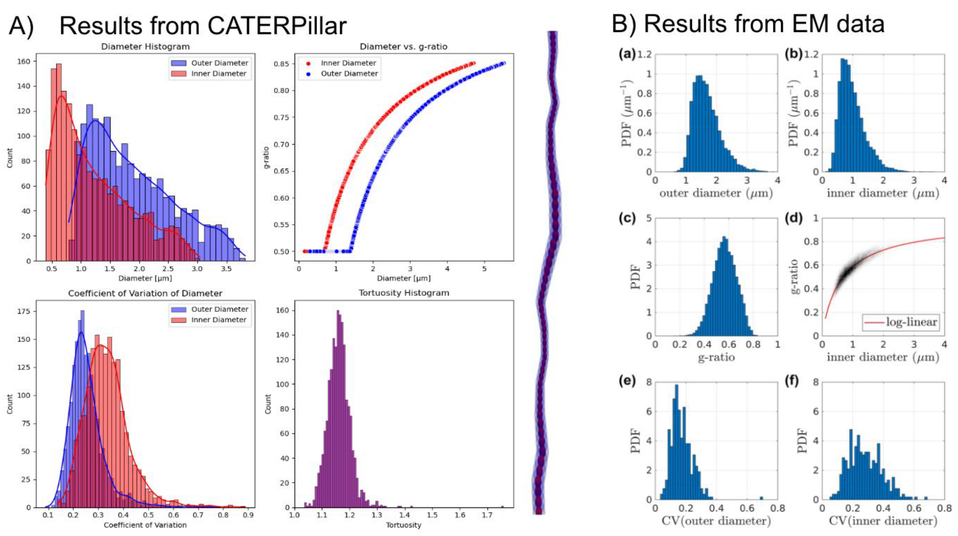
WHY DO WE NEED PHANOTOMS ?

Given a numerical phantom, Monte Carlo (MC) diffusion simulations can be employed to model the random movement of water molecules as they diffuse and interact with the synthetic cell membranes within the phantom. **Enhancing the realism of the phantom** can improve the accuracy of the results, as the MC simulator generates a synthetic DW-MRI signal based on the water molecules' trajectories.



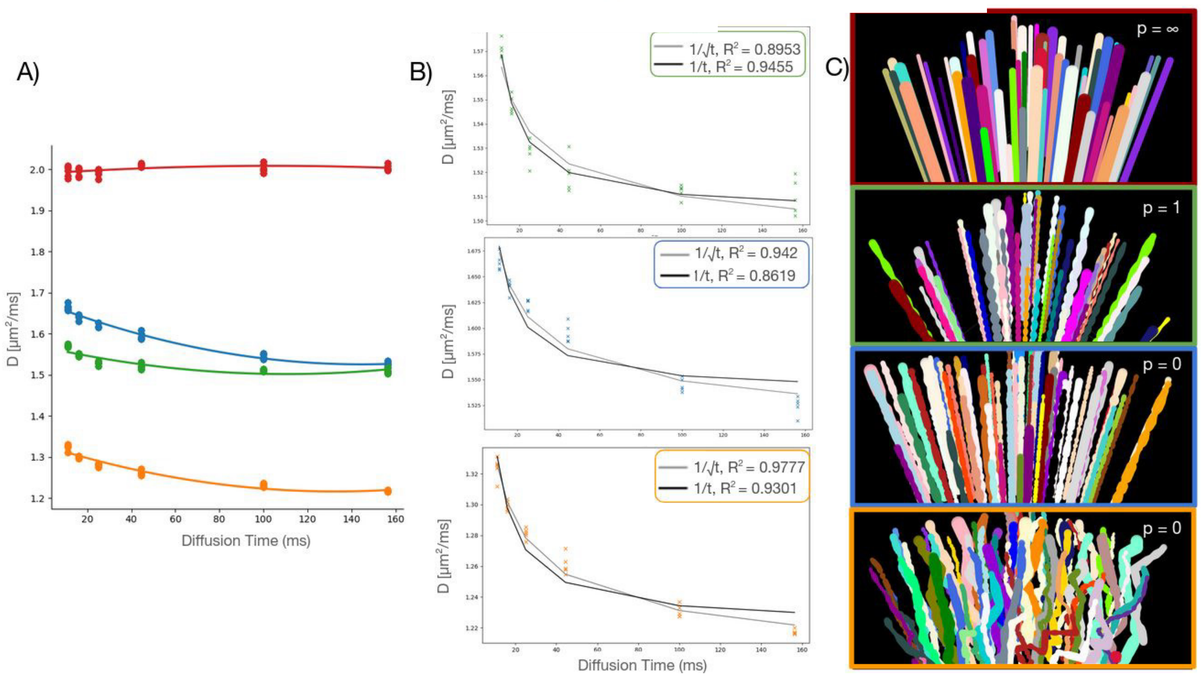
AXONS

Analysis 1: Histograms for various morphological parameters are shown. With a beading amplitude of 0.3x the mean radius and a mean tortuosity of 1.15, these distributions closely match those from previous electron microscopy (EM) data [2].



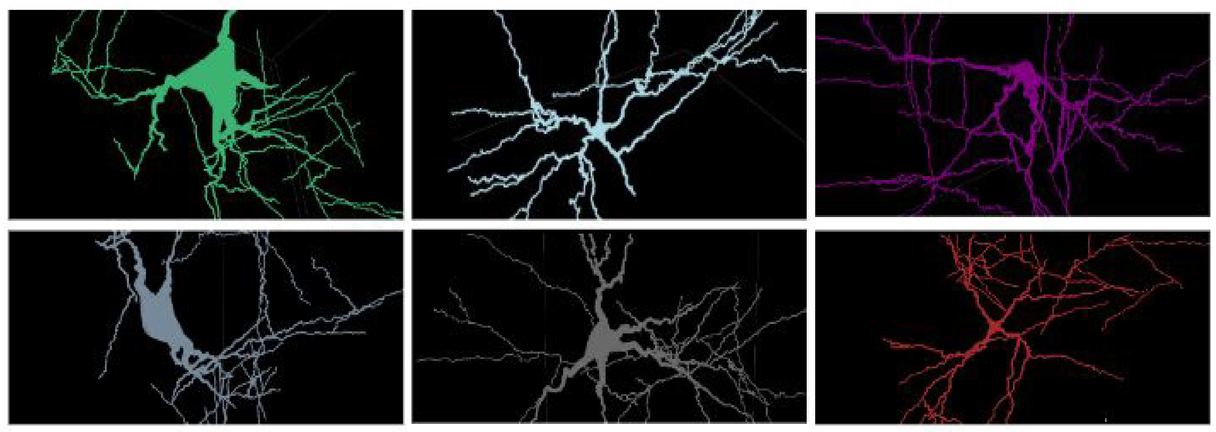
Analysis 2: The time dependence of intracellular water 1d diffusivity was evaluated across various substrates, including straight axons, periodically beading axons, stochastically beading axons, and axons that are both tortuous and stochastically beading. According to the effective medium theory [4] :

$$D(t) \simeq D_\infty + c \cdot t^{-\vartheta}, \quad \vartheta = \frac{1}{2} \qquad \vartheta = \frac{p+d}{2}$$

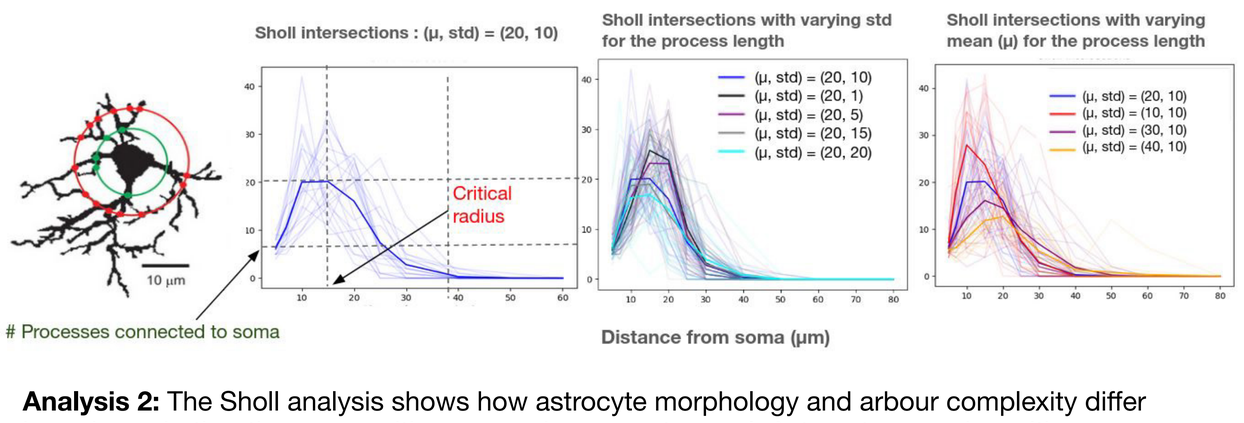


ASTROCYTES

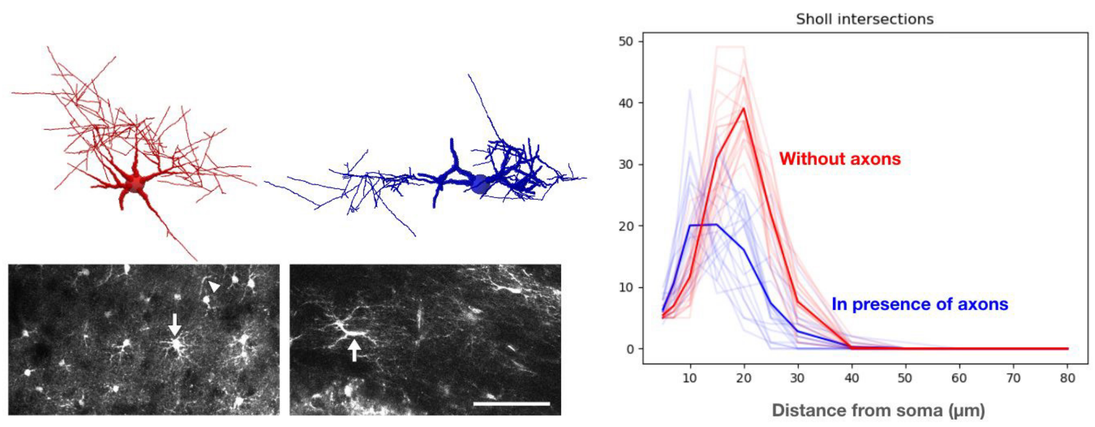
Examples of grown astrocytes :



Analysis 1: The Sholl analysis, commonly used to describe arbour complexity, was applied here. The results align with previous Sholl analyses conducted on histology data [3].



Analysis 2: The Sholl analysis shows how astrocyte morphology and arbour complexity differ based on whether they grow with axons or in an empty voxel. Astrocytes growing with axons resemble fibrous astrocytes found in white matter, while those without axons resemble star-shaped astrocytes found in grey matter (photon-microscopy image from [1]).



CONCLUSIONS

With the appropriate parameters, the CATERPillar tool can produce **realistic numerical phantoms**. The generated axons and astrocytes have been shown to exhibit morphologies consistent with previous histological findings [1, 2, 3]. Future work will involve conducting MC simulations to explore how this level of **realism impacts the synthetic signal**. Also, we intend to develop a Graphic User Interface (GUI) for CATERPillar and to make it publicly available.

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