

A parametric active 4D model for the automatic construction of developmental atlases from confocal images of shoot apical meristems

Guillaume Cerutti, Carlos Galvan-Ampudia, Jonathan Legrand, Teva Vernoux, Christophe Godin

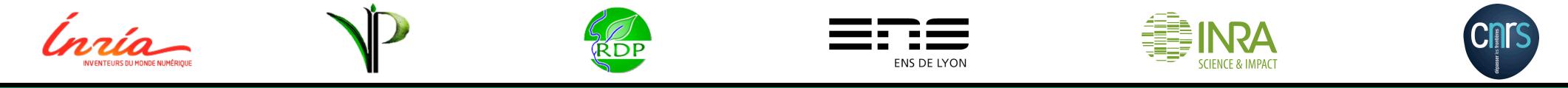
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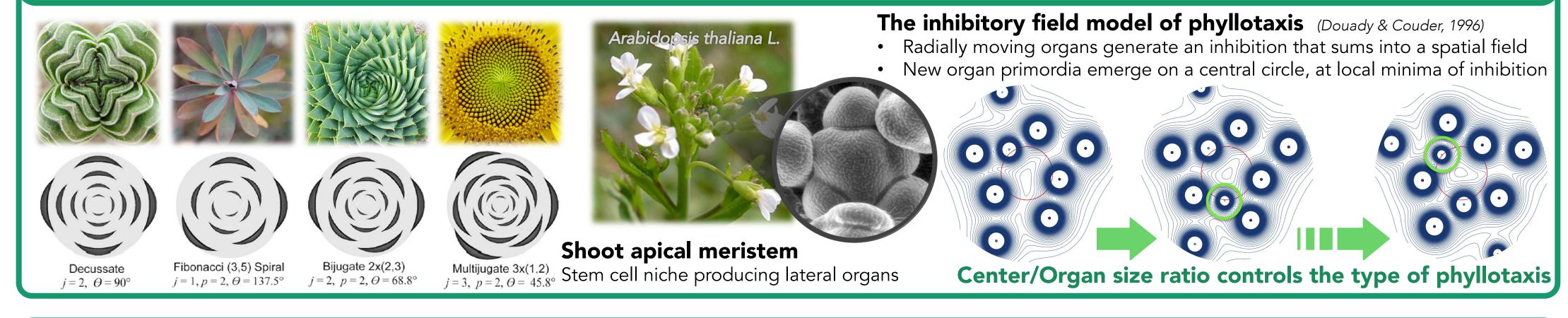


Understanding phyllotaxis by building a quantitative atlas of SAM development

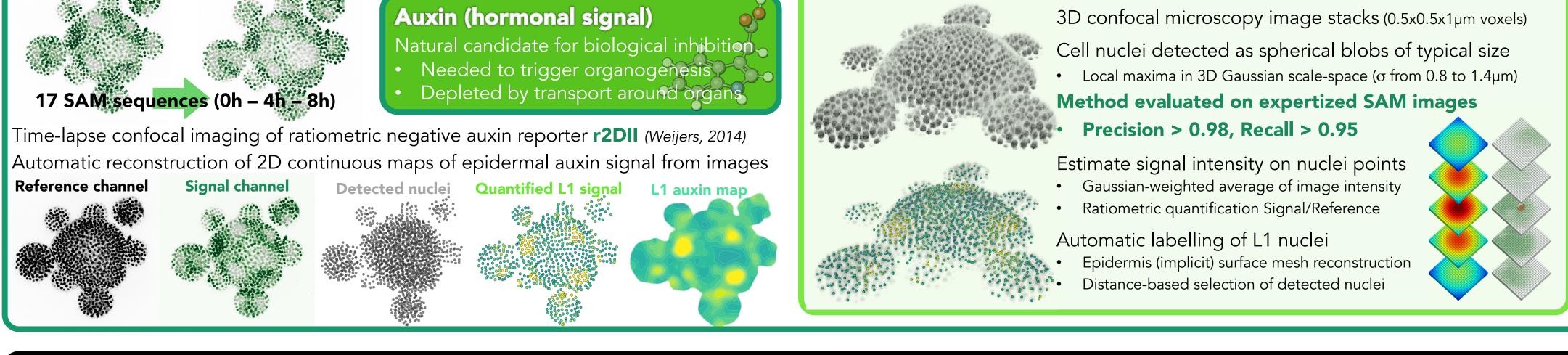
A parametric active 4D model for the automatic construction of developmental atlases from confocal images of shoot apical meristems

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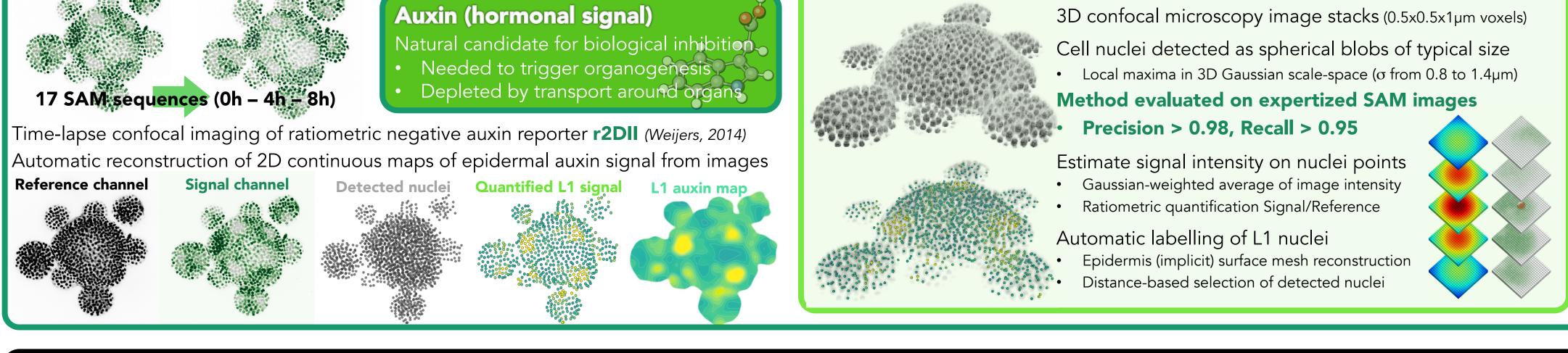
Phyllotaxis as self-organized pattering of organs at the shoot apical meristem: the Inhibitory Field theory



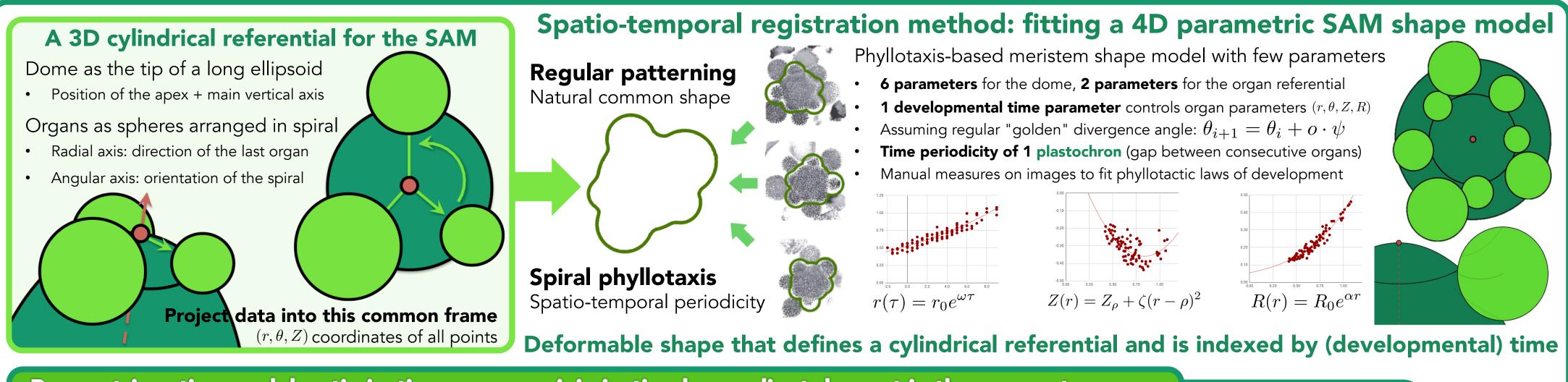
Quantifying auxin dynamics in the SAM to understand patterning



Automatic 3D nuclei detection and signal quantification pipeline



How to aggregate all the information from different time sequences into a single developmental atlas?

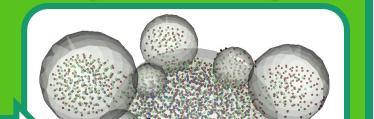


Parametric active model optimization: energy minimization by gradient descent in the parameter space

Optimize the shape model on the whole registered sequence point cloud

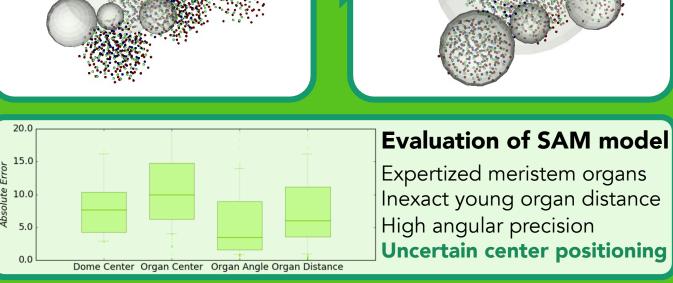
Energy functional with a classical formulation: **external** + **internal** terms $E(\mathcal{M}, \mathcal{P}) = \omega_{ext} E_{ext}(\mathcal{M}, \mathcal{P}) + \omega_{int} E_{int}(\mathcal{M})$ Evaluated on a voxel grid





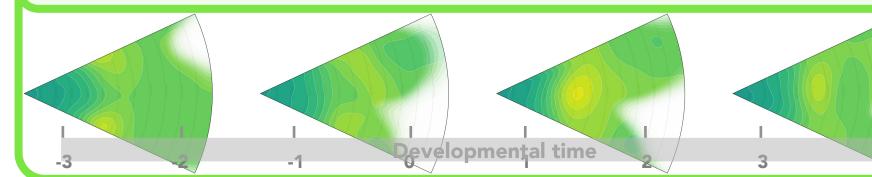


- External energy measures the fit to points: maximize the total density inside the model $E_{ext}(\mathcal{M}, \mathcal{P}) = \sum \left(\nu_{\min} - \nu_{\mathcal{P}}(\mathbf{x}) \right)$ $\nu_{\mathcal{P}}(\mathbf{x}) = \sum \frac{1}{2} \left(1 - \tanh\left(\mathbf{k}(\|P - \mathbf{x}\| - \mathbf{R})\right) \right)$
- Internal energy constrains the model shape: minimize the deviation from a vertical axis
- Energy minimization by **iterative variation** of the model parameter values
- Compute the energy variation associated with moving each parameter in both directions
- Amplitude of variations and change probability controlled by a cycling temperature
- Orientation is set manually but could be optimized (separately from other parameters)
- Possible local optimization of organ parameters afterwards (same energy)



Directly transform nuclei points into the 3D SAM referential & index the sequence by developmental time

Average dynamics of auxin in primordium development: formation of an "inhibitory field" in the peripheral zone only



Formation of an auxin maximum from the center

- Constrained by older organs (depletion zone)
- Appearance of a very focused auxin minimum
- Acting in the peripheral zone during 2-3 plastochrons

Directional inhibition (central ring) not isotropic

Perspectives of improvement & further developments

- Measure local spatio-temporal correlations of auxin & growth
- More accurate dome center location using CZ marker (CLV3)
- Better estimation of developmental time using auxin itself?



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