

MTG as a standard representation of plants in FSPMs

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Introduction

Two decades ago, a mathematical formalism was introduced to represent the complexity of plant branching structures at different scales with a unified approach. Using Multiscale Tree Graph (MTG), it was possible to capture the topology and the geometry of a multitude of plant species at different scales in a precise manner. However, the use of this formalism was initially dedicated to quantitative acquisition and analysis of plant branching systems. Its use in mechanistic models of plant growth has progressively emerged in various works to support multiscale modeling. In this paper, we review how the MTG formalism has been applied to models of plant development and extend it to comply fully with the requirements of Functional-Structural Plant Models (FSPM) at different scales.

Methods

Formalizing plant structure representation – To represent branching, different mathematical formalisms have been proposed such as Axial Tree (Prusinkiewicz et Lindenmeyer, 90), MTG (Godin and Caraglio, 1998), which define plant multiscale topological structures as a serie of nested tree graph, and more recently a structure-of-scales (Ong and Kurth, 2012) that, inspired from MTGs, models the scales as a partially ordered sets and allows to manage an extensive range of scales. Here we review how MTGs can be embedded in the context of FSPMs. This includes the possibility to grow MTG using developmental rules expressed for instance in the formalism of L-systems, and to encode the dynamic structure at different developmental stages as a time-series. We also discuss new extensions such as the possibility to manipulate continuous representations of plant properties at different scales.

Generic algorithms - Various algorithms have been designed to manipulate MTGs in a generic manner. We defined multiscale traversal (basipetal or acropetal) and user-defined visitors to model flows through plant structure at different scales, interaction with the environment as well as 3D visualization. Other algorithms are provided such as scale insertion or removal (see Figure), or a merge operator that concatenates several MTGs.

Universal coding of plants - MTGs correspond to computational data structures that can be described as simple bracketed strings. This notation is generic and provides simple means to describe any plant architecture as a universal string of characters. For Multiscale Axial Tree, a restricted family of MTGs, this notation corresponds to the lstring notation in the context of L-Systems (Boudon et al. 2012). This coding strategy has also been extended to encode dynamic multiscale structures.

Results and Discussion

In this section, we illustrate how the formalism of MTGs can be used in different FSPM applications. These applications concern acquisition and reconstruction, transport, interaction with the environment as well as simulation of plant growth.

Mapping real plants to MTG - MTG can be built either: i) from a textual description of a

plant structure provided manually or automatically using digitizing techniques, ii) from root phenotyping pipelines using the RSML format, and iii) from LIDAR or image shoot phenotyping methods available in OpenAlea.

Modelling multiscale transport - One important application of FSPM is the simulation of resource transport between plant components inside the plant architecture. Here, we use multiscale traversal algorithms to solve the flow of resources or hormones. Our approach is computationally efficient in memory and time, and has been applied to model shoot and root hydraulic architecture (Albasha et al., 2019), as well as source/sink carbon allocation at different scales (Reyes et al., 2019).

Interaction with the environment - Plant environment is usually represented as a separated spatial data structure (eg. 1D layers, grid of voxels, octree). This spatial structure models the geometric neighborhood of each plant entity. A mapping between these two structures is maintained to allow information transfer between the spatial and the topological structures. For example, the radiative balance or water uptake in a soil is computed using the spatial structure while the results are back-projected on the topological one.

Simulation of growth - The MTG formalism is the central data structure of the OpenAlea platform. Connexions with several FSPM simulation frameworks (GroIMP, L-Py or LIGNUM) have been developed by using the MTG data-structure as a unifying representation of plants. MTG growth can also be carried out in a procedural, data-driven manner, by interpolating different stages to form a temporal MTG, like in the ADEL model.

Conclusion

The MTG formalism has been extended to model and simulate FSPM at different scales. A package is available in OpenAlea with full documentation (<https://mtg.readthedocs.io>). Web tutorials are implemented using Jupyter Notebooks and are saved as interactive and reproducible documents with specific MTG and 3D widgets (see <https://bit.ly/2QaYgVJ>).

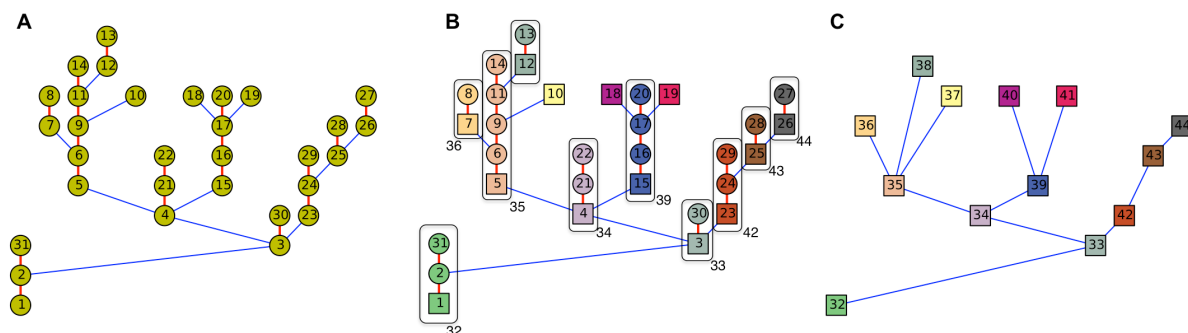


Figure: Automatic visualisation of an MTG at two different scales: A) The MTG is drawn as a tree at the lowest internode scale. Edges are drawn in red (successor) and blue (ramification). B) Automatic insertion of an axis scale. First vertex of each axis is marked to build a quotiented tree (square node). C) The same MTG drawn at the axis scale.

References

- Albasha et al., 2019, <https://doi.org/10.1093/insilicoplants/diz007>
 Godin and Caraglio, 1998, <https://doi.org/10.1006/jtbi.1997.0561>
 Ong et al., 2014, <https://doi.org/10.1093/aob/mcu155>
 Prusinkiewicz and Lindenmayer, 1990, <https://doi.org/10.1007/978-1-4613-8476-2>
 Reyes et al., 2019, <https://doi.org/10.1093/aob/mcz122>

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