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AMAPstudio: An editing and simulation software suite for plants architecture modelling

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ABSTRACT

AMAPstudio is a software suite dedicated to plants architecture modelling, designed for botanists and agronomists, providing features to edit, visualise, explore and simulate multi-scale plant descriptions.

AMAPstudio is based on the multi-scale tree graph (MTG) data structure, which is commonly used to represent plant topology. The user can explore and edit the topology and the geometry of one or several plants. Specific data can be extracted with combinations of criteria and can be visualised in tables and graphs. Simple analysis functions can be run and data can be exported to external tools, e.g. R or any other statistical computing environment, for more specific analyses.

AMAPstudio is also a framework in which modellers can integrate their own plant simulation models to build plant growth or scene dynamics scenarios and explore the results.

Models can be of different kinds, they can address more or less functioning and interaction with other plants or with the environment, possibly enabling to run ecological studies.

AMAPstudio is an open software built according to the Capsis methodology. It is scenario oriented and brings particularly interactive editors easing the daily work and knowledge transfer. It is a free open-source software (LGPL) available on all Java compatible operating systems and it can be downloaded on http://amapstudio.cirad.fr.

1. Introduction

Plant growth modelling helps to answer questions in agronomy, forestry and ecology. The plant architecture studies (Hallé et al., 1978; Barthélémy and Caraglio, 2007) resulted in various kinds of plant structure and development models (Prusinkiewicz, 1998), and many simulation software (Fourcaud et al., 2008).

In the 1980s, one of the first plant architecture growth simulators was designed by the *AMAP* laboratory (de Reffye et al., 1988). The *AMAP* software suite contained a plant architecture growth engine and a landscape manager aimed at computer graphics. Around 660 parameter files have been designed for as many plant species. It was followed by the development of the *AmapSim* software (Barczi et al., 2008) that introduced physiological ages (Barthélémy et al., 1997) and the reference axis model (de Reffye et al., 1991) to improve botanical accuracy.

Almost at the same time, the *L-Studio/VLab* software (Prusinkiewicz and Lindenmayer, 1990) was developed by Prusinkiewicz and collaborators to simulate plant growth based on *L-systems*. With this formalism, the development of plants is computed according to a set of rewriting rules. Another software based on the *L-systems* is *GroIMP* designed by Kurth (Kniemeyer and Kurth, 2008). It is an open-source software that extends the *L-systems* principle to general graph rewriting with relational growth grammars (RGGs).

Later, the OpenAlea component-based framework was designed "to facilitate the integration and interoperability of heterogeneous models and techniques from different scientific disciplines" (Pradal et al., 2008). Its VPlant package is more dedicated to plant architecture modelling, it is based on the multi-scale tree graph (MTG) formalism (Godin and Caraglio, 1998). The whole platform provides a visual programming interface to build and connect a wide range of tools dealing with plant models from the meristem to the scene scales, but also to deal with data analysis and image processing.

Other software like *Arbaro* (Weber and Penn, 1995) and *XFrog* (Lintermann and Deussen, 1998) with poorer botanical knowledge or other approaches like self-organising models (Palubicki et al., 2009) can be used to build plant structures. They are more dedicated to computer graphics, video games and image production.

In the mid-2000s, some scientists and students pointed out a lack for software with particularly developed interactive edition features, to facilitate the daily work on plants architecture measurements and observations (i.e. importing, checking, editing,

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visualising and exporting). This software would be focused on scientific purposes, dedicated to plant growth models, centred on plants architecture (Fourcaud et al., 2008) and not limited to a single modelling formalism nor a particular model. The *AMAPstudio* project (Griffon and de Coligny, 2012) has been developed in the *AMAP* laboratory since the end of 2008 to address these specific needs.

AMAPstudio proposes a generic data structure dedicated to plant topology and geometry encoding like in other software, but coming with many features to handle it interactively. It is able to manage an individual plant (or part of it) with its components (axes, shoots, organs), as well as a scene made of individual plants plus other objects. Besides its features for experimental data management, AMAPstudio is also a framework to host individual-based plant growth models, based on the *Capsis* framework (Dufour-Kowalski et al., 2012), designed for the forestry modelling field since 1999.

In this paper, Section 2 introduces AMAPstudio's main design options concerning the software features and the proposed methodology for models integration. To explain accurately the scope of AMAPstudio, Section 3 lists different kinds of integrated models, putting emphasis on ecological studies that have be run by coupling growth models with environmental models. Finally, Section 4 discusses the main singularities of the AMAPstudio approach.

2. Software design

2.1. Main options

In AMAPstudio, plant representation is based on the multi-scale tree graph (MTG) formalism (Fig. 1). This tree graph represents the topological organisation (branching, succession and decomposition) of plant components at several levels of detail. Any type of attribute may be attached to any plant component. Attributes can be quantitative (e.g., length, surface, weight) or qualitative (e.g., nature or type of an organ). Some attributes can be used to compute plant geometry (see Section 2.4).

Studying plants at the individual or at the scene level (several plants) raises different kinds of issues. To better address these issues, AMAPstudio was designed as a software suite. The *Xplo* software is designed to handle single plants. It contains a plant editor and can host some plant growth simulators. The *Simeo* software proposes spatialised scene level features, including plants layout and editing features as well as dynamics simulators. Both software try to keep a similar user interface policy to make their use as easy and intuitive as possible.

2.2. Interactive editors

Xplo and Simeo bring *interactive editors* to work on the plant architecture with classical import/export capabilities and specific features. The two software being part of the same suite, each one can read the plant files written by the other and it is possible to select a plant in one and open it directly in the other.

Xplo can import data from digital acquisition devices (e.g. tacheometer) and is also able to accept direct input of observations (i.e. manual measurements), it has a spreadsheet like central table to edit all plant elements and their attributes, synchronised in real time with a central and customisable 3D view to show the plant mockup (see Section 2.4). It also comes with a set of flexible extraction features to quickly select some elements of the plants by creating new columns in an extraction table, filter the values on the fly and compute simple statistics. Finally, the resulting data can be plotted directly in Xplo or exported to other software for further analysis.

Simeo proposes a set of plugins to layout plants according to several patterns. The terrain where the plants are added can either be flat, with a single slope or rely on any height map. It is possible to select plants and move them easily with the mouse, or set their coordinates more accurately through an editor, and similarly enter angles to rotate them. The customised scene can be exported to biophysical simulators with dedicated connection plugins, e.g. an Archimed-MIR (Dauzat et al., 2008) radiative balance simulator. The results can be added in new attributes for the impacted plant components and can then be explored inside AMAPstudio or exported to other software for further analysis (Fig. 2).

All these features were made highly interactive (Griffon and de Coligny, 2012) to be usable by any scientist or student needing to make basic actions quickly. Most of them can be managed by AMAPstudio's undo/redo system.

2.3. A simulation framework

AMAPstudio does not only supply interactive editors for plants structures. It comes with a complementary approach to integrate plant growth models relying on the *Capsis* generic framework (Dufour-Kowalski et al., 2012). This methodological and technical framework is not a model but rather an environment to host temporal dynamics models. The hosted models can be very different, e.g. distribution-based models, individual-based models, statistical or process-based models, spatially explicit models, etc.

The framework was adapted to be used in AMAPstudio's two separate software, focusing on plant growth models. Xplo hosts single plant level growth models and Simeo embeds dynamics models at the scene level (i.e. several plants), thus enabling to consider the possible competition for resources between neighbouring plants. The models may indeed be very different, some of them including a more or less detailed description of the environment.

In order to integrate his plant growth model in AMAPstudio, any candidate modeller must contact the AMAPstudio developers and accept a simple charter which main terms are: (i) the software core and mutualised libraries are distributed under the terms of a free license to be accessible to everyone; (ii) the candidate modeller is the project leader, he is in charge of the actual development, his model stays his property, he may choose a distribution license of

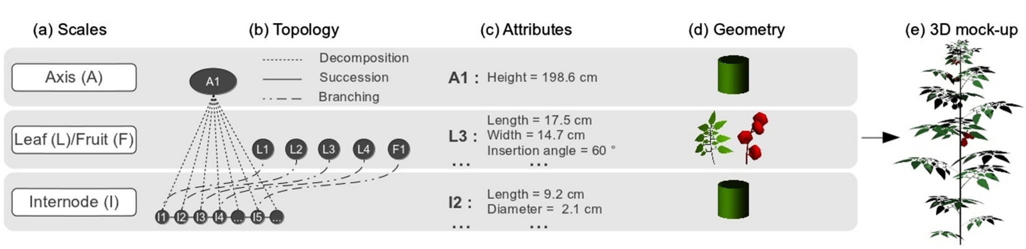

Fig. 1. An example of a tomato topology and geometry description. This plant is represented at axis, leaf/fruit and internode scales (a), the main axis is decomposed into successive internodes which can branch into leaves and fruits (b). Each plant component can have attributes and geometry information (c and d). The default geometry builder can compute a plant 3D mock-up (e).