RECORD
An Integrated Platform for Agro-ecosystems Study

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Abstract: The complexity of models developped in order to improve the agricultural systems and the need to have efficient tools to build them, simulate and analyse them have motivated the conception and the development of the new modelling and simulating platform RECORD. This paper describes how this initiative of the French National Institute for Agricultural Research has been conducted. A pragmatic strategy consisting in integrating heterogeneous tools into a same framework has been used. The example of the integration of the 3 different tools: VLE, R, Python illustrates how the users' requirements have been fullfilled. The platform is currently used in various projects, and on the basis of the first experiences, we conclude on the interest of this strategy. We underline that this strategy must be accompanied by efforts on developping user's training and coaching on these powerful tools. Finally software design should facilitate collaborative developments, which will motivate our future works.

1 INTRODUCTION

Agriculture is currently driven by continuously evolving challenges (e.g. climate change, environmental concerns, market globalisation, food safety and quality) and requires the development of innovative sustainable production systems. Modelling and simulation approaches are usefull in identifying the agricultural systems that respond to current social, economic, political and environmental concerns. However, building, testing, evaluating and using models (i.e. simulating different combinations of management, soil and climate conditions and policy and environmental constraints) is far from being a straightforward task. Numerous models that can address questions about agro-ecosystem functioning already exist. The major issue now is how to combine or couple these models and use them at different spatial and temporal scales rather than develop new models. To overcome the problems which arise when building, simulating and reusing models, generic computing platforms have been created. Most of these platforms capitalise on advances in computer science (e.g. object-oriented, modular and generic programming) and propose model repositories to facilitate their use and re-use (e.g. CropSyst (Van Evert and Campbell, 1994) or ICASA (Bouma and Jones, 2001)).

To take advantage of these developments the French cropping-system research community tries to define a strategy to developp an integrated modelling platform, named RECORD (REnovation and COORDination of agro-ecosystems modelling), to gather, link and build models and companion tools to answer new agricultural questions (Bergez et al., 2012). We present in this paper the pragmatic approach we have used to developp the platform. It is essentially based on dedicated software development and reuse of existing tools. The first section gives an overview of the functional requirements of the platform. Section 2 explains how the RECORD platform was designed in order to fulfill the initial requirements.

2 REQUIREMENTS FOR THE PLATFORM

The functional requirements for the platform were defined following a survey targeting modellers from the Environment and Agronomy department of INRA and seminar in 2007.

Scope and Users. The platform must be able to simulate cropping systems and interactions with the surrounding territory. Four types of users were identified: i) researchers working on and designing crop-

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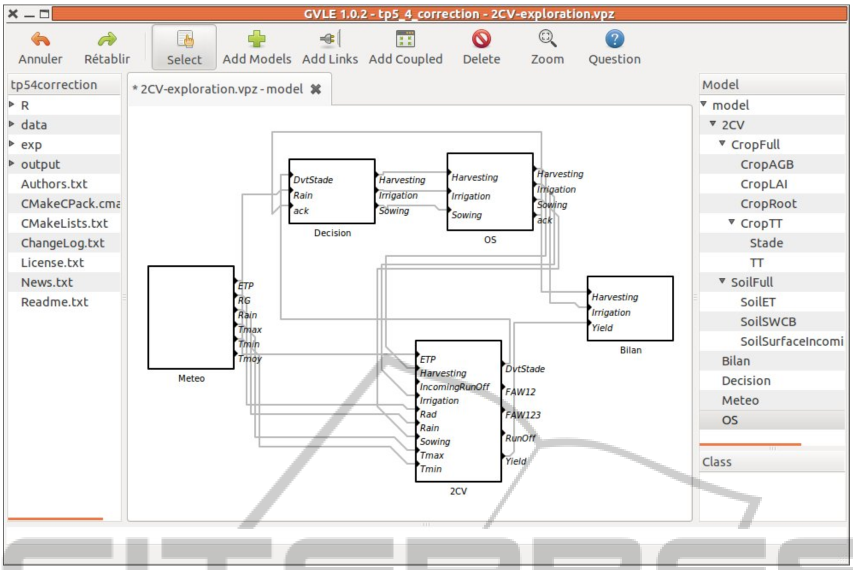

Figure 1: The coupling of a decision model, an assessment model called *Bilan*, and the corn crop model 2CV designed into VLE. Up right, the hierarchical structure of the model is given into a tree structure. The model embeds coupled models (e.g. 2CV, CropFull) and atomic models (e.g. Decision, SoilSWCB).

ping systems ii) researchers using cropping system models iii) extension service personnel who wants to test new cropping-systems proposals and iv) graduate students being trained in modelling.

Accepting Various Time and Spatial Scales. Hourly simulations up to several decades for sustainability studies have to be permitted. Spatial aggregations include a plot or a set of plots representing one or more farms, including, if necessary, interstitial areas and larger areas such as a territory when dealing with natural resources (e.g. a catchment). Transfers between different spatial units must also be modelled (e.g. water exchange, pests, genes, spores).

Accepting Various Formalisms. Most current models are dynamic with discrete time steps. However, the platform also should be able to incorporate static and stochastic models and different formalisms (e.g. difference equations, differential equations, Markov chains, state charts, cellular automata).

Focusing on Management. It is particularly important that the platform be able to handle management models for cropping systems. Modelling factors such as technical operations sequences, competition among agricultural tasks, spatial distribution of agricultural practices and choice of crop rotations in a field must be possible.

Using Existing Codes. Existing crop models cover a wide variety of crops, crop management options and spatial and temporal scales. The architecture of the platform should enable integration of these different types of models, either by recoding or by encapsulating existing code. The design of the platform should also allow model developpers to share easily their models and generic developments through a collaborative development strategy.

Using Models. The platform should facilitate i) implementation of optimisation methods by simulation, ii) implementation of methods of multicriteria choice, iii) comparison of cropping-systems models and iv) use of data-mining techniques to exploit simulation results. Deployment of models on web sites should be facilitated by generic web development.

3 METHODS AND TOOLS

Applications in agriculture or environment requires frequently the integration of several models, the possibility to share them and to explore them with numerical methods. For modelisation and simulation, the platform relies on DEVS theory and VLE software. The use of R software is favoured for statisticals works on models (parameterization, evaluation). Finally, python language and its libraries offer a good solution for web development.

DEVS Theory. DEVS (Discrete Event System Specification) is a theoretical formalism for modelling and simulating dynamic systems with discrete events. It provides a robust solution for the coupling and integration of heterogeneous models and the implementation of complex hierarchical systems as it was proved by formal mathematical proofs (Zeigler et al., 2000). There are two types of models in DEVS, atomic and coupled models, which exchange information in the form of events. Based on DEVS theory, the abstract simulator DSDE (Barros, 1998), is able to modify model structure during a simulation with an atomic model called executive.

VLE Software. VLE (Quesnel et al., 2009) is a free and open-source software developed in C++ which provides simulators, modelling tools, libraries, an IDE (Integrated Development Environment) and a SDK (Software Development Kit). It is a generic modelling, simulation and analysis environment based on the DEVS formalism, and implements a DSDE simulator. VLE offers a library of extensions which correspond to commonly-used mathematical formalisms: cellular automata, statecharts, ordinary differential equations (including classical numerical integration schemes such as Runge Kutta and QSS (Cellier et al., 2008)), difference equations and a decision making extension based on planification of activities. We identified the three last cited extensions as a basis for modeling agro-ecosystems. Solutions for complex models that involve large territories are provided. For example modelling hundreds of plots is achieved by using "executive" models that generate the plots and their connections from GIS (Geographical Information System) data. A GUI (Graphical User Interface) is used to edit models, to set initial conditions and to perfom simple simulations (Figure 1). For multi-simulation, one can express experiment plans as combinations of initial conditions and parallelisation of simulations on different cores can be performed.

Statistical and Mathematical Works with Models. Statistical methods for parameter estimation, validation and sensitivity analysis are necessary for implementing and analysing agro-ecosystem models (Wallach et al., 2006). Platform RECORD relies on a package *rvle* that links VLE to the statistical language R (R Development Core Team, 2011) in order to perform models calibration and exploration. For example, Table 1 gives indices resulting from a sensitivity analysis performed with *fast99* (Saltelli et al., 1999) on the crop model 2CV. It concerns 5 decision variables for irrigation and targets a net margin output. Based on this analysis, one can search for the couple of values of water supply and stock (ie. the variables that impact the most the output), that lead to a maximal expected net margin. The stochastic behavior of the model comes from climatic data produced by a a stochastic generator of climatic series available into the platform. Results of a simulated annealing optimisation, performed with R function *optim*, suggest the couple $(16\text{ mm}, 121\text{ mm})$ which leads to an expected output of 898 euros per hectare.

Concerning optimisation of agro-ecosystems models, challenges such as multi-objective (e.g. economic and ecologic criterion) and optimisation under uncertainty (when e.g. models depend on climatic data) arise rapidly; see e.g. (Crespo et al., 2010). Current works also concern embedding optimisation into simulation. For example, optimising the behavior of an agent that reacts to a system such as a biophysical model, by mean of e.g. reinforcement learning (Garcia, 1999) requires that the optimisation is finely coupled to simulation.

Table 1: Indices (ordered by total effect) of 5 decision variables resulting from a sensitivity analysis.

variable	main effect	interactions	total
water stock	0.54	0.29	0.83
water supply	0.37	0.39	0.76
irrigation delay	0.20	0.20	0.40
threshold on soil water	0.002	0.042	0.044
threshold on available water	0.003	0.040	0.043

Web Applications. The models in the RECORD platform could be of real interest as educational tools to improve understanding of agro-ecosystems or as tools for decision makers to integrate agronomic, social, economic and environmental issues. However, direct use of these models by non-scientists or by users with limited computed skills could be problematic because i) they often require significant parameterisation to adapt them to individual contexts, ii) model validity is context-dependent and iii) working directly on the platform requires a minimum level of training. Therefore, we proposed a web-oriented tool, designed to develop web applications around the models implemented on the platform (Figure 2). This tool is based on the development of a specific package: PyVLE that enables the use of VLE from Python applications. This package provides a set of functions that enable the management of VLE simulations from Python scripts. Therefore, VLE simulators can be parameterized, launched from Python and results are available for further uses such as graphical representations. A framework (such as Pylons, Django or Zope) to help in developing the application is used. The database holds the information used to specify the various simulated contexts (e.g. climate, soil, varietal characteristics, crop distributions). There is one model per context, and several contexts are simulated at the same time. The results are aggregated into indicators and graphs which are easily understandable by professionals. Some applications are already on-line and used by scientists, students and agricultural advisors.

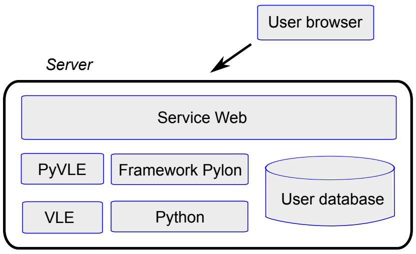

Figure 2: The main elements of the RECORD web architecture.

4 CONCLUSIONS AND DISCUSSION

Since 2007, choices have been made for the development of the platform RECORD. First, it has been decided that all features that were required should not be part of one unique tool, in light of the large range of disciplines that are involved. Nevertheless the technical solutions should not restrain the different communities to a confined set of methods and tools. Technical solutions for model development, model analysis and web applications are the following:

- The software VLE provides an IDE for designing and coupling models. Coupling properties are ensured by the DEVS theory which is the basis of VLE. This IDE can be used to perform the first simulations.
- R and its libraries are used for analysing and exploring models. The platform relies on a specific R package that links R to VLE.
- Python and its libraries are the basis of web applications development for RECORD projects, thanks to a link between Python and VLE.

A large set of methods and tools are thus possibly carried out into the platform. Due to this integration strategy, there are few assumptions that are made regarding the methods that are involved. For example, parameter estimation of a model using R can be performed in different ways. The challenge of RECORD is to identify well suited methods with the help of experts and to build training courses which are provided through an E-learning web site and 3-days practice sessions (2 per year).

We finally argue that integrating tools is the best solution to develop a collaborative platform. Another important task that the platform team addresses is to facilitate the collaborative work. The solutions proposed and which are currently under construction comprise the package management system into VLE, attachment of meta-data to packages and models for documentation and configuration.

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