O.23 - Formal tools of automation may support the design of decision systems for IPM

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Abstract

We consider here pathosystems whose modelling in terms of epidemics and damage makes it difficult, or even impossible, to compute optimal crop protection strategies, such as protecting from grapevine mildews. IPM strategies and decisions should use available epidemiological knowledge as well as expertise which includes knowledge and facts about phytosanitary products, resource management, behaviour of plots and cultivars and local warning systems for bioclimatic risk. We argue here that this expertise can be used to design decision frameworks and that formal tools facilitate deep and consistent design which can then be transferred to technical advisers and growers. We provide some key issues from an example of such design named GrapeMilDeWS (Grapevine powdery and downy Mildews Decision Workflow System). From the automation point of view, GrapeMilDeWS is a controller of a dynamic system, and was modelled with the graphical language of Statecharts. In the field of human pathology, some scientists are also promoting formal means of studying consistency of decision and diagnostic guidelines. Formal design of decision strategies requires interdisciplinary scientific effort, which we believe could contribute to theoretical and practical innovation. We end up by showing how formal tools could be used to describe requirements that a desirable crop protection decision method should have. In the case of incomplete knowledge about a pathosystem, testing the conformance of different decision methods according to a shared and well-defined requirement set may help to enhance agricultural practices and scientific exchange about these.

Background and objectives

There is a strong trend in modern agronomics to use simulation as an aid for designing and evaluating agricultural techniques and practices. Simulation requires some mathematical modelling, including differential equations, discrete event systems and behavioural representation through programming code. Once modelled, the whole system includes a model of what is under analysis, and a model of the 'environment' that has to mimic or represent some reality. When it comes to studying the decision itself, then this 'environment' has to include actual agricultural actions consecutive to decisions, and the behaviour of the crop (the latter is often called biophysical system, see for example Cros et al, 2003). We have focused on pest management decisions from the perspective of automation sciences and will use consistent vocabulary. We will name the decision system the 'controller' and the 'environment' of such a decision system the 'controlled system'. Real agricultural decisions may seem difficult to assimilate to the outputs of a control system like industrial automata. Yet, we don't consider here simulation for predicting the behaviour of actual growers but rather modelling for designing and checking recommendations about a set of sequential crop protection decisions. Simply put, we want to be able to represent and analyse the decision part in a crop protection method.

Pathosystems designate the interactions between pest and host under the influence of climate and man. We consider here pathosystems for which modelling of epidemics and damage makes it difficult, or even impossible, to compute optimal crop protection strategies. This is the case for downy and powdery mildews of grapevine. In such cases, IPM (integrated pest management) strategies and decisions need to use available epidemiological knowledge but also rely a great deal on expertise. This includes knowledge and facts about pesticides and fungicides, resource management, behaviour of plots and cultivars and local warning systems for bioclimatic risk.

Our purpose is to contribute to IPM by designing controllers (decision systems) for pathosystems. By using formal tools, we aim to facilitate detailed and consistent design which can then be transferred to technical advisers and growers. From the control system point of view, the problem is that the 'controlled system' (pathosystem at the plot scale) is difficult to simulate. Then, the experimental part is crucial for evaluating the control system. Still, the number of pathosystem scenarios is high and climate dependent, and corresponds to some complexity in the number of states of the controller. This is why we are investigating model-checking techniques for checking internal consistency and logical properties of controllers for IPM.

In human pathology, some scientists claim that verification techniques would contribute to enhance the quality of the growing number of medical practice guidelines and protocols (ten Teije et al, 2006). We will show here some similarities of our achievements for a phyto-pathosystem and those made in human pathology (ten Teije et al, 2006).

Results and discussion

An expert IPM solution was designed by phyto-pathologists at INRA Santé Végétale in Bordeaux (Léger et al, 2007). It was named 'GrapeMilDeWS' (Grapevine powdery and downy Mildews Decision Workflow System). GrapeMilDeWS was designed at the plot scale and targets two of the prevailing fungal diseases in the vineyard: powdery mildew (*Erysiphe necator*) and downy mildew (*Plasmopara viticola*). Its French nickname is 'mildium' (contraction of the two diseases' names in French).

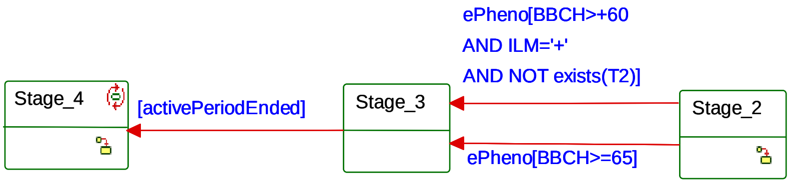
GrapeMildDeWS was experimented in 2005 and 2006 on four plots, and has been experimented on more plots since (6 in 2007). It is structured as a set of decision stages and evaluations (see table). For each stage, at most one treatment against powdery mildew and one treatment against downy mildew can be decided. Some are mandatory (M, only 'when to perform' them has to be decided) and other are optional (O, made only when decided necessary), which leads annually to between 2 and 5 treatments for powdery mildew and between 2 and 7 for downy mildew. GrapeMildDeWS is designed so that treatments against the two diseases are sprayed in one operation when they are necessary.

Phenology	State	Powdery Mildew	Downy Mildew
	Stage0	/	O
5/6 Leaves	E1	/	/
	Stage1	M	O
8/10 Leaves	E2	/	/
	Stage2	O	O
Mid Flowering	Stage3	M	M
	Stage4	O	O
Cluster Closure	E3	/	/
	Stage5	O	O
Early Ripening	Stage6	/	M

Decision stages and observation times for GrapeMildDeWS

Three evaluations are made on the plot, two on leaves (E1 and E2) and the third (E3) on bunches, to evaluate the dynamics of both epidemics. They are much more time consuming than the quick surveys that growers usually do, but are less frequent and are precise enough to make decisions to spray or not to spray. Other variables taken into account for decisions are local area information about downy mildew epidemic pressure, as well as rain forecasts.

Within each stage, the sequence of decision is detailed (Léger et al, 2007) and the events that trigger the change from one stage to the next are also given, as exemplified in the following figure.



Triggers of stage change

BBCH designates in this figure the generic phenological scale (60 to 69 are the flowering stages). activePeriodEnded represents the end of the homologated efficiency duration of phytopharmaceutical product against the target pathogen

GrapeMilDeWS is meant to reduce the number of treatments, with similar objectives for quantities and qualities of harvest as growers have when using conventional practices. In 2005 and 2006, a reduction of approximately 50% of the number of treatments was obtained in comparison to the average number of treatments observed in the Bordeaux region.

GrapeMilDeWS was originally recorded in a set of quite informal documents (text and tables), with incomplete information and some inconsistencies. In order to make GrapeMilDeWS transferable, the experts who designed it were interviewed and the knowledge was elicited from them, in order to build a formal model. The Statechart modelling language has been chosen as the target formalism for the model. It is an extension of finite automata, with a graphical representation and semantics that make it possible to generate executable computer code. The interviews were conducted by confronting experts with successive Statecharts graphics. Compared to the approach by (ten Teije et al, 2006), Statecharts have the same function as Asbru. Asbru is a language for describing medical protocols which has been provided with semantics that make the description executable, as Statecharts are.

Statecharts can be verified (model-checked) using appropriate model transformations. As for Asbru, it was also shown that a model in Asbru could be converted into the formalism of the KIV verification tool. These verification tools allow for checking internal consistency and properties of model behaviour. For example, for GrapeMilDeWS, it would be possible to check internal consistency like ‘can it be that 2 successive treatments against downy mildew be made with less than 5 days interval?’ or check if maximum number of treatments against downy mildew occur only for severe epidemics on the plot. The answer to the latter question is definitely no because well motivated local information can trigger treatments in the absence of symptoms on the plot itself.

The advantage of model-checking is the genericity, and the capacity to increment the number of answerable questions about the behaviour by incrementing knowledge of the controlled system, without requiring a proper ‘biophysical model’, which is replaced by automata representing time constraints imposed by the pathosystem. We will come back to expression of time later.

Ten Teije et al explain in their article that another use of a model in Asbru, besides verification, can be ‘critiquing the physician’: this is comparison of actual decisions in regards to what decision the model would provide. This comparison can be used to enhance either actual practice, or the model itself. With different objectives, we performed a comparison between the GrapeMilDeWS model and the actual decisions taken by its designers during the experiments of 2005 and 2006. Thanks to careful knowledge engineering, we considered that the Statecharts model was a proper description of GrapeMilDeWS. The comparison was meant to assess if, with similar inputs, the model makes decisions consistent with those made by the experts during experiments. The comparison was very satisfactory about decisions, but revealed some facts about representation of time and anticipation by experts.

Indeed, we had made before starting elicitation the hypothesis that GrapeMilDeWS could be treated as a ‘reactive system’: each event and data refresh provides an update of state; and the assumption was that, once an evaluation or a treatment is ordered, it is performed ‘as soon as possible’. Some synchronicities between events on trial plots which are not explainable by GrapeMilDeWS model seem due to a ‘batching behaviour’. Even if decisions are taken separately for each plot, observations for example may be planned so as to organise the workload. To represent this, it is necessary to replace the hypothesis ‘action consecutive to event should be performed as soon as possible’ by ‘action consecutive to event needs to happen between date a and date b’ or alternatively ‘maximum delay for performing action is d'. Such time information can be provided in the Asbru language for medical protocols. It can also be provided with generic formalisms such as timed automata or timed Statecharts.

Conclusion

We have exemplified here that formal modelling tools such as automata or UML Statecharts can be used to support clear design of IPM decision systems. These tools allow the analysis of logical properties of the decision system and for eliminating inconsistencies and ambiguities in order to obtain transferable knowledge. Verification tools are an alternative to simulation of pathosystems when complexity and lack of knowledge makes simulation difficult. We have shown that similar concerns and approaches have arisen about medical guidelines. In (Mace et al, 2007), informal temporal diagrams for crop management sequences and decision making about weeds were established from interviews of farmers, where the timeline resembles the decomposition of growing season in stages found in GrapeMilDeWS. Besides a timed description of decision, the time scales that farmers take into account were put into evidence in (Mace et al, 2007).

It seems to us that, because formal tools for describing sequences and time seem pertinent from phytopathology to pest management as well as for medical protocols, the exchange of experiences should be encouraged.

References

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References to related works can be found out on:

https://itap.cemagref.fr/pages-personnelles/olivier-naud/

Principles of GrapeMilDeWS model are given in (Leger et al 2007). Please check web page above for updated references about details of the model & comparison of model with experts' behaviour.

Other precisions:

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