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# An expert-based crop protection decision strategy against grapevine's powdery and downy mildews epidemics: Part 1) formalization

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**Abstract**: A formal model was built in the discrete event paradigm for dynamic systems 1) to test the feasibility of the spraying decision strategy "GrapeMilDeWS", 2) to facilitate its transfer and usability, 3) to build a simulator that would allow testing climatic scenarios and scalability of the solution at the estate level. The knowledge elicitation process was made incrementally with the 4 designers of GrapeMilDeWS. The elicitation method uses the graphical language of Statecharts as a mediation tool between the experts and the knowledge engineer. Besides graphics, Statecharts are also a mathematically formal language. We present here the design principles that guided the experts in their design, how these principles have been formalized, the knowledge elicitation methodology that we set up and the questions that arouse from questioning formally the spraying strategy.

**Key words:** Decision, Statecharts, Elicitation, IntegratedIPM, viticulture

## Introduction

With the growing consciousness of environmental and health issues among the public, sustainable agriculture is a major research topic. The present case study is about French vineyard. Vine growers consume about 20% of the pesticides used in France while vineyards' area is 3% of the farmland (Aubertot et al., 2005). The development of fungal pathogens is climate dependant, and outbreaks are difficult to handle. Thus, growers have developed intensive and mostly preventive crop protection techniques. Integrated Pest Management (IPM) would then be desirable for sustainable viticulture. IPM aims at reducing the amount of inputs while keeping the revenue of farms, through the use of biological control as well as pesticides when necessary (Kogan, 1998). Unfortunately, the complexity of the vine-pathogens system and current lack of detailed epidemiological knowledge does not allow to calculate optimal solutions within a limited set of options, as it can be the case for cereal crops. So pest management procedures for viticulture need to be based on expertise.

We consider here IPM as a process included in an overall agricultural production process. Design of production processes in agriculture has benefited from simulation for a long time now. Simulation models use a number of paradigms (Ascough II et al., 1997; Attonaty et al., 1994; Cros et al., 2003), including discrete event systems (Cournut and Dedieu, 2004).

Rule based decision support systems are common in agriculture (Girard and Hubert, 1999; Shaffer and Brodahl, 1998). Our approach of decision making is process based. We present here a contribution to the design of decision procedures, with a representation that belongs to the family of Discrete Event Systems (DES) formalisms.

An expert IPM solution was designed by our phyto-pathologists fellows (Clerjeau, 2004). We named it "GrapeMilDeWS" (Grape Mildews Decision Workflow System). GrapeMilDeWS aims at controlling two of the prevailing vineyard diseases: Powdery Mildew

(*Erysiphe necator*) and Downy Mildew (*Plasmopara viticola*). It is based on the following hypothesis: Expert knowledge, expertiseinformation and field observations can substitute numerous and systematic treatments. GrapeMilDeWS was experimented during two years on four plots, and it demonstrated its efficiency at this scale, with satisfactory harvest and greatly reduced number of crop protection operations(Cartolaro et al., 2007). Yet the process description was originally very informal, and its implementation still relied on the knowledge of the researchers. Formalising GrapeMilDeWS allowed all necessary hidden knowledge to be elicited. Modelling has indeed two objectives. First, the formal model would guaranty a better transfer of technology disambiguating the GrapeMilDeWS features. Second, a formal model can be included in a simulation model of a virtual farm, to check for usage of resources, induced costs, and to test the system against scenarios that were not experimented in the field.

In the following sections we present an IPM solution for controlling the vine pathosystem, designed using expert knowledge; statecharts which were identified as a pertinent formalism to model the system; and knowledge elicitation method which was conducted to build the formal model with the experts. Finally the teachings of this formalisation are discussed.

## Design principles

The goal of GrapeMilDeWS is to avoid yield losses: disease symptoms are tolerated and monitored. This is achieved by the following strategy. Low epidemics can be controlled with a reduced number of systematic treatments applied at certain phenological stages (two against downy mildew and two against powdery mildew). Careful monitoring early in the season allows to identify potentially severe epidemics, in order to apply additional treatments (five optional sprayings are available against downy mildew and against powdery mildew, three extra treatments may be done). Another principle of GrapeMilDeWS is to make decisions plot by plot, according to their specific epidemics conditions.

The main indicators are collected, at the plot scale, through observations of symptoms on the leaves as well as on the bunches. These observations give an estimate of the level of the epidemics. The observation results are then, translated into three discrete variable: M, O, Og. Variable M stands for downy mildew, O and Og stand for powdery mildew respectively on leaves and bunches. The number of symbolic values for each variable varies from two to three depending on the disease, and the observation date. These symbolic values encode the qualitative expert notion in the following manner: ('0') for absence of epidemics or low epidemics; ('+') for moderate to high epidemics; and eventually ('++') for very high epidemics. The values of the thresholds between these different modalities evolve with the phenological development of the vines. It allows adjusting the consequences of an epidemic to the evolution of the plant susceptibility during its development. Field observations are the only indications used as far a powdery mildew is concerned. Two extra indicators are used to assess downy mildew epidemics.

- The local area risk level (ILM) gives information at a larger geographical scale than the plot, of the risk of development of the disease. It is based on a large disease monitoring network and on a climatic risk model. This information is provided through the official warning service bulletins (SRPV-Aquitaine, 2007). ILM is also a discrete variable, with two values: (0) low risk and ('+') medium to high risk.
- The forecasted rain events from the weather forecast of MeteoFrance.

Thus ILM and rain forecasts are updated by exogenous sources of information at any time while O, Og and M are controlled by GrapeMildDeWS which triggers their update via requesting observations.

When a spraying is required for one disease, decision about adding the treatment against the other will be taken in the same decision stage. Joining a much as possible the treatment against powdery and downy mildews, when both are needed, is consistent with the operational constraints that growers have to deal with.

Still to alleviate the work load, GrapeMilDeWS is constrained on the number of observations. W.r.t the pathosystems at hand: grapevine powdery mildew and grapevine downy mildew , the majority of the field observations are done before flowering.

Their objective is to detect the severe epidemics by quantifying the early symptoms of the diseases on the foliage, before the period of high susceptibility of the bunches. This allows, when required, to position treatments limiting the proliferation of inoculums on the foliage.

During the period for which the bunches are most susceptible, protection is provided using systemic product against both target diseases. The application is done at the flowering stage and can be supplemented by an optional treatment depending on the early observation data as well as weather forecasts.

The number of treatments past that period of susceptibility of the bunches is limited. A third observation is done in the field. It provides first an overview of the sanitary status of the plot and assesses the opportunity of more treatments.

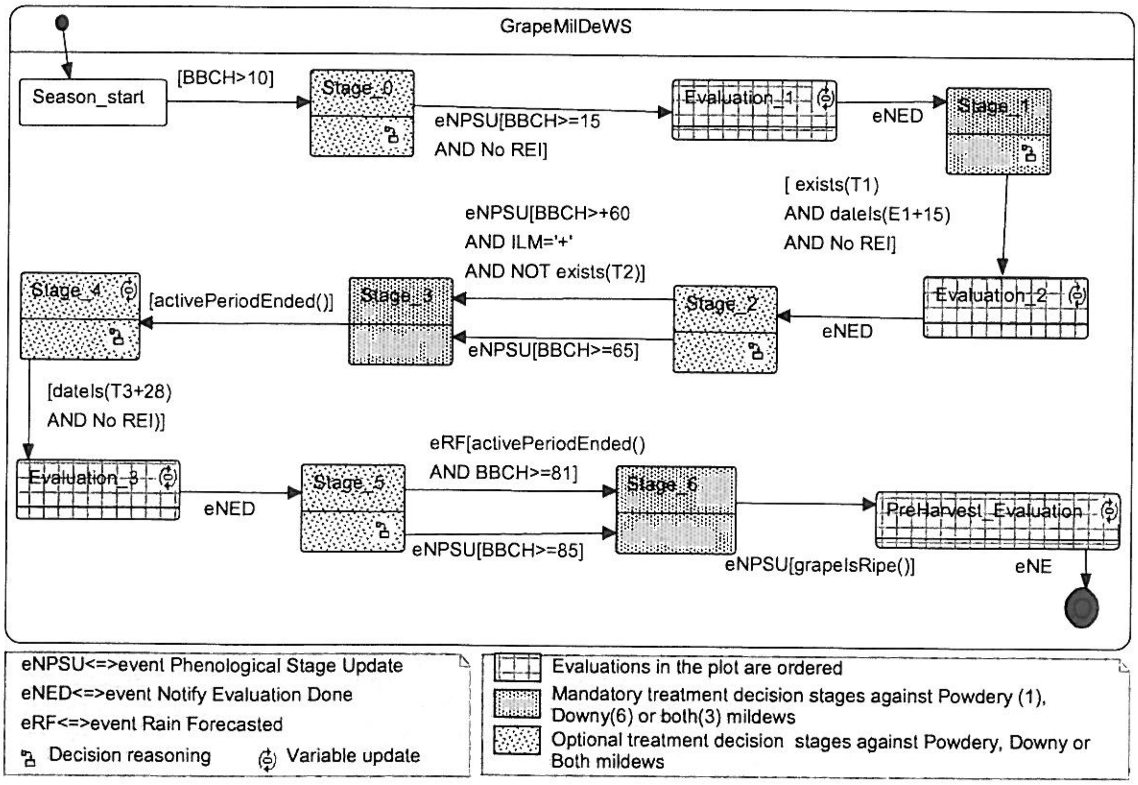

Fig. 1. Synoptic view of the GrapeMilDeWS crop protection decision process with the interleaving of observations and decision stages.

A systematic treatment against downy mildew is ordered at the beginning of ripening to limit the development of foliar diseases at the end of the season, and thus ensure enough foliage for the maturation of the grapes. The process is represented with ist temporal constraints in Fig.1.

## Formalisation methodology

In GrapeMilDeWS, the continuous phenomena that constrain the crop protection process (diseases incidence, local area downy mildew risks, rain forecasts and phenology) are discretized in an abstract time scale. Therefore the decision system can be assimilated with a DES.

Beyond simulation, DES formalisms have been shown to be suitable for qualitative analysis and control of various systems (Cohen, 2007; Lunze, 2000). GrapeMilDeWS can be viewed as a "control system with humans in the loop". The information from the vine plot is aggregated in synthetic discrete values. These are attached to a finite number of states, which can be reached during the season. Reacting to external events, transitions are fired, which generate internal and output events. The output events are decisions for actual sprayings on the plot executed by human operators.

We chose the graphical language of Statecharts, introduced in (Harel, 1987), for our formal model.

### *The Statechart formalism*

The modeling work, intrisically, by the elicitation and formalization of the knowledge it implies, should help the designers of a decision process to specify it precisely.

Statecharts which are now standard in Unified Modeling Language (UML 2.0) (OMG, 2007), combine finite state automata following two principles: "parallelism" (concurrent automata) and hierarchical "nesting". "Nesting" means that each state can be broken down into a sub-automaton that describes the behavior of the system with a finer granularity.

Transitions are labeled with triggering events, actions (which are generated events) and boolean conditions. The conditions are being tested on the variables defined in the Statechart. Finally, decision nodes allow to represent transitions with several options from the same state and within the same event (Harel and Kugler, 2004).

Such expressiveness allows for complex synchronization between automata. Transitions are deemed to be instantaneous, allowing statecharts to be seen as reactive systems .After implementation into executable code, the behavior of these visual specifications can be tested with different initial conditions and external stimuli. See an illustration of the syntax in Fig.2.

From these Statecharts, we can simulate the result of the decision-making process. These results are characterized by the number of treatment and the distribution of these treatments over time.

Within the group project "Vin et Environnement" (Soler, 2004), we have chosen the number of treatment as a simple and relevant indicator of environmental performance. Our aim is to substitute reasoned risk management to conventional approaches which are mostly preventive and systematic.

### *Eliciting the knowledge from the experts*

Our elicitation method uses "intermediate" knowledge models, able to ensure the mediation between the phyto-pathologists, designers of the GrapeMilDeWS, and the knowledge engineer (KE) in an iterative elicitation process. From these "intermediate models of knowledge", correctly formed automata and calculable models are then elaborated.

**Knowledge acquisition process.** The main elicitation method consists in iterative individual interviews of about an hour each. The KE prepares the subject of the interview and the documents needed. Each expert is interviewed over statechart diagrams and finally a synthesis of all editions is done to close the round when each expert has been interviewed. Group sessions may also be used at the end of the round to clarify eventual divergences between the experts. Rounds are repeated until more interviews does not improve the knowledge acquired and consensus is high enough.

We will call hereunder *diagrams* the informal statecharts used during experts' interview and *models* the formal statecharts which we simulate with Rhapsody from I-Logix. Diagrams are informal statecharts oriented towards communication. They have to be understood by both the KE who designs them and the experts who are interviewed. On the other hand, the models are the formal synthesis of the diagrams: an executable software. The informal and formal Statecharts have the same structure of states and events. The differences lie mostly in the labelling. Syntax of function calls and manipulation of variables of the formal Statecharts is better replaced by more natural language in the informal diagrams.

**Interviews** are divided in two parts. The first half hour is dedicated to validating the diagram from the previous synthesis, checking that the experts and the KE have a common understanding of the GrapeMilDeWS, but also that expert agree on the process. Contradictory positions would be quickly observed and addressed via group sessions. The changes, additions and modifications from each expert are recorded on the diagram.

The goal of the second part of the interview is to foray deeper into the details of the process. It allows the expert to build up on the latest progress of the other experts.

**Group sessions.** There is no specific procedure defined for group sessions. All the experts are invited. The goal of such session is to quickly settle points of discrepancies which could not be synthesized using the interview information.

### *Short description of elicited model for GrapeMilDeWS*

As shown in Fig.1, GrapeMilDeWS's process breaks down in seven Stages which alternate with three evaluations. The statechart has been simplified in this figure and only the up most level is shown. The sequence of decision and temporal constraints are visible, where as the decision logic is hidden in the sub-statechart.

An evaluation is an action state during which GrapeMildDeWS waits for data to be refreshed.

A Stage is a global decision state. The sub-states of a stage display the decision logic of the GrapeMilDeWS. Stage_4 is detailed as an exemple in Fig.2. A stage is also a temporal period defined by the phenology (we use the BBCH scale (Lorenz et al., 1995)) and temporal conditions relative to the previous sequence of actions ordered by GrapeMildDeWS (i.e. end of active period , legal restricted entry interval after the spraying of chemical products on the plot or fixed delay after an observation or an application). For example, the activation of Stage_5 is triggered by the execution of the third evaluation , which is itself positionned about one month after the flowering treatment during Stage_3. The exit of Stage_5 is controlled by one of the following: (i) the phenology reaching mid rippening (BBCH>=85) or (ii) after the beginning of rippening, if the crop is not protected and if rain is forecasted then in that later condition the last treatment at Stage_6 is ordered earlier. This event between Stage_5 and Stage_6 is thus dependent of the fourth treatment and the length of active period of the products used in Stage_5.

Product choices have been modeled but again are hidden here for clarity.

The treatment decisions in each stages are taken according to the estimators O, Og, M and ILM. A Stage is entered and the current values of the four variables are used to "route" through the decision nodes and select the correct decision state. Activation of the decision state generated a treatment order if necessary. On Fig.2 : variables [O=='0'] and [M=='++'] activate state High_dmildew. Entry into that state generates the *doDMildewTreatment order.*

GrapeMildDeWS does not capture the operational resources and response of the vineyard. It throws requests, which the grower may fulfil at its will and receives notifications about execution of decisions.

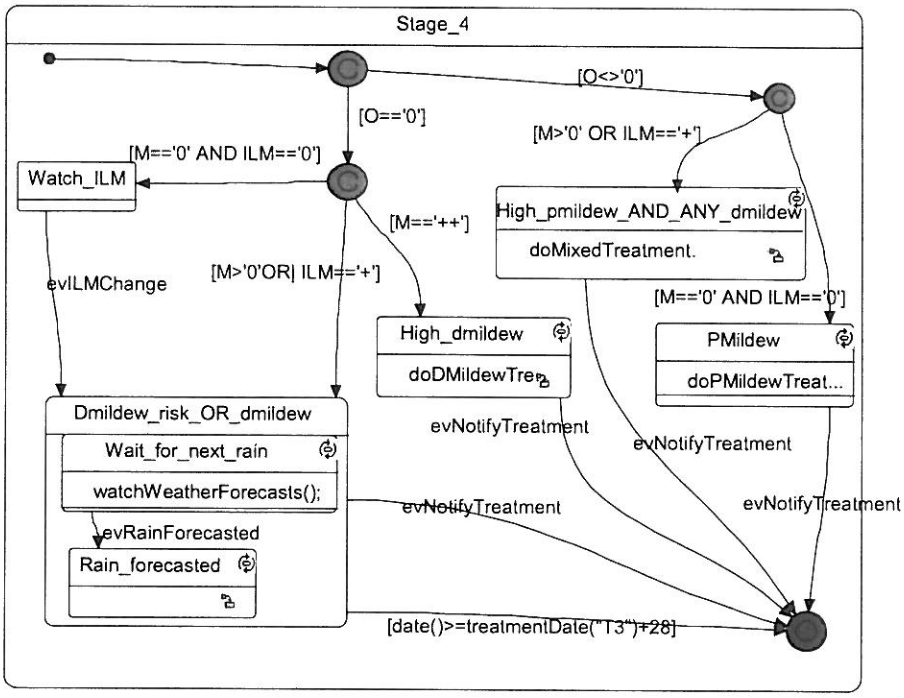

Fig. 2. Decision logic detail in Stage_4's sub-statechart – berries starting to touch

## Discussion

We have presented the aim of GrapeMilDeWS, the formalism chosen for the model, and the way we elicited the formal model. We shall now discuss some of the insight it gave us over GrapeMildeWS.

Elicitation itself, was very teaching. Working with a software engineering approach for instance allowed questioning about what would happen in case a treatment order could not be carried out before a forecasted rain. New contaminations are then most likely for downy mildew during the rain. The expert then provided a corrective solution for that eventuality: use of a curative product in the first 24 to 48 hours following the rain. If the application cannot be done during the period, then curative treatment is considered useless useless and a preventive product would be again preferable so as to avoid further contaminations.

Therefore, it provided new ideas to reduce even more the number of application with more intelligent use of curative and protectant products. Thus formalisation permitted to gain a more detailled view of the process and to create new work hypothesis that then should be experimented in the field.

On a more critical note, The formalism has the advantage of being quite intuitive (Cruz-Lemus *et al.*, 2005)but it is best at representing Reactive Systems. Typically, crop protection is a lot about forecasting and adjusting to uncertain future events. Indeed, during the experimental crop protection period, the experts were adjusting to the weather forecast and anticipating the future. This is quite difficult to represent with statechart. Had we tried to formalise this type, of knowledge, we would have lost the benefit of a humanly accessible statechart program. We have found comparing the experimental run of GrapeMilDeWS and simulated runs, that there is a cascade of automatic consequences from the second application to the third observation, which are taken into account by the expert while preparing the second spraying they already had in mind the third and fourth treatment in mind.

If anticipation is hard to represent using statechart, such formalism is great to control the temporal dependancies if variables in connection to the decision taken. Namely, our primary analysis showed there is a link between (i) the timing of the first evaluation which update powdery and downy mildews in field variables, (ii) the moment the first symptoms are found in the area (i.e. ILM changes to '+'), (iii) the timing of the first application and (iv) the decision concerning the powdery mildew application during stage_2. Observed using simulated phenological data, we cannot yet conclude if this particular scenario is possible in real life, but pointing it out is a relevant information that may have been hard to identify in a language did not enhance time computing so well.

Instead of using systematic simulation to analyse the sensitivity of the model to its variable variations, we will prefer formal model checking methods (Hélias, 2003; Largouët, 2000) to control the quality of this design. These methods permit to guarantee mathematically, sequential or temporal properties of a process. Making sure the desired situation allways happen or that accident can never exist. Further expert elicitation will thus be necessary to identify the nature of these desired properties for crop protection decision systems. Along with mathematical work to assess the scalability of GrapeMilDeWS at the whole vineyard scale, these works are to lead to transfert.

In the mean time, large scale experimentations with a prototype decision support system (DSS) will be starting next year to evaluate the process independantly from its expert designers, with volontary vine growers. In this contest, the rightness of the expert human decision doesn't hold anymore. The GrapeMilDeWS will be tested in a context where it will hold more knowledge on epidemics and crop protection than most vine growers do. The result of this interactions will be interresting us.

## Conclusion

In this article, we have presented the novel approach to modelling an IPM decision system for tactical decisions. We represented our Grapevine powdery and downy Mildews Decision Workflows system, both in its principle and through a short presentation of the modeled result. The elicitation of the knowledge from the IPM expert was an important aspect of the work. We modelled GrapeMilDeWS as a discrete event system, using Statechart, an automaton based graphical programming language. The resulting model has both the advantage of being an accesssible transfert document, as well as a working simulator. Our future work will be focusing on ameliorating the model in a conception loop with the experts; proving the scalability of the solution at the estate scale; and experimenting a DSS prototype software to assess acceptance within the vine growers population of such drastic change in practices.

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