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EN VUE D'UNE PUBLICATION OU D'U

à faire parvenir, par la voie hiérarchique pour accord

Direction : DCC
Centre : Marcoule
Réf. : SCD/CONF. 92.20

Titre du document[1]:
Organisation hiérarchique de graphes causaux.
Hierarchical organisation of causal graphs.

AUTEURS	AFFILIATION[2]	DEPT./SERV./SECT. (ex. ../../...)	VISA (d'un des auteurs)	DATE
P. DZIOPA	C.E.A.	DPR/SCD/LIA		20/10/92

Nature[3] : 9100968

D. MATHIEU
SCD / LIA
Tél. 66.79.62.53
3/11/92

RAPPORT	THESE	REVUE	CONF/CONGRES	MEMOIRE DE STAGE	LIVRE	POLYCOPIE DE COURS	AUTRE
☐	☐	☐	☒	☐	☐	☐	☐

TITRE (Revue, Congrès) : Mathematical and Intelligent Models in System Simulation

ORGANISME OU ORGANISATEUR : IMACS

PAYS : BELGIQUE **VILLE :** BRUSSELS **Date :** 12-16 avril 1993

EDITEUR :

COLLECTION : **N° Vol :**
Date Parution :

LANGUE : Anglais **Elément Programme :**

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HIERARCHICAL ORGANISATION OF CAUSAL GRAPHS

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ABSTRACT

This paper deals with the design of a supervision system using a hierarchy of models formed by graphs, in which the variables are the nodes and the causal relations between the variables are the arcs. To obtain a representation of the variables evolutions which contains only the relevant features of their real evolutions, the causal relations are completed with qualitative transfer functions (QTFs) which reproduce roughly the behaviour of the classical transfer functions. Major improvements have been made in the building of the hierarchical organization. First, the basic variables of the uppermost level and the causal relations between them are chosen. The next graph is built by adding intermediary variables to the upper graph. When the undermost graph has been built, the transfer functions parameters corresponding to its causal relations are identified. The second task consists in the upwelling of the information from the undermost graph to the uppermost one. A fusion procedure of the causal relations has been designed to compute the QTFs relevant for each level. This procedure aims to reduce the number of parameters needed to represent an evolution at a high level of abstraction. These techniques have been applied to the hierarchical modelling of a nuclear process.

KEY WORDS

Supervision, simulation, causal graphs, hierarchical modelling, causal reasoning

1. INTRODUCTION

Large industrial plants were created to face the ever-growing need of ever more evolved products of modern societies. The design of such facilities is a highly complex task, but once they have been built, these plants have to be controlled to run properly. For a long time the only way to improve the quality, the productivity and the security requirements was to build control loops. But to manage the complexity of extended systems, a local view on every different part of the process is no longer sufficient : a global understanding of the plant behaviour is necessary. This task is imparted to human operators. Supervision tends to manage complexity by combining the different tasks of controlling and watching over a process.

Supervision systems have nowadays become a necessary part of the plant management. Their goal is to help the operator in his decision making. It is essential for him to know how the process has evolved to reach its present state in order to take proper decisions. Unclear information about the process evolution may lead to reversed actions and may worsen the problem instead of curing it.

A prediction of the future behaviour of the process and an explanation of its past evolution are needed to bring such a help to the operator. In the work presented in this paper, the prediction is done by the simulator PROTEE [5], which uses a model in the form of a causal graph describing the process dynamics. The nodes of the graph represent relevant variables and the arc relating a variable A to a variable B means that A has a dynamic influence on B.

A causal graph has the advantage of showing an explicit representation of the causality, which is a good basis for explanations. The causality is hidden while using a classical numerical model. On the other hand, a numerical model gives far more accurate values of the variables, than a purely qualitative one. PROTEE combines both approaches : it entails an explicitly causal model and a numerical description of each causal link and of each variable.

However the supervisor is not able to fulfil all its aims with only one model. To really help the operator, it has to be able to give a global or a very detailed point of view of the process behaviour ; it may be necessary to have a detailed description of only a local sub-system (focusing for a diagnosis, for instance), and still work with a global view on the other parts of the plant. A completely detailed view of the plant incorporates all the variables needed in the management of all the stages of the production. Until now, PROTEE had to run the simulation with a detailed model representing all the variables which were considered as necessary from a supervision point of view ; this means all the variables representing important physical phenomena, likely to be of interest for the operator understanding. Nevertheless, when PROTEE is used for a complex workshop, including several coupled sub-processes, the causal graph may include several tens of variables, which make it unclear for the human operator.

Moreover, while a human operator is supervising a plant, most of the time nothing unusual happens, so there is no need to scan all the nooks of the plant. In a normal situation a global view on the process should be sufficient and it would be useless to run the simulation with the whole detailed model. But in any abnormal situation, whatever the abnormality is, the global view is no more sufficient but the most detailed is not always needed. Every situation can be faced with a description of a different abstraction level which takes a place between the most global view and the most detailed one [8].

A hierarchical organisation enables to run only a model with the proper level of abstraction. In any case, when the operating conditions change, in an abnormal situation or simply after a request from the operator, the supervision system should be able to select the proper level, to continue the simulation with the model suited to this level and afterwards to go back to the initial model.

The most detailed views will incorporate all the variables necessary to understand a subsystem behaviour, but from a functional point of view : the models used here represent the behaviour of a system, and not a technical description based on the physical form of the devices. For instance, a global view of a feedback mechanism involves only the output ; a more detailed one involves the set point and the output (in order to verify its global operation) ; a much more precise one involves moreover the control variables and/ or the disturbances ; but the description is still a general description for a control loop, whatever be the actuator and the sensor.

The models, corresponding to the different abstraction levels, that may be needed between the two extreme models, will differ by the number of variables describing the mass, energy and information flows and their dynamics. This enables to build several models which can be put in a hierarchical organization. The top of the hierarchy will be hold by the most global model, which is the most abstract one ; the basis will be the most detailed one. The other models will be classified so that all the variables of a model, which are relevant at its level, will be found in all other lower models.

Before explaining how the hierarchical organization of the models should be built, the models structure and the tools necessary for simulation are presented. The next section deals with the method of building hierarchical graphs. Once the graphs have been built the undermost one has to be identified ; this is detailed in the fourth section. To ensure the coherence of the dynamics through the hierarchy, the parameters of the upper model have to be computed from the undermost one as shown in the fifth section. Finally an example derived from nuclear industry is presented.

2. MODELLING FOR EVENT BASED SIMULATION

The principal task of a supervision system is to assist the operator in watching over the process and analysing the situation. An image of the normal behaviour of the process is thus useful. Such a reference behaviour is produced by the simulator PROTEE. A representation which seems to be suited to the mental model of the operator is a causal graph, based upon a commonsense

explanation of the physical phenomena occurring in the process. The model is made of nodes and arcs. The nodes (A, C and G in figure 1) represent the variables relevant for the operator and the arcs are causal links between these variables. This causal graph is intended to be used for the simulation of the process behaviour.

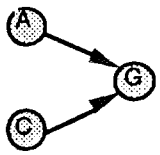

Figure 1 : A causal graph

For the supervision task, there is no need to know precisely the values of the variables all the time. Knowing, for instance, the values reached by a variable when its derivatives are zero could be a sufficient information. So qualitative reasoning is a very active research area. The reference algorithm in the field of qualitative simulation is QSIM [3], where variables are represented by landmarks (a particular value, as zero, or an interval). But with this algorithm, it is possible to obtain several behaviours of a physical system with the same initial conditions. Thus the interpretation of this qualitative simulation is difficult because some of the behaviours are not compatible with the described system, some of them are globally equivalent, and, as a consequence, it is difficult to find out which of the predicted behaviour is really the actual one.

The proliferation of behaviours is partly due to the fact that the simulator is able to detect the arrival at a landmark, but not to date it. A numerical simulator is far more efficient to deal with time, but it does not suit to the supervision, because numerical simulation of differential equations does not contain an explicit causality.

As neither the qualitative nor the numerical simulations are suited to the needs of supervision, an hybrid modelling method has been created. This model relies on a causal graph, but the variables are numerical functions of time and the arcs bear numerical parameters.

These parameters are those well known in classical control theory : delay, gain and settling time. So the term qualitative transfer function (QTF) [2] is used to summarize the information relative to an arc. A QTF enables to compute the behaviour of the output node of an arc thanks to the evolution of the input node. For a given QTF the shape of the response to a known excitation is defined a priori by a piece wise linear function. Only the shapes of the responses to classical inputs, such as steps and ramps, are used. These shapes are approximations of the well known responses by the corresponding classical transfer functions. Figure 2 gives the step response of a first order transfer (doted curve) and the respective qualitative response (continuous curve).

In this representation an event is a triple {time, amplitude variation, slope variation} which enables to build an orthogonal base of the piece wise linear evolution. Each evolution can thus be uniquely described [4] by a succession of events. The Qualitative Responses to one event is a succession of events, as in figure 2, and the global evolution of the variable is a superposition of qualitative responses to steps and ramps. To prevent the creation of too much events too close together a temporal granularity is used. An event is not considered relevant if its occurring time is closer to the occurring time of the last event than the granularity.

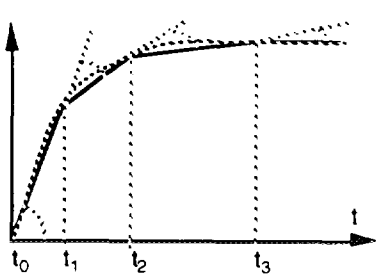

Figure 2 : Response by a first order QTF to a step input

The evolutions of each variable source of the graph have to be described therefore by piece wise linear functions to be consistent with the representation of the Qualitative Response (QRs). So the problem is to segment the real data measured on the process into linear functions. The signals measured on the process are sampled. During an initialization time, a least squares algorithm is used to find the first linear segment. Afterwards every new sample is compared with the current straight line equation and, if the difference is higher than a given threshold, this measurement is stored. When several successive points have been stored, a new straight line equation can be computed. The intersection of this new line and the former gives the occurring time of the new event [6].

The simulation of the evolution of all the variables of the graph thus consists in the propagation of events along the graph and the superposition of their influences when several arcs are connected to the same variable. In order to deal with explanation, if requested by the operator, every event relative to a variable is stored in the variable history together with its cause (an event occurred previously on another variable of the graph). This storage, even with an optimal granularity, demands a lot of memory after a long simulation time. Building a hierarchy of graphs reduces highly this problem.

3. BUILDING THE STRUCTURE OF THE GRAPHS

The hierarchical structure has to contain different levels of abstraction to be suited to its aim. A model should be associated at each level of abstraction. The models that are used are represented by causal graphs in which the arcs carry QTFs. To deal with a hierarchical organization, all the necessary graphs have to be built. However a completely independent building of each of the models would not be possible, because at each level the model has to contain all the variables of the just upper graph, and its own dynamics have to represent the dynamics of the just lower graph. This implies a two steps construction of the models. Firstly the structure is built from the uppermost graph to the undermost one. Then, the parameters of the last graph are identified. The last step is the "up welling" of the dynamics through the hierarchy.

Following the terminology of Rasmussen [8], the first model, the uppermost one, has only to deal with the phenomena of greatest interest for the general goal of the plant. This model will be used nearly all the time to overview the whole plant. The variables to be represented will be the major energy, mass and information flows. The arcs between these variables have to represent the basic phenomena with the help of which an operator will understand easily and quickly the status of the production at the plant scale. Figure 1 gives an example of such an uppermost graph with the three variables A, C and G, and the two causal relations A-G and C-G.

The second graph is built from the uppermost graph. It has to be a little less abstract, because it will be used to detail the phenomena occurring at the scale of the processes which are composing the total plant. The construction of the second graph is made by adding new variables to the upper graph. In figure 3, the nodes B, D, E and F have been added. Three cases occur : a new source, as B (for instance, the set-point of a feedback loop) ; a new sink, as D (for instance a subsidiary measurement) ; or intermediary variables as E and F. These variables are not relevant at the former level but become essential at the present one. The definition of the essential variables depends of the needs of the supervision. These variables may be state variables, inputs or outputs, whose evolution are not relevant for the overview of the global goal of the production. However they are now needed to explain phenomena closer to the process.

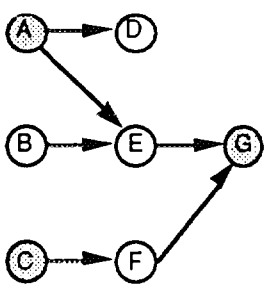

Figure 3 : Graph built from the uppermost graph

For intermediary variables, E and F, an arc of the upper graph has to be considered as a path in the present graph. A path is defined between two variables belonging to the upper graph and may contain new variables of the present graph. The path C-F-G is associated to the upper arc C-G.

All the arcs of the upper graph must have a corresponding path in the present level graph. The opposite may not be true. It is possible to find paths in the present graph that are of no use in the upper graph and thus that are not represented. A path may not be represented because the phenomenon it points at has no relevance for the aim of the upper graph. No detailed knowledge of the process dynamics is needed at this stage. The explanatory interest of the links and possibly their order of magnitude are highly sufficient for this analysis.

The next graphs in the hierarchy are built following the same method. That means that the total number of variables and arcs always grows and that the final graph, the undermost one, is very large. The undermost graph has to contain all variables that may be needed while the supervision system runs. The number of nodes and arcs in the graph should be reasonably suited to the need of description at the level of the devices making up the processes which form the whole plant.

4. UNDERMOST GRAPH IDENTIFICATION

Once the structure of the undermost graph has been built, the next step in the elaboration of the hierarchy is the identification of all the arcs composing this undermost graph. Only these arcs will be identified. This will reduce the identification costs to the identification of a unique model instead of identifying all the models needed by the hierarchy.

In consequence, the QTFs relative to the arcs of a higher graph will be computed in order to reproduce the dynamics of the corresponding paths in the lower graphs. Independent identifications for each level would cause a coherence problem : how could it be possible to guaranty that the dynamic of a high level arc represents exactly the dynamics of low level paths ?

The most efficient answer is to identify only the undermost graph and to treat the information contained in its arcs to fill up the corresponding arcs in the just higher graph, and so on until the top of the hierarchy is reached.

The problem lays in the genericity of the QRs. Only first and second order representations will be studied. This translates the fact that if a man may recognise a first order from a second order by the shape of their classical step responses, the distinction is no more possible to the naked eye between a second and a higher order. A first order step response is described by two parameters :

$$y(t) = a \cdot \left(1 - e^{-\frac{t}{T}} \right) \qquad (1)$$

a is the final value, corresponding to the product of the gain and the step amplitude, and T is the time constant. Changing one of these parameters results in fact in a simple scaling factor for time or amplitude. So with a homothety on the time axis it is possible to reproduce the behaviour of any first order, whatever its settling time may be, and with a homothety on the amplitude axis, all the gains and steps amplitudes will be reproduced. This method is very convenient for a simple first order or a transfer with a first order numerator or a derivator, but it is not suited for the second order whose step response has the following general equation :

$$y(t) = a \cdot \left(1 - \frac{T_1}{T_1 - T_2} \cdot e^{-\frac{t}{T_1}} - \frac{T_2}{T_2 - T_1} \cdot e^{-\frac{t}{T_2}} \right) \qquad (2)$$

a is the final value, corresponding to the product of the gain and the amplitude of the step, and T_1 and T_2 are the time constants.

Here the equation depends on three parameters and two of them (T_1 and T_2) have influence on the same variable (the time t) ; thus it is no more possible to reproduce all the behaviours with two homotheties. To solve this problem it is proposed to use a Strecj approximation to a non oscillatory response (3) in order to describe a second order system.

$$f_{Strecj}(p) = \frac{g}{(1+T\cdot p)^n}\cdot e^{-d\cdot p} \qquad (3)$$

where g is the static gain, T the time constant, d the delay and n the transfer function order.

The aim of the QTFs is not to reproduce all the particularities of the corresponding transfer function. A qualitative approximation of the shape of the responses to a step and a ramp is highly sufficient. For example the first order step response represented by four events allows to obtain an error smaller than 5% [5]. A generic shape can be found by using the response of a second order Strecj approximation. This response obeys equation (4) :

$$y(t) = a\cdot\left(1-\left(1+\frac{t}{T}\right)e^{-\frac{t}{T}}\right) \qquad (4)$$

This response has the advantage to be generic : that means that with a scaling factor on the time axis and a scaling factor on the amplitude axis, it is possible to describe all the responses of that type. It is always possible to find a second order Strecj function approximating a second order because for any T_1 and T_2, such that $T_1 < T_2$, the minoration and majoration are given by (5).

$$1-\left(1+\frac{t}{T_1}\right)\cdot e^{-\frac{t}{T_1}} \le 1-\frac{T_1}{T_1-T_2}\cdot e^{-\frac{t}{T_1}}-\frac{T_2}{T_2-T_1}\cdot e^{-\frac{t}{T_2}} \le 1-\left(1+\frac{t}{T_2}\right)\cdot e^{-\frac{t}{T_2}} \qquad (5)$$

The qualitative response associated to (4) is easily described by four events. Nevertheless the use of a single transfer function as in (3) is not always sufficient. By adding a first order on the numerator of the Strecj function, it is possible to reproduce all the behaviours qualitatively distinguishable. So the general form of the functions is given in equation (6) :

$$f(p) = \frac{g+g_d\cdot p}{(1+T\cdot p)^n}\cdot e^{-d\cdot p} \qquad (6)$$

The qualitative response associated with (6) where n=2 is easily described by four events too. The methods of fusion given thereafter are to be used to transform the classical transfer functions into Strecj approximations.

5. DATA UP WELLING

The fusion of knowledge is a very important part in the design of knowledge based systems. It is aimed at reducing the size of the model [1]. In our case, the fusion is really guided, because the structure of the upper graph is already known. The graph theory could be used to find the connex components in a graph to reduce it to a smaller graph. But this sort of reduction would not take into account the relevance of the variables for human understanding.

So it is proposed to search the paths in the lower graph which correspond to arcs in the upper graph. The search is not difficult because the initial and final variables - or nodes - are the same in both graphs. The sole difficulty of this operation is the occurrence of multiple paths from a variable to another one. This case will be treated just after the easy one, when the path is solely made of cascade QTFs, as show in figure 4.

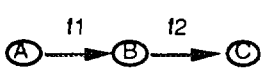

Figure 4 : Two arcs in cascade

Supposing that the first arc describes a transfer function f_1 and the second one f_2, an approximate transfer f of the form (3) is investigated. For example :

$$f_1(p) = \frac{g_1}{1+T_1 \cdot p} \cdot e^{-d_1 \cdot p} \quad (7)$$

$$f_2(p) = \frac{g_2}{1+T_2 \cdot p} \cdot e^{-d_2 \cdot p} \quad (8)$$

$$f(p) = \frac{g}{(1+T \cdot p)^n} \cdot e^{-d \cdot p} \quad (9)$$

In that case, it is easy to determine that $g = g_1.g_2$ and $d = d_1+d_2$. To simplify the explanation, let be $T_1<T_2$. The problem is to choose between $n = 1$ or $n = 2$ and then to compute T. Let $y_{f1.f2}(t)$, $y_1(t)$ and $y_2(t)$ be the temporal responses of the composed function and its first order approximation and second order approximation. The delays have been omitted to simplify the presentation.

$$y_{f_1 \cdot f_2}(t) = 1 - \frac{T_1}{T_1 - T_2} \cdot e^{-\frac{t}{T_1}} - \frac{T_2}{T_2 - T_1} \cdot e^{-\frac{t}{T_2}} \quad (10)$$

$$y_1(t) = 1 - e^{-\frac{t}{T}} \quad (11)$$

$$y_2(t) = 1 - \left(1 + \frac{t}{T}\right) e^{-\frac{t}{T}} \quad (12)$$

The differences between (10) and (11) and between (10) and (12) give respectively the errors $e_1(t)$ and $e_2(t)$.

$$e_1(t) = e^{-\frac{t}{T}} - \frac{T_1}{T_1 - T_2} \cdot e^{-\frac{t}{T_1}} - \frac{T_2}{T_2 - T_1} \cdot e^{-\frac{t}{T_2}} \quad (13)$$

$$e_2(t) = \left(1 + \frac{t}{T}\right) \cdot e^{-\frac{t}{T}} - \frac{T_1}{T_1 - T_2} \cdot e^{-\frac{t}{T_1}} - \frac{T_2}{T_2 - T_1} \cdot e^{-\frac{t}{T_2}} \quad (14)$$

It is then easy to compute the integral errors :

$$\int_0^\infty e_1(t) \cdot dt = \frac{T_1^2}{T_1 - T_2} + \frac{T_2^2}{T_2 - T_1} - T \quad (15)$$

$$\int_0^\infty e_2(t) \cdot dt = \frac{T_1^2}{T_1 - T_2} + \frac{T_2^2}{T_2 - T_1} - 2 \cdot T \quad (16)$$

The integral error can be made zero in both (15) and (16). In the first case, this occurs for $T = T_1+T_2$ and in the second case for $T =(T_1+T_2)/2$. The approximation of the first order (n=1) must be used when T_1 and T_2 are very different, whereas the second order function is to be used when T_1 and T_2 are close together. By studying the quadratic error (17) and (18) in both cases, it is possible to determine which approximation must be used. As can be seen in figure 5, the first order must be used when $T_1/T_2 < 0.17$ and the second order must be used when $T_1/T_2 \geq 0.17$.

$$\int_0^\infty e_1(t)^2 \cdot dt \quad (17) \quad \text{and} \quad \int_0^\infty e_2(t)^2 \cdot dt \quad (18)$$

The same kind of computations can be made for the fusion of more complicated transfer functions (with a numerator, or a second order denominator with a first order numerator...). The fusion results always in transfers as in (3) and (6) with n=2. Therefore, the qualitative response expressed as a series of events (figure 2) is easily parametrized. But the most difficult problem is still to study : the parallel path between two variables.

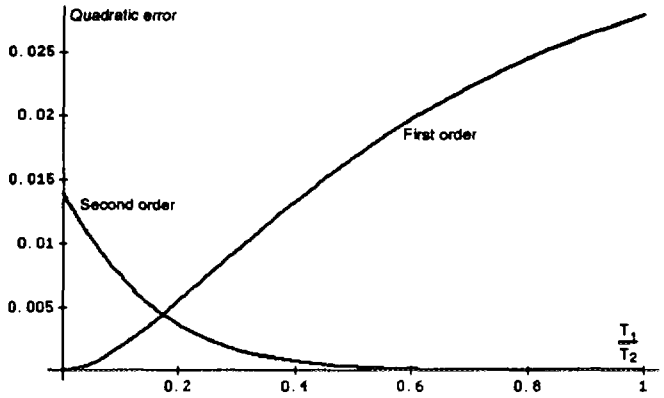

Figure 5 : Quadratic errors with a first and a second order approximation

The question is what would be the meaning of two parallel paths. When a human operator is questioned, no phenomenon will be described by two different parallel arcs. Only fusion of path has to be studied, as in figure 6.

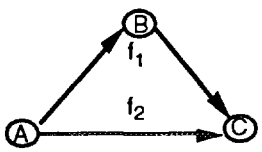

Figure 6 : Two parallel paths

Three cases must be envisaged to deal with the multiple paths : if the delays on both paths are not too different a single QTF can be computed ; if the delays are very different, only one path is relevant ; the last case is to retain both paths with all their variables. This involves the use of an order of magnitude reasoning [7] to determine if the delays are not very different.

Let f_1 (7) and f_2 (8) be the numerical transfer functions described by the two paths in figure 6. In this case the transfers are no more composed by product but by summation. So it is easy to determine that the static gain g of the approximating function will be the sum of the two gains $g = g_1+g_2$. If the delays have the same order of magnitude, the approximate delay would be the smaller one ; otherwise there is no true analytical solution to the approximation. The temporal response to a step by the sum of the transfers, when they have the same delay, is (19).

$$y_{f_1+f_2}(t) = g_1 - g_1 \cdot e^{-\frac{t}{T_1}} + g_2 - g_2 \cdot e^{-\frac{t}{T_2}} \qquad (19)$$

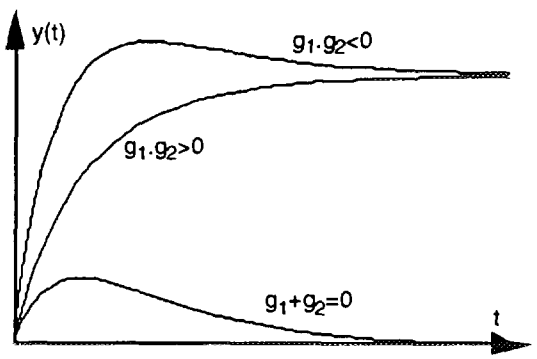

Figure 7 : Shapes of two paths depending on the sign of their static gains

The study of the global behaviour of this function enables to distinguish three different shapes, as may be seen in figure 7. These shapes differ by the signs of the static gains of the two paths : if

the gains have the same sign then the sum of two first order looks like a first order and can be approximated as this ; if the gains are opposite, the response looks like a second order associated with a pure derivator ; at last, if the gains have different signs, the shape presents the bump characteristic of the presence of a zero which cannot be omitted.

The easiest case is the case of a null static gain, the exact transfer is then (20).

$$f_1(p)+f_2(p)=\frac{(T_2\cdot g_1+T_1\cdot g_2)\cdot p}{(1+T_1\cdot p)\cdot(1+T_2\cdot p)} \tag{20}$$

This transfer can be approximated by the minimization of the integral error. This gives the function (21).

$$f_{Strecj}(p)=\frac{(T_2\cdot g_1+T_1\cdot g_2)\cdot p}{\left(1+\frac{T_1+T_2}{2}\cdot p\right)^2} \tag{21}$$

If the gains sum is not zero, then their signs are to be examined. If $g_1.g_2 > 0$, the approximating function has the form (22).

$$f_{Strecj}(p)=\frac{g_1+g_2}{1+T\cdot p} \tag{22}$$

The integral error is given in (23).

$$\int_0^{\infty}\left((g_1+g_2)\cdot e^{-\frac{t}{T}}-g_1\cdot e^{-\frac{t}{T_1}}-g_2\cdot e^{-\frac{t}{T_2}}\right)\cdot dt \tag{23}$$

(23) is zero for :

$$T=\frac{g_1\cdot T_1+g_2\cdot T_2}{g_1+g_2} \tag{24}$$

For the last case, $g_1.g_2 < 0$, the behaviour induced by the zero is relevant and has to be retained and the approximating function should have the following form (25).

$$f_{Strecj}(p)=\frac{g_1+g_2+(T_2\cdot g_1+T_1\cdot g_2)\cdot p}{\left(1+\frac{T_1+T_2}{2}\cdot p\right)^2} \tag{25}$$

Once again, the QR associated to (6) with n=2 is sufficient to describe the response of the system. The same kind of computation can be made for the other f_1 and f_2 function types.

These methods are useful to fusion simultaneous paths. If the paths are not simultaneous, there are two solutions : to modify the upper graph so that the ambiguity is raised, this is compulsory when both paths have comparable gains ; to ignore the weakest behaviours, the derivators will thus be neglected in regard to gains, as the small gains in regard to the large ones.

The fusion of data from the lower graph to the upper graph fulfils the needs of detailed description at the bottom level and the need of general view at the top level. This enables a modification of the temporal granularity of the description of the behaviours. As can be seen in the fusion methods, the higher in the hierarchy the graph is, the larger the time constants are. This means that the events are far more distant at a high level that at a low level.

At the highest level, only few events per variable are necessary to describe the plant evolution and there are only few relevant variables. The storage in the variables histories is thus much more

efficient. This enables to store only the history of a variable at the highest level where the variable appears. A modification of the system granularity is then needed at every level.

The more the model is abstract, the less it needs precision and the larger the granularity may be. The granularity should be modified in the same proportions than the time constants at each level. The granularity at each level should be at least smaller than the most relevant settling time, otherwise all dynamics would be ignored.

The fusion method explained hereupon has been used to build a hierarchy of models for an industrial reprocessing plant. The following section gives some experimental results.

6. AN APPLICATION

The supervisor using the predictor PROTEE is dedicated to a pulse columns plant. The plant is composed of two coupled pulse columns, their feed subsystems, and the buffer system connecting the two columns. These processes are parts of the plant used to separate uranium and plutonium from fission products, which are nuclear waste : figure 8 represents the operating diagram of the two coupled pulse columns and figure 9 represents the most detailed associated causal graph.

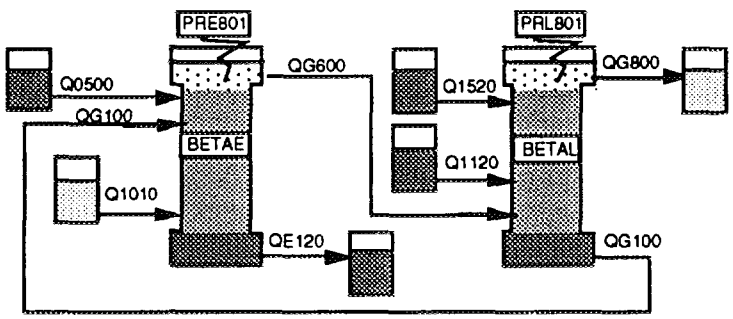

Figure 8 : The coupled pulse columns

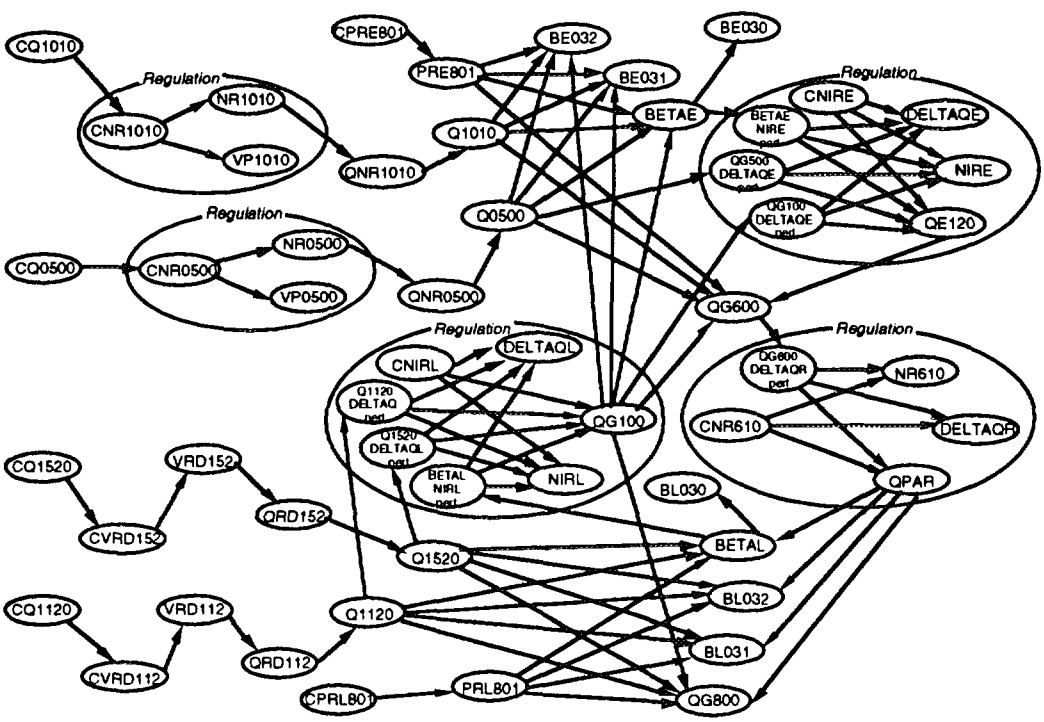

Figure 9 : The undermost graph representing the pulse columns

Pulse columns are liquid-liquid extractors : they mix and then separate an aqueous phase and an organic phase. The first pulse column in figure 8 is used to extract the uranium and the plutonium from the acid load solution (Q0500) using the organic phase (Q1010). The outlet acid solution (QE120) only contains the fission products which can be afterwards confined in a glass matrix. The organic phase containing uranium and plutonium (QG600) is injected in the second column so as to be washed again by water (Q1120) and acid (Q1520). The second column is used to wash the uranium and plutonium solution so as to clean it up from fission products. These fission products are carried back to the first column in an aqueous solution (QG100). At last the outlet organic solution (QG800) contains only the uranium and the plutonium. To increase the efficiency of the extraction, both columns are submitted to pressure pulsation (PRE801 and PRL801) ; the efficiency of the whole process is best symbolised by the retention (BETAL and BETAE) which are unmeasurable variables.

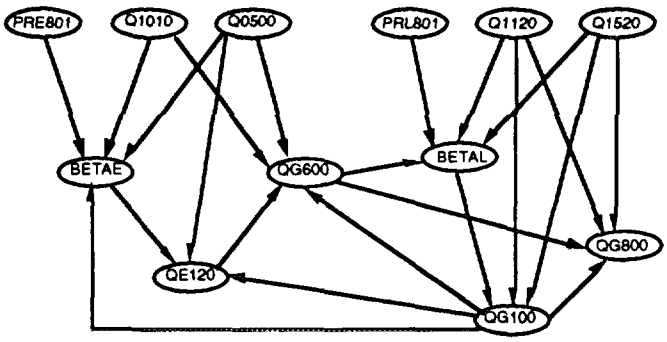

Figure 10 : The uppermost graph of the reprocessing plant

A two levels hierarchical organization of models has been built for this process. The complete, undermost graph of the plant contains 55 nodes and 84 arcs (figure 9). The uppermost graph is reduced to 12 nodes and 21 arcs (figure 10).

It had been proved that the two paths from the organic phase flowrate Q1010 to the flowrate QG600 (a direct one and one involving the retention BETAE) could not be fusionned in the uppermost graph without introducing non simultaneous multiple paths. Figure 11 gives the measured behaviour of QG600 (figure 11.a), the one computed with the influence of the retention BETAE (figure 11.b) and the one computed after fusionning both paths (figure 11.c). The same occurs for Q1120, QG800 and BETAL.

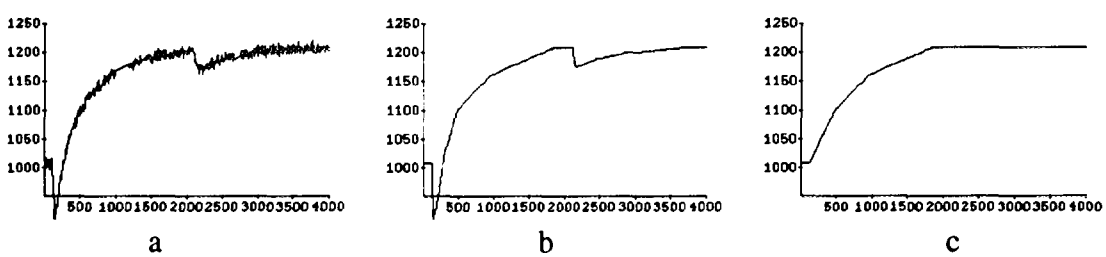

Figure 11 : Evolution of QG600 and two approximations

The results obtained with the upper graph and the detailed one (Figure 9 and 10) are quite similar as can be seen in the following evolutions (figure 12). The continuous curve has been computed with the lower graph and the dotted one with the upper graph. The lower graph includes 6 intermediary variables between QG600 and BETAL. The path of the upper graph fusionning this information contains only a second order Strejc approximation.

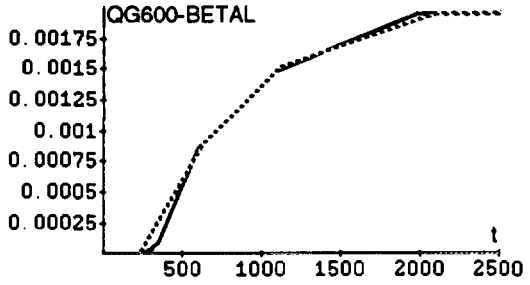

Figure 12 : QR between QG600 and BETAL obtained with the bottom graph and with the top graph

7. DISCUSSION

The approach proposed in this paper enables not only to build a hierarchical organisation of models but also to ensure the coherence of the dynamical behaviour of the variables through the different levels.

The interest of having different representation levels is to be able to look only at the relevant variables with a suited description. To build them one has to build the structure first from the top level graph down to the bottom graph. This undermost graph is then identified using simple classes of functions. This unique identification, coupled with the compilation of the dynamics to "upwell" the data from the undermost graph up to the uppermost one ensures the global coherence of the hierarchy.

These methods have been applied to model an industrial reprocessing plant, with the aim of supervising it. The results that have been obtained with both the supervisor and the hierarchical organisation are satisfactory. Until now, the use of a more precise level is made after a human request. The next step will be the realisation of a module which will be able to change the modelling level automatically if an incident is detected.

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