Modeling Dynamic Systems for Diagnosis
PEPA/TOM4D Comparison

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Abstract: Researchers have long been seeking the most suitable formalism and method to build models of dynamic systems for diagnostic tasks. In this paper, we claim that the main difficulty stems from the lack of global formalism capable of taking into account structural, functional and behavioral knowledge. To illustrate this point, we propose a comparison between two modeling approaches.

1 INTRODUCTION

In the last two decades model-based diagnosis has been an important area of research in which numerous new methodologies and formalisms have been proposed, studied and subjected to experiments (Console et al., 2000) and (Le Goc et al., 2008). This is motivated by the practical need for ensuring the correct and safe operation of large complex systems. Since (Reiter, 1987), most of frameworks have been based on logic formalism. Despite major contributions in the domain of temporal logic, a difficulty remains in taking observation time into account in diagnosis reasoning. Therefore many works have been proposed to define more or less specific formalisms to overcome this limit to the logical representation of timed knowledge, such as the discrete event system (D.E.S) formalism and the multi-modeling approach of (Chittaro et al., 1993). Moreover, these approaches have seldom been used in the context of diagnosis. More recently, PEPA formalism (Performance Evaluation Process Algebra) (Console et al., 2000) and the TOM4D methodology (Timed Observation Modeling for Diagnosis) (Le Goc et al., 2008) have been proposed to provide expressive languages to enable efficient modeling of dynamic systems for diagnosis, comprising a component centered modeling paradigm.

The goal of this paper is to bridge research into process algebras and timed observation modeling (Le Goc et al., 2008) by providing a comparison between PEPA and TOM4D. This comparison is performed with a concrete example(Section 2).

2 A HYDRAULIC SYSTEM

The dynamic system studied in (Console et al., 2000) is described in Figure 1. We use this example to compare PEPA and TOM4D.

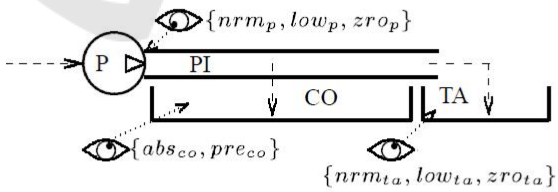

Figure 1: Hydraulic system of (Console et al., 2000).

" *The system is formed by a pump P which delivers water to a tank TA via a pipe PI; another tank CO is used as a collector for water that may leak from the pipe. For the sake of simplicity, we assume that the pump is always on and supplied with water. Pump P has three modes of behavior: OK (the pump produces a normal output flow), leaking (it produces a low output flow), and blocked (no output flow). Pipe PI can be OK (delivering the water it receives from the pump to the tank) or leaking (in this case we assume that it delivers a low output to the tank a when receiving a normal or low input, and no output when receiving no input). Tanks TA and CO are always in OK mode, i.e., they simply receive water. We assume that three sensors are available (see the eyes in Figure 1): flowp measures the flow from the pump, which can be normal (nrm_p), low (low_p), or zero (zro_p); $level_{TA}$ measures the level of the water in TA, which can be normal (m_{ta}), low (low_{ta}), or zero (zro_{ta}); $level_{co}$ records the*

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presence of water in CO, which can be either present (pre_{co}) *or absent* (abs_{co})".

3 PEPA MODEL

The PEPA model is based on classical process algebras enhanced with timed information. Process algebras are abstract languages based on a component oriented approach (Console et al., 2000) where each component is modeled in isolation and then each of the models of the components is composed using the operators provided by the calculation in order to obtain the entire model. In PEPA, the model of a physical system is usually divided into two parts: A behavioral model(BM) and a structural model(SM).

3.1 Structural Model

SM describes the structure of the system in terms of its components. Each component is represented as an instantiation of generic model. In the example studied (cf. Figure 1), four generic behaviors are defined: the "P" behavior (Pump), the "PI" behavior (Pipe), the "TA" behavior (TA tank) and the "CO" behavior (CO tank); also four component instances can be declared: $P^{(1)} : P$; $PI^{(1)} : PI$; $TA^{(1)} : TA$; $CO^{(1)} : CO$. $P^{(1)}$ **:** P means that the component $P^{(1)}$ is an instance of a component whose behavior is P. The connection between them is ensured by the cooperation operator $\underset{L_i}{\bowtie}$ where the sets L_i define the activities on which the components must cooperate. Equation SD_1 describes the SM of the hydraulic system. The SM of the example is:

$$SD_1 \overset{def}{=} (P^{(1)} \underset{L_1 \cup \{end\}}{\bowtie} (PI^{(1)} \underset{L_2 \cup \{end\}}{\bowtie} (TA^{(1)} \underset{\{end\}}{\bowtie} CO^{(1)})\,)$$

where $L_1 = \{nrm_p, low_p, zro_p\}$, $L_2 = \{nrm_1, low_1, zro_1, abs_2, pre_2\}$, $H = \{nrm_0, nrm_1, low_1, zro_1, abs_2, pre_2\}$. The $TA^{(1)}$ tank, for example, cooperates with the $CO^{(1)}$ tank with the "end"

3.2 Behaviour Model

The behavior of each component type is described as a nondeterministic choice between the various modes. For example, the BM of the pipe is the following: $PI = PIok_1 + PIlk_1 + End$;
$PIok_1 = nrm_p.PIok_2 + low_p.PIok_3 + zro_p.PIok_4$;
$PIok_2 = nrm_1.abs_2.PI$;
$PIok_3 = low_1.abs_2.PI$;
$PIok_4 = zro_1.abs_2.PI$;
$PIlk_1 = nrm_p.PIlk_2 + low_p.PIlk_2 + zro_p.PIlk_3$;
$PIlk_2 = low_1.pre_2.PI$; $PIlk_3 = zro_1.abs_2.PI$;
End = end.End

For each behavior, a set of equations is defined to specify the relations between the component variables. In particular, the actions of PEPA are used to express conditions on input, output and state variables. $PI = PIok_1 + PIlk_1 + End$ means that the component PI may either be in OK behavior ($PIok_1$) or in leaking behavior ($PIlk_1$). The additional identifier End allows the component to evolve into a final state.

4 TOM4D MODEL

TOM4D is a multi-model approach that combines CommonKads templates with the conceptual framework proposed in (Zanni et al., 2006) and the tetrahedron of states (T.O.S), (Chittaro et al., 1993). These elements are merged according to the Timed Observations Theory (cf Figure 2 more details in (Le Goc, 2006)). In this theory, it is usual to define an observation class C^i=$\{(x_i, \delta^i_j)\}$ as a singleton to associate one variable x_i with a constant δ^i_j. The concept of observation class is close to the notion of discrete event in the D.E.S domain. Figure 3 describes the three main steps of the TOM4D modeling process: The Knowledge Interpretation step uses a CommonKADS template to interpret and organize available knowledge (an expert, a set of documents, etc.) of a dynamic system.

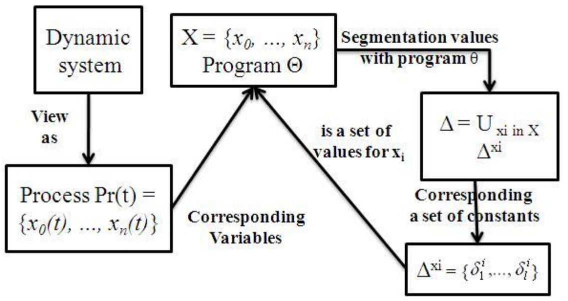

Figure 2: Timed Observation Theory: abstract.

The scenario model $M(\omega)= < SM(\omega), FM(\omega), BM(\omega)>$ of the system is consistent with knowledge available on its evolution over time. This model is necessary to provide, by using the tetrahedron of states, a physical and a logical interpretation of the terms used (variables, constants, etc.). In the example studied two physical dimensions are given for the variables: volume (m^3) and flows of water ($m^3.s^{-1}$) (leaking and normal output). This leads to using the Hydraulic T.O.S. where no pressure (Pr), no resistivity (R) or pressure moment (Pp) are evoked in the

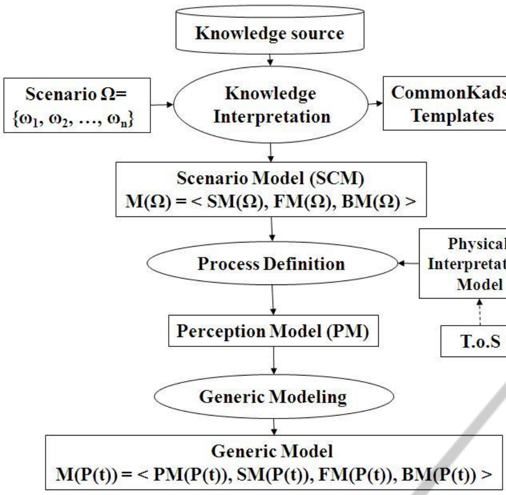

Figure 3: TOM4D Modeling Process.

available knowledge. Thus it is easy to design an abstract generic hydraulic component forming a relation between an input flow $Qi(t)$, an internal volume $V(t)$ and two output flows, a normal output flow $Qs(t)$ and an uncontrolled output flow $Qf(t)$ (Figure 4a). Such a component is generic because it can be used to model all the components of the system.

4.1 Perception Model: PM

The abstract generic hydraulic component is sufficient to define the role of each variable of the system and the associated concrete components.

Table 1 shows the component-variable-value association that can be made according to the abstract generic hydraulic component.

Table 1: component-variable-value association.

COMPS	X	dimen-sion	Action (PEPA)	Δ
c_1	x_7	V	nrm_0, low_0,zro_0	2,1,0
	x_1	Qs	nrm_p,low_p,zro_p	2,1,0
c_2	x_6	V	nrm_{pi},low_{pi},zro_{pi}	2,1,0
	x_4	Qs	nrm_1,low_1,zro_1	2,1,0
	x_5	Qf	$pres_2$,abs_2	1,2
c_3	x_2	V	$nrm_{TA}low_{TA}$,zro_{TA}	2,1,0
c_4	x_3	V	$pres_{CO}$, abs_{CO}	1,2

4.2 Structural Model

A TOM4D structural model $SM(P(t))$ is a 3-tuple $< COMPS, R^p, R^x >$ (cf. Figure 4) where:

- $COMPS$=$\{c_1, c_2, c_3, c_4\}$ is the finite set of constants denoting the system components,
- R^p is a set of equality predicates defining the interconnections between the components. R^p=$\{out(c_1)$=$in(c_2)$, $out_1(c_2)$=$in(c_3)$, $out_2(c_2)$=$in(c_4)\}$
- R^x is a set of equality predicates linking each variable. R^x=$\{$ $out(c_1)$=x_1, $out(c_3)$=x_2, $out(c_4)$=x_3, $out_1(c_2)$=x_4, $out_2(c_2)$=$x_5\}$.

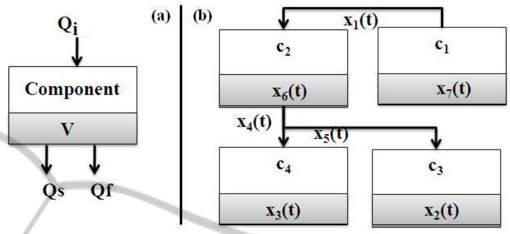

Figure 4: Structural Model $SM(P(t))$.

4.3 Behavioral Model

The behavior model $BM(P(t))$ is a 3-tuple $< S, C, \gamma >$ where $S = \{s_i\}_{i=1...l}$ is a set of states (s_0 for example corresponds on x_6=0 $\wedge$ x_4=0 $\wedge$ x_5=1), C is a set of timed observation classes C^i=$\{(x_i, \delta^i_j\}$ (C^6_1 = $\{(x_6,0)\}$ for example) and γ: $S \times C \rightarrow S$ is the state transition function that implements the state evolution in the system modeled (i.e. $\gamma(s_1, C^6_3) = s_2$).

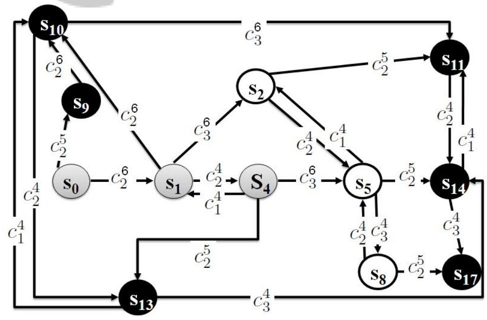

Figure 5: Behavioral Model of the Pipe.

The *ok* and *leaking* PEPA modes of the pipe correspond to the grey and black states in Figure 5, respectively.

4.4 Functional Model: FM

A functional model FM is a 3-tuple $< \Delta, F, R^f >$ where Δ is the set of values assumable by the different variables (Δ_{x_1}= $\{2, 1, 0\}$ for example), F is a set of functions (The result of the T.o.S and structural model denotes 7 functions) and R^f is a set of equality predicates defining a variable as a function of the others. The graph of $FM(P(t))$ is shown in figure 6).

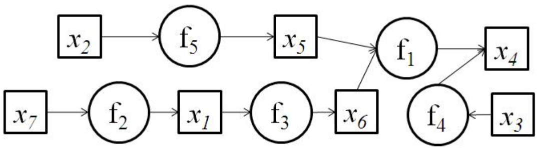

Figure 6: Functional Model of the hydraulic system.

5 DISCUSSION AND CONCLUSIONS

The example studied shows that the TOM4D structural model plays the same role as the declaration of generic component instances, the connection equations and the activities declaration in PEPA formalism.

The functional TOM4D models play the same role as the so called ”behavioral” model of components in Reiter’s theory. There is no equivalent in PEPA because the process algebras are centered with the description of the behavioral properties of the connected components. In this perspective, the value of a variable at a particular time depends on the different activities at work in the process. Consequently, the FM cannot be modelled in the modeling process.

Process algebras define the set of states through a set of symbols corresponding to an expert’s language items, contrary to TOM4D where the states are anonymous: their meanings are provided with the value of the whole set of variables used when the system enters a state. The set of PEPA actions plays the same role as the set of timed observation classes and the behavior definition is similar to the set of transition relations of the TOM4D behavioral models. Such a behavioral model is not covered by Reiter’s theory. In other words, a diagnosis model built according to Reiter’s theory is formulated with a structural model and a functional model in the TOM4D meaning. A diagnosis model built according to PEPA is formulated with a structural model and a behavioral model.

On the other hand, the TOM4D methodology obliges the experts to define the way they ”see” the system in order to model in terms of perception. There is no equivalent in PEPA because it considers the diagnosis model as a consequence of both the system structure and the behavior of its components. This was one of the reason for proposing TOM4D.

An important property of the TOM4D methodology is the use of T.O.S. T.O.S. facilitates the introduction of a physical interpretation to model behaviors having a physical meaning.

From the technical viewpoint, the PEPA model is more compact than TOM4D models. A compact representation is an advantage for the modeler since the lower the number of symbols there are to be defined, the better the model will be.

One the advantages of TOM4D is precisely that its makes explicit the different relations between the terms used by an expert to formulate their knowledge (variable, value, state transition condition, etc). In other words, TOM4D obliges experts to clarify their knowledge when analyzing the system to be modeled according to four points of view: perception, structure, function and behavior. From this standpoint, the graphical representations of TOM4D models are clearly an advantage for interpreting and validating them.

Finally, TOM4D methodology provides concepts and tools to help the modeler to define the correct level of abstraction for efficient diagnosis. The experiments we performed with TOM4D methodology show that this level of abstraction corresponds to that used by an expert to formulate their knowledge of diagnoses applied to dynamic systems.

We are now investigating these approaches to characterize the properties of their diagnosis algorithms (computational and pertinence properties).

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