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A Water Treatment Application for Model-based Decision Support System

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ABSTRACT

It lays out some basic ideas for how model-based systems technology can be used in a decision support system for a drinking water treatment plant. The purpose of this system is to discover abnormalities in plant performance, pinpoint potential reasons, and suggest suitable corrective actions. A library of model fragments representing desired processes, disturbances, and potential interventions forms its foundation. As a way to solve the diagnostic problem, these fragments and the observations are used to automatically make possible models of how the damaged plant might behave. A potential therapy idea would be an extension of such a model by models of interventions such that the outcome is consistent with remedial goals. We go into greater detail on how the fundamental reasoning processes can be used to leverage the model and consistency-based problem solving.

Keywords-- Plant, Interventions Form, Treatment, Water, Organic Components, Therapy

I. INTRODUCTION

Knowledge-based systems offer a way to make expert knowledge accessible to professionals or non-experts who do not have an in-depth understanding of a certain field. This feature is especially important in the field of ecology and environmental issues because every person, organization, and business has an impact on the environment—usually in a negative way—but it is unrealistic to expect them to fully comprehend these effects and how to prevent or mitigate them. Environmental decision support systems need to get domain knowledge from experts in ecology and/or environmental issues and give users a way to describe their specific problems. The systems should then use the information given and the domain knowledge to come up with solutions and show the results in a way that is easy to understand. We opted for model-based methods to tackle this challenging objective. The following are some basic presumptions that guide our work:

Our method is a groundbreaking combination of process-oriented modeling and consistency-based diagnosis. Together, they make up G+DE, a generalized diagnosis engine. We will talk about the ideas in this paper and how they could be used in a decision support system. We will not go over the formal theories and technical details that were cover.

Our work's application setting is a water treatment facility. Despite not precisely being an environmental system, this appears to be a decent place to start for a first-hand practical assessment of G+DE. Like an ecological system, it consists of physical, chemical, and biological processes about which only a limited amount of qualitative knowledge and information is known. However, its fixed structure and small number of pertinent phenomena make it a strong candidate for a first try.

It is also possible to test the decision support system for operators in real plants and easily move to real biological and environmental systems by adding events that affect natural water sources, like an algal bloom as seen. We provide a brief overview of the water treatment process and application background in the following section. We provide an overview of the modeling formalism in Section 3. We then give the components of the therapy suggestion and the scenario assessment based on this. Lastly, we talk about a few unresolved problems we ran across with deviation models being used for therapy and diagnosis.

II. THE COURSE OF THERAPY

The natural source of the water to be treated is a river (like Rio Guaíba) or reservoir (like Lomba do Sabão). It goes through a series of process phases after being pumped to the water treatment plant, which we will briefly outline below:

Arrival Room

This is when there are fewer mollusks or algae. You can identify algae by their color, which can be either green or brown. Adding an oxidation agent, such as ozone, activated carbon, or copper sulfate, is the solution.

Pre-chlorination and Pre-alkalinization of the Arrival Canal

Actions are taken so that alkalinity · 20} and pH 6.5 £ pH £ 7 if the alkalinity is £19 and pH is £ 6.5. Chlorine is first supplied to the system if necessary so that it can react with the organic components and eliminate them.

Chicanery in the Workplace

Three processes occur in the water: coagulation, stirring, and reactivity with aluminum sulfate ($Al_2(SO_4)3$). The goals are to remove solid (undissolved) materials such as algae, organic matter, dirt, and salts, as well as dissolved substances like NH_3, NO_2, and NO_3. In the water, $Al_2(SO_4)3$ dissociates to produce positive (Al^{+++}) and negative ($SO4^{--}$) charges. These charges draw opposite charges from dissolved and undissolved materials to create flocks. By agglutinating smaller flocks, the water is churned to generate larger ones. This is accomplished by the tank's slope, curves, and obstructions. As a result, there is a greater chance that molecules carrying different charges may come into contact, which causes the flocks to get larger. separation of flocks and water, or solid and liquid phases. The speed at which the water moves through the tank is slow. The flocks build a growing layer at the bottom of the tank during this time as they sink. This procedure concludes with measurements of turbidity and color.

Water Canal for Decantation

To ensure that any organic matter that has not been removed oxidizes and to leave free chlorine in the water, chlorine is added to the water once more (interchlorination). This free chlorine will eliminate any bacteria that might still be present in the water.

Screens

In this stage, unremoved tiny flocks and maybe microorganisms like bacteria and algae are held in sand layers. The goal is to eliminate material in order to lessen turbidity and color. The water must meet all legal requirements as it exits the filters.

Canal with Filtered Water

The last tweaks are applied. At the filters' exit, measurements are made of the following: alkalinity, pH, color, turbidity, and free chlorine content.

III. MODELING APPROACH

We present an overview of the modeling formalism that forms the basis of the decision assistance system in the following: The compositional modeling approach divides this into two sections:

- Domain theory, which is a library of behavior constituent kinds and mathematical axioms that reflect general knowledge (i.e., generic processes).
- The description of the scenario that contains details about a particular system in a certain state expressed in terms of observable items, their values of object variables (such as measurements) and their relationships (see Table 1).

We offer a generalization of both component-based and process-based modeling paradigms while adhering to structure-to-behavior reasoning and compositional modeling concepts. This perspective states that the domain theory and a scenario description make up the two components of the system model, also known as the system description. The graphic in Table 1 provides an overview, and we briefly go over each section.

3.1 Domain Concepts

The domain theory encapsulates our understanding of the domain, which includes every system within a specific class (such as water treatment facilities or hydrological ecosystems). We differentiate between behavior constituents (which could be processes or other model pieces) and structural elements (objects and interactions).

Table 1: Model structure for systems

Domain Theory	
Ontology	Object Types (hierarchical)
	Object Relations
	Quantity Types
Behavior Constituent Types	Structural Conditions (objects and relations present)
	Quantity Conditions (constraints on quantities)
	Structural Effects (objects and relations created)
	Quantity Effects (constraints and influences)
Basic Axioms	
Situation Description	Objects
	Relation Tuples
	Quantity Value Assignments

- Object categories found in structural descriptions, such as different kinds of device components (such as resistors and broken wires), spatially distinct things (such as water body levels, pipes, and tanks), etc. It is possible to organize object types hierarchically.

- Connections for describing objects as "configurations". Examples include component connectedness and spatial linkages (contained below). It is possible to specify certain significant aspects of relationships, such as uniqueness.
- The fundamental components of behavioral descriptions are quantities. It is possible to define many quantity types (with various domains) and to provide objects of a certain type with a variety of related quantities that play specific roles (e.g., the resistor's resistance, the water tank's dissolved iron concentration, etc.). A language for behavior descriptions and the deductions that yield behavioral components from a structure description must also be provided by the domain theory. It presents
- Types of behavior constituents these are physical occurrences that are thought to influence how the system behaves as a whole. Basic component rules like Ohm's Law and logical-or processes like those found in the Qualitative Process Theory (QPT) (Forbus, 1984) can be represented by them. Algal blooms, water transportation, and alkalinization are a few examples. They happen deterministically in specific scenarios, and their occurrence has certain consequences.

By utilizing the differentiation between structural and quantitative elements for both causes and consequences, we arrive at

- Structural conditions: claims on the existence of entities and relationships (such as sedimentary iron).
- Quantity conditions: declarations regarding quantity values (such as a low pH in the reservoir).
- Structural effects: the formation of new objects and relationships, or even their elimination (such as the "generation" of dissolved iron from bound sedimentary ones).
- Quantity effects: these can be described as limitations on variables (for example, a decrease in pH and a rise in dissolved iron content in sedimentary iron). As in QPT, we also permit influences—that is, partially stated effects—in this context.

A behavior constituent type's abstract form can therefore be expressed as

Quantity Conditions ⊥ Structural Conditions Quantity Effects ⊥ Structural Effects

More specifically, we say that an instance of the behavior constituent arises for every constellation of objects that satisfies the structure and quantity constraints, and that instance imposes the corresponding consequences on the constellation. A process is depicted in both textual and graphical notation.

We also include a part devoted to the basic rules that govern the mechanisms of model building, the combination of effects, and the forecast of time (continuity, integration, etc.). These "basic axioms" are domain-independent laws, such as the one of behavior constituent occurrence mentioned just above, and cannot be provided arbitrarily by the modeler.

We commit very little at this point regarding the formalism for defining the quantity effects (constraints, differential equations, etc.), the expressiveness of structural conditions and effects (e.g., non-existence of certain objects as a condition or destruction of objects as a structural effect), and the quantity domains (symbolic, qualitative, real, etc.).

3.2 Overview of the Situation

An object structure, that is, instances of the object types and individual tuples of object relations (e.g., the components and the connection structure of a device), characterizes a given system under examination. Both objects and related tuples will be referred to as structural elements in the text that follows.

A quantity value assignment describes a certain state of the system. These could be basic hypotheses, goals specified (like a certain amount of iron), or real measurements (like an increased amount of iron in the drinking water), depending on the activity and environment.

3.3 Expressing Deeds

Particular physical prerequisites, referred to as quantitative and structural conditions, may be necessary for the application of particular actions. They do not, however, immediately become active when these physical prerequisites are met, in contrast to regular processes. They also need some human intervention in order to become effective. Such an intervention can consist of a whole series of human actions (such as adding material to a container, attaching a pipe to it, and turning on a valve), which must be considered when organizing the operation or determining how much it will cost. Nonetheless, it is sufficient to think of them as atomic entities when debating appropriate remedies.

So, an easy way to add actions to the modeling language is to show human actions as a special type of object called an "action trigger," which is needed for the actions to happen.

Action triggers are never able to manifest as structural byproducts of other actions or processes because they are contingent solely on human decision-making and activity. Additionally, even if they are instances of the same action type, we must ensure that distinct action instances have distinct action trigger objects. If not, a single object might be the cause of multiple occurrences of the same sort of action. Making sure that the position of action triggers is distinct for each instance of an action type is one method to accomplish this within our modeling formalism without the need for further ideas. An open connection action's trigger, for example, must be unique to each opening rather than the container itself if a container has many connections to other tanks. This is because, in the latter scenario, opening one connection would also open the others.

3.4 Models of Deviations

In many cases, taking into account the absolute values of items has no bearing whatsoever on the situational evaluation or treatment plan. Instead, thinking solely in terms of (qualitative) deviations from nominal values may be adequate. They can be used, for instance, to convey the idea that a higher-than-normal chlorine supply tends to drop pH levels below the designated range.

Descriptions of deviations may reflect the idea that it might not be necessary or possible to precisely and statistically define what normal behavior looks like. Such a deviation can be expressed for each variable as x := xact - xref.

Deviation models, which can be made from absolute models, can be used to spread changes from some nominal or reference behavior that may not be stated. During the step of evaluating the scenario, one can start with a measurement-based deviation from the desired state and work to find other changes in quantities that affect the deviation.

IV. SITUATION ASSESSMENT

As previously mentioned, the first problem to be tackled is to formulate theories about the existing state of affairs based on the system's observational data. The situation evaluation would just need to identify the active processes that each of the observations' relevant items in the system truly represent. Generally speaking, observations are not comprehensive and may contain erroneous information. For example, if the iron concentration of the incoming water is not tested, then the iron statement is either incomplete or merely an estimate (e.g., a default concentration value). In this instance, the scenario assessment must either finalize the user's description (e.g., speculating on the presence of iron) or update ambiguous data (e.g., the default concentration).

As a result, we permit user-defined assumptions to qualify quantity allocations.

It is also possible to make assumptions about the existence of structural components.

It is not possible to finish the scenario description at random. Certain items, like iron in the entering water, can be "introduced" without any further explanation, while other objects, like iron in the treated water, can only be accepted if they make sense in relation to the rest of the model. In order to accomplish this, some object types can be designated as introducible, enabling the insertion of those objects into the system model. This gives you the most control over the problem-solving process because you can "deepen" your search for causes when you select a more limited collection of introducibles. Since they define what cannot be expected to be explained, introducibles serve as a representation of the model's boundaries. For instance, one may agree that iron can be present in the entering water without additional explanation, but iron in one of the treatment tanks requires other processes (upstream) to be active in order for its concentration to be determined. Now, we can say that the acceptable scenario assessment solutions are the structures that are the least consistent and still hold a maximum set of user-specified assumptions. These solutions are based on both assumptions that can be argued against and elements that can be introduced. It is okay for a structure to be accepted if it has at least the structural parts that the user has stated as facts (without assumption) and all the other structural parts are either introducible or a required result of a behavior constituent that is happening (through structural effects). Solutions always include all of these effects because it is clear that a structure without these important structural effects doesn't match up with how the laws of behavior work.

In relation to set inclusion, minimalism is understood. It should be noted that we do not select one solution over another based on the absolute cardinality of structural elements included in that solution; rather, we simply exclude "superfluous" or "unnecessary" items from consideration.

Figure 3 shows a simplified picture of what goes into and comes out of this part of the decision support system, using the four types of input and output: fact, assumption, introducible, and consequence. Quantity assignments may pertain to the absolute values, derivatives, and deviations of variables. Facts and conjectures about quantities and structure make up the user input. In this case, it means that variables aren't acting the way the system should. For example, in our application area, this could mean that the iron or turbidity level is too high at a certain point in the treatment process. The situation assessment part then builds a consistent model by adding introducibles and changing user assumptions to meet the minimality requirement that was already mentioned.

Typically, there are multiple minimal answers, and the outcome is not unique. In this instance, further measurements might help rule out some of them, and measurement or test proposal techniques similar to those commonly employed in component-oriented diagnostics can be applied. If not, the user must be shown the results

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and given the opportunity to review them. This brings up the problem of generating explanations, particularly as the scenario assessment's outcome includes factors that the user did not express at all but that the system introduced or deduced.

V. THE THERAPY PROPOSAL

Following the identification of the existing state, the question of whether it is compliant with the goal performance or if compliance requires action is raised. Thus, the outcome of the situation assessment and a description of the objectives to be met by corrective activities (if any) provide input to the therapy proposal. In the broadest sense, therapy would be a set of steps that, when taken together, make the system in a way that requires a lot of planning and is in line with the goals that were set. In this work, we just focus on one more particular issue:

1. We assume that a set of quantity assignments can explain the goals rather than imposing complex limits on a number of system variables, such as limiting the concentration of iron to a specific level.
2. A therapy is a set of doable steps that, when used in a certain situation, change variables that aren't in line with their objective values in the right direction (without changing the right variables). For example, lowering the iron concentration while maintaining the other objective variables is an intermediate step if the concentration is too high. We can be more precise about the input to therapy suggestions under these presumptions:
3. The intermediate goals are easily defined by taking the derivatives of the goal variables and expressing them with a sign that is opposite to the variable's deviation.

The current scenario: since we committed to it, everything that came about as a result of the situation assessment stage must be included, with the caveat that the derivatives of non-goal variables must now be treated as assumptions. This is because we take it for granted that actions and their consequences are introduced instantly. Consequently, if the activities have an impact on derivatives, we must permit them to modify their values discontinuously.

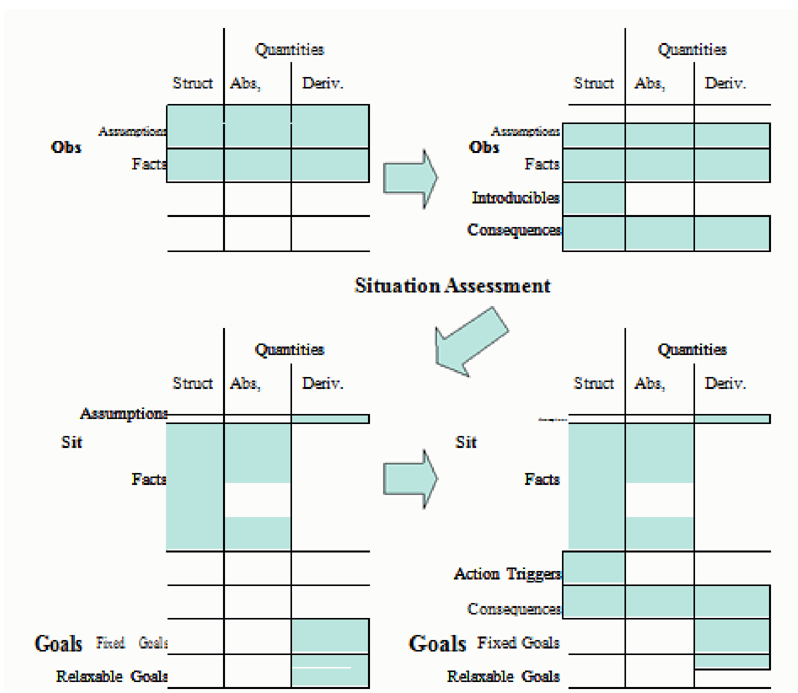

Figure 1: The two steps' input, output, and relationship

The current scenario: since we committed to it, everything that came about as a result of the situation assessment stage must be included, with the caveat that the derivatives of non-goal variables must now be treated as assumptions. This is because we take it for granted that the acts and their consequences will be introduced instantly. Consequently, if the activities have an impact on derivatives, we must permit them to modify their values discontinuously.

As seen in Fig. 1, this we also provide a way to drop some of the intermediate goals, since achieving them all might not be feasible. This can be accomplished by declaring the rigid objectives as true and the feasible ones as conjectured. After that, a therapy is a group of action cues that, when put together with the current situation, create a model with the bare minimum of stable structures that support the largest possible set of intermediate goals. While it employs the same diagnosis algorithms as the scenario assessment stage, this approach differs in that the introducible serve as the action triggers. A schematic representation of the therapy proposal process is shown in Fig. 1. Reducing the number of actions will typically not be sufficient, so it may be best to choose the one with the lowest possible cost.

VI. CONCLUSION

We described a decision support system that performs scenario evaluation and therapy recommendation using consistency-based diagnosis and process-oriented modeling. It is predicated on several suppositions. The biggest problem with both processes is that they only look for a solution through system snapshot analysis, which is a static point of view.

The first step does not provide information about how a disturbance develops over time; it merely determines the current condition. Although this sounds reasonable as a starting point for a therapy proposal that must be adapted to the current situation, one-step therapy might not be practical for many other applications that call for a series of interactions.

As of right now in the project, a first version of the decision support system is being constructed, and graphical editors are available for the scenario description and the domain theory, as well as the consistency-based problem solver. This version will be very interactive, allowing the user to steer the search for a consistent model while presenting inconsistencies to him. A version that generates consistent solutions automatically will be created based on this experiment.

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