Using SCADE for Decision Support in Dam Management *

María del Mar Gallardo[1], Pedro Merino[1], and Laura Panizo[1] and Antonio Linares[2]

[1] Dep. Lenguajes y Ciencias de la Computación, University of Málaga, Spain

BEFESA AGUAS, SAU, Spain

Abstract. Formal methods have been widely used to analyze discrete systems such as software. However, in recent years their field of application has been extended to deal with hybrid systems, that is, systems that combine both continuous and discrete behaviors. This paper presents the experimental use of formal methods in a new application domain, the management of dams. Such systems present hybrid behaviors which are not properly dealt with by classic numerical models. We use the tool SCADE, based on the formal language Lustre, to model, simulate and verify dam elements in order to obtain a Decision Support System (DSS) suitable for use by the dam operator.

1 Introduction

A Decision Support System (DSS) is a specialized type of information system for business and organizational decision-making activities. One emerging field of application of DSS is water resource management. In this domain, DSSs are mainly used as flood simulation and prediction tools. They include numerical models of dams, rivers, and other water management systems. In this context, DSSs need to work with a huge amount of data, like weather forecasts, water levels in real-time, etc. The output of a DSS could be, for instance, the evolution of water at different points along the river. If it is obtained rapidly, it provides valuable information for the managing staff.

Currently, increasing numbers of DSSs are implanted in different basins, such as the DSS *SAD Ebro* [7]. Traditionally, these systems have used numerical models which are a powerful and precise simulation tool of continuous variables, such as river flow. Artificial intelligence has also contributed to the development of DSS in this area, defining heuristics to introduce probabilities and uncertainty [6]. However, an important challenge of these proposals is how to integrate the discrete part, which typically appears in a dam. Current DSSs consider dams as black boxes with the ability to control the water flow, but they do not consider the real behavior of its elements and the complexity of managing them in order to obtain a precise goal, such as releasing $2Hm^3$ in an hour to avoid having the river burst its banks. The operator's decisions should take into account a lot of parameters like the behavior of each outflow element, the current level of the

* Partially supported by the Spanish MEC under grants P07-TIC3131 and TIN2008-05932

del Mar Gallardo M., Merino P., Panizo L. and Linares A. (2009).
Using SCADE for Decision Support in Dam Management.
In *Proceedings of the 7th International Workshop on Modelling, Simulation, Verification and Validation of Enterprise Information Systems*, pages 125-131
DOI: 10.5220/0002194801250131

dam, the water demand for citizens or the minimum flow needed for energy production. The aim of this paper is to use formal methods to implement this combination of discrete and continuous behavior in order to improve the functionalities of DSSs with a more precise management of dams. Using formal models, we can take advantage of powerful features, such as automatic verification, automatic code generation or automatic generation of operational procedures.

Recently, formal methods techniques have been extended to cover both continuous and discrete behavior [8, 3]. They have been used in some attempts to model and verify water resource management subsystems such as a hydroelectric power plant in [2] or supervisory water level control for cascaded river power plants in [4].

In this paper, we present a model of a dam using the SCADE suite [1], a tool based on the language Lustre that provides facilities for modeling, simulating and verifying hybrid systems. Our model uses data flows to implement the continuous behavior and safe state machines to implement the discrete part. This model is used for decision support at the dam, allowing the operators to a) simulate the effect of actions like opening or closing spillways, b) to verify that these actions will enable the dam to reach a safe state, and c) to generate sequences of actions in order to make the system evolve towards a safe state. Compared with related work, our approach offers interesting advantages, such as the ability of verifying certain critical properties to be preserved in dams. Finally, it is also scalable, that is every element in the system may be easily replicated.

2 Dam Management

A dam is a complex water management system that can have different objectives, the most common being the regulation of floods and water supply for human consumption and irrigation. To meet these objectives, a dam has different types of outflow elements. Figure 1 shows the different outflow elements in the dam used as an example. *Wide Surface Spillways*, *Intermediate Outflows* and *Low Level Outflows* are gates used for flood regulation; they are usually opened in emergency situations.

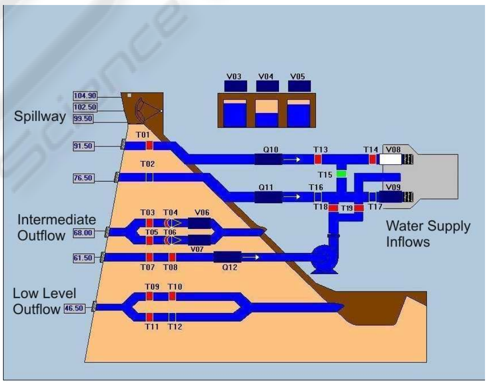

Fig. 1. Dam Section and Control Room.

They have a high outflow capacity when the height of stored water rise above them. *Water Supply Inflows* are pipes used to obtain water for human consumption. They conform the water supply system, together with valves and machinery located downstream on one side of the dam. That guarantees the water supply when gravity does not allow it naturally. Figure 1 shows 3 pipes at different heights connected to the water supply canal. In our reference dam there is a special structure that transfers water from other reservoirs. This subsystem increments water level in the dam in a controlled way.

The operational procedure of a dam can be very complex depending on the number of outflow elements and the limitations imposed by nature and official regulation rules. Dams have different states depending on the water level, and a set of operational procedures is associated to each state to ensure the safety of the dam and the population downstream, as well as the efficient use of water.

3 Modeling a Dam with SCADE

A dam is composed of different outflow elements. The DSS is very dependant of the model of dam elements and the environment. A first model have been developed, applying simplifications in the number of gates and their behavior. The model is shown in Figure 2.

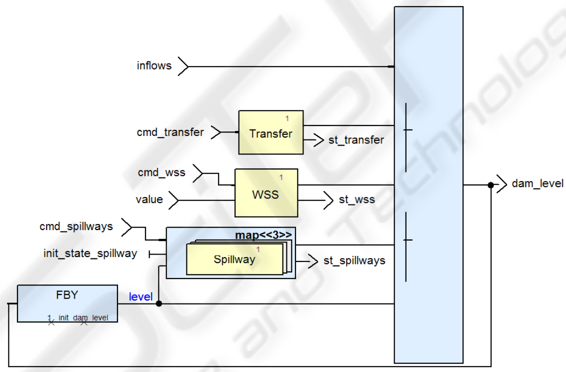

Fig. 2. Dam Model.

Three elements conform the dam: wide surface spillways, the water supply system and the transfer from other reservoirs. These nodes mix finite state machines and data flows. Additional blocks are needed to analyze the system, for instance, the inflow caused by rain and the river, or the behavior of users. Communication between the dam with user and rain models is performed by dam inputs: `inflows`, `cmd_transfer`, `cmd_wss`, `value` and `cmd_spillway`. Dam outputs are the state of each gate and the current water level. The behavior of modeled elements is as follows:

– **Wide Surface Spillway**: This element has been modeled with a nested state machine with two main states, `Open` and `Close`, as shown in Figure 3. `Init` state is also included for correct initialization. There are two opening positions:

Intermediate and Complete. Transitions from these states are fired by user commands (close, open_i, open_c). Besides, delay states have been introduced to model the time needed to open and close gates. For simplicity, the contribution of spillways only depends on the opening degree. If the water level is below the height of the gates, spillways do not work properly. Each spillway has a cmd input to receive user commands, a dam_level input and an init_state for correct initialization. It has two outputs: its contribution to dam level and its current state (st).

– **Water Supply System**: This node models pipes, valves and machinery for water supply. This node acts as a valve with different degrees of openings. It has been modeled with a state machine with two states: steady and delay. In the first one, water flows and gates are opened a fixed degree. When user want to modify the degree, a command is sent, and a transition to delay state is produced; where the new degree of opening is loaded. This node has inputs to receive user commands and opening degrees. It has two outputs: its contribution to dam level and its current state.
– **Water Inflow from other Reservoirs, Transfer**: This node is similar to the spillway model, but in this case, transfer increases the water level and its contribution to the dam level is independent of the modeled dam.

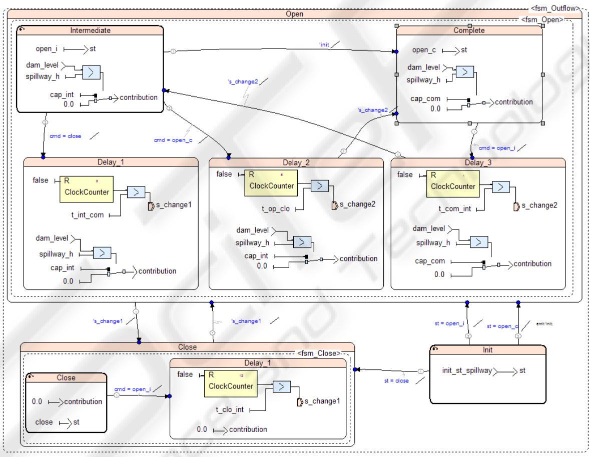

Fig. 3. Spillway State Machine.

4 Decision Support Systems with SCADE

The normal operation of DSS is based on the simulation of models with different parameters, some of them real-time data collected from sensors. SCADE can be used for this purpose because it offers a complete simulation environment. In the following paragraphs, we describe the roles of SCADE as a DSS.

Simulation: SCADE allows two simulation modes: step by step and batch modes, both allow the manual change of input values. Figure 4 shows a simulation step of a dam model. To run a simulation, it is needed a scenario, which provides the inflow value for each simulation step; and a model of the user, that contains the set of operational procedures carried out. In Figure 4, the user model is very simple and does not consider status information of the dam. Finite state machines can be used to model user behavior.

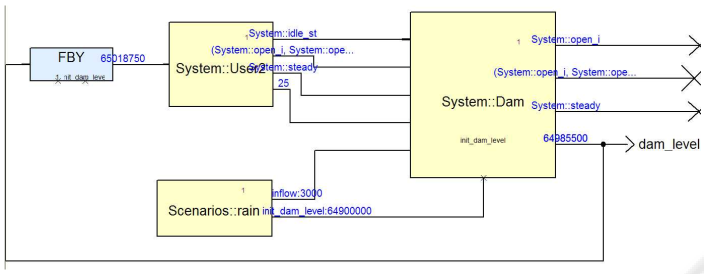

Fig. 4. Simulation Scenario.

Training: This task can be oriented to form new dam operators with different objectives, from avoiding a disaster to minimizing water wasted or released in case of flooding. To this end, a real user has to manually interact with the dam model through its inputs in each cycle. The dam returns to the user data about gates' state (`st_spillways`, `st_transfer`, `st_wss`) and the water level.

Verification of Safety Properties: In addition to the usual safety properties, the SCADE verification module is used to analyze specific properties regarding the dam management, that are informally described in the dam operation manual. The methodology used is shown in Figure 5. The user model reflects the operational procedure under analysis. Some examples of interesting properties to be analyzed are: (1) *after user carries out some operations, the water level is reduced to the desired level in N ticks (N simulation steps)*; or (2) *if dam level reaches a threshold, then the water level is reduced to the desired level in N ticks*. Using a simple user model, we have implemented and validated these properties. The analysis of the first one lasted 58.797 sec., with a depth of 20 transitions in the search space. The second property lasted 190.203 sec. with a similar depth. This huge increment in time could be more significant if the user model is extended or if properties are more complex.

Automatic Synthesis of Operational Procedures: Automatic synthesis has been analyzed previously in other areas, such as industrial controllers [8, 5]. The challenge is to manage the dam, satisfying user objectives. An example is shown in Figure 5. The user model has to be carefully designed to not discard any procedure. The objective has to be expressed as a property that the system does not fulfil. The counter example returned will be the sequence of actions needed to fulfill the property.

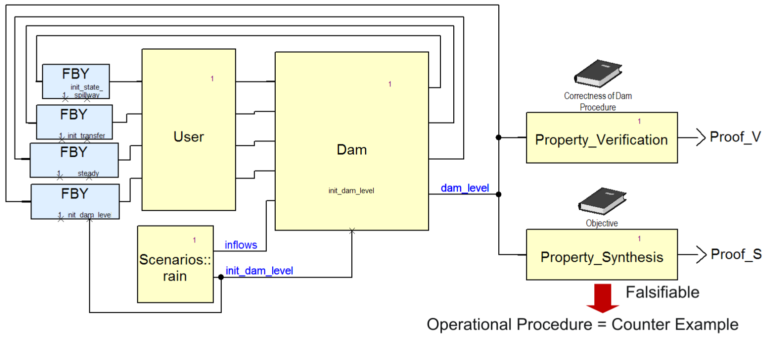

Fig. 5. Verification and Automatic Synthesis Scenario.

5 Conclusions

In general, modeling the dam with SCADE has been feasible with a moderate effort, showing that Lustre is a powerful language that allows the implementation of part of these systems. However, since Lustre does not support non-deterministic behaviors, other formal methods have to be used to introduce these behaviors in the model. Verification of non-trivial properties may be unfeasible, if the system grows in complexity. When the model includes real variables, analysis may return non-concluding results. For this reason, integer inputs and outputs are used. Automatic synthesis of operational procedures strongly depends on the user model which is in fact the module that implements the DSS functionality. Future work includes the construction of a graphical user interface, suitable for dam operators. It should integrate different parts of a DSS, built with different formal methods and technologies such as numerical modeling.

Acknowledgements

Authors would like to thank Agustín Merchán, Spanish expert in dams, for his help.

References

1. SCADE Language Reference Manual. http://www. esterel-technologies.com.
2. Ferrari-Trecate, G., Mignone, D., Castagnoli, D., and Morari, M.: Mixed Logic Dynamical Model of a Hydroelectric Power Plant. In *ADPM'2000*.
3. Frehse, G.: PHAVer: Algorithmic Verification of Hybrid Systems Past HyTech. In *HSCC'05*.
4. Glanzmann, G., von Siebenthal, M., Geyer, T., Papafotiou, G., and Morari, M.: Supervisory Water Level Control for Cascaded River Power Plants. In *Int. Conf. on Hydropower*, Stavanger, Norway, 2005.
5. Jessen, J.J., Rasmussen, J.I., Larsen, K.G., and David, A.: Guided Controller Synthesis for Climate Controller Using UPPAAL Tiga. In *FORMATS*, 2007.
6. Rajasekaram, V., and Nandalal, K.D.W.: Decision support system for reservoir water management conflict resolution. *Journal of Water Resources Planning and Management*, 2005.

7. Romero, R., Linares, A., García, E., and López, L.: Resevoir management in real time flood forecastig and decision support in the Ebro river basin. In *ACTIF/FloodMan/FloodRelief*, 2005.
8. Torrisi, F., and Bemporad, A.: HYSDEL - A tool for generating computational hybrid models for analysis and synthesis problems. *IEEE Trans. on Control Systems Technology*, 2004.