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A DEVS Based Modelling and Simulation Methodology — COSIM

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Abstract: In order to overcome some shortcomings of DEVS, this paper proposes a modeling and simulation methodology named COSIM, which is introduced from structure and behavior description of simulation system. Then the core components of COSIM, Atomic Component (AC) and Compound Components (CC) are presented with their formal definition. Moreover, COSIM specification is introduced in the form of graphic items and text formats. Finally an implementation example is given.

Keywords: DEVS, System Structure, Behavior

1 Introduction

Discrete Event System Specification (DEVS) is a modular and hierarchical formalism for modeling and analyzing general systems that can be discrete event systems which might be described by state transition tables, and continuous state systems which might be described by differential equations, and hybrid continuous state and discrete event systems. In DEVS, a simulation system is composed of Atomic models and Coupled models. Atomic models are expressed in a basic formalism. Coupled models are expressed using the coupled model specification — essentially providing component and coupling information.

However, DEVS falls shot of addressing the following issues:

- Due to the rapid development of Modeling and Simulation (M&S) and software technology, some problems of DEVS have emerged. On the one hand, it is difficult to describe dynamic system behaviors of Coupled models using DEVS. On the other hand, advanced computer science technology including automata is widely used. As a result, the combined method is proposed by some researches. For example, visual state transition chart is combined with DEVS by extending Finite State Machine (FSM).
- Moreover, DEVS models are white box components, whose external and internal transition functions are both defined before running. However, along with the development of simulation technology many business simulation software such as ADAMS are developed, which are black box system to users. Therefore Hybrid Input and Output Automata (HIOA) and visual state transition chart are introduced to express model behavior which treats simulation systems as black boxes.
- Although DEVS introduces modeling formalisms and simulation algorithms, it does not provide implementation specifications for software development.

One effective way to resolve the above problems is to design and implement an M&S methodology which is named by COSIM. The main theory of COSIM is to describe a simulation system structure by Atomic Components and Compound Components, which are similar as DEVS. However, COSIM adds implementation description of dynamic behavior using automata, which is driven by COSIM simulation engine. In sum, COSIM has three core components, Atomic Component (AC), Compound Components (CC) and Engine Component (EC) using automata based description to drive ACs and CCs. And we can see from figure 1 that EC is always part of AC and CC.

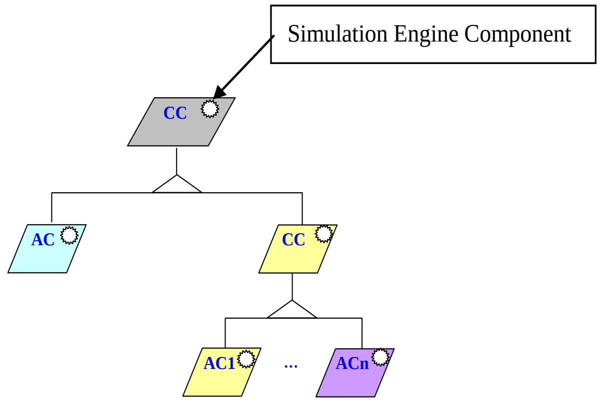


Figure 1: Overview of COSIM components

The rest of the paper we will discuss AC and CC from the perspective of system structure and present a description specification of system structure and behavior.

2 COSIM Structure Description

From system engineering theory, any system is composed of structure and behavior. System structure defines what components forms a system and behavior defines how elements behave and evolve.

In this section we mainly introduce the structural components which form a COSIM specified simulation system.

From simulation system structure perspective, we regard the system as a number of "black boxes" (subsystems and components). The boxes connect to each other with ports and events. The basic encapsulated form of the boxes is a component. Components constitute any simulation system. The data stream and event stream of components can be implemented by Engine Component, which reads dynamic behavior scheduling and calls relevant interfaces of components temporally.

Executing the simplest function in a simulation system, AC is a basic implementing component. Being the smallest reusable modules, AC cannot be separated into smaller elements (or components). Here we give the Formal Definition of Atomic Component (AC) as follows:

$$AC =< inputPort, outputPort, inputEvent, outputEvent, fsm_0, Constraint, SemanticInterface > \quad (1)$$

Where:

- The *inputPort* refers to several input ports that can only receive data, which is the consumed data of *AC*. The formal definition of *inputPort* in detail is:

$$inputPort = \{(ip_1, ip_2, \cdots, ip_n) \mid ip_1 \in X_1, ip_2 \in X_2, \cdots, ip_n \in X_n\} \quad (2)$$

Where: X_i is a set of data candidates of ip_i.

- The *outputPort* refers to several output ports that can only send data, which is the produced data of *AC*. The formal definition of *outputPort* in detail is:

$$outputPort = \{(op_1, op_2, \cdots, op_n) \mid op_1 \in Y_1, op_2 \in Y_2, \cdots, op_n \in Y_n\} \quad (3)$$

Where: Y_i is a set of data objects of op_i.

- The *inputEvent* refers to several input event ports that can only receive event data, which often lead *AC* states to change. The formal definition in detail is:

$$inputEvent = \{ie_1, ie_2, \cdots ie_N\} \quad (4)$$

Where: ie_i is a set of event data objects.

- The *outputEvent* refers to several output ports that can only send event data, which often compel the other component states to change. The formal definition of *outputEvent* in detail is:

$$outputEvent = \{oe_1, oe_2, \cdots oe_N\} \quad (5)$$

Where: oe_i is a set of event data objects.

- *Constraint* describes the relationships among the *inputPort, outputPort, inputEvent and outputEvent* such as the temporal sequence, status sequence, etc.
- The *SemanticInterface* defines components' semantic interfaces such as its professional field.
- fsm_0 is the basic finite state machine portraying component's behavior. The formal definition in detail is: $fsm_0 =< S, S_0, iE_0, \delta >$.

Where:

$$S = \{("INIT", A_1), ("RUN", A_2), ("STOP", A_3), ("PAUSE", A_4), ("EXIT", A_5)\} \quad (6)$$

Where: A_i is the compelled change from S_i, calling some specific simulation functions. And the formal definition for others:

$$S_0 \in S\,,\ \begin{array}{l} iE_0 = \{evRun, evInit, evPause, \\ evStop, evTimeAdvance\} \end{array},$$

$$iE_0 \in inputEvent\,,\ \delta : S_0 \times iE_0 \to S\,. \qquad (7)$$

The compelled state changes at fsm_0 are shown in figure 2.

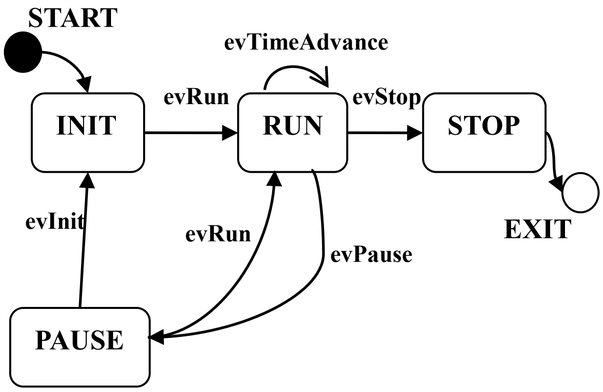


Figure 2: State transitions of fsm_0

fsm_0 is the basic finite state machine of AC and also the top-level machine of CC, it contains the basic simulation states and sequential status transitions. In the state changes of hierarchical components, fsm_0 sends event iE_0 to initiate the simulation processes.

According to its description of considered factors such as function, problem, information and process, a system can be decomposed into compound components and the components can be further decomposed into atomic components and compound components. Then a leveled system structure is formed, also shown in Figure 1. Moreover, the atomic components can constitute compound components; the compound components and other CC or AC can constitute a bigger CC until a system is formed. The above two different analytic methods are top-down and bottom-up. The former method is often applied in system requirement analysis and in the design phase. It mainly deduces system structure by system behavior. The latter method is to compose "big" components according to component features, then generate components or systems with specific behaviors, the method is mainly applied in the detailed design and implementation phase.

CC is also composed of inputPort, outputPort, inputEvent and outputEvent. Additionally, it includes sub-components such as ACs, other CCs, connection components among them, and interior event-driven state changes. Here we also give Formalization of Compound Component (CC) as follows:

$$\begin{array}{l} CC =< inputPort, outputPort, inputEvent, \\ outputEvent, D, \{C_d \mid d \in D\}, Couplings, \\ FSM, Containt, SemanticInterface > \end{array} \qquad (8)$$

Where:

- The *inputPort* refers to the input port of *FSM*. It connects with the input ports of C_d.
- The out*putPort* refers to the output port of *FSM*. It connects with the output ports of C_d.
- The *inputEvent* refers to the input event port of *FSM*.
- The out*putEvent* refers to the output event of *FSM*.
- *D* refers to the index of sub-components, and $\{C_d \mid d \in D\}$ is sub-ACs and sub-CCs of *CC*.
- *Couplings* refer to internal component linking of CC. The formal definition for *Couplings* is:

$$\begin{array}{l} Couplings = \{cpl_0, cpl_1, \cdots, cpl_n\}, \\ cpl_i = \{(C_a, oP_j) \to (C_b, iP_k) \mid \\ a, b \in D \cup \{FSM\} \cup \{CC\}\} \end{array} \qquad (9)$$

Where ***Finite State Machine (FSM)*** is defined as:

$$\begin{array}{l} FSM =< inputPort, inputEvent, \\ outputEvent, fsms, R_{sf} > \end{array},$$

$$fsms = \{fsm_0, fsm_1, \cdots, fsm_n\},$$

$$R_{sf} : S_{ij} \to fsm_j\,,\ i \neq j\,,\ S_i \in fsm_i\,, \qquad (10)$$

The state of fsm_0 $("RUN", fsm_{i,i\neq 0})$ is a compound state.

The other state definition is same as the basic state machine of AC.

$$fsm_{i,i\neq 0} =< S, S_c, iE, S_0, C, \delta >.$$

- *Constraint* describes the relationships among the *inputPort, outputPort, inputEvent, outputEvent, Couplings and FSM,* especially CC's temporal sequence, status sequence etc.
- The *SemanticInterface* represents CC's semantic interfaces such as its professional field.

When connecting ACs and CCs to build a

simulation system, two types of link are considered, which are the data link and event link respectively. The data link is the continuously temporal matching of a data provider and a data consumer, which includes data type match, temporal sequence match and update frequency match, etc. Event link is the discontinuously temporal match of an event provider and an event consumer, which includes an event profile, an event data structure and an event time stamp, etc.

3 COSIM Behavior Description

In COSIM specification, system behavior is described using automata. And in this section, we mainly introduce the method to describe component behavior.

Dynamic component behavior not only includes responding to external incentive events but also generating output data and events in the process. After introducing the concepts of AC and CC, we now try to study more about state transitions and output of a simulation system.

Currently, the dynamic component behavior is described using FSM of AC or CC, connecting with other sub-components by ports and events. When the external events of compound components are input to the dynamic behavior component, it analyzes the input events and generates state transformation. In the transformation it is likely to send scheduling events to other sub-components and then it transforms to a new state. When the port data of sub-component changes, its state machine will feel the data changes and generate the resolution of a guarded condition among the states.

States and their transformations are basic modeling elements of system dynamic behavior. A simple state and a compound state form layered states, and the state transitions constitute system dynamic characteristics. The main triggering conditions of state transformations contain the triggering events of external input, judgment of logical time, and the changes of guarded condition triggered by the updating input ports. Action is the scheduling of AC and CC conducted by dynamic behavior components. Actions can be taken inside the states or in the process of sate transformations. This paper adopts state machine theory to carry out dynamic behavior modeling. The input and output of state machine components are shown in figure 3.

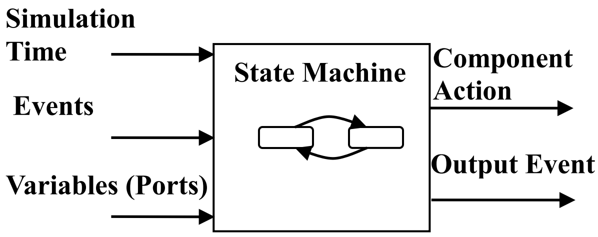


Figure 3: Input and output of state machine component

With state machine components we can clearly describe the process of a system receiving events and disposing events. So the state machine is suitable for the modeling of discrete event systems and hybrid systems. With richer descriptive semantics, visual state charts present the method of visual modeling on state machine components.

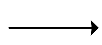
4 COSIM Specification

Using discussed structure and behavior description, COSIM formal specification help domain users to model practical systems. By referencing UML graphic specification, COSIM bridges DEVS with UML behavior modeling method.

The output of graphic modeling actually is model description script in the XML text, which is later parsed and used by COSIM engine to implement simulation system.

4.1 Structure Specification

Table 1: Graphic items of COSIM structure specification

Item	Meaning	Information
	Component	Model Name, Index, Semantic Tag, Type, Domain, Version etc.
	Event Port	Port Name, Event Object, Type, Direction etc.
	Data Port	Port Name, Data Content, Type, Direction etc.
	Initialization Port, Parameter Port	Port Name, Data Content, Type, Direction etc.
	Connection	Source Port Name, Type, Time, Type; destination Port Name, Type, Time, Type.

Compatible with the above graphic expression, text specification of model structure is discussed as follows:

The start and end of model is tagged with <CosimComponent> and </CosimComponent>.

Meta data of model is defined as figure 4 shows.

There are four types of ports, which are Event Port, Data Port, Initialization Port and Parameter Port. Different ports form model interfaces. Here we study the ports in detail.

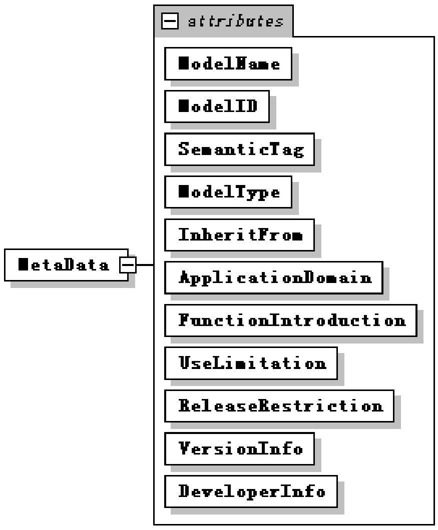


Figure 4: Meta data of COSIM model

1) Event Port attributes are shown in figure 5.

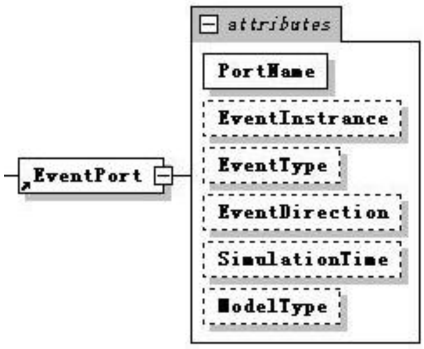


Figure 5: XML schema view of Event Port

2) Data Port attributes are shown in figure 6.

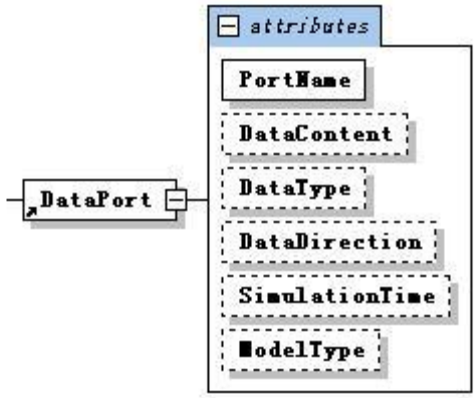


Figure 6: XML Schema View of Data Port

3) Initialization Port attributes are shown in figure 7.

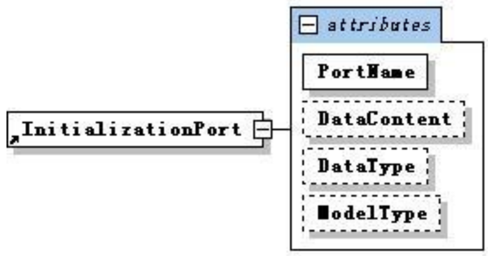


Figure 7: XML schema view of Initialization Port

4) Parameter Port attributes are shown in figure 8.

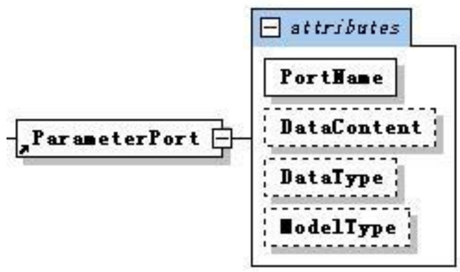


Figure 8: XML schema view of Parameter Port

Connection is important for compound models. System formal modeling specification checks connections among models to verify their validity. Furthermore, simulation engine connection management service work according to connection information defined.

Model connection functions dynamic coupling pair at run-time. Simulation time of connection represent the connection information must be used with time stamp, in order to insure correct temporal logic.

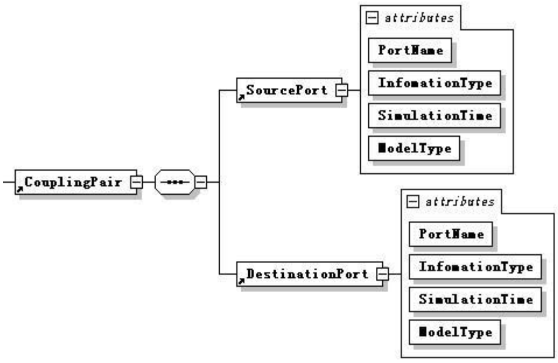


Figure 9: XML schema view of coupling connection

4.2 Behavior Specification

COSIM behavior specification uses state chart and sequence chart to specify system behaviors. State chart can present Atomic Model behavior. State chart and sequence chart are combined to describe Compound Model behavior for several reasons.

Firstly, they are designed to model a system from different perspectives. The former takes a component model as the only subject, independently portraying the responses of the model to outside incentives using states and transitions. On contrast, the latter is a graphic presentation of a scenario, portraying interactive and temporal activities among various models.

Secondly, they both present dynamic behaviors of discrete event systems, while having some common elements which are used in different ways.

Lastly, the former is more appropriate for description of single model's scheduling and the latter is more suitable for presentation of various models' temporal iterations.

Table 2 shows the graphic items of dynamic model behavior specification.

Table 2: Graphic items of COSIM behavior specification

Chart	Item	Meaning
State Chart		Initial State
		Last State
		State
		Concurrent States
		Judgment
		Transformation
		Transition
Sequence Chart		Component Model
		Life Line
		Incentive
		Event

4.3 COSIM Application Example

Figure 10 shows graphic structure presentation of a simulation system. Figure 11 shows graphic behavior presentation of a simulation system.

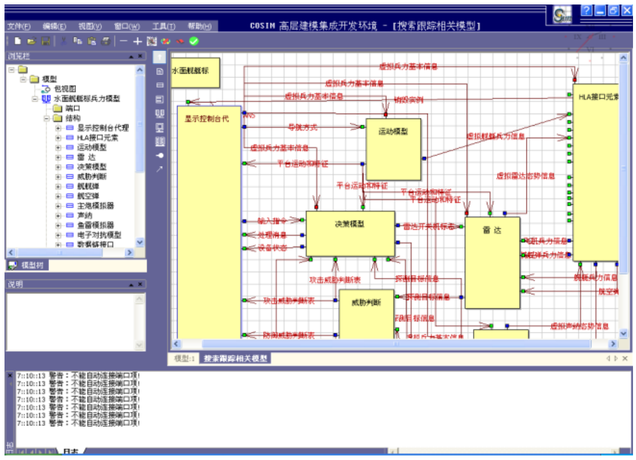


Figure 10: Graphic structure presentation of a simulation system

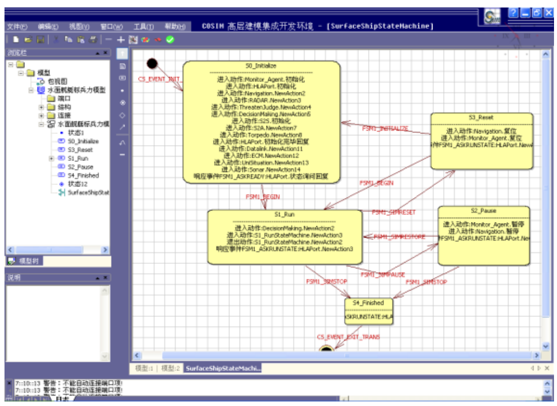


Figure 11: Graphic behavior presentation of a simulation

system

5 Conclusion

A DEVS based modeling and simulation methodology, COSIM is introduced from structure and behavior view respectively. And the COSIM specification is introduced in the form of graphic items and text formats. However, due to the paper length limit we cannot fully introduce the proposed method, which we will studied more detailedly in the near future.

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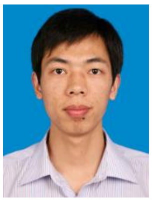

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