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ROUTING STRUCTURE OVER DISCRETE EVENT SYSTEM SPECIFICATION: A DEVS ADAPTATION TO DEVELOP SMART ROUTING IN SIMULATION MODELS

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ABSTRACT

The Discrete Event System Specification (DEVS) formalism has become an engine for advances in modeling and simulation technology. Many extensions of the DEVS formalism have been developed across the years in order to solve different types of situations. However, when the acceptance of input events and the generation of output events are related to model capabilities, the current formalisms come up with complex modeling solutions. This paper presents a new simulation formalism called Routed DEVS (RDEVS) in which routing information is used to manage directed events. The behavior supported by the new formalism is useful to create simulation models of web application architectures. However, it could also be applied to other contexts. The RDEVS formalism is based on DEVS and is closure under coupling (i.e. models can be built hierarchically). The formal specification of RDEVS formalism and a briefly description of its framework implementation are presented in this work.

1 INTRODUCTION

The Discrete Event System Specification (DEVS) is a modeling formalism based on systems theory that provides a general methodology for hierarchical construction of reusable models in a modular way. Since its introduction in late 70s (Zeigler 1976), the formalism has been used to simulate several systems related with multiple domains, including mobile applications (Kim et al. 2016), social networks (Bouanan 2015), supply chain management (Godding and Sarjoughian 2003; Gholami et al. 2014), and software engineering (Bogado, Gonnet, and Leone 2014; Risco-Martín et al. 2016; Blas, Gonnet, and Leone 2017).

The core of DEVS includes a modeling and simulation (M&S) framework structured in three main components: model, simulator and experimental frame (Zeigler, Praehofer, and Kim 2000). The model describes the system specification, structure, and behavior. The simulator refers to the computational system that executes the instructions detailed in the model. The experimental frame represents the conditions under which the system is observed, building the experimentation and validation context to be used on the model. Each component is specified as an individual element in order to maintain its independence. Keeping independency between components provides multiple benefits to the framework, such as: the same model can be executed by different simulators, or several experiments can be changed to study different situations (Bogado, Gonnet, and Leone 2014). Given that components need to interact with each other in order to accomplish their functions, the framework include a set of relationships that allow to define these interactions. These relations include the modeling relation and the simulation relation. While the modeling relation determines when a model can be said to be a valid representation of a source system within an experimental frame, the simulation relation specifies what constitutes a correct simulation of a model by a simulator (Wainer and Mosterman 2010).

Over the years, DEVS has finding an increasing acceptance in the model-based simulation research community becoming one of the preferred paradigms to conduct modeling and simulation enquiries (Wainer and Mosterman 2010). Following the approach proposed in the M&S framework, new variants, extensions and abstractions have been developed using the core of concepts defined by the original formalism. Several authors have improved the formalism capabilities in response to different situations, giving useful solutions to a wide range of simulation problems. Some of these solutions include Cell-DEVS (Wainer 2004), Dynamic Structure DEVS (Barros 1995), Fuzzy-DEVS (Kwon et al. 1996), Min-Max-DEVS (Hamri, Giambiasi, and Frydman 2006), Parallel DEVS (Chow and Zeigler 1994), and Vectorial DEVS (Bergero and Kofman 2014). Moreover, the separation of concerns in the model/simulator components included in the M&S framework allowed researchers to develop alternative simulations algorithms in order to complement the existent solutions (Kim, Kim, and Park 1998; Muzy and Nutaro 2005; Shang and Wainer 2006; Liu 2010; Liu and Wainer 2010). So, it is evident that the DEVS formalism grows along with the evolution of the problems treated with discrete event simulation techniques. As problems complexity increase, new mechanisms are required to deal with them.

Cloud computing (CC) has recently emerged as a new paradigm for hosting and delivering services over the internet (Zhang, Cheng, and Boutaba 2010). Conceived as a new discipline of software engineering, CC presents a new set of problems that must be solved using new or improved techniques. That is the case of web applications (WA). Actually, the main research topics related to WA involve different areas, such as: requirements elicitation (Valderas and Pelechano 2011, Breaux and Rao 2013), architectural evaluation (Kossmann, Kraska, and Loesing 2010; Wallis, Henskens, and Hannaford 2010) and testing (Artzi et al. 2010; Nguyen, Kästner, and Nguyen 2014; Li, Andreasen, and Ghosh 2014). In this context, this paper proposes a DEVS adaptation called Routed DEVS (RDEVS) designed to support the simulation of WA components in order to study its behaviors. This new formalism defines a set of models that use routing information to identify the events source and destinations. According to this information, models allow to determine the acceptance of input events before executing their instructions. Also, models are capable to send output events to a specific group of receptors or the same event to different receptors according to its actual state. Although the proposal is centered on WA, the RDEVS formalism can be also applied to similar problems from other contexts (e.g. mobile applications and systems-of-systems).

The remainder of this paper is organized as follows. Section II describes the CC environment, highlighting the WA context and the problems detected when WA community requires discrete event simulation models. Section III presents the RDEVS formalism including the models formal specifications. Section IV proves the closure under coupling of the RDEVS formalism in order to guarantee the hierarchical composition of the models. Section V introduce the software framework developed to support the RDEVS formalism. Finally, Section VI is devoted to conclusions and future work.

2 RELATED WORK

CC is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction (Mell and Grance 2011). Usually, CC architectures are designed using the layered architecture pattern. Blas et al. (2016a) have proposed a five layers architecture (adapted from literature) in which end users interact with WA located at the application layer. This layer is at the top of the proposed architecture and allows consumers access to applications installed on the data-centers of a cloud provider. Then, WA architectures should be deployed on this layer.

The software architecture design can be considered the earliest design specification of any software product. Since this design is composed of a set of components and its connections, it can be used as a vehicle to predict and estimate the final behavior of a software product (Roldán, Gonnet, and Leone 2013; Li, Liang, and Avgeriou 2013; Bogado, Gonnet, and Leone 2014). Applying this approach at CC level, an

integrated approach to analyze the behavior of WA can be built by combining architectural designs and simulation techniques. If the set of available elements to specify a WA architecture is defined (e.g. using a metamodel), a simulation model can be build applying a systematic transformation from each architectural component into a simulation model. Then, designers could evaluate different WA architectures over the same infrastructure before moving to the next step of the development process. Also, they could analyze the impact of architectural changes over the final product quality and make recommendations based on this evaluation. Given that WA systems are discrete event systems, the DEVS formalism can be used to define such simulation models. Then, WA architectures can be studied using discrete event simulation models. A full description of this approach was presented in a previous work (Blas, Gonnet, and Leone 2016b).

A quick analysis of the DEVS simulation models proposed in (Blas, Gonnet, and Leone 2016b), reflects immediately the complexity of their structure. Bass et al. (2012) defines software architecture as the structure, or structures, of the system, which comprise software elements, the externally visible properties of those elements, and the relationships among them. According to this definition, software architectures illustrates a set of components linked by connections. These connections are based on the software elements relationships required to solve all possible requests. Then, connections are derived from the components interaction that have place when software needs to solve a specific request. So, the connections specification is defined at the architectural level but its definition is attached to the request types involved in the software. When the software architecture is used as unique source of the software specification to build a simulation model, the final simulation model reflects all connections without knowing which components are required to solve a specific request type. Then, the simulation models instantiated during the transformation process must manage the complexity of the requests flows. This is the approach used by Blas et. al (2016b). However, although this is a good approach, is not scalable. When the number of architectural components grow, the configuration of the simulation models involved in the transformation becomes a problem since the designer must know the flows of the requests. Clearly a new mechanism, that allows to manage this type of behavior inside the models without increasing the complexity of the structure, is required.

To this purpose, the following sections introduce an adaptation of DEVS formalism called Routed DEVS (RDEVS) in which the models are capable to manage the flow of events using their state information. The core of the RDEVS formalism is to abstract the events flow in order to simplify the simulation models. For example, in the WA context (if input events represent different end-user requests that navigate inside the architectural components) the RDEVS architectural model will manage the flow of each request type using the set of connections specified at architectural level. The RDEVS internal models will reflect the behavior of the architectural components that can decide to accept/deny requests using routing information. Then, by using the RDEVS formalism, simulation models will have the knowledge to determine the requests treatment. Since RDEVS is an adaptation of DEVS formalism, the new approach can use DEVS simulators to execute RDEVS models.

3 ROUTED DEVS FORMALISM

The Routed Discrete Event System Specification (RDEVS) formalism is an extension of the DEVS formalism based on the premise that a simulation model must process only the set of events that comes from authorized senders and have been sent specifically to it. To guarantee this premise, the formalism requires that each simulation model has an unique identifier that defines its existence as part of the routing process. A simulation model will accept input events if and only if: i) the sender identifier is of an authorized model; ii) the model identifier is included in the set of possible receptors of the event. Then, all events of RDEVS include the information required to identify its sender and all possible receptors.

The RDEVS formalism defines three types of models: essential, routing and network. Each model represents an abstraction level used to define different elements required as part of the routing process definition.

3.1 RDEVS Essential Model

Essential model specifies the behavioral description of a simulation model that represents a component involved in the routing process. Formally, essential models are defined in the RDEVS formalism, as an atomic model of the DEVS formalism, by the structure

$$M = < X, S, Y, \delta_{int}, \delta_{ext}, \lambda, \tau >$$

where

$X \equiv$ set of input events,
$S \equiv$ set of sequential states,
$Y \equiv$ set of output events,
$\delta_{int}: S \rightarrow S \equiv$ internal transition function,
$\delta_{ext}: Q \times X \rightarrow S \equiv$ external transition function, where
$Q = \{ (s,e) \mid s \in S, 0 \leq e \leq \tau(s) \} \equiv$ total state set,
$e \equiv$ time elapsed since last transition,
$\lambda: S \rightarrow Y \cup \emptyset \equiv$ output function,
$\tau: S \rightarrow R^{+}_{0,\infty} \equiv$ time advance function.

3.2 RDEVS Routing Model

The routing model defines the basic simulation model where the routing process takes place. In order to accept/deny input events and redirect output events, the model includes a set of elements that depict the routing information. It uses the behavioral specification of an essential model in order to define its own specification over the routing process. That is, the routing model encapsulates the description of an essential model with the routing specification required to determine the occurrence of the events. Multiple routing models can use the same essential model definition with different routing information in order to create different routing processes.

Formally, routing models are defined by the structure

$$R = < \omega, E, M >$$

where

$\omega = (u, W, \delta_r) \equiv$ routing information, where
$u \in \mathbb{N}_0 \equiv$ model identifier,
$W = \{ w_1, w_2, \ldots, w_p \mid w_1, w_2, \ldots, w_p \in \mathbb{N}_0 \} \equiv$ set of source model identifiers that represents the allowed routing models of R (from which can receive events),
$\delta_r: S_M \rightarrow T \equiv$ routing function used to direct output events, where S_M is the state of M and
$T = \{ t_1, t_2, \ldots, t_k \mid t_1, t_2, \ldots, t_k \in \mathbb{N}_0 \} \equiv$ set of destination model identifiers,
$E = < X_E, S_E, Y_E, \delta_{int,E}, \delta_{ext,E}, \lambda_E, \tau_E > \equiv$ essential model used by R,
$M = <X_M, S_M, Y_M, \delta_{int,M}, \delta_{ext,M}, \lambda_M, \tau_M> \equiv$ DEVS atomic model that specifies the routing process, where
$X_M = \{ (x, h, T) \mid x \in X_E, h \in \mathbb{N}_0, T = \{ t_1, t_2, \ldots, t_k \mid t_1, t_2, \ldots, t_k \in \mathbb{N}_0 \} \} \equiv$ set of identified input events, with
$x \equiv$ input event defined in E,
$h \equiv$ sender model identifier,
$T \equiv$ set of target model identifiers,
$S_M = S_E \equiv$ set of sequential states,
$Y_M = \{ (y, h, T) \mid y \in Y_E, h \in \mathbb{N}_0, T = \{ t_1, t_2, \ldots, t_k \mid t_1, t_2, \ldots, t_k \in \mathbb{N}_0 \} \} \equiv$ set of identified output events, with
$y \equiv$ output event generated by E,

$h \equiv$ sender model identifier (that is, the u value),
$T \equiv$ set of target model identifiers,
$\delta_{int,M}$: $S_M \rightarrow S_M = \delta_{int,E} \equiv$ internal transition function,
$\delta_{ext,M}$: $Q_M \times X_M \rightarrow S_M \equiv$ external transition function that only accepts events that have been sent to R from some allowed model (when u belongs to the set of target models T and the source identifier h is included in W) or from an external source (when u=0 and W=ø), defined as

$$\delta_{ext,M}(s,e,x') = \begin{cases} \delta_{ext,E}(s,e\_c+e,x) & \text{if } (u \in T \wedge h \in W) \vee (u = 0 \wedge W = \varnothing) \\ & \text{with } x'=(x,h,T) \text{ and setting } e\_c=0 \text{ after the execution} \\ s & \text{otherwise} \\ & \text{updating the elapsed time accumulated value as } e\_c=e\_c+e \end{cases}$$

with
$Q_M = \{ (s,e) \mid s \in S_M,\ 0 \le e \le \tau_M(s) \} \equiv$ total state set,
$e \equiv$ time elapsed since last transition,
λ_M: $S_M \rightarrow Y_M \cup \varnothing \equiv$ output function that generates identified events, defined as

$$\lambda_M(s) = (\lambda_E(s),\ u,\ \delta_r(s))$$

τ_M: $S_M \rightarrow R^+_{0,\infty} \equiv$ time advance function.

3.3 RDEVS Network Model

Network model describes a complex simulation model with an specific objective that requires send/receive identified events over a routing process. Its definition includes a set of routing models and, indirectly, the couplings between them in order to identify its influences. It also requires two translation functions in order to match the events from other models with the identified events used in the model. Then, a RDEVS network model can interact with (one or more) RDEVS network models or, simply, with DEVS models, according the purpose of the simulation.

Formally, network models are defined by the structure

$$N = < X,\ Y,\ D,\ \{ R_d \},\ \{ I_d \},\ \{ Z_{i,d} \},\ T_{in},\ T_{out},\ Select >$$

where
$X \equiv$ set of input events,
$Y \equiv$ set of output events,
$D \equiv$ set of model identifiers (routing model references), where $d \in \mathbb{N}_0,\ \forall d \in D$,
For each $d \in D$, R_d is a routing model, defined as

$$R_d = < \omega_d,\ E_d,\ M_d >$$

where $u_d = d$,
For each $d \in D \cup \{ N \}$, I_d is the set of influences over d where $d \notin I_d$,
For each $i \in I_d$, $Z_{i,d}$ is a translate function between events of i and events of d, where
$Z_{i,d} = T_{in}$ if $i = N$,
$Z_{i,d} = T_{out}$ if $d = N$,
$Z_{i,d}$: $Y_{M,i} \rightarrow X_{M,d}$ if $i \neq N \wedge d \neq N$,
T_{in}: $X \rightarrow \{ (x, h, T) \mid x \in X,\ h \in \mathbb{N}_0,\ T = \{ t_1, t_2, \ldots, t_k \mid t_1, t_2, \ldots, t_k \in \mathbb{N}_0 \} \} \equiv$ input translation function that takes an input event and returns an identified input event, where

$x \equiv$ input event defined in N,
$h = 0 \equiv$ sender model identifier where zero indicates that the event came from an external source,
$T \equiv$ set of target model identifiers that must process the input event,
T_{out}: $\{ (y, h, T) \mid y \in Y, h \in \mathbb{N}_0, T = \{ (t_1, t_2, ..., t_k) \mid t_1, t_2, ..., t_k \in \mathbb{N}_0 \} \} \rightarrow Y \equiv$ output translation function that takes an identified output event and returns an output event, where
$y \equiv$ output event allowed in N,
$h \equiv$ sender model identifier,
$T = \varnothing \equiv$ set of target model identifiers (empty set indicates events sent to an external destination),
Select: $2^D \rightarrow D \equiv$ function for tie-breaking between simultaneous internal transitions.

4 ROUTED DEVS CLOSURE UNDER COUPLING

According to Zeigler (2000), a system formalism is closed under coupling if the resultant of any network of systems specified in the formalism is itself a system in the formalism. The proof of this property is a very important key in a system formalism because it ensures the hierarchical composition of the models. That is, it allows to build models recursively with any arbitrary levels of hierarchy in a modular manner.

To prove that RDEVS formalism is closed under coupling and, therefore, models can be built in hierarchical manner, is necessary to obtain:

- The equivalent RDEVS routing model from the RDEVS network model (Proof #1).
- The equivalent RDEVS essential model from the RDEVS routing model (Proof #2).

If both models can be obtained, the hierarchical composition will be allowed because a network model (treated as its behaviorally equivalent to a routing model) will be able to become component of larger network models. The same will happen with the routing model and its essential model, since the routing model (treated as its behaviorally equivalent to the essential model) will be able to be use as part of larger routing models. Then, by transitivity, a dynamic system specified by a network model will be behaviorally equivalent to an essential model and will be able to be use as part of larger routing models.

Sections 4.1 and 4.2 detail the equivalences required to ensure RDEVS closure under coupling.

4.1 Proof #1: RDEVS Network Model to RDEVS Routing Model

The network model described by the structure

$$N = < X, Y, D, \{ R_d \}, \{ I_d \}, \{ Z_{i,d} \}, T_{in}, T_{out}, Select >$$

where each $d \in D$ references a routing model R_d defined as

$$R_d = < \omega_d, E_d, M_d >$$

defines an equivalent routing model structured as

$$R = < \omega, E, M >$$

in which:

- $\omega = (u, W, \delta_r) = (0, \varnothing, \delta_r) \mid \delta_r: S_M \rightarrow T \wedge T = \varnothing \equiv$ routing information that represents R as equivalent model of N. Zero is used to identify the new model. Since N uses the translation functions to determine events sources and destinations, W and T are specified as an empty set. Following this configuration, the R model acts as an external source to other models.

- $E = < X_E, S_E, Y_E, \delta_{int,E}, \delta_{ext,E}, \lambda_E, \tau_E > \equiv$ essential model used by R in which:
  - $X_E = X \equiv$ set of input events of E defined as the set of input events of N. Given that R and N are equivalent and R is composed by E, the inputs must be the same.
  - $S_E = \times_{i \in D} Q_i \mid Q_i = \{ (s_i, e_i) \mid s_i \in S_{M,i},\ 0 \le e_i \le \tau_{M,i}(s_i),\ \forall i \in D \} \equiv$ set of sequential states of E specified as the product of the Q_i sets defined for each model that compose N. Each Q_i is defined as an ordered pair that contains the state and the elapsed time of the R_i model.
  - $Y_E = Y \equiv$ set of output events of E defined as the set of output events of N. As in the input events, the outputs must be the same.
  - $\delta_{int,E}(s) = s' \equiv$ internal transition function of E that transforms different parts of the state, where the state of the E model is defined following the S_E definition as $s = (\ldots,(s_j, e_j),\ldots)$ and $s' = (\ldots,(s'_j, e'_j),\ldots)$. Given that the state of E is defined using the set of models included in N, an internal transition of E may involve simultaneous internal transitions of multiple components. Then, considering that the imminent components are collected according to the time value σ in a set structured as

    $$IMM(s) = \{ i \in D \mid \sigma_i = \tau_{E,i}(s) \}$$

    one model i^* must be selected in order to execute its internal transition. This selection can be done using the tie-breaking function of N. Then $i^* = Select(IMM(s))$ and, therefore, the imminent internal transition to be executed belongs to the R_{i*} model. However, the execution this transition will bring the execution of all external transitions of the components influenced by R_{i*}. So, the state transformation is specified as

    $$s'_j = \begin{cases} \delta_{int,M,j}(s_j) & \text{if } j = i^* \\ \delta_{ext,M,j}(s_j, e_j + \tau_E(s), x_j) & \text{if } i^* \in I_j \wedge x_j \neq \emptyset \text{ with } x_j = Z_{i^*,j}(\lambda_{M,i^*}(s_{i^*})) \\ s_j & \text{otherwise} \end{cases}$$

    while the elapsed time transformation is defined as

    $$e'_j = \begin{cases} 0 & \text{if } (j = i^*) \vee (i^* \in I_j \wedge x_j \neq \emptyset) \\ e_j + \tau_E(s) & \text{otherwise.} \end{cases}$$

  - $\delta_{ext,E}(s, e, x) = s' \equiv$ external transition function of E that modifies the set of state pairs that belongs to R_i models linked to N inputs, where the state of E is defined following the S_E specification as $s = (\ldots,(s_i, e_i),\ldots)$ and $s' = (\ldots,(s'_i, e'_i),\ldots)$. Considering that components are collected in a set $C = \{ i \in D \mid N \in I_i \wedge x_i \neq \emptyset \}$, then

    $$s_i^* = \delta_{ext,M,i}(s_i, e_i + e, x_i) \qquad \text{with } x_i = Z_{N,i}(x),\ \forall i \in C$$

    so the state transformation is defined as

    $$(s'_i, e'_i) = \begin{cases} (s_i^*, 0) & \text{if } (N \in I_i \wedge x_i \neq \emptyset) \\ (s_d, e_d + e) & \text{otherwise.} \end{cases}$$

  - $\lambda_E(s): S_E \rightarrow Y_E \cup \emptyset \equiv$ output function of E that generates an output event if and only if the model that is going to execute its internal transition (that is, i^* model) is linked the outputs of N, specified as

$$\lambda_E(s) = \begin{cases} Z_{i*,N}\left(\lambda_{M,i*}(s_{i*})\right) & if\ N \in I_{i*} \\ \emptyset & otherwise. \end{cases}$$

- τ_E: $S_E \rightarrow R^+_{0,\infty}$ ≡ time advance function of E that select the most imminent event time of all the components included in N (i.e. finding the smallest remaining time σ until internal transition of all the simulation models included in N). This function is defined as $\tau_E(s) = min\ \{\ \sigma_i = \sigma_{M,i}(s_i) - e_i \mid i \in D\ \}$.

- $M = < X_M, S_M, Y_M, \delta_{int,M}, \delta_{ext,M}, \lambda_M, \tau_M >$ ≡ DEVS atomic model that specifies the routing process of R. M definition is depicted at routing model level, specifying the routing process using components of E as M elements. Then, the equivalence transformation of N into R, it cannot change this specification. M must follow its definition using the components of E defined above.

4.2 Proof #2: RDEVS Routing Model to RDEVS Essential Model

The routing model described by the structure

$$R = < \omega_R, E_R, M_R >$$

with $M_R = < X_{M,R}, S_{M,R}, Y_{M,R}, \delta_{int,M,R}, \delta_{ext,M,R}, \lambda_{M,R}, \tau_{M,R} >$, defines an equivalent essential model structured as

$$M = <X, S, Y, \delta_{int}, \delta_{ext}, \lambda, \tau>$$

in which $X = X_{M,R}$, $S = S_{M,R}$, $Y = Y_{M,R}$, δ_{int} is derived from $\delta_{int,M,R}$ definition, δ_{ext} is derived from $\delta_{ext.M,R}$, $\lambda = \lambda_{M,R}$ and $\tau = \tau_{M,R}$.

According to this equivalence proof, each component of the M_R model that composes a RDEVS routing model can be directly mapped to a new model component that defines a RDEVS essential model. This equivalence is valid because both models (M and M_R) are based on the structure of a DEVS atomic model. Since the specification of M_R uses the content of ω_R and E_R, all the information required to execute the routing process will be also included in M.

5 ROUTED DEVS SOFTWARE FRAMEWORK

A software framework implementation of the RDEVS formalism was developed in order to provide a modeling and simulation environment to fully support the implementation of routing structures over discrete event systems. Given that RDEVS is based on the DEVS formalism, RDEVS models can be executed using the DEVS simulation algorithm and experimental frame. Then, RDEVS implementation can extend existent implementations of DEVS formalism.

In this context, the proposal was to develop the RDEVS software framework (RDEVS_SF) as an extension of DEVSJAVA (ACIMS 2005). The set of Java classes implemented involve several concepts related to RDEVS formalism, such as:

- *EssentialModel.java*, *NetworkModel.java* and *RoutingModel.java* to define the types of models detailed as part of RDEVS.
- *RoutingFunction.java* and *RoutingFunctionElement.java* to define the δ_r required as part of the routing information in RDEVS routing model.
- *IdentifiedEvent.java* to define the structure of all the events manipulated by the simulator.
- *TranslationFunction.java*, *InputTranslationFunction.java* and *OutputTranslationFunction.java* to define the processes required in RDEVS network model to adjust external events.

In order to use the DEVS simulation algorithm and the graphical tools available, some of the classes defined in RDEVS_SF were hierarchically related to DEVSJAVA classes. This dependency allows to use DEVS Suite (ACIMS 2009) as graphical environment for RDEVS models defined in RDEVS_SF. Figure 1 shows a screenshot of a basic example implemented in RDEVS_SF where: i) project explorer shows the set of classes implemented as part of the designed framework; ii) DEVS Suite is used to depict models structures.

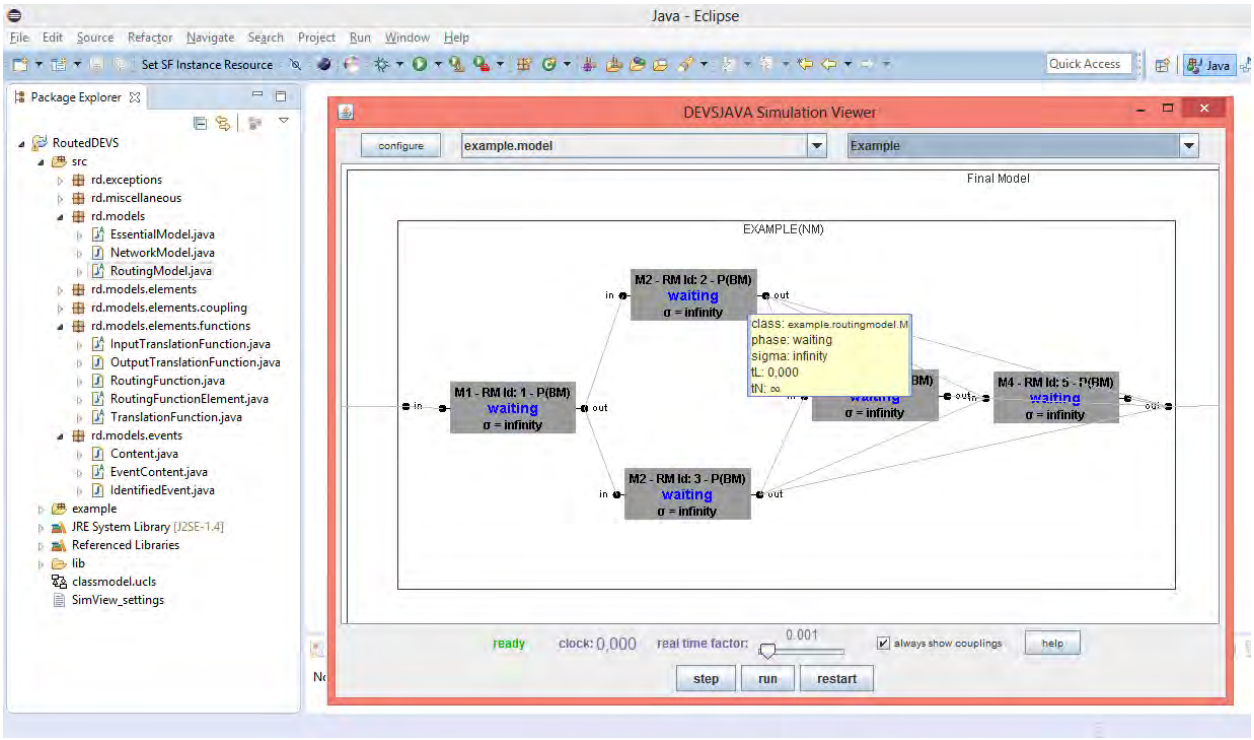

Figure 1. Simulation model example implemented in RDEVS_SF.

6 CONCLUSIONS AND FUTURE WORK

The DEVS formalism gives several benefits when is used to develop simulation models related to software engineering. However, when architectural designs must be mapped into simulation models, the complexity of managing the events flow becomes a problem. In this paper, an adaptation of DEVS was described in order to provide a scalable solution to this problem. The RDEVS formalization and its closure under coupling are the main properties of the formalism presented in this work. Also, a brief description of the software framework implemented to support the formalism proposed has been included.

Although RDEVS was developed to solve a specific modeling problem detected when web applications architectures are mapped to simulation models, it can be applied to other contexts. Similar problems are exhibit at mobile applications, hardware architectures, communication protocols and systems-of-systems. When the events flow is independent of the components behavior, the designer can use RDEVS to support the modeling task with a proper separation of concerns (that is, the events flow manage and the components behavior). While essential models represent the behavior of the components, the routing and network models set up the context in which the routing process is allowed. Since an essential model can be used as part of different routing models, an unique behavior specification can be replicated in multiple instances with different destinations. Although this problem can be solved using the DEVS formalism, the final models will be much complex since each model will have to manage the events flow individually.

Since RDEVS essential models are equivalent to DEVS atomic models, considering the closure under coupling of RDEVS formalism, is possible to combine RDEVS models with DEVS models. Then, more powerful simulation models can be built by combining both formalisms. Additionally, existent DEVS models can be used as part of RDEVS models. The same approach can be applied to other DEVS extensions that can be reduced to DEVS atomic models.

Given the independence of components identified as part of the M&S framework proposed in DEVS, the RDEVS models can be executed using DEVS simulation algorithm. However, the design of an adapted algorithm that takes advantage of the routing properties is proposed as future work.

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