BEHAVIORAL MODEL SPECIFICATION TOWARDS SIMULATION VALIDATION USING RELATIONAL DATABASES

by

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ABSTRACT

Many contemporary systems that are inherently large-scale and complex can be specified using system-theoretic and object-oriented modeling concepts and principles. To examine these systems via simulation and in particular in terms of model validation, it is important to use model repositories. The structure and behavior of dynamical systems can be represented as atomic models having inputs, outputs, states, and functions. Scalable System Entity Structure Modeler with Complexity Measures (SESM/CM) offers a basis for developing modular atomic and composite simulation models as well as non-simulatable models. It allows simulation models to be stored, retrieved, and managed in relational databases. The environment, however, does not provide capabilities for characterizing and storing behavioral aspects of models or their transformation for simulation execution.

This thesis describes a design and implementation for capturing some behavioral aspects of atomic models and the transformation of the models captured in SESM/CM into their compatible simulatable formats in DEVSJAVA a simulation environment capable of executing discrete-event models. The combined modeling and simulation capability offers a process where users can develop models in the extended SESM/CM modeling environment and validate their behavior using the DEVSJAVA simulation environment. The proposed extensions to the SESM/CM are demonstrated using a simulated anti-virus computer network model.

To

My Wife, My Grandmother and My Parents

ACKNOWLEDGMENTS

I wish to express sincere appreciation to my advisor Professor Hessam S. Sarjouhian, for his time to time advice, enthusiastic support and encouragement that made the completion of this thesis possible. I would also like to thank Professors James Collofello and Hasan Davulcu for serving on my thesis comittee.

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CHAPTER 1

INTRODUCTION

Architecture of a system is mainly influenced by its requirements and in particular its quality attributes [Bass98]. The quality attributes of a system and software are categorized as runtime (e.g., performance and communication patterns) and non-runtime (e.g., maintainability, availability and reusability). Generally, it is easier to achieve desired quality attributes in smaller systems by means of traditional software or system engineering processes such as design, coding and testing. But as these systems grow, which in turn leads to the growth of their structural and behavioral complexity, this traditional design approach becomes increasingly inadequate and impractical. For these kinds of large-scale, complex systems, modeling and simulation becomes an important practice for analysis, design, and development.

The structures of such systems can be defined using fundamental system theoretic and Object-Oriented concepts and principles such as composition where atomic and composite components are combined using ports and couplings. Modeling approaches founded on the principles of system theory and object orientation can help to design these systems hierarchically.

In addition to aid the modeling of these large-scale systems, it is important to employ repositories like Relational Database Management Systems (RDBMS), since they provide systematic, scalable and efficient medium for storing and accessing models [Fu02]. One of the most important benefits of using a database repository (in addition to creating, storing, modifying and deleting model components) is its support for reusability. Having a scalable, reusable model repository further supports simulation and consequently model validation, which is the key in the system development life-cycle.

1. Simulation and Validation of Component Based Models

Simulation is an imitation of the operation of a real-world process or system over time. It involves the generation of artificial history of the system and the observation of that history to draw inferences concerning the operating characteristics of the real system [Bank01]. It is used to study system in a design stage, before the system is actually built. A simulation model is developed to study the behavior of the system. Simulation modeling can be used both as an analysis tool for predicting the effect of the changes to the existing systems and as a design tool to predict the performance of new system under varying set of circumstances.

In order to validate a system, the modeler needs to simulate and compare the model and its behavior with the real or imaginary system for different sets of experimental conditions. These experimental conditions include input scenarios, model initialization and output scenarios. Input and output scenarios are mainly characterized by the input variables/output variables, their data types and their values while model initialization includes the specification of state of the model, which is characterized by the initial values of the state variables of the model. System state is an important aspect in characterizing the behavior of the system, as behavior of the model is defined as the collection of the state variables that contain all the information necessary to describe the system at any time.

Large-scale hierarchical models can be built by reusing persistent models. This in turn requires the storage of the models, in both structural and behavioral form, in a permanent repository such as database. This specification and storage of the structural (i.e., model name, its parts and sub-components) and behavioral (i.e. input/ output variables and states) aspects of the model allows the modeler to achieve the simulation, analysis and validation of the model.

1.1. Rationale for Dynamic Characterization of Atomic Model Components. System theory distinguishes between the system structure and behavior, where structure is the inner constitution of the system while the behavior is its outer manifestation. It offers capabilities to model structural and behavioral dynamical systems using the concepts of atomic and composite components [Wym93, Zei00]. Atomic models are the basic models which cannot be decomposed into other models while the composite models are models that can be composed of other atomic and/or composite models. The structure of atomic model is represented in terms of name, input ports and output ports while that of coupled model is defined in terms of name, input ports, output ports and couplings. The external behavior of an atomic model includes the relationship between its input and its output, while the internal behavior includes the state, state transition, functions and output mechanisms. Similarly, the external behavior of a composite model is visible via its input and output ports and couplings. The internal behavior of a composite model is the resultant of the behaviors of its sub-components which are connected via couplings. Hence, composite models primarily focus on the constitution of sub-components and their communication with each other as well as with the other sub-models of their parent model, while the actual behavior of the system is determined by the resultant of the behaviors of the atomic models in the system.

As mentioned above, specification of the behavioral aspects of the system is required to achieve the model simulation and validation. These behavioral aspects of the system can be expressed in terms of the dynamic characteristics of an atomic model such as specification of inputs arrived at input ports, outputs sent to output ports and states of the system. This essentially involves specification and storage of input variables, output variables and state variables, variable types and variable values.

Once a model is built in terms of both structure and behavior, it is important to verify whether the model behavior is correct or not. This involves the observation of the behavior of the model (e.g., state changes) in response to different input regimes and initial conditions. For this, model needs to be simulated with an appropriate simulation engine. This requires transformation of the model specification in to simulation compatible format. Once the modeler has that format, the model can be simulated under different scenarios and consequently validated.

2. Approach and Goals

The primary goal of this thesis is to specify the behavioral aspects of atomic model to support creation of simulation models and their validation. This involves the design and development of dynamic characteristics of atomic model. This includes representation of input variables, output variables and state variables in the relational databases. It also involves the design and development of the user interface to support the capturing of these behavioral aspects of atomic model and development of a mechanism to store them in a database. Furthermore, it is important to support representation and storage of non-simulatable models (NSM), which are similar to complex data structures like list, bag or set.

These non-simulatable models can be used as components of simulatable atomic models. Once the model is specified, it needs to be transformed into a simulation compatible format to achieve simulation in the simulation environment.

In this research, we are using and extending the Scalable entity Structure Modeler (SESM/CM) [Sar02, Fu02, Smo03], which is a modeling environment suitable for developing modular hierarchical systems. Current version of SESM/CM provides a modeling engine with a graphical user interface for creating, modifying, storing and reusing the structural aspects of the atomic and coupled models. These structural features involve name (identity) of the model, input/output ports (interface), couplings and modular hierarchical structures (specialization and aggregation relationships). It provides a relational database for storing and managing structure of atomic and coupled models and is suitable for development of large-scale models.

SESM/CM offers a basis for modeling behavioral aspect of atomic models. It does not, however, provide capabilities for characterizing behavior of atomic models and non-simulatable models, which involves the specification of how it can process inputs, transition through different states and generate outputs. Furthermore, since SESM/CM is a modeling environment, it does not provide facilities for simulation. Therefore, to support simulation, the atomic and composite models in SESM/CM must be transformed to their simulation compatible formats.

This research, therefore, focuses on extending the SESM/CM environment such that it can support some parts of behavior modeling of atomic models and inclusion of non-simulatable models. To enable model to simulation transformation, a modeling-to-simulation approach is designed and developed to support simulation of models partially described in SESM/CM in DEVSJAVA environment, where DEVJAVA is a simulation environment capable of executing hierarchical models specified in Discrete-Event System Specification. This combined modeling and simulation capabilities offer a process where users can develop models, simulate their behavior and carry out model validation, while relying on model storage and reuse in a systematic fashion.

The secondary goal of this research is to improve the performance and usability of the SESM/CM by providing an alternate design of data transfer mechanism between the SESM/CM client and the database.

The high-level objectives of this thesis are mentioned below. These objectives collectively required analysis, design, implementation, testing and demonstration of the SESM/CM modeling environment as follows:

- Support capturing, storing, and retrieving dynamic characteristics of an atomic model components,
- Develop mappings for converting atomic and coupled models in RDBMS to those that can be simulated in DEVSJAVA, and
- Use an efficient communication model in order to ensure acceptable performance and availability for large-scale models.

3. Contributions

The primary contributions of this thesis are in line with the objectives of the thesis. They are

- development of designs for characterizing the behavioral aspects of atomic models. It involves devising schemes for representation of input variables, output variables and state variables in a modeling environment, in simulation compatible models and in database. This approach also supports storage of Non-Simulatable models and their relationships with Simulatable models. To support these features, the database schemas are extended in order to enable combined use of simulatable and non-simulatable models within the SESM modeling framework,

- development of detailed design for transforming simulatable models captured in SESM to appropriate forms (such as XML and JAVA) such that they can be executed in the simulation environment like DEVSJAVA. This involves the design and development of two new modules each for the transformation of graphical models to XML or Java models,

- implementation of extended features of SESM to support efficient modeling behavior of dynamic systems. It involves addition of new capabilities to SESMs different modules like server, client, database and network environment without changing the overall architecture of modeling environment. This also includes testing and validation of the extended functionality of the prototype SESM environment and its use with the DEVSJAVA environment using example from the domain of computer networks and viruses, And

- extension of an architecture for SESM to support the local copy of data for each client using observer design pattern to achieve better performance and availability and to support distributed and collaborative modeling using SESM.

4. Thesis Overview

This thesis is organized as follows. In this chapter **(chapter 1)** , we have discussed the rationale and importance of the specification and storage dynamic characterization (behavioral specification) of models in addition to structural specification. We have also discussed the need for simulation and validation of these models.

Chapter 2 gives an overview of background and research related to the thesis topic. It involves the detailed description of SESM/CM modeling engine and its constituents architecture and design which is the foundation of this research. It also describes other approaches for modeling and simulation of component-based systems.

Chapter 3 presents basic concepts of behavioral modeling and the extension of the SESM/CM architecture to support some aspects of the dynamic characterization of atomic models. It describes the importance of Non-Simulatable Models (NSM) and their utility. It also summarizes the mechanism for the generation of simulatable models by transforming them into XML and Java models.

Chapter 4 discloses the detailed software analysis and design extended to support behavioral modeling in SESM modeling engine. It involves extensions to server, client and database modules. This section renders UML (Unified Modeling Language) as well as ER (Entity-Relationship) diagrams. It provides the detailed design for the new transformation modules. Finally, it suggests an alternate design for an efficient communication between client and server.

Chapter 5 exhibits the user interface design which involves extensions of the three GUI areas namely, model tree structure, model components and command menu. It involves the redesign of the model menu. It also explains the design for the transformation of models stored in the database into the simulation compatible models.

Chapter 6 gives implementation details of the new and extended features discussed and designed in the previous chapters. It discusses the technology used for software development like Java, JDBC and XML. It also demonstrates an example of Anti-Virus Model, which includes building of new models exhibiting the new features introduced in this thesis. It also explains the experiments conducted on this model and their simulation results.

Chapter 7 discusses future research and conclusions.

CHAPTER 2

BACKGROUND

1. Scalable System Entity Structure Modeler (SESM)

This research is primarily concerned with the SESM [Smo03, Fu02] modeling environment. It deals with the usage and extension of this environment to incorporate and demonstrate the various aspects of this thesis, mentioned in the thesis objectives section.

1.1. System Entity Structure (SES) Formalism. System Entity Structure (SES) formalism [Zei84] is a structural knowledge representation scheme that systematically organizes a family of possible structures of the system. The fundamental object of the SES formalism is an entity, also known as model. It represents a physical object in the real world and has identification, attached variables and a range set. This range set is an enumeration of values that the variable can assume. This entity can be of two types, atomic entity and composite entity. Atomic entities cannot be broken down into sub entities, while Composite entities are broken down into other entities, either atomic or composite. SES provides three types of relationships among the entities, namely aspect (alternative representation of the system or model), decomposition (Part-Whole relationship) and specialization (Parent-Child relationship). These relationships are useful to build the models hierarchy.

This model hierarchy enforces certain axioms [Zei00], which include

- Alternating Entity Aspect/Specialization: Each node has a mode which is either entity or specialization
- Uniformity: Any two nodes with the same names have identical attached variable types and isomorphic sub-trees.
- Strict Hierarchy: No label appears more than once down any path of the tree.
- Valid Brothers: No two brothers have same label
- Attached Variables: No two variable types attached to the same item have same name.

1.2. SESM Architecture. SESM is based on a new approach to modeling large-scale systems and some basic concepts of the SES formalism, explained in the previous section. SESM follows Hybrid Client-Server [Fu02] type of architecture, which combines the features of different flavors of client-Server architectures. It is composed of four main constituents, namely Client (User Interface), Network Environment (communication medium), Server (Modeling engine) and Database Management System (DBMS) as shown in Figure 1.

- DBMS: It stores the model data in hierarchical manner
- Server: It initializes and manipulates the model database as per the users request
- Client: It allows users to display and modify the models in the database
- Network Environment: It acts as a channel between client, server and database

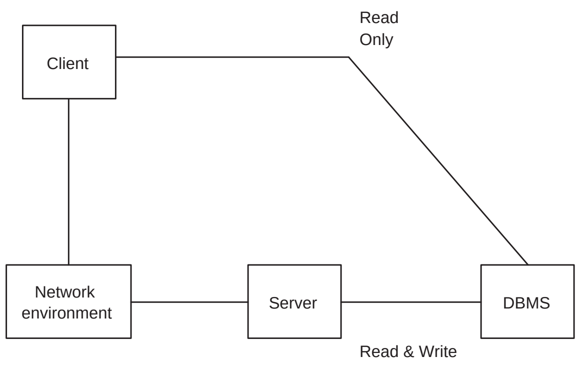


Figure 1. SESM Client-Server Architecture

Client and Server independently initialize and maintain their connectivity with the database. Client has “Read-only” access which means it can independently read the model data from the database while for writing to the database, it has to communicate via the server, which writes the data to the database. The server has both “Read and write” access which means it can read and write data from and to the database. In this way, SESM allows multiple readers (i.e., multiple clients and server) of the data but only single writer (i.e., server) and hence it provides the consistency of the model data in the database. In this architecture, client and server are loosely coupled and hence result in better design and implementation. It produces less network traffic between client and server and gives better scalability by shifting the large number of queries from server to the database.

1.3. SESM User Interface. SESM provides a user-friendly graphical interface, which is provided with menus for creation, modification and manipulation of hierarchical modular models. These models are categorized into atomic model (individual model) and coupled model (composition of other atomic or coupled models), which can be used for models described in Discrete Event System Specification (DEVS). Every model in SESM

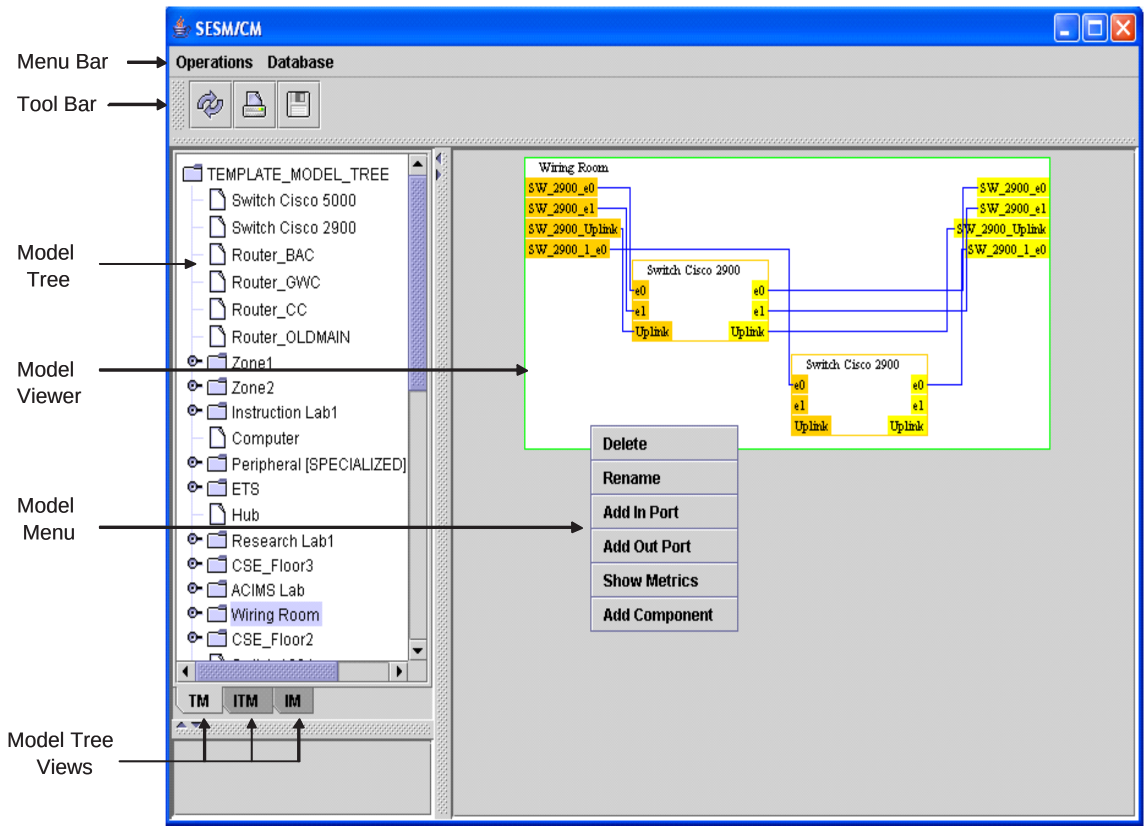


Figure 2. SESM Modeling Environment Graphical User Interface

is considered as an object with input and output ports which form a well-defined interface for the interactions with other models. The sub-components are connected to each other with internal couplings while they are connected to the parent coupled model with external input couplings and external output couplings. Hence with the use of port, couplings and components, SESM allows capturing the "structural" representation of hierarchical models as defined by DEVS.

As shown in Figure 2, user can create atomic and coupled component-based models using ports and couplings [Wym93]. SESM graphical interface provides a menu bar with menus, "Operations" and "Database". The Operations menu offers options to "Create

Template Model", "Create Instance Template Model" and "Create Instance Model". The Database menu offers an option to "Initialize Database" which essentially erases the entire data (i.e., all the models) in the database. The model Tree displays the tree view of hierarchical models stored in the database. There are three views of these models namely, Template Model (TM), Instance Template Model (ITM) and Instance Model (IM). Model Viewer area displays a specific model that is currently selected in the model tree. It shows the model with model name, ports and couplings (in case of coupled models). Model menu gives functionalities to manipulate the model displayed in the model viewer. Toolbar provides the features for printing, saving as well as refreshing the models on the graphical user interface.

2. Databases as Model Repositories

Large scale systems are increasingly developed by using model-based analysis and design techniques. As these systems grow in size and complexity, a methodical approach is required to have a repository, which can provide the capabilities like usability, scalability, modifiability and storage of models. Relational database is an appropriate option for these repositories as it provides functionalities like creation, modification, storage and most importantly reuse of the stored models. It offers modular hierarchical representation of the models in the database by providing the relationships like composition (Part-Of relationship) and specialization (IS-A relationship). It allows user to enforce the constraints on the models stored in the relations set. It also provides scalability and flexibility by providing the data independence where data is decoupled from the application development. And finally, it uses Structured Query Language (SQL) as an interaction medium, a standard language for the relational databases; which is important for application portability.

The rationale [Fu02] behind the use of relational database is that the relational model supports the formal specification of the logical relationships such as those in three views and SES. The simplicity of the relational model also allows the DBMS vendors to optimize the management systems for performance and scalability. Compared to relational databases, the third generation databases like OODB and ORDB are still constantly evolving. Furthermore, both OODBMS and ORDBMS lack the full support for the current standards. The lack of standardization means less support for developing SESM, and it makes the SESM vendor specific. As a result, after comparing the three types of the database technologies, the relational database was selected to be an appropriate medium of repository for SESM. Implementation of SESM uses MS-Access relational database.

3. Related Research and Environments

3.1. Modeling. An alternative approach for systematically representing models is via the Unified Modeling Language (UML) [Boo94, Boo99].

3.1.1. *UML.* UML is a graphical language used for visualizing, specifying, constructing and documenting the artifacts of a software intensive system [Boo99]. It provides the modeler a standard way to specify system blueprints, covering conceptual things like business processes and system function as well as concrete things like classes which may be written in specific programming language and database schemas. It is appropriate for modeling systems ranging from enterprise information systems to distributed web-applications to real-time embedded systems.

UML and SESM are similar in how they represent a systems structure (i.e., component and relationships) as both of them support "is-a" and "part-of" relationships. But they are different as UML is intended for the object-oriented software engineering [Fow99] while the SESM is targeted for representing simulation models and their structures. UML supports access rights of an attribute (e.g., public or private) while SESM supports communication between the models using ports and couplings. Though UML supports the behavior of the model in terms of methods specification, tools such as Rational Rose do not offer capabilities to fully specify behavior of the model - i.e., with UML, a modeler can declare the methods to define the behavior and specify a state-chart to show state transitions, but the details of the methods has to be done using IDEs. In UML, the behavior of the composed model is a resultant of its own behavior and the behavior of all of its sub-components, whereas in SESM models the behavior of the composed model is just the resultant of the behavior of its sub-components as the composed model doesn't have its own behavior. Another major difference is in UML, the models are stored in a flat file, whereas in SESM, models are stored in a relational database, which offers scalability and better reusability.

UML model such as class diagram is typically not refined enough to provide all the relevant aspects of the specification. There is a need to describe the additional constraints of the object of the model. Object Constraint Language (OCL) is used as a formal language for the specification of constraint for the UML models. UML modeler can use OCL for application specific constraints to specify invariants on classes and types in the class model, type variants for stereotypes, pre-conditions, post-conditions and guard conditions on operations and methods. OCL is a pure expression language where expressions are evaluated to check particular constraints. But it is not a programming language; hence one cannot write program logic or flow control using OCL and hence cannot change anything in the model. In short, OCL can be used to express constraint that cannot be captured in UML but it cannot be used for specifying or altering the state of the model.

A real-time extension of UML is called UML-RT, which supports structural modeling of a system similar to SESM. UML-RT is also based on system concepts and methods. The semantics of the ports and connections in UML-RT are different than the semantics of the couplings and ports in SESM, when applied to discrete-event system specification. One of the essential differences between UML-RT and a combination of SESM and DEVSJAVA is that the latter has well-defined simulation engine. In contrast, simulation using UML-RT is limited since it provides execution which requires users to specify simulation protocols.

3.2. Simulation. Simulation involves designing the model of a system and carrying out experiments on it as it progresses through time. Simulation is an important activity since it allows the modeler to experiment that might be hard or cannot be analytically predicted. It can give a valuable insight into the system and into the relative importance of the different choices about the design of the system. It allows compression of time and prediction of the behavior of the system. There are different types of simulators available. This thesis briefly describes DEVSJAVA and Extend; both of which support modeling discrete systems.

3.2.1. *DEVSJAVA.* This research uses DEVSJAVA [acims04, Sar03, Sing04], which is a modeling and simulation environment, supporting a hierarchical, modular DEVS simulation models. It supports the basic and advanced capabilities for observing behavior of models in logical and (near) real-time. DEVS models are based on DEVS formalism, which can be mathematically expressed [Zei00, Zei03] as,

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

Where

X is the set of inputs

$X : \{(p, v) | p \in \mathit{InPorts}, v \in X\}$

S is a set of states

Y is the set of outputs

$Y : \{(p, v) | p \in \mathit{OutPorts}, v \in Y\}$

$\delta_{int} : S - > S$ is the internal transition function

$\delta_{ext} : Q \times X^b - > S$ is the external transition function, where

$Q = \{(s, e) | s \in S, 0 \leq e \leq ta(s)\}$ is the total state set

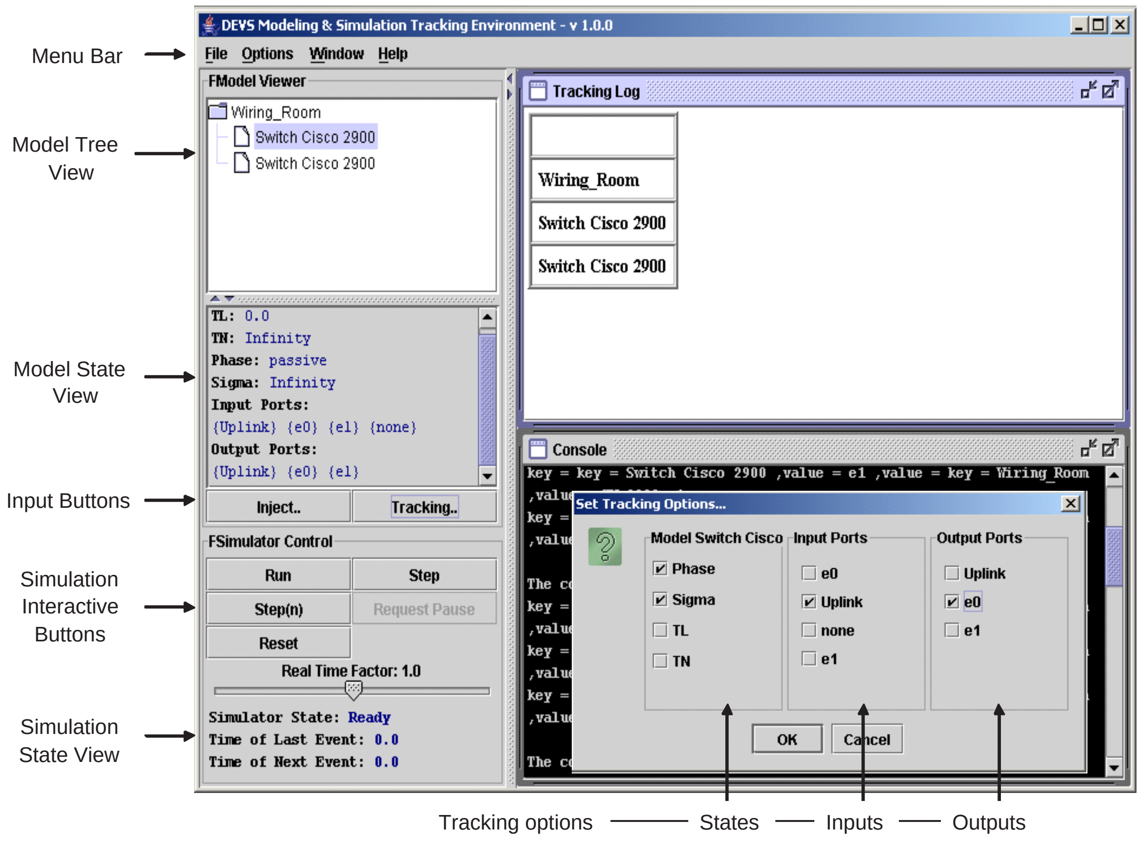
e is the time elapsed since last transition

$\delta_{con} : Q \times X^b - > S$ is the confluent transition function

$\lambda : S - > Y^b$ is the output function

$ta : S - > R^+_{0,\infty}$ is the time advance function

This modeling approach supports discrete-event (and thus discrete-time) dynamics as well as continuous dynamics [Kof03]. DEVSJAVA is an implementation of DEVS formalism in Java, which allows the modeler to specify and execute (i.e., simulate) the models. As mentioned earlier, these models are of two types, atomic models and coupled models. Atomic models are the basic models from which the larger models are built. They



```
TL: 0.0
TN: Infinity
Phase: passive
Sigma: Infinity
Input Ports:
{Uplink} {e0} {e1} {none}
Output Ports:
{Uplink} {e0} {e1}
```

```
Simulator State: Ready
Time of Last Event: 0.0
Time of Next Event: 0.0
```

```
key = key = Switch Cisco 2900 ,value = e1 ,value = key = Wiring_Room
```

Model Switch Cisco: [✓ Phase] [✓ Sigma] TL TN

Input Ports: e0 [✓ Uplink] none e1

Output Ports: Uplink [✓ e0] e1

Figure 3. DEVSJAVA Simulation Environment Graphical User Interface

are defined to have time base, inputs, states, outputs and functions for determining next states and outputs given current states and inputs. The coupled models are composed of the other atomic and/or coupled models connected together by couplings in hierarchical manner. Both of these models are supported with input and output ports to facilitate the communication with the other models and the outside world.

Figure 3 shows the DEVSJAVA implementation [Sar03, Sing04] of the model - Wiring Room, showed earlier in SESM environment in Figure 2. The graphic user interface of DESVJava environment displays the model in a Tree view. It also displays the current state of the model as well as that of the system during simulation. It is provided with different buttons

- Inject: It is used to inject the inputs in the model during the setup of an experiment
- Tracking: It gives an interactive dialog shown in the figure, which can be used to select the input, output or state variables that need to be tracked during the simulation.
- Step: It runs the simulation of the model step-by-step and allows user to see the inputs and outputs generated as well as the state changes for the models at a step level.
- Run: It runs the whole simulation and produces the entire results of the simulation at the end of the simulation
- Reset: It restarts the simulation process and also resets the system clock to zero.

3.2.2. *Extend.* Extend [Ext00] is offered by Imagine That, Inc. Extend combines the block diagram approach to model building and an authoring environment for creating new blocks. It is based on process oriented world view and capable of continuous, discrete event and combined modeling. Most important parts of Extend model are the blocks, libraries where the blocks are stored, the dialogs associated with each block and the connectors. Elemental blocks include generator, queue, activity, resource pool and exit. Activity entities, called items, are created at generator blocks and move from block to block with the help of connectors. Modelers can build models by placing and connecting blocks and filling in the parameters. Collections of these blocks are grouped together to form a hierarchy which is essentially a library.

Extend stores the model data in the form of text files which can be opened, closed, read and edited using Extend as well as any other word processor. It comes with a compiled

C-like simulation programming language called ModL. It contains simulation support as well as support for custom user interface and message communication. It is also provided with a statistics library which supports the collection, analysis and plotting of simulation data. This modeling environment is similar to DEVSJAVA and others such as MATLAB that do not support some important capabilities such as multi-view and scalable persistence.

4. Motivation

All the approaches of modeling and simulation described above have distinguishable features which support structural and/or behavioral aspects for modeling, simulation or storage. DEVSJAVA offers modeling and simulation interface but the model creation in DEVSJAVA is limited to writing code in Java language which requires low level programming expertise in Java. Extend supports easy graphical model creation as well as structural and behavioral model definition, but it stores the models in flat files and hence cannot provide expected scalability. UML is a widely accepted technique for modeling but it doesn't support multiple views as well as the simulation of the models. SESM is a modeling environment which stores the models in the relational database and hence achieves hierarchical and scalable model construction. But it needs to be extended to support the storage of the behavioral aspects of the models.

Therefore, there is a need of an environment that

- facilitates easy creation of models from both structural and behavioral perspective without any dependency on programming
- supports storage of models in the repository

- aids simulation of the models

CHAPTER 3

SESM SYSTEM ARCHITECTURE WITH SUPPORT FOR BEHAVIORAL MODELING

Modeling and simulation of systems has become de-facto standard in the analysis and development of large-scale systems. It is important to employ modeling and simulation methods that can support model specification and simulation execution. Model Specification in turn involves the structural and behavioral specification of the model, while the simulation execution involves the transformation of these specified models into their simulatable format. In particular, separating the real (or imagined) system, specification models, and simulatable models are important for model validation and simulation verification.

Many kinds of models maybe defined using composition and specialization concepts. These models, in general, are referred to as base and lumped models. The former refers to a model that is most closely represents a system (i.e., the real system and base model are homomorphic to one another). The later refers to a model that is an abstraction of the base model. A lumped model, therefore, can represent the real system via a base model or directly the system itself. The base and lumped models are homomorphic to one another.

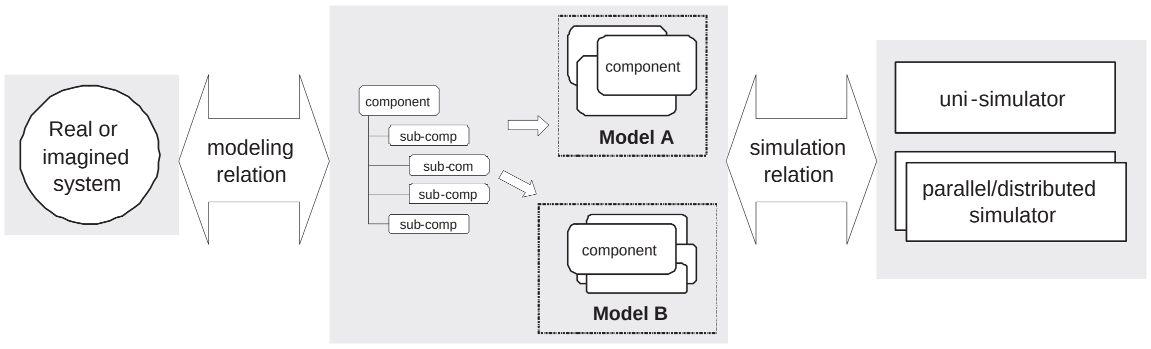


Figure 4. Modeling and Simulation Relations

1. Modeling Environment

Specification models are developed during the modeling phase. A modeling engine supports specification of models using a modeling language. The ability to support specification of large-scale models plays a key role in defining the modeling and simulation relations.

A modeling environment, therefore, needs to support modelers to specify their models in an iterative and incremental fashion. In other words, impediments in validation and verification can be better overcome using a modeling environment that can support not only representation of a family of models, but also with support for handling scalability of models and therefore their relationships. The scalability is important in managing the relationships among models developed within the modeling phase. Furthermore, scalability also plays a key role in the modeling and simulation relations as shown in Figure 4.

An existing SESM modeling environment is extended to enable the above types of modeling to offer new capabilities toward model behavioral specification, simulation and validation. The key parts of this framework are the modeling engine, repository, and a translator. The Modeling Engine supports specification of template, instance template,

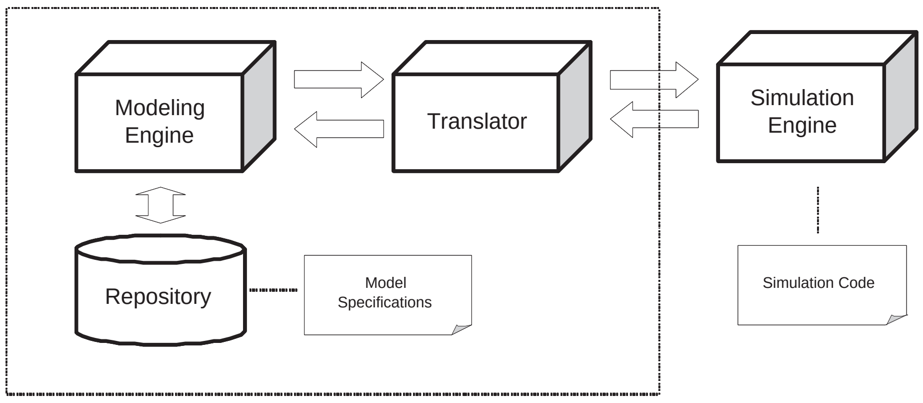


Figure 5. Modeling Framework

and instance models. The Repository contains the models in a relational database. The Translator maps instance models into simulation code.

This modeling environment allows modeling a family of models that may be closely related, yet are serve different purposes. For complex, using alternative decompositions, two models can represent two different aspects of a model. Models can be mutually exclusive if they do not share model components. Similarly, using specialization, a system may have two or more aspects or resolutions. Handling of multi-aspect and multi-resolution are important in modeling of heterogeneous systems.

1.1. Modeling Approach. The proposed model framework shown in Figure 5 supports modeling of a system using three complementary types of models called Template Model, Instance Template Model, and Instance Model. The basic approach is component-based modeling where a system is viewed as a collection of components which are composed using input and output ports and couplings.

A template model specifies atomic and composite models as components with in-

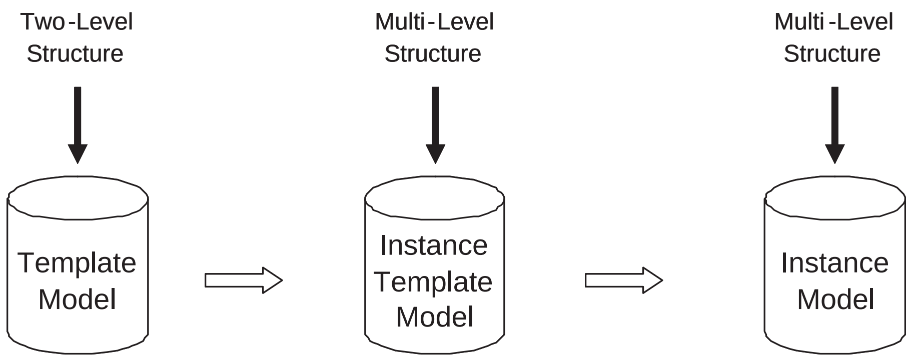


Figure 6. SESM/CM Model Types

put and output ports and values. An atomic template model specification contains state variables and a name. The components of each of these three model types are restricted to have the same type - a template model can have other template models and not models of instance template or instance models. A composite template model specification has couplings and a name. Composite template models are restricted to have atomic and/or composite template models as children. Furthermore, the name assigned to atomic and composite models must be unique such that any composite model can be uniquely identified within its hierarchical decomposition. A composite template model is defined to have a hierarchy of length two.

An instance template model is the same as a template model. This type of model is defined to have a finite hierarchy of length greater than two. Furthermore, this model does not specify multiplicity of a model component within any composite model - a model can have one to a finite number of copies of the same instance template model. An instance model is an instantiation of an instance template model where the multiplicity of model instances is specified.

A Template Model can be specialized into one or more specialized components. The ability to specialize complements composition. Composition and specialization together support different types of models depending on the intent of the modeler. A conceptual view of relationships among these models is shown in Figure 6.These types of models need to be constructed in three stages - template model, instance template model, and instance model developments - as described above. A modeler first creates Template Models, Instance Template Models, and then Instance Model in a sequential manner. In the stage of instance model generation, a modeler decides which specialized model component is to be used. Of course, it is possible to iterate among these stages. As noted above, one essential advantage of this modeling approach is the ability to create alternative models depending on desired alternative resolutions and aspects.

As shown in Figure 7, the consistency among these models is maintained automatically in SESM/CM. Due to unique composition of model components, changes to a model are enforced across the entire model. For example, if a modeler adds an input port to component H which is a grandchild of component M, the grandchild of component C i.e. other H component, must have the same structure and behavior.

2. Approach for Behavioral Specification

As mentioned earlier, model specification defines a system in terms of its structure and behavior. Structure of the system is defined in terms of name, ports and couplings while the behavior of the system is defined in terms of the behavior of atomic models.

2.1. Representation of an Atomic Model. System theory distinguishes the models into two categories namely atomic models and coupled models. Atomic models

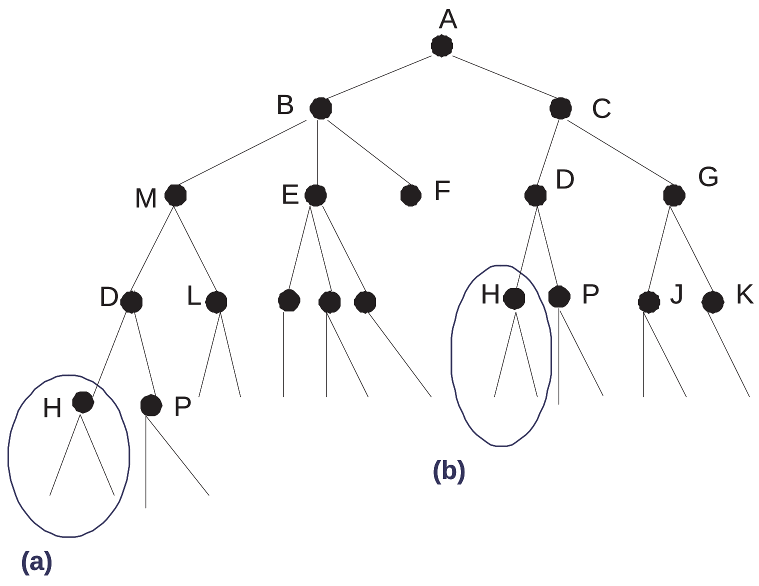


Figure 7. Metrics Consistency and Uniformity

are the basic models which cannot be further divided into sub-models while coupled models are composed of sub-models. Atomic model defines its own behavior while the behavior of the Coupled model is defined as the combined behavior of its sub-component atomic models. Input-Output specification of the Coupled model is same as that of Atomic model. Hence, to specify the behavior of the system, it is necessary to specify the behaviors of all the atomic models inside the system. The behavior of an atomic model is defined in terms of dynamic characteristics of the model such as input variables, output variables, state variables and state transition functions as shown in figure 8.

2.1.1. *Input/Output Variables.* Behavior of the model is defined as the change in the state of the model. Discrete Event System Specification defines the change in the state of the model as a consequence of some event occurred to the system or occurred within the system. These events are mainly categorized into inputs arrived at the system, outputs sent

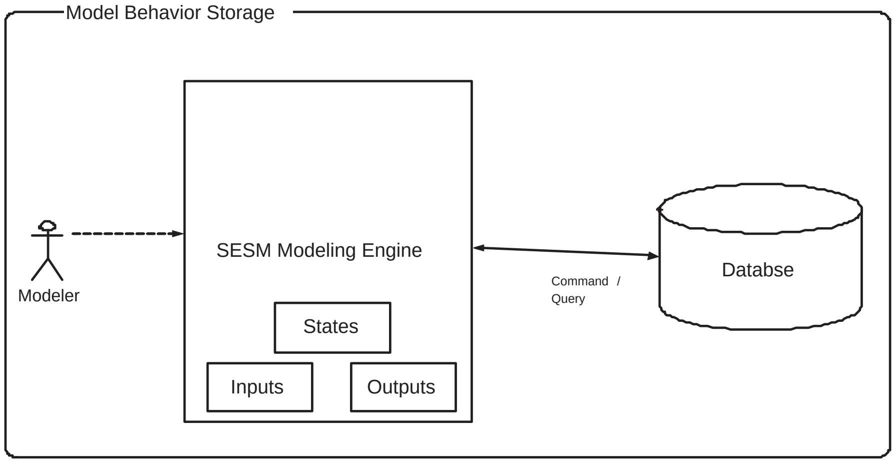


Figure 8. Extension of Behavioral Features of SESM

out from the system and change in the internal state of the system.

Every model defined in DEVS formalism is provided with input and/or output ports for the communication with the other atomic and/or coupled models which are connected to each other by means of couplings. Inputs arrives at the system essentially arrives on the input port, while the output generated from the system essentially sent to the output port of the system. The inputs and outputs are in the form of variables which has defined name, data type and value(s). Name provides an identity to the variable.Every input/output port is associated with zero or more variables while every input/output variable must be associated with either input or output port.

2.1.2. *State Variables.* State of the system at a particular point of time is defined in terms of all of the state variables associated to its atomic models. State variables are associated directly to atomic model unlike port variables, which are associated to the model through ports. Similar to port variables, state variable are also defined in terms of name (identity), data type (either primitive or NSM) and value(s). As coupled model doesn't have a defined state, there are no state variables associated with it, while each atomic model is associated with zero or more state variables. Values of all the state variables collectively define the state of the model.

2.2. Representation of Non-Simulatable Models(NSM). In addition to these models, it is also important to represent non-simulatable models which may be used as part of atomic models. These models are distinct compared with the template models since they do not have input/output ports. Such non-atomic models are referred to as non-simulatable since their behavior is not time-dependent. Examples of these models are object-based user defined complex data structures such as a list or a queue, which are useful to hold multiple values.

As stated above, input-output-state variables are defined in terms of name, data type and value(s). The data type of these variable is an important aspect. This data type can be divided into two types; either primitive data type (supported by the programming language such as integer, character, string, etc) or non-simulatable (NSM) models.

2.3. Generation of Simulation Models. The specification models need to be transformed into simulation code for execution by one or more simulation engines. A simulatable model need to be executed using a simulation engine - i.e., simulatable models are mapping of specification models into a particular realization (model code) amenable to specific simulation engines. This is a two step process as shown in figure 9.

2.3.1. *Database to XML Transformation.* There are various choices for the storage type of the transformed models, but we choose to convert and store them as a well-formed XML document as XML is considered as the best option to handle structured or semi-structured data/documents. The XML document contains the information about the

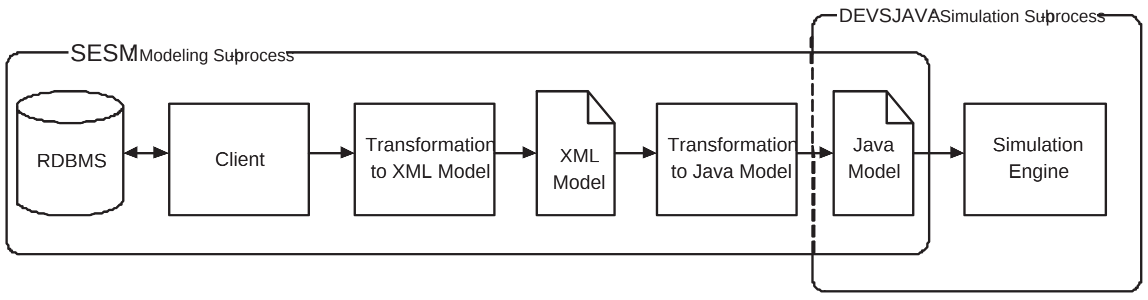

SESM Modeling Subprocess
DEVSJAVA Simulation Subprocess
RDBMS
Client
Transformation to XML Model
XML Model
Transformation to Java Model
Java Model
Simulation Engine

Figure 9. Transformation of SESM models to XML and DEVSJAVA Models

structure of the model such as model name, input port number and names, output port number and names, information about the sub-components and the couplings between them and behavior of the models in terms of inputs, outputs, state variables and non-simulatable models. This will facilitate the component based approach for model validation.

2.3.2. *XML to Java Models Transformation.* Once created, these XML models with structural and behavioral capabilities need to be simulated to test their completeness and correctness. To demonstrate these capabilities, we will employ DEVSJAVA which support execution of models written in the Java Programming language. Therefore, in order to simulate models stored in SESM, they need to be transformed into Java syntax which can be compiled and executed in DEVSJAVA. Hence, it is necessary to develop a modeling-to-simulation mapping to transform atomic, coupled, and non-simulatable models into forms that can be compiled using the Java compiler and executed using the DEVSJAVA simulation engine.

CHAPTER 4

BEHAVIORAL SPECIFICATION OF MODELS IN SESM

1. SESM/CM Design Overview

SESM uses a hybrid architecture which combines the advantages of various flavors of client-server architectures to reach a balanced solution. This architecture is shown in Figure 1. As discussed earlier, similar to the client/server architecture, the hybrid architecture has a server that writes to the database, with potentially multiple clients interacting with the database. Clients are also connected to the DBMS, which allowing them to retrieve model data concurrently. But, the clients cannot write to the database. The client must connect to the server in order to modify the database. This architecture supports single writer but multiple readers of the database concurrently and thus provides a restricted flavor of network environment.

By design, the SESM system includes the SESM package, the Network Environment package, SESM client, and SESM server as shown in Figure 10. The SESM package should serve as an API used to access the SESM representation model data stored on the DBMS. There are three main components in the SESM package; Connectivity, SESM Query, and SESM Modifier.

The Connectivity component is used to connect to the DBMS. It handles all the

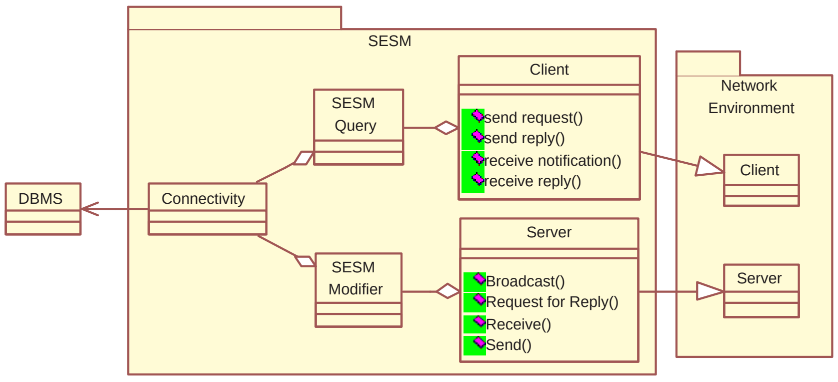


Figure 10. SESM System Components Overview Diagram

communication between the SESM system and the DBMS. The SESM Query component retrieves data from the DBMS using SQL and maps the data into object-oriented SESM models. The SESM Modifier component modifies the SESM representation of models on the DBMS. The component translates the requested modification into appropriate SQL statements. The SESM Server extends the Server provided by the Network environment package. Messages received by the SESM Server are processed, and modifications are performed accordingly. The SESM Client utilizes the SESM Query component to retrieve and display the SESM representation model visually on its graphical user interface (GUI). The user also modifies the model through the SESM clients GUI. The network Environment package manages the communication between the SESM Client and the SESM Server by providing the components that can be extended by the SESM Client and SESM Server.

Having described the existing architecture of SESM, it is necessary to describe the design focus of this research. This involves the design for the specification of some of the behavioral aspects of atomic models in SESM such as specification of input-output-state variables, their data type and their values. It also includes the transformation of atomic and coupled models into simulation compatible (DEVSJAVA) format. To achieve this, existing architecture of SESM is extended. Extensions were made to the client, server and database designs while keeping the overall architecture of the system same.

2. Database Schema Design for Atomic Model Dynamics

Models developed in SESM are primarily structural. They are described and stored in a relational database in terms of structural features of the model components such as identity (i.e., model name), hierarchy (i.e., decomposition), input/output interface (i.e., port names) and their creation time. In order to execute (simulate) these models to observe their behavior in response to input stimulus, they need to be extended in terms of behavioral aspects of the model. In particular, it is important for an atomic model specification to support modeling of input and output variables, state variables, and functions. Reusability of structural and behavioral aspect of these models can be achieved by storing them in a database. This section presents the SESM behavioral requirements, its relational database schema and extended Entity-Relationship diagram.

2.1. Requirements. Requirements for the model development based on the three model categories mentioned in chapter 3 are described in terms of Model, Port and Coupling [Fu02]. These requirements help in the specification of structure of the models and their relationship in the relational database. But in addition to the structural requirements, there are behavioral requirements which are described in terms of port variable, state variable and NSM variable as follows,

Port Variable:

- Port variable can be associated with atomic as well as coupled model
- Port variable must have variable name, variable type and value
- Port variable type may be either primitive or NSM
- Port variable of a model cannot exists without being associated to port name and port type (in or out)
- Multiple port variables can be associated to each distinct single port
- Model can have multiple port variable names of same variable type

State Variable:

- State variable can be associated only with atomic model
- State variable must have variable name, variable type and value
- State variable type may be either primitive or NSM
- State variable of a model cannot exists without being associated to an atomic model
- Multiple distinct state variables can be associated to a single model
- Model can have multiple state variable names of same variable type.

NSM Variable:

- NSM variable must have a name (identification)
- NSM variable name must be unique

- NSM variable can be associated with zero or more models
- NSM variable must be associated with a model as an input, output or state variable
- NSM variable can exists without being associated to a model

2.2. ER Extensions. An Entity-Relationship diagram developed for the SESM/CM modeling environment is extended by adding new entities and relationships in order to incorporate the additional behavioral requirements. Figure 11 shows the newly added entities and relationships within dotted lines. Table 1 shows the entities and relationships in the E-R diagram along with their descriptions. The newly added entities and descriptions are represented in bold letters.

2.3. Entities in extended SESM E - R diagram.

2.3.1. *portVariable (Port Variable) entity.*

- Attributes
  - owner (Template Model Name)
  - tName (Port Name)
  - tType (Port Type)
  - varName (Port Variable Name)
  - varType (Port Variable Type)
  - varValue (Port Variable Value)
- Description

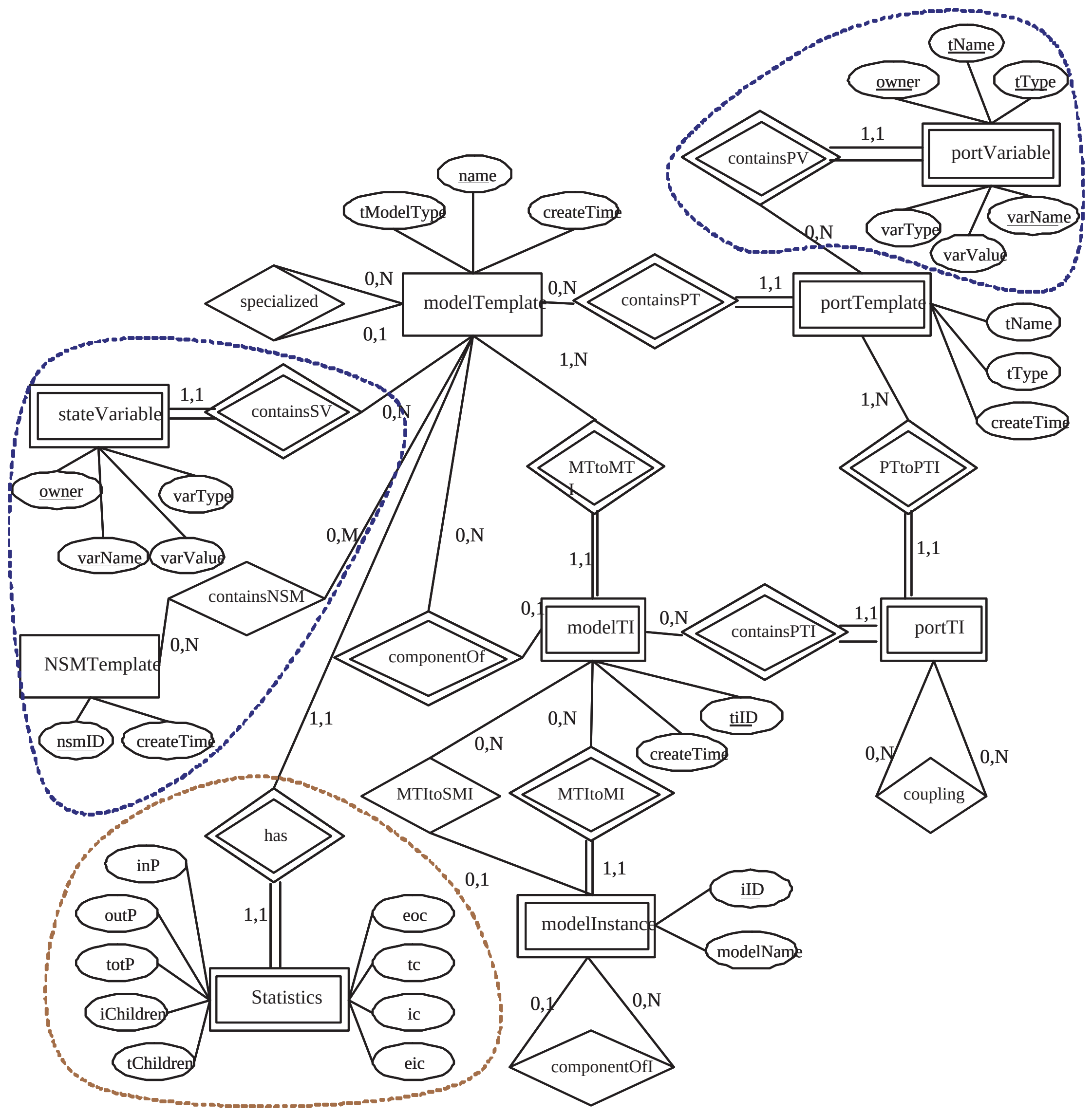


Figure 11. Extended SESM E-R Diagram

Table 1. SESM Entities and Relationships

Entity/Relationship	**Description**
containsPT	Template Model contains Template Port
containsPTI	Instance Template Model contains Instance Template Port
modelTemplate	Template Model
portTemplate	Port Template
modelTI	Instance Template Model
modelInstance	Instance Model
MT to MTI	Template Model to Instance Template Model
MTItoMI	Instance Template Model to Instance Model
MTItoSMI	Instance Template Model to Specialization Instance Model
PortTI	Instance Template Port
PTtoPTI	Template Port to Instance Template Port
Specialized	Template Model can be specialized
componentOf	Decomposition of Coupled Template Model
componentOfI	Decomposition of Coupled Instance Model
Coupling	Coupling between two Ports
containsMET	Template Model contains Metrics
Metrics	Metrics generated for the Template Model
containsNSM	**Template Model contains Non-Simulatable Model**
NSMTemplate	**Non-Simulatable Model Template**
containsPV	**Port contains Port Variable**
portVariable	**Port Variable**
containsSV	**Template Model contains State Variable**
stateVariable	**State Variable**

- The portVariable entity represents the port variables associated with the Port Template.
- The portVariable is a weak entity of portTemplate because a portVariable should not exist if the portTemplate associated with it does not.
- The portVariable and portTemplate are linked by containsPV (Port contains port Variable) relationship
- All attributes are single-valued and not null-able
- The attribute tType is the type of the port and its value set is string of IN and

OUT.

2.3.2. *stateVariable (State Variable) entity.*

- Attributes
  - owner (Template Model Name)
  - varName (State Variable Name)
  - varType (State Variable Type)
  - varValue (State Variable Value)
- Description
  - The stateVariable entity represents the state variables associated with the modelTemplate
  - The stateVariable and modelTemplate are linked by containsSV (Port contains port Variable) relationship

2.3.3. *NSMTemplate (Non-Simulatable Model Template) entity.*

- Attributes
  - nsmID (Non-Simulatable Model name)
  - createTime (Time of Non-Simulatable Model porting)
- Description
  - The NSMTemplate entity represents the Non-Simulatable model (i.e., complex data structures)

– All attributes are single-valued and not null-able

– The attribute, nsmID, is the primary key for NSMTemplate since NSM Model is uniquely identified by its nsmID. The value set of this attribute is alphanumerical string.

– The attribute createTime records the time when the NSM Model was ported. It can be used to sort NSM Models

2.4. Relationships in extended SESM E - R diagram.

2.4.1. *containsNSM.* containsNSM defines the relationship between Template Model and Non-Simulatable Model. The cardinality of this relationship is M ModelTemplate to N NSMTemplate as Model Template can have zero or more NSM Templates as their elements while NSM template also can be a part of zero or more Model Template. In short, NSM Template can exist without being associated with any Model Template and doesn't have dependency relationship with Model Template.

2.4.2. *containsPV.* containsPV defines the relationship between the Port Template and Port Variable. It is the identifying relationship of the weak entity, Port Variable. The cardinality of this relationship is 0, N portVariable to 1 PortTemplate. Since portVariable is a weak entity, it has total participation in the relationship, while PortTemplate has partial participation in the relationship since some ports might have zero port variables. In short, existence of the port variable is dependent on the existence of the port.

2.4.3. *containsSV.* containsSV defines the relationship between the Model Template and State Variable. It is the identifying relationship of the weak entity, State Variable. The cardinality of this relationship is 0, N stateVariable to 1 ModelTemplate. Since stateVariable is a weak entity, it has total participation in the relationship, while ModelTemplate has partial participation in the relationship since some model templates might have zero state variables. In short, existence of the state variable is dependent on the existence of the model.

2.5. Extended SESM Relational Database Schema. Based on the extended ER-Diagram shown in Figure 11, the schema of the SESM relational database is extended as follows. Foreign Keys are shown as ***bold-italic*** and Primary Keys are shown as **bold**. All other column names are shown in plain font.

Port Variable:

Table 2. Relational Database Schema Specification for portVariable Table

portVariable					
owner	***tName***	***tType***	**varName**	varType	varValue

owner is a foreign key from ModelTemplate (name)

tName is a foreign key from PortTemplate (tName)

tType is a foreign key from PortTemplate (tType)and can be either IN or OUT

varName is an alphanumerical String with maximum length of hundred characters

varType is an alphanumerical String with maximum length of hundred characters

varValue is an alphanumerical String with maximum length of hundred characters

Primary key owner, tName, tType, varName

State Variable:

owner is a foreign key from ModelTemplate (name)

varName is an alphanumerical String with maximum length of hundred characters

Table 3. Relational Database Schema Specification for stateVariable Table

stateVariable			
owner	**varName**	varType	varValue

varType is an alphanumerical String with maximum length of hundred characters

varValue is an alphanumerical String with maximum length of hundred characters

Primary key is owner, varName

NSM Template:

Table 4. Relational Database Schema Specification for NSMTemplate Table

NSMTemplate	
nsmID	createTime

nsmID is an alphanumerical String with maximum length of one hundred characters

createTime is an integer

The primary key is nsmID

2.5.1. *Schema in Data Definition Language (DDL).*

PORTVARIABLE

CREATE TABLE PORTVARIABLE (

OWNER VARCHAR (100),

TNAME VARCHAR (100),

TTYPE VARCHAR (5) CHECK (TTYPE IN (IN, OUT)),

VARNAME VARCHAR (100),

VARTYPE VARCHAR (100),

VARVALUE VARCHAR (100),

PRIMARY KEY (OWNER, TNAME, TTYPE, VARNAME),

FOREIGN KEY (OWNER) REFERENCES MODELTEMPLATE (TID) ON DELETE CASCADE,

FOREIGN KEY (TNAME) REFERENCES PORTTEMPLATE (TNAME) ON DELETE CASCADE,

FOREIGN KEY (TTYPE) REFERENCES PORTTEMPLATE (TTYPE) ON DELETE CASCADE

)

STATEVARIABLE

CREATE TABLE STATEVARIABLE (

OWNER VARCHAR (100),

VARNAME VARCHAR (100),

VARTYPE VARCHAR (100),

VARVALUE VARCHAR (100),

PRIMARY KEY (OWNER, VARNAME),

FOREIGN KEY (OWNER) REFERENCES MODELTEMPLATE (TID) ON DELETE CASCADE

)

NSMTEMPLATE

CREATE TABLE NSMTEMPLATE (

NSMID VARCHAR (100),

```
CREATTIME INTEGER,
PRIMARY KEY (NSMID)
)
```

2.6. Additional constraints. Entity Relationship diagram and data definition language define different types of constraints like key constraints (primary key, foreign key), cardinality constraints (one-many or many-many), participation constraints (partial or total), check constraints, etc. But there are other constraints which cannot be specified diagrammatically in E-R diagram or syntactically in DDL due to their limitations. These constraints need to be specified in the underlying programming language (i.e., Java in case of SESM). Some of these additional constraints are

- The input-output-state variable name and NSM template name must be assigned by the modeler (user).
- User can add port variables to only ports that already exist in the model.
- Input, output or state variable data type can be either primitive data type (for example, integer, float or string in Java language) or of type NSM template.
- When user is choosing NSM template as an input, output or state variable, he should get a choice of only those NSM templates which are already present in the database.
- User can delete or modify input-output ports or Input-output-state variables which are associated with the selected model.

2.7. Extended SESM Transactions. SESM environment provides the modeler the ability to send command and queries. SESM transactions are primarily categorized into three types, Add transactions, Delete Transactions and Modify Transactions which are further divided into sub-categories such as Add Input port, Add Output port, Delete input Port, etc. Detailed use case diagrams with additional behavioral requirements for these transactions are shown in Figure 12, 13 and 14 respectively.

Out of the transactions mentioned in these use cases, current version of SESM/CM supports following transactions

Add Template Model - add/create a new Template Model

Add Port - add/create an input port or output port to an existing Template Model

Add Component - Add a Template Model as a component to an atomic Template Model or a coupled Template Model

Add Specialization - add/create a new Template Model as a specialization model specializes an atomic model or a specialized model

Add Coupling - add/create couplings between two ports

Add Instance Model - add Instance Models from a Template Model

Delete Template Model - Delete an existing Template Model

Delete Port - Delete an existing input port or output port from a Template Model

Delete Component - Delete a component from a coupled model

Delete Coupling - Delete a coupling between two ports

Delete Instance Model - Delete an Instance Model and all its components

Modify Template Model Name - Modify Template Model's name

Modify Instance Model Name - Modify an Instance Model's name

Modify Port Name - Modify port's name

Modify Model Type - Modify Template Model's type

Show Metrics - Shows structural Metrics of a template Model.

But all of these transactions are primarily structural. And as mentioned before, we need to specify the dynamic characteristics of the model to simulate it and further validate it. This leads to an additional set of transactions. These transactions are again of type add (SQL INSERT), delete (SQL DELETE) and modify (SQL MODIFY). Specific examples of each type of SQL statement with specific key words are shown below for a portVariable table,

- SQL INSERT: INSERT INTO PORTVARIABLE VALUES ('PROCESSOR', 'ALERTSIGNAL', 'IN', 'ENT3', 'ENTITY', 'MAG01');
- SQL DELETE : DELETE FROM PORTVARIABLE WHERE OWNER = 'PROCESSOR' AND PORTNAME = 'ALERTSIGNAL' AND PORTTYPE = 'IN' AND VARNAME = 'ENT3' AND VARVALUE = 'MAG01';
- SQL UPDATE: UPDATE PORTVARIABLE SET VARTYPE = 'DOUBLEENT' AND VARVALUE = 'MAG02' WHERE OWNER = 'PROCESSOR' AND PORTNAME = 'ALERTSIGNAL' AND VARVALUE = 'MAG01';

The specification of all the extended transactions is as follows,

2.7.1. *Add Transactions.*

Add Input Port Variable

- Input:
  - Port Name
  - Variable Name
  - Variable Data Type

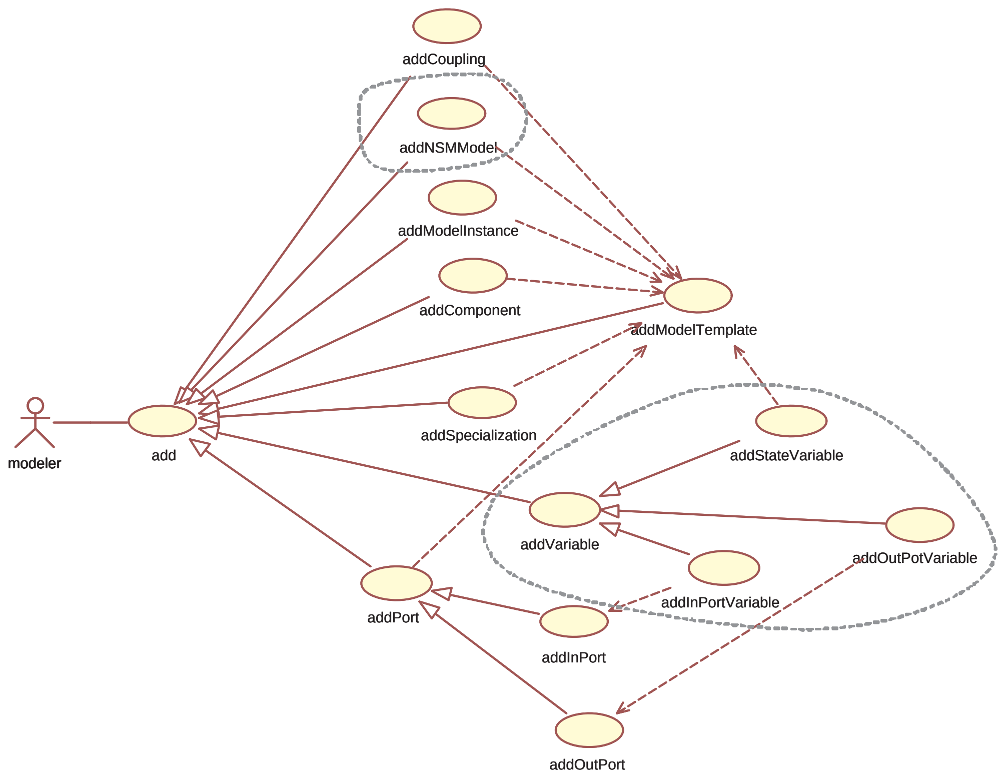


Figure 12. Add Transaction Use Case Diagram

  - Variable Value

- Restriction:
  - Variable must be assigned to port that already exists
  - Port type must be by default “IN”.
  - Inputted port variable (variable name) doesn’t exist for that input port in the template model

- Output:
  - A new row gets added to portVariable table

- Short Transaction:
  - Extract the information regarding the owner model template and port type
  - Extract the information regarding port name, variable name, variable data type and variable value entered by the user
  - Create an appropriate event with the input values and send it to server
  - Add port variable on a specified port of a selected model (SQL INSERT on portVariable Table)

Add Output Port Variable

- Input:
  - Port Name

  - Variable Name
  - Variable Data Type
  - Variable Value

- Restriction:
  - Variable must be assigned to port that already exists
  - Port type must be by default "OUT"
  - Inputted port variable (variable name) doesn't exist for that output port in the template model

- Output:
  - A new row gets added to portVariable table

- Short Transaction:
  - Extract the information regarding the owner model template and port type
  - Extract the information regarding port name, variable name, variable data type and variable value entered by the user
  - Create an appropriate event with the input values and send it to server
  - Add port variable on a specified port of a selected model (SQL INSERT on portVariable Table)

Add State Variable

- Input:

  - Variable Name
  - Variable Data Type
  - Variable Value
- Restriction:
  - Variable must be assigned to model template that already exists
  - Variable must be assigned only to atomic model
  - Inputted state variable (variable name) doesn't exist in the template model
- Output:
  - new row gets added to stateVariable table
- Short Transaction:
  - Extract the information regarding the owner model template
  - Extract the information regarding variable name, variable data type and variable value entered by the user
  - Create an appropriate event with the input values and send it to server
  - Add state variable to a selected model (SQL INSERT on stateVariable Table)

2.7.2. *Delete Transactions.*

Delete Input Port Variable

- Input:
  - Port Name

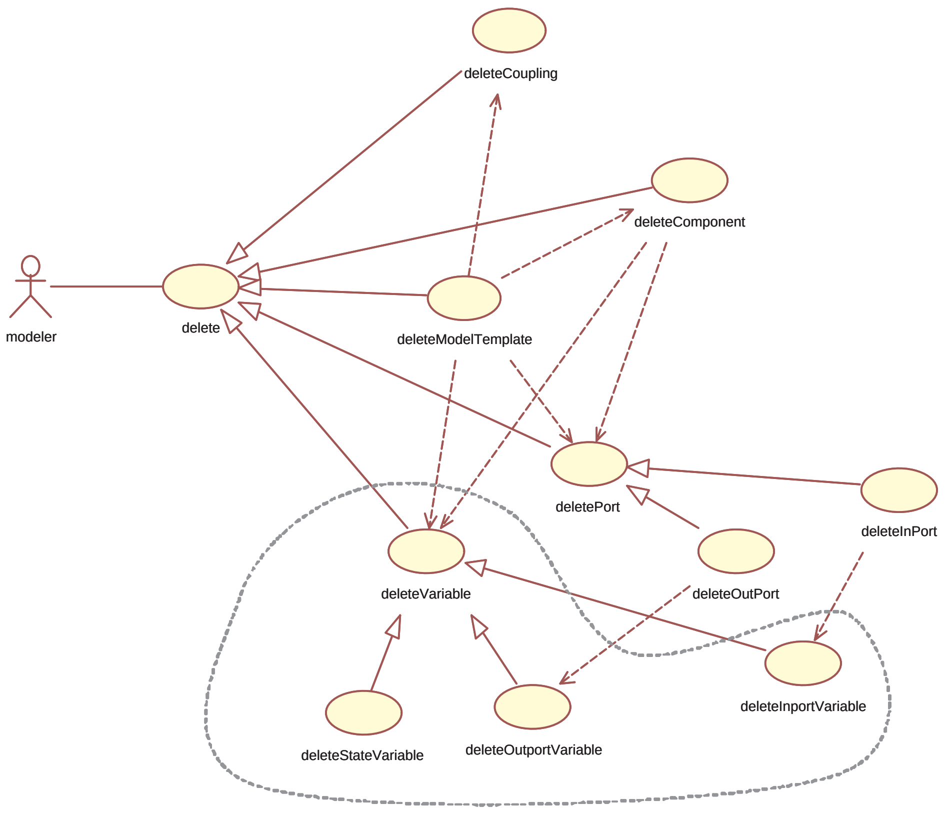


Figure 13. Delete Transaction Use Case Diagram

  - Variable Name
  - Variable Value
  - Variable Data Type

- Restriction:
  - Port type must be by default “IN”.
  - Variable and corresponding port must already exist

- Output:
  - An existing row gets deleted from portVariable table

- Short Transaction:
  - Extract the information regarding the owner model template and port type
  - Extract the information regarding port name, variable name, variable data type and variable value entered by the user
  - Create an appropriate event with the input values and send it to server
  - Delete port variable on a specified port of a selected model (SQL DELETE on portVariable Table)

Delete Output Port Variable

- Input:
  - Port Name

  - Variable Name
  - Variable Value
  - Variable Data Type
- Restriction:
  - Port type must be by default “OUT”
  - Variable and corresponding port must already exist
- Output:
  - An existing row gets deleted from portVariable table
- Short Transaction:
  - Extract the information regarding the owner model template and port type
  - Extract the information regarding port name, variable name, variable data type and variable value entered by the user
  - Create an appropriate event with the input values and send it to server
  - Delete port variable on a specified port of a selected model (SQL DELETE on portVariable Table)

Delete State Variable

- Input:
  - Variable Name

- Restriction:
    - Variable must already exists
- Output:
    - An existing row gets deleted from stateVariable table
- Short Transaction:
    - Extract the information regarding the owner model template
    - Extract the information regarding variable name
    - Create an appropriate event with the input values and send it to server
    - Delete state variable from the selected model (SQL DELETE on stateVariable Table)

In addition to these direct delete operations, there are other delete operations which in turn mandate the execution of the above delete operations. They are,

Delete port

- Requirement: When a port of a model is deleted, all the variables associated with the port must be deleted.
- Design: This is achieved by means of database design by enforcing the referential integrity constraint between the portTemplate and portVariable table in terms of columns owner, tName, tType and by cascading the tables upon delete and update actions.

- Execution: Due to the database design, whenever port is deleted from the portTemplate table, corresponding rows from the portVariable table having the same values for owner model, port name and port type is deleted.

Delete Template Model

- Requirement: When an atomic model is deleted, all the state variables associated with the model as well as all the port variables associated with all the ports of the model must be deleted. Also, when the coupled models is deleted, all of its port variables and all the variables associated with its sub-components must be deleted.
- Design: This is again achieved by means of database design by enforcing the referential integrity constraint between the portTemplate and portVariable table in terms of columns owner, tName, tType, between ModelTemplate and stateVariable in terms of column owner and by cascading the tables upon delete and update actions.
- Execution: Due to the database design, whenever the model template is deleted, all the corresponding ports get deleted which in turn delete all the port variables as mentioned above. It also deletes corresponding rows in the stateVariable table having the value for column owner same as that of the model deleted.

2.7.3. *Modify Transactions.*

Modify Input Port Variable

- Input:
  - Port Name

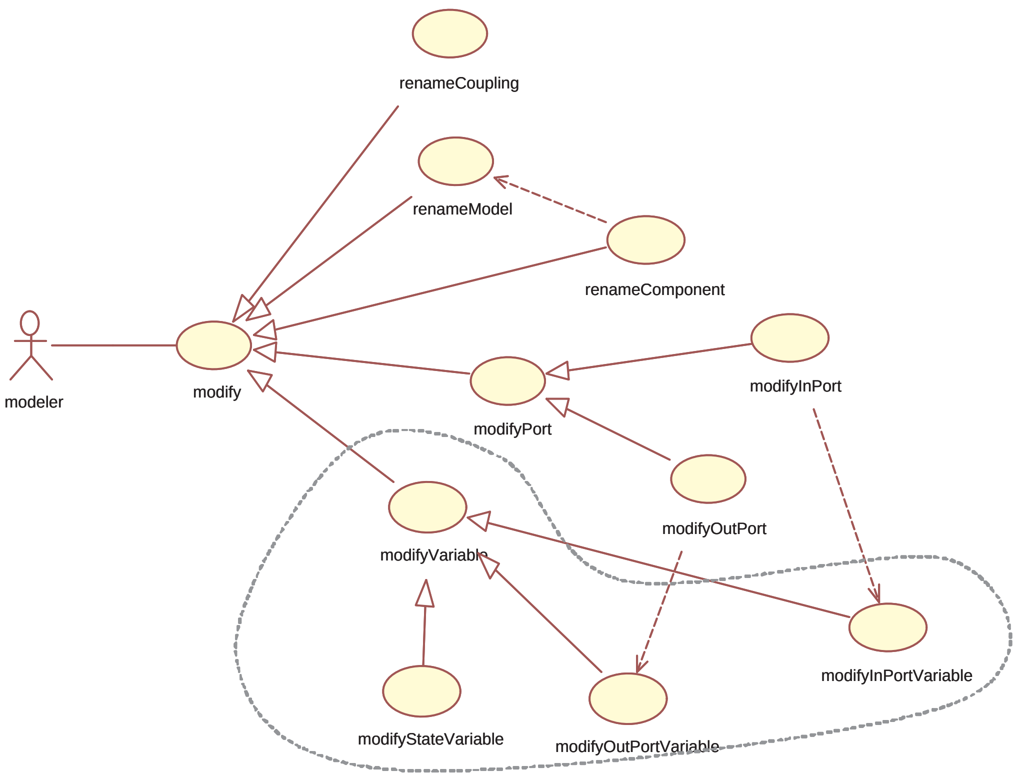


Figure 14. Modify Transaction Use Case Diagram

  - Variable Name
  - Variable Value
  - Variable Data Type
  - New Variable Value

- Restriction:
  - Port type must be by default “IN”.
  - Variable name, type, value and corresponding port must already exist

- Output:
  - An existing row gets modified from portVariable table

- Short Transaction:
  - Extract the information regarding the owner model template and port type
  - Extract the information regarding port name, variable name, new variable type and new variable value entered by the user
  - Create an appropriate event with the input values and send it to server
  - Modify port variable on a specified port of a selected model (SQL MODIFY on portVariable Table)

Modify Output Port Variable

- Input:

  - Port Name
  - Variable Name
  - Variable Value
  - Variable Data Type
  - New Variable Value

- Restriction:
  - Port type must be by default "OUT"
  - Variable name, type, value and corresponding port must already exist
- Output:
  - An existing row gets modified from portVariable table
- Short Transaction:
  - Extract the information regarding the owner model template and port type
  - Extract the information regarding port name, variable name, new variable type and new variable value entered by the user
  - Create an appropriate event with the input values and send it to server
  - Modify port variable on a specified port of a selected model (SQL MODIFY on portVariable Table)

Modify State Variable

- Input:

  - Variable Name
  - Variable Type
  - Variable Value

- Restriction:
  - Variable name, type and value must already exist
- Output:
  - An existing row gets modified from stateVariable table
- Short Transaction:
  - Extract the information regarding the owner model template
  - Extract the information regarding variable name, variable type and variable value entered by the user
  - Create an appropriate event with the input values and send it to server
  - Modify state variable of a selected model (SQL MODIFY on stateVariable Table)

In addition to the transactions required for the specification of behavioral aspects of atomic model, two more utility transactions are added to SESM. They are useful from the point of view of transformation of the graphical and database models (in terms of structure and behavior) specified in SESM into the XML and DEVSJAVA simulation compatible models. These are Export (Figure 15) and View (Figure 16) transactions respectively.

Rationale for Model Storage on Server

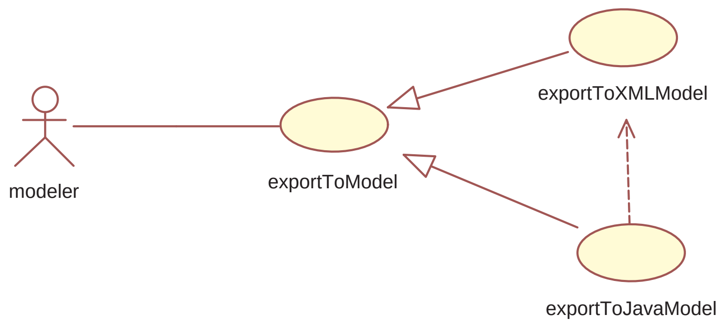


Figure 15. Export Transaction Use Case Diagram

As SESM is based on client-server architecture, there are various options for storing the transformed models (such as XML and Java model). Modeler can store the models on client side or on server side. But this research concentrates on the second approach of storing the models on the server side. In this approach, the models are stored in the form of flat files (such as Java or XML file) at a specified location on the server. The rationale behind storing the models on server side is reusability. Since, there are multiple clients can connect to the server and create models, if the models transformed by one modeler is stored on the server, they are accessible to all other modelers. Therefore, other modelers can use these models without recreating them. This saves time and effort of model creation. On the contrary, if the models are saved on client side, each client has to generate his own set of models which results in the duplication of efforts.

2.7.4. *Export Transactions.*

Export to XML Model

- Input:
  - No input

- Restriction:
  - Model Template must exists in the database
- Output:
  - XML model is created and stored at the particular location on server
- Short Transaction:
  - Extract the information regarding model in terms of model name, Model type, ports, couplings (if coupled), port variables, state variables , variable types and variable values
  - Create an appropriate event with the extracted information and send it to server
  - Form a XML document (model) with the received information
  - Store the XML model at a particular location on server

Export to DEVSJAVA Model

- Input:
  - XML model
- Restriction:
  - Model Template and corresponding XML model must already exist in database and a specified directory respectively on server
- Output:

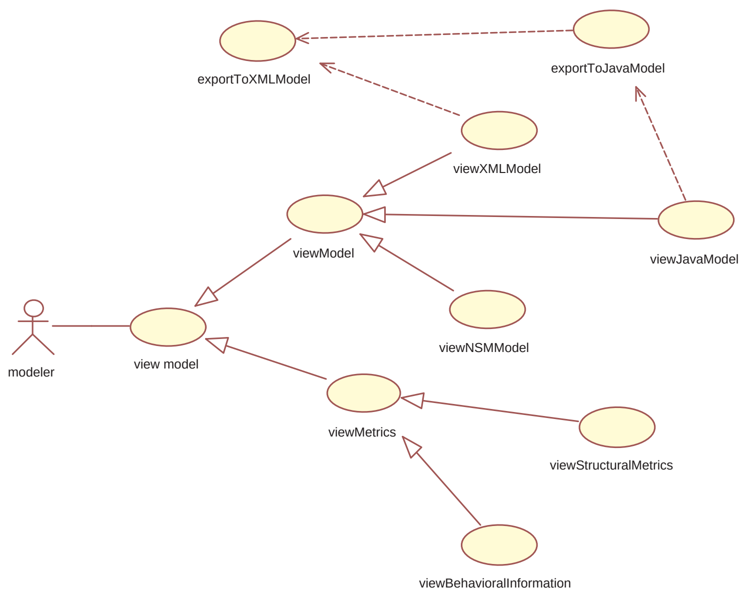


Figure 16. View Transactions Use Case Diagram

  - Java (DEVSJAVA) model is created and stored at the particular location

- Short Transaction:

  - Send an event to server to get the corresponding XML model from the server
  - Extract the information regarding model in terms of model name, Model type, ports, couplings (if coupled), port variables, state variables , variable types and variable values by parsing the XML model
  - Create an appropriate event with the extracted information and send it to server
  - Form a Java model with the extracted information
  - Store the Java model at a particular location on server

2.7.5. *View Transaction.*

View XML Source Code

- Input:
  - XML model
- Restriction:
  - XML model must already exists
- Output:
  - XML model is viewed in the XML editor
- Short Transaction:
  - Send an event to server to get the corresponding XML model from the server
  - Read the model and display the model to the user

View Java Source Code

- Input:
  - Java model
- Restriction:
  - Java model must already exists
- Output:

  - Java model is viewed in the Java editor

- Short Transaction:

  - Send an event to server to get the corresponding Java model from the server
  - Read the model and display the model to the user

View Behavioral Information

- Input:

  - Template Model

- Restriction:

  - Template model must exists in a database

- Output:

  - Behavioral information is viewed

- Short Transaction:

  - Extract the behavioral information from the model in terms of port and state variables
  - Display this information to the user in to tabular form

2.7.6. *Data Query.* Data query is a query needed to support model manipulation transactions. These transactions use data queries to retrieve information regarding a model that is partitioned and stored in several tables. Given the design of the manipulation transactions, the data queries are often performed on a single set of data (a single table) and no sorting is required. These queries are therefore SQL SELECT statements executed on a single table. Due to the fact that a wide variety of data queries with different conditions and return data are needed, they are not listed individually here.

3. SESM Server Design Extensions

As described earlier, SESM architecture is hybrid client-server type architecture. In this, client can access the data from the database directly by connecting to it, but for writing the data to the database, it needs to go through the server which essentially writes the data for client. Therefore, server should support the network behavior (i.e., correct ordering of transactions to the database) such as sending the notification and requesting the inputs as shown in Figure 17. It needs to have logic to process messages from the client and modify the database. It needs to perform add, delete and modify operations to the models stored in the database. Use-case diagram in Figure 18 for the server explains these operations.

Figure 19 represents the package diagram for the SESM server. It shows the relationship between SESM transaction (Add, Delete and Modify) and SQL transactions (add a row to the table and delete a row from the table, etc). Server design is divided into two packages corresponding to these two types of transactions, namely, DBMS and dbAccess respectively.

As we have mentioned above, we are reusing and extending the existing server design by adding new attributes and methods to the existing class structure. Following are the

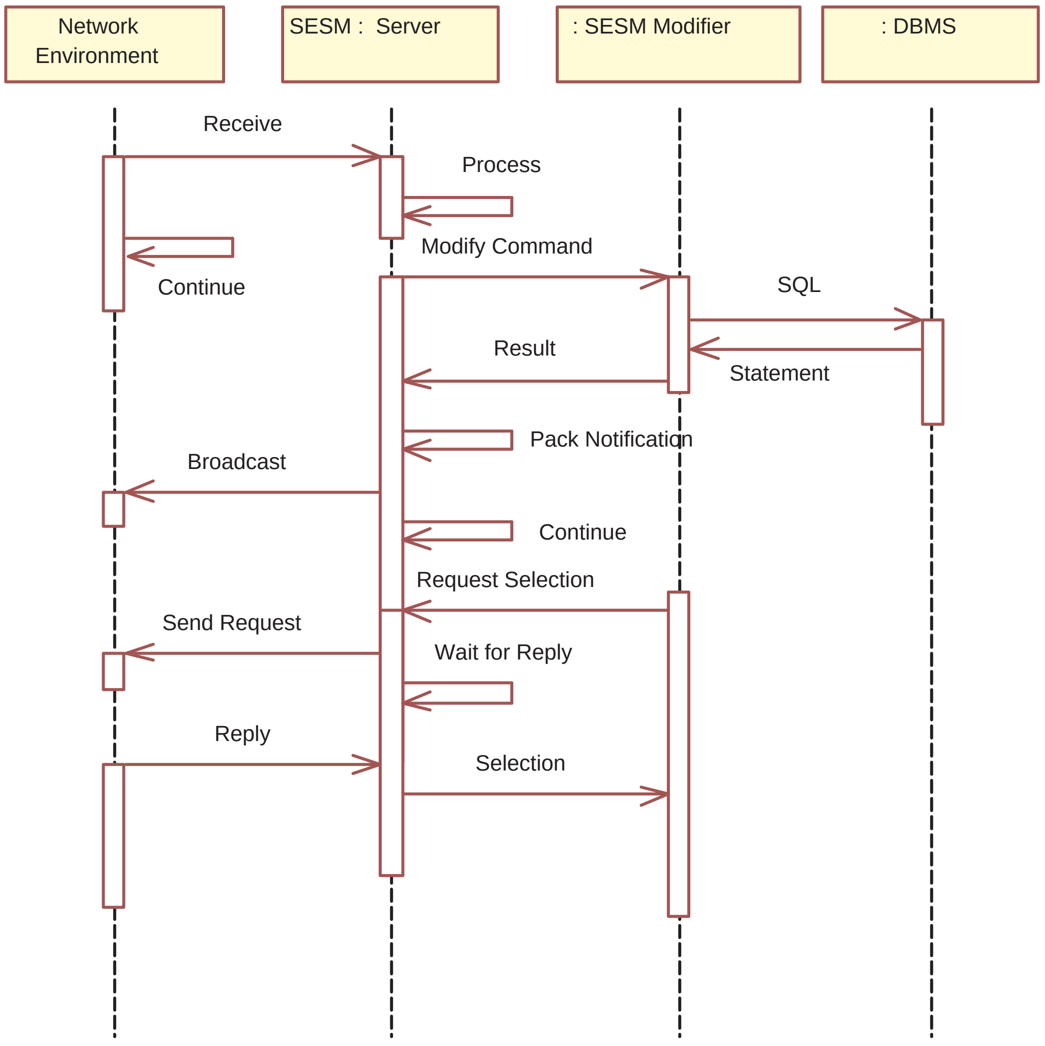


Figure 17. SESM Server Interaction Diagram

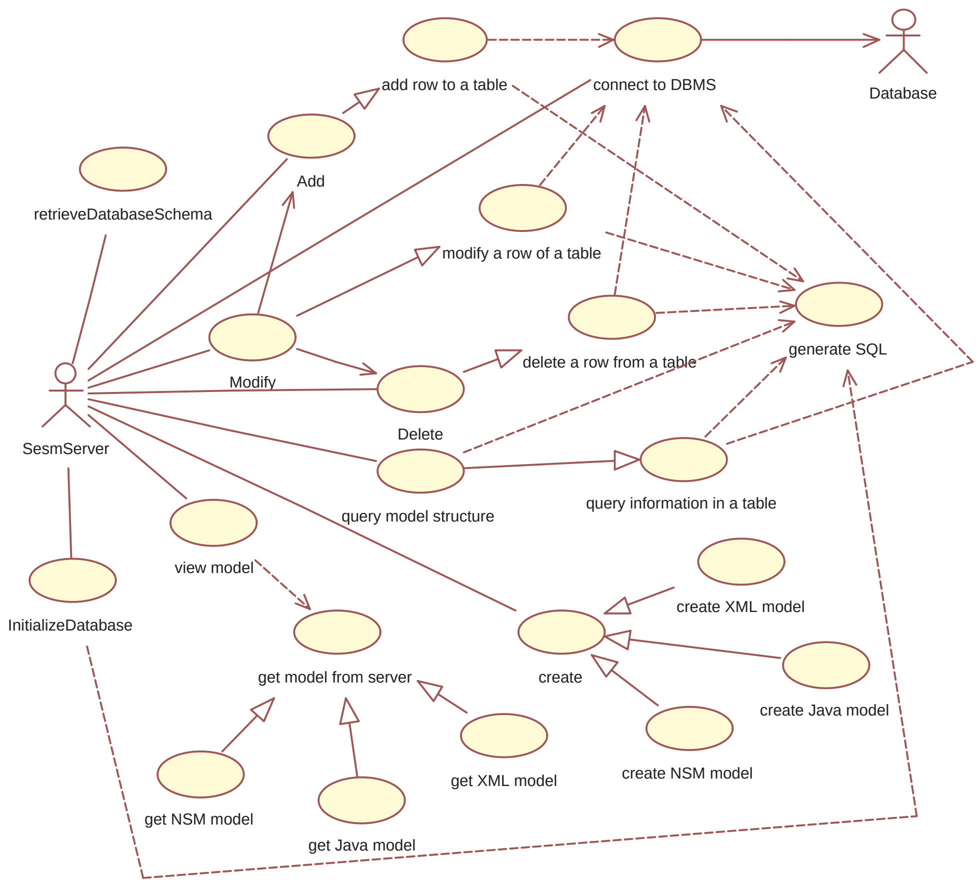


Figure 18. SESM Server Use Case Diagram

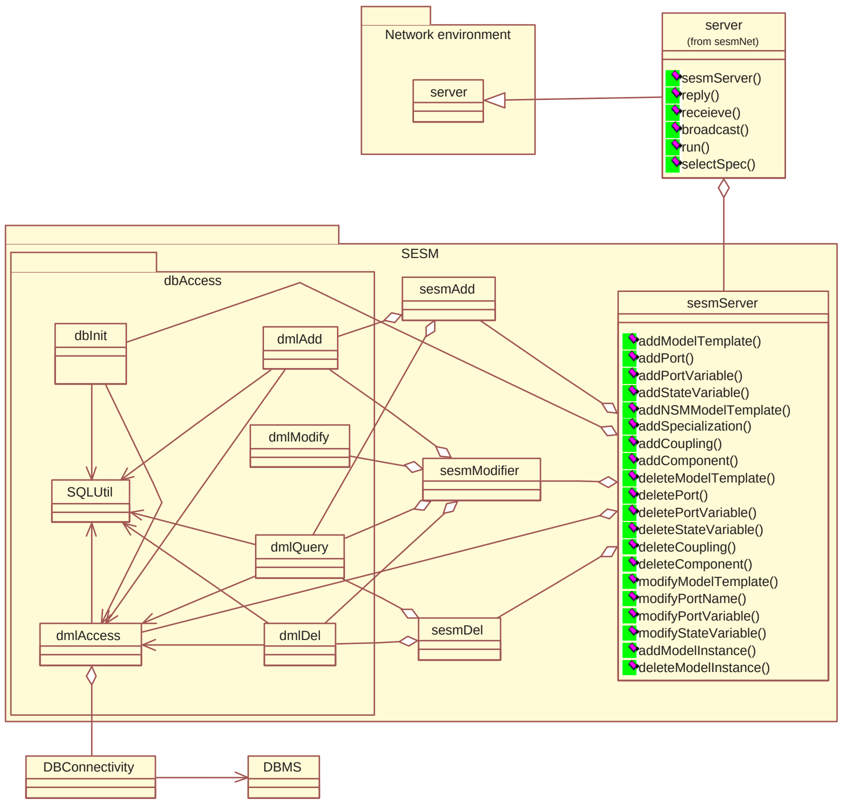


Figure 19. SESM Server Component Diagram

extension to the existing classes in the server design.

3.1. dbms package. This package provides classes (sesmDb, sesmAdd, sesmDel, sesmModify and sesmQuery), with the methods that are directly mapped to the transactions. Classes in this package cannot directly access the database. For that, they have to go through the short transactions defined later in the dbAccess package. This package focuses on defining the transactions of SESM.

sesmDB Class

The sesmDB object provides all the operations required to manipulate the database according to the SESM. The primary functions of this object are checking correctness of the input and interface with users.

- Existing Attributes
  - theQuery: SESM.sesmQuery object used to perform queries retrieving SESM model information
  - add: SESM.sesmAdd object used to perform add operations in SESM models
  - delete: SESM.sesmDel object used to perform delete operations on SESM models
  - modify: SESM.sesmModify object used to perform modify operations in SESM models
- New Methods
  - addNsmModelTemplate: add a new NSM model template to the relational database

  - delNsmModelTemplate: delete existing NSM model template from the relational database
  - addPortVariable: add a port variable to an specific existing port of a model
  - addStateVariable: add a state variable to a model
  - delPortVariable: delete a port variable of specific existing port of a model
  - delStateVariable: delete a state variable of a model
  - modifyPortVariable: modify a port variable of specific existing port of a model
  - modifyStateVariable: modify a state variable of a model

- Existing Methods:
  - addModelTemplate: add a new model template to the relational database
  - addPort: add a port to an existing model
  - addComponent: add a component to an existing model
  - addSpecialization: create a specializing model from an existing model
  - addCoupling: couple two existing ports
  - addModelInstance: create a new model instance from a model template
  - delModelTemplate: delete an existing model template
  - delPort: delete a port from a model template
  - delComponent: delete a component from a model template
  - delCoupling: delete an existing coupling
  - delModelInstance: delete an existing model instance at the root level
  - modifyModelTemplate: modify the name of an existing model template

  - modifyPortName: modify the name of a port
  - modifyModelName: modify the name of an existing model instance
  - requestUserInput: request the user to select a specializing model for a specialized model. Abstract method should be implemented by the collaborative environment

sesmAdd Class

The sesmAdd class extends the SESM.dbAccess.dmlAdd class to perform add transactions of SESM.

- Existing Attributes
  - theQuery: SESM.access.dmlQuery object used to query for model information
- New Methods
  - modelNsmT: add a new NSM model template to the relational database
  - portVariable: add a new port variable to an existing port of a model
  - stateVariable: add a new state variable to a model
- Existing Methods:
  - modelT: add a new model template to the relational database
  - port: add a port to an existing model
  - compomentOf: add a component to an existing model
  - specialization: create a specializing model from an existing model

  - coupling: couple two existing ports
  - instance: create a new model instance from a model template

sesmDel Class

The sesmDel class extends the SESM.dbAccess.dmlDel class to perform delete transactions of SESM.

- Existing Attributes
  - theQuery: SESM.access.dmlQuery object used to query for model information
- New Methods
  - modelNsmT: delete an existing NSM model from relational database
  - portVariable: delete an existing port variable of an existing port of a model
  - stateVariable: delete an existing state variable to a model
- Existing Methods:
  - delModelTemplate: delete an existing model template
  - delPort: delete a port from a model template
  - delComponent: delete a component from a model template
  - delCoupling: delete an existing coupling
  - delModelInstance: delete an existing model instance at the root level

sesmModify Class

The sesmModify class extends the SESM.dbAccess.dmlModify class to perform modify transactions of SESM.

- Existing Attributes
  - theQuery: SESM.access.dmlQuery object used to query for model information
  - add: SESM.access.dmlAdd object used to restore the modified values
  - delete: SESM.access.dmlDel object used to delete the old values
- New Methods
  - portVariableName: modify an existing port variable of an existing port of a model
  - stateVariableName: modify an existing state variable to a model
- Existing Methods:
  - modifyModelTemplate: modify the name of an existing model template
  - modifyPortName: modify the name of a port
  - modifyModelName: modify the name of an existing model instance

3.2. dbAccess package. This package provides classes (dbInit, dmlAccess, dmlAdd, dmlDel, dmlModify, and dmlQuery, query, and SQLUtil), which can manipulate and query the relational database. The schemas defined here are for the relational database. Therefore, all transactions included in the SESM.access package are short transactions expressed in SQL.

SQLUtil Class

The SQLUtil class provides static methods to generate SQL statements from generic variables.

- Existing Methods:
  - dropTable: generate SQL DROP TABLE (DML) statement to drop a table
  - createTable: generate SQL CREATE TABLE (DDL) statement to create a table
  - insert: generate SQL INSERT (DML) statement to insert a new row into a table
  - delete: generate SQL DELETE (DML) statement to delete a row from a table
  - update: generate SQL UPDATE (DML) statement to update rows in a table
  - query: generate SQL SELECT (DML) statement to query the database

dmlAccess Class

The dmlAccess class provides connectivity between the application and the RDBMS. Other than controlling a connection between the application and the relational database, this class also manages all transactions to enforce atomicity.

- Existing Attributes
  - userID: the user name for the relational database
  - password: the password for the relational database
  - ip: the ip address of the relational database system
  - dbID: the identification of the relational database management system

  - dbConnect: the JDBC connection provided by the relational database management system vendor.

- Existing Methods:

  - open: open a connection to the relational database
  - close: close the current opened connection
  - exeSQL: execute a SQL statement (perform an atomic transaction) without return values
  - connectionInfo: get the current connection information
  - checkConnection: check to see if a connection is opened
  - startTransaction: start a long transaction
  - endTransaction: end a long transaction

dbInit Class

The dbInit class contains static variables mapped from the SESM database schema and it provides the method to initialize the relational database

- New Attributes

  - NSMTEMPLATE, NSM_ID, PORTVARIABLE, PT_VARNAME, PT_VARTYPE, PT_VARVALUE, STATEVARIABLE, ST_OWNER, ST_VARNAME, ST_VARTYPE, ST_VARVALUE

- Existing Attributes

  - SESM Database Schema: static variables
  - dbConnect: connectivity to the relational database.

- Existing Methods:
  - initDB: initialize the relational database currently connecting to. All the previous data in the database is erased. The schema is then defined in the relational database.
  - createAllTables: defines all the table schema
  - dropAllTables: drops all the table schema

dmlAdd Class

The dmlAdd class performs add operations (SQL INSERT) on database.

- Existing Attributes
  - dbConnect: connectivity to the relational database
  - theQuery: to query the data from the database.
- New Methods
  - modelNSMT: insert a new row into the NSMTemplate table
  - portVariableT: insert a new row into the portVariable table
  - stateVariableT: insert a new row into the stateVariable table
- Existing Methods:
  - modelT: insert a new row into the modelTemplate table

  - modelTI: insert a new row into the modelTI table
  - port: insert a new row into the portTemplate table
  - portTI: insert a new row into the portTI table
  - compomentOf: insert a new row into the componentOf table
  - coupling: insert a new row into the coupling table
  - modelI: insert a new row into the modelInstance table
  - MTItoSMI: insert a new row into the MTItoSMI table
  - componentOfI: insert a new row into the componentOfI table
  - addRow: insert a new row to a particular table

dmlDel Class

The dmlDel class performs delete operations (SQL DELETE) on the database

- Existing Attributes
  - dbConnect: connectivity to the relational database.
- New Methods
  - portVariableT: delete a row in the portVariable table
  - stateVariableT: delete a row in the stateVariable table
- Existing Methods:
  - modelT: delete a row in the modelTemplate table
  - modelTI: delete a row in the modelTI table

  - port: delete a row in the portTemplate table
  - portTI: delete a row in the portTI table
  - compomentOf: delete a row in the componentOf table
  - coupling: delete a row in the coupling table
  - modelI: delete a row in the modelInstance table
  - MTItoSMI: delete a row in the MTItoSMI table
  - componentOfI: delete a row in the componentOfI table
  - deleteRow: delete a row in a particular table

dmlModify Class

The dmlModify class performs modify operations (SQL UPDATE) on database

- Existing Attributes
  - dbConnect: connectivity to the relational database.
- New Methods
  - portVariable: modify a row in the portVariable table
  - stateVariable: modify a row in the stateVariable table
- Existing Methods:
  - modelName: modify the model template name (Name) in the modelTemplate table

- modelType: modify the model template type (modelType) in the modelTemplate table
- instanceName: modify the model instance name (modelName) in the modelInstance table
- modifyRow: modify a row in a particular table

dmlQuery Class

The dmlQuery class performs query operations (SQL SELECT) on database

- Existing Attributes
  - dbConnect: connectivity to the relational database.
- New Methods
  - modelNSMT: query the NSM template(s) from NSMTemplate table
  - portVariableT: query port variable name from portVariable table
  - portVariableTypeT: query port variable data type from portVariable table
  - portVariableValueT: query port variable value from portVariable table
  - stateVariableT: query state variable name from stateVariable table
  - stateVariableTypeT: query state variable data type from stateVariable table
  - stateVariableValueT: query state variable value from stateVariable table
  - getNsmModels: query the names of all the existing NSM models
- Existing Methods:

  - modelT: query the modelTemplate table
  - modelTI: query the modelTI table
  - port: query the portTemplate table
  - portTI: query the portTI table
  - componentOf: query the componentOf table
  - coupling: query the coupling table
  - modelI: query the modelInstance table
  - MTItoSMI: query the MTItoSMI table
  - componentOfI: query the componentOfI table
  - getData: query a particular table

3.3. sesmNet package.

ServerUtility Class

This new class is added to provide the utilities to the server to deal with the events sent by the user to create, view, modify three different types of the models namely, XML, Java or NSM models.

- Methods
  - createFile: generic method which creates different types of files for models (XML, Java, NSM) in appropriate folders on the server.
  - isFilePresent: generic method to check whether a particular type of method is present in a particular folder on server.
  - getOverWritePermission: generic method to get the permission for overwriting the file in a particular folder on server

- writeToFile: generic method to write the contents of the file and send return event to client upon completion
- getFile: method to get XML file on the server to create corresponding Java model
- viewFile: generic method to process view event of the client and send him a correct file from the server to view it on client
- addNsmToDB: method to add NSM model to database.

In addition to this, the existing code of the sesmNet.sesmServer, sesmNet.sesmClient and sesmEvent.sesmEvent classes is extended to incorporate the functionalities related to the creation, deletion and modification of port variables, state variables and creation, modification and viewing of NSM models, XML models and Java Models.

The sequence diagram details sequence of server operations for adding a state variable to an atomic model depicting the relationship between different SESM transactions and SQL transactions is shown in Figure 20.

4. SESM Client Design Extensions

In SESM architecture, client is one of the four major components. The client can create, delete or modify the model data by sending a request with required parameters to the server as shown in Figure 21. The clients requests are serialized if they are intended to modify the model. The serialization ensures that the server receives only a single request at a time. When the server receives the modification request, it broadcasts the notification to all the clients associated with it. When the client receives the notification from the server, it reads the model data directly from the database, refreshes the GUI accordingly and notifies the user about the modifications made. If a request for reply from the Server

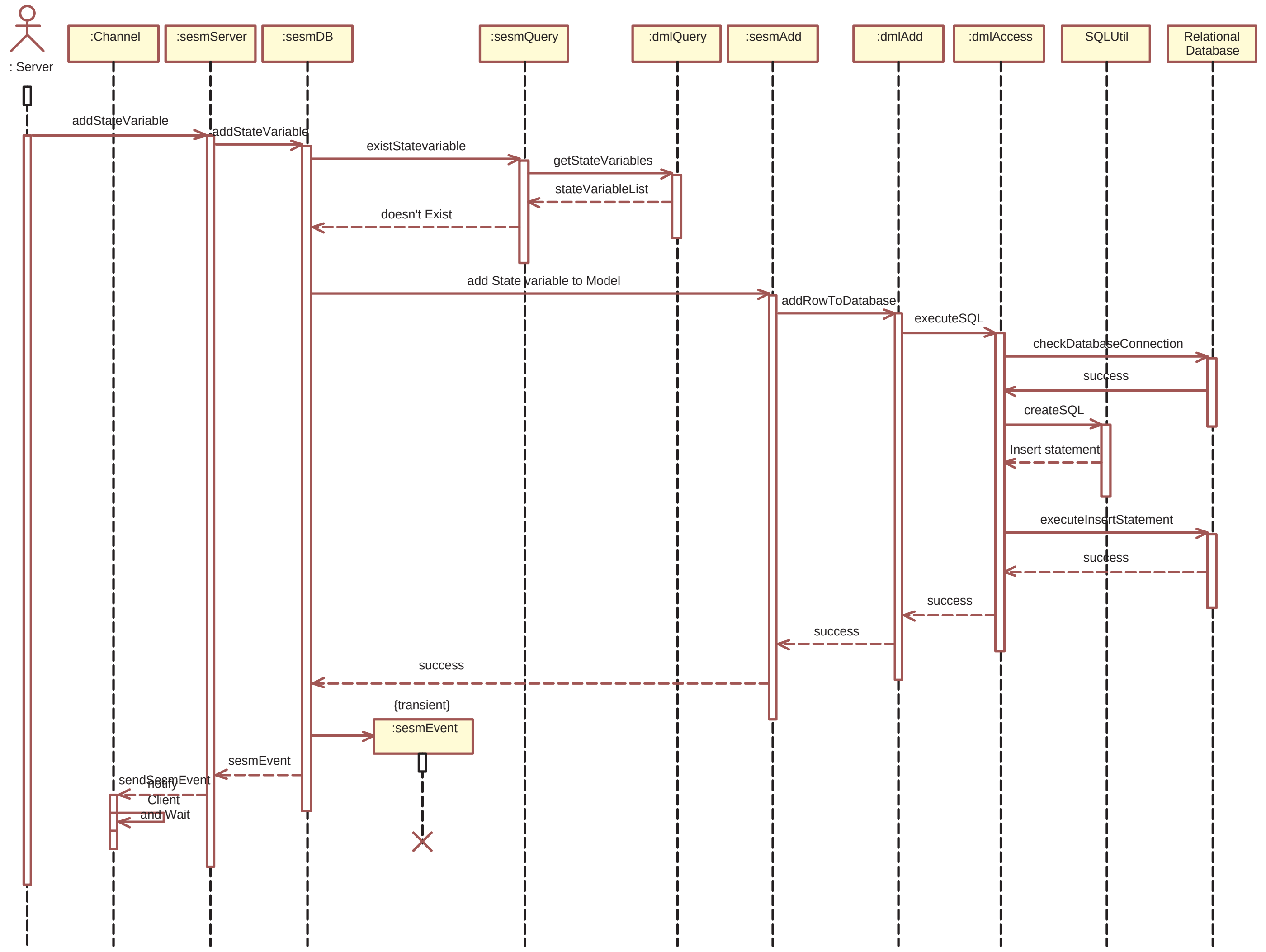


Figure 20. SESM Server Sequence Diagram : Add State Variable Operation

was received, the Client interacts with the user to obtain the reply and send it back to the Server. However, if the transaction (modification) is not complete, server sends out a notification to a specific client who is requesting the modification with the reason of failure. Thus, requesting client receives the feedback of the incomplete transactions.

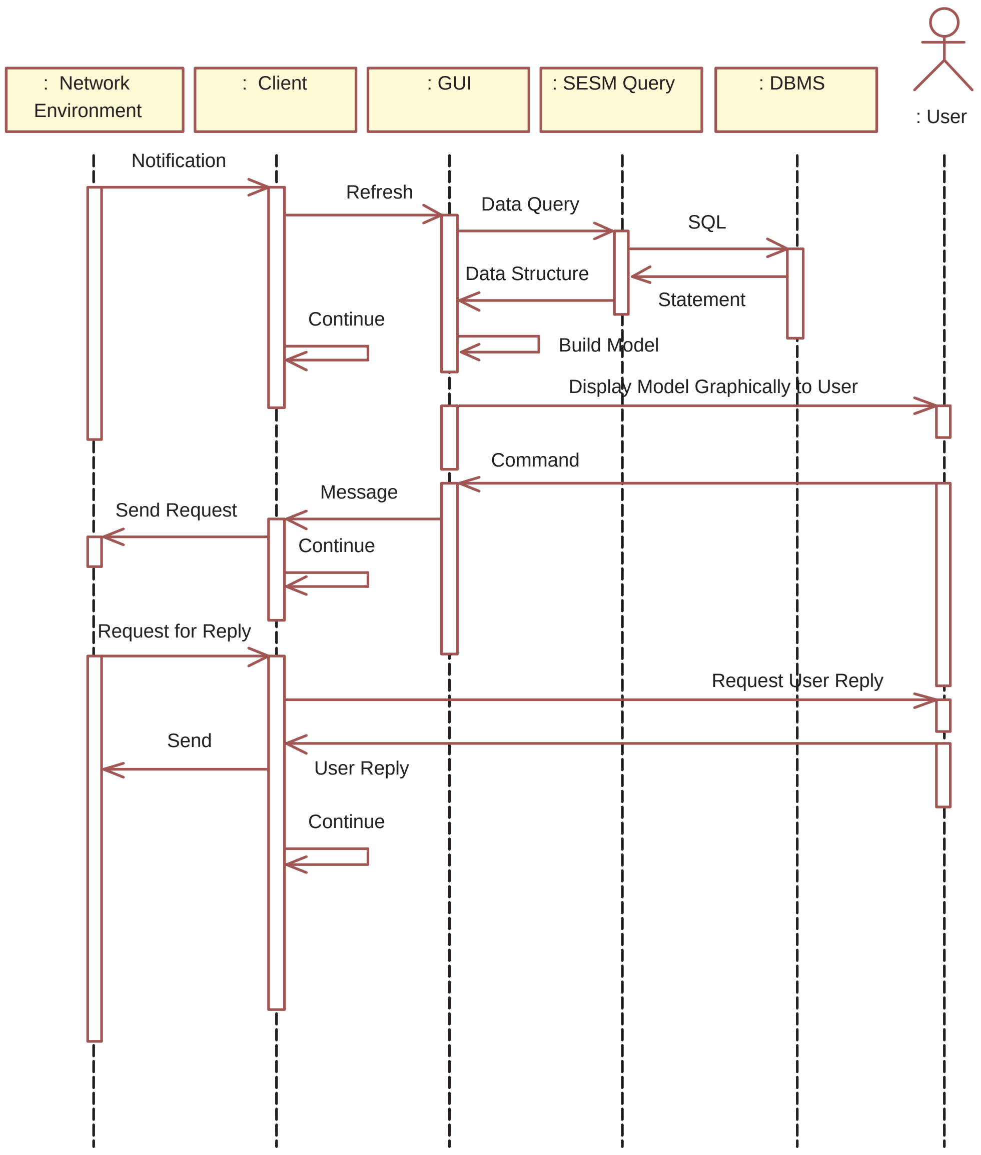


Figure 21. SESM Client interaction diagram

CHAPTER 5

USER INTERFACE DESIGN

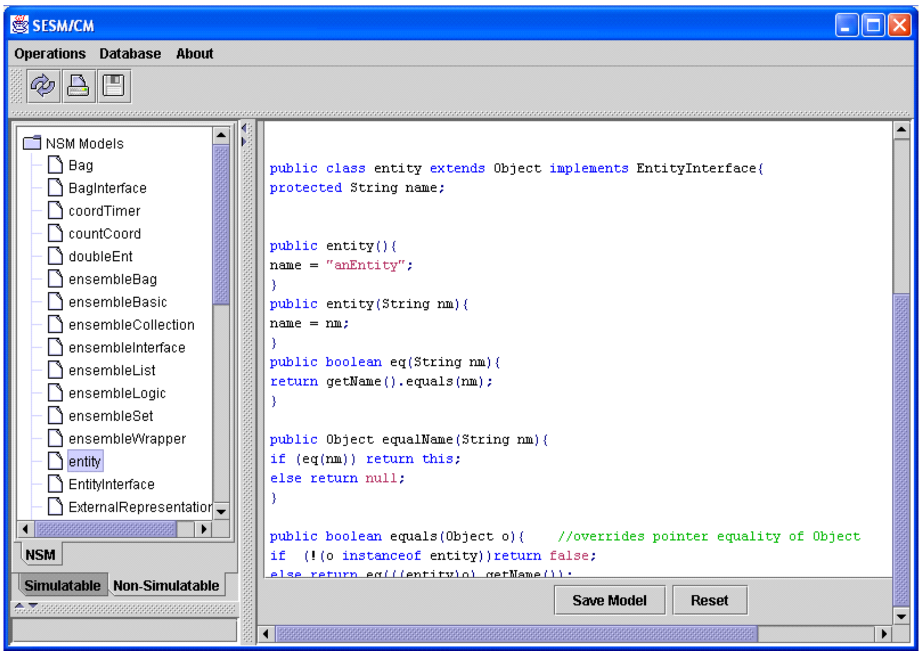
1. Client GUI Analysis

The graphical user interface (GUI) of the SESM modeling environment (as shown in Figure 2) is divided in to three main divisions, namely

- Model Tree Structure: This view represents the model data, stored in the database, in a hierarchical tree like structure. It maintains three types of trees - Template Model tree (TM), Instance Template tree (ITM) and Instance Model Tree (IM).
- Model Components: This view creates graphical representation of model structure, ports, couplings and components to make them easy to read and manipulate.
- Command Menu: This is a pop-up menu provided to the user to interact easily with the visual models and to manipulate them.

All these three areas of the client GUI are extended in order to support the objectives of this research as well as to provide better interaction and better view for the user.

1.1. Model Tree Structure Extension. This view is extended to support Non-Simulatable Model Tree (NSM) as shown on the left-hand side in Figure 22. Also, simulatable model trees and non-simulatable model tree are separated from each other by putting



```
public class entity extends Object implements EntityInterface{
protected String name;


public entity(){
name = "anEntity";
}
public entity(String nm){
name = nm;
}
public boolean eq(String nm){
return getName().equals(nm);
}

public Object equalName(String nm){
if (eq(nm)) return this;
else return null;
}

public boolean equals(Object o){    //overrides pointer equality of Object
if  (!(o instanceof entity))return false;
else return eq(((entity)o).getName());
```

Figure 22. Non-Simulatable Model Tree and View

them in two different tabs, specifically, Simulatable and Non-Simulatable. Non-Simulatable tree displays all the non-Simulatable models available to the user in an alphabetical order, but doesn't support the composition or hierarchical structure of the model.

This GUI also supports the creation of new NSM models. A new pop-up menu is provided for NSM trees non-leaf node, which allows a user to add new NSM models on a server. On server, NSM model name is stored in the database along with the creation time, while the model source code is stored on the server as a flat file at a specified location. When user clicks on the "add new NSM" menu, it asks user for the model name and then creates the model on server and refreshes the NSM tree view to reflect the addition of new model.

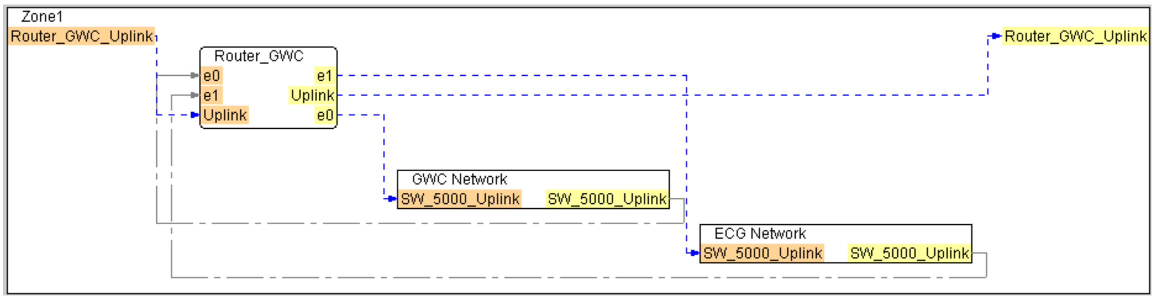


Figure 23. Model Visualization Enhancements

1.2. Model Components Extension. This view is also extended to support the visualization of the code of the non-simulatable model in addition to graphical representation of simulatable models as shown on the right hand side of Figure 22. This view extracts the source code of the model selected by the user on the tree (i.e., entity in this case) and views it on the right-hand side. It also provides a facility to manipulate the non-simulatable model at the source code level by supporting the editing and saving of the source code.

The graphical representation of the atomic and coupled models is enhanced by differentiating in their shapes by showing atomic models as rectangles while the coupled models as rounded rectangles. Forward and feedback couplings are also differentiated from each other by providing them with different line types. These enhancements are shown in Figure 23. In this diagram, “Router_GWC” is an atomic model while “GWC Network”, “ECG Network” and “Zone1” are coupled models. Forward couplings are shown by “dotted lines” while feedback couplings are shown as “center-lines”.

1.3. Command Menu Extension.

Re-structuring of model menu

Visual model command menu is restructured from the previous version of modeling

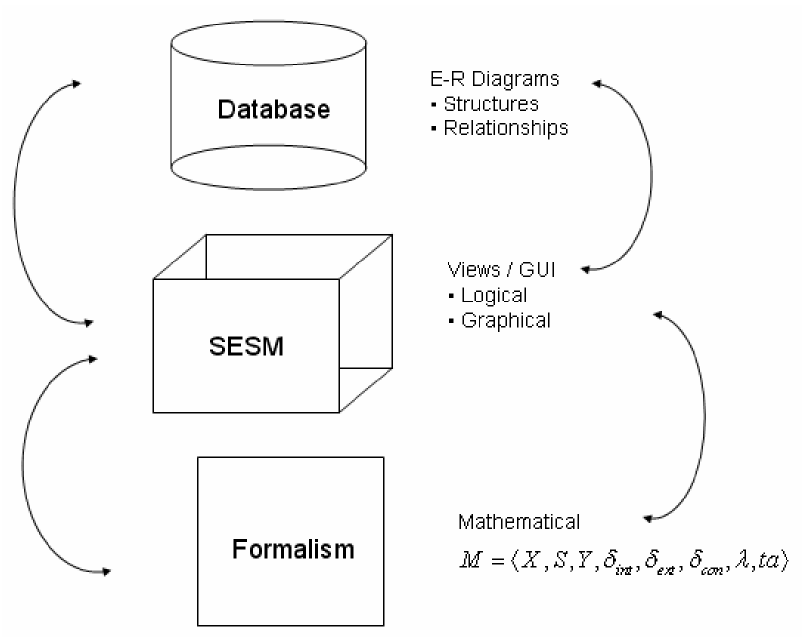


Figure 24. Relationship between Formalism, Database and GUI

environment i.e., SESM/CM. The rationale for changing this is to keep the consistency between the System View (i.e., mathematical representation of model), SESM views/GUI (i.e., graphical or logical representation of model) and Database (i.e., structural and relational representation of the model) as shown in Figure 24.

As shown in the figure, the formalism defines the models in terms of X (set of inputs), S (set of states) and Y (set of outputs). The database is also designed to have similar relations such as port variable table (inputs and outputs) and state variable table (states). In order to make the user specification of the model consistent with the system formalism and database, the model menu for capturing these specifications graphically is designed as shown in Figure 25.

This is a high level menu which is divided into different types of modeling activities. The middle portion of the menu is divided into three parts input port, output port and

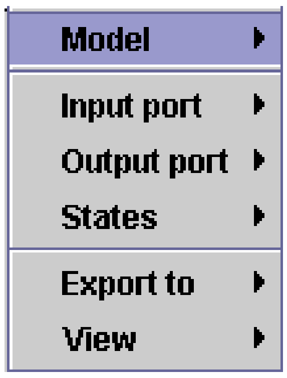


Figure 25. Model Menu for an Atomic model

states correspond to inputs, outputs and states described in the formalism and database.

Capturing Behavioral Aspects

Model menu incorporates the menu items to provide facility to capture different structural as well as behavioral aspects of the model. Structural aspects (i.e., creating a model template, adding a component, port, coupling) of the model are supported in the previous version of SESM/CM. Therefore, this research primarily concentrates on offering a mechanism to the user to specify the behavioral aspects of the model. This mainly involves the design of the user interface for specification and modification of input, output and state variables. It also involves redesign of structural model menu items. Figure 26 shows menu for the specification of an input port variable.

When the user clicks on the menu, corresponding input dialog appears, as shown in Figure 27, to accept inputs from the user. It takes the inputs such as port name, variable name, variable data type and variable value from the user. It is designed in such a way that for all combo-boxes except for the data type combo-box, the data is generated at run time depending on the model selected and the data corresponding to that model existed in the

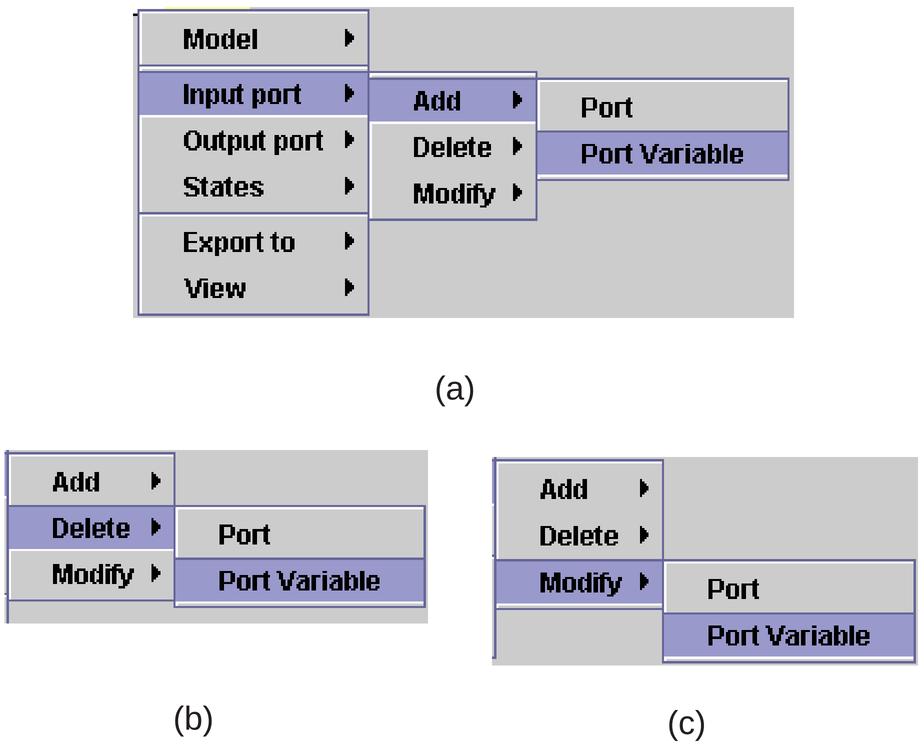


Figure 26. Model Menu for a. Adding, b. Deleting, c. Modifying Input Port Variable

database. This achieves automatic input validation. Also, it makes sure that user enters all the other required input parameters. Variable data type can be one of the primitive data types (i.e., character, integer, float, double, long, boolean or string) or one of the non-simulatable models.

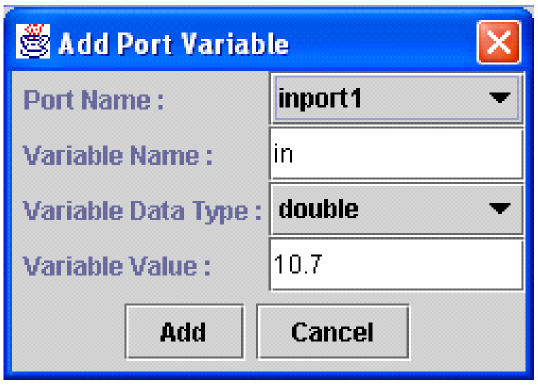
User can access these non-simulatable models by using the “configure” item in the data type combo-box which allows user to select the NSM from the list by showing it in a dialog box as shown in Figure 28. Similar interfaces are created for the output variable and state variable specification.

Some structural user interfaces are also created for the operations “Delete Component” and “Modify Component” to delete or modify the sub-component of a model respectively as shown in Figure 29 and Figure 30.

Model Transformation

SESM is a modeling engine that supports the development of models which may be simulated using a simulation engine. Therefore, once their structure and behavior is specified, they can be simulated to observe behavior and enable model validation. To achieve this, models need to be converted into simulation compatible format. In this case, it is DEVSJAVA format as this research is using DEVSJAVA as a simulation environment.

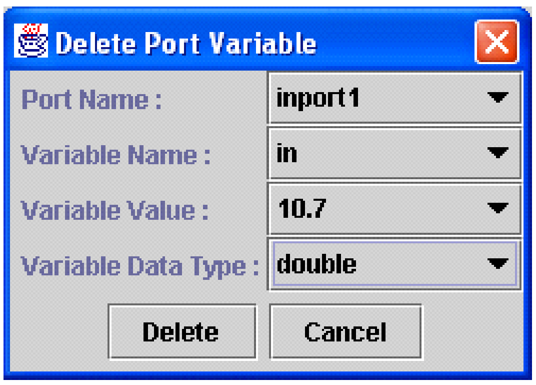
To support this, SESM is provided with an additional menu item, “Export to”. This menu item further gives options to export the model to either XML model (i.e., XML format) or DEVSJAVA model (i.e., Java format) as shown in Figure 31. When user clicks the menu item, SESM creates the corresponding model as a flat file on server at an appropriate location and sends a notification to the client regarding the creation and location of the model.



Add Port Variable

Port Name :	inport1
Variable Name :	in
Variable Data Type :	double
Variable Value :	10.7

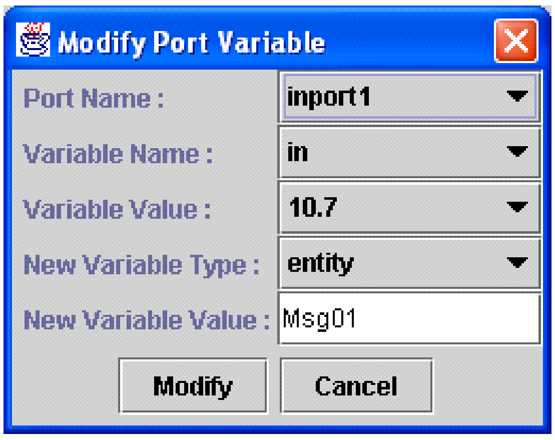
(a)



Delete Port Variable

Port Name :	inport1
Variable Name :	in
Variable Value :	10.7
Variable Data Type :	double

(b)



Modify Port Variable

Port Name :	inport1
Variable Name :	in
Variable Value :	10.7
New Variable Type :	entity
New Variable Value :	Msg01

(c)

Figure 27. Interface for a. Adding b. Deleting c. Modifying Input Port Variable

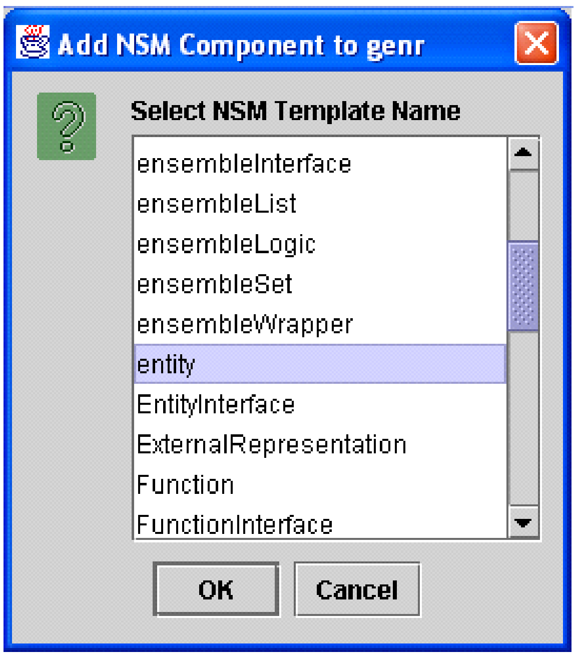


Figure 28. Interface for Selecting the NSM as a Variable

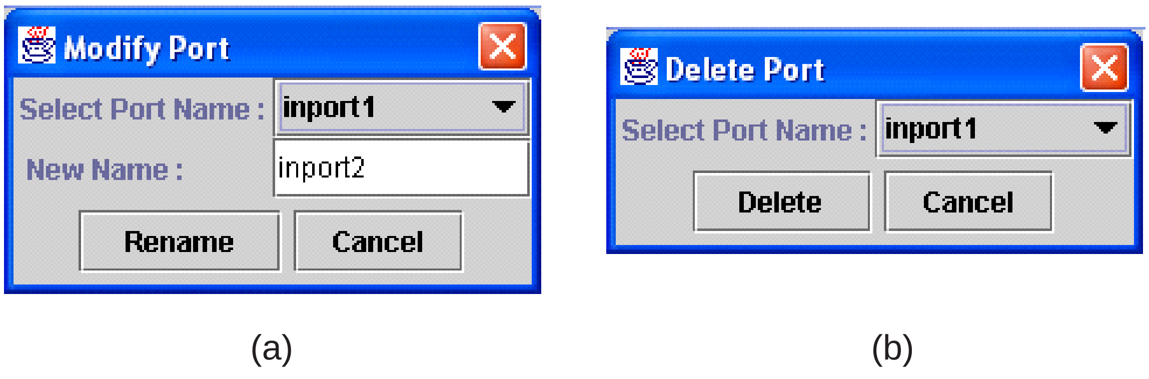


Figure 29. Interface for a. Modifying b. Deleting Port of a model

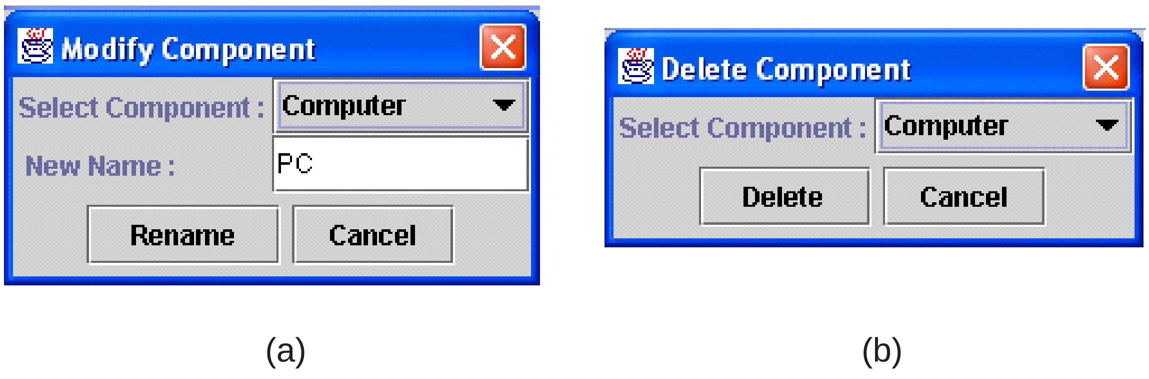


Figure 30. Interface for a. Modifying b. Deleting Component of a model

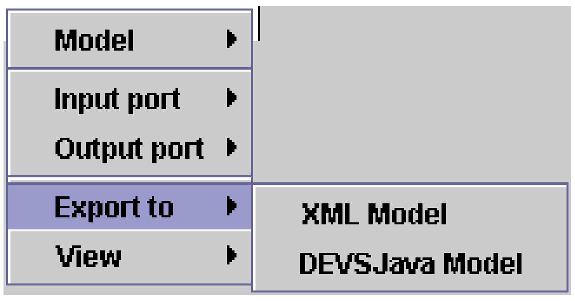


Figure 31. Menu for Model Export

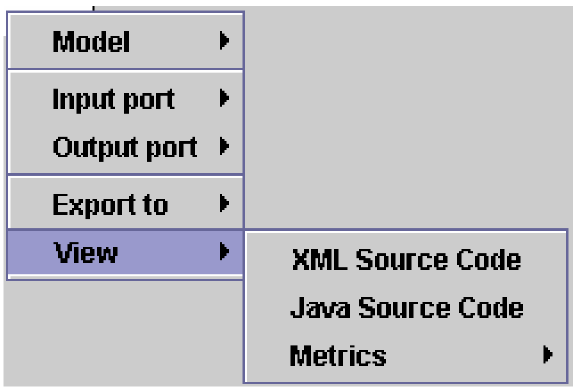


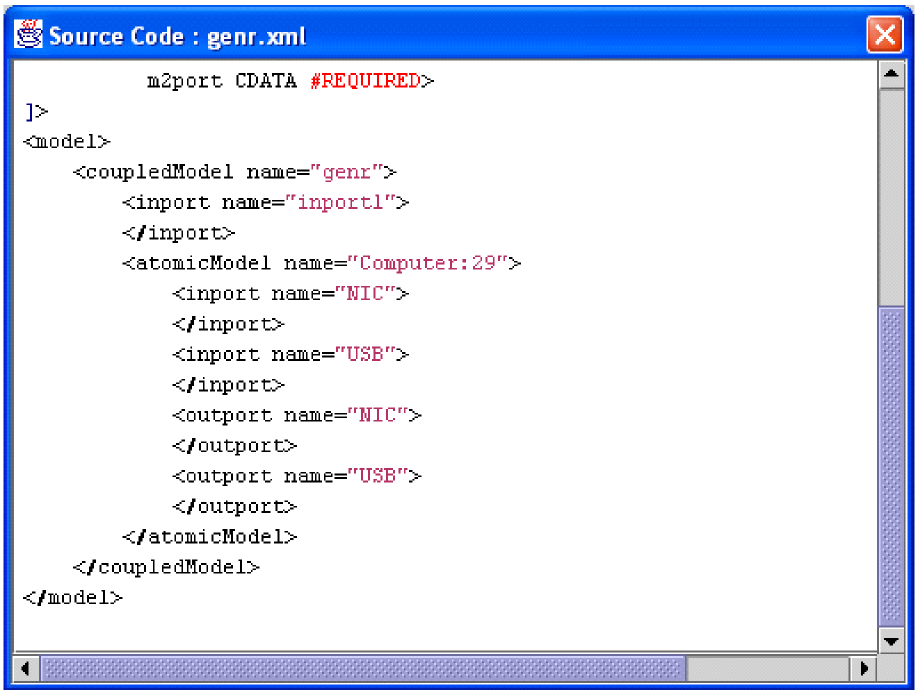
Figure 32. Menu for Source Code View

Once the model is created on server it is necessary to have a mechanism for the user to view the source code of the same. For this, SESM is supported with a menu called "View". This menu is again divided to view XML Source Code, Java Source Code and Metrics of a model as shown in Figure 32.

When the user clicks on the menu to view XML or Java source code, corresponding model in the form of a flat file is requested from the server and showed to the user in the GUI as shown in Figure 33 and Figure 34. respectively.

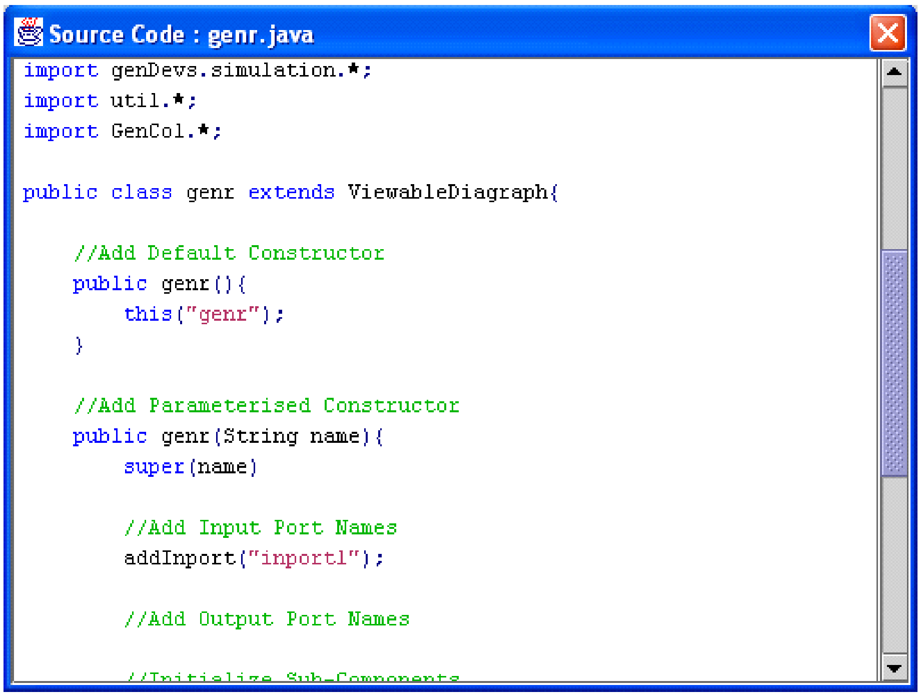
Model Metrics

Under "View" menu item there is another sub-menu item which allows user to see the structural metrics and behavioral information about the model. The behavioral information of the model shows ports, port variables, state variables, variable types and variable values (see Figure 35).



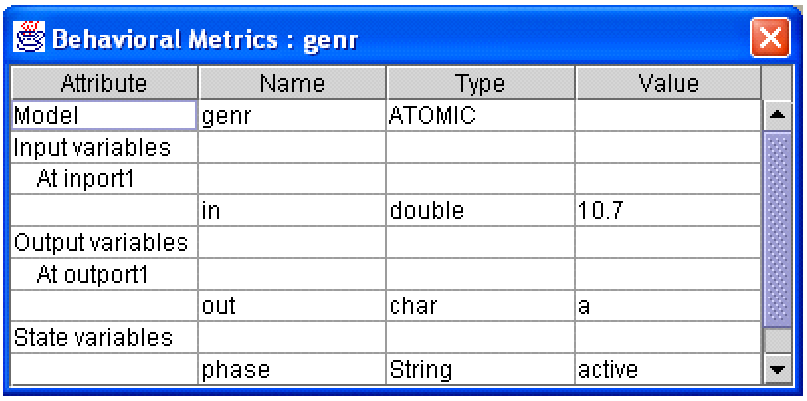
```
           m2port CDATA #REQUIRED>
]>
<model>
    <coupledModel name="genr">
        <inport name="inport1">
        </inport>
        <atomicModel name="Computer:29">
            <inport name="NIC">
            </inport>
            <inport name="USB">
            </inport>
            <outport name="NIC">
            </outport>
            <outport name="USB">
            </outport>
        </atomicModel>
    </coupledModel>
</model>
```

Figure 33. Model Viewing GUI for XML Model



```
import genDevs.simulation.*;
import util.*;
import GenCol.*;

public class genr extends ViewableDiagraph{

    //Add Default Constructor
    public genr(){
        this("genr");
    }

    //Add Parameterised Constructor
    public genr(String name){
        super(name)

        //Add Input Port Names
        addInport("inport1");

        //Add Output Port Names

        //Initialize Sub-Components
```

Figure 34. Model Viewing GUI for Java Model



Attribute	Name	Type	Value
Model	genr	ATOMIC	
Input variables			
At inport1			
	in	double	10.7
Output variables			
At outport1			
	out	char	a
State variables			
	phase	String	active

Figure 35. Behavioral Information of Model

2. GUI Design Extension

The sesmUI package is designed to support displaying a set of classes. sesmUI package is restructured and is now divided into sesmUI.menu, sesmUI.graphics, sesmUI.panel and sesmUI.builder sub-packages to support visual object based command menu and constraint-based drawing respectively. Another sub-package is created within sesmUI.menu package called sesmUI.menu.subMenu to support functionality of different submenus formed after the restructuring of the menus from the previous version. These new packages (i.e., panel, builder and sub-menu) support the behavioral aspects of an atomic model and also non-simulatable model functionality. The GUI is implemented using the Swing and AWT packages in the Java Foundation Classes (JFC).

sesmUI package is restructured. It has now only two classes, namely sesmGUI and rootModel. More detailed descriptions of the new package are given below. The sesmGUI class represents the overall GUI that user will interact with. The rootModel class provides basic capabilities such as refresh and mode. The sesmUI. graphics package consists of a set of classes for visualizing a single or multi-level model. These classes collectively define the set of constraints (e.g., diagonal placement of model components) that are necessary for organizing components in a systematic fashion. sesmUI.builder is new package created due to the restructuring of the classes. This contains all the old classes related to the tree building functionality (such as treeBuilder, treeSelectionListener, modelNode and message) and a new class NSMBuilder which essentially support building and storing of new NSM models and viewing of existing NSM models.

sesmUI.menu package is altered as mentioned before to restructure the menus to make these menus hierarchical and mainly consistent with the formalism. And a new package, named submenu is added within a sesmUI.menu package. Class representation of this package is shown in Figure 36.

Classes in this package provides the functionality corresponding to capturing the user inputs related to the specification of the behavioral aspects of the model, model transformation and model view. This supports capturing and packing this information in to an appropriate event and sending that event to the server for further processing.

Another new package is created within sesmUI called panel. Class representation of this package is shown Figure refsemUI.panel Class Diagram. This package provides the functionality of providing the user interface for the actual specification of different values for sub-components, input-output ports, input-output port variables and state variables.

These panels contains different user interface components such as text boxes, combo boxes, lists, buttons, etc. to enter the actual values or to interact with the actual system.

An extensive sequence diagram for client for the same “Add State Variable” operation for server shown in Figure 20 is shown in Figure 38.

3. Model Transformation Design

A new package is created for the transformation of the model. This transformation involves the conversion of the graphical model whose information is stored in the database in the form of relations, into simulation compatible models. For this, a two step approach is developed which involves the conversion of the model first into XML model and then from XML to DEVSJAVA model.

The rationale behind the two step conversion instead of directly converting into DEVSJava model is to provide reusability. DEVSJAVA is a simulation engine specific to carry out simulation of discrete event models while on the other hand SESM is a generic

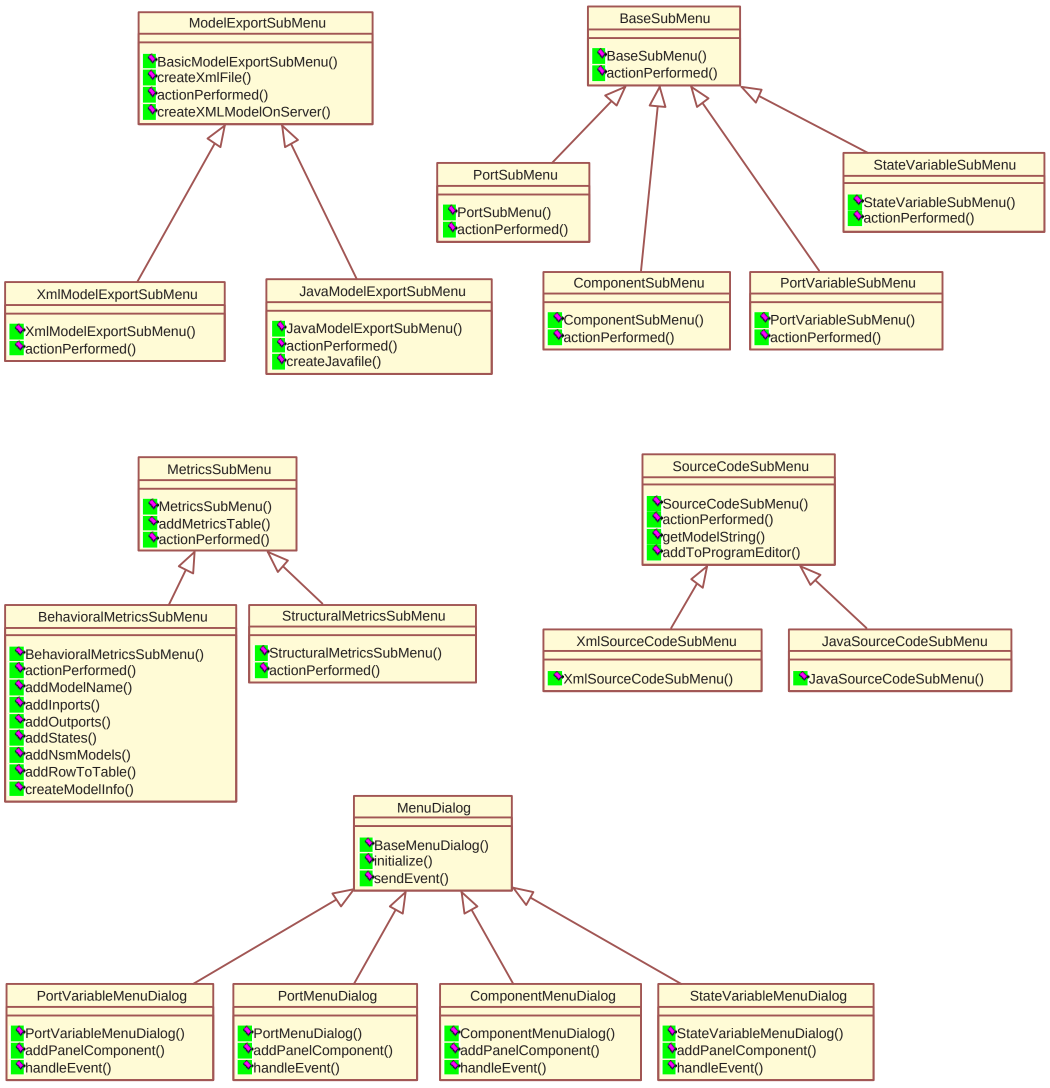


Figure 36. semUI.menu.subMenu Class Diagram

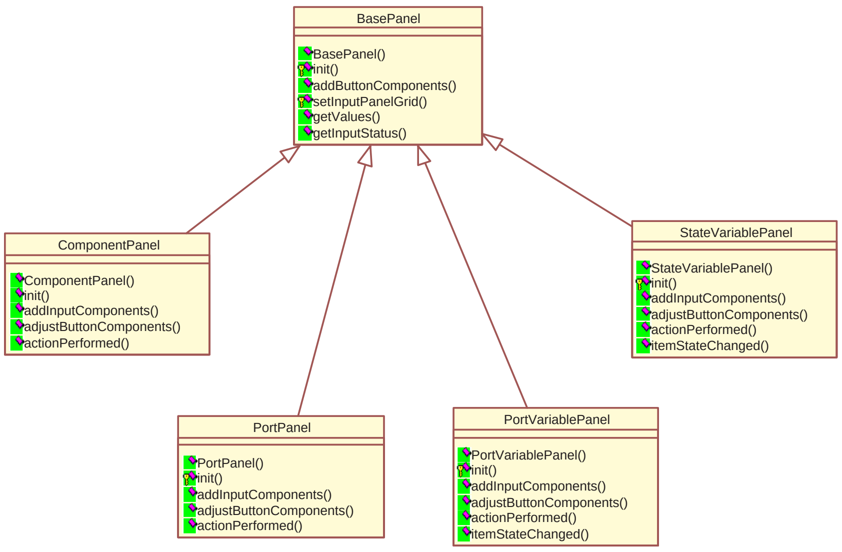


Figure 37. semUI.panel Class Diagram

modeling engine which can support three types of models (i.e., continuous, discrete time and discrete event). Since, XML is generic, once the modeler has XML model he can simulate it using any type of simulator provided he has a mechanism to convert this XML model to the model compatible to his simulation environment. But, this research is concentrating on XML and DEVSJAVA combination as it uses DEVSJAVA as a simulation environment.

In SESM, transformation package is created which is further sub-packaged in to "xml" package and "java" package which correspond to conversion of model to XML and Java models respectively.

3.1. tranformation.xml package. This package is divide into two packages namely, transformation.xml.xmlFormatter and transformation.xml.metaDevsXml. Class diagram for xmlFormatter package and metaDevsXml package are shown in Figure 39 and 40.

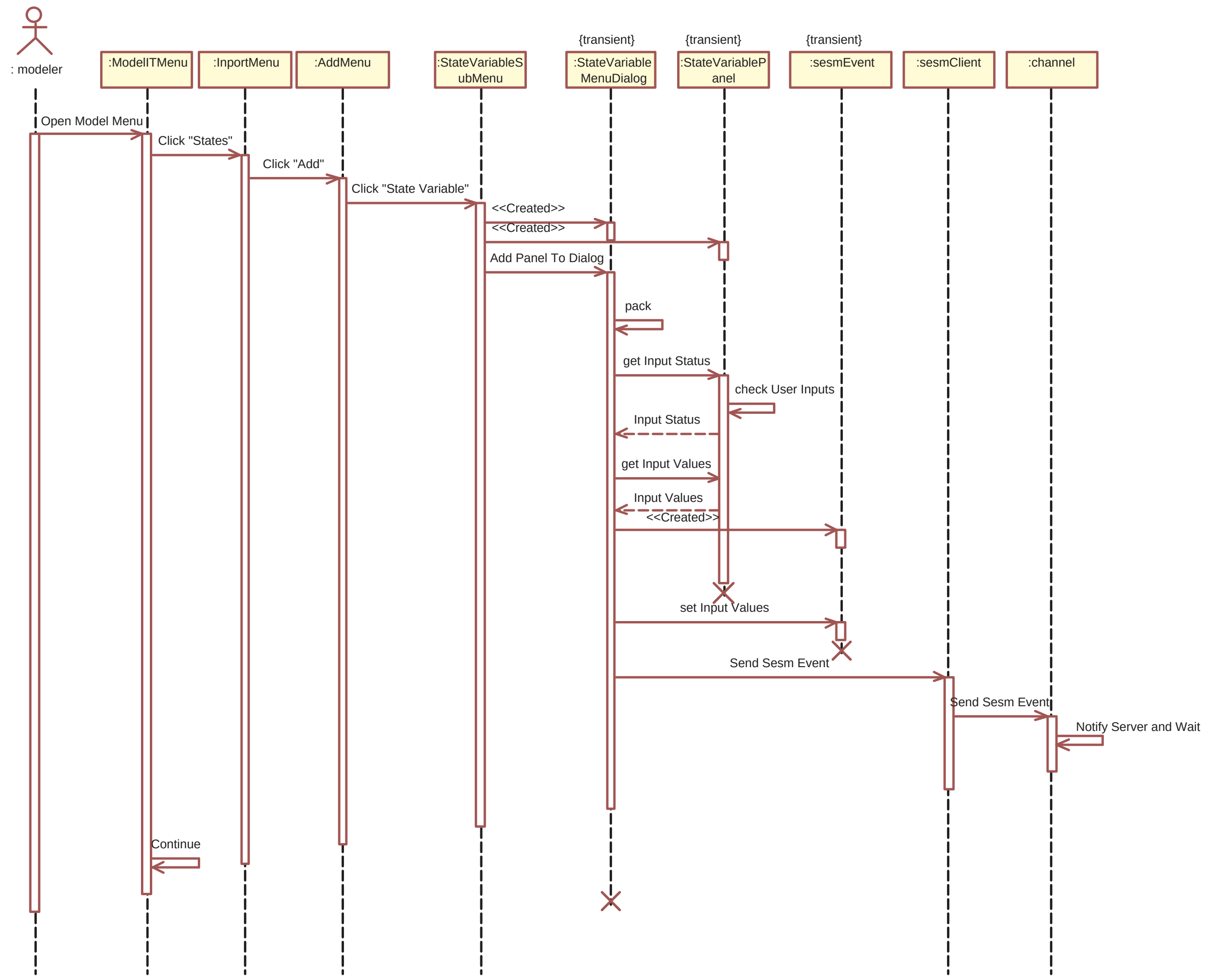


Figure 38. Client Sequence Diagram : Add State Variable Operation

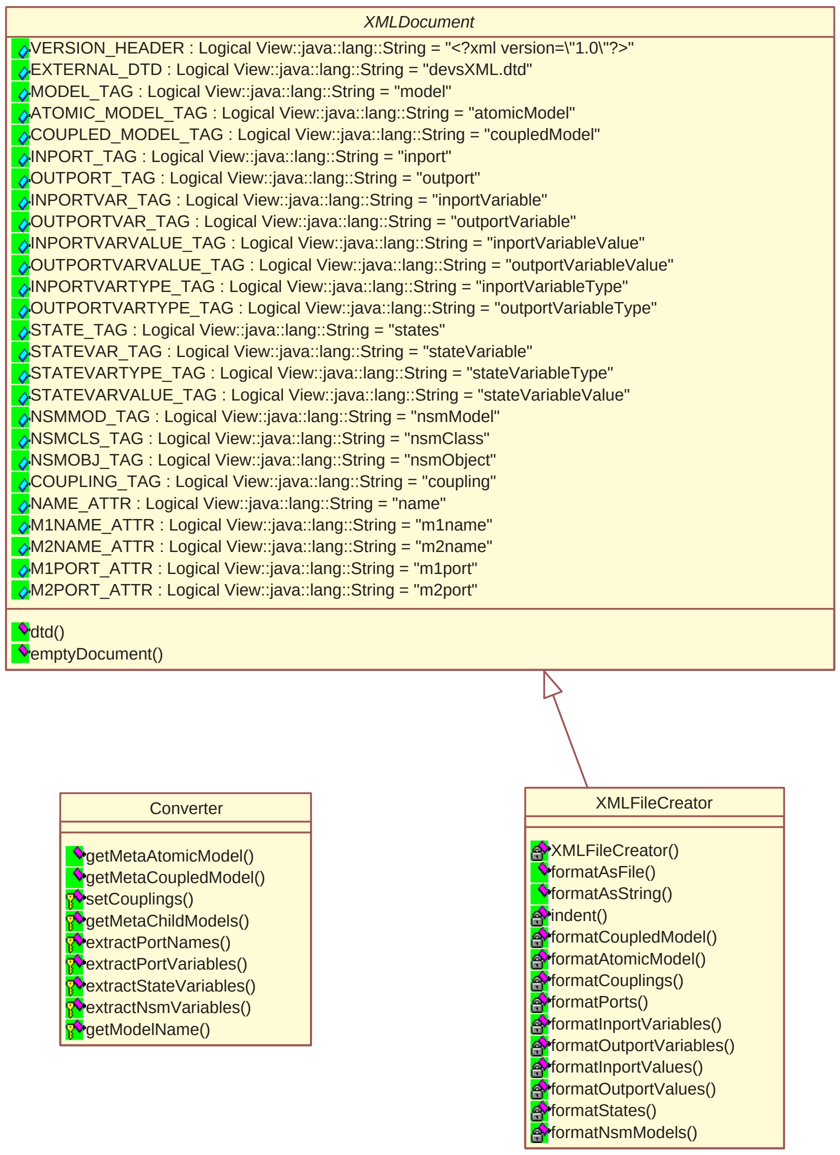

XMLDocument
VERSION_HEADER : Logical View::java::lang::String = "<?xml version=\"1.0\"?>"
EXTERNAL_DTD : Logical View::java::lang::String = "devsXML.dtd"
MODEL_TAG : Logical View::java::lang::String = "model"
ATOMIC_MODEL_TAG : Logical View::java::lang::String = "atomicModel"
COUPLED_MODEL_TAG : Logical View::java::lang::String = "coupledModel"
INPORT_TAG : Logical View::java::lang::String = "inport"
OUTPORT_TAG : Logical View::java::lang::String = "outport"
INPORTVAR_TAG : Logical View::java::lang::String = "inportVariable"
OUTPORTVAR_TAG : Logical View::java::lang::String = "outportVariable"
INPORTVARVALUE_TAG : Logical View::java::lang::String = "inportVariableValue"
OUTPORTVARVALUE_TAG : Logical View::java::lang::String = "outportVariableValue"
INPORTVARTYPE_TAG : Logical View::java::lang::String = "inportVariableType"
OUTPORTVARTYPE_TAG : Logical View::java::lang::String = "outportVariableType"
STATE_TAG : Logical View::java::lang::String = "states"
STATEVAR_TAG : Logical View::java::lang::String = "stateVariable"
STATEVARTYPE_TAG : Logical View::java::lang::String = "stateVariableType"
STATEVARVALUE_TAG : Logical View::java::lang::String = "stateVariableValue"
NSMMOD_TAG : Logical View::java::lang::String = "nsmModel"
NSMCLS_TAG : Logical View::java::lang::String = "nsmClass"
NSMOBJ_TAG : Logical View::java::lang::String = "nsmObject"
COUPLING_TAG : Logical View::java::lang::String = "coupling"
NAME_ATTR : Logical View::java::lang::String = "name"
M1NAME_ATTR : Logical View::java::lang::String = "m1name"
M2NAME_ATTR : Logical View::java::lang::String = "m2name"
M1PORT_ATTR : Logical View::java::lang::String = "m1port"
M2PORT_ATTR : Logical View::java::lang::String = "m2port"
dtd()
emptyDocument()
Converter
getMetaAtomicModel()
getMetaCoupledModel()
setCouplings()
getMetaChildModels()
extractPortNames()
extractPortVariables()
extractStateVariables()
extractNsmVariables()
getModelName()
XMLFileCreator
XMLFileCreator()
formatAsFile()
formatAsString()
indent()
formatCoupledModel()
formatAtomicModel()
formatCouplings()
formatPorts()
formatInportVariables()
formatOutportVariables()
formatInportValues()
formatOutportValues()
formatStates()
formatNsmModels()

Figure 39. transformation.xml.xmlFormatter Class Diagram

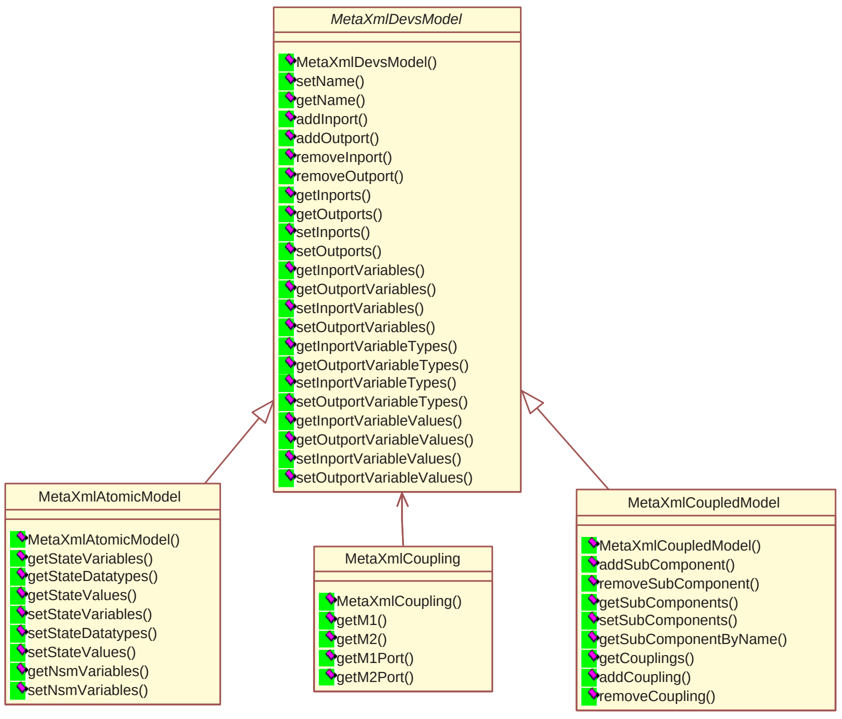


Figure 40. transformation.xml.metaDevsXml Class Diagram

Converter class extracts the information of the graphical model in terms of model name, model type, sub-components, ports, couplings, port variables and state variables. XMLFileCreator class formats the extracted values by converter in to a XML file. It uses XMLDocument which stores all the constant values for the different tags in the XML document.

xmlFormatter package consists of classes such as metaXmlAtomicModel, metaXml-Coupling and metaXmlCoupledModel which provide get and set method to store the information extracted by the converter class explained before. These methods are specific to atomic model, coupling and coupled model while the information common to all these is stored in the super class metaXmlDevsModel.

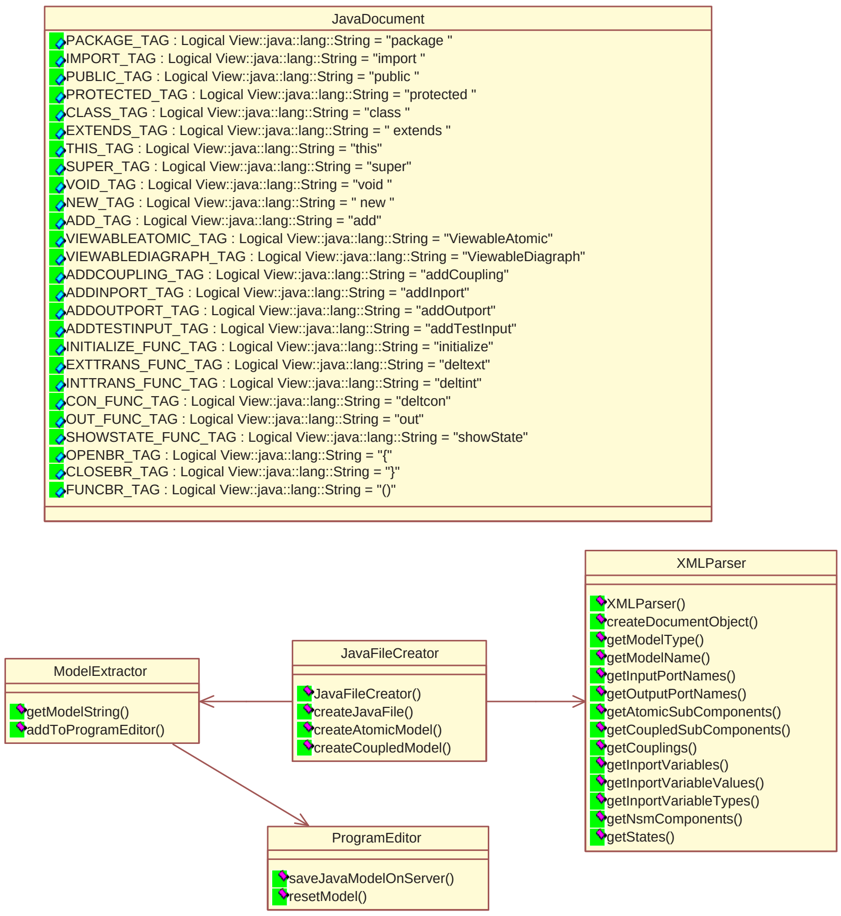

JavaDocument
PACKAGE_TAG : Logical View::java::lang::String = "package "
IMPORT_TAG : Logical View::java::lang::String = "import "
PUBLIC_TAG : Logical View::java::lang::String = "public "
PROTECTED_TAG : Logical View::java::lang::String = "protected "
CLASS_TAG : Logical View::java::lang::String = "class "
EXTENDS_TAG : Logical View::java::lang::String = " extends "
THIS_TAG : Logical View::java::lang::String = "this"
SUPER_TAG : Logical View::java::lang::String = "super"
VOID_TAG : Logical View::java::lang::String = "void "
NEW_TAG : Logical View::java::lang::String = " new "
ADD_TAG : Logical View::java::lang::String = "add"
VIEWABLEATOMIC_TAG : Logical View::java::lang::String = "ViewableAtomic"
VIEWABLEDIAGRAPH_TAG : Logical View::java::lang::String = "ViewableDiagraph"
ADDCOUPLING_TAG : Logical View::java::lang::String = "addCoupling"
ADDINPORT_TAG : Logical View::java::lang::String = "addInport"
ADDOUTPORT_TAG : Logical View::java::lang::String = "addOutport"
ADDTESTINPUT_TAG : Logical View::java::lang::String = "addTestInput"
INITIALIZE_FUNC_TAG : Logical View::java::lang::String = "initialize"
EXTTRANS_FUNC_TAG : Logical View::java::lang::String = "deltext"
INTTRANS_FUNC_TAG : Logical View::java::lang::String = "deltint"
CON_FUNC_TAG : Logical View::java::lang::String = "deltcon"
OUT_FUNC_TAG : Logical View::java::lang::String = "out"
SHOWSTATE_FUNC_TAG : Logical View::java::lang::String = "showState"
OPENBR_TAG : Logical View::java::lang::String = "{"
CLOSEBR_TAG : Logical View::java::lang::String = "}"
FUNCBR_TAG : Logical View::java::lang::String = "()"
XMLParser
XMLParser()
createDocumentObject()
getModelType()
getModelName()
getInputPortNames()
getOutputPortNames()
getAtomicSubComponents()
getCoupledSubComponents()
getCouplings()
getInportVariables()
getInportVariableValues()
getInportVariableTypes()
getNsmComponents()
getStates()
ModelExtractor
getModelString()
addToProgramEditor()
JavaFileCreator
JavaFileCreator()
createJavaFile()
createAtomicModel()
createCoupledModel()
ProgramEditor
saveJavaModelOnServer()
resetModel()

Figure 41. transformation.java.javaFormatter Class Diagram

3.2. tranformation.java package. This package is divide into two packages namely, transformation.java.javaFormatter and transformation.java.metaDevsjava. Class diagram for javaFormatter package and metaDevsjava package are shown in Figure 41 and 42.

XMLParser class extracts the information of the model from XML model in terms of model name, model type, sub-components, ports, couplings, port variables and state variables. JavaFileCreator class formats the extracted values by XMLParser in to a Java file.

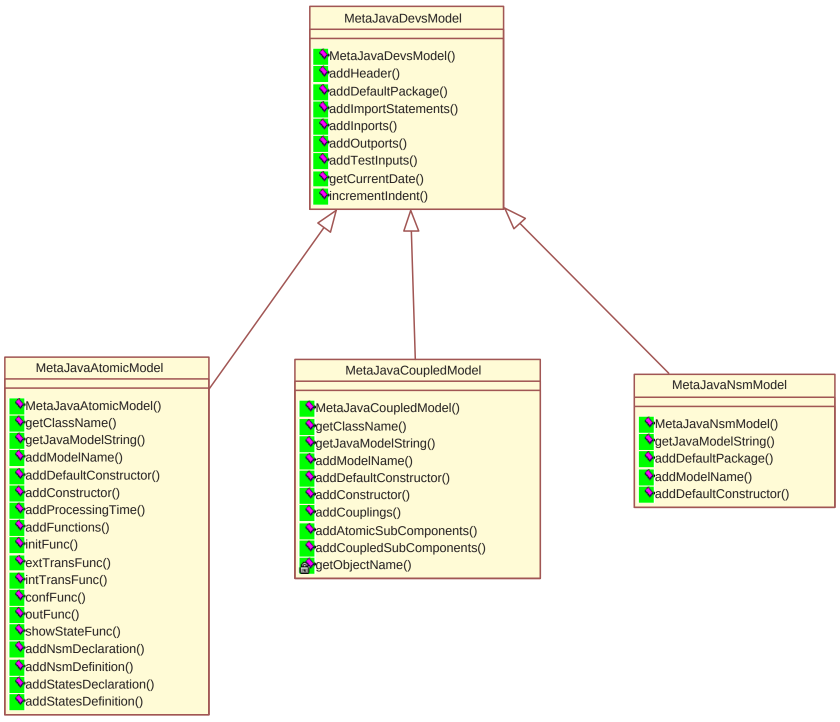


Figure 42. transformation.java.metaDevsJava Class Diagram

It uses JavaDocument which stores all the constant values for the different Java keywords and DEVS formalism keywords in the Java document.

javaFormatter package consists of classes such as metaJavaAtomicModel, metaJavaNsmModel and metaJavaCoupledModel which provide methods to add the information to the corresponding Java model. These methods are specific to atomic model, NSM model and coupled model while the information common to all these is stored in the super class metaJavaDevsModel.

Transformation package consists of two more classes which are common to both xml and java sub-packages. The first one is Model extractor class which extracts the model from the server and sends it to second class, ProgramEditor which displays the model source code to the user. It uses an external class Colorer which colors the source code shown by the program editor at run time.

4. Re-factoring SESM Client/Server Communication

The design of a software environment such as SESM needs to account for requirements such as performance and usability. Performance refers to the systems responsiveness, either the speed at which the computer operates by counting the operations (instructions) performed or the total effectiveness of the computer system including throughput and response time. Since communication may take longer than the computation, performance is often a function of communication/interaction between the components [Bass98]. This is especially true in case of distributed and collaborative modeling environments where we need to account for communication as well as network constraints such as bandwidth, delays, etc. Therefore, in order to keep the response time or the availability of the system constant, we need to ensure that the system performance is acceptable given particular network configurations. Similar to performance, usability of a system such as SESM is important for demanding tasks such as modeling. That is, the extended SESM environment not only needs to be functionally correct, but also simplify (e.g., hide low-level details and provide appropriate abstractions) user activities. These capabilities, therefore, are important to be accounted for in the SESM software architecture specification.

The performance of the SESM degrades rapidly as the size of the model repository increases. Since the architecture of SESM is client/server, the response time is affected not only by carrying out model operations (e.g., adding a port), but also by communication between the client and server. The current communication model requires retrieving the entire model for every change that is made to the model. Lack of efficient communication

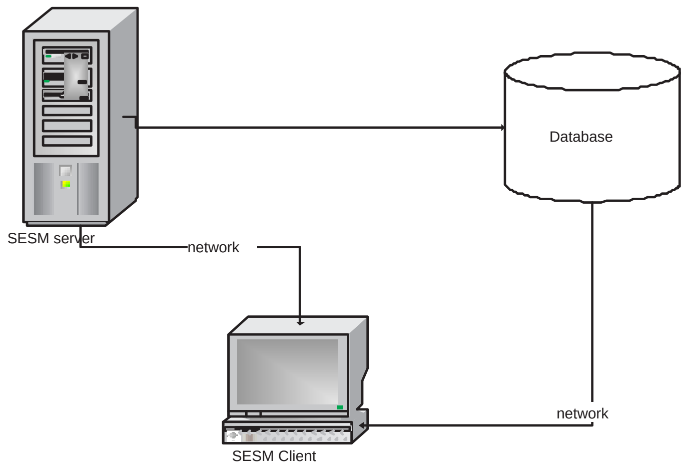


Figure 43. Communication between SESM components

(i.e., sending only the changes to the model and making changes to the overall model locally) adversely affects the usability of SESM. Therefore, the communication of the SESM design needs to be revised to allow efficient data transfer between the client, server, and the database.

This task requires analysis of SESM design which includes examination of existing class, sequence, and state-chart diagrams as well as architectural design given the communications among client, server, and the database as shown in Figure 43. The performance characteristics of SESM (e.g., profiling, CPU profiling, thread coverage and code coverage analysis) were carried out using existing tool called OptimizeIt [Opt03]. For example, the coverage analysis deals with different types of coverage such as line-method-class-path-condition-decision coverage.

The examination of the implementation of the SESM modeling environment and the database tables and their relationships was also necessary. For example, when the SESM modeling environment is initialized, it launches the client GUI (shown in Figure 1). During this phase, the modeling environment fetches all the models created and embed them in the client GUI in the form of user interactive tree structure (as shown on the left panel of Figure 1). However, this design approach, includes re-fetching and re-building of data, has several Limitations as described next.

- Data transfer from database to the modeling engine is required whenever a model tree needs to be rebuilt. The rebuilding of a model is a consequence of any change in the structure of the model tree which includes Adding/deleting new Template Model, existing Model, In/Out port or coupling and Renaming the model.
- The percentage of change in a model is usually very small as compared to the size of all the models. Hence, the response time and availability of the system is affected and suffers from scalability point of view - adding more components to the database.
- Modeler may perform many hundreds to thousands of operations.

4.1. Communication Design. In this new design approach, we are proposing the Observer (Publisher-Subscriber) design pattern [Gof94] which defines a one-to-many dependency between objects so that when one object changes state, all its dependents are notified and updated automatically. Application of this design pattern to SESM is shown in Figure 44, where SESM server acts as a publisher while all the clients connected to it act as subscribers.

Every SESM-client registers with the SESM-server when it executes the SESM modeling environment for the first time. The server provides an interface for client to register or to un-register with the server. Server also keeps track of all the registered clients. It can use a data structure like hash table to list all the registered clients. During initialization,

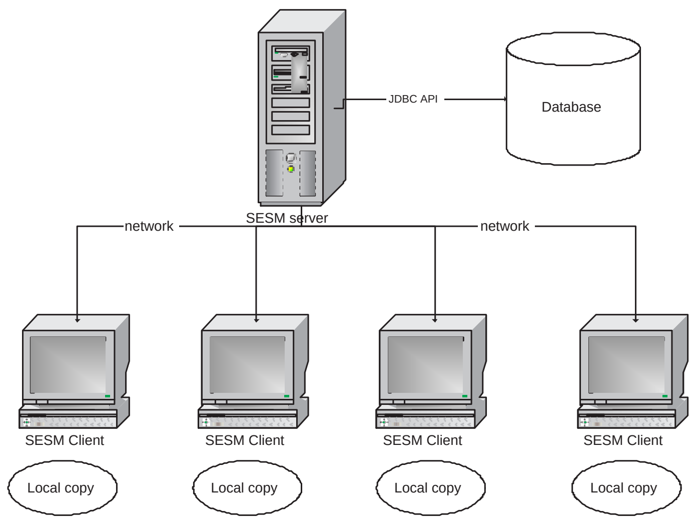


Figure 44. Publisher-Subscriber Pattern

the client will fetch all the models from the server and save it locally in the form of a data structure like Vector or ArrayList of models. This is a local copy of the data for client.

When the client makes any change to the model, corresponding event is generated and sent to the server for validation. Server maintains the first-in-first-out queue to order the request events received from all the registered clients. If the change is valid, server updates the database and sends a notification to all the active clients. This notification is also an event containing the entire information about the change. Once the client receives this notification event, it will check the model hierarchy to find the applicability of that change and make changes in the local copy. After updating the local copy with the latest change, the client will refresh the entire tree model in the client GUI as before, but this time it takes data from the local copy rather than fetching it from the database. The client also maintains the queue to store the notifications received from the server. The advantages of the proposed changes are

- Eliminating unnecessary data transfer between the application and the database and
- Loose coupling between client and server and thus higher degree of reusability.

CHAPTER 6

IMPLEMENTATION AND DEMONSTRATION

Implementation of the extended features in the SESM modeling environment prototype is carried out using some of the technologies used for the previous version of the SESM/CM such as Java programming language and MS-Access database. The additional technology used in this research is eXtensive Markup Language (XML).

1. Approach And Tools

1.1. Meta-Modeling. XML [XML04] is a markup language that is used to aid exchange of the data between applications, systems, businesses and over the web. It is an excellent tool for carrying out transactions. With XML, one can define the data structures and make them platform independent. XML is different than HTML as it is self-describing, easily readable and it allows user to create his own tags and is not dependent on the predefined tags.

In this research, we use XML for model transformation. The models (Atomic and Coupled) that are stored in the database and represented to the user in the graphical format need to be transformed in to the simulatable format and stored on a server so that it can be simulated and validated. We chose XML for the following reasons

- Structure: It allows structure by providing the hierarchical method of describing the data by embedding one element into the other. It is also useful in modeling the complex relationships like composition and inheritance. It also allows the multiple occurrences of the same element.

- Platform Independence: XML is a standard developed by World Wide Web Consortium (W3C) and is independent of any system, vendor, hardware or software and hence can be retrieved long after the software and hardware they were created in has become obsolete.

- Parser Availability: XML parsers are freely available for all platforms, and hence no need to write programs to read XML documents. Also, since the structure of the document is embedded in the document itself, you don't have to change the parser even if the structure of the XML document changes.

- Browser Support: XML document doesn't require the browser support since being a flat file; it can be viewed and edited in any editor.

- Different output formats: XML document can be restructured using XSLT. It can also display the data in a variety of different ways by recasting the document into HTML or PDF. Further, one can change the way the document looks by simply applying different style sheets to the XML document.

- DTD: A Document Type Definition (DTD) requires the XML document to conform to predetermined structures, can prevent many human variations, and this prevent time spent editing the document after it is written

- Reusability: It is very powerful and flexible. I t allows the reusability of tags and contents.

- Acceptance: XML is widely accepted and used by major industries in the market such as W3C, OMG, IBM, Microsoft, Sun, Apple, HP, Adobe, Netscape, etc.

- Plug-and-play simulation: Once the XML models developed in SESM, as these models are independent of everything they can be transformed and simulated in any simulation environment provided corresponding parser and transformation mechanism is in place. In short, it provides the plug and play simulation of the SESM models.

1.2. Apache Ant. Apache Ant [Ant04] is a Java based build tool designed to automate complicated repetitive tasks and thus is well suited for automating standardized build processes. Ant accepts instructions in the form of XML documents (build file) and thus is extensible and easy to maintain. It is developed purely in Java programming language and hence is easily portable on different platforms. Build file is developed for an individual project. The build file contains different properties, which are essentially name-value pairs and the actions that the build file should perform (for example, initialize, compile, etc.) called targets. These targets are sometimes dependent on each other.

This research has extensively used Ant for automating the entire build process for development of SESM modeling environment. This includes creation of a directory structure, initialization, compilation, class path settings, building distributable and cleaning. Ant build file developed is attached as an appendix.

1.3. Implementation Details. The SESM modeling environment is a single machine single user client-server system architecture implemented in Java technology [Java04].

One of the main reasons for using Java language is its support for Object-Oriented concepts and Java Database Connectivity (JDBC) APIs [JDBC04], which is heavily biased towards relational databases and its Structured Query Language (SQL). These concepts and APIs are extensively used even in the extended environment for the storage and retrieval of the input-output-state variable and Non-simulatable model (NSM) specifications which represents the dynamic behavioral characteristics of the atomic and coupled models. As SESM modeling environment is a stand alone application and mainly developed for Windows operating system, the obvious choice for the relational database is MS-Access [Off02]. Windows provides ODBC driver for MS-Access, which allows the connection to MS-Access database from Java using JDBC-ODBC bridge mechanism. SESM Server and Client implementations are extended to incorporate the design extensions for behavioral aspects of the atomic models and transformation mechanisms for the atomic and coupled models as mentioned in chapters 3, 4 and 5. Database is also extended to incorporate new tables for Port Variables, State Variables and NSM models and their associated relationships with Model Template and Port Template. The Client and Server are executed on separate threads and communicate with each other via Network Environment.

2. Anti-Virus Model Example

Demonstration of the extended SESM features, which include the behavioral specification of the atomic models in terms of their dynamic characteristics such as input variables, output variables and state variables as well as the transformation of atomic and coupled models to their simulatable counterparts, is carried out with the help of a simple Anti-Virus Network model. This involves creation of the models for this experiment by specifying structural and behavioral characteristics using SESM user interface, transforming these models

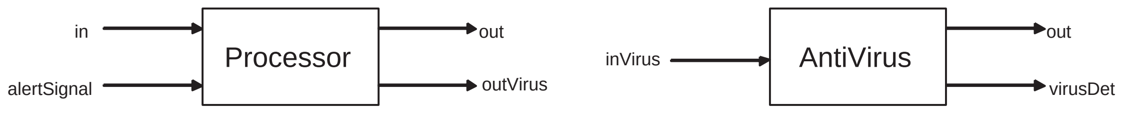


Figure 45. a. Processor and b. AntiVirus Model

into DEVSJAVA format and simulation of these models in DEVSJAVA simulation environment for various input conditions which eventually leads to the validation.

2.1. Experiment Scenario. An Anti-Virus system is intended to protect a network of computers from potential virus attacks. The primary objective of this system is to keep the computers on the network secured and virus-free.

A simplified model of Anti-Virus system consists of a network of Workstations.The *SimpleNetwork* is a coupled model consists of two *WorkStation* coupled models. Messages arriving on port *in* of the *SimpleNetwork* are sent to *in* port of *Processor* of the first *WorkStation* while those arriving on port *alertSignal* of the *SimpleNetwork* are sent to the *alertSignal* port of both *Processor* components.

The *Processor* (shown in Figure 45 a) of a *Workstation* receives input messages where some of them are infected with virus. Any received input message that is not infected is sent to its destination after it is processed by the *Processor*. Each message has a unique ID. The type of event arriving on input port in is string (e.g., msg01) where "01" is the messages' unique ID. Upon receiving a message on input port *in*, the *Processor* begins processing the message for a some length of time (in this case it is 10 time units). If the Processor does not receive any external input events, it will send the processed input message to its destination via port *out*.

The *Processor*, however, may receive an alert signal (message) on input port *alertSig-*

nal. Input messages arriving on *alertSignal* port have the same type as those arriving on port *in.* A message arriving on port *in* is considered suspected if its ID matches the ID of another message arriving on port *alertSignal.* In this case, a message arrived on port *in* of the *Processor* is sent to the *outVirus* port of the *Processor.* The *Anti-Virus* (shown in Figure 45 b) determines if the message is infected with the uniform probability of 50 percent. *Anti-Virus* model also needs processing time to take the decision (in this case it is 2 time units). If a suspected message (message arriving on port *inVirus* of *Anti-Virus*) is determined to be infected with virus, it is sent to the *virusDet* port of the Anti-Virus model. Otherwise, *Anti-Virus* sends the uninfected message from its output port *out* to its associated *Processor* for processing on input port *in* of the *Processor.* Each *Processor* and *Anti-Virus* has a First-In-First-Out (FIFO) queues to store input messages and alert messages respectively.

To carry out the simulation experiment, it is necessary to generate messages for ports *in* and *alertSignal.* Two generators are defined to feed the *SimpleNetwork.* One generator (*GenrMsg*) generates messages and sends them to the *SimpleNetworks in* port. The other (GenrVirus) generates alert message and sends to *SimpleNetworks alertSignal* port. The type of messages generated by these generators is the same as those that can be handled by the *Processor* and *Anti-Virus.*

2.2. Experiment Analysis. The experimental domain is studied to find out different basic atomic models involved in it. These are

- *Processor* (Figure 46 a): processes the messages generated by the generators. It is supported with two input ports namely, *in* to receive input messages and *alertSignal* to receive alert messages about the suspected infection and two output ports namely, *out* to send uninfected message to the next workstation in the network and *outVirus*to send the potential infected message to the *AntiVirus* model.

- *AntiVirus* (Figure 46 b): checks whether the message is infected with the virus. It is provided with one input port *inVirus* to receive the message suspected for infection from *Processor* and two output ports namely, *out* to send the uninfected message to the *Processor* for further processing and *virusDet* to discard the message infected with the virus.

- *GenrMsg* (Figure 46 c): generates the messages to be sent to the Simple network of work-stations. It has one output port *outMsg* to send the newly generated messages.

- *GenrVirus* (Figure 46 d): generates the alert messages for the corresponding infected messages. It has one output port outVirus to send the newly generated virus alert messages.

- *TransdSN* (Figure 46 e): collects the information about the simulation experiment. It has four input ports, *inMsg* to collect information about the message generated, *inVirus* to collect information about the alert generated, *inNet* to collect information about the uninfected messages and *virusNet* to collect the information about the infected messages.

The atomic models are composed together to form coupled models. They are,

- *WorkStation*: Atomic models *Processor* and *AntiVirus* are coupled together to form a coupled model called *WorkStation* (shown in Figure 47). It is supported with two input ports namely, *in* to receive input messages and *alertSignal* to receive alert messages about the suspected infection and two output ports namely, *out* to send

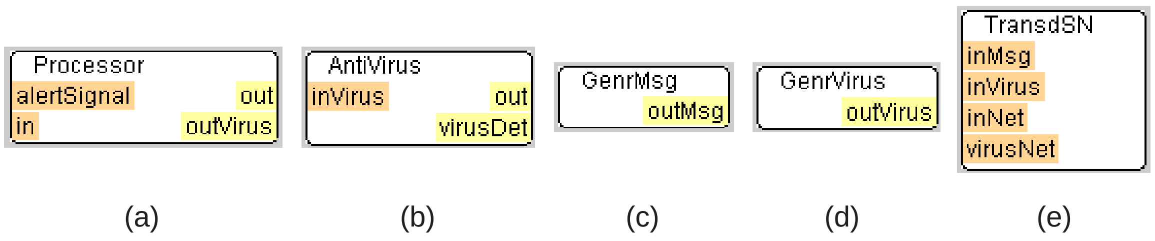


Figure 46. a. Atomic Models a. Processor, b. AntiVirus, c. GenrMsg, d. GenrVirus, e. TransdSN

uninfected message to the next workstation on the network and *virusDet* to discard the message infected with the virus.

- *SimpleNetwork*: a simple network is created by coupling the two *WorkStation* models together called *SimpleNetwork* (shown in Figure 48). The ports of SimpleNetwork Model are similar to the *WorkStation* model as it is a combination of two WorkStations.

- *ExpFrame*: Both generators (i.e., *GenrMsg* and *GenrVirus*) and a transducer (i.e., *TransdSN*) are coupled together to form an Experimental Frame model called *ExpFrame* as shown in Figure 49. It has two input ports, *in* to receive uninfected messages and *virus* to receive potentially infected messages and two output ports, *outMsg* to send the message generated by *GenrMsg* and *outVirus* to send alert messages generated by the *GenrVirus*.

- *AntiVirusExp*: *SimpleNetwork* and *ExpFrame* models are coupled together in a coupled model called *AntiVirusExp* model (shown in Figure 50). This is the highest level coupled model which contains all the other models defined before and hence defines the whole simulation model setup. This model has only two output ports, *out* to send

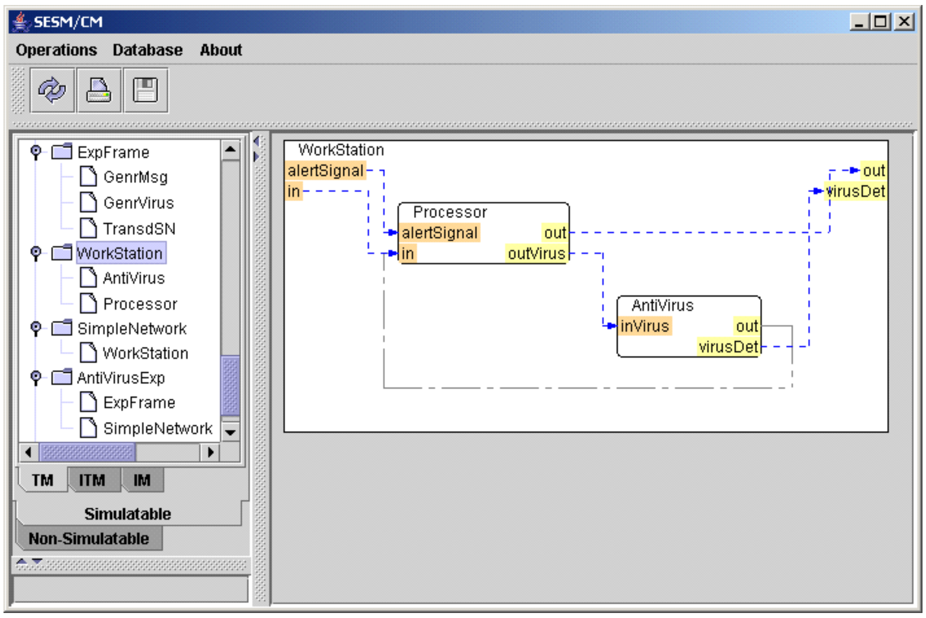


Figure 47. WorkStation Model

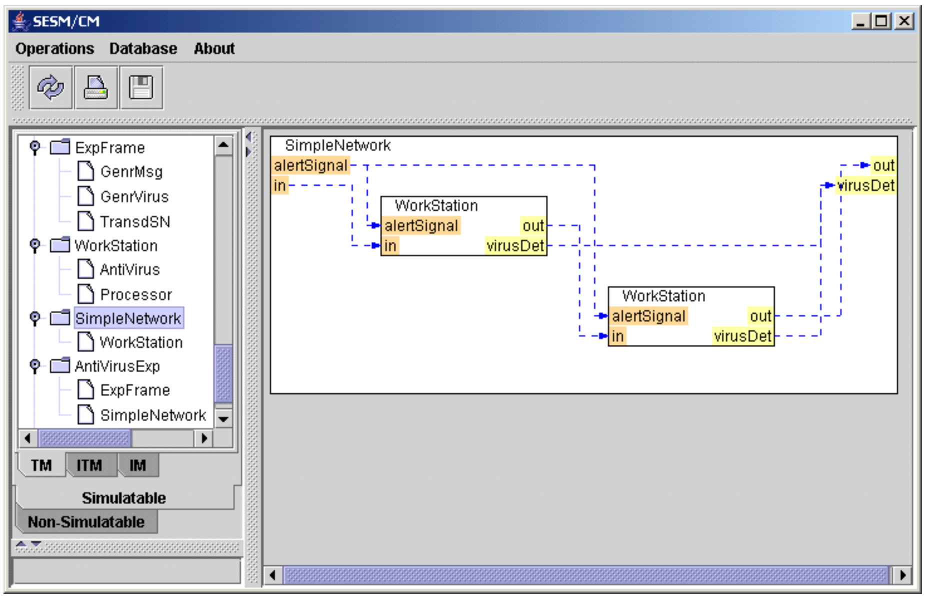


Figure 48. SimpleNetwork Model

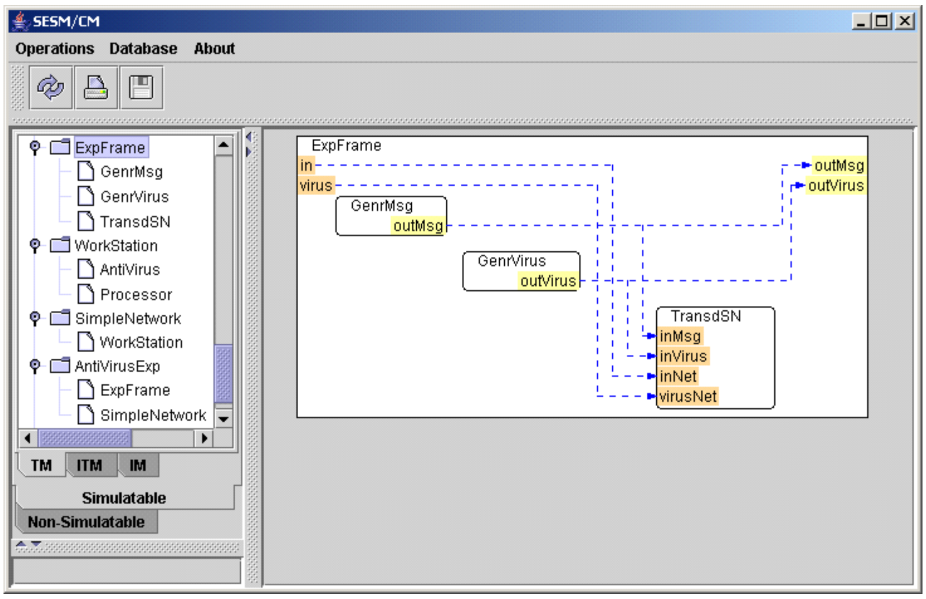


Figure 49. Experimental Frame Model

out the uninfected message to the next workstation on the network and *virusDet* to discard the uninfected messages.

All of these atomic and coupled models are coupled together with the help of external input couplings, external output couplings and internal couplings as shown by the dotted (represents feed forward couplings) and center (represents feed back couplings) lines in Figure 47, Figure 48, Figure 49 and Figure 50.

3. Simulation Experiments

The models mentioned above are developed graphically in SESM using the different features supported by SESM/CM. These model constructed here are primarily structural as they have model name, sub-components, and couplings. But before conducting the simulation experiments on this Anti-Virus model, it is necessary to specify the behavioral

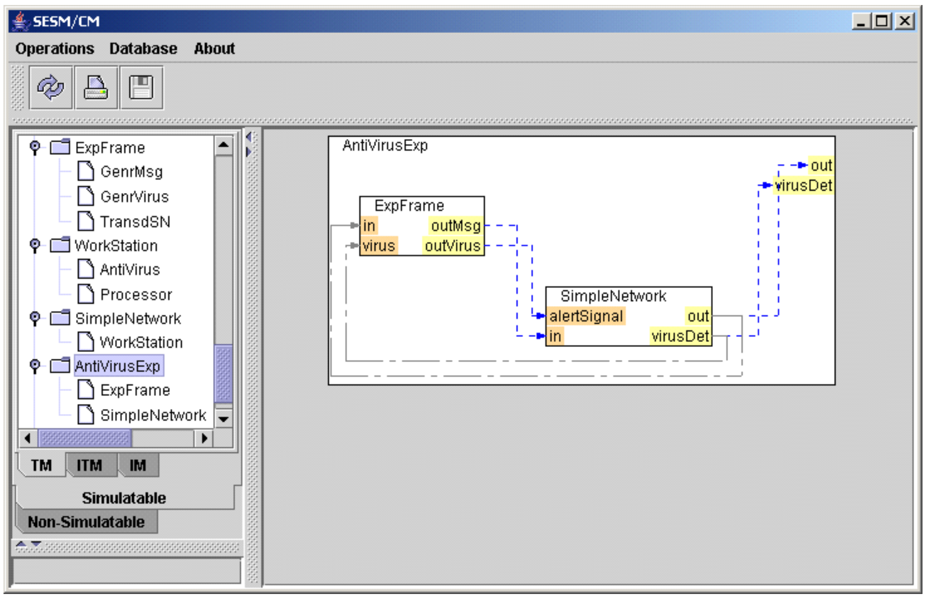


Figure 50. AntiVirusExp Model

characteristics of these models. Some of these behavioral characteristics need to be tracked during the simulation experiment to analyze and validate the models. The behavioral characteristics i.e., variables for different models are listed in Table 5.

The dynamic characteristics of the model's variables are specified using the graphical user interface developed in this thesis. Also processing time (sigma) for all models is specified as shown in table 6. This processing time is a parameter that is used for configuring the simulation scenarios and setups.

These models are then transformed into simulation compatible format by exporting them to DEVSJAVA models. These exported models are partial DEVSJAVA models as they contain the definitions of input, output and state variables and declaration of the different functions, such as initialize function, internal transition function, external transition function, confluent function and output function, etc. To make these models simulatable in

Table 5. Input, output and state variables of models in the experiment

Atomic Model Name	**Variable Type**	**Variable Name**
GenrMsg	State	phase
		sigma
		jobProduced
	Output	outMsg
GenrVirus	State	phase
		sigma
		jobProduced
	Output	outVirus
TransdSN	Input	inMsg
		inVirus
		inNet
		virusNet
	State	phase
		sigma
		total_ta
Processor	Input	Job1 (In port)
		Job2 (alertSignal port)
	State	phase
		sigma
		jobProc
		queueSize
		queueElements
		alertQueueSize
		alertQueueElements
	Output	out
		outVirus
		jobSuspect (outVirus port)
AntiVirus	Input	Job1 (inVirus port)
	State	phase
		sigma
		jobProc
		queueSize
		queueElements
	Output	out
		virusDet

Table 6. Simulation setup Parameter

Atomic Model Name	**processing time**
Processor	10
Anti-Virus	2
GenrMsg	variable
GenrVirus	variable
Transducer	1000

DEVSJAVA, they need to be completed by defining these functions using any convenient Java language compatible IDE.

Upon having correct simulatable DEVSJAVA models, 74 different experimental cases are conducted for the different input scenarios and different behaviors shown by the models such as percentage of infected and uninfected messages and turn-around time are checked in terms of the values of their variables listed in the table. These scenarios are categorized as follows

- Same fixed standard inter-arrival time for both the generators, i.e., both of them have inter-arrival time of either 5, 10 or 15 time units
- Different fixed standard inter-arrival time for both the generators, i.e., if one of them has inter-arrival time of 5 time units then other has either 10 or 15.
- Fixed standard inter-arrival time for one while extreme variable frequency for the other, i.e., one of them has inter-arrival time of 5, 10 or 15 time units while other has either 2,3,13,14 (considering the extreme cases) time units.
- Variable frequencies of inter-arrival time for both the generators, i.e., both are generating messages at 2,3,13 or 14 time units.
- Fixed standard inter-arrival time for one while random for the other, i.e., one of them

Table 7. Simulation Experiments Set 1

Cases	**Standard Fixed Inter-Arrival Time**								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
GenrMsg	5	10	15	5	5	10	10	15	15
GenrVirus	5	10	15	10	15	5	15	5	10

Table 8. Simulation Experiments Set 2a

Cases	**Extreme Fixed/Variable Inter-Arrival Time**											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
GenrMsg	5	5	5	5	10	10	10	10	15	15	15	15
GenrVirus	2	3	13	14	2	3	13	14	2	3	13	14

has inter-arrival time of 5, 10 or 15 time units while other has inter-arrival time of anything between 0 and 15.

- Variable frequencies (extreme conditions) of inter-arrival time for one while random for the other, i.e., one of them has either 2,3,13 or 14 time units while other has inter-arrival time of anything between 0 and 15.

- Random inter-arrival time for both the generators, i.e., both of them have inter-arrival time of anything between 0 and 15.

These experiments are nothing but the Different combinations of inter-arrival time for the two generators as summarized in Tables 7, 8, 9 10 and 11.

Table 9. Simulation Experiments Set 2b

Cases	**Extreme Fixed/Variable Inter-Arrival Time**											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
GenrMsg	2	3	13	14	2	3	13	14	2	3	13	14
GenrVirus	5	5	5	5	10	10	10	10	15	15	15	15

Table 10. Simulation Experiments Set 3

Cases	Extreme Variable Inter-Arrival Time															
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
GenrMsg	2	2	2	2	3	3	3	3	13	13	13	13	14	14	14	14
GenrVirus	2	3	13	14	2	3	13	14	2	3	13	14	2	3	13	14

Table 11. Simulation Experiments Set 4

Cases	Random Inter-Arrival Time														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
GenrMsg	5	10	15	R	R	R	2	3	13	14	R	R	R	R	R
GenrVirus	R	R	R	5	10	15	R	R	R	R	2	3	13	14	R

4. Simulation Results

The simulation results for the different experimental scenarios conducted on Anti-Virus Experiment are carefully analyzed. For all experiments, charts for percentage infected and uninfected messages and maximum average turn-around time are plotted. These charts are shown in figures.

As shown in figure 51, the curves for all the alert times have the same pattern. Hence the main factors that are affecting the change in the maximum average turn-around time is the inter-arrival time of messages and processing time of *Processor* and *Anti-Virus* model. Since, the processing time for the messages in the *Processor* model is fixed at 10 time units, the frequency of messages generated with inter-arrival times that are less than 10 time units is more than the messages getting processed in the *Processor*. These messages gets queued in the messages queue in the *Processor* model and waited before getting processed. This results in the longer turn-aound time and hence longer average turn-around time. But the frequency of the messages generated with inter-arrival time of 10 or higher is equal to or

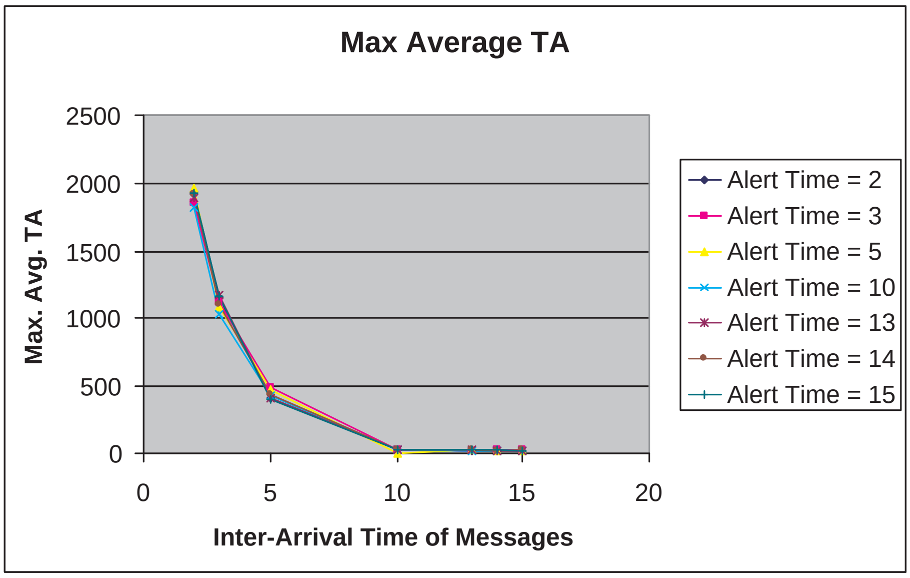


Figure 51. Max. Avg. TA for Different Alert Messages

slightly higher than the messages getting processed in the *Processor* which results in shorter turn-around times.

Figures 52 and 53 also show that the turn-around is affected mainly by the inter-arrival time of normal messages. figure 52 shows that the turn-around time for messages whose inter-arrival time is less than 10. It increases rapidly as the inter-arrival time reduces since this results in increase of message frequency which increases the waiting time in queue. Figure 53 shows that the turn-around time for messages whose inter-arrival time is equal to or greater than 10. It decreases as the inter-arrival time increases beyond 10.

Figures 54 shows the percentage of uninfected messages for different inter-arrival times of messages as well as alerts while figure 55 shows the percentage of infected messages for different inter-arrival times of messages as well as alerts.

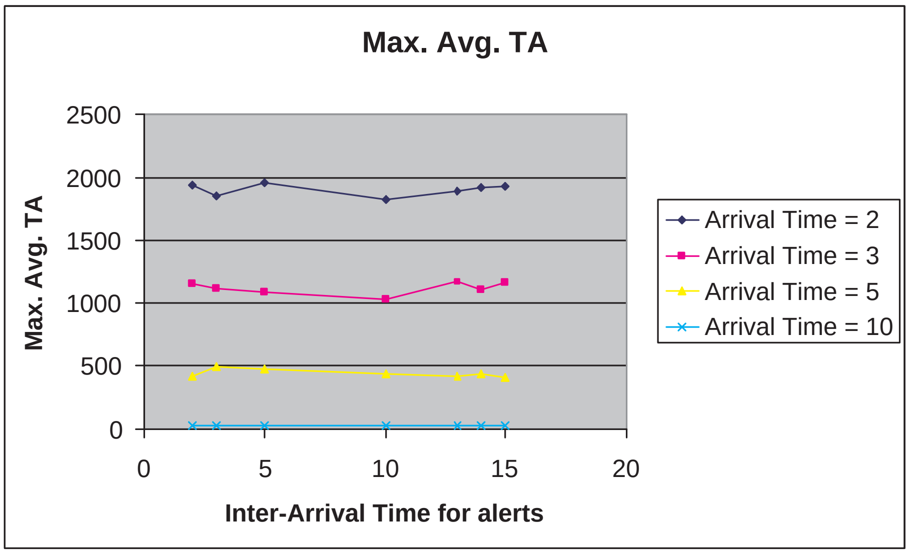


Figure 52. Max. Avg. TA for Different Normal Messages

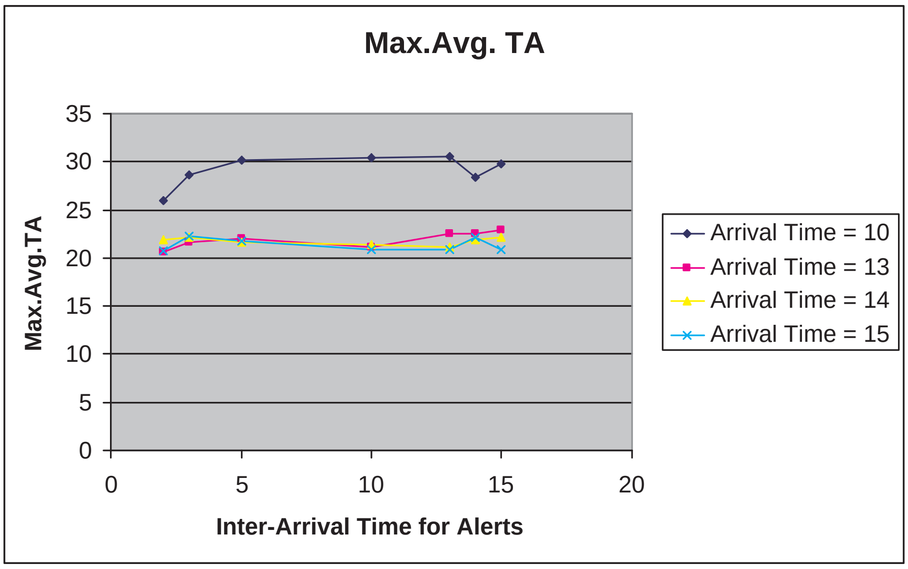


Figure 53. Max. Avg. TA for Different Normal Messages

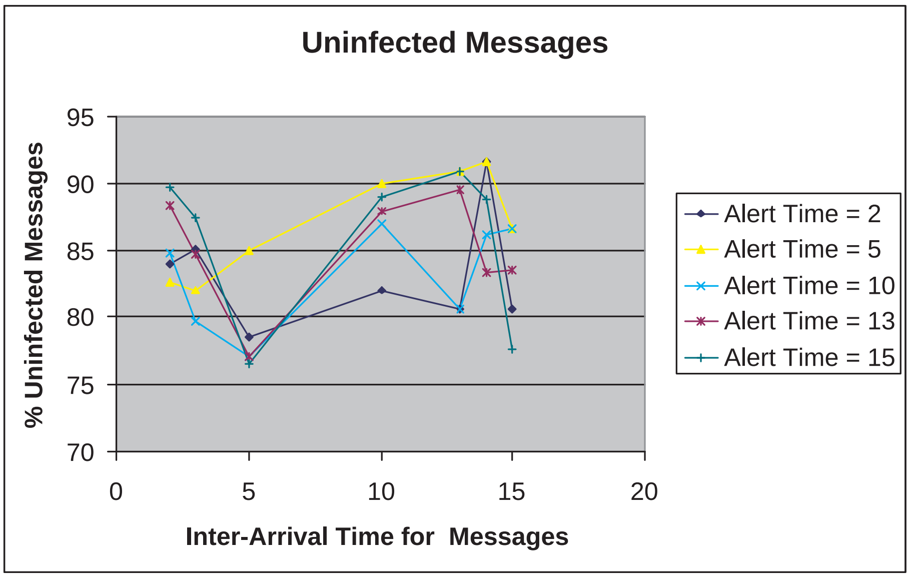


Figure 54. Percentage Uninfected Messages

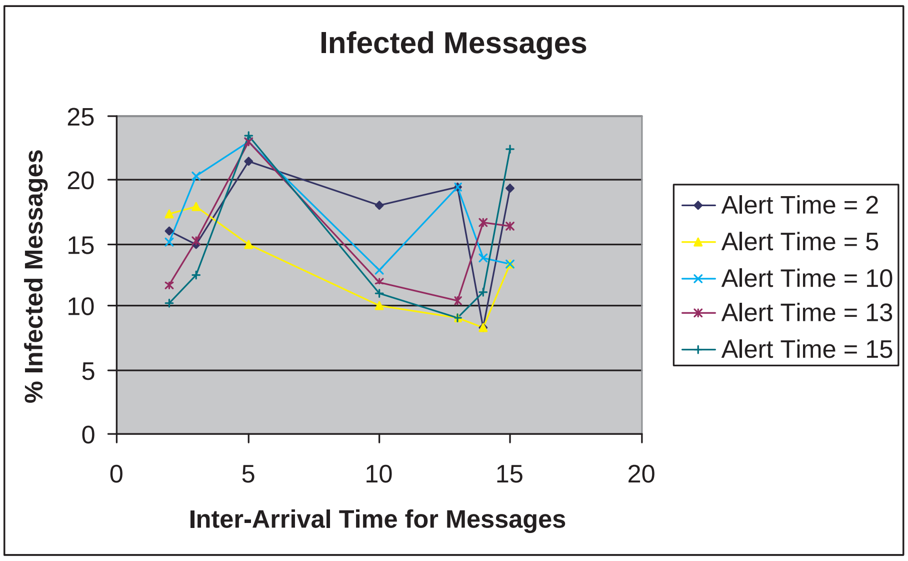


Figure 55. Percentage Infected Messages

CHAPTER 7

CONCLUSION AND FUTURE RESEARCH

1. Conclusion

Increase in the size of the system leads to the increase in the structural and behavioral complexity of the system. Such complex systems are analyzed, designed and developed by using modeling and simulation approach, This approach is based on principles of system theory and object-orientation. Simulation model of a system is developed to study the structural and behavioral complexity of the system over time. For this, modeler needs to specify the model in terms of its structure and behavior and to make them persistent to achieve model reusability. Therefore, the specification and the storage of structural and behavioral aspects of the model are important to achieve the simulation, analysis and validation of the model.

This research is primarily concerned with the specification of the behavioral aspects of atomic models. It has used and extended the Scalable System Entity Structure Modeler (SESM/CM) modeling environment. The software architecture of SESM is primarily client-server type and is composed of four main components i.e., Client, Server, Network Environment and RDBMS. This architecture offers simplicity and higher degree of modular design and implementation. This architecture allows multiple clients and server to read the data from RDBMS but only server has rights to write to it. Client and server interact with each other via network environment. This research also used DEVSJAVA as a simulation environment to demonstrate, test and validate atomic and coupled models which are developed in extended SESM environment and transformed into simulation compatible format. This research described an extension of SESM/CM architecture to incorporate these features, while retaining the overall architecture of the system.

It conceptualized the necessity and approach for capturing and storing behavioral aspects of an atomic model in the relational database management system. These behavioral aspects can be defined in terms of the dynamic characteristics of model such as input variables, output variables and state variables. For this, the existing entity-relationship diagram is extended (as shown in section 4.3) to support port variables (both input and output), state variables and NSM models tables. These NSM models are essentially complex data structures which act as a type of input, output or state variable. Furthermore, the relationships between these tables and other tables such as Model Template, Port Template, etc are also defined. The software design, analysis and implementation of the SESM/CM are extended to accommodate the capturing of behavioral aspects and mapping of the object-oriented models to their relational counterparts. This involves the extensions of client and server modules in terms of capturing user inputs, transactions in SQL and modeling of constraints using programming logic that cannot be expressed in E-R diagram or relational model.

Second part of the research is concentrated on the transformation of atomic and coupled models in to their simulatable counterparts to achieve their simulation and validation. This involved the creation of new module for the transformation of the models stored in the database into XML and DEVSJAVA models. These transformed models are stored on the server as flat files at a specified location and retrieved back when required for viewing or editing.

Extension of graphical user interface is an important aspect of this research. It includes the redesign of the existing model menu to make it compatible with the system formalism and addition of the menu items and corresponding user input dialogs to facilitate the specification of the behavioral aspects, transformation of the models and viewing of these transformed models and their metrics. It also added one more tree view for NSM models, in addition to the existing model tree views for template models, instance template models and instance models. This tree view has a functionality to add modelers own NSM model and a capability to edit and save the existing NSM model.

These new features along with the existing features are demonstrated with the help of Anti-virus model experiment. In this various models are created using SESM in terms of structural and some of the behavioral features and then transformed into simulation compatible models. These transformed models are simulated against various input conditions to test the behavioral changes of the overall system.

2. Future Research

This research partially specifies or measures the structural and behavioral aspects of the atomic models. In order to achieve total structural and behavioral specification and measurement, SESM needs to be extend in the following areas,

2.1. Computation of Additional Metrics. SESM/CM facilitates computation of nine basic structural metrics - (Immediate Children, Total Children, Input Ports, Output

Ports, Total Ports, Internal Couplings, External Input Couplings, External Output Couplings, Total Couplings). However, additional structural and behavioral metrics may be obtained from the models. In structural metrics, higher-level metrics such as fan-in (the number of couplings between an input port and many output ports) and fan-out (the number of couplings between an output port and many input ports) can be computed. Also the present metrics compute the number of couplings at one level. This may be extended, for example, to compute the total number of couplings of a component till its lowest level of decomposition. In behavioral part, metrics in terms of input variables, output variables and state variables can be computed.

2.2. Support for storage of State Transition of Atomic Models. This research described the specification of some of the behavioral aspects of an atomic model. But the behavior can be completely captures only when the state transition of atomic models is specified. Therefore, this research can be further extended to support the specification of the state transition of atomic models and their storage in the relational database system.

2.3. Transformation of State Transition to Functions. The detail procedure of transformation of the models stored in the database into their simulation compatible format to achieve their simulation and hence validation, is explained in this research. This mechanism also can be extended to transform the state transition specification in the database to their corresponding transition functions such as external transition function, internal transition function, etc. in XML or Java model.

2.4. Transformation from Simulatable Model to Database Model. Transformation of the models stored in the database to their simulatable counterparts is defined in this research. This work can be extended to have a reverse mechanism to transform the existing simulatable model in to the database model to achieve reuse of these models instead of recreating them in modeling engine and hence complete the Modeling-Simulation-Modeling cycle.

2.5. User Interface Enhancements. User interface of SESM modeling environment can be further enhanced to have drag and drop as well as cut-copy-paste facilities to speed up the modeling process as it will avoid the manual adding-deleting of the models while creating the large hierarchical models.

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