A Proposed DEVS Standard:
Model and Simulator Interfaces, Simulator Protocol

DRAFT 1.0

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1 Introduction

This document describes the Discrete Event System Specification (DEVS) standard adopted by the DEVS Standard Working Group. The DEVS formalism has been applied in numerous research and industry contexts and many DEVS versions have been developed. They are implemented on various computer platforms with different program languages. They also vary in modeling level, distribution level and simulation mode such as real-time simulation and virtual-time-mode simulation. To standardize all these implementations and facilitate future development, this document sets out standardized descriptions for DEVS models, simulators, and their interaction. However, the current version is limited in scope to specification of virtual-time simulation of non-hierarchical coupled models.

The standard is derived from the architectural description for the GenDEVS [2] package of interfaces and classes in Java that underlie the DEVSJAVA modeling and simulation environment which provides the capability to build discrete event models and to simulate these models. The GenDEVS description employs the object oriented features of classes and interfaces provided by Java that implement the Parallel DEVS formalism. The standard presented in this document employs the same features but interprets them in a manner that is not limited to Java implementation. This works because particular features of the Java language are either not employed, or if employed, then they are given definitions that are independent of Java implementation. For example, we use the concept of interface from Java but define it in a language neutral manner. In the process of generalization, we have allowed the standard to deviate in some ways from the original source. These concern changing of names and organization of the interfaces that preserve the original behavior but may make it easier to understand. The end result is an abstract generic standard to which the GenDEVS implementation could conform with a change in names of some of its methods.

Besides allowing DEVS models implemented in different languages to be simulated together (e.g., in a distributed environment), a major goal is to allow non-DEVS models to participate in such simulations. This is reflected in a reinterpretation of the interface specifications derived from the GenDevs implementation that may prove confusing to those familiar with the original. In the latter, the term coreSimulatorInterface suggested that any DEVS simulator (a “device” that can execute a DEVS models, such as coordinator or atomicSimulator) should implement this coreSimulatorInterface. In the new standard, this name “core” refers to “essential” in that as long as a processor implements this interface, it can participate in a simulation driven by a DEVS coordinator. This means that a simulator of a standalone atomic model (called an atomicSimulator) need not satisfy the coreSimulatorInterface while a simulator of a model that is in a coupled model must do so. Similarly a coordinator of a coupled model need not satisfy the coreSimulatorInterface although compliance is required of a coordinator of a coupled model that is a part of a larger hierarchical composition. Some illustrative examples will demonstrate how simulation of DEVS with non-DEVS federations can be achieved using the standards developed here.

1.1 Brief DEVS Review

To understand how the standard works, we need to know there are two classes of DEVS models (Atomic model and Coupled model) and several types of DEVS simulation modes, e.g., virtual-time mode and real-time mode. An Atomic model is a basic component which has relatively simple functionality. It has input ports, output ports, states and internal or external transition functions. A coupled model is composed by multiple atomic models or coupled models that have been previously defined. By coupling one model’s output port to another model’s input port, a message can flow from one model to another model.

Corresponding to different simulation modes, the standard has virtual-time mode and real-time mode simulators. In virtual-time mode simulation, the simulator interprets time as logical time so the simulation can skip from one event time to the next without waiting for the actual time interval to expire. However, in real-time simulation, time is interpreted as wall clock time, so the real-time simulator will wait for the interval to its next scheduled event to expire before handling the event.

From the above introduction, we can see that the standard will have multiple simulation scenarios. For example, considering the combinations of model type and simulation mode we have: simulating an atomic model in virtual-time mode, simulating an atomic model in real-time mode, simulating a coupled model in virtual-time mode and simulating a coupled model in real-time mode.

In addition to the model type/simulation mode combinations, the standard allows for the use of different forms of distribution of model components, e.g., single processor vs. multi-processor, and different implementation platforms, such as Windows vs Unix, different programming languages, such as Java vs C++, and different networking and middleware frameworks such as .Net vs Apache.

1.2 Conceptual Architecture of the Standard

Figure 1 illustrates our architectural approach to accommodate the various combinations and permutations of possible application, both currently known, and those that will emerge in the future. The basic idea is two define two sets of interfaces, the DEVS model Interface and the DEVS Simulator Interface, as well as a DEVS Simulation Protocol that operates between the two. The interfaces protocols are based on those in GenDEVS except that they are removed from Java dependence as mentioned earlier.

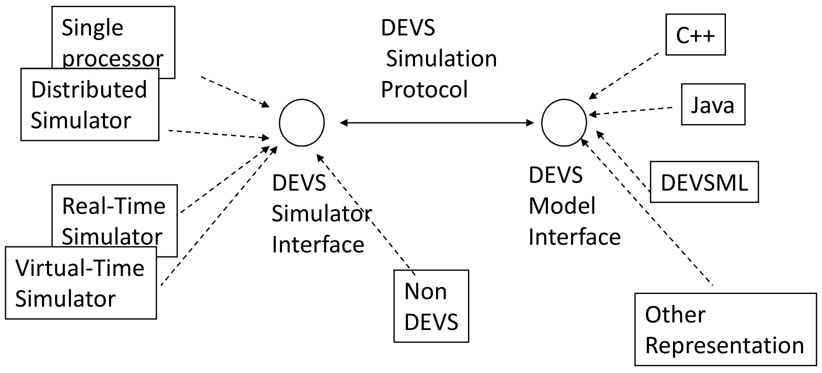


Figure1: Conceptual Architecture of Standard

1.3 Layered structure – brief introduction of each layer

The DEVS standard uses a layered structure, as in Figure 34.

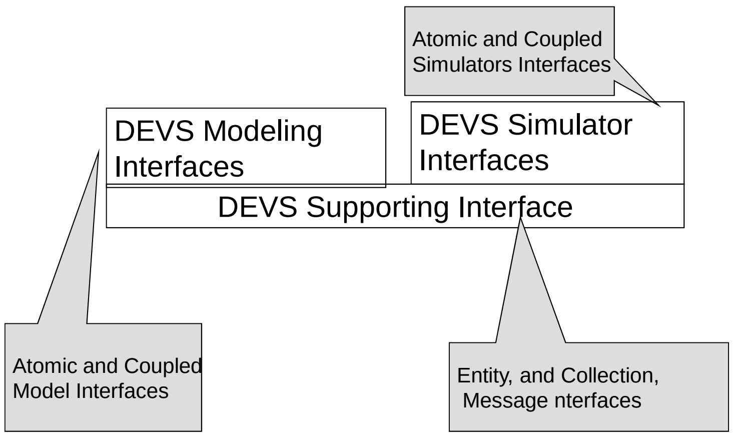

Atomic and Coupled Simulators Interfaces
DEVS Modeling Interfaces
DEVS Simulator Interfaces
DEVS Supporting Interface
Atomic and Coupled Model Interfaces
Entity, and Collection, Message nterfaces

Figure3: layered structure

The lower layer provides the data structure layer to support DEVS modeling and simulation. It defines an interface for the basic entity class as well as a set of supporting data structures and such as bags, sets, relations, and functions. It also includes iterators, called ensemble methods, that facilitate the specifications at the next layer. The second layer provides the DEVS modeling and simulation specification proper. It includes two parts, the DEVS modeling interfaces and DEVS simulator interfaces, respectively. This layer provides basic DEVS atomic and coupled specifications that match up to corresponding simulators through the DEVS protocol.

1.4 DEVS Interfaces

There are three sets of DEVS interfaces: DEVS Supporting Interfaces, DEVS Modeling Interfaces, and DEVS Simulator Interfaces.

DEVS Supporting interfaces provide a supporting environment for implementing DEVS implementations. It specifies some basic data structures such as Entity, Content, Message, Port, etc. These interfaces are essential for DEVS modeling and simulation environment.

DEVS Modeling Interfaces define the modeling environments to build DEVS models. It defines the basic functions a DEVS model needs to implement.

DEVS Simulator Interfaces provide the simulation environment in DEVS to run simulations. It defines the functions different simulators need to implement.

By carefully defining these DEVS interfaces we have a clear structure for the DEVS environment. This makes it possible to implement a subset of the whole system and define a just-as-needed DEVS environment based on different application scenarios. For example, if we are interested in the real time application such as real-time data management, we only need to implement the part corresponding to real time simulation interface. Similarly, if an application needs only atomic models such as some embedded programs which have sole functionality, only the part corresponding to Atomic interface is needed to be implemented.

In the following figures, each circle represents an interface that defines a subgroup of related functions. An interface can extend several parent interfaces. This is shown by a dotted line connecting the child and parent. An arrow will show the direction from parent to child unless it is clear from the context. By extending several interfaces, a child interface will inherit the attributes and functions from its parents. It can also add its own functions and attributes so it will have its own personality.

1.5 DEVS Supporting Interfaces

DEVS supporting interfaces start with the EntityInterface for defining the entity, or base object class, from which all classes will be derived. For example, this could be the Object class in Java or the entity class in DEVSJAVA. We note this allows different implementations to employ different classes to implement the EntityInterface while still allowing such implementations to interoperate through the exposed functions defined by it.

The Collection interface defines the basic functions of a collection of objects each of which implements the EntityInterface. Consistent with the base object nature of EntityInterface, Collection is derived from the latter. The behaviors of Collections and ensembleCollections are uniquely specified using Object Behavior Specification in Reference [x].

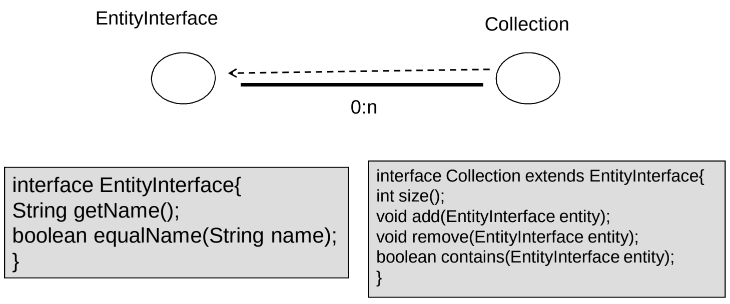

EntityInterface
Collection
0:n
interface EntityInterface{
String getName();
boolean equalName(String name);
}
interface Collection extends EntityInterface{
int size();
void add(EntityInterface entity);
void remove(EntityInterface entity);
boolean contains(EntityInterface entity);
}

Figure 4: DEVS Supporting Interfaces

```
interface EntityInterface{
String getName();
boolean equalName(String name);
}

interface Collection extends EntityInterface{
int size();
void add(EntityInterface entity);
void remove(EntityInterface entity);
boolean contains(EntityInterface entity);
}
```

1.6 Message-related Interfaces

DEVS standard message concepts are briefly reviewed in Figure 5. DEVS models have output ports through which messages are transmitted to input ports of receiving models following routing that is specified by couplings.

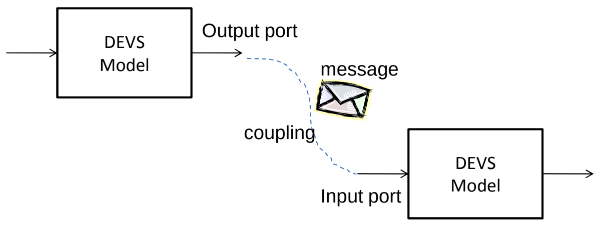
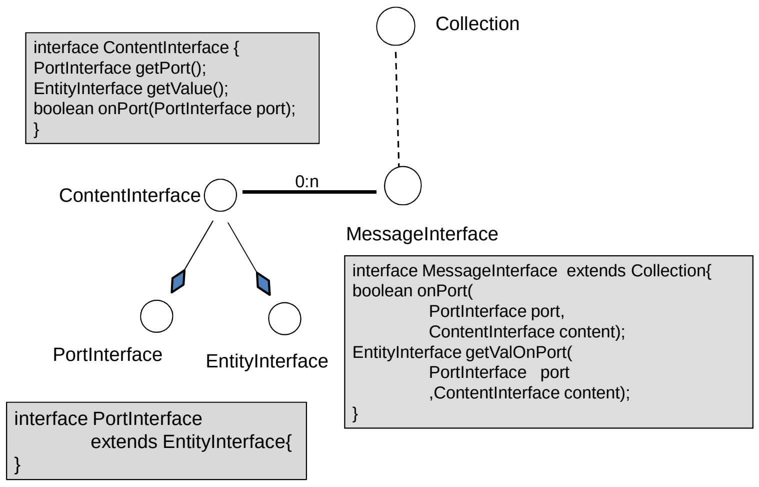


Figure 5: DEVS Message concepts

The corresponding message interfaces are illustrated in Figure 6. ContentInterface defines a content (port-value pair) by providing a method, getPort, to get its port (implementation of PortInterface) and getValue, to get its value (an EntityInterface implementation). The MessageInterface is a collection of contents. It has a predicate, onPort, for whether a content has a given port. It also has a query, getValOnPort, that returns the value that is paired with a given port in a given content.



```
interface ContentInterface {
PortInterface getPort();
EntityInterface getValue();
boolean onPort(PortInterface port);
}
```

```
interface MessageInterface  extends Collection{
boolean onPort(
            PortInterface port,
            ContentInterface content);
EntityInterface getValOnPort(
            PortInterface   port
            ,ContentInterface content);
}
```

```
interface PortInterface
            extends EntityInterface{
}
```

Figure 6: Message-related interfaces

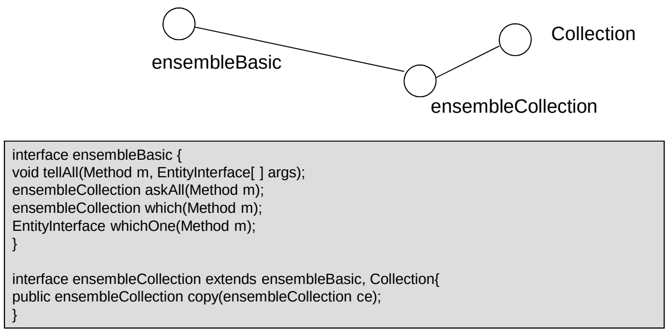
```
interface ContentInterface {
PortInterface getPort();
EntityInterface getValue();
boolean onPort(PortInterface port);
}

interface MessageInterface  extends Collection{
boolean onPort(
            PortInterface port,
            ContentInterface content);
EntityInterface getValOnPort(
            PortInterface   port
            ,ContentInterface content);
}

interface PortInterface
            extends EntityInterface{
}
```

1.7 Ensemble Interfaces

We use the concept of ensemble method to introduce the capability of iteration over Collection members. As in Figure 7, an ensembleCollection extends the standard Collection with inclusion of the ensembleBasic interface that defines the ensemble methods, tellAll, askAll, which, and whichOne.



```
interface ensembleBasic {
void tellAll(Method m, EntityInterface[ ] args);
ensembleCollection askAll(Method m);
ensembleCollection which(Method m);
EntityInterface whichOne(Method m);
}

interface ensembleCollection extends ensembleBasic, Collection{
public ensembleCollection copy(ensembleCollection ce);
}
```

Figure 7: Ensemble Interfaces

interface ensembleBasic {

void tellAll(Method m, EntityInterface[ ] args);

ensembleCollection askAll(Method m);

ensembleCollection which(Method m);

EntityInterface whichOne(Method m);

}

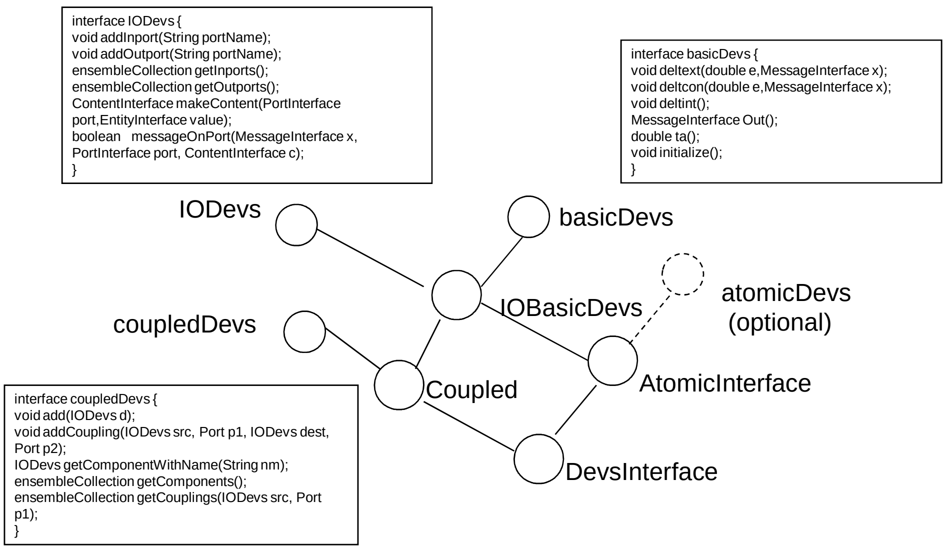
interface ensembleCollection extends ensembleBasic, Collection{

public ensembleCollection copy(ensembleCollection ce);

}

2 DEVS Modeling Interfaces

Figure 8 shows the structure of DEVS modeling Interface.


```
interface IODevs {
void addInport(String portName);
void addOutport(String portName);
ensembleCollection getInports();
ensembleCollection getOutports();
ContentInterface makeContent(PortInterface
port,EntityInterface value);
boolean   messageOnPort(MessageInterface x,
PortInterface port, ContentInterface c);
}
```

```
interface basicDevs {
void deltext(double e,MessageInterface x);
void deltcon(double e,MessageInterface x);
void deltint();
MessageInterface Out();
double ta();
void initialize();
}
```

```
interface coupledDevs {
void add(IODevs d);
void addCoupling(IODevs src, Port p1, IODevs dest,
Port p2);
IODevs getComponentWithName(String nm);
ensembleCollection getComponents();
ensembleCollection getCouplings(IODevs src, Port
p1);
}
```

Figure 8 DEVS Model Interfaces

```
interface DevsInterface extends AtomicInterface,Coupled{
}
interface AtomicInterface extends atomicDevs,IOBasicDevs{}

interface Coupled extends coupledDevs,IOBasicDevs{
}

interface IODevs {
void addInport(String portName);
void addOutport(String portName);
ensembleCollection getInports();
ensembleCollection getOutports();
ContentInterface makeContent(PortInterface port,EntityInterface value);
boolean   messageOnPort(MessageInterface x, PortInterface port, ContentInterface c);
}

interface basicDevs {
void initialize();
void deltext(double e,MessageInterface x);
void deltcon(double e,MessageInterface x);
void deltint();
MessageInterface Out();
double ta();
}

interface coupledDevs {
void add(IODevs d);
void addCoupling(IODevs src, PortInterface p1, IODevs dest, PortInterface p2);
String getComponentWithName(String nm);
ensembleCollection<String> getComponents();
ensembleCollection<String,Port> getCouplings(IODevs src, PortInterface p);
}
```

Among these interfaces, IODevs interface defines the functions needed for message exchange, including addInport(), addOutport(), makeContent() and messageOnPort(). It also has methods getInports() and getOutports() that return the input and output ports, respectively. These methods are optional since they are useful for model manipulation but not necessary for model execution. Any model, whether DEVS or non-DEVS, can implement these functions so it can interoperate with other implementers of this interface, in the sense of receiving input and sending output.

The basicDevs Interface defines the basic functions a DEVS model needs to implement such as deltext(), deltint(), out(), ta() and so on. The basicDevs interface is the interface that is exposed to the atomic simulators. An additional interface, atomicDevs, provides a convenient set of primitives for defining the basic functions in an atomic model. However, since the basic functions can be defined without using such primitives, we set the atomicDevs interface as optional, although recommended. Of course, any interface that extends this interface need not implement its features in its absence.

```
interface atomicDevs {
 void Continue(double e);
 void passivate();
 void passivateIn(String phase);
 void holdIn(String phase, double time);
 void holdIn(String phase, double time, Activity a);
 boolean phaseIs(String phase);
}
```

The IOBasicDevs interface extends the String interface and basicDevs interface. It provides a common basis for implementing atomic models and coupled models.

Combining IOBasicDevs with atomicDevs, we get AtomicInterface which defines the functions an atomic model need to implement. Of course, if atomicDevs is omitted, then AtomicInterface reduces to IOBasicDevs.

CoupledDevs interface defines the functions that are used in DEVS coupled models. It has methods add() and addCoupling() that enable adding components and couplings to the model. It also has optional methods getComponentWithName() and getComponents() methods for retrieving a component by name and for accessing all components; and getCouplings() to access the component/port pairs associated with a component and a port.

Combining IOBasicDevs with CoupledDevs, we get Coupled which defines the functions a coupled model needs to implement.

2.1 Extending the "Core" interfaces

The above interfaces define the "core" of DEVS modeling. Later extensions of the DEVS standard can be added based on these core interfaces. For example, to support dynamic structure modeling, a dynamicStructure interface can be defined to be implemented by an atomic model.

```
interface dynamicStructureInterface {
 void  addCoupling(String srcName, String p1, String destName, String p2);
 void  removeCoupling(String srcName, String p1, String destName, String p2);
 void  addModel(String ModelName);
 void  removeModel(String ModelName);
 void  addInport(String ModelName, String port);
 void  addOutport(String ModelName, String port);
 void  removeInport(String ModelName, String port);
 void  removeOutport(String ModelName, String port);
}
```

Note that since changes to model structure are specified within a model, we use strings rather than objects in the signatures. These strings must be used to find the objects associated with these names.

Simulator Interfaces

Figure 4 shows the structure of DEVS simulator Interface and structure[1].

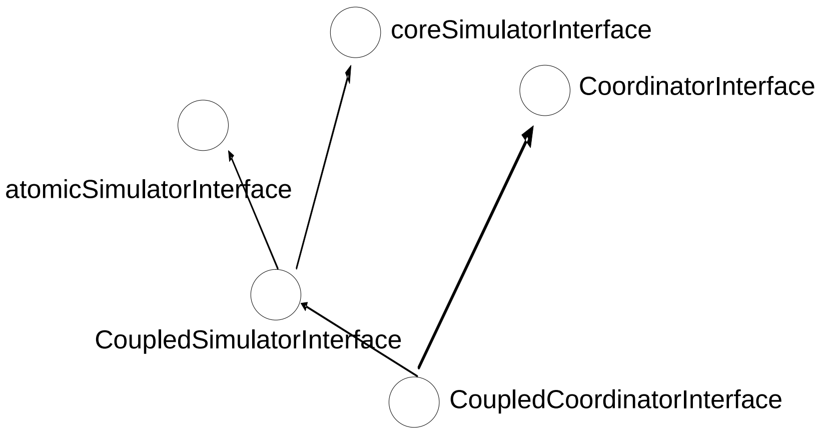


Figure 4: DEVS Simulator Interfaces

In contrast to the other interfaces,the atomicSimulatorInterface and CoordinatorInterface are not for simulators of components in a coupled model, i.e., they are for the processors that drive a simulation. The atomicSimulatorInterface is for

[1] Note that the above Figure 4 is different from the GenDevs implementation in DEVSJAVA. For example, in GenDevs, coupledSimulator interface extends coresimulator interface and also couplingProtocolInterface, ActivityProtocolInterface and Hieparent interface. We have removed the ActivityProtocolInteface for simplicity purpose. Also, we combined couplingProtocolInterface and Hieparent into the CoupledSimulator interface. We also make the CoupledCoordinator interface extend Coordinator interface and CouopledSimulator interface. This is not the case in the GenDevs implementation.

simulating a single stand-alone DEVS atomic model. The CoordinatorInterface is for simulating a coupled model.

For some reason (probably because I am used to the GenDevs implementation), I feel the name of coreSimulatorInterface is kind of confusing. This name suggests that any DEVS simulator (here I mean a "device" that can execute a DEVS model, such as coordinator or atomicSimulator) should implement this coreSimulatorInterface. This is different from what is shown in Figure 4. In Figure 4, it is actually a componentSimulator interface (not the coordinator itself) that can work with a coordinator. In other words, as long as a simulator implements this interface, it can participate in a simulation driven by a coordinator (assuming such a coordinator exists). This brings out my second discussion. From Figure 1, it seems two of the major goals of the standardization is to allow 1) a non-DEVS model to work with a DEVS model; 2) models implemented in different languages can be simulated together (e.g., in a distributed environment). If this is true, it will be very helpful to demonstrate how that can be achieved using the standards developed here. Some illustrative examples may be developed (at the conceptual level). This might be part of the next step (it will also help to test/refine the interfaces developed here).

The basic interface for DEVS and non-DEVS simulators is CoreSimulatorInterface.

```
 interface coreSimulatorInterface{
void setSimulators(Collection<CoreSimulatorInterface>);
 void initialize();
 Double nextTN(); //Double is a class that wraps a double value
 void computeInputOutput(Double t);
 void applyDeltFunc(Double t);
void putContentOnSimulator(CoreSimulatorInterface sim, ContentInterface c);
 void sendMessages();
}
```

// is setSimulators() implementation specific? i.e., it suggests a simulator know all other simulators. Can we have a different implementation? OR should this be part of the standardization?

//BPZ: I think it should be in the standard although we don't tie down the form in which the simulators are expressed. This is because to do sendMessages federates have to know the other simulators.

The AtomicSimulatorInterface provides the methods needed for stand-alone simulation of atomic DEVS models. Methods needed for simulation of atomic models as components in coupled models are provided by the CoupledSimulatorInterface, which extends the AtomicSimulatorInterface and the CoreSimulatorInterface. The

CoordinatorInterface provides the methods needed by a coordinator to simulate a coupled model. To handle simulation of hierarchical coupled models, we note that a processor can coordinate the processors below it as well as participate with peers in a coupled model above it. To allow such downward and upward facing interfaces, the CoupledCoordinatorInterface extends both the CoordinatorInterface and the CoupledSimulatorInterface. This enables a processor satisfying the CoupledCoordinatorInterface to participate both as a coordinator for its own coupled model as well as providing a CoupledSimulatorInterface to the coordinator above it.

The following interfaces are for simulation of DEVS models that satisfy the DEVS modeling interfaces as described above.

```
 interface AtomicSimulatorInterface {
 void initialize();
 Double nextTN();
 void computeInputOutput(Double t);
MessageInterface getOutput();
 void applyDevsDeltfunc(Double t, MessageInterface x);
void simulate(int numIter);
void simInject(double e,MessageInterface m);
}
```

Note that applyDevsDeltfunc() employs DEVS model interfaces to compute the atomic model transition function as illustrated in the next section.

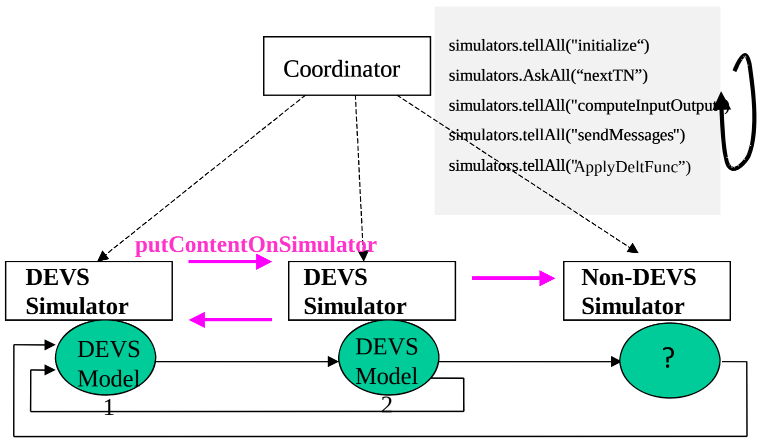
```
interface CoupledSimulatorInterface extends AtomicSimulatorInterface,CoreSimulatorInterface{
      CoupledSimulatorInterface getSimulatorOf(String ModelName);
       void addPair(Pair cs,Pair cd);   //add coupling pair
       void removePair(Pair cs, Pair cd); //remove coupling pair
       void setParent(CoordinatorInterface p);
       CoordinatorInterface getParent();
      }
```

```
interface CoordinatorInterface {
 void setSimulators();
 void addSimulator(IOBasicDevs comp);
 void addCoordinator(Coupled comp);
 coupledDevs getCoupled();
 void addExtPair(Pair cs,Pair cd) ;
 void informCoupling();
 Relation convertInput(MessageInterface x);
void simulate(int numIter);
}
```

```
interface CoupledCoordinatorInterface extends CoupledSimulator, CoordinatorInterface{
void putMyMessages(ContentInterface c);
 void sendDownMessages();
}
```

3 Simulation Protocol

DEVS treats a model and its simulator as two distinct elements. The simulation protocol describes how a DEVS model should be simulated whether in standalone fashion or in a coupled model. Such a protocol is implemented by a processor which can be a simulator or a coordinator.



Coordinator
simulators.tellAll("initialize")
simulators.AskAll("nextTN")
simulators.tellAll("computeInputOutput")
simulators.tellAll("sendMessages")
simulators.tellAll("ApplyDeltFunc")
putContentOnSimulator
DEVS Simulator
DEVS Simulator
Non-DEVS Simulator
DEVS Model 1
DEVS Model 2
?

Figure 5 Federation of DEVS with Non-DEVS Simulators

3.1 DEVS and non-DEVS Simulation with the CoreSimulatorInterface

Recall that DEVS and non-DEVS models can participate in a simulation as illustrated in Figure 1. CoreSimulatorInterface provides the interface to both DEVS and non-DEVS simulators to interoperate according to the DEVS simulation protocol. To help understand how the methods in CoreSimulatorInterface are used and to understand the DEVS simulator protocol to be discussed later, we give an informal description of the manner in which a coordinator would conduct a simulation with a collection of simulators. The coordinator would synchronize the activities of the simulators to guide them through a cycle of method applications as follows:

```
public void  simulate(ensembleCollection<CoreSimulatorInterface> simulators)
    {
1.   simulators.tellAll("setSimulators",simulators);
2.   simulators.tellAll("initialize");
3.   tN = Min(simulators.AskAll("nextTN"));
4.   while( (tN < DevsInterface.INFINITY)) ) {
5.   simulators.tellAll("computeInputOutput",Double,tN);
6.  simulators.tellAll("sendMessages");
7.  simulators.tellAll("applyDeltFunc",Double,tN);
8.  tN = Min(simulators.AskAll("nextTN"));
    }}
```

Each line is given the following explanation:

1. the coordinator tells each of the simulators in the collection the others' addresses.
2. the coordinator asks each simulator to perform the initialization function.
3. the coordinator requests that each simulator sends its time of next event and takes the minimum of the returned values to obtain the global time of next event
4. the coordinator enters the following cycle until activity ceases:
5. each of the simulators applies its computeInputOutput() method to produce an output that consists of a collection of contents (port/value) pairs – for DEVS simulators this is a composite message computed according to the DEVS formalism based on its model's current state
6. each of the simulators partitions its output into messages intended for recipient simulators and sends these messages to these recipient simulators – for DEVS simulators these recipients are determined from the output ports in the message and the coupling information that will have previously been received from the coordinator
7. each of the simulators executes its ApplyDeltFunc method which computes the combined effect of the received messages and internal scheduling on its state, a side effect of which is produce of time of next event, tN – for DEVS simulators this state change is computed according to the DEVS formalism and the tN is updated using its model's time advance
8. the coordinator obtains the next global time of next event and the cycle repeats

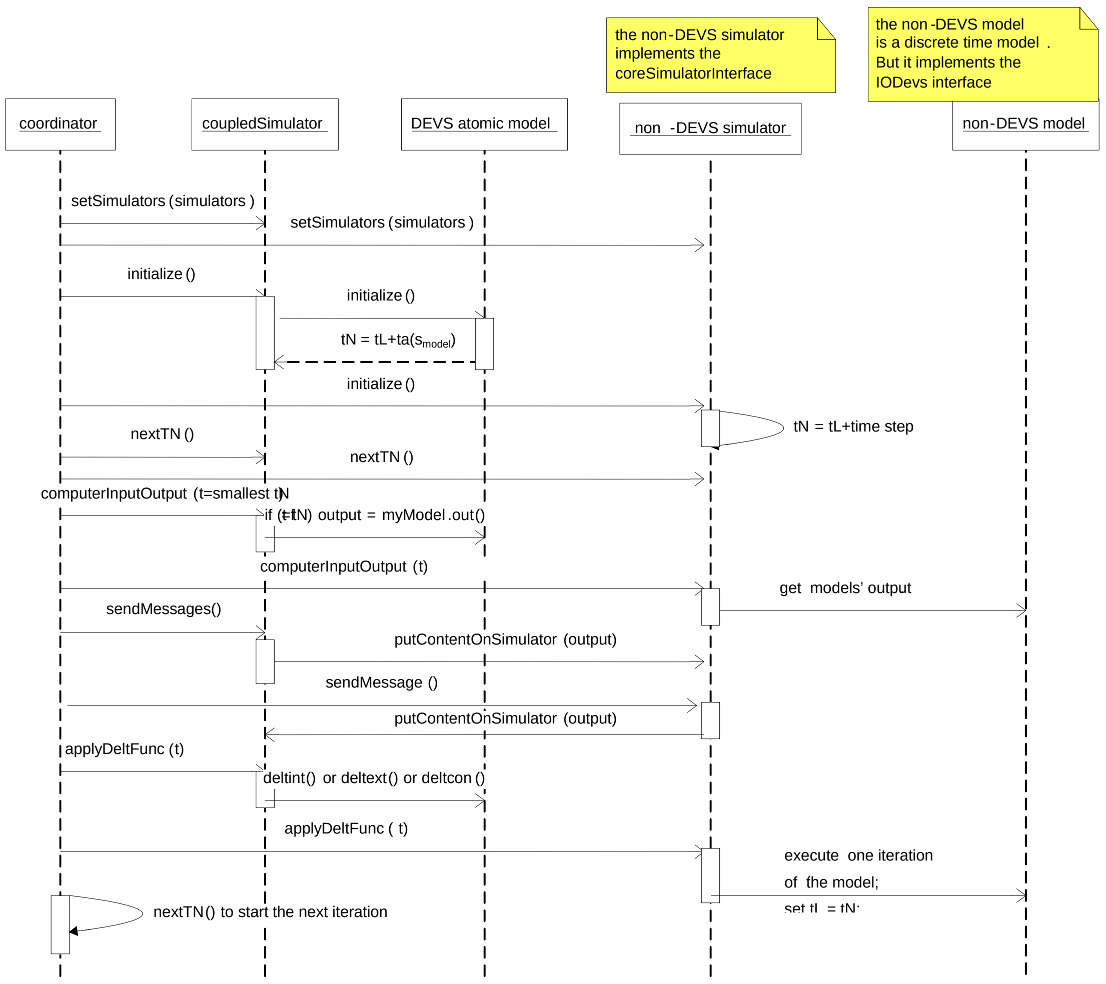
Implicit in the above pseudo-code are the following constraints involving methods in the CoreSimulatorInterface:

- The sendMessages() method "must" employ the putContentOnSimulator() method as follows: for any simulator to which it wishes to send a content, it must call the recipient's putContentOnSimulator() method with the recipient and the content as arguments.

- Further, in applying its computeInputOutput() method, a simulator “must” be able to interpret the contents (satisfying the ContentInterface) it has received from the other simulators.

Notice that we cannot enforce the “must” requirements just given, and cannot prove that the simulation executes a desired behavior, unless we are given further information about format. One way to do this is where the simulators are truly DEVS simulators in that they satisfy the interfaces and constraints given below. Failing this additional rigor, the interoperation involving DEVS and non-DEVS is purely at the technical level similar to that of a federation of simulators in HLA. This contrasts with the situation in which the federation is in fact derived from a DEVS coupled model for which correct simulation of the coupled model is guaranteed according to the DEVS formalism.

Figure 6 displays a sequence diagram to illustrate how a DEVS simulator can work with a non-DEVS simulator where both implement the coreSimulatorInterface described above. The entire simulation is coordinated by a coordinator following the simulation protocol described in section 3.1. The DEVS simulator has been assigned a DEVS atomic model and therefore implements the coupledSimulatorInterface. The non-DEVS simulator is assumed to iterate a model with a fixed time step, although the model need not be easily separable from the simulator. The discrete time model underlying the non-DEVS simulator is assumed to generate output and be capable of interpreting input at every iteration. Moveover, the model is assumed to implement the IODevs interface so that it can output and interpret DEVS messages as content (port-value) containers.

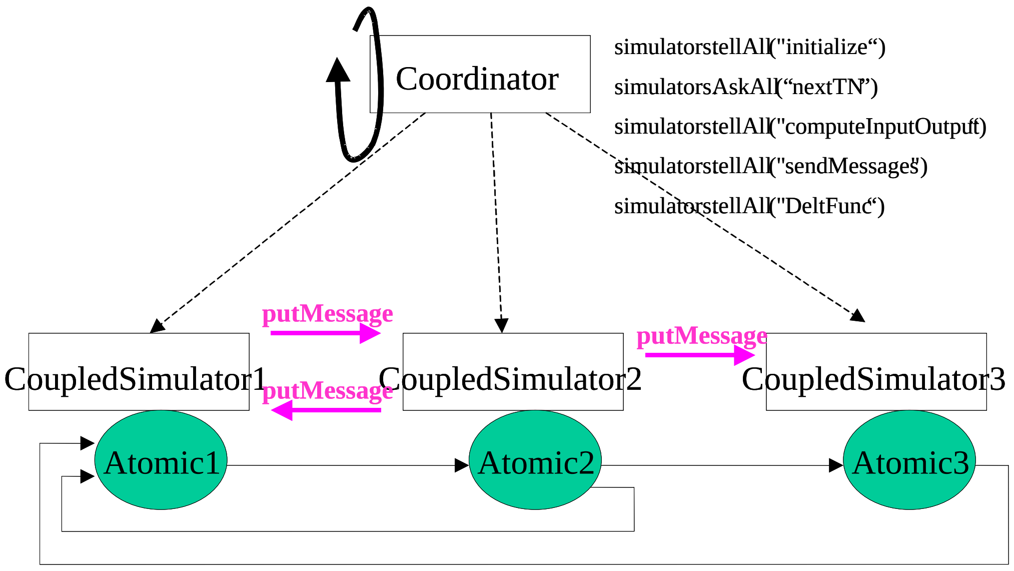


the non-DEVS simulator implements the coreSimulatorInterface
the non-DEVS model is a discrete time model. But it implements the IODevs interface
coordinator
coupledSimulator
DEVS atomic model
non -DEVS simulator
non-DEVS model
setSimulators (simulators)
setSimulators (simulators)
initialize ()
initialize ()
tN = tL+ta(s_model)
initialize ()
tN = tL+time step
nextTN ()
nextTN ()
computerInputOutput (t=smallest tN
if (t=tN) output = myModel.out()
computerInputOutput (t)
get models' output
sendMessages()
putContentOnSimulator (output)
sendMessage ()
putContentOnSimulator (output)
applyDeltFunc (t)
deltint() or deltext() or deltcon ()
applyDeltFunc (t)
execute one iteration
of the model;
nextTN() to start the next iteration

Figure 7 DEVS simulation protocol for a federation of DEVS with Non-DEVS Simulators

3.2 DEVS-to-DEVS Simulation with the CoreSimulatorInterface

To simulate a coupled model composed of atomic models in virtual-time, we use a coordinator to control the whole simulation cycle. For each atomic model, there is CoupledSimulator to take care of it. The figure below shows the relationship between coordinator, coupledSimulator, the coupled model and its atomic model components.



Coordinator
simulatorstellAll("initialize")
simulatorsAskAll("nextTN")
simulatorstellAll("computeInputOutput")
simulatorstellAll("sendMessages")
simulatorstellAll("DeltFunc")
putMessage
putMessage
putMessage
CoupledSimulator1
CoupledSimulator2
CoupledSimulator3
Atomic1
Atomic2
Atomic3

Figure 8: Simulating "one-level" coupled model in virtual-time mode

As we can see from figure 8, for each atomic model, there is a CoupledSimulator corresponding to it. The coordinator is the main thread. It will tell all the CoupledSimulators to initialize, send nextTN, computeInputOutput, sendMessages and applyDevsDeltfunc.

Note that if model Atomic1 wants to send a message to Atomic2, CoupledSimulator1 will find the message destination (CoupledSimulator2) based on its *ModToSim* data and *coupling information* (described below). Then it will call CoupledSimulator2's putMessages() and directly put the message to CoupledSimulator2. So the message doesn't go through the coordinator.

Figure 9 displays a sequence diagram showing how the simulation works.

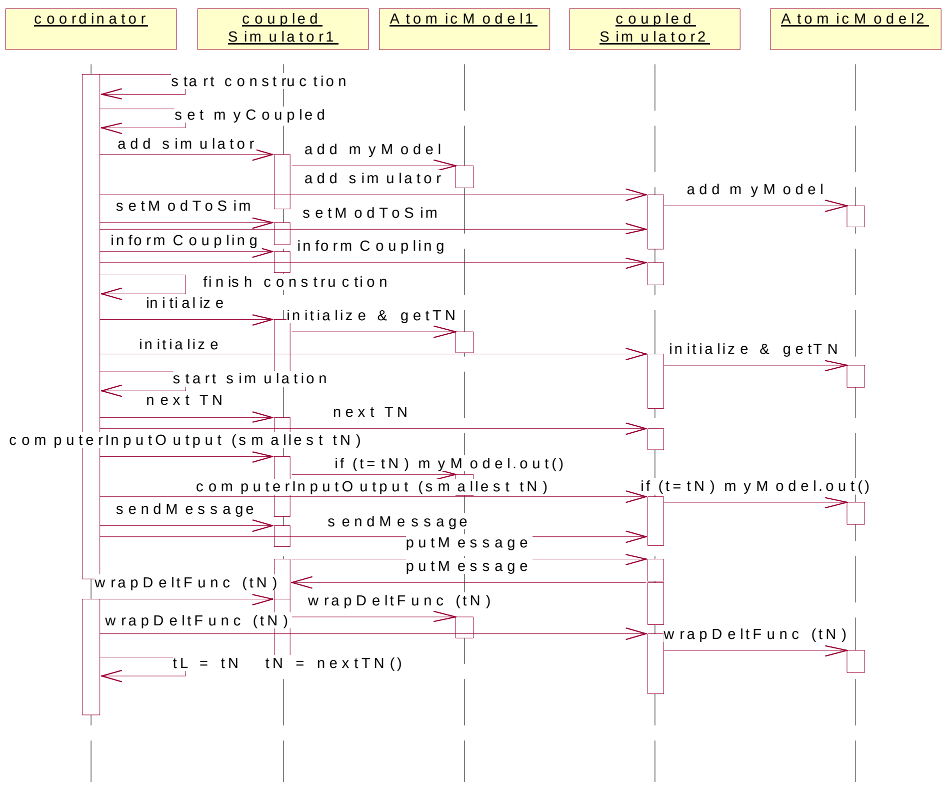


Figure 9: Sequence diagram of simulating "one-level" coupled model in virtual-time mode

As you can see from the sequence diagram, the coordinator actually controls the whole simulation process. The pseudo-code of the coordinator is similar to that discussed earlier:

```
public void  simulate(int num_iter)
{
    int i=1;
    simulator.tellAll(“initialize”);
    tN = Min(simulators.AskAll("nextTN"));
    while( (tN < DevsInterface.INFINITY) && (i<=num_iter) ) {
            simulators.tellAll("computeInputOutput");
            simulators.tellAll("sendMessages");
            simulators.tellAll("ApplyDevsDeltFunc");
```

```
                tN = Min(simulators.AskAll("nextTN"));
                i++;
            }
        }
```

From figure 9 we can also see that in coordinator's construction phase, for each atomic model, it will add a CoupledSimulator. Then it will call the setModToSim() and informCoupling() to download the *modelToSim* data and *coupling information* to all the CoupledSimulators. Here the *modelToSim* data stores the mapping information between each model and its corresponding simulator. The *coupling information* records the mapping information between one model's output port and another model's input port so we know where the message will flow to. By having these two data tables (the coordinator downloads it to the simulators), a simulator can send its model's output message directly to another simulator. Specifically, in CoupledSimulator's sendMessages(), if there are output messages generated by its model, the CoupledSimulator will first find the message's destination model based on the *coupling information*. Then it will find the corresponding simulator of that model based on the *modelTosim* data. Finally it will call that simulator's putContentOnSimulator () to put the contents of a message on the input of that simulator. Below we show the sendMessages() and putContentOnSimulator () functions.

```
public void sendMessages() {
  MessageInterface o = getOutput();
  if( o!= null && !o.isEmpty()) {
    Relation r = convertMsg((message)getOutput());//assume computeInputOutput done first
    Iterator rit = r.iterator();
    while (rit.hasNext()){
      Pair p = (Pair)rit.next();
      content co = (content)p.getValue();
      Object ds = p.getKey();
      CoreSimulatorInterface sim = modelToSim.get(ds);
      Sim.putContentOnSimulator(co);
      }
    }
```

```
public void putContentOnSimulator (ContentInterface c){
input.add(c);
}
```

3.3 Simulation of an Atomic model in virtual-time

In GenDEVS, the simplest simulation scenario is to simulate an Atomic model in virtual-time. The following flow chart shows the simulation protocol for simulating an atomic model in this manner. This protocol should be implemented by an atomic model simulator that implements the AtomicSimulator interface described above.

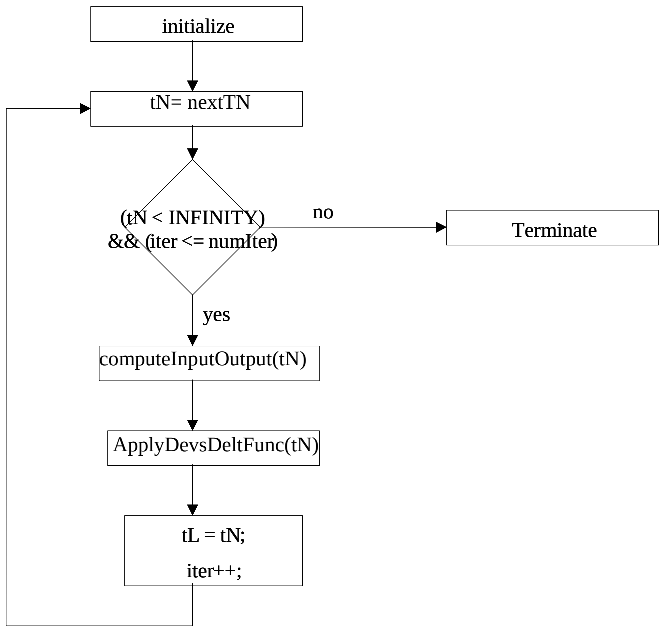


Figure 10: AtomicSimulator

```
public  void  applyDevsDeltfunc (double t,MessageInterface x){
 if(x == null){
    System.out.println("ERROR RECEIVED NULL INPUT  " + myModel.toString());
    return;
  }
  if (x.isEmpty() && !equalTN(t)) {
    return;
  }
  else if((!x.isEmpty()) && equalTN(t)) {
    double e = t - tL;
    myModel.deltcon(e,x);
  }
  else if(equalTN(t)) {
    myModel.deltint();
  }
  else if(!x.isEmpty()) {
    double e = t - tL;
    myModel.deltext(e,x);
  }
  tL = t;
  tN = tL + myModel.ta();
}
```

3.4 Simulation of a coupled model in virtual-time

In GenDevs, an atomic model is a basic component. By coupling several atomic models together, we can have a coupled model. So, a coupled model has several components. These components might be Atomic model or be Coupled model (hierarchical construction). In a coupled model, all the components are coupled together by linking one component’s output port to another component’s input port.

First let’s consider a relatively simple kind of Coupled model. In this kind of Coupled model, all components are atomic models. Because no component is coupled model, the coupled model is actually a “one-level” coupled model.

To simulate this kind of coupled model in virtual-time model, we need a coordinator to control the whole simulation cycle. For each Atomic model, there is a CoupledSimualtor to take care of it. The figure below shows the relationship between coordinator, coupledSimulator, the coupled model and its Atomic model components.

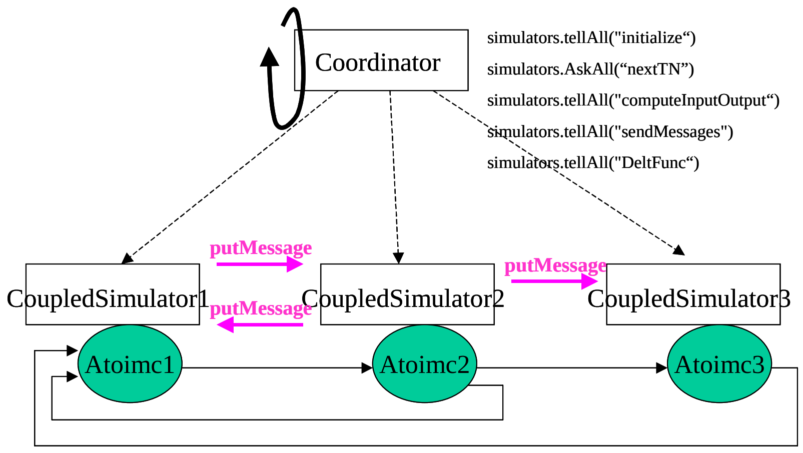

Coordinator
simulators.tellAll("initialize")
simulators.AskAll("nextTN")
simulators.tellAll("computeInputOutput")
simulators.tellAll("sendMessages")
simulators.tellAll("DeltFunc")
putMessage
putMessage
putMessage
CoupledSimulator1
CoupledSimulator2
CoupledSimulator3
Atoimc1
Atoimc2
Atoimc3

Figure 11: Simulating "one-level" coupled model in virtual-time mode

As we can see from figure 8, for each atomic model, there is a CoupledSimulator corresponding to it. The coordinator is the main thread. It will tell all the CoupledSimulators to initialize, send nextTN, computeInputOutput, sendMessages and wrapDeltfunc.

Note that if model Atomic1 wants to send a message to Atomic2, CoupledSimulator1 will find the message destination (CoupledSimulator2) based on its *ModToSim* data and *coupling information* (described below). Then it will call CoupledSimulator2's putMessages() and directly put the message to CoupledSimulator2. So the message doesn't go through the coordinator.

Below is the sequence diagram showing how the simulation works.

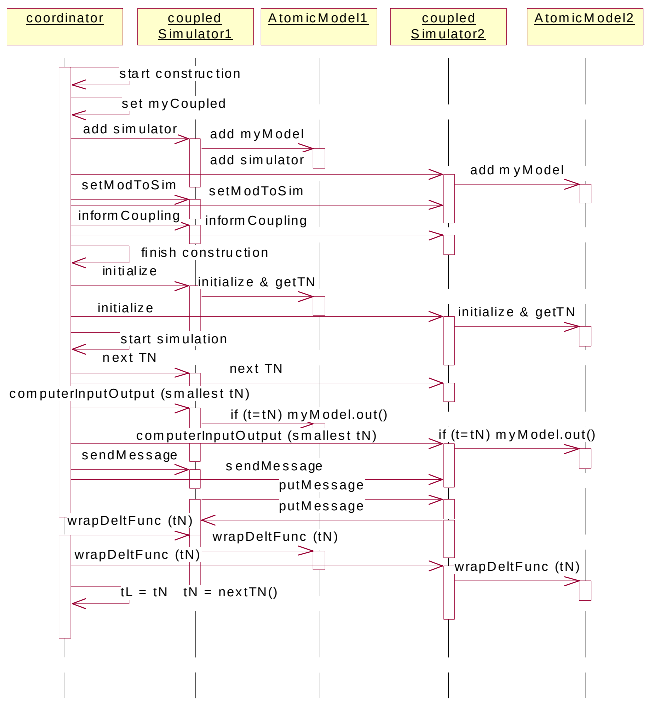


Figure 9: Sequence diagram of simulating "one-level" coupled model in virtual-time mode

As you can see from the sequence diagram, the coordinator actually controls the whole simulation process. The psuedo-code of the coordinator looks like this:

```
public void  simulate(int num_iter)
{
    int i=1;
    tN = simulators.AskAll("nextTN");
    while( (tN < DevsInterface.INFINITY) && (i<=num_iter) ) {
```

```
                        simulators.tellAll("computeInputOutput");
                        simulators.tellAll("sendMessages");
                        simulators.tellAll("DeltFunc");
                        tN = simulators.AskAll("nextTN");
                        i++;
                }
        }
```

From figure 10 we can also see that in coordinator's construction phase, for each atomic model, it will add a CoupledSimulator. Then it will call the setModToSim() and informCoupling() to download the *modelToSim* data and *coupling information* to all the CoupledSimulators. Here the *modelToSim* data stores the mapping information between each model and its corresponding simulator. The *coupling information* records the mapping information between one model's output port and another model's input port so we know where the message will flow to. By having these two data table (the coordinator download it to the simulators), a simulator can send its model's output message directly to another simulator. Specifically, in CoupledSimulator's sendMessages(), if there are output messages generated by its model, the CoupledSimulator will first find the message's destination model based on the *coupling information*. Then it will find the corresponding simulator of that model based on the *modelTosim* data. Finally it will call that simulator's putMessage() to put the message to that simulator. Below we show the sendMessages() and putMessages() functions.

```
public void sendMessages() {
  MessageInterface o = getOutput();
  if( o!= null && !o.isEmpty()) {
    Relation r = convertMsg((message)getOutput());//assume computeInputOutput done first
    Iterator rit = r.iterator();
    while (rit.hasNext()){
       Pair p = (Pair)rit.next();
       content co = (content)p.getValue();
       Object ds = p.getKey();
       if(modelToSim.get(ds) instanceof CoupledSimulatorInterface){
          CoupledSimulatorInterface sim = (CoupledSimulatorInterface)modelToSim.get(ds);
          sim. putContentOnSimulator (co);
    }
}

public void putContentOnSimulator (ContentInterface c){
input.add(c);
}
```

4 Future Development

Reference [1] provides a description of DEVSJAVA architecture that includes capabilities for real-time and distributed simulation of hierarchical models, a more extensive scope than is covered in this reformulation as a DEVS standard for implementation. We feel it is important to get the basic level discussed here formulated and agreed to by the DEVS community before proceeding on to incorporate the more extensive capabilities that can be built on top of it.

5 References

[1]The Architecture of GenDevs Distributed Simulation in DEVSJAVA, Xiaolin Hu
Dept of Computer Science, Georgia State University, Updated by Bernard P. Zeigler
ACIMS, January 2008 Available at www.acims.arizona.edu

[2]Bernard P. Zeigler, Objects and Systems: Principled Design with Implementation C++/Java, Springer-Verlag, NY, 1997.