하이브리드 구조실험을 위한 데이터 모델에서의 상호작용의 표현

Representation of Interactions in Data Model for Hybrid Structural Experiments

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요 지

하이브리드 구조실험에서는 전체구조물을 여러 개의 부분구조물로 나누어서 실험과 해석을 수행한다. 실험을 위한 부분구조물들과 해석을 위한 부분구조물들은 지역적으로 서로 다른 장소에서 실험과 해석이 수행될 수 있으며, 이 부분구조물들의 실험과 해석은 시뮬레이션 코디네이터에 의하여 통제된다. 하이브리드 구조실험을 수행하는 동안에 시뮬레이션 코디네이터와 부분구조물들은 서로 간에 데이터 교환이 이루어지는 상호작용을 하게 된다. 본 논문은 이러한 상호작용을 기술하고 있는데, 하나의 하이브리드 구조실험 예제에 대하여 시뮬레이션 코디네이터와 부분구조물들 사이의 상호작용을 데이터 모델의 하나인 리하이 모델의 클래스와 객체를 통하여 표현하였다. 시뮬레이션 코디네이터와 부분구조물들은 각자의 데이터 저장을 위한 객체를 가지도록 구성하였고, 서로간의 연결은 동일한 형식의 인터페이스 링크를 사용하여 처리하였다. 본 논문에서 설명한 객체들은 일관된 방법에 의하여 구현하였는데, 하이브리드 구조실험을 위한 컴퓨터 시스템의 개발에 사용할 수 있다.

핵심용어 : 하이브리드실험, 부분구조물, 상호작용, 데이터 모델, 리하이 모델

Abstract

The hybrid structural experiment decomposes a structure into independent substructures that can be tested or simulated. The substructures being tested or simulated may be distributed at different facilities of different locations, and are managed by the simulation coordinator. There exist interactions among the simulation coordinator and the substructures since they give and receive the commands and feedbacks during the experimental process. These interactions are described in this paper for an example hybrid structural experiment using the classes and objects in the Lehigh Model which is one of the data models for structural experiments. The simulation coordinator and the substructures have the objects for the interaction data files, and are linked together through the same types of the interface links. The objects for the interactions presented in this paper can be implemented in a consistent way, and be used for developing the computer system for the hybrid structural experiments.

Keywords : *hybrid experiment, substructure, interaction, data model, Lehigh Model*

1. 서 론

Structural engineers have investigated the behaviors of structures by physical experiments or analytical computations. A physical experimental method uses a physical specimen, applies the loads, and measures the structural responses. An analytical computational method needs a computer simulation model to perform the analytical process. The hybrid structural experiment combines the physical experiments and the analytical computations for decomposed substructures to predict the behaviors of the entire structure. This approach is especially useful for the distributed hybrid pseudo-dynamic experiment, and allows to overcome the size and geographical limitations of the experiment.

Data models for the hybrid experiments formally

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organize and represent the information involved in the experiments. The formally represented information can be used for developing the computer systems. Some noticeable data models for earthquake engineering experiments including the hybrid experiments have been developed in support of the George E. Brown Jr. Network for Earthquake Engineering Simulation(NEES; http://nees.org/, 2009), which is a shared national network of 15 experimental facilities in the United States. The Oregon State Model(Oregon State University and Network Alliance for Computational Science and Engineering, 2003) was for tsunami wave basin experiments, and the Reference NEESgrid Data Model(Peng et al., 2004) for shake table experiments. The Lehigh Model(Lee et al., 2008) was intended for the large-scale structural experiments, and explored the explicitly categorized classes for representing the information involved in the hybrid experiments. The NEEScentral Model(NEESit, 2009) was developed for general structural experiments, and has recently extended its applications to the hybrid experiments.

The Lehigh Model(Lee et al., 2008) and the NEES central Model(NEESit, 2009) contributed towards the comprehensive data models for the hybrid experiments by providing the essential classes for the decomposed physical and analytical substructures and the simulation coordinator managing the substructures. However, there are still many parts of the models that need to be refined and described in detail. They include the interactions among the simulation coordinator and the substructures. Lee et al.(2009) discussed the links and interactions among classes in the Lehigh Model for the hybrid experiments. The classes for the simulation coordinator and substructures of a hybrid structural experiment are linked through a same class, but their interactions have not been fully inspected.

The objective of this paper is to give the detailed descriptions of the interactions among the simulation coordinator and substructures in the Lehigh Model for the hybrid structural experiments. The organization of the Lehigh Model is compared with that of other data model. An example of the hybrid experiments is presented, and the interactions existed in the example hybrid experiment are represented using the classes defined in the Lehigh Model. Then a possible implementation of the objects of the classes is provided to consider the practical usability of the model and to discuss feasible applications into other data models for the hybrid structural experiments.

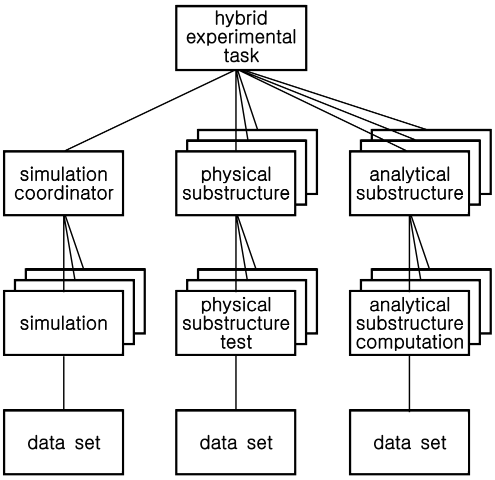
2. Comparison of Organizations of Data Models for Hybrid Experiments

Fig. 1 compares the conceptual organizations of the Lehigh Model(Lee et al., 2008; 2009) and the NEEScentral Model(NEESit, 2009). Only parts for the hybrid experiments from the data models are compared, and the main classes are shown in the figure.

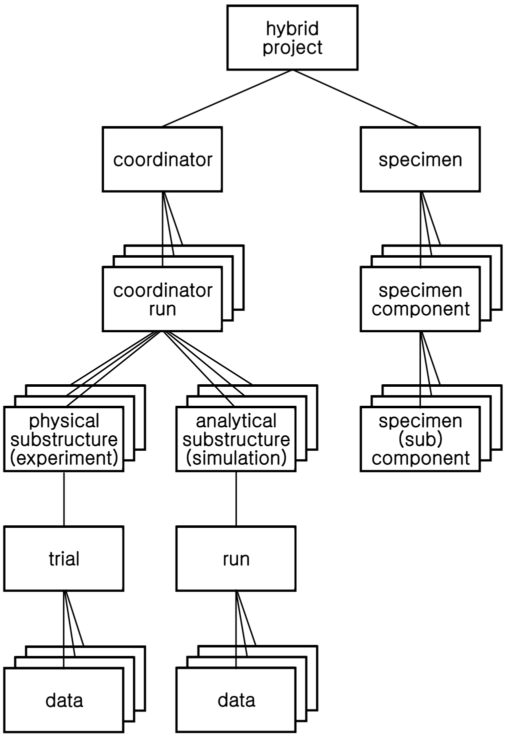
For the Lehigh Model in Fig. 1a, one hybrid experimental task involves a simulation coordinator, a number of physical substructures, and a number of analytical substructures. The simulation coordinator involves a number of simulations. Each physical substructure involves a number of physical substructure tests, and each analytical substructure a number of analytical computations. Each simulation involves a data set, each physical substructure test a data set, and each analytical substructure computation a data set.

Compared with the Lehigh Model, the NEEScentral Model in Fig. 1b has a different organization. One hybrid project involves a coordinator and a specimen. The coordinator involves a number of coordinator runs, and each coordinator run involves a number of physical substructures and a number of analytical substructures. Each physical substructure involves a trial which involves a number of data, and each analytical substructure involves a run which involves a number of data. The specimen involves a number of specimen components. Each specimen component may involve a number of specimen subcomponents.

The conceptual organizations in Figs. 1a and 1b show that the Lehigh Model and the NEEScentral



(a) Lehigh model(after Lee et al.(2008, 2009))



(b) NEEScentral model(after NEESit(2009))

Fig. 1 Comparison of organizations of data modelsfor hybrid structural experiments

Model have their own focuses of representing the information involved in the hybrid experiments. The Lehigh Model makes a clear distinction among the simulation coordinator, the physical substructures, and the analytical substructures. This provides easy understanding of the model, but the interactions among the simulation coordinator, the physical substructures, and the analytical substructures need to be thoroughly described. The NEEScentral Model puts more emphasis on the links among the coordinator, the physical substructures, and the analytical substructures by placing the substructures at the lower level of the coordinator. The specimen and the facility(not shown) are not closely related with the coordinator and each of the substructures. For the cases that the specimen and facility information is important, the models needs to provide easy access to the information from the coordinator and each of the substructures.

The Lehigh Model is considered in this paper, and the interactions among the simulation coordinator and the substructures are discussed in the later sections using an example hybrid experiment.

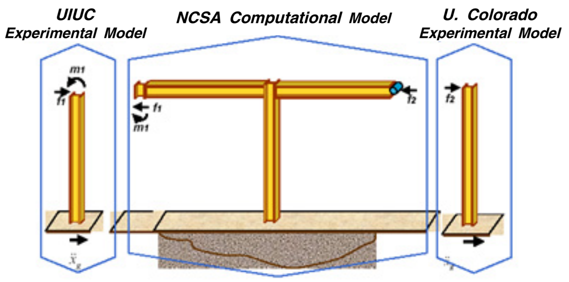
3. Interactions in Example Hybrid Experiment

3.1 Example Hybrid Experiment

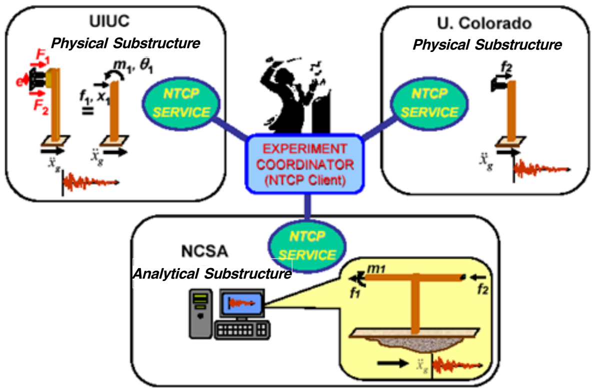
An early significant example for the hybrid structural experiments is the Multi-site Online Simulation Test(MOST; The MOST Experiment, 2003). The computer techniques related with the MOST experiment are described by Pearlman et al.(2004). Fig. 2 shows the outline of the experiment. A two-bay single story steel frame is divided into two experimental substructures and one analytical substructure in Fig. 2a. Two experimental substructures are tested at the University of Illinois of Urbana-Champaign(UIUC) and the University of Colorado. One analytical substructure is simulated at the National Center for Supercomputing Applications(NCSA). The three substructures are integrated by the NEESgrid Teleoperations Control Protocol(NTCP) server, and the simulation coordinator provides the overall management of the experiment(Fig. 2b).

3.2 Interactions in Example Hybrid Experiment

For the example hybrid experiment shown in Fig. 2, there exist interactions among a simulation coordinator, two physical substructures, and an analytical substructure. Fig. 3 shows an example of the interactions,



(a) Divided substructures



(b) Integration of substructures

Fig. 2 Hybrid structural testing
(after Pearlman et al. (2004))

which is arbitrarily made for the discussion in this paper. In the figure, the simulation coordinator involves two simulations(MOST Simulation 1 and MOST simulation 2), each physical substructure two tests(Left Column Test 1 and Left Column Test 2; Right Column Test 1 and Right Column Test 2), and the analytical substructure two computations(Center Frame Computation 1 and Center Frame Computation 2). The two sets of date and time are arbitrarily selected for the simulations, physical substructure tests, and analytical substructure computations. A simulation(e.g., MOST Simulation 1) is related with ones of the physical substructure tests(e.g., Left Column Test 1 and Right Column Test 1) and one of the analytical substructure computations(e.g., Center Frame Computation 1).

In Fig. 3, each of the simulations sends commands to and receives the feedbacks from the related physical substructure tests and analytical substructure computation while the hybrid experiment is performed. For example, the MOST Simulation 1 sends the commands(command L1a, L1b, L1c,....) to and receives the feedbacks(feedback L1a, L1b, L1c,....) from the Left Column Test 1. There are series of commands and feedbacks defined by the time steps of the hybrid experiment. After the hybrid experiment goes to the end, the accumulated commands and feedbacks can be saved as computer files such as the csv format files. For example, the MOST Simulation 1 will have three command files(LeftColumnCommand1.csv, RightColumnCommand1.csv, and CenterFrameCommand1.csv) and three feedback files(LeftColumnFeedback1.csv, RightColumnFeedback1.csv, and CenterFrameFeedback1.csv). The Left Column Test 1 will have one command file(LeftColumnCommand1.csv) and one feedback file(LeftColumnFeedback1.csv).

The interactions in Fig. 3 regarding the information on the commands and feedbacks among the simulation coordinator and the physical and analytical substructures can be represented formally by using the classes and objects defined in the Lehigh model for the hybrid experiments.

4. Representation of Interactions in Example Hybrid Experiment

The interactions in an example hybrid experiment shown in Fig. 3 are represented using the Lehigh Model. This section presents the classes for the hybrid experiments, the objects for the interactions in the example hybrid experiment, and then the display of the windows of the possible implementation for the objects. Table 1 shows the corresponding numbers for the classes, objects, and windows which are shown in Figs. 4, 5, and 6, respectively. In Table 1, the class, object, and window numbers are grouped for the simulation coordinator, and the physical and analytical substructures. For example, the simulation coordinator in the table involves the simulation coordinator class(Class No. 1) in Fig. 4a which are related with the MOST simulation coordinator object(Object No. 1) in Fig. 5a and the MOST Simulation Coordinator window(Window No. 1) in Fig. 6a. Some of the object and window numbers in Table 1 do not have corresponding class

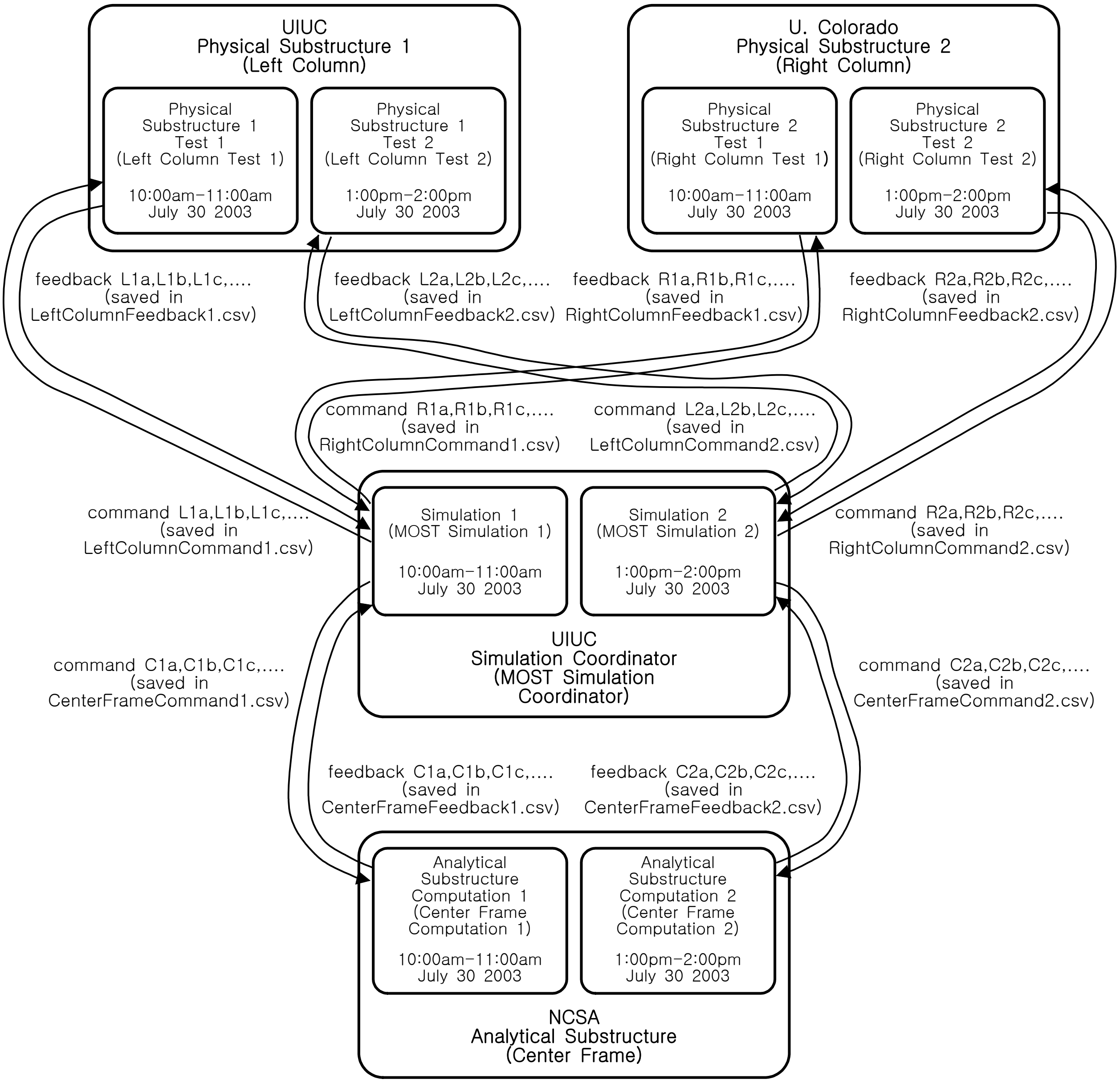


Fig. 3 Interactions in example hybrid experiment
(Sets of date and time are arbitrarily selected.)

numbers. This means the objects and windows are from the classes not shown due to space limitations in Fig. 4. The representation of the interactions in the example hybrid experiment in this section can be better understood when Table 1 and Figs. 4, 5, and 6 are compared together.

4.1 Classes for Hybrid Experiments

Fig. 4 shows the main classes of the Lehigh Model for the hybrid experiments. The classes and attributes in the figure and later figures are represented using a modified entity-relationship diagram developed for entity-based product and process models(Hong et al., 1994; Lee et al., 1998). Each rectangle in Fig. 4 indicates an entity category(referred to as a class). Each attribute of the class is shown below the rectangle with a horizontal bar. If the attribute is singe-valued, the bar ends with an empty circle, and if the attribute is multi-valued, the bar ends with a black circle. The value set of an attribute(the set of possible

Table 1 Corresponding classes, objects, and windows

	Class Number	Object Number	Window Number
Simulation Coordinator (MOST Simulation Coordinator)	1	1	1
	2	2	2
	2	3	3
	not shown	4	4
	4	5	5
	4	6	6
	5	7	7
Physical Substructure 1 (Left Column)	8	8	8
	9	9	9
	9	10	10
	not shown	11	11
	4	12	12
Physical Substructure 2 (Right Column)	8	13	13
	9	14	14
	9	15	15
	not shown	16	16
	4	17	17
Analytical Substructure (Center Frame)	10	18	18
	11	19	19
	11	20	20
	not shown	21	21
	5	22	22

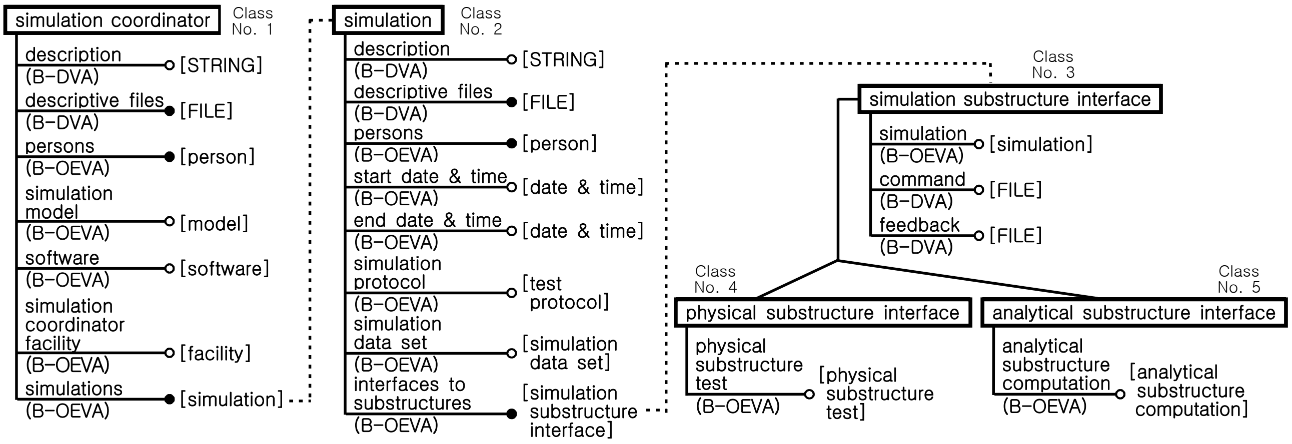
values for the attribute) is represented in square brackets. The attribute type is identified in parentheses. Attributes of a class are classified into two main types: (1) "data-valued" attributes(DVA) whose values are alphanumeric or otherwise indecomposable; and (2) "object entity-valued" attributes(OEVA) whose values refer to other classes.

Figs. 4a, 4b, and 4c show the classes for the simulation coordinator, the physical substructure, and the analytical substructure for a hybrid experiment. The full description for the classes is presented by Lee et al.(2009), and a reduced description in this paper. Most of the attributes of the classes in Fig. 4 are self-explanatory. The class numbers of the classes are used later for comparison with the objects and windows in Figs. 5 and 6.

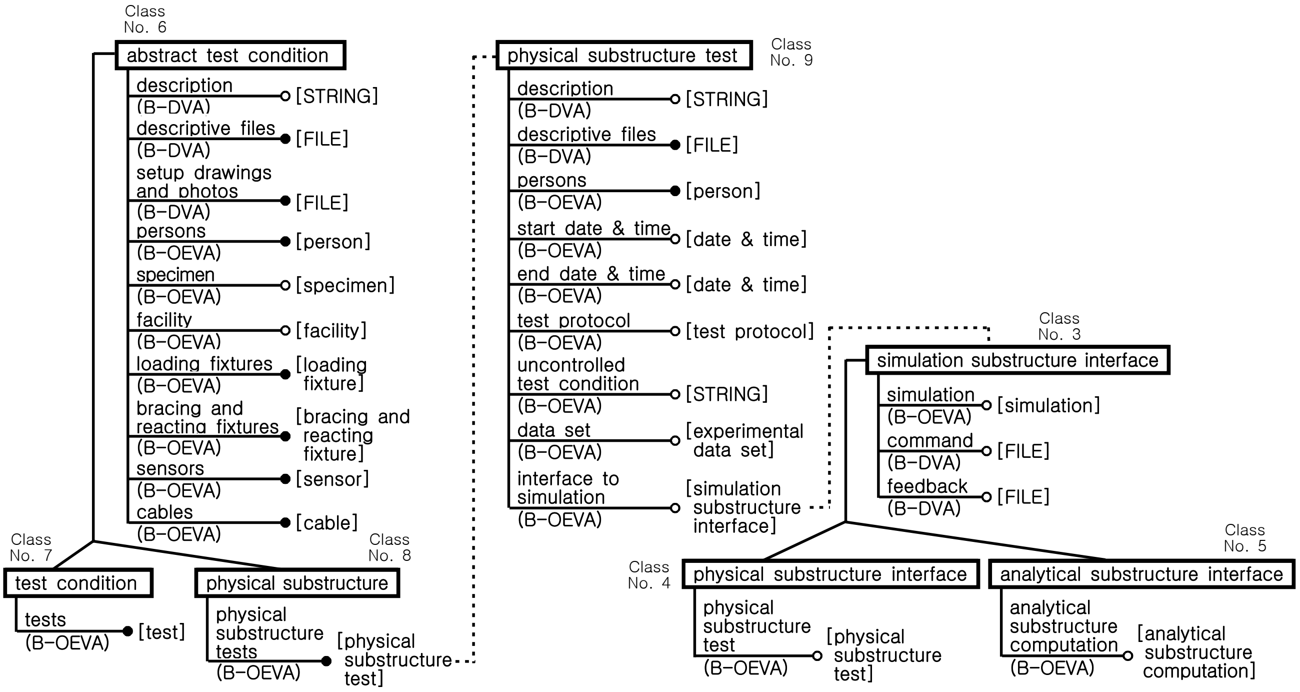
The simulation coordinator class(Class No. 1) in Fig. 4a represents the information involved in the simulation coordinator of a hybrid experiment. The simulation coordinator class includes the attributes for the description, the simulation model and the simulation coordinator facility, and the multi-valued attribute for a number of the simulations, whose value set refers to the simulation class. The simulation class(Class No. 2) includes the attributes for the description, the start date & time, the end date & time and the simulation date set, and the multi-valued attribute for the interfaces to substructures, whose value set refers to the simulation substructure interface class. The simulation substructure interface class(Class No. 3) is a generalization of the physical substructure interface class(Class No. 4) and the analytical substructure interface class(Class No. 5) which are used for the links with the physical substructures and the analytical substructures, respectively. The attributes for the simulation, the command, and the feedback of the simulation substructure interface class(Class No. 3) are inherited by the physical substructure interface class(Class No. 4) and the analytical substructure interface class(Class No. 5).

In Fig. 4b, the abstract test condition class(Class No. 6) is a generalization of the test condition class(Class No. 7) and the physical substructure class(Class No. 8). The attributes for the abstract test condition class, such as the specimen and the facility attributes, are inherited by the test condition class and the physical substructure class. The test condition class is for the typical experiments. The physical substructure class is for the hybrid experiments, and the value set of the multi-valued attribute for the physical substructure tests refers to the physical substructure test class. The physical substructure test class(Class No. 9) includes the single-valued attribute for the interface to simulation. The value set of the attribute refers to the simulation substructure interface class(Class No. 3) which is the same as in Fig. 4a.

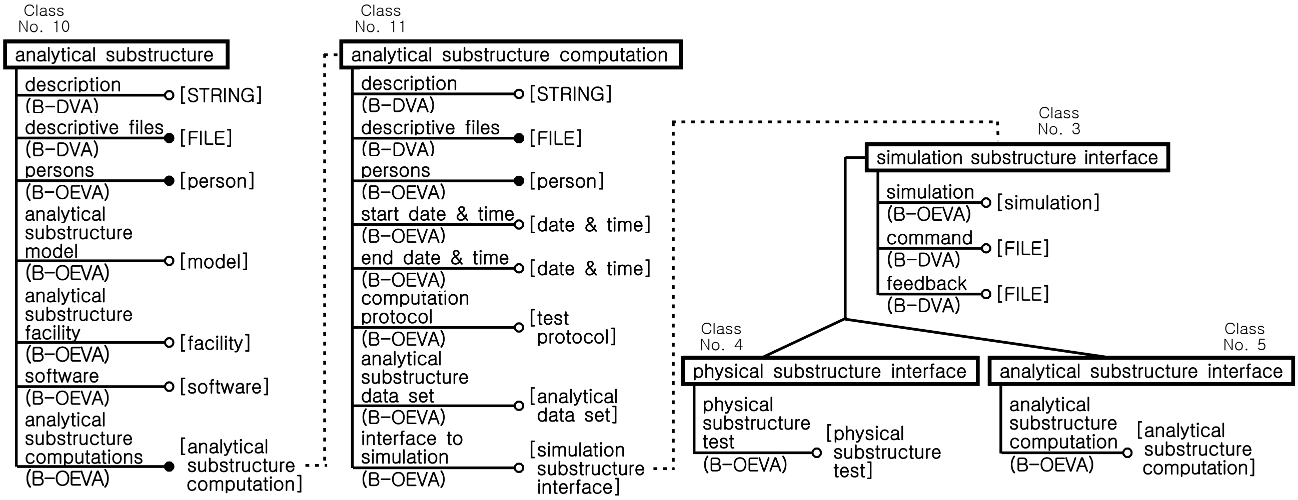
The analytical substructure class(Class No. 10) in Fig. 4c represents the information involved in the analytical substructures of a hybrid experiment. The analytical substructure class includes the multi-valued attribute for a number of the analytical substructure computations. The value set of the analytical substructure computations attribute refers to the analytical substructure computation class. The



(a) Classes for simulation coordinator



(b) Classes for physical substructure



(c) Classes for analytical substructure

Fig. 4 Classes for hybrid experiments(after Lee et al. (2009))

analytical substructure computation class(Class No. 11) includes the single-valued attribute for the interface to simulation. The value set of the attribute refers to the simulation substructure interface class(Class No. 3) which is the same as in Figs. 4a and 4b.

It is known in Figs. 4a, 4b, and 4c that a simulation and its related physical substructure tests and analytical substructure computations are linked through the simulation substructure interface class which is a generalization of the physical substructure interface class and the analytical substructure interface class.

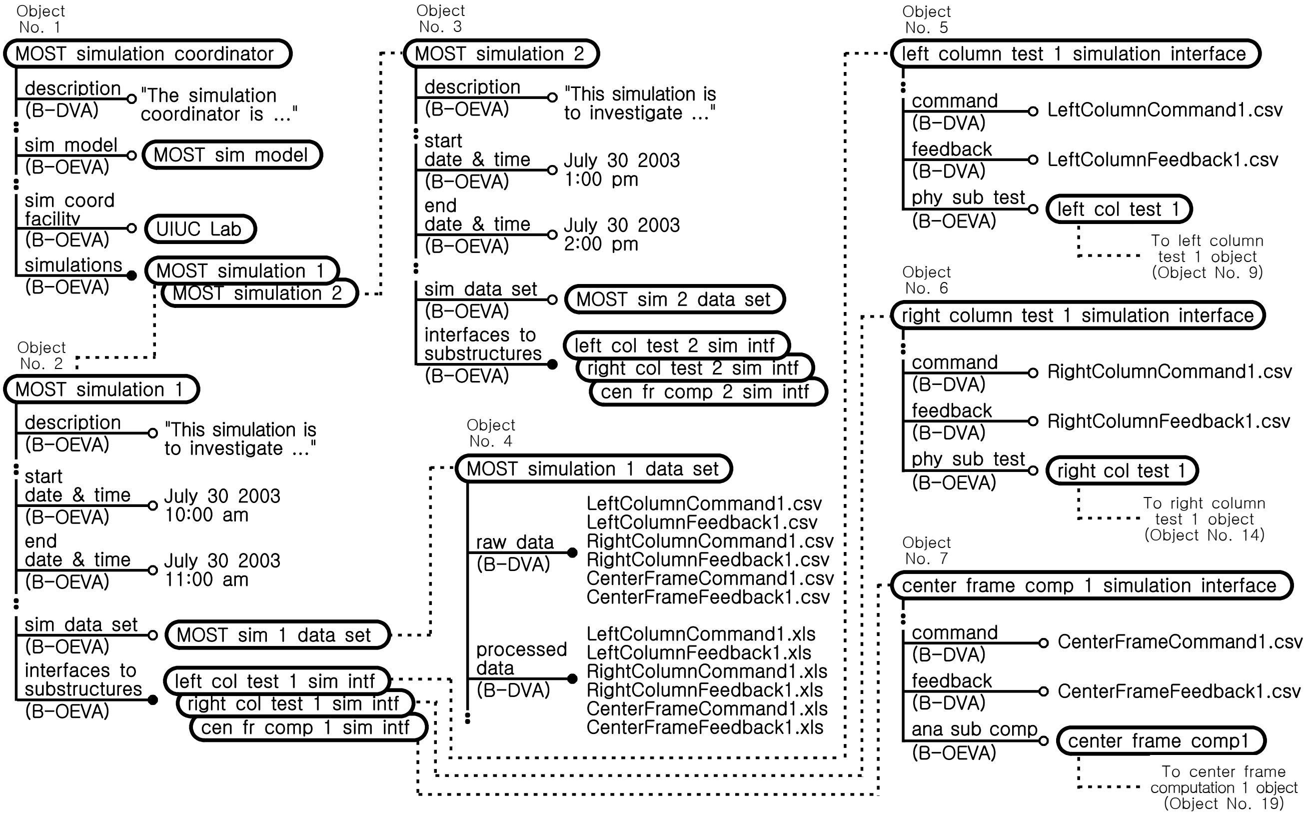
4.2 Objects for Interactions in Example Hybrid Experiment

Fig. 5 shows the objects for the interactions in an example hybrid experiment shown in Fig. 3. Each rounded rectangle in Fig. 5 denotes an object. The objects in Fig. 5a are for interactions of the MOST simulation coordinator in Fig. 3 and are from the classes in Fig. 4a. The objects in Figs. 5b and 5c are for interactions of the Left Column and the Right Column in Fig. 3 and are from the classes in Fig. 4b. The objects in Fig. 5d are for interactions of the Center Frame in Fig. 3 and are from the classes in Fig. 4c.

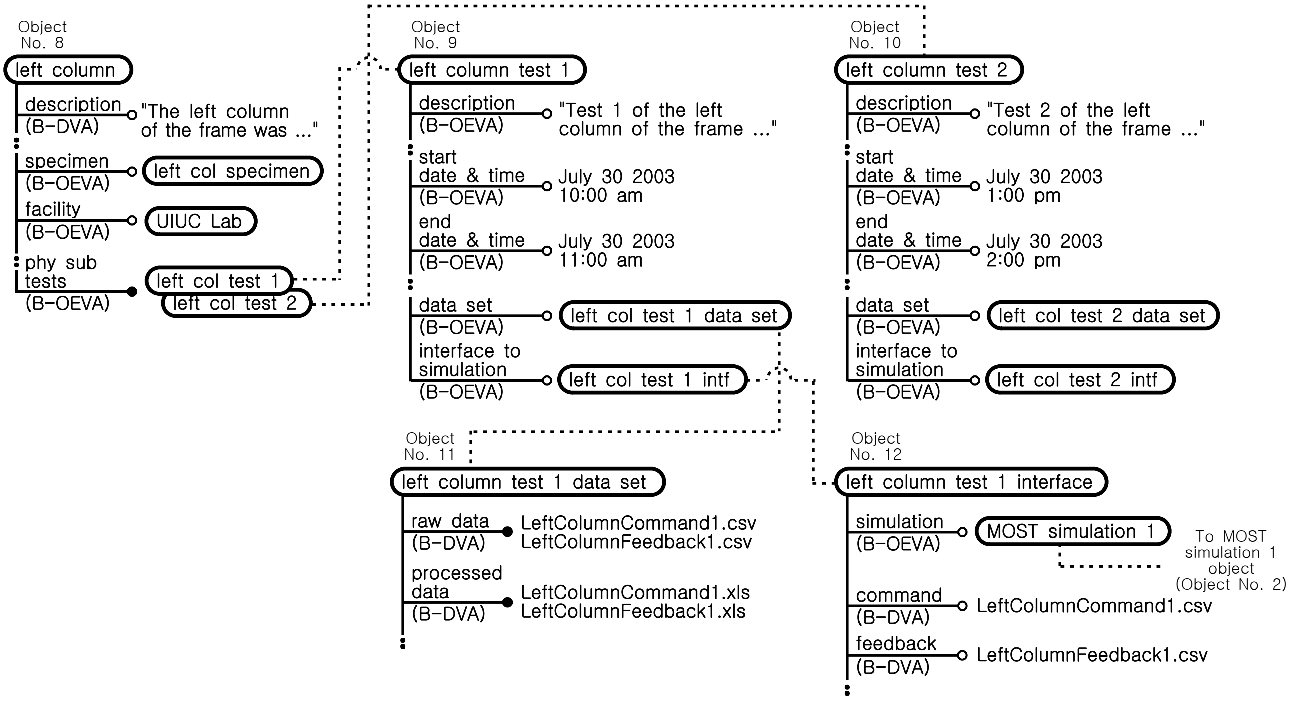
The MOST simulation coordinator object(Object No. 1) in Fig. 5a is from the simulation coordinator class(Class No. 1) in Fig. 4a, as presented in Table 1. Using the table, the objects in Fig. 5 and their corresponding classes in Fig. 4 can be easily found and compared. The MOST simulation coordinator object(Object No. 1) in Fig. 5a involves the simulation model attribute whose value refers to the MOST simulation model object, the simulation coordinate facility attribute whose value refers to the UIUC Lab object, and the simulations attribute whose values refer to the MOST simulation 1 object and the MOST simulation 2 object.

The MOST simulation 1 object(Object No. 2) in Fig. 5a involves the attributes for the description and the start date & time, and the end date & time. The object also involves the simulation data set attribute whose value refers to the MOST simulation 1 data set object. The MOST simulation 1 data set object(Object No. 4) involves the raw data attribute whose values are the three command files and three feedback files for the three substructures(see Fig. 3), and the processed data attribute whose values are the xls format files. The MOST simulation 1 object(Object No. 2) also involves the interfaces to substructures attribute whose values refer to the three interface objects for the three substructures, which are the left column test 1 simulation interface object, the right column test 1 simulation interface object, and the center frame computation 1 simulation interface object. The left column test 1 simulation interface object(Object No. 5) involves the attributes for the command and feedback files. The object also involves the physical substructure test attribute whose value refers to and links to the left column test 1 object(Object No. 9). The right column test 1 simulation interface object(Object No. 6) and the center frame computation 1 simulation interface object(Object No. 7) are similarly formulated, and involve the links to the right column test 1 object(Objet No. 14) and the center frame computation 1 object(Object No. 19). It needs to be noted that the MOST simulation 1 data set object(Object No. 4) involves the three command files and three feedback files for the three substructures, but each of the objects for the substructures(Object Nos. 5, 6, and 7) involves a command file and a feedback file. The MOST simulation 2 object(Object No. 3) is similar to the MOST simulation 1 object(Object No. 2).

The left column object(Object No. 8) in Fig. 5b involves the specimen attribute whose value refers to the left column specimen object, the facility attribute whose value refers to the UIUC Lab object, and the physical substructure tests attribute whose values refer to the left column test 1 object and the left column test 2 object. The left column test 1 object(Object No. 9) involves the data set



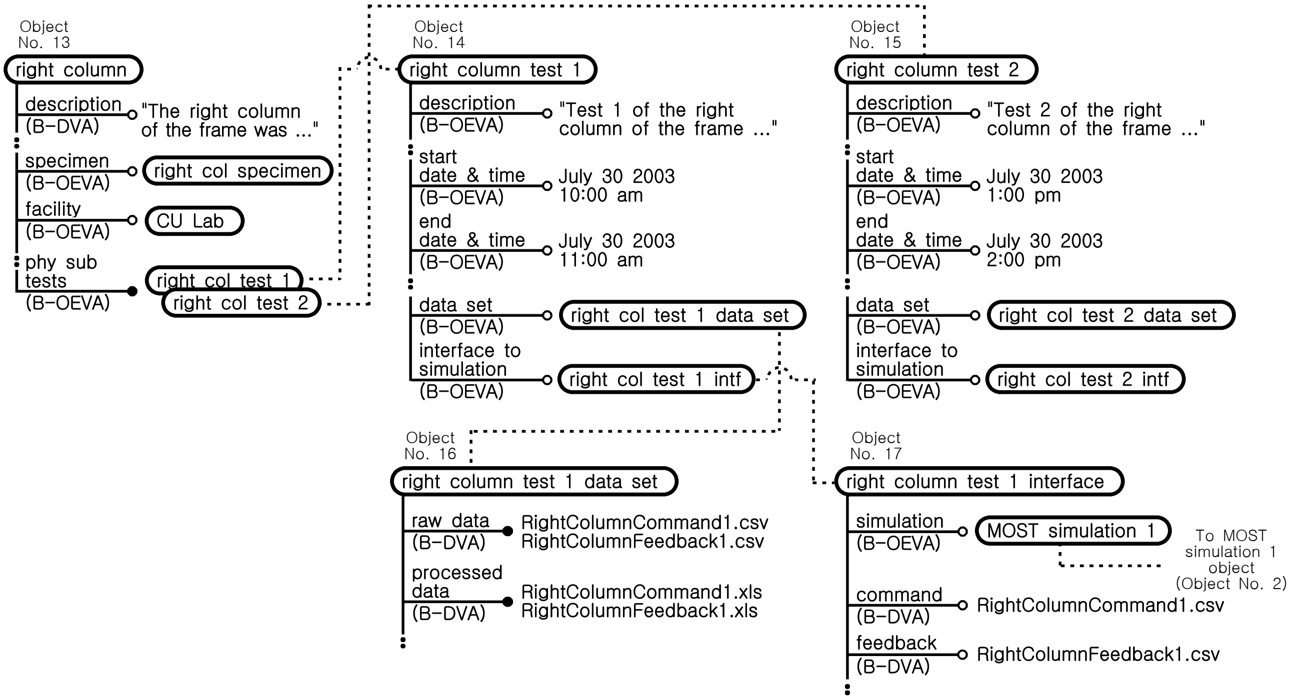
(a) Objects for simulation coordinator(MOST simulation coordinator)



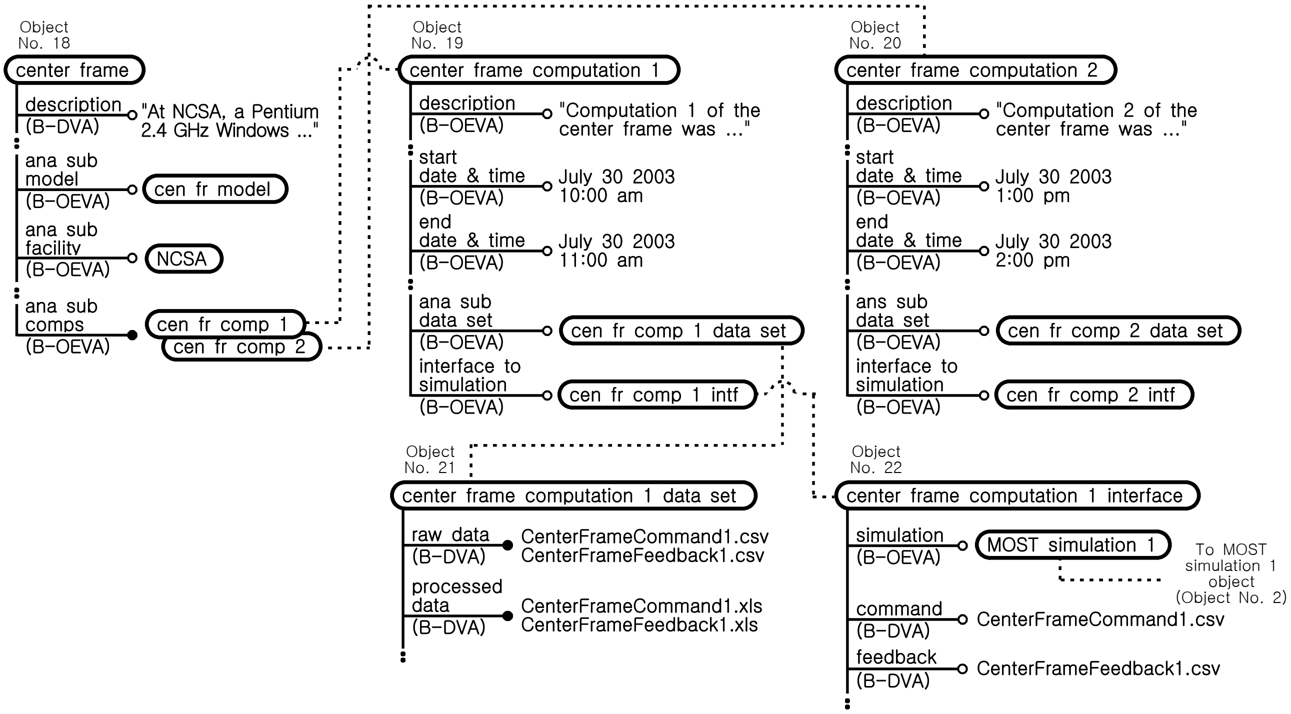
(b) Objects for physical substructure 1(left column)

Fig. 5 Objects for example hybrid experiment

attribute whose value refers to the left column test 1 data set object. The left column test 1 data set object(Object No. 11) involves the raw data attribute whose values are the command and feedback files for



(c) Objects for physical substructure 2(right column)



(d) Objects for analytical substructure(center frame)

Fig. 5 Objects for example hybrid experiment(continued)

the left column, and the processed data attribute whose values are the xls format files. The left column test 1 object(Object No. 9) also includes the interface to simulation attribute whose value refers to the left column test 1 interface object. The left column test 1 interface object(Object No. 12) involves the simulation attribute whose value refers to and links to the MOST simulation object(Object No. 2), and the attributes for the command and feedback files. The left column test 2 object(Object

No. 10) is similar to the left column test 1 object (Object No. 9).

The objects for the right column in Fig. 5c and the objects for the center frame in Fig. 5d are similar to those in Fig. 5b. The objects for the right column in Fig. 5c involve the command and feedback files in the right column test 1 data set object(Object No. 16) and the link to the simulation in the right column test 1 interface object(Object No. 17). The objects for the center frame in Fig. 5d involve the command and feedback files in the center frame computation 1 data set object(Object No. 21) and the link to the simulation in the center frame computation 1 interface object(Object No. 22).

4.3 Possible Implementation of Objects for Interactions in Example Hybrid Experiment

Fig. 6 shows the possible implementation of the objects for the interactions in Fig. 5. The display of the windows in Fig. 6 uses the format developed by Marullo(2007) and described by Lee et al.(2009) for the implementation of the objects in the Lehigh Model. Thus the implementation in Fig. 6 is fully possible.

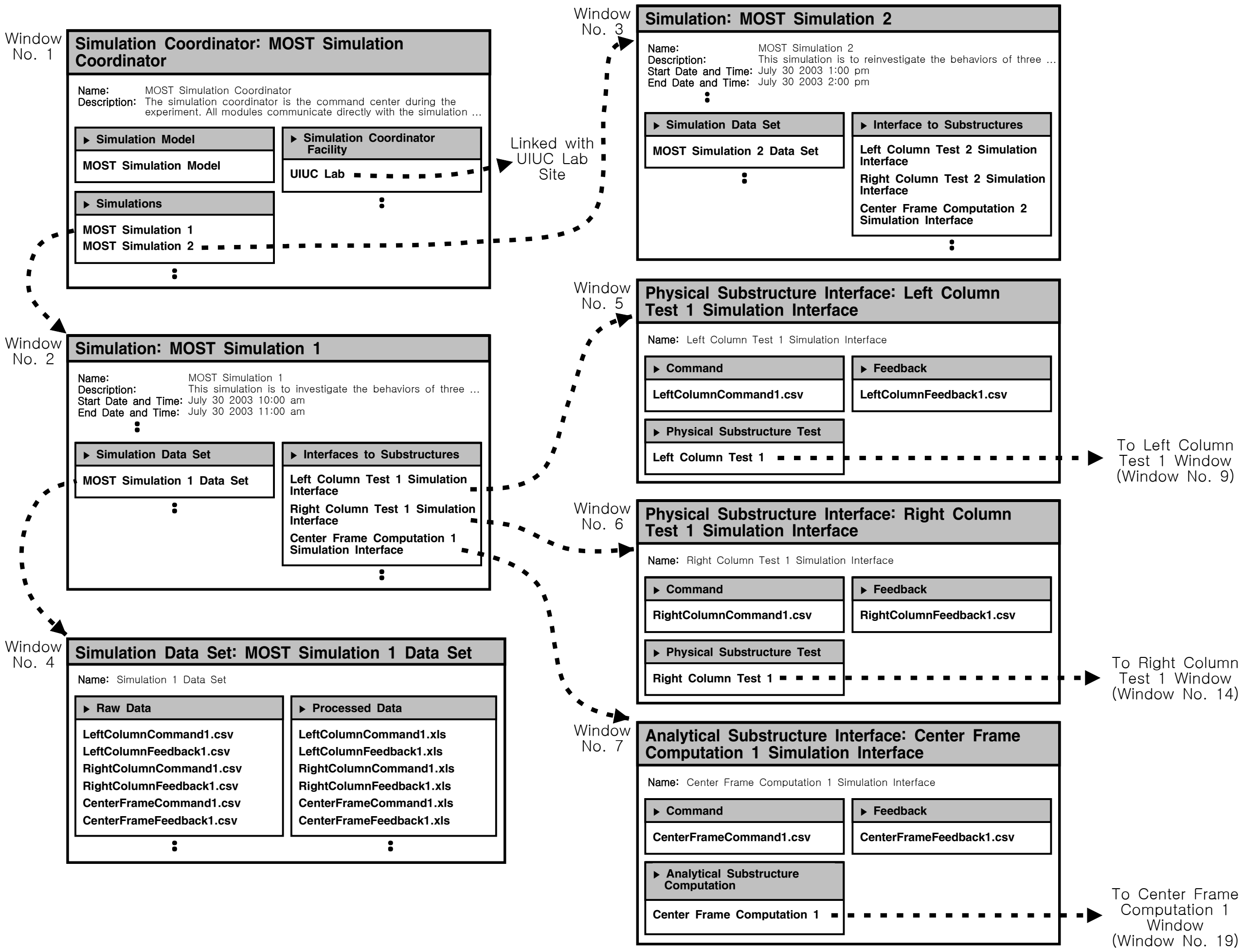
The windows in Fig. 6a are for the interactions of the MOST simulation coordinator in Fig. 3 and are from the objects in Fig. 5a. The objects in Figs. 6b, 6c, and 6d are for the left column, the right column, and the center frame in Fig. 3, and are from the objects in Figs. 5b, 5c, and 5d, respectively.

The MOST Simulation Coordinator window(Window No. 1) in Fig. 6a is from the MOST simulation coordinator object(Object No. 1) in Fig. 5a, as presented in Table 1. It is seen in Table 1 that the number of an window exactly matches the same number of the object. This means that there is one-to-one correspondence between the objects in Fig. 5 and the windows in Fig. 6, and makes easy understanding of the objects of the Lehigh Model and direct implementation of the objects for developing a computer system.

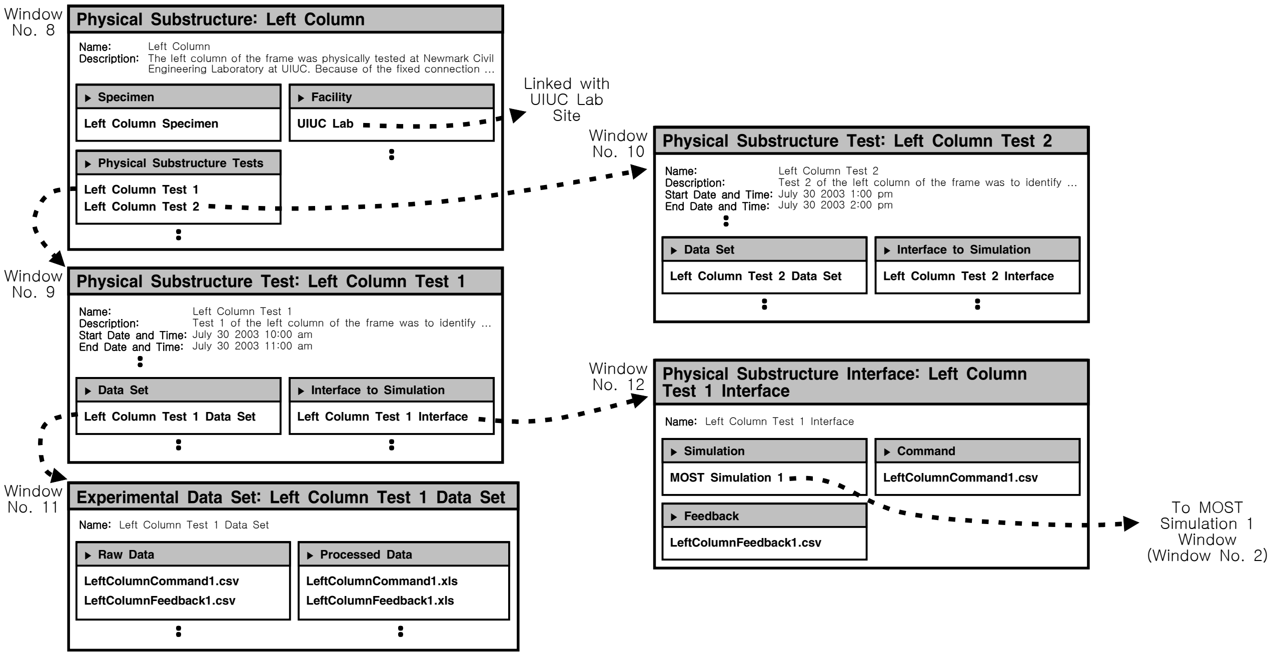
The MOST Simulation Coordinator window(Window No. 1) in Fig. 6a includes the name and description items. The items of the Simulation Model, the Simulation Coordinator Facility, and the Simulations lead to other windows or other site of the Internet. For example, the UIUC Lab of the Simulation Coordinator Facility item can be linked with the UIUC Lab site. The Simulations item includes MOST Simulation 1 and MOST Simulation 2 which lead to the MOST Simulation 1 window(Window No. 2) and the MOST Simulation 2 window(Window No. 3).

It should be noted that there are close relationships between the items of the MOST Simulation Coordinator window(Window No. 1) in Fig. 6a and the attributes of the MOST simulation coordinator object(Object No. 1) in Fig 5a. All attributes of the MOST simulation coordinator object in Fig. 5a are implemented as items in the MOST Simulation Coordinator window in Fig. 6a. The value of the "data-valued" attribute(DVA) (e.g., the description attribute) of the MOST simulation coordinator object is implemented to appear in the MOST Simulation Coordinator window. The values of the "object entity-valued" attributes(OEVA)(e.g., the simulations attribute) of the MOST simulation coordinator object are implemented to lead other windows from the MOST Simulation Coordinator window. This applies to all objects in Fig. 5 and all windows in Fig. 6.

The MOST Simulation 1 window(Window No. 2) in Fig. 6a includes the Simulation Data Set item which leads to the MOST simulation 1 Data Set window (Window No. 4), and the Interfaces to Substructures item which leads to the Left Column Test 1 Simulation Interface window(Window No. 5), the Right Column Test 1 Simulation Interface window (Window No. 6), and the Center Frame Computation 1 Simulation Interface(Window No. 7). The MOST Simulation 1 Data Set window(Window No. 4) includes the raw data item which includes the command and feedback files for the substructures, and the processed data item which includes the xls format files. The Left Column Test 1 Simulation Interface window(Window No. 5) includes the Command and Feedback items which incudes the command and

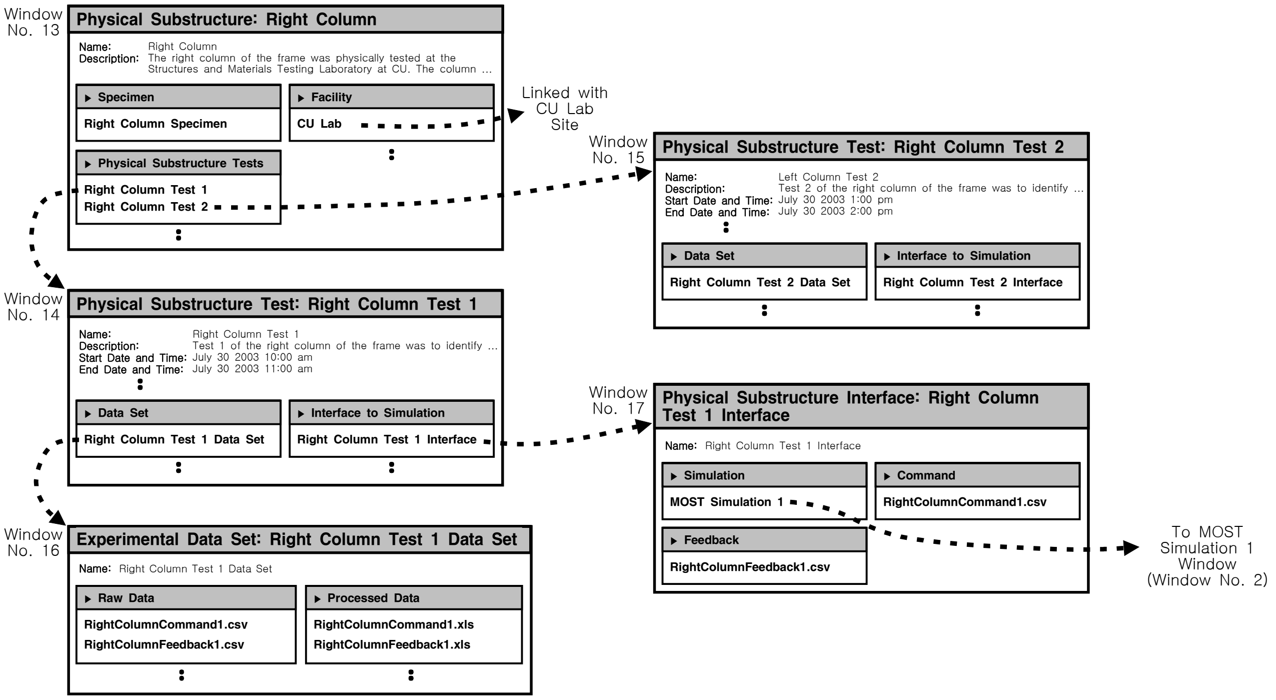


(a) Windows for simulation coordinator(MOST simulation coordinator)

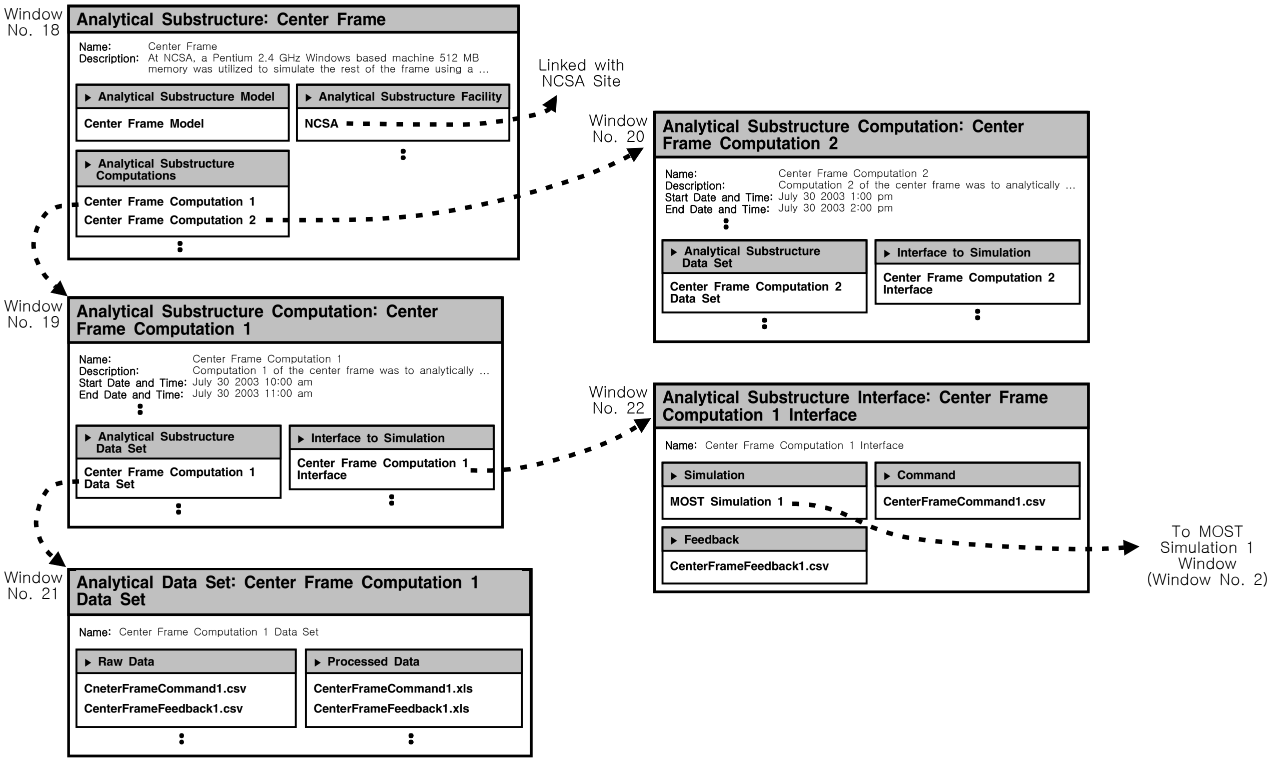


(b) Windows for physical substructure 1(left column)

Fig. 6 Possible implementation of objects for example hybrid experiment



(c) Windows for physical substructure 2(right column)



(d) Windows for analytical substructure(center frame)

Fig. 6 Possible implementation of objects for example hybrid experiment(continued)

feedback files for the left column, and the Physical Substructure Test item which leads to the Left Column Test 1 window(Window No. 9). The Right Column Test 1 Simulation Interface window(Window No. 6) and the Center Frame Computation 1 Simulation Interface window(Window No. 7) are similarly implemented, and lead to the Right Column Test 1 window(Window No. 14) and the Center Frame

Computation 1 window(Window No. 19). The MOST Simulation 2 window(Window No. 3) is similar to the MOST Simulation 1 window(Window No. 2).

The Left Column window(Window No. 8) in Fig. 6b includes the Physical Substructure Tests item which leads to the Left Column Test 1 window(Window No. 9) and the Left Column Test 2 window(Window No. 10). The Left Column Test 1 window(Window No. 9) includes the Data Set item which leads to the Left Column Test 1 Data Set window(Window No. 11), and the Interface to Simulation item which leads to the Left Column Test 1 Interface window(Window No. 12). The Left Column Test 1 Data Set window (Window No. 11) includes the command and feedback files for the left column, and the Left Column Test 1 Interface window(Window No. 12) includes the simulation item which leads to the MOST Simulation 1 window(Window No. 2). The Left Column Test 2 window(Window No. 10) is similar to the Left Column Test 1 window(Window No. 9).

The windows for the right column in Fig. 6c and the windows for the center frame in Fig. 6d are similar to those in Fig. 6b. The windows for the right column in Fig. 6c includes the command and feedback files in the Right Column Test 1 Data Set window(Window No. 16) and the link in the Right Column Test 1 Interface window(Window No. 17) to the MOST Simulation 1 window(Window No. 2). The windows for the center frame in Fig. 6d includes the command and feedback files in the Center Frame Computation 1 Data Set window(Window No. 21) and the link in the Center Frame Computation 1 Interface window(Window No. 22) to the MOST Simulation 1 window(Window No. 2).

5. Concluding Remarks

The hybrid structural experiment requires the proper management of the information related with the simulation coordinator and the substructures during the experiment process. The information includes the divided specimens for substructures at different facilities, and the commands and feedbacks among the simulation coordinator and the substructures. This paper has described the interactions among the simulation coordinator and the substructures for an example hybrid experiment, has provided the representation of the interactions using the classes and their objects in the Lehigh Model, and has presented a possible implementation of the objects for developing a computer system.

The implemented system for the hybrid structural experiments is intended to be used by the researchers and engineers. The usefulness of the system may be determined by considering the configurations of the display windows and items and the user interface functions such as the saving and retrieving of the information. The user interface functions are technical issues of the implementation and are not addressed in this paper. The configurations of the windows and the items depend directly on the organizations of the classes and objects in the Lehigh Model. By providing an way of formulating and representing the interactions among the simulation coordinator and the substructures, this paper contributes towards developing the comprehensive system for the hybrid structural experiments. The specific features and contributions are as follows:

(1) The simulation coordinator and each of the substructures in the example hybrid experiment have their own data sets which include the command and feedback files, and have the interface links to its related simulation coordinator or substructures.

(2) The simulation coordinator is linked with all the substructures and includes the command and feedback files for all the substructures.

(3) Each of the substructures is linked with the simulation coordinator and includes the command and feedback files for the simulation coordinator.

(4) The strong relationships among the simulation coordinator and the substructures makes a clear and distinct access to the information involved in the interactions.

(5) The objects and their attributes for the interactions in the example hybrid experiment can be directly implemented into display

windows and items in the windows in a computer system.

The representation of interactions presented in this paper is for the example hybrid experiment, but can be extensively used for other kinds of hybrid experiments. The way of representing the interactions depends on the organizations of classes of the Lehigh Model. For other types of data models which have different organizations of the information, the interactions would be represented differently. However, the underlying ideas of representing the interactions in this paper can be applied for other types of data models for the hybrid structural experiments.

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