REFERENCE DATA MODELS FOR SUPPORTING THE NETWORK FOR EARTHQUAKE ENGINEERING SIMULATION (NEES)

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ABSTRACT

NEES (the George E. Brown, Jr. Network for Earthquake Engineering Simulation) is a national, networked resource for next-generation experimental earthquake engineering research and education in the United States. The goal of NEES is to support open access to and use of NEES's facilities and data by the earthquake engineering community. The system infrastructure to support the NEES activities is the NEESgrid which is intended as a distributed virtual "collaboratory" cyber-infrastructure for earthquake experimentation and simulation. This paper describes an effort in developing reference data models for NEESgrid shake table experiments and large scale structural testing. Data models provide the "semantic" information describing the project and experimental data. Brief description of the data models and some of their features are presented in this paper. The proposed reference data models are shown to be flexible and extendible. Validation and usability of the reference data models have demonstrated that the data models are sufficiently comprehensive to save and organize the experimental data from typical earthquake engineering simulations.

KEY WORDS

NEESgrid, data model, cyberinfrastructure, data and metadata, earthquake simulation.

INTRODUCTION

In order to facilitate collaboration within the NEES framework, one of the key services that NEESgrid needs to support is with respect to the data and metadata for earthquake engineering simulations. It is well known that engineering design and manufacturing activities generally involve a large set of independent but interrelated data items (Law and Jouaneh 1986; Law et al. 1987). Traditional hierarchical, network, and relational database models, which are designed for highly structured commercial applications, do not adequately support technical engineering problem domains. Influenced by the field of artificial intelligence, semantic relationships such as classification, association, aggregation and generalization can be used for organizing and structuring engineering data (Law 1988). Besides the mechanism needed to represent and manipulate data, data model development also requires some knowledge on the intended use of the data (Law et al. 1991). For this

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purpose sample data sets are being developed that demonstrate the features of the data models along with scenarios for the use of the data and models. Specifications for the tools necessary to support entering, importing, storing, searching, and extracting data from the repository are being proposed and developed. This paper briefly describes the current effort in developing a reference NEESgrid data model, focusing on shake table experiments and large-scale structural testing.

A data model is in essence a representation of the data and their interrelationship and provides a conceptual or implementation view of the data. A **data model** can be viewed as the "grammar", "vocabulary" and "content" that represent the types of "information" stored in a "system". The **grammar** defines the relationships among the data elements in the system; the **vocabulary** defines the terminology used to describe these elements; the **content** defines what is to be included in the system. Within the scope of the NEESgrid data/metadata effort, **data** is defined as *all* project related information and encompasses *observational* (or *acquired*) *data* recorded prior to the experiments and during the experiments by means of sensors, cameras and the like; *computational* (or *generated*) *data* for and as a result of simulations, post-processing, etc.; *literature* in the form of reports, journal papers, drawings, etc. Associated descriptive and related data, i.e. **metadata** (or data about the data), are defined and published in a prescribed (by NEESgrid) format and language.

DATA MODELING TOOL AND APPROACH

There are many existing data modeling techniques and tools that are available to help design a data model and to structure the data. A brief review of relevant techniques and approaches has been reported earlier (Peng and Law 2004a). This section briefly discusses the tool selected for developing the NEESgrid data model and the basic concepts of object-oriented data modeling.

PROTÉGÉ – AN ONTOLOGY DEVELOPMENT TOOL

To facilitate the design of the NEESgrid data model, we selected Protégé (http://protege.stanford.edu), which is an open-source software package designed to help developing ontology for knowledge-based systems (Gennari et al. 2002). Ontology represents explicit formal specifications of the terms in the domain and the relations among them. As open source software, Protégé has attracted a wide variety of plug-ins from around the world to enhance its capabilities. Some of these software plug-ins allow a model developed in Protégé to be exported in many standard formats, including UML (Unified Modeling Language (Arlow and Neustadt 2001)), XML Schema (http://www.w3.org/XML/Schema), RDF (Resource Description Framework, http://www.w3.org/RDF/), OWL (Web Ontology Language, http://www.w3.org/2001/sw/ WebOnt/), and others.

In Protégé, a graphical user interface (GUI) is provided to facilitate ontology development. The interface enables the modeling of an ontology of classes to describe a particular subject with a set of concepts and their relationships. The interface also allows direct entering of specific instances of data and the creation of a knowledge base. Figure 1 shows an example of the GUI, with the view of classes shown in the left window, and the view of detailed attributes of a class (e.g. Project class) shown in the lower right window.

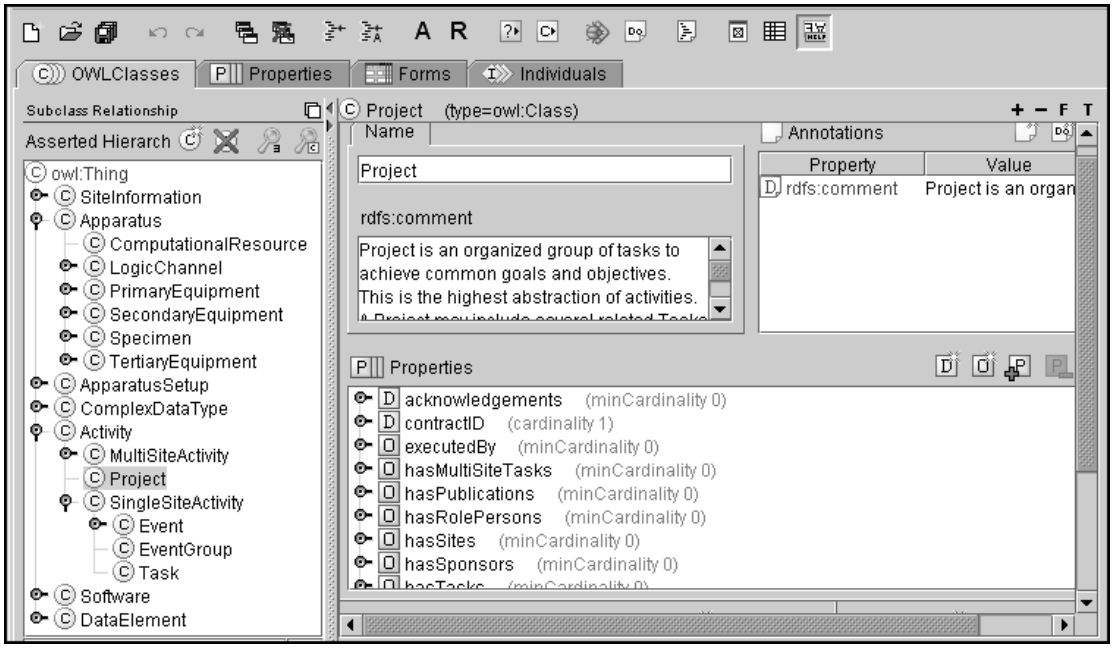


Figure 1: Protégé Interface with OWL Plug-in

OBJECT-ORIENTED DATA MODELLING

In an object-oriented data model, information is modeled as **objects**, which can be any sorts of entities (Rumbaugh et al. 1990). The general representation of certain type of objects is called a **class**, which represents explicit description of concepts in a domain. The creation of an object of a certain class is called **instantiation**. The relationship between an object and a class can be viewed analogically in a procedural language in that a variable being a particular instance of a pre-defined type such as an integer. For example, ***Project*** is modeled as a class, and a Mini-MOST experiment (Nakata et al. 2004) is an object instance of the ***Project*** class.

An object encapsulates certain related data as **slots**, which are also called **attributes** or **properties**. Slots can have different **facets** describing the value type, allowed values, the number of values (**cardinality**), and other features of the values the slot can take. A value-type facet describes what types of values can fill in the slot. Some common value types are string, number, Boolean, enumerator, and object instance. Allowed objects and the variety of values (e.g. minimum number, maximum number) of a slot are often referred to as a **range** of a slot. Slot cardinality defines how many values a slot can have, such as single (at most one value) or multiple (more than one value). For example, "minute" is a slot of class ***Time***, with data type defined as integer, cardinality one and range from 0 to 59.

One important feature of object-oriented modeling is the concept of class hierarchies, with slots of a **superclass** being inherited by its **subclasses**. This **inheritance** feature allows us to define the common slots used by several classes at the highest possible level in the hierarchy, which avoids the duplication of slots at the lower levels. A superclass can have subclasses that represent concepts that are more specific than the superclass.

A REFERENCE DATA MODEL FOR NEESGRID

As depicted in Figure 2, the NEESgrid data/metadata effort is working towards producing end-to-end solutions that integrate site specifications database, project level model, domain specific data models, and common elements. To capture all these data, the reference data model is designed to include six base classes, namely SiteInformation, Activity, Apparatus, ApparatusSetup, DataElement, and ComplexDataType. The high-level class diagram of the reference data model is presented in Figure 3, which shows the association relationship among classes. (The ComplexDataType class, which is employed to support other base classes, is not shown in the figure.) The association relationship exists between classes when an object of one class *knows/contains* an object of another class. For example, a Project object knows about its Tasks objects, a Project also contains Organizations, Sites, and RolePersons. RolePerson is in turn defined as the combination of a Person and his/her role in a Project. The arrow in Figure 3 denotes the direction of the relationship *contains*; i.e., **A** → **B** indicates that class **A** *knows*/*contains* class **B**.

OVERVIEW OF THE REFERENCE DATA MODEL

The following gives a brief description about the six groups of base classes defined in the NEESgrid reference data model.

- **SiteInformation**: SiteInformation is modeled to represent a typical experiment site and its associated personnel, facilities, equipments and other information. In the reference data model, Site is modeled as the aggregation of other component classes, such as RolePerson, Organization, PrimaryEquipment, and SecondaryEquipment. This group of classes is intended to be associated with the site specifications database (Kutter et al. 2004) that is currently under development by the NEES community.
- **Activity:** Activity is designed to support project level modeling. Common properties of Activity classes include objective, description, start time and end time. The duration of an Activity can be calculated by using start time together with end time. The start time of an Activity can be used to identify which Activity happens first, i.e. to sort out the sequence of several Activities. There are four basic types of Activities, including Project, Task, EventGroup and Event. A ***Project*** is a collection (organized group) of tasks designed to achieve specific goals and objectives of a project. A ***Task*** contains one or more EventGroups, and each Task typically serves a specific role in a Project. An ***EventGroup*** is defined as a collection of related Events. An ***Event***, which is the atomic level of Activity, refers to each single run of an experiment or a simulation.
- **Apparatus:** Apparatus is defined as any equipment (such as shake table or sensors), specimen, or computational resource that may be used in an Activity. Explicit modeling of Specimen is not considered in the current version of the reference model (Peng and Law 2004a). Only the most basic modeling is provided (as a collection of descriptive files, drawings, and/or photos). This design reflects current approach used to describe specimen in earthquake engineering experiments. However, if so desired, the Specimen class can be extended to support other, more detailed, models.

- **ApparatusSetup:** ApparatusSetup models the arrangement and setup of apparatus for all experiments. Universal modeling of ApparatusSetup is very difficult. Not only are there different types of experiments (such as shake table, pseudo-dynamic tests, centrifuge, and tsunami) and different materials (such as concrete, steel, wood, etc.), but also the geometry of specimen and the arrangement of sensors may be too complicated and cumbersome to model. For example, the "as-built" locations of sensors may be different from the "design" locations, and the exact physical locations (i.e., the coordinates x, y, z values) of sensors may be very hard to be recorded. Therefore, current design for the ApparatusSetup model focuses on tools and methodologies that can capture and organize CAD drawings, sketched drawings and notes, photos, narrative descriptions, and electronic notes, etc.
- **DataElement:** DataElement represents all types of data that may be generated or processed during an Activity. The DataElement normally serves as Input/Output to an Activity. Types of DataElement include text document, publication, earthquake record, photo, CAD drawing, movie, etc. In NEESgrid data/metadata effort, it is assumed that the data is saved in or translated into computer-readable format. Therefore, a DataElement object is represented in the format (such as a file) that can be saved in computer memory, on disks, or in some kind of data storage repository.
- **ComplexDataType:** ComplexDataType is defined in the reference data model to represent any data type that is not a simple data type such as integer, float, Boolean, or character string. Some of the example subclasses of ComplexDataType include Folder, RolePerson, Unit, DateTime, Location, Measurement, Angle, etc.

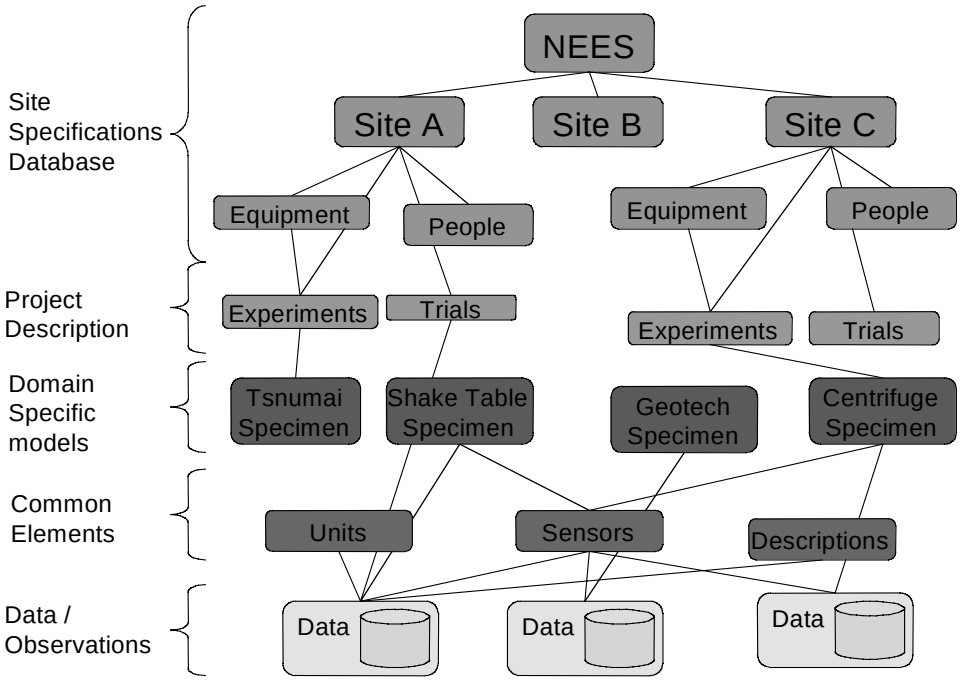


Figure 2: Overall Data Model for NEESgrid (Courtesy of Chuck Severance)

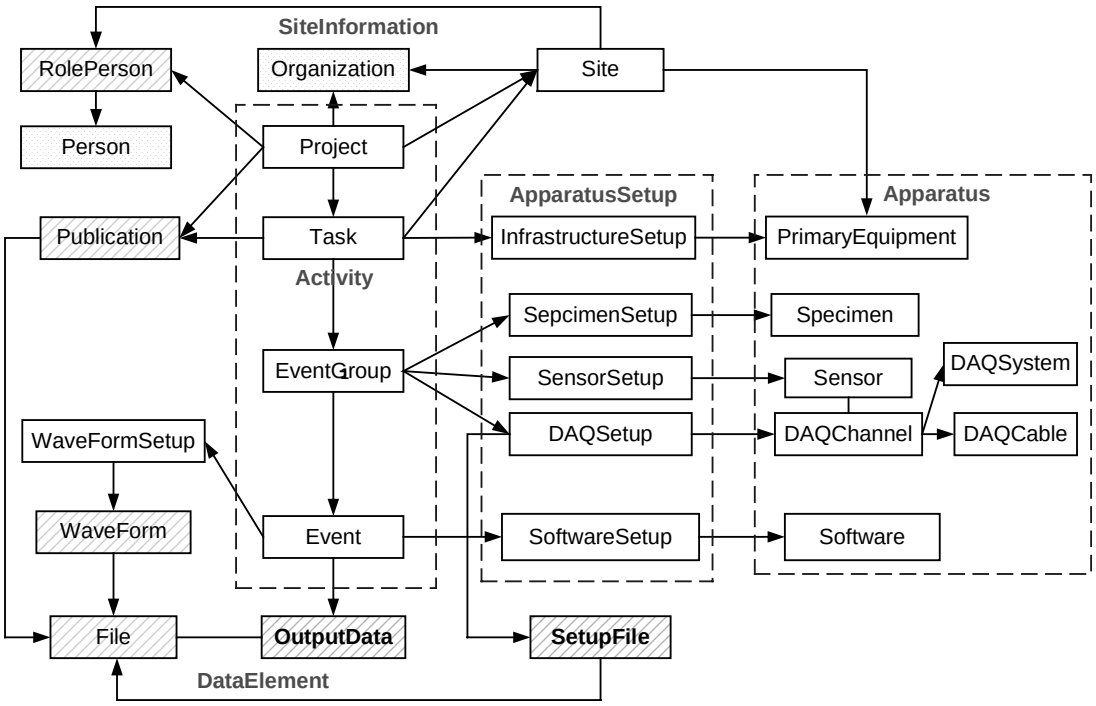


Figure 3: High-level Class Diagram of the Reference Data Model

FEATURES OF THE REFERENCE DATA MODEL

The following briefly describes two important but unique features of the developed reference NEESgrid data model. Details of these features have been discussed elsewhere (Peng and Law 2004b). The reference data model explicitly models certain Activities that are carried out at multiple Sites. Figure 4 shows an example project that has a single site Task (e.g. Task1) and a MultiSiteTask (e.g. M_Task1). The MultiSiteTask M_Task1 has Tasks that are undertaken at both Site1 and Site2. The MultiSiteEvent M_E1 has an Event E2 at Site1 and an Event E4 at Site2, and the MultiSiteEvent M_E2 has an Event E3 at Site1 and an Event E5 at Site2. As shown in Figure 4, although Project does not directly *contain* Task2 that takes place at Site2, Task2 can still be accessed from the Project since M_Task1 *contains* Task2. This design enables the support of the types of experiments that are carried out either simultaneously or independently at several Sites.

The reference data model includes a sensor model that is designed specifically to support earthquake engineering experiments. The data acquisition equipment is modeled as a collection Sensor, DAQCable, DAQChannel, and DAQSystem. Figure 5 shows the relationships and the slots of these classes. Typically a data acquisition system involves at least three main components: (1) the sensors which respond to a physical stimulus and generate analog voltage signals; (2) a DAQchannel which receives the signal and uses predefined filter, gain, offset, excitation, sensitivity information for Analog-to-Digital and Engineering Unit conversions; and (3) a PC unit which uses some communications link to retrieve the data.

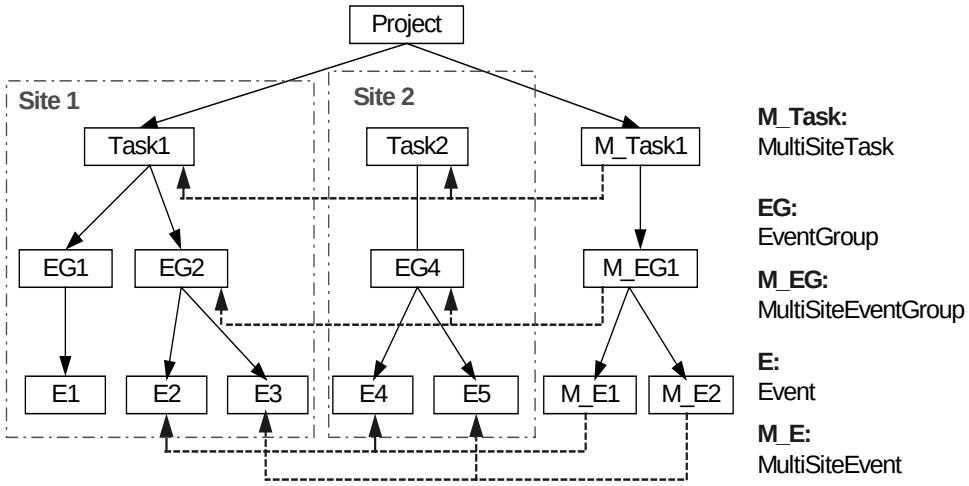


Figure 4: Layout of an Example Project

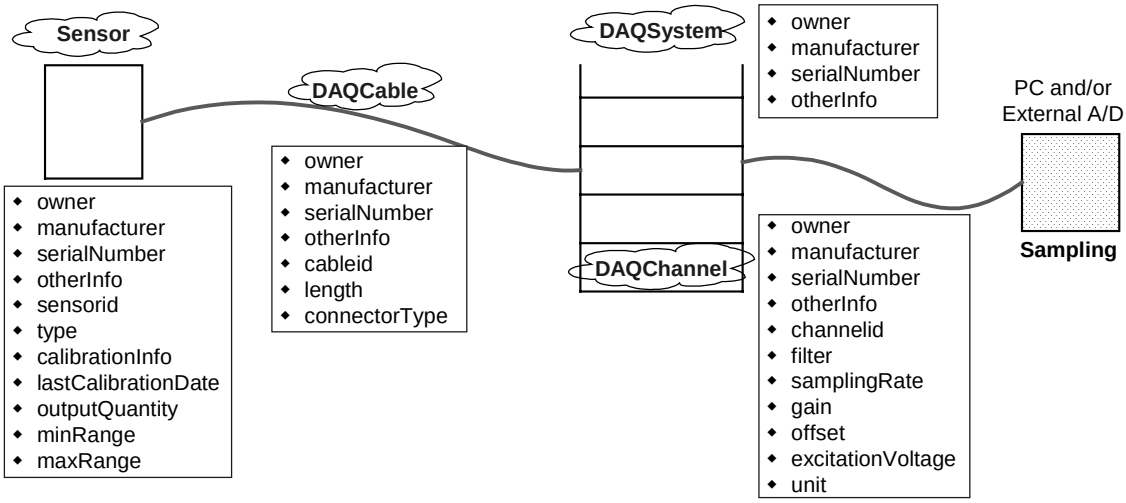


Figure 5: Setup and Modeling of DAQ Devices

VALIDATION AND USABILITY TEST

The usability of the reference data model has been tested with legacy experimental data (Peng and Law 2004c). Legacy data from several earthquake experiments have been used. For illustration purpose, this paper focuses on the data sets obtained from a Mini-MOST experiment (Nakata et al. 2004).

MINI-MOST EXPERIMENT

The main purpose of the Mini-MOST experiment is to show the capability of the various NEESgrid service components using a small-scale physical experimental setup (Nakata et al. 2004). The Mini-MOST experimental hardware, as implied by its name, is small in size and can be easily packed and shipped to experimental sites. The Mini-MOST experiment

provides a platform for researchers to become familiar with the NEESgrid software and to gain first-hand experience in using the NEESgrid services. For the validation test of the reference data model, the data sets generated from a particular Mini-MOST test on February 28, 2004 at University of Illinois at Urbana-Champaign (UIUC) are employed.

INPUTTING EXPERIMENTAL DATA

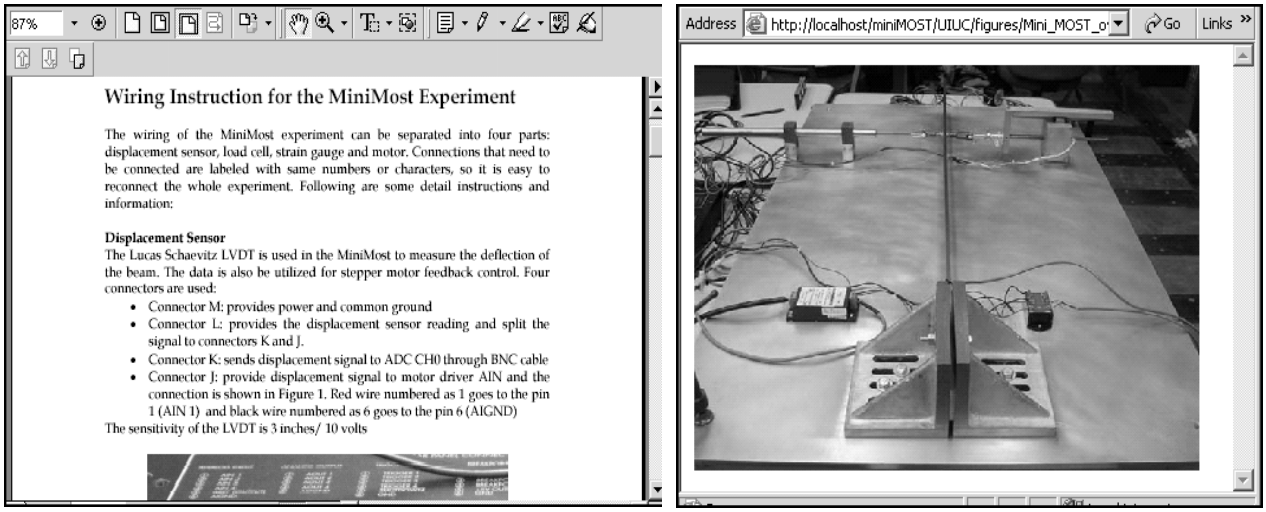
For validation purpose, data generated from the Mini-MOST experiment was ingested using Protégé (Gennari et al. 2002) and saved as files in a local file system. As we mentioned earlier, besides defined classes and their properties, Protégé can also be used to handle instances of data. Data related to Mini-MOST experiment can be entered using the slots (properties) as defined in the reference data model. If a slot is defined as primitive type, such as Integer, Real Number, Time, or String, etc., we can simply type in the value. If a slot is defined as Objects, then we can either choose a previously created object or create a new one. If a slot is defined as of type "URI" (Universal Resource Identification, which would normally refers to a file), we can save the file in a particular location and then enter the URI for the file location. The metadata, i.e. information about the data, are saved as an OWL (http://www.w3.org/2001/sw/WebOnt/) file. Other experimental data, such as specimen photos and sensor readings, can be stored in a file on a web server with its URI saved in the OWL file.

BROWSING EXPERIMENTAL DATA

For validation purpose, we implemented a project viewer to retrieve the saved data and to view the data on a web browser according to the data model. The server program is implemented using Java Servlet technology (http://java.sun.com/products/servlet/); and the parsing of the OWL file is handled by using Jena (McBride et al. 2004).

Since the data is organized according to the project it belongs to, the project viewer is started with a webpage that contains a list of projects. When we click on a particular project, say miniMOST-1, the details of the project will be shown on the browser. The details include the values for all the slots defined for Project class. If a slot is defined to have data with primitive data type, the value is shown directly in the webpage. If a slot is defined to be a reference to other object, then a link is shown in the webpage. We can then follow these links to browse the details of contained objects. For example, we can navigate and access all the Tasks that belong to the Project by following specific links. We can further follow links to access EventGroups, as each Task in a project may contain one or more EventGroups. Since an EventGroup is defined as a collection of Events, each Event can be accessed from the EventGroup object. An Event, which is an entity at the atomic (or lowest) level of an Activity, refers to a single run of an experiment or a simulation. Experimental results, such as SensorReading, can be accessed from an Event object.

The details of other objects, such as InfrastructureSetup, can also be retrieved by navigating the project viewer. An InfrastructureSetup object essentially is a collection of texts, documents (in the format of Word, PDF, Excel, etc.), figures and drawings stored as files. Files are saved in a web server and their URIs are saved as metadata. The files can be dynamically downloaded and shown on a web browser, as illustrated in Figure 6.



(a) MiniMost_Wiring.pdf (b) MiniMOST_Overall.jpg

Figure 6: Access of Files Representing the InfrastructureSetup

SUMMARY AND DISCUSSIONS

This paper has discussed the approach for the development of a reference NEESgrid data model. Brief description of the developed data model and some of its features are also presented. Six base classes are presented and the relationships among these classes are defined. These classes represent the essential elements to support the end-to-end solution of NEESgrid data efforts. We believe the proposed reference data model is sufficiently flexible and extendible: (1) new classes can easily be introduced; (2) the slots of a particular class can be added, deleted, or modified; (3) and the relationships among the classes can be altered. Other models, such as specimen model, unit model, geometry/location model, and Site model, can be appended to (or even replace certain parts of) the reference data model. Although the NEESgrid reference data model is intended to focus on the data requirements for shake table experiments, large portion of the model is of sufficient generality to be used for other types of experiments, such as centrifuge, pseudo-dynamic tests, field tests, etc.

To validate the reference data model, we have populated the model with the Mini-MOST experimental data. This validation process helps evaluate the completeness, flexibility and usability of the data model. The usability test has demonstrated that the data model is sufficiently comprehensive to save and organize all the Mini-MOST data. In addition, as the experimental data are organized according to the data model, browsing and accessing them are fairly intuitive and straightforward. Efforts will continue to validate, evaluate and refine the reference data model using other experimental projects and data.

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