Reusing Simulation Models for Weapons Effectiveness Analysis

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Abstract: Simulation-based weapons effectiveness analysis involves complex modeling tasks to represent weapons, natural environment and operational environment. An integrated M&S (Modeling and Simulation) environment provides useful tools and services to partly automate the modeling tasks. Along with the M&S environment, a model repository can help model developers to ease the required tasks by sharing predefined and already validated models, generated from inside and outside the M&S environment. In this paper, we introduce our M&S environment, OpenSIM (Open Simulation Engine for Interoperable Models), and illustrate how the model repository in OpenSIM can enable users to reuse models for weapons effectiveness analysis. OpenSIM manages weapon ontology and thesaurus dictionaries to assess structural and contextual similarity between weapon models. We present semantic information and similarity measures of OpenSIM and illustrate how the model repository of OpenSIM helps users locate reusable weapon models.

1 INTRODUCTION

As modern weapon systems require significant money to develop, evaluating their effectiveness becomes necessary before the actual development (Department of Defense, 2001) is taken place. Evaluating weapons effectiveness is a hard task, since we have to consider not only weapon systems themselves but also various war factors including natural environment (i.e. sea, ground, air), operational environment (i.e. anti-air warfare, anti-surface warfare), and external systems (i.e. command and control systems) (Hong, 2011). These factors are hard to control in real world. Therefore, simulation technology is believed to be a realistic solution for analyzing and predicting weapons effectiveness (Wang, 2010).

Simulation-based weapons effectiveness analysis involves complex modeling tasks to represent weapons dynamics and engagement environments. An integrated M&S (Modeling and Simulation) environment provides useful tools and services to partly automate the modeling tasks, and helps users to save development cost and time (Cho, 2007). Along with the M&S environment, a model repository can also help model developers to ease the required tasks by sharing predefined and already validated models (Benali, 2010).

Many research works have been proposed to construct and manage model repositories for various M&S applications. Although the existing repositories have been partly successful in providing efficient services, such as registering and retrieving models, they still lack flexible matching services regardless of structural discrepancies between models (Yilmaz, 2011). Most of the existing repositories employ key-word based search techniques to find reusable candidates. However, they are not powerful in taking into account the contextual similarity between similar weapon models. Also, utilizing the reuse repositories may be limited, if users are unable to access the stored models from anywhere on various execution environments. Weapon models are usually developed by many experts from various disciplines, possibly dispersed over the network. Therefore, a distributed repository can greatly facilitate collaborative modeling among the experts.

In this paper, we introduce a distributed model repository to support reuse of models for simulation-based weapons effectiveness analysis. Our repository has been implemented in an integrated M&S environment, OpenSIM (Open Simulation Engine for Interoperable Models) which is under development by our research team (Lee, 2011). OpenSIM manages a reuse repository in the cloud

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computing environment to store large amount of data for representing weapon models. Utilization of the reuse repository can be greatly improved, since users can access the weapon models from anywhere and on various execution and operating systems with the help of cloud data storage and services. OpenSIM describes models with three dimensions – structure, attributes, and behaviors. Weapon ontology has been constructed to organize similar models and assess structural similarity between models. Thesaurus dictionaries are also managed to resolve textual discrepancies appeared in the names of attributes and operations in weapon models. Similarity metrics are defined to quantify the structural and contextual similarity between models and to guide the semantic search process. With the help of the model repository and tools/services of OpenSIM, model developers can efficiently conduct their weapons effectiveness analysis by improving reusability of weapon models.

This paper is organized as follows. Section 2 introduces the architecture of model repository in OpenSIM. Section 3 presents the reuse framework in OpenSIM to enable semantic search for reusable models. Weapon ontology, thesaurus dictionaries and the semantic search algorithm are explained in Section 3. Section 4 presents implementation results of our reusing framework. We conclude in Section 5 with future research works to achieve.

2 MODEL REPOSITORY IN OPENSIM

OpenSIM is an integrated simulation environment to help model developers perform weapons effectiveness analysis. OpenSIM provides a suite of tools and services for developing, executing and analyzing simulations of weapon systems. In order to facilitate the modeling process in OpenSIM, we provide a repository that stores reusable weapon models as shown in Figure 1. Clients can access the reuse repository from anywhere with the help of *Storage Manager* in OpenSIM. Storage services help clients to register their models and search reusable models according to their simulation objectives. With the help of *Resource Registrant*, each model is registered to the model repository with syntax (e.g. interface information) and semantic (e.g. weapon category) information. All these information are zipped with an index bitmap to save space. In order to support semantic search for weapon models, queries are analyzed in *Query Analyzer*. Morphological analysis is performed on the weapon models to resolve textual discrepancies in the names of attributes and operations. The *Searcher* ranks candidates with the help of *Ranking Module*, and recommends reusable models to the client. Detailed explanation on the semantic information and the search algorithm will be given in Chapters 3.

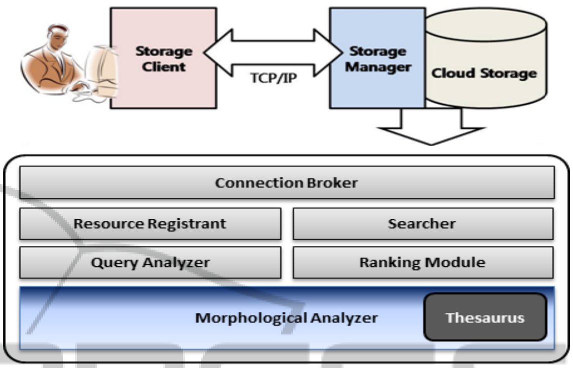

Figure 1: Model Repository Architecture in OpenSIM.

3 REUSE MECHANISM

Many weapon models have been developed by various organizations. Although they exhibit different forms in development programming languages and platforms, they are *similar* in their structures, attributes and operations. New weapon systems are usually developed in order to improve parts of the old ones. Therefore, there are very high chances to reuse the existing weapon models for analyzing the effectiveness of new weapons. In order to maximize reusability, OpenSIM recommends a model that has maximum similarity in structure, attributes, and operations. Structure similarity is assessed based on our weapon ontology, while attributes and operations similarity are assessed by resolving textual discrepancies based on our weapon thesaurus dictionary. Section 3.1 – 3.3 present the details.

3.1 Weapon Ontology

Ontology formally represents knowledge as a set of concepts within a domain, and the relationships between those concepts (Silver, 2010). We construct weapon ontology to organize weapon models.

Figure 2 shows a part of weapon ontology to organize guided missiles. Guided missile models are represented and related to others according to military organizations (i.e. Air force, Army, Navy), engagement types (i.e. air-to-air, air-to-ground, ground-to-air, etc.), range (i.e. short, middle, long), guidance method (i.e. radar, laser, optic, GPS, etc.), development details (i.e. platform, programming language), and resolution (i.e. high, medium, low).

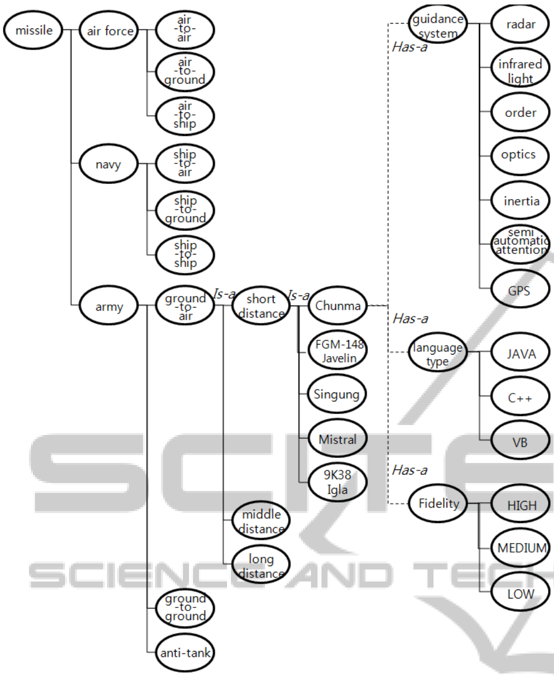

Figure 2: Weapon Ontology for Guided Missiles.

An index bitmap is associated with a weapon model, in order to represent the ontology information space-efficiently. All the structural information, including military organization, warfare type, range, fidelity, programming language, and guidance systems, are represented with 25 bits as shown in Figure 3. These bitmap indexes provide significant performance advantages over traditional value-list indexes for complex queries, such as searching for reusable models, according to Oneil (Oneil, 1997). Structural similarity can be assessed by logical operations (e.g. `and (&)`) between bitmaps.

3.2 Weapon Thesaurus

Models may have attributes and operations with different names, even though they have similar meanings. We construct a weapon thesaurus dictionary in order to group models that have similar meanings in attributes and operations. Figure 4 shows a part of our thesaurus dictionary for guided missiles. For example, *hit rate*, *hit_rate*, *hit ratio*, *hit* and *accuracy* may have the same meaning, even though their textual appearances are different.

25 bits

Military (3bit)	Warfare (3bit)	Range (3bit)	Fidelity (3bit)	PL (3bit)	Guidance (10bit)

Field Name	Example
Military	Army(001), Navy(010), AirForce(100)
Warfare	Air-to-Air(001), Ground-to-Air(010)
Range	Short(001), Medium(010), Long(100)
Fidelity	High(001), Medium(010), Low(100)
Programming Language	C++(001), Java(010)
Guidance Type	Radar(0000000001), Infrared light(0000000100)

Figure 3: Structure Index Map (in part).

By looking up the names of attributes and operations in the thesaurus dictionary, we can assess how a model is similar to other models regardless of their textual appearances.

X	Wingspan	Altitude	Accuracy	Length
x	wingspan	altitude	accuracy	length
currentx	wingspread	flightaltitude	accuracyrate	scope
current_x	wingwidth	flight_altitude	accuracy_rate	spread
coordinate	wing_width	flightlevel	hit	lineardimension
coordinate_x	wingbreadth	flight_level	hitrate	lenear_dimension
Speed	Diameter	Length	Altitude	Ceiling
speed	caliber	spread	flightlevel	serviceceiling
pace		lineardimension	flight_altitude	practicalceiling
velocity				

Figure 4: Weapon Thesaurus Dictionary for Guided Missiles (in part).

3.3 Semantic Search Process

In order to locate reusable models, our search algorithm calculates similarity in three dimensions – structure, attributes, behaviours (or operations). Given a user model `X`, structural similarity with other model, `Y`, is calculated by the following equation:

$$S\_Similarity(X,Y) = \sum_{\forall i=1..25} (Index\,(X_i)\ \&\ Index\,(Y_i))*w_i$$

where, $Index(X_i)$ is the i^{th} bit in the index bitmap of model `X`, and w_i is a weight factor for comparing the i^{th} bit, and `&` is logical `and` operation.

Two models can be considered as similar if they have many attributes in common. In order to resolve morphological discrepancies between attributes, we first look up the thesaurus dictionary to replace an attribute name with the representative name in the thesaurus dictionary. Then, attributes similarity, `A_Similarity(X,Y)`, between model `X` and model `Y` can be calculated by cross-checking all attributes of model `X` and model `Y`, and counting the number of attributes that belong to both of the models. `O_similarity(X,Y)`, the measure for assessing similarity on operations between model `X` and model `Y`, can be determined with the same process as in `A_Similarity`.

Finally, the search algorithm determines the overall similarity, `Similarity`, by calculating the weighted sum of `S_Similarity`, `A_Similarity`, and `O_Similarity`. High `Similarity` valued models are recommended to users as reusable candidates.

4 IMPLEMENTATION

A distributed M&S resource storage has been constructed in OpenSIM based on Apache Hadoop and HDFS (Hadoop Distributed File System) (Apache, 2011). Apache Hadoop is a software framework that supports the distributed processing of large data sets across clusters of computers. Applications are able to work with thousands of nodes and petabytes of data within the Hadoop framework. HDFS is a distributed, scalable, and portable file system written in Java for the Hadoop framework. HDFS provides services to replicate data across multiple hosts for high reliability, to rebalance data by moving copies around, and to keep the replication of data high. Detailed explanation on cloud data storage and services are found in the works of Franklin (Franklin, 2005) and Chuck (Chuck, 2010).

Weapon models and their associated data resources are stored across three machines with the help of HDFS. Clients can transparently access weapon models stored in the OpenSIM repository through TCP/IP communication, regardless of their execution environments and operating systems. Section 4.1 – 4.3 illustrate how we can reuse weapon models in OpenSIM repository through an example of Mistral missile.

4.1 Registration

Users register their weapon models to the repository in OpenSIM. Figure 5 shows a registration tool in OpenSIM. Upon completing modelling tasks on OpenSIM, users register their models to the repository.

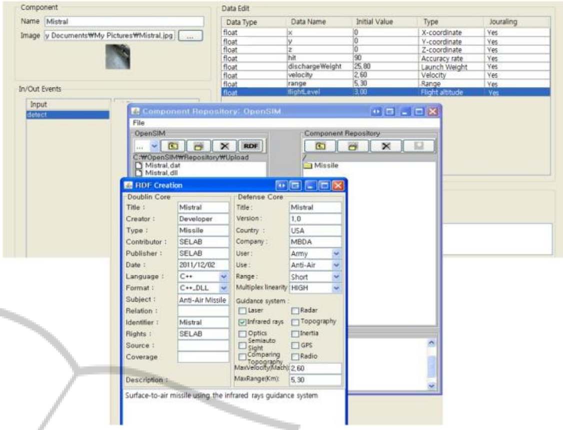

Figure 5: Registration Process in OpenSIM.

Attributes, Operations, and general information (e.g. model name, creator, publisher, implementation details (e.g. programming language, operating system), component type (e.g. C++, DLL, etc.), ownership) can be selectively published for users discretion. For example, attributes such as `(x,y,z)` position of a missile, and operation names, such as `fireTarget`, are published by users. All published data are then automatically represented in XML and RDF data files as shown in Figure 6. An index bitmap is also associated with the registered model based on the weapon ontology discussed in section 3.1.

Suppose the Mistral model has been developed by army to analyze the effectiveness of short-range, infrared ray missile in the anti-air warfare. Also, suppose this model has been developed by C++ with detailed dynamics and attributes (high resolution).

By matching this information with the weapon ontology in Figure 2, the index bitmap of this model is defined as `00100100100100100000000100`. This index bitmap is specified in the last row of the RDF data file in Figure 6.

4.2 Semantic Search

Semantic search in OpenSIM is performed throughout the three phases – structure matching, attribute matching and operation matching phase. Suppose a modeller wants to reuse available missile models that have been developed by army for analyzing weapons effectiveness in anti-air warfare. Suppose the modeller also wants to reuse short-distance and infrared ray guided missiles. Figure 7 shows a wizard provided in OpenSIM to perform the structure matching.

```
<?xml version="1.0" encoding="EUC-KR"?>
<MissileData>
<attribute>
<attributeCount>8</attributeCount>
<coordinateXName>x</coordinateXName>
<coordinateXValue>0</coordinateXValue>
<coordinateYName>y</coordinateYName>
<coordinateYValue>0</coordinateYValue>
<coordinateZName>z</coordinateZName>
<coordinateZValue>0</coordinateZValue>
<accuracyRateName>hit</accuracyRateName>
<accuracyRateValue>90</accuracyRateValue>
<launchWeightName>dischargeWeight</launchWeightName>
<launchWeightValue>25.80</launchWeightValue>
<lengthName>-</lengthName>
<lengthValue>-</lengthValue>
<caliberName>-</caliberName>
<caliberValue>-</caliberValue>
<speedName>velocity</speedName>
<speedValue>2.60</speedValue>
:
                              :
</attribute>
<operation>
<operationCount>1</operationCount>
<operationName>fireTarget</operationName>
<operationDescriptione>Calculates (x,y,z) to encounter a targer
                             </operationDescriptione>
                             :
</operation>
</MissileData>
```

(a) XML data file for Mistral weapon model – in part

```
<?xml version="1.0" encoding="EUC-KR"?>
<RDF
xmlns="http://www.w3.org/TR/WD-rdf-syntax#"
xmlns:dc="http://selab.mju.ac.kr#"
xmlns:inducement="http://selab.mju.ac.kr/inducement/"
>

<Description about="Mistral.dll">
       <dc:Title>Mistral</dc:Title>
       <dc:Creator>Taesup</dc:Creator>
       <dc:Type>Missile</dc:Type>
       <dc:Contributor>SELAB</dc:Contributor>
       <dc:Publisher>SELAB</dc:Publisher>
       <dc:Date>2011/11/21</dc:Date>
       <dc:Format>C++_DLL</dc:Format>
       <dc:Subject>anti-air weapon</dc:Subject>
        :
           :
       <dc:Name>Mistral</dc:Name>
       <dc:Version>1.0</dc:Version>
       <dc: Fidelity>HIGH</dc:MultiFidelity>
       <dc:Country>USA</dc:Country>
       <dc:Company>MBDA</dc:Company>
       <dc:Military> Army</dc:Army>
       <dc:Use>Anti-Air</dc:Use>
       <dc:Distance>Short</dc:Distance>
       <dc:Guidancet>
              <Description>
                     <inducement:Laser>Used</inducement:Laser>
                     <inducement:Radar>Unused</inducement:Radar>
                     <inducement:Infrared>Unused</inducement:Infrared>
                     <inducement:Order>Unused</inducement:Order>
                     <inducement:Optics>Unused</inducement:Optics>
                     <inducement:Inertia>Unused</inducement:Inertia>
                                :
                                :
              </Description>
       </dc:Guidancet>
       <dc:maxSpeed>2.60</dc:maxSpeed>
       <dc:maxRange>5.30</dc:maxRange>
     :
       <dc:BitMap>001 001 001 0000000100 001 001</dc:BitMap>
</Description>
</RDF>
```

(b) RDF data file of Mistral Model – in part

Figure 6: Data files for registering weapon models.

Upon selecting the search criteria, such as military organization, and warfare type, SQL query is automatically generated in OpenSIM with the corresponding index bitmap. Structure matching is performed by the steps specified in section 3.3. Table 1 summarizes structure matching results in descending order. The three models with highest structure matching score are selected for further attributes and operations matching. Based on the missile thesaurus dictionary, attributes with similar meanings are grouped. In this example, KP-SAM, Mistral, and 9K38 are selected from the structure matching, and their attributes are cross-checked after resolving their textual differences with the help of the missile thesaurus dictionary. Figure 8 shows the OpenSIM tool to show the results from the attributes and operations matching. Based on the modelling and simulation objectives, users can choose reusable models that have desired attributes. Operation names are also checked based on the thesaurus dictionary, and operations with the similar meaning are grouped for users to select reusable models. Detailed descriptions on the operations are also available to help users choose reusable models

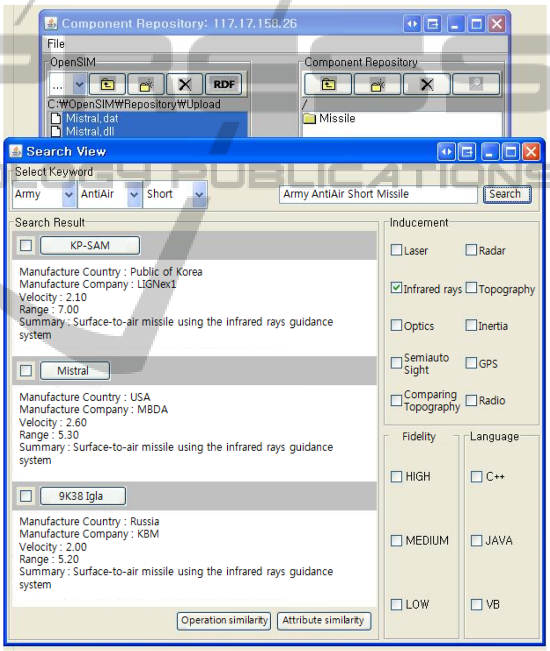

Figure 7: OpenSIM wizard for Structure Matching.

Table1: Structure Matching Results – in part (Top 10)

Missile	Index bitmap	Matching Score
Sin-Goong (KP-SAM)	001 001 001 001 010 0000000100	13
Mistral	001 001 001 001 001 0000000100	13
9K38 Eaglar	001 001 001 010 001 0000000100	13
FGM-148	001 001 001 001 100 0001000000	12
BGM-71 TOW	001 000 001 010 100 0000010000	12
Chun-Ma (KSAM-1)	001 001 001 010 010 0000000010	12
KM-SAM	001 001 000 100 100 0000101010	9
9K115-2	001 000 001 100 010 0000010000	8
HyunMu-2	001 010 100 001 100 0000100000	5
HyunMu-1	001 010 100 001 001 0000100000	5

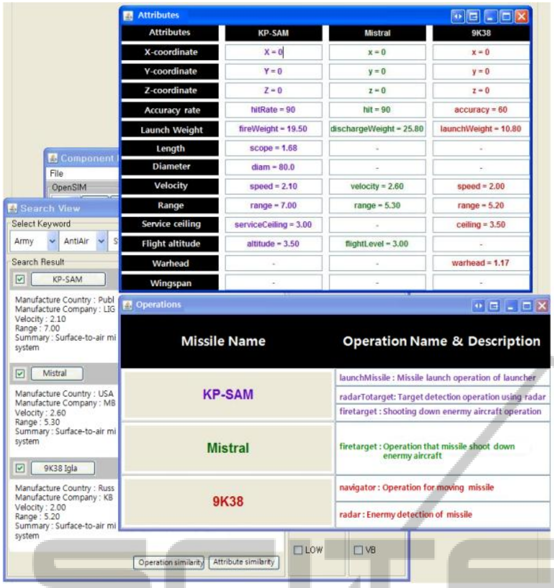

Figure 8: Attributes and Operations Matching Results.

5 CONCLUSIONS

In this paper, we introduced a cloud repository in OpenSIM for improving reusability of weapon models. OpenSIM is an integrated modelling and simulation environment to help users perform weapons effectiveness analysis. OpenSIM provides a set of tools and services to register and discover reusable models. Weapon ontology has been constructed to assist structure matching. Weapon thesaurus dictionaries are also provided in OpenSIM to resolve textual discrepancies appeared in the names of attributes and operations. Reusable models are recommended based on structure similarity, attribute similarity and operation similarity. The OpenSIM reuse repository is distributed over the cloud computing environment. Weapon engineers and simulation experts can cooperate easily by accessing reusable weapon models in any places on various operating and execution environment.

Although OpenSIM can successfully supports semantic discovery of reusable models by considering structure, attributes and operations similarity, search results can be further improved by considering more semantic information. So far, we have dealt with *Is-A* and *Has-A* relationship between models. However, various model relationships, such as, *part-of*, *relates-to*, can be added for accurate semantic discovery. We also would like to research various metrics to properly quantify similarity between models.

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