International Journal of Advanced Science and Technology
Vol.84 (2015), pp.47-54
http://dx.doi.org/10.14257/ijast.2015.84.04

Multi-resolution Modeling of 3D Visualization Simulation Based on Meta-model

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Abstract

Generally, the 3D visualization simulation includes the 3D entity model, virtual environment and physical data field (including electromagnetic field and underwater acoustic field). In order to improve the flexibility and scalability of the model or simulation, and effectively solve the contradiction between simulation complexity and the limited resources, we propose the multi-resolution modeling (MRM) method of 3D visualization simulation based on meta-model. The paper firstly learns from the simulation soft FLAMES (the Flexible Analysis Modeling and Exercise System). Based on the simulation framework of behavior modeling and object-oriented, we design the reference frame of meta-modeling for 3D visualization simulation. Then, the meta-model can be formally described by using the BNF (Backus-Naur Form). Finally, we realize the multi-resolution modeling by using the different levels of detail.

Keywords: *Multi-resolution modeling, visualization simulation, BNF, FLAMES, Meta-model*

1. Introduction

With the rapid development of 3D visualization simulation, on the basis of the different simulation requirements, to create and combine the different resolution model is the inevitable trend of the development of simulation technology [1]. The study of the MRM has been carried out. [2] proposed an improved TIN mesh simplification algorithm to utilize multi-resolution 3D modeling, so that the model resolution and data amount could be regulated according to requirement. [3] built a multi-resolution rail road network mode. [4] proposed a multi-resolution framework for application of system dynamics modeling to sustainable manufacturing. [5] discussed the possibilities of applying the Model Driven Architecture (MDA) approach on Multi-Resolution Models. There are some other applications with MRM [6]. However, the study is still limited in many fields, and the coherence problem has been difficult. [7] listed five interaction classes between battlefield environment and the simulation entities and achieve the MRM for it. But the five interaction classes is not fully collect and the modeling is only limited the fixed range. Therefore, the paper learns from the FLAMES [8], lists other five interaction classes for 3D visualization simulation. Based on the theory of meta-model, we achieve the multi-resolution describing in the different levels of detail.

ISSN: 2005-4238 IJAST

2. The Model of 3D Visualization Simulation

2.1. The Model Composition of 3D Visualization Simulation

On the basis of a large number of visualization simulation systems' development, we summarize that the three-dimensional visualization simulation includes the three-dimensional entity model, virtual environment and physical data field (including electromagnetic field and underwater acoustic field).

The 3D entity model includes the shape, material and texture. For example, the aircraft model needs to describe the scale of shape, the color of material and the fidelity of texture. The virtual environment model includes the sound, special effect, terrain, ocean and atmosphere. These environment models can be described by parameterization or otherwise. The physical data field model can be obtained by direct measurement and the compute of transfer equation in addition to other factors. For example, the underwater acoustic field can be achieved by solving the transfer equation of underwater acoustic and the energy intensity.

2.2. The Interaction Classes of Visualization Simulation and System Entities

The visualization simulation modeling mainly reflects the interaction among the various models in applications. And in FLAMES, the using of the acknowledge model and information model can better reflect the behavior of combat entities, which can fully demonstrate real operational characteristics and interaction behavior of simulation entities. As thus we build a series of interaction classes. Figure 1 shows the interaction frame of 3d visualization simulation.

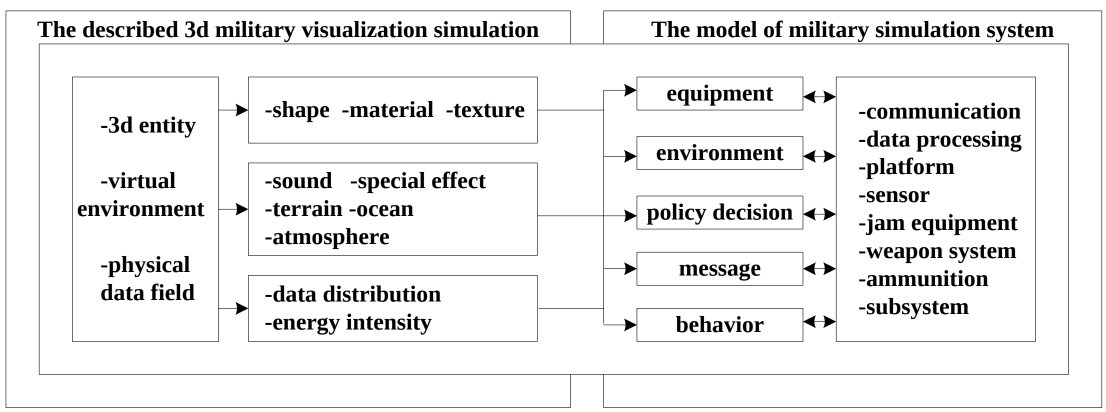

Figure 1. The Interaction Frame of 3d Visualization Simulation

3. The meta-modeling of 3D Visualization Simulation

3.1. Meta-model

It is used to define the construct and rule of semantic model, and commonly known as the language of the definition of the expression model. It describes the information "how to build the model and the semantic of model or how to integrate and operate reciprocally" [9]. Meta-model owns a higher abstraction degree than model, and the versatility and consistency are better, so that to build the meta-model of 3D visualization simulation is to analyze and solve model's application issues.

For resolving the problem of inconsistent transient and frequent polymerization and de polymerization, we can use the meta-model to achieve the meta-modeling for 3D visualization simulation.

3.2. Reference Frame of Meta-modeling

The building of meta-model can improve the reusability of model. By analyzing the modeling process, we build the reference framework of meta-modeling. Figure 2 shows the reference framework of meta-modeling for visualization simulation. The framework achieves meta-modeling of model, property, action, interaction, and condition and so on. And the framework also provides guidance for building meta-model.

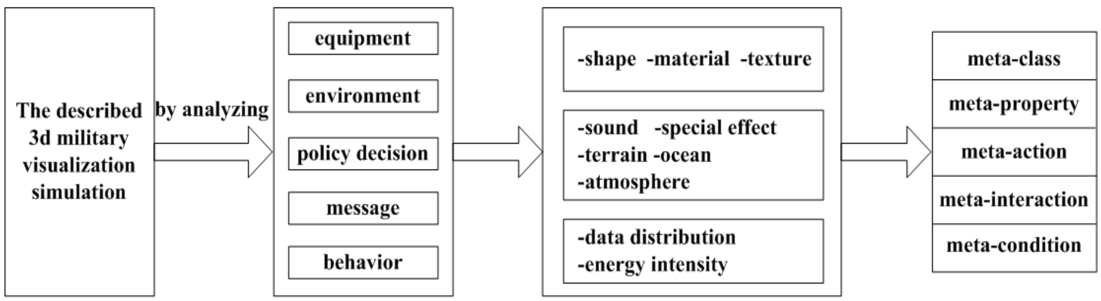

Figure 2. The Reference Framework of Meta-modeling

[10] gives the concept of Multi-Resolution-Model Family(**MF**). The set of different resolution models of the same entity is called multi-resolution-model family. We further proposed the rigorous mathematical definition of **MF** based on this definition.

Definition. 3.1. *If we can use $N(N\geq1)$ models $M_1, \ldots, M_N$ to express an object* ***E****, and the resolution of the N models are different, so the set $M=\{M_1, \ldots, M_N\}$ composed of the models $M_1, \ldots, M_N$ is called an multi-resolution* ***MF*** *of object* ***E****.*

We use an example in two resolution levels to discuss the principles of multi-resolution modeling. Let multi-resolution object ***E*** keep properties at high-resolution level (*HRL*) and low-resolution level (*LRL*) at any time, and the state of *HRL* and *LRL* state is always consistent, which is shown in Figure 3.

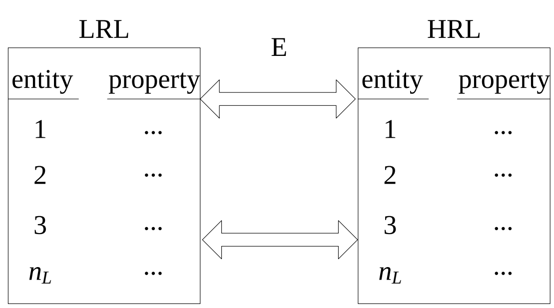

Figure 3. Two Levels Resolution Modeling

Definition. 3.2. We set a high resolution entity for E_H, low resolution entity for E_L, the high and low resolution entities can be respectively as follows:

$$E_H = [P_1^H, P_2^H, \cdots, P_s^H]^T$$
$$E_L = [P_1^L, P_2^L, \cdots, P_t^L]^T \quad (1)$$

Generally, high resolution entity contains more information than low resolution entity, so the simulation relation between them can be expressed as:

$$E_H = K \cdot E_L \quad (2)$$

Where, s, t respectively represent the number of multi-resolution entity model, and content s≤t; K is for the s*t order transformation matrix between the high/low resolution entity model, P for the attribute values of entity.

Meta-modeling is a way to create a meta-model activity. It is a modeling to special information and entity for each different feature, so you can achieve the multi-resolution three-dimensional visualization model modeling.

Meta-model is a highly abstraction of a relationship of subsystem with specific role in system, which indicates an interaction possibly occurrence, or an attribute of simulation system, but there is no specific instantiate data [11]. Establish meta-model aims to improve the reusability of simulation model and use for different areas, by instantiating meta-model to content the different requirements of the model.

For three-dimensional visualization, the first thing to do is analyze their visual entity, get fruiting body with specific purpose and role, and analyze the properties and information exchanging of each fruiting, in order to establish the meta-model to be visualized. We can use the meta-model theory to achieve the meta-model modeling of three-dimensional visualization entity effectively and solve the problem of inconsistent of the transient model and the problem of polymerization depolymerization during simulation process and other issues, thus improving the efficiency of the visualization process.

We analyze the modeling process based on meta-modeling theory, and propose reference framework of meta-model, which is shown in Figure 4. Meta-model of 3D visualization are the final result of meta-modeling, and also the most basic components of the model.

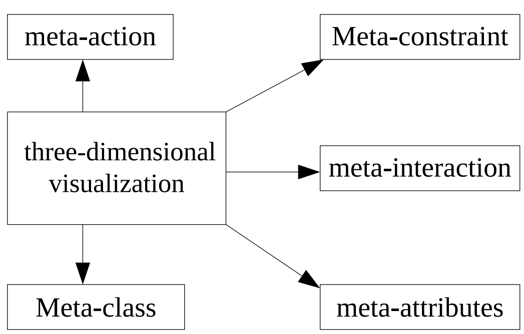

Figure 4. Reference Frame of meta-modeling

(1) meta-class. Meta-class is the prototype of defining variables and methods of some kind of visual entities; it contains information about object motion mode, including its name, methods, properties, and events, and is also the result of further abstraction of class for the model.

(2) meta-attribute. To highlight the importance of attributes, we list meta-attribute from meta-model separately, meta-attribute mainly refers to the indispensable attribute of meta-object, and we can obtain it from further abstraction to the model attribute.

(3) meta-action. Meta-action mainly refers to the corresponding action changes of meta-model when the dynamic changes are occurred within visualized. The dynamic changes of external influence are described in meta-interaction.

(4) meta-interaction. Meta-interaction is the highly abstract of the interaction between entities, but also a key element of battlefield environment modeling, such as the modeling of interactive between land and the department of transportation, some of the essential interactive features, such as the impact of surface moisture to the transport capacity of transport troops, these interactions need to be required as meta-interaction.

(5) meta-constraint. Constraint is the restrictions which model must content when a behavior and interactions occurs, we can change other variables or dismiss to satisfy the constraints. Meta-constraint is also a further abstraction to constraint; constraint is a hot research point of modeling and simulation at present.

After establishing the various element of meta-model, we can structure models of different spectral resolution by the combinations of different element model, this also achieves the reusability of meta-model.

3.3. Formal Description of Three-Dimensional Visualization Meta-Model

Make a formally description of three-dimensional visualization meta-model, we can achieve a more accurate multi-resolution model by grammar, providing adequate grammar assurance for the next implementation of model reusability, but also providing an exchange platform for simulation users and developers.

To make a formal description of meta-model, we chose BNF (Backus Naur Form). BNF is a typical meta-language [12, 13], it can express grammatical rules strictly, and the description grammar is a context-free grammar. We carry out a specific formal description of interactions among ship, copter and sea for example (the test scene is given in Figure 5 and Table 1).

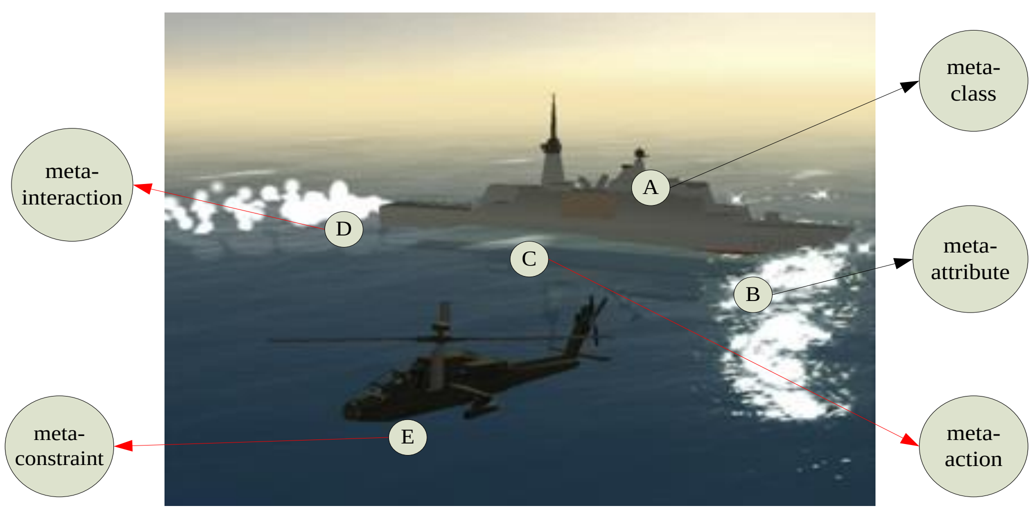

Figure 5. A Test Scene for a Specific Formal Description of Interactions

Table 1. A Specific Formal Description for Example

<Scene> ::=[<Sea> <ship> <copter>]
<Sea> ::=[<Illumination> <Reflection effect> <Wind> <Spray>
<Trail>…]
<ship>::= …
<copter>::= …
…

In Figure 5, the point "A" is meta-class. The entities are ship, copter and sea. The point "B" is the meta-attribute. The sea surface owns the attribute of reflection. The point "C" is the meta-action. Spray is generated with wind, the sea surface is changed. The point "D" is the meta-interaction. When the ship passed, the trail will be left. The interaction is between ship and sea. The point "E" is meta-constraint. The copter cannot be below the sea surface.

4. The Realization of Multi-Resolution Model

We can realize the multi-resolution of model by language. That can not only provide syntax assurance for realizing the reusability of model, but also provide the mean of achieving for simulation developer. Therefore, we chose the above typical meta-language BNF, which can strictly represent grammar rules and the grammar is context-free. In order to realize the different resolutions for 3D visualization simulation, we use the decomposition and merging of BNF code. And the multi-resolution modeling can be achieved in the different levels of detail.

Example 4.1. *Let us consider the following example about levels of detail for ocean in the virtual environment.*

<Virtual environment>:: = <Sea>

<Sea>:: = <Ocean>

And

<Virtual environment>:: = <Sea>

<Sea>:: = <Ocean>

<Ocean>:: = <Nature>

<Nature>:: = <Wave>

And

<Virtual environment>:: = <Sea>

<Sea>:: = [<Wind> <Illumination> <Ocean> <Undersea creatures> <Seabed>]

<Wind>:: = [<Speed> <Direction>]

<Ocean>:: = <Nature>

<Nature>:: = <Wave>

<Illumination>:: = …

<Ocean>:: = …

<Undersea creatures>:: = …

< Seabed>:: = …

The first one only describes the virtual environment until the level of the ocean. The second one describes the classification of ocean that belongs to the natural environment, and the ocean wave. The last one is specific to describe the included wind, illumination, ocean, undersea creatures and seabed of sea. It is obvious for us to know that the described virtual environment belongs to the different levels of detail and the latter one is more detail than the former one.

In the above test scene, the **MF** of ship and copter all contain five resolution levels. The corresponding vertex number and polygon number are given in Table 2 and 3. The Table 4 is the **MF** of the sea.

Table 2. The Resolution Levels of Ship and the Corresponding Vertex Number and Polygon Number of Ship

Resolution level	5	4	3	2	1
Vertex number	9317	7957	4697	3668	2084
Polygon number	4610	3934	2286	1824	1016

Table 3. The Resolution Levels of Copter and the Corresponding Vertex Number and Polygon Number of Copter

Resolution level	5	4	3	2	1
Vertex number	3458	2202	1280	756	648
Polygon number	1497	938	524	288	262

Table 4. The MF of the Sea. The mean of "Y" is included, and the mean of "N" is not included. There are some Numbers which Represent their Respective Properties

Resolution level	6	5	4	3	2	1
Reflection effect	Y	Y	Y	Y	Y	N
Illumination	Y	Y	Y	Y	N	N
Wind velocity	12	12	12	12	8	4
Spray	Y	Y	Y	Y	Y	N
Fog density	0.0015	0.0015	0.001	0	0	0
Trail	Y	N	N	N	N	N

5. Conclusions

According to the requirement of solving the models' inconsistent transient and frequent polymerization and de-polymerization in 3d visualization simulation, by using of the meta-model theory, the multi-resolution modeling method of 3D visualization simulation based on meta-model is proposed. The method achieves the meta-modeling of visualization simulation, different combinations of meta-models with the different levels of detail. The future study will focus on how to improve the fidelity by using of the different resolution models.

Acknowledgments

This work is partially supported by the National Natural Science Foundation of China (61304144 and 61503124), the Opening Project of Key Laboratory of Mine Informatization, Henan Polytechnic University (KY2015-06), the Key Scientific Research Projects of Henan Higher, China (15A520018), and the Doctor Foundation of Henan Polytechnic University (60907/027).

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