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SIMULATION COMPOSITION APPROACH FOR AUV

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ABSTRACT

The computation of the simulation models is complex and the behavior sequence must be updated dynamically in AUV simulation system. The simulation system composability development framework is provided to solve these problems. The π calculus is extended to describe the time properties of models in the framework. And simulation models are formal described by the extended π calculus. Then the behavior composability is validated by reduction and bisimulation of π calculus. The framework is validated by the simulation composition example and the construction of AUV simulation test system. The framework can complete the description and the dynamical composability of various models in the distributed real time simulation system.

Keywords: *Composable Simulation, Simulation Model,; π Calculus, AUV*

1. INTRODUCTION

Modeling and Simulation is a powerful tool that can be used to support development of concepts, decision support as well as training, studies and analysis. Simulations can help us understand the dynamics of the systems and give us a tool to study them before they are even being developed. Designing, building and testing an Autonomous Underwater Vehicle (AUV) is difficult. Unlike most other mobile robots, AUVs must operate unattended and uncontrolled in a remote and unforgiving environment. Inaccessibility greatly complicates evaluation, diagnosis and correction of AUV system faults. In order to ensure complete reliability, AUV software and hardware need to be fully tested in the integrated simulation system.

However, development of simulation models can be a time and resource consuming process and involves some initial costs. Beside the initial cost there is also the issue of quality and usability of the simulation models. An AUV simulation model development involves different aspects including, hydrodynamic computing, simulation, and information processing. The models were in different software environment. And they ware developed by different developers. Handling the issue of quality and usability gets more difficult as simulation models get larger and more complex.

An approach to reduce the costs associated with the process and improve the usability of the developed model is to compose new simulation models by predefined and already existing validated simulation models [1]. So there is a growing interest for developing larger and more complex models through model composition [2], [3], [4], [5]. The defining characteristic of composability is the flexibility to combine and recombine simulation components into different simulation systems to meet diverse needs [6]. In discussing composability, there are different views in distinguishing the kind of problems that arise. Tolk [7] proposes different levels of interoperability ranging from no interoperability to conceptual interoperability and introduces the concept of "pragmatics" to encapsulate simulation context. Petty and Weisel [8] define nine levels of composability from applications to behavior and propose two perspectives to study composability, engineering and modeling.Syntactic(engineering) composability determines whether the components can be connected. To be syntactically composable, simulation components have to be compatible with respect to data passing mechanisms and timing assumptions. In contrast, semantic (modeling) composability addresses whether the combined computation of the composed simulation system is semantically valid. Based on above composability theory, many composability approaches were put forward in recent years. Composable Discrete-Event scalable Simulation (CoDES) proposes a layered approach to semantic composability validation with increasing accuracy and complexity. There are three layers to check for logical properties, temporal properties and behavioral equivalence of simulation models [9]. BOM Modeling Framework (BMF) is a BOM based composable modeling

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framework for war simulation [10]. And the kernel model was used to the design of BOM component framework. The joint simulation system (JSIMS) is being developed by the US Department of Defense and is intended to deliver commander and command staff training [11]. Examines simulation composability form the JSIMS perspective and explores the overall technical approach and the related issues.

AUV simulation system is a distributed real time system. Although composable simulation model development is a desired method for improving the model development process and reducing the development costs. There are seldom simulation composition approaches today which manages to real time information communication. So the real time behaviors are not validated effectively during the composable process.

This paper proposes a framework of simulation composition approach based on real time behavior validation for AUV simulation. The formation of AUV simulation models is described by π calculus. And the behavior composability is validated by reduction and bisimulation of π calculus. This paper is organized as follows. Section 2 discusses the framework of model composability. Section 3 provides the formation of simulation model. Section 4 gives a behavior composition method based on π calculus. Section 5 discusses a prototype of an AUV simulation system implemented using composability approach based on behavior validation. A summary and discussion of future work are presented in Section 6.

2. AUV SIMULATION MODEL COMPOSABILITY

Four steps can be distinguished when building AUV simulation system based on models composition: model selector, model formation, model composability validation and model composing. Figure 1 shows the development process of AUV simulation system based on composable simulation models. The *Model Selector* is responsible for simulation models selection and discovery. It needs the ability to formulate a set of search criteria, access a *Model Repository* of properly indexed models, perform relevant assessment of plausible models. The *Model Composers* can search the plausible models in the AUV simulation *Model Repository* coherent a given conceptual model by the *Model Selector*. The *Model Repository* is a database for atom models and composed models. A composed model undergoes syntactic and semantic checks by the *Model Validator* before the validated simulation model is passed to the *Composing Actuator*. The *Composing Actuator* supervises models interaction, time management, data management and result reporting. All these functions are executed in the processing layer in the framework. The GUI layer provides a graphical interface to support establishing conceptual models and simulation models execution.

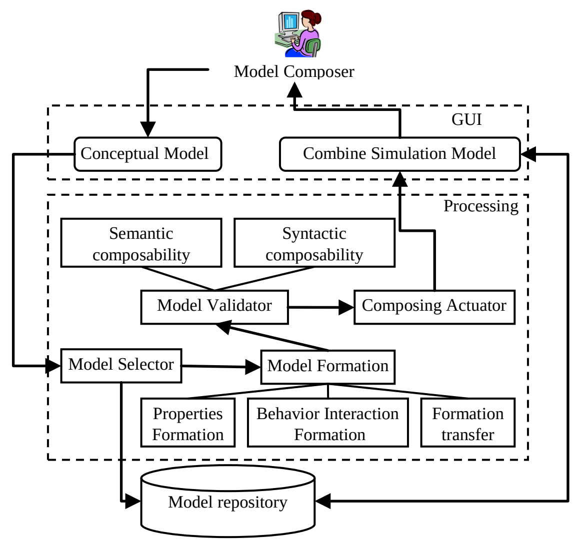

Figure 1: Composed Auv Simulation Model Development

To support the above developing process, a class diagram of composing architecture is proposed in Figure 2. The model formation is aggregated of property formation, behavior interaction formation and formation transfer. Model formation is responsible to format the properties of a model. Behavior interaction formation is responsible to format the behavior between models during the composing. Formation transfer is responsible to transfer the formation of models and behaviors to π calculus. Based on formation, there are two classes derived from composability validation, semantic composability validation and syntax composability validation. They are also the two layers of simulation model composing. The semantic composability validation depends on two functions, behavior compatibility validation and behavior replacement validation.

While the composing approach is viewed as a black-box to simulation users, a number of default and extensible attributes and methods are defined to support behavior validation based composing model development. This paper only proposed the approach of simulation model formation and semantic composability validation.

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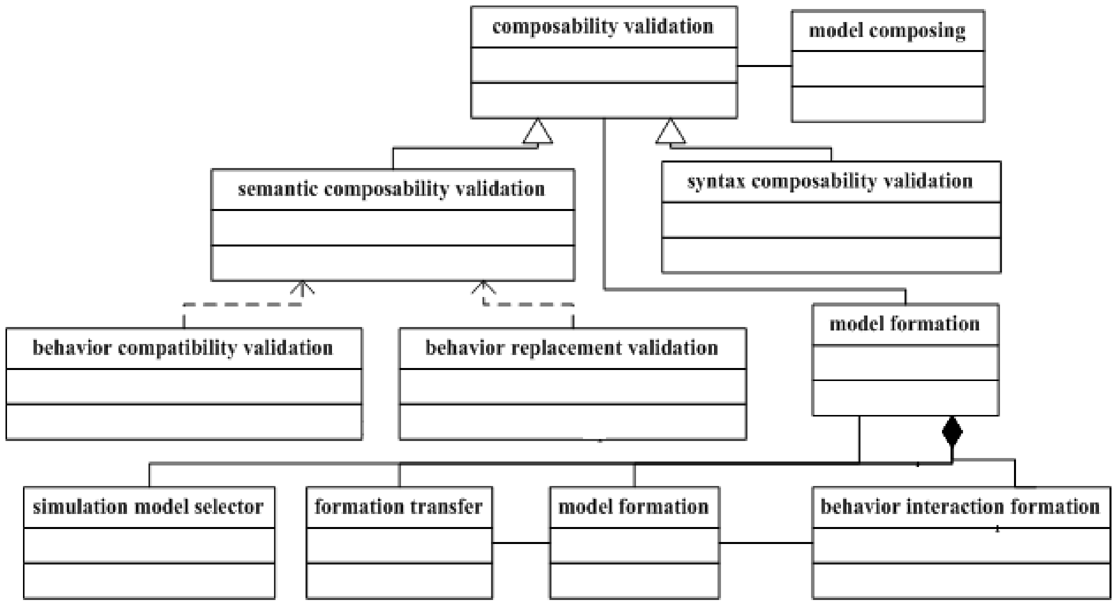

Figure 2: Framework Of Auv Simulation Model Composing Approach

3. SIMULATION MODEL FORMATION

To support the automatic completion of behavior composability validation, the formations fall into two categories. First, it is the model formation. It formally describes properties, interfaces and states of a simulation model. The behavior interaction formation comprises the second category. It is the format description of interactive behaviors between simulation models.

3.1 Property Formation

AUV simulation model ($AUVSM$) can be described as following structure:

$$AUVSM = (S, I, M, f_m, A, R_{IA}) \quad (1)$$

Where S denotes the state sets of $AUVSM$ during the behaviors executed. I denotes the sets of the external interface processes in $AUVSM$. M is the set of m , m is the information produced by the interface, m is composed by one or several variables. $f_m : I \to 2^M$ is a mapping function , denotes the corresponding relationship between every interfaces and all of its sending information. A is a set of $actions$, an $action$ is an interior action coherent to an interface of $AUVSM$. R_{IA} is a mapping $interface \to \sigma$, σ is a orderly array of actions that can complete the $interface$, R_{IA} is the relationship between the $interface$ and the interior action.

R_{IA} is a connection between a set of interior action and a external interface. The detail information of interior actions is also defined in $AUVSM$. An action is formally defined as a tuple:

$$Action = \{SA, S_s, S_e, pt, m\} \quad (2)$$

Where SA is the interior states in $Action$, it is the sub set of S in the $AUVSM$, $SA \subset S$. S_s is the start state in $Action$, $S_S \subset SA$. S_e is the end state in $Action$, $S_e \subset SA$. pt is the type of $Action$. $m \subset M$, m is the message that received or send by $Action$.

There are two types of $Action$, receive and send. Receive denotes the state S_s receive the message m , and then transfer to the state S_e . Send denotes that state S_s send the message m , and then transfer to the state S_e . $pt = \phi$, if there is no transferring message between S_s and S_e .

3.2 The formation of behavior interaction

Behavior interaction is an ordered action sequence of a simulation model. It is the basis of behavior composition reasoning. The actions in the behavior interaction should participate in the communication of models.

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$P_{SM} = \langle Interface_1, Interface_2, ..., Interface_n \rangle$ is an interaction sequence of an AUVSM during one of its communications with other AUVSM. A corresponding state transferring sequence $SMP = \langle \sigma_i, ..., \sigma_j, ..., \sigma_k \rangle$ can be got by R_{IA}. SMP starts from the state S_i, $S_i \in \sigma_i$ and S_i is the start state of $AUVSM$, and end in the state S_k, $S_k \in \sigma_k$. If S_k is one of the end state of $AUVSM$, SMP is defined as the complete interaction sequence. The complete interaction sequence denotes that simulation model can go to the end successful during the corresponding communication with other models. So it is necessary for a model successful composition that there is at least one complete interaction sequence of the model.

If there are two simulation models $SM_1 = \{S_1, I_1, A_1, R_{IA1}\}$ and $SM_2 = \{S_2, I_2, A_2, R_{IA2}\}$, the composition unit between them is defined in the following.

$$\infty = \{p_-, p_+, M, B_T\} \tag{3}$$

Where $p\_ \in \{p \mid p \in SM_1 I_1 \cup SM_2 I_2\}$ is the external interface process that sending out message to other models. $p_+ \in \{null\} \cup \{p \mid p \in SM_1 I_1 \cup SM_2 I_2\}$ is the external interface process that receiving message from other models, and $p\_ \in SM_1 \cdot I_1 \cdot P \wedge p_+ \in SM_2 \cdot I_2 \cdot P\}$ or $p\_ \in SM_2 \cdot I_2 \cdot P \wedge p_+ \in SM_1 \cdot I_1 \cdot P\}$. $M = f_m(p_-)$ is the set of message corresponding to the process $p\_$, and $M \subseteq f_m(p_+)$. $BT = (t_1, t_2)$ is a pair of time step, $p\_$ is executed at , t_1 is executed at t_2.

The composition unit is a formally description of model interaction. And the strict limit of simulation composition is that the type of process is contrary in the unit. $p_+ = null$ is allowed and it denotes that one model send message and the other model cannot receive the message, so the interaction is failure. If there are two simulation models $SM_1 = \{S_1, I_1, A_1, R_{IA1}\}$ and $SM_2 = \{S_2, I_2, A_2, R_{IA2}\}$, $CP = \ < \infty_1, \infty_2, \cdots, \infty_n >$ is defined as a complete interaction path between SM_1 and SM_2. An interaction path is a successful communication between two models. The condition is that every model can transfer from start state to the end state, and two models are executed at the same time step. All of the conditions can be formalized in the following: (1) $\infty_1 \cdot p_+ \neq null (1 < i < n-1)$; (2) $P_{SM1} =< \varphi(\infty_1, SM1), \varphi(\infty_2, SM1), \cdots, \varphi(\infty_n, SM1) >$ is complete interaction sequence of SM_1 .And $P_{SM2} =< \varphi(\infty_1, SM_2), \varphi(\infty_2, SM_2), \cdots, \varphi(\infty_n, SM_2) >$ is also a complete interaction sequence of SM_2. $\varphi(\infty, SM)$ denotes the set of processes that are not only in ∞ but also in SM. (3) $\infty \cdot BT \cdot t_1 = \infty \cdot BT \cdot t_2$

3.3 Behavior interaction based on π calculus

The conceptual world of the π calculus comprises two sorts of entity: processes, which compute in parallel and exchange information by communication and the channels on which they communicate. The process in π calculus denotes the P in interface of $AUVSM$. The channel in π calculus denotes the transferring σ in Action of $AUVSM$. B_T of ∞ is one of conditions in which models can communicate with each other. So the time information is added to the process in π calculus in order to describe BT. The action types receive and send can be denoted by the process expression $(t)a(\vec{x})$ and $(t)\overline{a} < \vec{x} >$. The corresponding relationship between π calculus and the formation of $AUVSM$ is described in table 1. An interaction sequence of $AUVSM$ can be described as a structural process expression in π calculus. And composition unit can also be described as several structure process expressions in π calculus. There are two simulation models, position computing and force computing, in Figure 3. An interaction sequence can be described as a structural process expression in π calculus. An interaction sequence of position computing is in the following.

$$(t)P_{pc} = (t)Op1(IEF).\tau.(t)\overline{Op3} < Corrdinate, Angle >$$

$$+(t)Op2(NIEF).(t)\overline{Op3} < Coordinate, Angle > \tag{4}$$

In the interaction sequence, the message is received by the channel Op_1 and Op_2, and it is sent by the channel Op_3 at the time step t.

Table 1 : Relationship Between Π Calculus And AUVSM

Action type	process	message	channel	Process expression
receive	a	x	a	$(t)a(x)$
		$x_1, \ldots, x_n$		$(t)a(\vec{x})$
send	a	x	$\overline{a}$	$(t)\overline{a} < x >$
		$x_1, \ldots, x_n$		$(t)\overline{a} < \vec{x} >$

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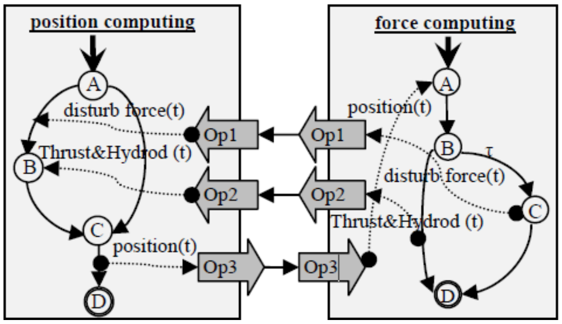

Figure 3: The Interaction Between Position Computing And Force Computing

Structural congruence and reduction are the formally basics of behavior interactions. AUV simulation system is a real time distributed system. The B_T of SM must be described as the conditions of behavior interactions during the reduction in π calculus. The reduced base is extended to describe the time step information in π calculus. A time reduced base is corresponding to a composition unit of two simulation models. Only the composition processes which are exactly at time t can take part in the process reduction. And the processes at other time are all reduced during the model compositions. A complementary pair of actions is defined as a time reduced base in the following conditions. (1)The two actions happed in the same time step t. (2)There are no other guard conditions for two actions. (3)The two actions are not in the same expression.

4. THE BEHAVIOR COMPOSITION BASED ON Π CALCULUS

We consider a composition to be valid and its components to be semantically composable if and only if (i) components to be integrated behave correctly to form a valid composition both externally with respect to their neighbors, and internally when safety and liveness properties are preserved over time, and (ii) the resulting composition produces valid output. Constraint validation is the process of verifying the communication of connected components for semantic correctness [11]. These two conditions can be guaranteed by a complete interaction path. If there is at least a complete interaction path between two models, these models both can successful transfer form start state to end state during the interaction. So all of behaviors must be safety and liveness during the interaction and the input/output data between models is correct. If the computation of every model is correct, the output of the composition model must be correct.

4.1 Behavior Composition Proving

A complete interaction path can be validated by the process reductions in π calculus. A composition unit is described by several structure processes, and an interaction path is corresponding to a time reduced base in π calculus, that is $P \xrightarrow{\overline{x}(y)x(u)} P'$. All of the possible interactions should go to the end, if there are no time reduced bases in the structure processes. If there are several time reduced bases in one reduced step in the expression, there would be several branches during the reducing process. Every branch is called a reducing branch. All of reducing branches that are not generated until there are no time reduced bases existed in the process expression. And therefore, the complete interaction path theorem and proofing is in the following.

Theorem Two simulation models are behavior composable, if and only if there is at least a null process branch existing after their interaction path is reduced by all of the time reduced bases.

Proof If the two models are composable, there must exist a successful interaction process between them. According to the above definition, a successful interaction process is a complete interaction path. And a complete interaction path can be de-scribed by a process summation in π calculus. The every interaction units of the process can be described by reduced base in π calculus. From the reduction rule of π calculus, a process summation can be reduced to one or several branches by reduced bases, and there is at least a null process in the branches. Therefore, if the two simulation models are composable, there must be a null process branch after the summation reduced.

A time reduced base denotes an interaction unit between two models. Therefore, if there is a null process branch after a process summation reduced, two models can transfer from start state to end state in the branch. So the branch is corresponding to a complete interaction path. The corresponding interaction process is successful, so the two models are behavior composable.

4.2 An Example

There are two simulation models *position computing* and *force computing* in Figure 3. The *force computing* model starts at the state A and receiving position message by the interface OP3 at the time step $t-1$. And then transfers to the state B and computing out AUV forces of time step t by the state C. And the disturb force, thrust and

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hydrodynamics are sent out to the position computing by the interface OP1 and OP2 in the end state D. The position computing model starts at the state A and receiving disturb force of time step t by interface OP1, and then transfers to the state B. After receiving thrust and hydrodynamic of time step t by interface OP2, the model transfers to the state C and computes out the positions and speeds of AUV at time step t. At the end, the current position is calculated out in the end state D of the model.

The process expression corresponds to the interactions between two models is in the following.

$$\begin{aligned}(t)P'_{(PC,EF)} &= (t)P_{PC}' \mid (t)P_{EF}' \mid (t+1)P_{EF}' \\ &= (t)Op1(IEF).(t)\overline{Op3}<Coordinate, Angle> \\ &\quad + (t)Op2(NIEF).(t)\overline{Op3}<Coordinate, Angle> \\ &\quad \mid (t)\overline{Op1}<IEF> + (t)\overline{Op2}<NIEF> \\ &\quad \mid (t)Op3(Coordinate, Angle)\end{aligned} \tag{5}$$

The expression (5) is reduced and generate two branches by time reduced bases. And the two branches are all reduced to the null process in the following expressions. So the two models are composable.

$$\begin{aligned}(t)P'_{(PC,EF)} &= (t)P_{PC}' \mid (t)P_{EF}' \mid (t+1)P_{EF}' \\ &= (t)Op1(IEF).(t)\overline{Op3}<Coordinate, Angle> \\ &\quad + (t)Op2(NIEF).(t)\overline{Op3}<Coordinate, Angle> \\ &\quad \mid (t)\overline{Op1}<IEF> + (t)\overline{Op2}<NIEF> \mid (t)Op3(Coordinate, Angle) \\ &\xrightarrow{IEF} (t)\overline{Op3}<Coordinate, Angle> \mid 0 \mid (t)Op3(Coordinate, Angle) \\ &\rightarrow new\, w\big((t)\overline{Op3}<w>.\overline{w}<Coordinate>.\overline{w}<Angle>\big) \mid 0 \\ &\qquad \mid (t)Op3(w).w(Coordinate).w(Angle) \\ &\xrightarrow{Coordinate, Angle} 0 \mid 0 \mid 0\end{aligned} \tag{6}$$

$$\begin{aligned}(t)P'_{(PC,EF)} &= (t)P_{PC}' \mid (t)P_{EF}' \mid (t+1)P_{EF}' \\ &= (t)Op1(IEF).(t)\overline{Op3}<Coordinate, Angle> \\ &\quad + (t)Op2(NIEF).(t)\overline{Op3}<Coordinate, Angle> \\ &\quad \mid (t)\overline{Op1}<IEF> + (t)\overline{Op2}<NIEF> \mid (t)Op3(Coordinate, Angle) \\ &\xrightarrow{NIEF} (t)\overline{Op3}<Coordinate, Angle> \mid 0 \mid (t)Op3(Coordinate, Angle) \\ &\rightarrow new\, w\big((t)\overline{Op3}<w>.\overline{w}<Coordinate>.\overline{w}<Angle>\big) \mid 0 \\ &\qquad \mid (t)Op3(w).w(Coordinate).w(Angle) \\ &\xrightarrow{Coordinate, Angle} 0 \mid 0 \mid 0\end{aligned} \tag{7}$$

5. THE AUV SIMULATION ESTABLISHED BY MODEL COMPOSITION

Based on the simulation model library of our laboratory, a distributed AUV simulation system is established by the behavior composition method. There are 123 computing models and 344 scene models. There should be a scene model, an underwater cameras simulation model, a motion control simulation model, a sonar simulation model, a navigator simulation model and date interface model in the AUV simulation system. We searched the models that satisfy the static conditions of the AUV simulation in the simulation model library, and found 16 computing models and 23 scene models. We format the found computing models and filter the behavior composable models.

Software MWB (Mobility Workbench) can complete the model formatting and reducing. MWB is developed by Uppsala University in Sweden, and it is a auto validation tool of π calculus [11-13]. It can describe and reduce π calculus and CCS. It is for Windows and Linux operation systems. The behavior composability of above 16 computing models is completed in MWB. We got 7 behavior composable models, including of 2 motion control simulation models, 2 sonar simulation models, 1 underwater cameras simulation model, 1 navigator simulation model, and 1 date interface model. The AUV simulation system can be successfully established by these models, but the computing efficiency of two control simulation models is different. The navigation simulation test and object simulation detection test are completed in the established simulation system and the motion tracks of the tests are shown in Figure 4 and Figure 5.

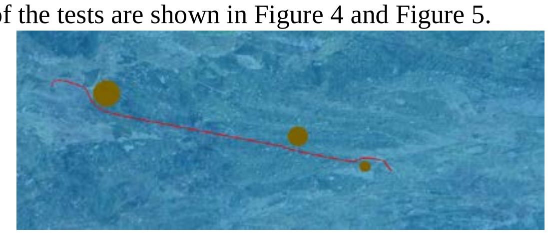

Figure 3: The Motion Track Of Navigation Simulation Test

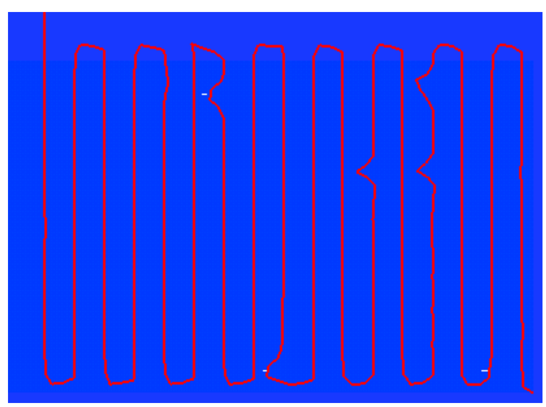

Figure 4: The Motion Track Of Object Simulation Detection Test

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6. CONCLUSION

We present an AUV simulation system development framework (AUVSDF) based on behavior validation which could be used to promote reusability, composability and interoperability of models in AUV simulation. The π calculus is extended so as to describe the time step of every action in the framework. And the reduction rules are established to adapt to time step information. A simulation model is formally described by the extended π calculus. AT the same time a behavior composition validation theorem based on the reduction of π calculus is provided and proofed. Lastly, an AUV simulation system is developed by the models which pass the behavior composition validation by the approach. The framework can explore all kinds of AUV simulation systems or other distributed real time simulation systems. This paper addresses the semantic validation of simulation model developed using base components. We are extending the validation process to include web services or other web component of simulation systems.

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REFERENCES:

[1] M. Petty, E. Weisel, “A formal basis for a theory of semantic composability”, *Proceedings of the Spring Simulation Interoperability Workshop*, April 4, 2003.

[2] J. Cowie, “Towards realistic million-node internet simulations”, *Proceedings of International Conference on Parallel and Distributed Processing Techniques and Applications*, 1999, pp.2129–2135.

[3] B. Delinchant, F. Wurtz, D. Magot, L. Gerbaud, “A component-based framework for the composition of simulation software modeling electrical systems”, *Simulation*, No.7-8, 2004, pp.347–356.

[4] S. Kasputis, H. Ng, “Composable simulations”, *Proceedings of the Winter Simulation Conference*, Vol.2, 2000, pp.1577–1584.

[5] A. Verbraeck, “Component-based distributed simulations”, *Proceedings of 18th Workshop on Parallel and Distributed Simulation*, May 16-19, 2004, pp.141-148.

[6] A. Tolk, “What comes after the semantic Web PADS implications for the dynamic Web”, *Proceedings of the 20th Workshop on Principles of Advanced and Distributed Simulation*, May 24- 26, 2006, pp. 55–62.

[7] M. Petty and E. W. Weisel, “A composability lexicon”, *Proceedings of the Spring Simulation Interoperability Workshop*, 2003.

[8] C. Szabo, Y. M. Teo, “An approach for validation of semantic composability in simulation models”, *ACM/IEEE/SCS 23rd Workshop on Principles of Advanced and Distributed Simulation*, June 22-25, 2009, pp.3-10.

[9] Qiang He, Yong Peng, Mingxin Zhang, Jianguo Hao, “A composable modeling framework base on bom in war simulation”, *International Conference on Computer Science and Service System*, June 27-29, 2011, pp.1900-1904.

[10] Brett Butler, “Simulation composability for JSMIS”, *Proceedings of 2nd International Workshop on Distributed Interactive Simulation and Real-Time Applications*, 1998, pp. 111-121.

[11] Y. Teo and C. Szabo. CODES: An Integrated Approach to Composable Modeling and Simulation, *Proceedings of the 41st Annual Simulation Symposium*, April 13-16, 2008, pages 103–110, Ottawa, Canada.