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Achieving reusability and composability with a simulation conceptual model

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Reusability and composability (R&C) are two important quality characteristics that have been very difficult to achieve in the Modelling and Simulation (M&S) discipline. Reuse provides many technical and economical benefits. Composability has been increasingly crucial for M&S of a system of systems, in which disparate systems are composed with each other. The purpose of this paper is to describe how R&C can be achieved by using a simulation conceptual model (CM) in a community of interest (COI). We address R&C in a multifaceted manner covering many M&S areas (types). M&S is commonly employed where R&C are very much needed by many COIs. We present how a CM developed for a COI can assist in R&C for the design of any type of large-scale complex M&S application in that COI. A CM becomes an asset for a COI and offers significant economic benefits through its broader applicability and more effective utilization.
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1. Introduction

A *Model* is a representation and abstraction of anything such as a real system, a proposed system, a futuristic system design, an entity, a phenomenon, or an idea. *Modelling* is the act of developing a model. *Simulation* is the act of executing, experimenting with or exercising a model or a set of models for a specific objective (intended use) such as analysis (problem solving), training, acquisition, entertainment, research, or education. Simulation cannot be conducted without a model and modelling is an integral part of simulation. Therefore, we refer to modelling and simulation activities collectively as Modelling and Simulation (M&S).

We define simulation *conceptual model* (CM) as a repository of high-level conceptual constructs and knowledge specified in a variety of communicative forms (eg, animation, audio, chart, diagram, drawing, equation, graph, image, text, and video) intended to assist in the design of any type of large-scale complex M&S application. A CM is expected to be made available for a community of interest (COI) such as air traffic control, automobile manufacturing, ballistic missile defense, business process reengineering, emergency response management (ERM), homeland security, military training, network-centric operations and warfare, supply chain management, telecommunications, and transportation. M&S application designers can be assisted by a CM in the design of large-scale complex M&S applications for solving problems in the COI for which the CM is provided (Balci and Ormsby, 2007).

The current era of net-centricity poses significant technical challenges in M&S of systems of systems integrated over a network such as Internet, virtual private network, wireless network, and local area network. Disparate systems with diverse characteristics are composed with each other to form a network-centric system of systems. We face serious technical challenges in achieving reusability and composability (R&C) for the design of simulation models representing such network-centric systems of systems.

A CM has been recognized as an integral part of M&S application development as the complexity and size of M&S applications have continued to increase with the availability of more powerful computer capabilities (Robinson, 2004, 2006, 2007; DMSO, 2006; Robinson *et al*, 2006, 2010; Arthur and Nance, 2007; Balci and Ormsby, 2007).

The objective of this paper is to extend the Balci–Ormsby approach (Balci and Ormsby, 2007), noting the potential benefits and increased effectiveness of a CM in achieving R&C in M&S application development. The focus on using a CM to achieve R&C in the design of any type of large-scale complex M&S application is driven by the recognized potential benefits: reduced development cost and time, effective use of subject matter expertise, increased quality (through the reuse and composition of certified artifacts), and reduced risk. R&C promote the 'do not reinvent the wheel' principle that seeks economies for sponsors or project funders.

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Reusability is the degree to which an artifact, method, or strategy is capable of being used again or repeatedly. *Composability* is the degree to which an artifact is capable of being constituted by combining things, parts, or elements. R&C stand out as two important quality characteristics of an M&S application. Other quality characteristics include accuracy, extensibility, interoperability, maintainability, modifiability, openness, performance, scalability, and usability.

The remainder of this paper is organized as follows. Section 2 introduces different types (areas) of M&S. Section 3 explains each of the reusability levels, elaborating the difficulties encountered. Composability levels and their achievability are described in Section 4. Section 5 identifies the role of a CM in achieving R&C for M&S application development. Reuse-based composable M&S application design using a CM is presented in Section 6. Section 7 states some conclusions.

2. Areas (types) of M&S

Many areas or types of M&S exist (Balci, 2010). A taxonomy of M&S areas is presented in Table 1. Use of the 17 M&S areas listed in Table 1 spans dozens of different disciplines for many objectives/intended uses. Each M&S area possesses its own characteristics and methodologies, is applicable for solving certain problems, and has its own community of users. Some M&S areas have their own societies, conferences, books, journals, and software tools.

Discrete M&S uses a model built in terms of logic and the simulation time is represented as a discrete variable. It is typically used in disciplines such as computer science, systems engineering, industrial engineering, operations research, business, civil engineering, and management science. This type of M&S is commonly referred to as *Discrete Event Simulation*. The 'event' in the name comes from the traditional use of the event scheduling (ES) simulation programming strategy. However, other programming strategies exist based on activity, process, object, and agent. Therefore, the term 'event' should be dropped from the name so as to include all possible programming strategies (world views).

Table 1 M&S areas (types)

A. Based on model representation
1. Discrete M&S
2. Continuous M&S
3. Monte Carlo M&S
4. System Dynamics M&S
5. Gaming-based M&S
6. Agent-based M&S
7. Artificial Intelligence-based M&S
8. Virtual Reality-based M&S
B. Based on model execution
9. Distributed/Parallel M&S
10. Web-based M&S
C. Based on model composition
11. Live exercises
12. Live experimentations
13. Live demonstrations
14. Live trials
D. Based on what is in the loop
15. Hardware-in-the-loop M&S
16. Human-in-the-loop M&S
17. Software-in-the-loop M&S

Continuous M&S uses a model consisting of differential equations and the simulation time is viewed as a continuous variable. It is typically used in disciplines such as aerospace engineering, computational fluid dynamics, computational solid mechanics, computational engineering, computational physics, materials science and engineering, and heat transfer.

Monte Carlo M&S uses a model built based on statistical random sampling. The model usually does not represent time-varying relationships. Monte Carlo M&S is typically used in disciplines such as Chemistry, Computational Engineering, Financial Probabilistic Modelling, Mathematics, Nuclear Engineering (Computational, Nuclear, Statistical) Physics, and Reliability Engineering.

System Dynamics M&S uses a model representing cause-and-effect relationships in terms of causal-loop diagrams, flow diagrams with levels and rates, and equations. The equations are used for simulating system behaviour. System Dynamics M&S is typically used in disciplines such as Business, Decision Sciences, Economics, Management, Organizational Sciences, Policy Studies, Social Sciences, and System Sciences (Balci, 2005).

Gaming-based M&S uses humans as part of its model. It is typically intended to train people. For example: *Management games* are performed to train managers for a business. *War gaming* is performed to train military commanders. The gaming known as Video Game is a kind of simulation that is intended for entertainment purposes. Gaming-based M&S is typically used in disciplines such as Business, Education, Management, and Training.

Agent-based M&S uses a model representing agents and their interactions. An *agent* is 'intelligent', adaptive, autonomous, goal/self-directed, can have the ability to learn, and can change its behaviours based on experience. Agent-based M&S inherits characteristics from artificial intelligence (AI)-based M&S and object-oriented M&S. An agent is represented by attributes, behavioural rules, memory, resources, decision-making rules, and rules to modify behavioural rules. An agent is similar to an object in object-oriented M&S. Agent-based M&S is typically used in disciplines such as Biological Sciences, Cognitive Sciences, Computational Sciences, Economics, Organizational Sciences, Physical Sciences, Social Sciences, and Sociology.

AI-based M&S involves a model intended to represent human intelligence or knowledge. An AI-based simulation model typically mimics human intelligence such as reasoning, learning, perception, planning, language comprehension, problem solving, and decision making. Rule-based knowledge representation is commonly used for building AI-based simulation models. AI-based M&S is typically used in disciplines such as Cognitive Science, Computer Science, Engineering, Language Translation, Neuroscience, Philosophy, Psychology, Game Playing, and Robotics.

Virtual reality (VR)-based M&S enables a person to interact with a three-dimensional visual representation of a real or imaginary system in an immersive, multisensory, and interactive manner. The user wears goggles, headsets, gloves, or body suits to interact with the simulation. The motion sensors pick up the user's movements and adjust his or her view and action accordingly during the interaction, and usually in real time. VR-based M&S is typically used in disciplines such as Architecture, Computer-aided Design and Manufacturing, Education, Entertainment (Movies, Video Games), Human–Computer Interaction, Medical Science, Real Estate, and Training.

Distributed M&S executes its model parts (eg, federation of models, submodels, model components, subcomputations) on geographically or locally distributed computers for the purpose of achieving faster execution time. Distributed M&S enables geographically dispersed people to interact with the running simulation typically for training purposes. The *High-Level Architecture* (HLA) has been traditionally used for building distributed M&S applications. *Parallel M&S* executes its model parts on multiple CPUs of the same computer for the purpose of achieving faster execution time.

Web-based M&S uses the HyperText Transfer Protocol for the communication among its model components and user interactions over a network. Users employ client computers to access or interact with the M&S application running on server computer(s) (Fishwick, 1997; Miller *et al*, 2000, 2001; Sabah and Balci, 2005; Balci and Page, 2009; Myers and Balci, 2009).

A *live exercise* is conducted in real time in a synthetic environment consisting of simulation models, real hardware and software systems, and humans under simulated scenarios for objectives such as training, operational test and evaluation, interoperability assessment, technology assessment, or acquisition.

A *live experimentation* is conducted in real time in a synthetic environment consisting of simulation models, real hardware and software systems, and humans under simulated scenarios for objectives such as operational effectiveness assessment, interoperability assessment, or technology (readiness) assessment.

A *live demonstration* is conducted in real time in a synthetic environment consisting of simulation models, real hardware and software systems, and humans under simulated scenarios for the purpose of demonstrating that a complex system possesses a set of quality characteristics (Balci and Ormsby, 2007).

A *live trial* is conducted in real time in a synthetic environment consisting of simulation models, real hardware and software systems, and humans under simulated scenarios for objectives such as interoperability assessment, or technology (readiness) assessment.

Hardware-in-the-*loop M&S* can be viewed as simulation-based hardware evaluation. A hardware system can be operated under simulated input conditions for the purpose of evaluating how well the hardware functions under such input conditions. For example, a space vehicle can be operated under simulated input conditions for the purpose of evaluating the vehicle's autopilot mode. Hardware-in-the-loop M&S is a cost-effective method for evaluating complex, mission-critical hardware before it is used in the real world.

Human-in-the-loop M&S is also called simulation-based training. A simulation model of a system, for example, airplane, air traffic control center, emergency management plan, or military operation is developed for the purpose of training people. Trainees interact with the visual simulation model for the purpose of learning, for example, how to fly an airplane (using the flight simulator), how to control air traffic at an airport, how to manage an emergency in response to a disaster, or how to make military decisions. Human-in-the-loop M&S can also be used as a cost-effective method for evaluating human performance and behaviour for a proposed system design.

Software-in-the-loop M&S can be viewed as simulation-based software evaluation. A software system can be executed under simulated input conditions for the purpose of evaluating how well the software system functions under such input conditions. For example, the software used to display the common operating picture in a combat operation on a handheld computer can be executed under simulated input data (eg, video, voice, images, text) received from many different sources. This approach enables an evaluation of how well the software satisfies its requirements. Software-in-the-loop M&S is a cost-effective method for evaluating a complex, mission-critical software system before it is used in the real world.

3. Reusability levels in M&S application development

Reusability is the degree to which an artifact, method, or strategy is capable of being used again or repeatedly. For M&S application development, the artifact, method, or strategy can be (a) a simulation program subroutine, function, or class, (b) a simulation programming conceptual framework, (c) a simulation model/software design pattern, (d) a simulation model component or submodel, (e) an entire simulation model, or (f) conceptual constructs for simulation in a particular problem domain.

Figure 1 depicts how well reusability can be achieved at different levels of M&S application development.

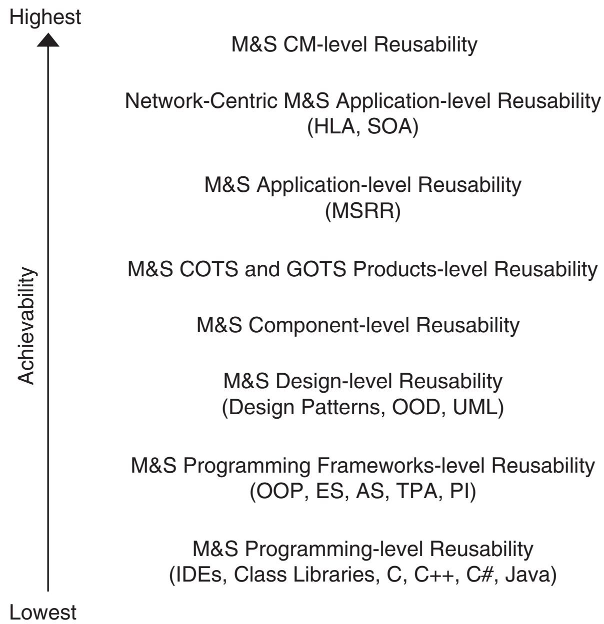

Figure 1 Levels of reusability *versus* achievability.

At the programming level, classes [under the object-oriented paradigm (OOP)] and subroutines/functions [under the procedural paradigm (PP)] are extracted from a library using an Integrated Development Environment (IDE) such as Microsoft Visual Studio. However, reuse at this level is extremely difficult due to the many options in programming languages (eg, C, Fortran, C++, Java), differences in operating systems (eg, Unix, Windows), and variations among hardware platforms (eg, Intel, Sparc) supporting language translators. An artifact programmed in Fortran and executing under the Solaris Unix operating system on a Sun Sparc workstation cannot be easily reused in an M&S application being developed in C++ under the Windows 7 operating system on an Intel-based workstation.

M&S programming frameworks are categorized under the OOP and procedural paradigm (PP). Balci (1988) describes four conceptual frameworks under PP for simulation programming in a high-level programming language: ES, activity scanning (AS), three-phase approach (TPA), and process interaction (PI). A simulation programmer is guided by one of these frameworks by reusing the concepts underlying that conceptual framework. However, an artifact programmed under one framework cannot be easily reused under another.

Reuse at the design level is feasible if the same design paradigm is employed for both the M&S application development and the reusable artifacts or work products. The reuse is also affected by the design patterns employed. For example, an M&S application being designed under the object-oriented design (OOD) approach can reuse work products created under the OOP. Unified Modelling Language (UML) diagrams are provided as an international standard to describe an OOD. UML diagrams assist an M&S designer in understanding and reusing an existing OOD.

However, reuse at the design level is still difficult since it requires the reuse of the same design paradigm. For example, a continuous simulation model consists of differential equations, and does not integrate well with OOP components. Monte Carlo simulation is based on statistical random sampling. A system dynamics simulation model represents cause-and-effect relationships in terms of causal-loop diagrams, flow diagrams with levels and rates, and equations. An agent-based simulation model represents agents and their interactions. An agent is 'intelligent', adaptive, autonomous, goal/self-directed, has the ability to learn, and can change its behaviours based on experience. Different types of simulation models are designed under different paradigms, and one paradigm cannot be easily accommodated within another. Yilmaz and Ören (2004) present a CM for reusable simulations under the conceptual framework of a model–simulator–experimental frame.

M&S component level reuse is intended to enable the assembly (composition) of a simulation model by way of employing already developed model components in a similar fashion as an automobile is assembled from previously produced parts. A component may correspond to a submodel or a model module. Reuse at this higher level of granularity is beneficial because it reduces development time and cost over that of reuse at the class or function level. However, this approach to reuse still poses difficulties since each reusable component can be implemented in a different programming language intended to run under a particular operating system on a specific hardware platform.

M&S Commercial Off-The-Shelf (COTS) (eg, Arena, AutoMod, and OpNet) and Government Off-The-Shelf (GOTS) products enable reuse of components within their IDEs. Such an IDE provides a library of reusable model components. A user can click, drag, and drop an already developed component from the library and reuse it in building a simulation model. However, such reuse is specific only to that particular COTS or GOTS IDE, and portability to another IDE would become a user responsibility.

Reuse at the application level is feasible if the intended uses (objectives) of the reusable M&S application match the intended uses of the M&S application under development. For example, the Department of Defense (DoD) provides a Modelling and Simulation Resource Repository (DoD, 2008) containing previously developed M&S applications. Some of these applications are independently certified for a set of intended uses. Some are not well documented and come in binary executable form only. Even if the source code is provided, understanding the code sufficiently to modify the represented complex behaviour is extremely challenging. Reusability of earlier developed M&S applications is dependent on run-time environment compatibility and the match between intended uses.

A network-centric M&S application describes the case in which the M&S components interoperate with each other over a network (eg, Internet, virtual private network, wireless network). Such an application consists of a federation of simulation models or model components interconnected over a network typically for the purpose of training geographically dispersed persons or groups.

HLA is a DoD, IEEE, and NATO standard for developing a network-centric M&S application by way of reuse of simulation models distributed over a network (IEEE, 2000). HLA enables the interoperability of a federation of simulation models running on different nodes of a network. If a simulation model is built in compliance with the HLA standard, then that model can be reused by other models interconnected through the HLA protocol over a network.

Service-Oriented Architecture (SOA) is yet another architecture based on the industry standard web services and the eXtensible Markup Language (XML). SOA can be employed for developing a network-centric M&S application by way of reuse of simulation models, submodels, components, and services over a network. For example, Sabah and Balci (2005) provide a web service for random variate generation (RVG) from 27 probability distributions with general statistics, scatter plot, and histogram of the requested random variates. The RVG web service can be called from any M&S application that runs on a server computer over a network using XML as the vehicle for interoperability. Reuse, composability, and interoperability are fully achieved regardless of the programming language, operating system, or hardware platform. However, this type of reuse is possible only for network-centric or web-based M&S application development.

We propose the use of a CM for the purpose of achieving R&C for the design of a large-scale complex M&S application in a COI. Examining the achievability scale presented in Figure 1, a CM created for a COI would provide the best R&C as will be explained later.

4. Composability levels in M&S application development

Composability is the degree to which an artifact is capable of being constituted by combining things, parts, or elements. Many COIs such as, air traffic control, automobile manufacturing, ballistic missile defense, ERM, homeland security, and supply chain management require composition of disparate capabilities. Modelling those compositions and simulating the capability interactions prior to employment is both efficient and risk averse. For M&S application development, the artifact can be (a) simulation model component or submodel, (b) simulation model design, (c) M&S application architecture, or (d) entire simulation model.

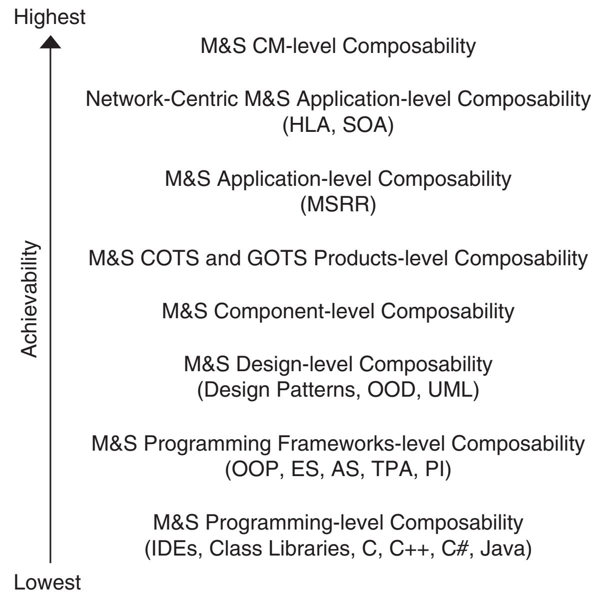

Figure 2 Levels of composability *versus* achievability.

Figure 2 depicts how well composability can be achieved at different levels of M&S application development.

At the programming and programming frameworks level, composing simulation code with existing ones is very much dependent on the programming language, programming paradigm (eg, OOP, PP), programming framework (eg, ES, AS, TPA, PI), and IDE. Composability cannot be meaningfully achieved at these levels.

Composing a simulation model design by way of assembling it with existing designs is feasible if the same design paradigm is employed. For example, the UML diagrams created to represent the design of a simulation model part can be assembled with the other UML diagrams created to represent other parts of the design. However, such assembly must ensure that the intended uses of all model parts match with each other and that the composition is semantically meaningful. Composability at the design level is infeasible when dealing with different types of M&S.

Component-level composability is the one commonly referred to as simulation composability. Bartholet *et al* (2004) advocate that simulation composability and component-based software development fundamentally share the same concepts and challenges. Page and Opper (1999) describe some risks associated with building simulation models by composition. Davis and Anderson (2003) identify the following factors contributing to the difficulty of simulation composition: (a) the complexity of the system being modelled, (b) the difficulty of the objective and the context in which the composite simulation will be used, (c) the strength of underlying science and technology, including standards, and (d) quality of human considerations such as the quality of management, having a common COI, and the skill and knowledge of the work force.

Component-based development of a shrink-wrapped or stand-alone M&S application is known to be an unsolved problem due the following reasons:

1. Components that need to be assembled with each other are coded in different programming languages intended to run under different operating systems on different hardware platforms.
2. The level of granularity and fidelity (degree of representativeness) provided in a component is not compatible when assembled with other components having different levels of granularity and fidelity.
3. A component sold only in binary form with no source code and documentation creates uncertainties when conducting verification and validation.
4. The intended uses of a component do not match the intended uses of the other components when the components are assembled together.
5. A component providing much more functionality than needed degrades the execution efficiency.

M&S COTS (eg, Arena, AutoMod, and OpNet) and GOTS products enable component-based model development within their IDEs. Such an IDE provides a library of reusable model components. A user can click, drag, and drop an already developed component from the library and reuse it in assembling a simulation model. However, such assembly (composition) is specific only to that particular COTS or GOTS IDE, and composition is generally infeasible with model components created in other IDEs for shrink-wrapped or stand-alone M&S application development.

DoD provides an M&S Resource Repository (DoD, 2008) containing previously developed M&S applications. Composing a larger shrink-wrapped or stand-alone M&S application by way of assembling already developed ones poses significant problems, including mismatch of intended uses (objectives) under which the M&S applications are created, interoperability issues, unavailable source code, lack of documentation, run-time execution environment incompatibilities, unavailable or unaffordable hardware, and lack of technical support.

Component-based network-centric software development is considered to be a solved problem based on the use of SOA, web services, and XML as the glue for interoperability. In this case, a simulation component can run as a web service on a server computer somewhere on the network (eg, Internet, virtual private network, wireless network) either as a service provider or consumer or both. Thus, an M&S application can be composed by way of assembling and orchestration of many simulation model components distributed over a network. Each component executes in its own programming language, operating system, and hardware platform and therefore, can be engineered independently of the other components. However, this type of composition is possible only for network-centric or web-based M&S application development.

The DoD Architecture Framework (DoDAF) (DoDAF, 2009a, b) is commonly used for describing the architecture of a network-centric system of systems. DoDAF can also be used for describing the architecture of a network-centric M&S application. Such M&S architecture can be composed by way of assembling DoDAF representations created for other M&S applications. Using the idea of composition, we can also create composite architectures by using existing ones. For example, a composite architecture combining the Client-Server Architecture and the Common Object Request Broker Architecture was used for the development of Battlespace Environment and Signatures Toolkit (NRL, 2004), which is an IDE for development and execution of missile signature simulation models.

5. The role of a CM in R&C

A simulation CM is a repository of high-level conceptual constructs and knowledge specified in a variety of communicative forms (eg, animation, audio, chart, diagram, drawing, equation, graph, image, text, and video) intended to assist in the design of any type of large-scale complex M&S application. The targeted ‘re-users’ can include M&S application designers, M&S project managers, and M&S analysts.

Many different types of M&S applications exist as described in Section 2. They are commonly employed in a COI such as air traffic control, automobile manufacturing, ballistic missile defense, business process reengineering, ERM, homeland security, military training, network-centric operations and warfare, supply chain management, telecommunications, and transportation. R&C are critically needed to facilitate the design of any type of large-scale complex M&S application in a particular COI.

We propose the development of a CM by following the life cycle presented by Balci and Ormsby (2007) to enable R&C independently of the M&S application type, M&S application design strategy, and M&S application implementation (programming) platform. The proposed CM should be built as a repository containing high-level conceptual constructs and knowledge for a particular COI (problem domain) at the highest level of abstraction as depicted in Figures 1 and 2.

We advocate that the highest degree of R&C can be achieved by providing COI (problem domain)-specific conceptual constructs and knowledge at the highest level of abstraction in a CM. The conceptual constructs and knowledge provided in a CM can assist the designer of any type of M&S application for R&C in the COI. Such a CM provides many roles and benefits including (Balci and Ormsby, 2007):

1. assist in designing not just one M&S application but many in a particular COI (problem domain),

2. assist in designing any type of M&S application,
3. assist in achieving reusability at the highest level (Figure 1),
4. assist in achieving composability at the highest level (Figure 2),
5. enable effective communication among the people involved in a large-scale M&S project such as stakeholders, potential users, managers, analysts, and M&S developers,
6. assist in overcoming the complexity of designing large-scale complex M&S applications in a COI,
7. provide a multimedia knowledge base covering the areas of expertise needed for designing large-scale complex M&S applications in a COI,
8. help a subject matter expert (SME) involved in an M&S project to understand another SME's work,
9. facilitate the collaboration among the SMEs for designing a large-scale complex M&S application in a COI,
10. assist in verification, validation, and certification (VV&C) of the M&S application,
11. support effective and efficient VV&C of the M&S application,
12. assist in the specifications of test designs, test cases, and test procedures for the M&S application,
13. assist in proper formulation of M&S application intended uses (objectives),
14. assist in the generation of new M&S requirements, and
15. provide significant economic benefits through repeated use of the CM.

The conceptual constructs and knowledge provided in a CM for a COI can be reused and composed with each other to create larger conceptual constructs and knowledge sets to assist in the design of a simulation model. The CM provides a framework that is much closer to the level of thinking of the simulation model designer. Because the conceptual constructs and knowledge elements are independent of any M&S application type, design strategy, or execution requirements, they can be reused and composed at the highest possible level of abstraction than is possible at lower levels of abstraction as depicted in Figures 1 and 2.

6. CM-based M&S application design

Following the life cycle presented by Balci and Ormsby (2007), a CM can be developed to provide the roles and benefits stated in Section 5. These benefits are realized within a particular COI. To illustrate the envisioned approach to achieving R&C with a CM, we employ a use case or a suitably complex example: the COI called ERM.

Disasters are typically categorized as man-made and natural. Man-made disasters include biological, critical infrastructure (eg, bridge, building, power plant, depot) destruction, chemical, fires, and nuclear disasters, created accidentally or intentionally (terrorist activities). Natural disasters include earthquakes, epidemics, floods, hurricanes, tornadoes, and tsunamis.

Based on the US National Response Plan (HLS, 2004), states and cities in the United States are expected to have an ERM plan. Under a given ERM plan, first responders, decision makers, authorities involved, and citizens are expected to be trained.

M&S is the only effective approach for assessing the operational effectiveness of a given ERM plan as well as for training. Anyone can develop a plan; but, the challenge is to make sure that the plan is operationally effective when responding to an incident. Live exercises, for example (VERTEX, 2007), are performed to test a given plan, but such exercises are limited in scope and do not provide the technical assurance required in assessing the operational effectiveness of a plan and performing training under all possible scenarios. Therefore, M&S is most commonly used in the ERM COI for plan assessment and training.

For example, US Joint Forces Command (USJFCOM, 2008) leads the Noble Resolve experimentation campaign plan to enhance homeland defense and improve military support to civil authorities in advance of and following natural and man-made disasters. The Noble Resolve is mostly an M&S-based experimentation.

To achieve the maximum potential for R&C, the CM should promote reapplication of ERM conceptual constructs and knowledge in the design of any type of M&S application for two purposes: (a) operational effectiveness assessment of the ERM plan, and (b) simulation-based training of the people based on the ERM plan. Since R&C potential extends to hundreds of cities and states, there exist hundreds of ERM plans, requiring the development of hundreds of M&S applications for the above purposes. If a CM were made available for this COI, designers of hundreds of M&S applications would realize the benefits stated in Section 5 and 're-inventing the wheel again and again' would be prevented resulting in significant economic gains.

COI problem domain SMEs should be employed in specifying the content of the CM as depicted in Figure 3.

Problem domain-specific authoritative expertise should be used in specifying the CM's conceptual constructs and knowledge. For example, in the ERM COI, SMEs can specify:

1. how best to equip a hazardous materials response team depending on the type of incident,
2. most effective strategies for evacuating an area in response to a particular disaster,
3. most effective strategies for search and rescue operations in a particular incident,
4. existing and emerging technologies (eg, sensors, surveillance cameras, unmanned vehicles, wireless devices) that

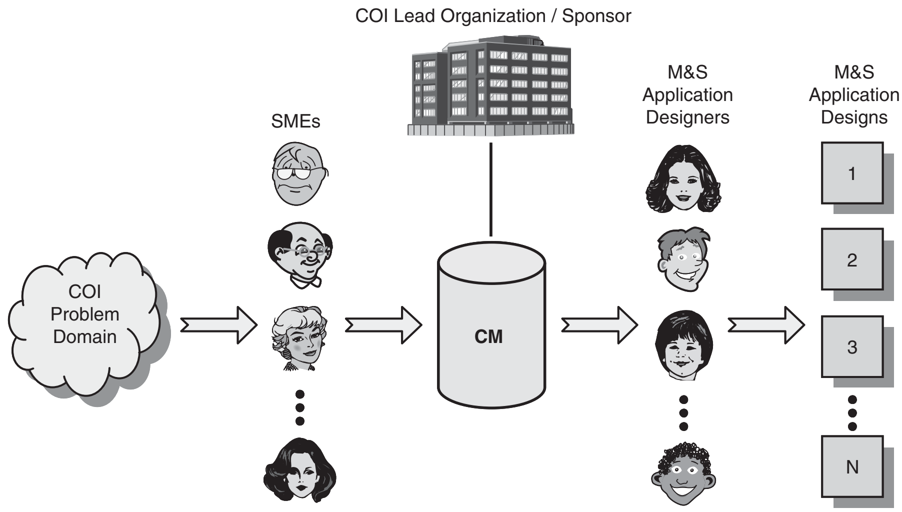

Figure 3 Creation and use of a CM in a COI.

can be employed for responding to a particular emergency incident,
5. most up-to-date knowledge about possible man-made disasters such as chemical or biological,
6. most effective responses to a particular disaster based on past experience,
7. best practices for accomplishing interoperability among the emergency response authorities who have jurisdiction over different geographical areas,
8. how to quickly establish an Internet protocol-based wireless communication among the first responders, decision makers, and citizens, when the existing communication systems go down as a result of a disaster,
9. case studies on past disasters documenting lessons learned, and
10. concepts of emergency response operations.

The conceptual constructs and knowledge specified by SMEs in the CM can be reused and composed by M&S application designers in the design of many M&S applications of many types as depicted in Figure 3.

We propose that the lead organization in the COI sponsors the development and maintenance of the CM and makes it available for use by all M&S application developers in that COI. Example lead organizations include Federal Emergency Management Agency in the ERM COI, Missile Defense Agency in the ballistic missile defense COI, National Institute of Standards and Technology in the manufacturing systems COI, US Department of Transportation in the transportation COI, Federal Aviation Administration in the air traffic control COI, and US DOD in the simulation-based training COI.

The CM should be a live resource continuously updated to reflect the most up-to-date authoritative expertise and should be provided over the Internet for easy access by geographically dispersed M&S application designers in the COI for which the CM serves. The CM should be developed as a multimedia repository to enable effective utilization of its content.

Another option is to provide the CM as a wiki. A wiki is a collaborative website designed to enable anyone who has access rights to contribute or modify the website's content. A wiki type of CM would open up the CM content for contribution or modification by all those people who consider themselves to be SMEs in that COI. Although the acquisition of knowledge is greatly facilitated with a wiki, the quality control becomes a serious challenge. If the lead organization/sponsor of the CM controls who can contribute or modify the CM content and establishes some kind of peer review, then a wiki type of CM might become feasible.

7. Conclusions

The stated objective of this paper is to extend the Balci–Ormsby approach (Balci and Ormsby, 2007) to achieving R&C, noting the potential benefits and increased effectiveness derived in large-scale complex M&S application design and development. This objective is realized in specific terms through:

- advancement of the concept of R&C with a CM in large-scale complex M&S application development within a COI, following the Balci–Ormsby approach,
- identification of the difficulties inherent in R&C within M&S applications, considering the multiplicity in types and the levels of modelling granularity,
- explanation of the significant challenges of R&C at the differing levels of model abstraction, and
- description of an application of the Balci–Ormsby approach to achieving R&C with a CM in the ERM COI.

A lead organization is strongly encouraged to fund the development and continuous update of a CM within its COI to achieve R&C by M&S application designers in that COI. Return on investment shall be realized by preventing 'reinventing the wheel again and again'. Economic benefits shall be gained by all COI companies and organizations in developing complex M&S applications. A CM should be a 'live' repository continuously updated to reflect up-to-date knowledge. CM content quality should be assured and the wiki approach with no peer review should be avoided. CM content should be generically applicable for any type of M&S application under any design strategy to assure its wider applicability. The content should be useful not only for M&S application designers, but also for managers, analysts, and stakeholders.

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