M&S JOURNAL

A DOD MODELING & SIMULATION COORDINATION OFFICE PUBLICATION | FALL 2013

The Reuse Issue

FROM THE EXECUTIVE EDITOR

REUSE: we are all familiar with this concept. Whether from wearing hand-me-downs in early childhood, participating in recycling programs, or purchasing products made from repurposed materials, we have all experienced the value of using things over again. Models and simulations also benefit from the reuse of items created by others. In the computer world, the concept of reuse can be traced back to the 1950s when programmers built libraries of software subroutines that could be reused in multiple projects. As this practice grew, so did the range of software assets considered for reuse: data, architectures, designs, programs, and related modules. Developers created repositories to store these assets and established formal processes to improve their reuse. They then evolved these early practices from just using piece parts to customizing complete systems and produced the equivalent of parts bins supporting a form of virtual mass production. Yet, despite all of these efforts, reuse has fallen short of reaching its full potential. Numerous studies explain the reasons behind disappointingly limited reuse, and the articles in this issue of the *M&S Journal* further illuminate these.

Cost savings and current Department of Defense (DoD) budgets have triggered a renewed emphasis on reuse, and Mr. Brett Telford and Mr. Ric Roca describe some current reuse initiatives in their articles titled "The Reuse Promise: Keeping Fingers Crossed" and "M&S Conceptual Modeling as an Enabler of M&S Reuse, Agile, and Open-Source: A TRS Initiative in Response to the M&S SC Priority Objectives" respectively. The concept of reuse is spreading to an ever-growing number of areas, and to capitalize on the proliferation of available assets, Mr. Hart Rutherford advocates for taking a broad spectrum approach in his article titled "Toward An Enterprise Approach to Managing M&S Investments." A review of the literature on reuse shows that both social and technical issues drive the success of reuse, and Mr. William Riggs discusses the impact of social media on reuse in his article titled "Reflections on Social Media to Facilitate M&S Reuse." Lastly, Mr. Kevin Dill's article, "Introducing GAIA: A Reusable, Extensible Architecture for AI Behavior" presents the development of a modular, extensible architecture for games in the M&S arena.

On a final note, one of the social aspects promoting reuse is awareness. To that end, I hope these articles prove useful in describing both the benefits and difficulty of reuse. I am sure you will find this issue of the *M&S Journal* invaluable and, of course, don't forget to pass it on.

GARY W. ALLEN, PHD
Associate Director for M&S Data
Modeling and Simulation Coordination Office (M&SCO)

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Guest Editorial: Reuse for M&S

Author

Dr. George Akst
Senior Analyst
U.S. Marine Corps Combat Development Command

REUSE IS ALREADY A TOPIC YOU ARE ALL FAMILIAR WITH, EVEN IF YOU DON'T REALIZE IT. HOW MANY TIMES HAVE YOU REUSED A JOKE YOU HEARD, PERHAPS ADDING YOUR OWN TWIST TO SUIT YOUR AUDIENCE? OR, IF YOU ARE IN A POSITION TO GIVE FREQUENT PUBLIC SPEECHES, HOW MUCH HAVE YOU REUSED PREVIOUS SPEECHES, EITHER ESSENTIALLY INTACT OR WITH EXTRACTS FROM RELATED EFFORTS? SOMETIMES, REUSE CAN TAKE ON A DIFFERENT PURPOSE FROM THE ORIGINAL—FOR EXAMPLE, HAVE YOU EVER MADE USE OF AN OLD BLANKET OR SHEET AS A DROP CLOTH FOR PAINTING? OK, YOU GET THE IDEA. SO, WHY DO WE HAVE TO DEVOTE AN ENTIRE ISSUE OF THIS ESTEEMED JOURNAL TO TALKING ABOUT SOMETHING THAT SHOULD BE HUMAN NATURE TO ALL OF US? PERHAPS THE REASON IS THAT, WHILE MOST OF US IN THE BUSINESS THINK THIS IS THE RIGHT DIRECTION TO HEAD, WE ALSO UNDERSTAND THAT FOR A VARIETY OF REASONS IT IS DIFFICULT TO NURTURE AND IMPLEMENT.

The senior Office of the Secretary of Defense (OSD) body chartered with guiding modeling and simulation (M&S) for the Department of Defense (DoD)—the M&S Steering Committee, of which I am a charter member—has been trying to encourage reuse across the M&S communities throughout its existence, with only limited success in my opinion. Not one to give up, we have again chartered a project to examine ways to encourage M&S reuse (see Mr. Telford's article in this issue of the *M&S Journal*: *The Reuse Promise: Keeping Fingers Crossed*). So, why has this been so tough? I'll try to answer that in the remainder of this short editorial, but please keep in mind that these thoughts represent my own viewpoint, and do not necessarily represent the views of the Steering Committee or the Marine Corps.

I think much of the answer lies in the incentive structure that currently exists within DoD, and in particular, within its acquisition system. So, if you want to take advantage of reusing existing M&S products, you must first determine whether there is something out there that is suitable to your needs. However, taking the time and effort to research the plethora of available M&S is often more difficult than simply planning/programming for a new development tailored specifically to your requirements. Nevertheless, even if you find something that appears relevant, understanding the full scope of that M&S and adapting it to meet your specific prerequisites may be difficult and time consuming. Then again, if you are already developing new M&S, acquiring the data rights and intellectual capital underlying that M&S development often requires additional time and resources. Such efforts may not be in your best interests, based on current incentives, which are often used to bring the project within schedule and budget.

So, what's the bottom line? From my perspective, the incentives for reuse are often missing from our business model within DoD. How can we fix this? Well, I again refer you to the newly initiated effort described in the Telford article as one way to figure this out. I have long thought that the solution would involve a series of carrots and sticks, implemented at the highest levels within OSD. Carrots can come in the form of incentives for program managers and other users to make the most reuse out of existing software—M&S in this instance—and when this is not possible, to ensure that M&S developed under their watch has full government rights and documented code so the government can reuse it in the future. Sticks could include stumbling blocks to make it more difficult to develop/use proprietary software. For example, DoD could institute additional requirements at major milestones to identify and justify the use/development of any proprietary software, and to obtain waivers from the highest levels within OSD before being given the go-ahead to proceed with that program.

I do not purport to have solved the problem in the thoughts outlined in the preceding paragraph, nor do I claim to have fully thought through all of the implications of these suggestions and the impacts of implementing such ideas. This is what I hope the Steering Committee-chartered team will begin to examine in their ongoing efforts to improve reuse of M&S throughout DoD. I would also add that the difficulty in succeeding in this effort is highlighted by the number of previous efforts that have failed to achieve substantial success in this endeavor. In this new era of fiscal austerity, it is more important than ever to reduce unnecessary expenditures and make better use of existing M&S. I urge your support in this latest effort—we're going to need it!

Author's Biography

Dr. George Akst

Dr. George Akst is the Senior Analyst for the Marine Corps Combat Development Command (MCCDC), Quantico, VA. In 2004, he was appointed as Senior Analyst upon the recommendation of the Commanding General, MCCDC and the Assistant Commandant of the Marine Corps.

Dr. Akst graduated cum laude from The City College of New York and received his Ph.D. in mathematics from the University of Illinois. He also attended the Program in National and International Security at the Kennedy School at Harvard University, and the Leadership for a Democratic Society program at the Federal Executive Institute in Charlottesville, VA.

He served in the Corps of Engineers in the Army Reserve, and graduated from the Engineer Officer Basic Course at Fort Belvoir. After receiving his Ph.D., Dr. Akst was a professor of mathematics at New Mexico State University and the California State University at San Bernardino.

Following his teaching career, Dr. Akst joined the Center for Naval Analyses (CNA), and entered the career of defense analysis and operations research. During his 19-year tenure, he was a research operations analyst and study director for numerous projects.

He entered the Federal service in 1998, as the Deputy Director of the Studies and Analysis Division, MCCDC. In this position, he managed all studies and analyses performed under the Marine Corps Studies System. He also provided oversight of all Marine Corps analytical modeling and simulation efforts. Recently, Dr. Akst was appointed as the U.S. voting representative to the NATO Systems Analysis and Studies Panel of the Science and Technology Office.

Dr. Akst's decorations include the Meritorious Presidential Rank Award, Navy Superior Public Service Award, USMC Certificate of Commendation, and the CNA Phil E. DePoy Award for Analytical Excellence. He is a member of Phi Beta Kappa, Sigma Xi, and the Military Operations Research Society (MORS). He has a wife, Barbara, and two children.

The Reuse Promise: Keeping Fingers Crossed

Author

Mr. Brett Telford
Director
U.S. Marine Corps M&S Management Office
brett.telford@usmc.mil

Abstract

THIS ARTICLE DISCUSSES HOW THE THEORY OF REUSING MODELS AND SIMULATIONS TO DATE HAS NOT BECOME STANDARD PRACTICE THROUGHOUT DOD. AS A RESULT, THE MODELING AND SIMULATION STEERING COMMITTEE IS SPONSORING AN EFFORT TO DETERMINE WHAT POLICY, STANDARD PRACTICES, AND/OR TOOLS ARE REQUIRED AT A DOD ENTERPRISE LEVEL TO PROMOTE THE EFFICIENT SHARING, USE, AND REUSE OF M&S TOOLS, DATA, AND SERVICES. THE TEAM—LED BY DOD ACQUISITION, TECHNOLOGY, AND LOGISTICS (AT&L) AND UNITED STATES MARINE CORPS (USMC) REPRESENTATIVES—WILL RESEARCH PREVIOUS, SIMILAR ATTEMPTS. THE IDEA IS TO PREVENT REPEATING PAST FAILURES AND PUT IN PLACE EFFORTS THAT ENABLE EFFECTIVE REUSE TO OCCUR WHEN IT MAKES PROGRAMMATIC SENSE.

Reuse of modeling and simulation (M&S) assets is the Valhalla of DoD M&S management and a critical part of the DoD M&S Steering Committee's (SC) efforts for FY13-15. While the SC's role in supporting M&S reuse is still evolving, it is accepted that reuse will save time and money in development. Reuse could also help DoD in other ways. For example, the more widely tools and models are used, the more likely the users of those models and tools will develop best practices. Admittedly, much of reuse's virtue is currently theoretical, and as Baseball Hall-of-Famer Yogi Berra once remarked, "In theory, there is no difference between theory and practice. In practice, there is."

The theory of M&S reuse can pull any potential advocate in multiple directions, all of which can be complex. As an entity primarily concerned with making policy, the M&S SC recognizes that it must scope its effort so the focus is on areas where it can actually make a difference. The M&S SC has delegated this task to the Acquisition Community (Ms. Kristen Baldwin of the Office of the Secretary of Defense (OSD) AT&L) and the Marine Corps (Dr. George Akst of Marine Corps Combat Development Command). As a first step, Ms. Baldwin and Dr. Akst have narrowed the initial reuse effort to develop policy, standard practices, and/or tools at a DoD Enterprise level and to promote the efficient sharing, use, and reuse of M&S tools, data, and services. Current plans are to have two primary thrust areas that include:

1. Investigating and detailing the issues and gaps preventing the DoD's ability to reuse models, simulations, and data;
2. Delivering an appropriate set of policies, incentives, practices, and tools (or some combination) that result in meeting the objective.

As the Reuse Team forms, Ms. Baldwin and Dr. Akst have committed support from other M&S SC members to include Training, Analysis, Intelligence, Joint (J8), National Guard Bureau, Navy, Air Force, and Army. Additionally, the DoD M&S Coordination Office (M&SCO) will provide both technical and administrative support.

This will be a big job. Even with the narrowing of the focus to policies, practices, and tools to be used at a DoD M&S Enterprise level, the work will take multiple years. The Reuse Team used the balance of FY13 to scan the horizon of work already done in the area of reuse to

prevent *re-inventing the wheel* and to begin the process of *harvesting* work that has already been done. The team will deliver an implementation plan of action the M&S SC can take to enable reuse across the DoD M&S Enterprise.

Harvesting work quickly leads one to learn that the concept of reusing software in general, and M&S products in specific, is not new. An initial audit of existing studies, papers, and other artifacts finds documentation going back as far as the 1980s. These materials highlight somewhat familiar ideas on how DoD could promote the reuse of M&S. While not specific to M&S, DoD's failed venture into development of a common programming language—Ada—can be seen as an attempt to reduce software developmental cost and schedule through reuse of developed code. The concept surrounding the development of Joint Modeling and Simulation System (JMASS), Joint Warfare System (JWARS), and Joint Simulation System (JSIMS) centered on developing common models that could support users across the acquisition, analysis, and training communities. The idea of delivering reusable models and simulations remains enticing, but elusive, as these efforts failed to deliver.

So why has developing processes or incentives that promote the procurement of reusable models and simulations been so difficult for DoD? The paper [1] identifies some of the reasons. First and foremost, diverse users will have diverse requirements for their models and simulations. Reasons include differing needs (requirements) of a model or simulation, such as execution speed, fidelity of the model, or the need for dramatically different visual/auditory representations. As a result, the authors state, "models used for the simulations of the same physical object would likely be quite different in different communities." The authors go on to state that as hardware performance continues to increase and its costs continue to decrease, the economics may make direct reuse of existing models and simulations impractical as users will perceive them as being "insufficient" to meet tomorrow's requirements.

As a result, it is unlikely that direct reuse of models and simulations will occur across user communities. However, that does not mean sharing and reuse on some level cannot, or should not, occur. For example, as the smallest Service with a limited Research Development Test & Evaluation (RDT&E) budget, the Marine Corps seeks opportunities to reduce the development costs associated with new systems, or for the sake of this discussion, M&S applications. The Marine Corps scans the horizon to see where investments have been made by the other Services that may provide opportunities for reuse. The analytical simulation Combat XXI is a good example. Jointly created with the Army, it has been used by the Marine Corps on a fairly consistent basis to support several studies. In addition, over the last few years the Marine Corps has been adding functionality to the Air Force's Synthetic Theater Operations Research Model (STORM) to reflect accurate Marine Corps amphibious capabilities. By reusing approximately 95% of the existing STORM code the Marine Corps realized dramatic savings in developing accurate representations of amphibious capabilities for strategic level analysis. Finally, the Marine Corps acquisition community is developing the Framework for Assessing Cost and Technology (FACT), which enables the linkage of systems engineering models and cost models. Even though the models were never designed to work together, FACT enables them to deliver greater insight into the impact of various design decisions across a system's life-cycle. Using models in new, previously unimagined ways is also a form of reuse.

The key to all of the above Marine Corps examples of reuse—tools, data, or services—was awareness of what existed and the incentive to reuse it. This is where DoD must be careful about establishing a policy requiring reuse of models and simulations. While it may seem to be as simple as mandating program managers or model users to reuse what is already available, assets and practices must be in place that enable them to discover and understand the capabilities and limitations of what is available. Since 2007, establishment of policies, best practices, standards, and even tools that enable access to knowledge about models and simulations across DoD has been a focus of the M&S SC. Yet, to date, only limited success has been found.

Recognizing that reuse is not an end unto itself, but rather a part of reducing the time and cost to field new capabilities needed by the DoD, the M&S SC has been seeking the right mix of *carrots and sticks* to motivate developers and users to consider reuse before developing something new. In 2009, the M&S SC funded a Center for Naval Analyses (CNA) study on business models for M&S reuse [2]. This study identified six barriers to reuse, as well as

recommendations for surmounting those barriers. In 2011, the M&S SC funded another CNA study on contracting for M&S [3]. This study demonstrated that DoD has the tools in place to write contracts that enable M&S reuse. It is likely that these two studies will be pillars of the M&S Reuse Team's effort to develop incentives that promote M&S reuse.

The timing for this effort is fortuitous as DoD implements its Better Buying Power (BBP) 2.0 efforts. The concepts surrounding the virtue of M&S reuse align with the objectives of BBP, particularly in enabling affordability and promoting effective competition. As perhaps the biggest user of M&S, the acquisition community must be involved because it is in a unique position to influence program managers, systems engineers, and contracting officers who use M&S across DoD. The Reuse Team will work closely with members of the DoD BBP team to ensure that efforts to promote reuse of M&S align with policy, best practices, or other guidance issued by AT&L.

Reuse of M&S offers opportunities to reduce the cost and time to field needed capabilities. However, reuse just for the sake of reuse will not result in savings. The Reuse Team will learn from previous studies and efforts to develop a way ahead that promotes effective reuse of models and simulations when it makes programmatic sense. The Reuse Team will identify what combination of carrots and sticks can be put in place to incentivize M&S users and developers to look towards reuse first, and the best practices and tools needed to make this happen. If successful, DoD can align reuse theory with practice. Otherwise, quoting Yogi Berra, "It's deja vu all over again."

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Author's Biography

Mr. Brett Telford

Mr. Brett Telford is the Director of the Marine Corps M&S Management Office. He began working for the Marine Corps in 2007 following a 20 year career in the United States Air Force (USAF). In this capacity, Mr. Telford acts as the Marine Corps point of contact for the development of Joint and Service level M&S policy. In addition, he leads a Marine Corps M&S Integrated Process Team (IPT) that seeks to leverage activities across the fleet and improve the use of M&S throughout the Marine Corps.

Mr. Telford entered military service in 1987 upon graduation from the USAF Academy. During his career he served in a variety of operational and program management positions ranging in scope from supporting wing level operations to the development of Air Staff budget submissions. As a certified Acquisition Professional Development Program (APDP) Level III Program Manager he led the development and fielding of classified aircrew trainers, constructive battlestaff simulations, and engineering level models.

Toward an Enterprise Approach to Managing M&S Investments

Author

Mr. Hart Rutherford
SimVentions, Inc.
HRutherford@SimVentions.com

Abstract

MODELING AND SIMULATION (M&S) STAKEHOLDERS URGENTLY REQUIRE NEW APPROACHES TO BETTER MANAGE THEIR M&S INVESTMENTS. WITH DEPARTMENT OF DEFENSE (DOD) BUDGETS PROJECTED TO BE AUSTERE, SENIOR LEADERS ARE ADVOCATING GREATER RELIANCE ON M&S TO HELP OFFSET OTHER ASPECTS OF SYSTEM ACQUISITION THAT ARE HISTORICALLY MORE COSTLY. A CRITICAL ELEMENT TO ACHIEVING SUCCESS IS EFFECTIVE USE OF M&S METADATA. METADATA IS DESCRIPTIVE INFORMATION ABOUT THE MEANING OF OTHER DATA. THIS IS A WELL-ESTABLISHED CONCEPT BUT ITS PRACTICAL USEFULNESS HAS BEEN SOMETIMES LIMITED IN THE PAST BECAUSE OF INADEQUATE TOOLS AND STANDARDS. HOWEVER, RECENT IMPROVEMENTS IN THESE AREAS, ALONG WITH A NEWLY REINVIGORATED AND ACTIVE M&S COMMUNITY OF INTEREST, PROVIDE A PLATFORM FOR IMPROVED COLLABORATION AND UNDERSTANDING OF M&S INVESTMENTS AND MORE FREQUENT REUSE OF EXISTING M&S RESOURCES. THE USAGE OF METADATA NEEDS TO MOVE FROM A TIME-CONSUMING, ANCILLARY ACTIVITY TO THE ROLE OF A KEY ENABLING CAPABILITY FOR M&S RESOURCE MANAGEMENT AND REUSE.

INTRODUCTION

Despite a tremendous amount of investment by the Department of Defense (DoD) in the development of models, simulations, and supporting data assets, relatively little information is assembled about the actual *inventory* of Modeling and Simulation (M&S) resources. In a vital coordination role, DoD M&S leadership strongly encourages discovery and reuse of these assets. Metadata and metadata support tools are key enablers.

The primary motive is to promote the availability of existing assets to provide practitioners the opportunity to evaluate resources for prospective reuse. The underlying goal is to improve and accelerate engineering results while lowering acquisition costs. A panel of experienced practitioners voiced the following concerns in a recent study of M&S asset reuse:

> The reuse of software, data, and other assets in DoD M&S development is neither as frequent nor as effective as it could be, and as a consequence, the potential benefits of reuse to the DoD enterprise are not being fully realized. Improvements in the enterprise culture and processes supporting reuse are needed to increase the frequency of reuse… Enhancements to the capabilities and coordination of DoD M&S asset repositories are needed to increase the effectiveness of reuse [1].

A key objective is to develop and sustain enterprise-level tools, data, and services to improve discovery and management of M&S assets within DoD.

Stakeholders gain enormous benefits from improved management and analysis of M&S investments not only through more efficient discovery and reuse of M&S resources,

but also through improved collaboration within the M&S Community of Interest (COI) and between other COIs. The linchpin for achieving this vision is a framework that positions resources in the context of the acquisition enterprise. Ultimately, the goal is to increase the return on investment of M&S assets through improved interoperability and reuse.

DOD M&S POLICY AND GUIDANCE

Several key DoD policy documents describe high-level goals for the M&S COI, and help shape our activities utilizing metadata, metadata catalogs, asset repositories, and other similar mechanisms. A brief survey of these directives and guidelines provides the context for how M&S investments should be managed.

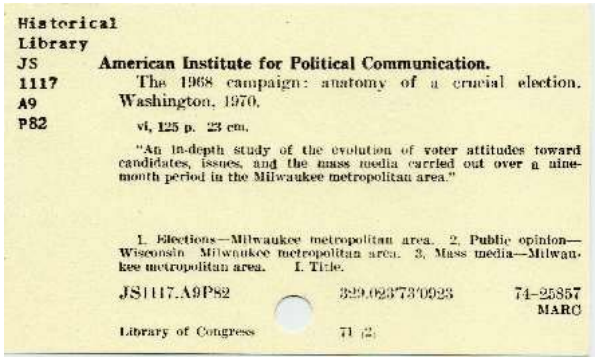
DoD Directive 5134.01 defines the roles and responsibilities for the Under Secretary of Defense for Acquisition, Technology, and Logistics (USD (AT&L)). This directive states, "USD (AT&L) shall establish and maintain the DoD management and administrative structure for M&S...develop policies, plans, and programs to coordinate, harmonize, and rationalize DoD M&S...and ensure that DoD M&S investments support operational needs and the acquisition process [2]."

DoD Directive 5000.59 DoD M&S Management states that the M&S Steering Committee shall "Advise and assist the USD (AT&L)" and that "M&S tools, data, and services shall be visible and accessible [3]."Finally, DoD Instruction 5000.70 Management of DoD M&S Activities "Establishes the Director, DoD Modeling and Simulation Coordination Office (M&SCO) as the focal point for coordinating all matters related to DoD M&S [4]."

The M&S COI plays a pivotal role and serves as a vital linkage across a very diverse set of practitioners: Joint and Service warfighting centers, non-DoD departments and laboratories, industry, U.S. Allies and coalition partners, academia, and professional associations.

WHAT IS METADATA?

The first step to effectively managing M&S assets is to describe them with properly constructed and semantically-rich metadata. Metadata are descriptive information about the meaning of other data. The simplest analogy to illustrate the concept of metadata is a card in an old-fashioned library card catalog as illustrated in figure 1.


Historical
Library
JS
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A9
P82

American Institute for Political Communication.
The 1968 campaign: anatomy of a crucial election. Washington, 1970.
vi, 125 p. 23 cm.
"An in-depth study of the evolution of voter attitudes toward candidates, issues, and the mass media carried out over a nine-month period in the Milwaukee metropolitan area."
1. Elections—Milwaukee metropolitan area. 2. Public opinion—Wisconsin Milwaukee metropolitan area. 3. Mass media—Milwaukee metropolitan area. I. Title.
JS1117.A9P82 329.023'730923 74-25857
MARC
Library of Congress 71 (2)

Figure 1: A Card From a Card Catalog

Information displayed on the card helps the library patron quickly and easily understand the content of the book. The patron bases much of their decision to check out the book based on reading this metadata on the card. The information found on every card in the library's catalog (as well as libraries universally) is structured identically and contains the same elements of information, both online or formerly in hardcopy. Similarly, Google® search results offer helpful information on the topic being queried but are, in comparison to the card catalog example, much more unstructured.

People generate and interact with metadata routinely but simply do not think of metadata in that way. Amazon.com® presents books and other products, for example, in a highly-structured format to help a potential buyer make a decision. This information is the metadata. Previous purchasers often post their comments and opinions about the book or other product on the same webpage. All of this information about the book and comments from others is metadata. The M&S COI closely follows this same pattern of presenting metadata and user feedback.

Discovery metadata are information about M&S assets (e.g., resources, contacts, and taxonomies). Discovery metadata are stored in catalogs. Structural metadata differs from discovery metadata in that they concern the rules governing metadata structure and format, such as schemas and transforms. Registries, such as the DoD Metadata Registry (MDR) in the Defense Information Systems Agency (DISA) Data Services Environment (DSE), store structural metadata.

Repositories contain the actual assets being described by metadata. Figure 2 summarizes the three main types of M&S information and where they reside.

Discovery metadata → catalogs
Structural metadata → registries
M&S assets → repositories

Figure 2: Where M&S Data Reside

Metadata are increasingly being collected automatically. Many cameras and smartphones, for example, collect the geographical position and exact time a photo was taken. This valuable metadata help you to organize your photo collection. Practitioners use M&S metadata to help organize, analyze, and potentially share their assets.

Pedigree of M&S Data

The seminal May 9, 2003, Department of Defense Chief Information Officer Memorandum, "DoD Net-Centric Data Strategy," (NCDS) articulated the first principles of sharing data in a collaborative, yet controlled manner. The Memorandum described general data visibility goals, established and defined the concept of COIs to govern the creation and sharing of data, and introduced the DoD Discovery Metadata Specification (DDMS) as a general metadata standard to exchange metadata across the enterprise.

DoD Directive 8320.02 "Data Sharing in a Net-Centric Department of Defense" provides the principles for data sharing and its companion document, DoD 8320.02-G "Guidance for Implementing Net-Centric Data Sharing," describes specific activities to implement data sharing. The Directive promotes accessibility through this key paragraph:

> Making data visible, accessible, understandable, and promoting trust are the cornerstones of net-centric information sharing. The creation of duplicative data and redundant capabilities often results from consumers' inability to locate, access, understand, or trust that existing data assets meet their needs.

To deconstruct that statement a bit further, discovery metadata make the data visible. Data are accessible in shared spaces in DoD enterprise systems such as government servers and collaboration software. Finally, structural metadata such as schema definition files and validation rules, make data understandable.

Practitioners commonly use the phrase, "label the data" (figure 3) when referring to the process of creating metadata to describe a resource. Metadata are essentially *labels* that describe the data asset in the same way that a soup can uses a label to describe its contents. Trust is built on the foundation of common, approved specifications that provide the structure of the metadata and the meanings of the (virtual) labels. This trust is vital for the interoperable exchange of metadata and the discovery of M&S assets.

Metadata First Principle

**"Label the data.
Trust the labels."**

Figure 3: Metadata First Principle

MODELING & SIMULATION COMMUNITY OF INTEREST DISCOVERY METADATA SPECIFICATION

The Modeling & Simulation Community of Interest Discovery Metadata Specification (MSC-DMS) is the approved metadata specification for M&S practitioners [5]. Since 2008, the MSC-DMS is the metadata specification tailored for the M&S COI that conforms to DDMS. The NCDS encourages community-focused specifications since practitioners frequently have the best understanding of their information resources and the expertise to describe them.

Since its inception, user change requests yielded three general categories of modifications to the MSC-DMS. The first category included requests to increase the specification's functionality. Secondly, periodic updates kept the MSC-DMS in alignment with the DDMS. Lastly, other modifications enabled the M&S metadata specification to reflect changes to the enterprise infrastructure (e.g., changes to metadata catalogs which collect metadata, index them, and make them searchable).

The MSC-DMS's function is to define discovery metadata components for detailing assets posted to shared community and organizational spaces. Discovery is the ability to locate data assets through a consistent and flex-

ible search. The MSC-DMS specifies a set of fields that describe and enhance data or service assets and serves as a reference for developers, architects, and engineers by building upon the foundation for discovery services reflected in the DDMS. Consequently, activities that publish the availability of these assets are urged to use the MSC-DMS so that associated searches will yield consistent discovery of assets including resources, contacts, and taxonomies.

Version 1.5 is the most recent version of the MSC-DMS. This update focuses on conformance with DDMS Version 4.0, which provided an extensive array of security and releasability markup tags. Since the DDMS concentrated on alignment with the Intelligence Community's metadata specifications over the past two years, the MSC-DMS benefited from their work on security tags.

MSC-DMS Version 1.5 features several significant updates. First, a new information element describes the metacard separately from the asset being described. New fields were added to collect information about the metacard to support proper collection in a catalog. This allows, for example, one person to be the *owner* of a model and another to be the *owner* of the metacard describing the model. This is helpful because in many cases, the model owner is typically the senior developer, while the owner of the metacard is the sponsor or someone with acquisition responsibility. The specification thus encourages collaboration between technical and acquisition teams.

A second highlight in Version 1.5 is the ability to associate related resources. For example, it might be useful to link a model with its original requirements document. Additionally, a model might also be linked to its accreditation document. This is an important capability since the decision to potentially reuse a model depends on the artifacts related to that model. A visual representation of these connections is provided in figure 4. This visualization capability is part of the Enterprise Metacard Builder Resource (EMBR) Portal tool described below.

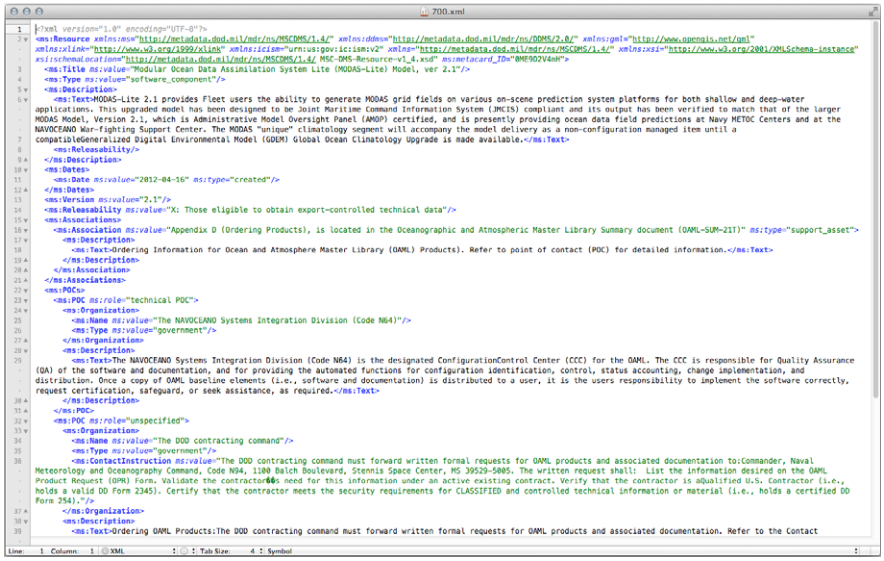
The final key feature of MSC-DMS Version 1.5 is the capability to add user ratings which provide for a qualitative assessment of a resource's usefulness. This feedback takes two forms. First, the specification uses a star rating, allowing users to rate their experience with the tool on a scale of 1 to 5 stars. A rating of 5 stars indicates a highly favorable experience with that M&S resource.

The second feedback mechanism is the ability to provide user comments. This type of feedback provides a data element for the user to contribute narrative comments based on their experience with the resource. Comments are appended to the metacard and provide invaluable information to help practitioners make judgments about the potential suitability of an M&S resource for reuse.

M&S METADATA SUPPORT TOOLS

The MSC-DMS specification is a structure based on the Extensible Markup Language (XML). Over time, however, the complexity of the specification increased beyond the point where users could create properly structured metacards without the aid of support tools.

In response, an effort began in 2010 to develop a tool that would help users create and edit DoD-compliant



```
700.xml
<?xml version="1.0" encoding="UTF-8"?>
<ms:Resource xmlns:ms="http://metadata.dod.mil/mdr/ns/MSCDMS/1.4/" xmlns:ddms="http://metadata.dod.mil/mdr/ns/DDMS/2.0/" xmlns:gml="http://www.opengis.net/gml"
xmlns:xlink="http://www.w3.org/1999/xlink" xmlns:icism="urn:us:gov:ic:ism:v2" xmlns="http://metadata.dod.mil/mdr/ns/MSCDMS/1.4/" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://metadata.dod.mil/mdr/ns/MSCDMS/1.4/ MSC-DMS-Resource-v1_4.xsd" ms:metacard_ID="0MF9D7V4mM">
  <ms:Title ms:value="Modular Ocean Data Assimilation System Lite (MODAS-Lite) Model, ver 2.1"/>
  <ms:Type ms:value="software_component"/>
  <ms:Description>
    <ms:Text>MODAS-Lite 2.1 provides Fleet users the ability to generate MODAS grid fields on various on-scene prediction system platforms for both shallow and deep-water
applications. This upgraded model has been designed to be Joint Maritime Command Information System (JMCIS) compliant and its output has been verified to match that of the larger
MODAS Model, Version 2.1, which is Administrative Model Oversight Panel (AMOP) certified, and is presently providing ocean data field predictions at Navy METOC Centers and at the
NAVOCEANO War-fighting Support Center. The MODAS "unique" climatology segment will accompany the model delivery as a non-configuration managed item until a
compatibleGeneralized Digital Environmental Model (GDEM) Global Ocean Climatology Upgrade is made available.</ms:Text>
    <ms:Releasability/>
  </ms:Description>
  <ms:Dates>
    <ms:Date ms:value="2012-04-16" ms:type="created"/>
  </ms:Dates>
  <ms:Version ms:value="2.1"/>
  <ms:Releasability ms:value="X: Those eligible to obtain export-controlled technical data"/>
  <ms:Associations>
    <ms:Association ms:value="Appendix D (Ordering Products), is located in the Oceanographic and Atmospheric Master Library Summary document (OAML-SUM-21T)" ms:type="support_asset">
      <ms:Description>
        <ms:Text>Ordering Information for Ocean and Atmosphere Master Library (OAML) Products). Refer to point of contact (POC) for detailed information.</ms:Text>
      </ms:Description>
    </ms:Association>
  </ms:Associations>
  <ms:POCs>
    <ms:POC ms:role="technical POC">
      <ms:Organization>
        <ms:Name ms:value="The NAVOCEANO Systems Integration Division (Code N64)"/>
        <ms:Type ms:value="government"/>
      </ms:Organization>
      <ms:Description>
        <ms:Text>The NAVOCEANO Systems Integration Division (Code N64) is the designated ConfigurationControl Center (CCC) for the OAML. The CCC is responsible for Quality Assurance
(QA) of the software and documentation, and for providing the automated functions for configuration identification, control, status accounting, change implementation, and
distribution. Once a copy of OAML baseline elements (i.e., software and documentation) is distributed to a user, it is the users responsibility to implement the software correctly,
request certification, safeguard, or seek assistance, as required.</ms:Text>
      </ms:Description>
    </ms:POC>
    <ms:POC ms:role="unspecified">
      <ms:Organization>
        <ms:Name ms:value="The DOD contracting command"/>
        <ms:Type ms:value="government"/>
        <ms:ContactInstruction ms:value="The DOD contracting command must forward written formal requests for OAML products and associated documentation to:Commander, Naval
Meteorology and Oceanography Command, Code N94, 1100 Balch Boulevard, Stennis Space Center, MS 39529-5005. The written request shall:  List the information desired on the OAML
Product Request (OPR) form. Validate the contractor's need for this information under an active existing contract. Verify that the contractor is a Qualified U.S. Contractor (i.e.,
holds a valid DD Form 2345). Certify that the contractor meets the security requirements for CLASSIFIED and controlled technical information or material (i.e., holds a certified DD
Form 254)."/>
      </ms:Organization>
      <ms:Description>
        <ms:Text>Ordering OAML Products:The DOD contracting command must forward written formal requests for OAML products and associated documentation. Refer to the Contact
```


Figure 4: MSC-DMS Metadata as XML

metacards without having to be an expert in XML or expertise with the MSC-DMS. An initial tool called Metacard Builder was developed through the collaborative efforts of M&SCO, The Johns Hopkins University Applied Physics Laboratory, and SimVentions, Inc. This Java-based, desktop tool provided a simple interface allowing users to type data into text boxes and the tool compiled properly-structured XML metadata. Metacard Builder gave the team sufficient proof that the concept was viable.

EMBR Portal

Further research and development produced the EMBR Portal (figure 5), which is the successor to the Metacard Builder. The EMBR Portal, a tailorable, web-based tool, similarly provides the capability to create, edit, and manage metadata without any experience developing XML or requiring any expertise in the MSC-DMS. Users search and discover M&S resources, and then evaluate them for tailoring or reuse.

The EMBR Portal markedly improves collaboration within the M&S COI. Metacards, for example, can be developed collaboratively, enabling more than one person to contribute information to a shared metacard.

Furthermore, the EMBR Portal has the capability to operate as a local catalog of metadata, storing metacards that can be shared and eventually submitted to the DoD M&S Catalog (figure 7). This capability is essential to sharing of metadata across DoD and offers new opportunities to sharing and leveraging M&S investments.

The EMBR Portal uses a real-time dashboard that displays the inventory of metacards in tabular lists and analytical charts. M&S portfolio managers and Portal users have the ability to visualize the utilization of their assets and how often they are utilized over time using the dashboard. These metrics provide initial data leading to return on investment (ROI) analyses.

M&S practitioners are shown in figure 6 as *resources* that can also be related to models and other assets. We have learned from the experience of M&S developers that the process of discovery and evaluation of assets for potential reuse is heavily influenced by the availability and knowledge of the people who currently operate a

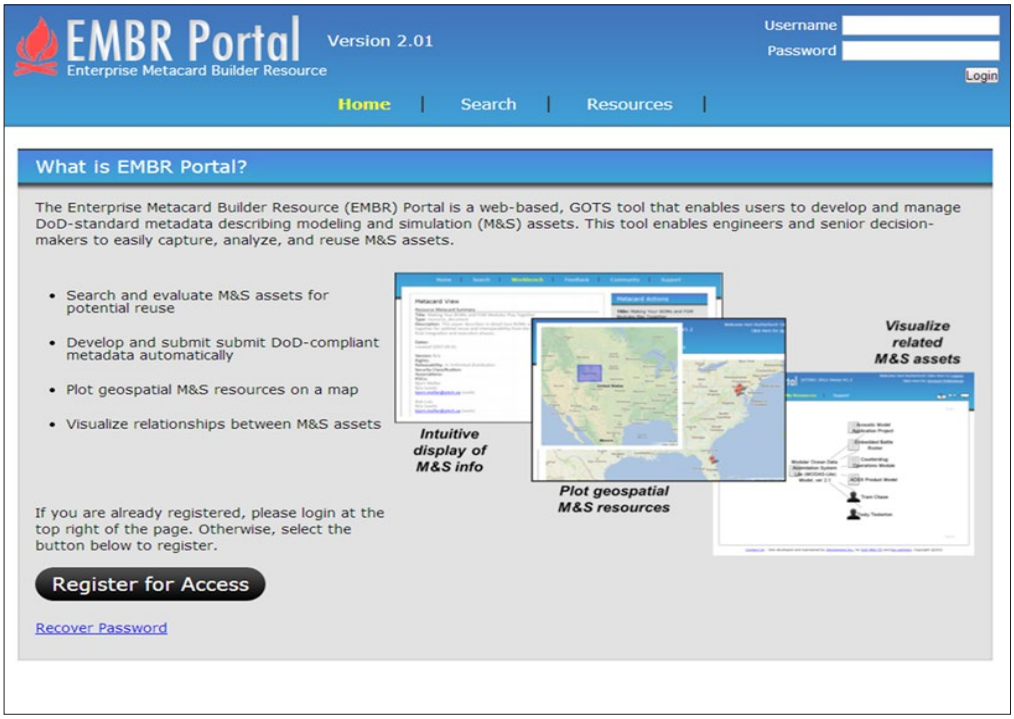


Figure 5: EMBR Portal Metadata Support Tool

model, or who were potentially involved in its development. Connecting assets to people and organizations helps improve collaboration and advance the goal of reuse.

The EMBR Portal was built and tested on low-cost, open source software and is considered a government off the shelf (GOTS) tool. Pilot testing and deployment to a limited set of users, including the Program Executive Office for Integrated Warfare Systems (PEO IWS) and the Navy M&S Office (NMSO), generated additional feedback on its usability. In 2012, the EMBR Portal was selected as the replacement for the M&S Information System (MSIS), to produce and store metadata describing widely-available resources. The Portal became operational in 2013.

The EMBR Portal tool is based on the MSC-DMS schema. The structure and the data elements of that specification directly drive the user interface. This important design decision allows future changes to the specification to be immediately reflected in the metadata support tool.

DoD M&S Catalog

The DoD M&S Catalog is a web-based card catalog for M&S metacards. It is the central storage point for metacards and provides a robust search capability. The M&S Catalog stores metadata describing three types of resources:

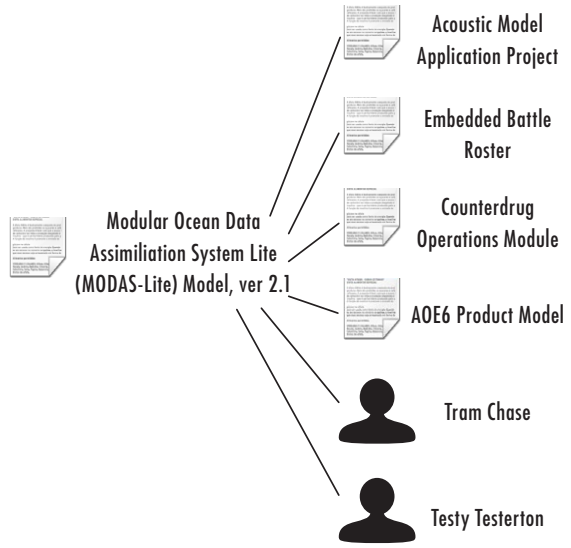


Figure 6: Graphically Relating M&S Resources

- Tools: software and hardware to support models and simulations
- Data: any type of data that models or simulations require
- Services: capabilities that provide design, development, or analysis support

The mandate for a catalog is explicitly stated in the NCDS. "Metadata catalogs will advertise the existence of shared data…" The NCDS also states, "COIs will establish and

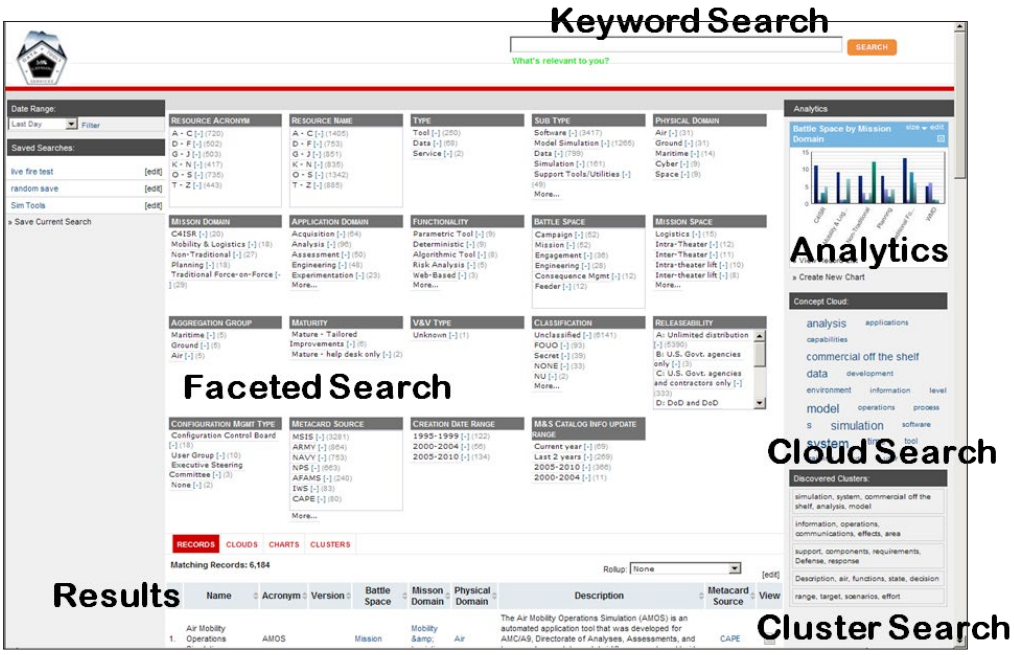


Figure 7: The DoD M&S Catalog

maintain catalogs. Each catalog may be organized according to the community-defined ontology." The DoD M&S Catalog provides a community-wide collection point for metacards describing assets from approximately a dozen different sources. This approach connects various M&S organizations to each other.

The DoD M&S Catalog also provides a connection to another key capability called the DoD Enterprise Catalog. The Enterprise Catalog accepts metacards in DDMS format and is the central collection point for metadata from all COIs. Since DDMS is a kind of *universal language* for metadata, the Enterprise Catalog ties communities together as a *catalog of catalogs*. This is another example of how the central goal to promote discovery and reuse of M&S resources to create opportunities for efficiencies in system acquisition across the entire DoD is being accomplished.

The DoD M&S Catalog began accepting metacards from industry and academia in 2013. Access to the catalog is granted via a common access card (CAC) or a valid DoD electronic certificate. This initiative will expand the number of resources available for discovery.

TYING IT ALL TOGETHER

Increased collaboration within the M&S COI has occurred because of the broad adoption of M&S metadata, improved metadata specifications, and the increasing use of metadata support tools. Discovery and reuse mechanisms are in place. It is more critical now than ever to further integrate these capabilities to reduce inconsistencies in data exchange and to remove the remaining obstacles to developers and users.

Structure and Automation

Current implementation of the DoD M&S Catalog allows the incorporation of any type of metadata formatted in any structure. While this approach offers a great deal of flexibility, it relies on direct human manipulation of the data. Manually managing the data creates delays in releasing this material to the community. This manual process is also an opportunity for introducing unintended errors in the data exchange process. Further work is needed to improve these processes and reduce the time it takes to make metadata visible and accessible.

Web services and other mechanisms will facilitate data exchange efficiently as the volume of metadata and the number of data producers continue to increase. These interfaces allow rapid exchange and incorporation of metadata into the DoD M&S Catalog and also prevent errors introduced through human manipulation of the data. While there will always be a need to capture and edit metadata manually through the use of tools such as the EMBR Portal, metadata needs to be exchanged and transmitted efficiently and rapidly.

Facilitation and Motivation

Future work should include the development of key architecture artifacts such as a DoD Architecture Framework (DoDAF) Operational View (OV)-1 diagram to describe metadata within an ecosystem of practitioners, data sources, tools, catalogs, and repositories. Other products such as an M&S metadata concept of operations should also be developed to describe the use cases present within this community. Use cases could be based on the development of *decision areas* for technical practitioners and senior decision makers. Capturing the right questions will help the community design a capability to produce data that answers them in a seamless and efficient manner.

Reuse should be encouraged as a key component to comprehensively managing M&S investments. This can run the gamut from educating potential re-users on asset discovery, availability, and features to acknowledging reuse successes through awards and formal recognition. Fundamental insights on incentivizing M&S reuse were developed under a DoD High Level Task in 2009 [6]. Three critical activities come to mind: leadership, assistance, and appropriate business practices. Leadership includes articulating and inspiring others to pursue a well-defined end-state; however, it also means establishing goals and benchmarks such as objectives for the research and development communities, design agents, program offices, and application-area users. Benchmarks allow metric-based insights on reuse to be deduced and then optimized. Assistance includes coordinating the development and use of requisite specifications and applications, promoting standards advancement and adoption, and providing comments, inputs, and lessons learned—generally to the M&S COI, but also to individual programs and efforts. This type of

assistance ensures that the success of M&S reuse does not rely exclusively on user-pull, but also contains an aspect of enterprise-push. Finally, although DoD is not a business that seeks to maximize profit, it utilizes regulatory and intellectual property rules that can help or impede reuse. It is possible, for example, to negotiate government-use licensing from vendors in order to enable DoD- or Service-wide redistribution and employment of M&S capabilities. Contrarily, current DoD regulations disallow the recouping of costs through subsequent use (reuse) of M&S assets. M&S asset reuse will be facilitated by encouraging DoD to take the initiative in leadership, assistance, and business practice development.

CONCLUSIONS

Improving discovery and reuse of assets continues to be a critical imperative for the M&S community. This article summarized the role of policy, the use of key specifications, and the increased capabilities of support tools to significantly improve stakeholders' insight into their investments. The EMBR Portal is a web-based metadata support tool that allows users to create, manage, collaborate on, and submit metadata to authorized catalogs, including the DoD M&S Catalog. Recent work to more closely integrate the metadata specification, metadata support tools, and the DoD M&S Catalog has lowered the technical barriers to metadata adoption, leading potentially to ROI analyses that were previously unattainable.

Acknowledgements

The author gratefully acknowledges the valuable insights and written contributions received from Dr. Ivar Oswalt. His ideas and positive vision for the M&S community added significant value to this article.

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Author's Biography

Mr. Hart Rutherford

Mr. Hart Rutherford is the manager of the M&S portfolio of products and services at SimVentions, Inc. Mr. Rutherford has over 20 years of professional experience as a combat systems engineer and program manager including technical leadership of M&S VV&A for the Navy's DD(X) program as well as a contributor to the development and maintenance of DoD M&S standards. Mr. Rutherford's military background includes eight years active and reserve service in the U.S. Navy as an AEGIS Operations Specialist. He holds a master's degree in Systems Engineering from Old Dominion University and B.S. in Computer Information Systems from Chapman University.

Reflections on Social Media to Facilitate M&S Reuse

Author

Mr. William C. Riggs
The Johns Hopkins University
Applied Physics Laboratory
William.Riggs@jhuapl.edu

Abstract

THE ONSET OF WEB 2.0 AND SOCIAL MEDIA TECHNOLOGY OFFERS OPPORTUNITIES AND CHALLENGES FOR THE MANAGED REUSE OF DOD MODELING AND SIMULATION (M&S) ASSETS AND RESOURCES. IN 2009, THE DOD MODELING AND SIMULATION COORDINATION OFFICE SPONSORED A STUDY OF ASSET REUSE MECHANISMS IN CONJUNCTION WITH THE LIVE-VIRTUAL-CONSTRUCTIVE ARCHITECTURE ROADMAP IMPLEMENTATION (LVCAR-I) PROJECT. THIS STUDY EXPLORED THREE ALTERNATIVE APPROACHES TO M&S REUSE. ONE OF THESE APPROACHES, THE SOCIAL MARKETING APPROACH, EXPLORED THE UTILIZATION OF SOCIAL MEDIA FOR PEER-TO-PEER COLLABORATION TO FACILITATE AN OVERARCHING STRATEGY FOR M&S REUSE. THIS ARTICLE DESCRIBES SPECIFIC FINDINGS AND RECOMMENDATIONS OF THE LVCAR-I ASSET REUSE MECHANISMS STUDY REPORT, AS WELL AS ONGOING INDEPENDENT ACTIVITIES WITHIN COMMUNITIES ENABLED BY M&S TO EXPLOIT SOCIAL MEDIA. THE PAPER ALSO EXPLORES AFFORDABLE EMERGING TECHNOLOGIES AND FACILITIES AVAILABLE TO M&S STAKEHOLDERS, INCLUDING SECURITY, INFORMATION ASSURANCE, AND USAGE METRICS.

INTRODUCTION

In a 2005 BBC news interview, Sir Tim Berners-Lee said,

"This is humanity which is communicating over the web, just as it's communicating over so many other different media…we have to work to make sure that it supports the sort of society that we want to build on top of it [1]."

When it comes to using internet resources to facilitate and enhance the reuse of modeling and simulation (M&S) within the Department of Defense (DoD), with other branches of the U.S. Government, and with foreign partners, this is no less true. Not only does the spread of Web 2.0 technology—weblogs, wiki sites, discussion boards, hosted services, and applications—provide opportunities for professional collaboration, networking and community building, it also presents challenges for M&S practitioners who wish to share M&S data and metadata efficiently and securely. For government, industry and academia, the onset of social media represents an ongoing challenge to institutional culture, public policy, and professional ethics. While progress within the communities enabled by M&S has been incremental, reversible, halting and irregular, there are now enough Web 2.0 sites within the public and private sector to provide sufficient material for reflection and (re)consideration of policies and priorities within the M&S Community of Interest (COI).

Recent Efforts

Many of the issues surrounding the implementation of Web 2.0 technology to actualize M&S reuse emerged as part of the Live-Virtual-Constructive Architecture Roadmap Implementation (LVCAR-I) Project. This effort, now in its fourth and last year, included outreach initiatives, studies, software, and standards development in the following areas:

- Interoperability of Live-Virtual-Constructive (LVC) architecture
- Common M&S capabilities, including M&S asset reuse mechanisms
- Service oriented architectures and emerging LVC technologies [2].

The M&S asset reuse mechanisms effort consisted of two phases: a study phase resulting in an implementation plan with recommended actions and objectives and an implementation phase focused on the development of Web 2.0 capabilities for transition to the M&S Core. M&S Core consists of core products and services developed and maintained under DoD Modeling and Simulation Coordination Office (M&SCO) sponsorship. The LVC Common Capabilities: Asset Reuse Mechanisms Implementation Plan (hereafter referred to as the "LVCAR-I Asset Reuse Mechanism Study") included an analysis of 13 online M&S catalogs, repositories, and registries maintained by DoD organizations. While the sites examined were different in scope, purpose, and implementation, the LVCAR-I team was able to discern patterns of reuse in terms of three basic approaches

1. *The Transactional Approach* utilizes store-and-forward mechanisms and associated discovery processes to foster reuse of LVC M&S assets.
2. The *Social Marketing Approach* emphasizes cultural barriers to LVC M&S reuse and the means to overcome those barriers.
3. The *Process-based Approach* emphasizes M&S systems engineering processes and standards that facilitate reuse, typically in conjunction with a program of record [3].

While the LVCAR-I Asset Reuse Mechanism Study encompassed all three of these approaches, the focus of this article is social marketing, defined as "identifying and leveraging the social relationships between Communities of Producers, Consumers, and Integrators to influence their behavior in order to improve the reuse of M&S assets within the DoD enterprise [3]."

The Social Marketing Approach recognizes that M&S reuse is a public good that benefits the entire M&S COI, as well as facilitating the affordable exploitation of M&S assets by one or more communities enabled by M&S (e.g., Training, Acquisition, Analysis, and Testing). In this context, Web 2.0 technologies extend the shared spaces maintained by these communities, facilitating the free exchange of information about M&S assets, capabilities, limitations, and—to the extent possible—costs. There are indications that such shared spaces can form spontaneously, and are in existence today. The Simulation Interoperability Standards Organization (SISO), in addition to its traditional website, now maintains discussion and social networking groups on Facebook® and LinkedIn®. An industry site Modsim.org, hosted in Germany, contains an online blog and Twitter® feed with information about products and activities within the worldwide simulation and training marketplace. LinkedIn hosts a number of groups relating to DoD M&S, including:

- Defense Modeling and Simulation
- DIME/PMESII, HSCB, and IW
- Army Modeling and Simulation Group
- Coalition Battle Management Language (C-BML)
- Military Operations Research Society (MORS)
- SimSummit
- Simulation, Visualization and Training Systems

In addition to these open and public sites, the LVCAR-I Asset Reuse Mechanism Study identified a series of DoD online resources with controlled access, typically using Common Access Card (CAC) and/or DoD Private Key Infrastructure (PKI). Significant among these resources are Forge.mil, an open source software repository managed by the Defense Information Systems Agency (DISA), and MilSuite, a collection of Army social networking tools accessible by CAC on Army Knowledge Online. These resources provide government-side hosting and a secure space for M&S stakeholders to collaborate at the unclassified level. Forge.mil also supports collaboration services, known as Community Forge, which enable software development teams to collaborate on cross-cutting projects as well as their own efforts [4]. MilSuite consists of three linked resources: an editable Military encyclopedia (milWiki), Military News Blog (milBlog), and a Military professional networking site (milBook). MilBook is the most interactive resource, with functionality and appearance similar to Facebook.

As the LVCAR-I Asset Reuse Mechanism Study noted, the Social Marketing Approach, "focuses on the long term improvement of behaviors that promote reuse of M&S assets" and influence "M&S producers, integrators, and users to adopt practices which extend the boundaries of shared spaces in the context of evolving institutional frameworks [3]." Intrinsic to this approach is a social marketing campaign designed to spread a coherent and positive message and analyzes the results achieved to determine whether attitudes and behaviors have changed so as to facilitate such desired outcomes with respect to M&S reuse. This approach directly addresses the disincentives that have caused M&S reuse mechanisms to fail in the past and also reflects the M&S stakeholder concerns surfaced during the LVCAR-I Asset Reuse Mechanism study phase: there is a broad desire for improvement of M&S reuse mechanisms with the DoD community. Investments in social media—the mechanisms by which reuse messages are conveyed—can be made in increments that accelerate return on investment rather than suffering from diminished returns. The net effect of many small successes yields the tipping point hypothesized by Malcolm Gladwell [5]. A successful social marketing campaign makes desirable behaviors habitual, with positive and long-lasting results.

Despite these advantages, the LVCAR-I Asset Reuse Mechanism study team identified a number of barriers were identified that might inhibit the potential success of the social marketing approach. Ingrained habits are not easily changed. If commitment to LVC reuse as a community value and a common good is lacking within the communities enabled by M&S, then the impact of DoD's commitment to M&S reuse is lessened, and undesirable behaviors may be rewarded rather than penalized. The LVCAR-I Asset Reuse Mechanism Study recognized that if short term results could not be assessed, then support for the use of social media and social marketing would be lessened. Consequently, the study recommended a hybrid approach that blended transactional, social marketing and process-based reuse mechanisms.

Among the recommendations of the LVCAR-I Asset Reuse Mechanism Study were the following:

- Explain what new reuse capabilities and practices are available (e.g., *M&S Journal*)
- Utilize wikis, RSS feeds, blogs, social networks
- Adopt reuse mechanisms early through respected individuals within the community
- Establish and disseminate messages through social networks for communities enabled by M&S
- Obtain feedback from stakeholders on how the messages are perceived
- Adapt social marketing technique based on feedback received
- Invite repository owners to advertise through social networks
- Initiate awards for successful reuse [3]

Lessons Learned

As the LVCAR-I Asset Reuse Mechanism effort matured in the implementation phase, the LVCAR-I Asset Reuse Mechanism team confirmed. The experience of building web-based tools that support social media and social networking yielded new and deeper insights into the costs and benefits of embracing Web 2.0 as the basis for asset reuse mechanisms. While the development of web-based tools proved efficient and effective, their deployment and support has presented ongoing challenges to the M&S community. One important consideration is security and the impact of security considerations on the use of social media. Cyber warfare is a real and ever-present threat. The more successful and visible a social networking site becomes, the more it tends to attract not only desired collaborators, but unwanted visitors and, in some cases, destructive activity. Continuous support of social media sites, including software and security upgrades, periodic security scans, and airtight authentication practices is not an option—it is an essential cost of doing business.

A related issue involves the security of information itself. By definition, information must be secured both as it is stored (e.g., on a web server) and while it is transmitted from one site to another. From a physical security standpoint, this process involves the security of transactional mechanisms, but in the realm of social media, the human dimension emerges. Early in the LVCAR-I study phase, the issue of trust emerged, as it became clear that communities of interest and practice are formed on the basis of trust and confidence at varying levels. Part of the task in social media is to build trust, a task that is often challenged by the vastness of cyberspace, and the all-too-often anonymous nature of transactions in the Web 2.0 environment, where even well-known M&S professionals

may interact—at a high professional level with persons they have not met in person. This poses real challenges to social marketing campaigns, and in the past has resulted in the demise of functional and flourishing cyber communities.

Another lesson learned from the LVCAR-I experience is the importance of assessing the quantity as well as the quality of interactions within the social media sites that facilitate M&S reuse. While there is no "one-size-fits-all" solution, experience suggests a few operating principles. Many social media sites host web application servers built from reusable software components. Drupal, a popular content management system, is an example of such an environment [6]. Social media sites such as Facebook commonly practice usage monitoring, including collection and analysis of online behavior. Effective use of these tools and methods is a learned skill, one that all those seeking to develop and deploy online resources concerned with M&S reuse should seek to master. While in most cases, the data collection mechanism is passive, active data collection measures, such as customer satisfaction surveys, and user-submitted comments.

The current increase in social media dedicated to M&S, particularly in the areas of interoperability, standardization and reuse, is a hopeful sign, but the DoD M&S community has yet to reach a point at which the medium institutionalize the message of M&S reuse. In an era of declining DoD budgets and resources, there is a continuing need for success stories that illustrate what works and what doesn't. Social media can provide a powerful resource to enhance public goods, but the commitment of a dedicated online community—that is in constant contact with itself—and with relevant stakeholder communities, is the prerequisite for measurable progress.

The Way Forward

The conceptual basis for technological progress on the World Wide Web has been simple: a graphical user interface to the internet, the ability to write to as well as read from web pages—these have been the essential building blocks of today's social media. At the same time, these technologies have shaped the habits of an emerging generation, and ultimately the business practices of society itself. Why should M&S business practices within DoD be different? When and where are they different, how are those differences shaped by the progress of social media both outside and within government, industry and academic communities and cultures? The term "plug and play" implies the evolution of well-understood and potentially sophisticated interfaces that regulate social media interactions across systemic and cultural boundaries. The pressure of declining budgets will increase the demands for more effective M&S reuse mechanisms, which demonstrably perform to expectations and deliver a positive return on investment. The LVCAR-I Asset Reuse Mechanism Study recommendations described in this paper remain valid, and continue to provide a consistent and sound path forward to institutionalization of M&S reuse within the COI.

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Author's Biography

Mr. William C. Riggs

Mr. William C. Riggs is a member of the Senior Professional Staff at The Johns Hopkins University Applied Physics Laboratory (JHU/APL). Mr. Riggs has 24 years professional experience as a project manager, technical lead and systems engineer in the development and integration of LVC architectures, terrain and target modeling, human behavior representation, and M&S standards development. He was the task lead for the LVC Asset Reuse Mechanism component of the LVCAR-I Project. Before coming to JHU/APL, Mr. Riggs was a senior systems engineer with the U.S. Army Future Combat Systems (FCS) program.

In this capacity, he authored the FCS System of Systems Simulation Support Plan and instantiated the M&S component of the FCS Distributed Product Description (DPD). Mr. Riggs' military background includes active and reserve service in the U.S. Army, attaining the rank of Major. He holds an M.S.F.S from Georgetown University, a B.A. in political science from Ohio State University, and has completed the requirements for the M.S. in technical management at The JHU Whiting School of Engineering.

M&S Conceptual Modeling as an Enabler of M&S Reuse, Agile, and Open-Source:

A TRS Initiative in Response to the M&S SC Priority Objectives

Author

Mr. Ric Roca

Joint Enabling and Assessment Capability Office – M&S Branch
ODASD(R)/Training, Readiness, and Strategy (TRS)
ric.roca@osd.mil

The Johns Hopkins University
Applied Physics Laboratory
ric.roca@jhuapl.edu

Abstract

REUSE, AGILE, AND OPEN-SOURCE CONCEPTS APPLIED TO MODELING & SIMULATION (M&S) ASSETS HAVE LONG BEEN ELUSIVE CHALLENGES THAT REMAIN HIGH PRIORITIES IN THE DEPARTMENT OF DEFENSE (DOD) M&S COMMUNITY [1], [2]. THIS IS REFLECTED EXPLICITLY (OR IMPLICITLY) IN MOST OF THE DOD M&S PRIORITY OBJECTIVES [3] PRESCRIBED BY THE DOD M&S STEERING COMMITTEE (SC) TO BE ADDRESSED DURING FY14-18. REUSE, AGILE, AND OPEN-SOURCE CONCEPTS ARE INTERPRETED, PRACTICED, AND REGARDED DIFFERENTLY BY DIFFERENT M&S STAKEHOLDERS; MOREOVER, THESE CONCEPTS LACK M&S-SPECIFIC STANDARDIZATION AND EXPECTATIONS REGARDING THEIR APPLICATION AND USEFULNESS. RECOGNIZING THAT THESE ARE FORMIDABLE ISSUES TO SOLVE, EACH OF THE COMMUNITIES REPRESENTED IN THE M&S SC WAS DIRECTED TO MAKE REASONABLE PROGRESS TOWARD THESE OBJECTIVES. IN RESPONSE, A PROPOSAL WAS SUBMITTED TO AND ACCEPTED BY THE SC FOR THE DEVELOPMENT OF A *TAILORABLE* DEFENSE HANDBOOK ON M&S CONCEPTUAL MODELING (CM) ALONG WITH M&S CM COMPLEXITY MANAGEMENT FRAMEWORK AND TEST CASE EXEMPLARS TO FACILITATE PROGRESS AND TO IMPROVE THE UNDERSTANDING OF REUSE, AGILE, AND OPEN-SOURCE PRACTICES AS APPLIED TO DOD M&S ASSETS.

The Need for M&S CM Standardization

Modeling and simulation (M&S) conceptual modeling (CM) is arguably central to an M&S engineering life cycle. There are detractors, however, who publicly or privately consider it an unnecessary burden that adds little value to a project. A June 2011 report from the North Atlantic Treaty Organization (NATO) Modeling and Simulation Group (NMSG) on CM considers it critical to understanding the military domain, implementing M&S products and services that reflect intended reality, and ultimately satisfying users' needs [4].

M&S CM means a variety of things to different stakeholders; thus, a basic problem affecting the quality of military models and simulation systems—and the potential for M&S reuse, Agile, and open-source—is the absence of an M&S CM standard or even a consensus on CM content [1], [2], [4]—[11].

A literature search found a modest amount of attention dedicated to M&S CM. Further, a 2010 panel of M&S professionals and scholars characterized the current state of M&S CM practice as lacking professionalism and regarded more as an art [11]—[13].

Three main streams of M&S CM work were stimulated by the Defense Modeling and Simulation Office (DMSO)/ Modeling & Simulation Coordination Office (M&SCO) during the past two decades including: 1) the Conceptual Model of the Mission/Space (CMMS)/Functional Description of the Mission Space (FDMS); 2) the Simulation Conceptual Modeling (SCM) as part of the Department of Defense (DoD) Recommended Practices Guide (RPG) for M&S Verification, Validation, and Accreditation (VV&A) [14]; and 3) the Federation Conceptual Model (FCM), codified in the DoD High Level Architecture (HLA) Federation Development and Execution Process (FEDEP) [15]/ Distributed Simulation Engineering and Execution Process (DSEEP) [16]. The first atrophied as a result of reductions in funding and personnel changes, whereas the latter two were labeled as descriptive (i.e., not prescriptive) and failing to provide specific guidance on CM content, development, and format [13].

MIL-STD-3022 [17] prescribes the inclusion of conceptual models in VV&A planning, but does not provide guidance. Likewise, existing simulation interoperability and distributed simulation standards (e.g., [15], [16]) are not intended, sufficient, or appropriate for the specification of semantics inherent to conceptual models [4].

The Simulation Interoperability Standards Organization (SISO) created a Standing Study Group (SSG)/Product Development Group (PDG) in 2003 to address M&S CM and to produce a standard or technical guide to help M&S practitioners develop effective and useful M&S conceptual models. The NMSG report concluded that M&S CM remains crucial to validating simulation system design and implementations that satisfy user needs; and that existing standards are not meant for conveying the exchange of semantics and concepts in simulation projects—the need still remains for a publication that consolidates recommended practices for the elaboration of M&S conceptual models [4].

The Acquisition Modeling and Simulation Working Group (AMSWG) shared a similar viewpoint as the NMSG report and included the following recommendations in their 2012 Acquisition Community Modeling and Simulation Strategy (AMSS): 1) supporting the efforts of the SISO Task Group to ensure the publication of an initial standard, 2) executing at least one test case of the standard, 3) identifying or developing a conceptual modeling tool, and 4) developing a learning objective and module in CM [9].

The NMSG report includes a paradigm for M&S CM process and product guidance but it remains uncertain if it will be endorsed by SISO or the DoD M&S community, or if an alternative standard or best practices guide on M&S CM will be published by the SISO SSG/PDG.

A Defense Handbook Alternative

In response to the M&S Steering Community (SC) Priority Objectives and the uncertainty of a near-term publication on M&S CM best practices, the Office of the Deputy Assistant Secretary of Defense (Readiness)/Training, Readiness, and Strategy (ODAD(R)/TRS) launched an initiative to prepare a Defense Handbook on M&S CM (Handbook). General oversight will be by the M&S Branch of the Joint Assessment and Enabling Capability (JAEC) Office in collaboration with M&SCO. This new endeavor will invite stakeholders to participate in the initial draft and/or review of the document. M&SCO, in its role as the DoD lead for the M&S discipline, will draw from the Handbook with an aim toward providing M&S services, formulating policy, delivering training, and offering advocacy.

The Handbook is envisioned to document, promote, and facilitate the use of respected or *de facto* concepts, best practices, lessons learned, exemplars, and/or other types of technical guidance on the elaboration of conceptual models instrumental to DoD and its contractors for M&S projects, processes, systems, or components. A comprehensive literature research effort and scholarly contributions from the various DoD and non-DoD M&S communities will form the basis of the Handbook's content.

Previous standardization efforts were criticized for not providing prescriptive guidance on M&S CM development, content, or format [13]. The RPG SCM and FEDEP/ DSEEP FCM provided a descriptive approach consisting of

notional guidance about what conceptual models should do and what documentation should be included. In contrast, a *prescriptive* approach would specify content, format, and a detailed structure for M&S CM. The RPG SCM team concluded that a prescriptive approach would not be feasible given the great variety of M&S applications the RPG was intended to support, despite recognizing its value [13].

In contrast to a military standard, a defense handbook does not impose requirements but instead provides authoritative technical guidance [18]. The Handbook is envisioned to be comprehensive and tailorable in the sense that it will include core principles that can be applied across all disciplines as well as optional formalisms of specific relevance and interest to communities of interest (COIs). Thus, through COI and disciplinary contributions, the Handbook will offer technical guidance on conceptual model content, development, and format that is practical and useful without imposing unnecessary or irrelevant cross-disciplinary burdens.

An Agile Handbook

The success and relevance of the Handbook, however, will not materialize if the effort chooses to follow a comprehensive traditional approach (which would require months, if not years, for its production and would be mired in endless philosophical debate). The Handbook is not intended to prescribe a single and fixed method by which all M&S practitioners should abide, but rather provide adaptive technical guidance based on best practices established by, and emerging from all disciplines with a stake in M&S and M&S asset reuse. A more nimble approach would also support on-going DoD initiatives to adopt Agile and open-source business models. The Handbook stands to benefit substantially from Agile and open-source approaches used in the development of software applications.

A 2013 Agile research study for ODASD(R) recommended the use of Agile acquisition and Agile software development as a way to increase the speed of delivering military training capabilities and to meet training needs by building on existing foundation layers, rather than by building software capabilities from scratch [19]. Extending this recommendation to the production of the Handbook would be beneficial for several reasons.

First, emerging Agile practices within the federal government acquisition community show potential cost and schedule reductions in the fielding of valuable military capabilities. Additionally, Agile software development is not a one-size-fits-all proposition such that practices and methods must be deliberately implemented [19]—[22].

Agile software development is an iterative software-development approach that responds to evolving requirements. Scrum, for example, is an Agile software development framework organized around a basic unit of development (i.e., the sprint), and adopts an empirical approach to optimize the quality of requirement specifications. Tasks are decomposed into small spiral increments that enable adaptive planning, rapid development and testing, and frequent functional deliveries that facilitate customer feedback.

The Agile concept for software development will be adapted to identify and compile principles and formalisms from recognized and on-going research in CM from the M&S, systems engineering, operations research, and other communities and disciplines. Accordingly, each piece of content in the Handbook will be considered a basic unit of development and its production managed as a sprint. Production of the Handbook will be expedited, readily socialized, and actively enhanced by leveraging any number of disciplinary collaborators with a stake in M&S and M&S reuse.

M&S CM as an Enabler of M&S Asset Reuse

Simulation composability, a counterpart of M&S asset reuse, has proven to be one of the most difficult challenges in the M&S frontier, prompting even the most experienced practitioners to dismiss the illusion of pure plug-and-play composability—calling instead for the elaboration of more realistic M&S systems engineering methods that address simulation system complexity in a way that minimizes the composition time and level-of-effort in simulation system design and development [1], [6].

Reuse encompasses a broad range of meaning among M&S stakeholders; thus the feasibility of a universal one-size-fits-all solution is unlikely. M&S CM has been found to promote reuse in the design of M&S applications for COIs [5]. This fits with the recognition that no problem is truly

disciplinary; rather, the reductionist nature of disciplines makes them unable to tackle complex large-scale multi-dimensional problems and a complex systems approach should be taken instead [23].

The M&S discipline has been somewhat mischaracterized as multidisciplinary and interdisciplinary, from the perception that multiple disciplines employ and/or collaborate in some form of M&S. But multidisciplinary refers to the sharing of the subject of research by multiple disciplines whereas interdisciplinary refers to the sharing of methods by multiple disciplines [23]. From that perspective, the M&S discipline is arguably transdisciplinary as it looks across, beyond, and through all disciplines (academic and otherwise), to encompass and merge all forms of knowledge, paradigms, and formalisms [23]. M&S is perhaps the one discipline that identifies, studies, derives, promotes, and advocates best practices for the representation of man-made systems and natural phenomena drawn from, and transcending all disciplines, as well as for the development of simulation systems.

Consequently, M&S CM and M&S asset reuse should be considered in a more deliberate, comprehensive, and flexible manner—one that accommodates the specific needs of COIs, rather than creates overarching and narrow prescriptions that are restrictive and impractical.

Effective M&S asset reuse policy that caters to the specific needs of disciplines and COIs must be balanced. For example, effective M&S asset reuse should start with a Service personnel-centric perspective grounded in sound mathematics, science, and engineering formalisms that generate relevant, high-quality, well-engineered, valid, reusable primitives and building blocks rather than with generic wrappers, user interfaces, or purported universal interoperability technologies. This approach would identify and sort out the particular dimensions of the problem space, facilitate component categorization, and enable their composition with other components into a simulation system within a reasonable amount of time and effort. This approach would also serve to lessen risky, costly, and vagrant solutions that are difficult to catalog, discover, validate, and/or integrate.

The M&S discipline can and should provide eclectic technical guidance to all other disciplines on the various aspects of the M&S engineering life cycle as a way to promote and facilitate the production of well-engineered models, model-primitives, operational infrastructure, and other reusable M&S assets. Well-engineered reusable M&S assets depend on a thorough understanding of the problem and solution spaces that are articulated in coherent M&S conceptual models.

Simulation system development typically begins with the specification of intended uses. Intended uses, however, means a variety of different things to different M&S stakeholders. Intended uses refer to declarations of purpose akin to hypothesis statements that include questions to be answered, decisions to be supported, knowledge or skill to be developed, and the information complement (i.e., simulation only provides part of the needed information) which serves that particular purpose. Intended uses provide the *context* of a problem space from which the scope (i.e., high level requirements) and mandatory provisions (i.e., detail level requirements) of a proposed M&S solution may be derived. Without a qualified declaration of intended uses models and simulation systems are at risk of becoming vagrant and their validation is compromised. This is due to the fact that validation is the process of ascertaining that *the right simulation system was built* for an intended use, but this cannot be determined without first establishing that *the right problem was addressed*, which is the seed of intended uses.

Reuse is a corollary of intended use. That is, the intended uses should be clearly established before an M&S asset is considered as part of a simulation environment, whether the asset currently exists or will be newly developed. Additionally, the type of asset (e.g., static, dynamic, stochastic, deterministic, continuous, or discrete) will influence the scope of the architectural approach. Other considerations include the level of reuse (e.g., component level, application level, federation level), granularity, accuracy, precision, and aggregation to name a few. These issues should be deliberately addressed, and for which M&S CM conventions would be helpful to M&S practitioners.

M&S CM Policy and Frameworks as Enablers of Agile and Open-Source in M&S

The Agile approach relies heavily on requirements that are clearly communicated and that converge on *the right problem space* and *the right system solution* as a result of frequent interaction and cooperation with customers who are well-acquainted with all aspects of their domain and can be considered as subject matter experts (SMEs). It also promotes building only necessary capabilities onto existing foundation layers. These key characteristics make Agile *agile* and make M&S CM critical to its relevance in both M&S asset reuse and M&S in general.

Open-source software (OSS) is typically developed in a public, collaborative manner and the source code made available and licensed freely to anyone for any purpose. Software licenses grant rights to users who would be otherwise restricted by copyrights. The main attractions of OSS over proprietary software include lower costs, security, relatively high quality, and perhaps most importantly, no vendor lock-in. However, OSS is not *free* and a particularly notable shortcoming is the lack of technical support and documentation. For OSS to be relevant to M&S in general and M&S asset reuse specifically, a disciplined approach to M&S asset development must be observed in order to facilitate asset cataloging, discovery, validation, and integration.

A critical distinction between computing in general and computerized simulation is arguably that simulation systems are meta-systems, such that their underlying models are essentially systems within systems. Models describe the behavior and characteristics of man-made systems or natural phenomena which are often not well understood and require teams of SMEs and systems engineers who are not always readily or concurrently available. Systems engineers are in short supply (particularly those that specialize in M&S projects), limiting the availability of prospective agile Scrum masters and development teams, or open-source support personnel. There simply are not enough skilled people to keep pace with the volume of rapidly-emerging M&S assets or maintain M&S asset catalogs. As a result, the production of M&S assets must include some capability to facilitate their cataloging, discovery, validation, and integration. This stark reality underscores the need for M&S CM formalism not only to document technical guidance, but also to enable Agile and other M&S reuse-enabling paradigms.

A simulation system is a complex set of integrated components intended to leverage the properties of each component. The relationship among components gives systems their added value while the greatest leverage in system architecting is found at the component interfaces [25]. Simulation projects routinely rely on SMEs for design, development, validation, and verification of models and simulation systems as well as to manage their inherent complexity. When the supply of M&S SMEs is limited, however, this complexity can be a significant and costly problem.

If M&S CM best practices and formalisms can be incorporated into frameworks, then this costly situation can be improved. Such a framework would need to facilitate both the identification and management of the significant dimensions involved in a problem space along with the components in the simulation environment that represent these dimensions and provide simulation system operational capabilities. Agile and open-source practices would be a useful approach if they enable non-SME systems engineers to gain a reasonable appreciation of the problem and develop appropriate solutions within a reasonable amount of time and effort. This does not suggest a shortcut for M&S systems engineering work, but rather a necessary instrument in the pursuit of M&S transdisciplinary understanding.

Two possibilities for the development of such frameworks include dusting off a couple of tried-and-true relics that have been invaluable to foundational science and engineering understanding. One is dimensional analysis and the second is complexity management.

Dimensional analysis (DA), a branch of algebraic theory, is the practice of checking relations among physical quantities by identifying their dimensions. The M&S community should note the following observation from Lord Rayleigh (1915) when employing DA: "It happens not infrequently that results in the form of 'laws' are put forward as novelties on the basis of elaborate experiments, when they might have been predicted *a priori* after a few minutes' consideration [24]."

DA has a broad range of applications and has been used widely in the study of physical properties. More recently it has been applied and extended to formulate dimensions in the life and social sciences. Of particular importance and relevance is the DA application to transfer-of-training metrics in the design of serious games and other simulation-based training.

Ironically, the Armed Services and other COIs have used both DA [26] and complexity management [27] concepts among other methods, to understand and manage complex disciplinary science and engineering problems. Regrettably, these concepts are not being leveraged (reused) to a great extent by the M&S community even though they would be beneficial for developing M&S CM frameworks and M&S assets, advancing M&S asset reuse and facilitating Agile and OSS.

Development of the Defense Handbook on M&S CM will include the creation of an M&S CM complexity management framework using and extending the Design Structure Matrix (DSM) method for complexity management to leverage DA for the identification and articulation of dimensions in a problem space correlated to corresponding model components in the simulation solution space. This initial framework exemplar will build on a proposition to extend the DSM to manage the dimensional complexities of models and simulation systems [6] and hopefully will inspire other framework paradigms for effective M&S asset reuse.

Summary

Reuse, Agile, and open-source practices are high priority challenges in the DoD M&S community. In response to the FY14-18 M&S SC Priority Objectives, and as a way to expedite these objectives, the ODAD(R)/TRS proposed the development of a flexible Defense Handbook on M&S CM along with an M&S CM complexity management framework and test case exemplars to facilitate progress, and to improve the understanding of reuse, Agile, and open-source practices pertaining to DoD M&S assets.

This initiative will build on past and current M&S CM research and lessons learned to incorporate the specific needs of a diverse M&S community while providing robust prescriptive formalisms informed by the various disciplines and M&S COIs.

Agile principles will be adopted and adapted to expedite the production of the Handbook, while a framework exemplar will employ DA and complexity management methods to facilitate the incorporation of Agile and open-source practices for the development and reuse of M&S assets, and to support the development of transdisciplinary understanding among M&S systems engineers.

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Author's Biography

Mr. Ric Roca

Mr. Ric Roca is a member of the Senior Professional Staff at The Johns Hopkins University Applied Physics Laboratory, Modeling & Simulation Group, VV&A Policy & Execution. He is serving as the Deputy Director of the Joint Enabling and Assessment Capability Office, Chief—M&S Branch, ODASD(R)/TRS through the Intergovernmental Personnel Act (IPA) Mobility Program. Mr. Roca has over 27 years of professional experience, primarily in federally-funded DoD M&S projects. He received a B.S.E. in electrical engineering from Tulane University School of Engineering, an M.S. in systems engineering from George Mason University, and is a Ph.D. candidate at the Old Dominion University M&S engineering program. His dissertation work is exploring the use of stereoscopic 3D virtual environments to leverage and study the adaptive properties of the oculomotor system to support visual skill training and research. He was a national finalist to the White House Fellowship Program based on a policy proposal advocating the proliferation of academic simulators as mediums to promote collaboration among federal government M&S researchers and public sector K-12 educators.

Introducing GAIA:

A Reusable, Extensible Architecture for AI Behavior

Author

Mr. Kevin Dill
Lockheed Martin Global Training & Logistics
kevin.dill@lmco.com

Abstract

TRAINING SIMULATIONS HAVE TRADITIONALLY USED TECHNIQUES SUCH AS SCRIPTING OR FINITE STATE MACHINES (FSM) FOR ARTIFICIAL INTELLIGENCE (AI) CONTROL OF NON-PLAYER CHARACTERS. THESE APPROACHES ALLOW THE SCENARIO CREATOR TO HAVE PRECISE CONTROL OVER THE ACTIONS OF THE CHARACTERS, BUT SCALE POORLY AS THE COMPLEXITY OF THE AI GROWS. ADDITIONALLY, THEY OFTEN GENERATE BEHAVIORS WHICH ARE RIGID AND PREDICTABLE, INSUFFICIENTLY REACTIVE TO UNEXPECTED SITUATIONS, AND NOT SUITABLE FOR REPLAY OR REPEATED USE. THE MOST COMMON ALTERNATIVE IS TO USE A HUMAN CONTROLLER, BUT THIS CAN LEAD TO PROHIBITIVE COSTS AND INCONSISTENT TRAINING QUALITY (PARTICULARLY IN SITUATIONS WHERE THE OPERATOR HAS DIFFICULTY OBSERVING THE TRAINING, OR WHEN THE OPERATOR IS RESPONSIBLE FOR SEVERAL SIMULTANEOUS TASKS).

IN A RELATED DOMAIN, THE LAST DECADE HAS SEEN A DRAMATIC INCREASE IN THE QUALITY AND COMPLEXITY OF THE AI FOUND IN MANY VIDEO GAMES. THE AI IS CUSTOM WRITTEN FOR EACH GAME. THE QUALITY OF THE AI IS OFTEN HEAVILY DEPENDENT ON THE SIZE OF THE BUDGET AVAILABLE WITHIN EACH PROJECT AND VERY LITTLE IS CARRIED FORWARD BETWEEN GAMES.

THIS PAPER PRESENTS THE GAME AI ARCHITECTURE (GAIA), WHICH USES A COMBINATION OF PROVEN GAME AI TECHNIQUES COUPLED WITH OTHER TECHNOLOGIES TO PRODUCE HIGH QUALITY AUTONOMOUS CHARACTERS WHO ARE REACTIVE, NONDETERMINISTIC, AND BELIEVABLE. IN ADDITION, GAIA SUPPORTS REUSE OF AI BEHAVIOR ACROSS MULTIPLE SCENARIOS AND MULTIPLE SIMULATION ENGINES. FINALLY, THE RESULTING BEHAVIOR IS EASILY EXTENSIBLE, ALLOWING USERS TO TAKE BEHAVIOR CREATED FOR A PARTICULAR CHARACTER IN A PARTICULAR SCENARIO, TRANSFER IT TO A DIFFERENT CHARACTER IN A DIFFERENT SIMULATION ENGINE, AND THEN EXTEND OR CUSTOMIZE IT AS NEEDED FOR THE NEW SCENARIO.

This paper describes the Game Artificial Intelligence (AI) Architecture (GAIA). GAIA is based on well understood game AI techniques, but supports reuse of AI behavior across multiple projects, even if those projects use different simulation engines. It builds on previous work on the Angry Grandmother character [1], [2], as well as aspects of the AI that the author created for Iron Man [3] and Red Dead Redemption [4], to create

characters that are autonomous, reactive, nondeterministic, and believable.

There is a distinction between an *AI architecture*, which is to say the computer code on which your characters are built, and the *AI configuration,* which are the settings, scripted commands, and other values that are used to control the behavior of a particular character (perhaps an insurgent, a sniper, or a vendor in a marketplace) within that architecture. To use a simple metaphor, the architecture is the type of canvas and paint that will be used to create a work of art and the underlying structure on which the work is done. The configuration is the actual painting. The same architecture (canvasses, oil paints, etc.) can be used to create many paintings, and different architectures (heavy art paper, construction paper, cloth, watercolors, pencils, chalk, crayons, etc.) have different advantages and disadvantages.

GAIA provides reusability at both the architecture and configuration levels. The architecture is built out of modular components such as reasoners, considerations, and actions, which are reusable. Thus, the code for each component is implemented once, but reused many times. This makes GAIA highly extensible, allowing one to rapidly implement the AI for characters by simply plugging together and configuring preexisting components, rather than writing new code from scratch.

In addition, the configurations themselves are reusable. Once the behavior for a sniper character is configured it can be reused elsewhere, even in a different simulation engine. Furthermore, the character can be used as a starting point for a new configuration—perhaps a guard, or a lookout. Thus, over time users can build up a library of configurations that can be reused or modified as needed, greatly reducing the cost of scenario creation.

Motivation

One can think of a training simulation as a piece of software which forces trainees through a particular decision-making process in order to teach them to better respond to similar situations in real life. Thus, the process of creating a scenario is one of *crafting an experience* that appropriately mimics real life, and that exercises the decision-making process that it is intended to train. This experience often includes characters—controlled either by a computer-driven AI or by a human operator—who fill all of the roles in the scenario other than those of the trainees.

If the simulation is going to provide *effective* training, then the trainee needs to be thinking about and reacting to the situation in the simulation in the same way that they would think about and react to a situation in real life. Thus, characters in the simulation need to act in the same ways that a real human would act—or at least create a sufficiently strong illusion of doing so that the trainee thinks about and reacts to them in the same way that they would with a human. In other words, characters need to create the *illusion of intelligence.*

Creating that illusion is often considered to be trivial for characters controlled by a human operator. There are several reasons why controlling a virtual character can be quite challenging, however. First, it may be difficult to see and understand everything that's happening in the simulation. Second, it may require the operator to select responses extremely quickly, which limits his/her ability to pick the best response (i.e., the one that will result in the most desirable training outcome). Third, the interface for specifying the desired response may be complex, making it hard to select the desired response in the time available.

In addition to the above challenges, operators with appropriate expertise are not always available, and represent an ongoing cost (i.e., you have to pay them for their labor). In comparison, AI configuration is a one-time cost. Once a working training scenario is developed, it can be used without further development costs. As a result, there is a strong desire for AI technology that will create configurations that can adequately replace human operators—but the resulting configurations *must* succeed at creating the desired training experience.

Close parallels can be drawn between the challenges involved in creating AI for training simulations and those involved in creating AI for video games. As with simulations, the process of creating a video game is one of crafting the experience for the user. As with simulations, creating AI for video game characters is a critically important part of that task. As with simulations, authorial control over the experience is critical, but at the same time the final

experience is highly *dynamic*. In other words, it's impossible to know everything that might happen every time a user plays the game. Thus, the AI needs to deliver the intended experience while still being flexible enough to handle unexpected situations on its own.

The last ten years has seen dramatic improvement in the quality of AI in many types of video games, and there are numerous books, articles, websites, and even whole conferences discussing the topic of AI for games (e.g., the AI Game Programming Wisdom series of books, the AIGameDev.com website, and the AI and Interactive Digital Entertainment conference). AI is typically written specifically for each game, however, with little if any reuse from previous efforts. This need for repeated reimplementation is not only tremendously expensive, it also prevents the developer from continuing to build on past success, and thus ultimately limits the level of quality that can be achieved to that which is possible within the scope of a single project.

The Game AI Philosophy

There is a distinct difference between AI as developed for games, and what one might think of as *traditional* or *academic AI*. We begin, then, with a discussion of the defining characteristics of game AI and how they differ from common academic approaches.

Avoiding Artificial Stupidity

Academic AI is typically focused on creating agents that are as intelligent as possible. That is, it attempts to create AI that will make the best decisions possible, but as a tradeoff it often accepts that the AI will occasionally make decisions that are wrong, or at least decisions that are not very human-like.

Games (and simulations), on the other hand, are focused on creating only the illusion of intelligence. In other words, the AI doesn't need to *be* intelligent as long as it *appears* intelligent. Success is attained any time the user thinks about and responds to the AI as if it were human, even if the underlying algorithm is actually quite simple. Similarly, failure occurs if the user's *suspension of disbelief* breaks—that is, any time that some action (or inaction) on the part of the AI reminds the user that the AI is only a machine program, and not a human.

It turns out that if the illusion of intelligence is the goal, it's less important to have the AI make decisions that are as perfect as possible, and more important to avoid decisions that are obviously, inhumanly wrong. For example, the AI must not walk into walls, get stuck on the geometry, fail to react when shots are fired nearby, and so on. Even some behaviors which actual humans display should be avoided, because those behaviors *appear* inhuman when performed by an AI-controlled character. For example, it is much more acceptable for a real human to change their mind—on the part of the AI, this gives the impression of a faulty algorithm.

If artificial stupidity can be avoided and reasonable behavior delivered, even if that behavior is not always the most appropriate choice possible, *the user will create explanations for what the AI is thinking that include far more complexity than is actually there.* This is the optimal outcome from the point of view of creating a compelling experience for the user.

Authorial Control

Academic AI typically seeks AI approaches that are as autonomous as possible. That is, general purpose problem solvers, solutions which require minimal human input (such as machine learning), and ultimately human-level intelligence. Games (and simulations), on the other hand, are precisely authored experiences in which developers are attempting to create a very specific experience for the user. They require the AI to be autonomous only to the extent necessary to support that goal.

Too little autonomy will cause the AI to be unable to respond appropriately to unexpected situations, resulting in the loss of the user's suspension of disbelief. This is obviously not the experience that the author had in mind. On the other hand, too much autonomy often leads to the selection of responses which also don't fit the experience that the author is trying to create. They might be appropriate to the situation, but they aren't what the author had in mind. They don't tell the story that the author wanted to tell. In the case of training simulations, they don't train the knowledge that the author wanted to teach.

As a result, game AI seeks to deliver *constrained autonomy* (i.e., characters performing autonomously within the bounds of the author's vision). This can be quite difficult to achieve, but is a critical aspect of success if characters are going to be more than scripted, predictable automatons.

Simplicity

Both the need for authorial control and the avoidance of artificial stupidity require that the configuration of game AI be an iterative process. Configuring an AI so that it will handle every possible situation—or at least, every likely one—while delivering on the author's intent and a compelling, human-like appearance, is far too difficult to get right on the first try. Instead, it's necessary to repeatedly test, find the worst problems, modify the AI to correct them, and then test again.

Brian Kernighan, a co-developer of Unix and the C programming language, is believed to have said that *debugging is twice as hard as writing the code in the first place. Therefore, if you write the code as cleverly as possible, you are, by definition, not smart enough to debug it.* The same advice could be applied to iterative development. Any time existing code changes, it is important to fully understand what's changing so that new bugs are not introduced in the process of fixing the old ones.

The Game AI community seems to have taken this advice to heart. If one looks at the sorts of decision-making algorithms used in games, they are typically quite simple. Of course, simplicity is relative. The fact that an underlying architecture is simple doesn't necessarily mean that configurations implemented using it won't be large and unwieldy. Furthermore, an architecture that allows one decision to be expressed in a simple and straightforward manner may be far more awkward when expressing a different decision. The game AI community continues to develop approaches which provide new and better ways to tame the complexity that is inherent in AI configuration.

Classic Approaches

This section describes several of the current most commonly-used approaches to AI control in training simulations. These approaches were also among the most popular for games 5-10 years ago, but are now typically only used on smaller, focused problems, or on games for which believable AI is not the primary focus.

Scripted AI

One classic architecture that has been widely used in both training simulations and video games is to write a script—much like the script for a movie or play—which specifies the detailed sequence of steps that the computer-controlled character should take. Because this script can be written with Subject Matter Expert (SME) input, it can be made to accurately reflect the actions that the character would take if the events in the simulation exactly match those expected by the script. A branching script can be written to contain a limited number of points where the AI will inspect the current situation and choose how to proceed. These branches allow a limited amount of responsiveness to events, but again those events have to be foreseen and the response fully encoded by the script creator (who is often a SME, not a software engineer or AI expert).

There are three significant problems with scripted AI. First, scripted AI has very limited reactivity. In other words, while it does a good job of creating a well crafted experience as long as the scenario progresses as envisioned by the author, simulations are by definition dynamic – that is, there is significant variability in the way that they can turn out. If a scripted AI ends up in a situation for which a branch was not explicitly written, it has no way to know what to do. If the resulting behavior is inappropriate to the actual situation then good training is unlikely to occur, and negative training may even result. Unfortunately, any scenario which contains enough variability to truly exercise the trainee's decision-making process is likely to be too complex to fully encode (even a game of Checkers is too complex to specify in this way) – the size of the state space is simply too large – so this sort of issue is almost certain to occur eventually.

The second problem is that scripts are too predictable. While users might get a good experience the first time that they train against a scripted scenario, when runs repeat the AI does the same thing each time. Trainees quickly learn to recognize and respond to these patterns, which is not the training objective.

Finally, scripted AI is extremely expensive to create, and is scenario specific. In other words, specifying complex behavior in this way is expensive and time consuming, and results in behavior which can't easily be ported or repurposed for a new scenario.

Despite their drawbacks, scripts are still widely used in certain types of games, although those games are typically quite different from most training simulations. For example, scripted AI is often used in games where it is more important for the AI to tell a story, and less important for it to handle the unexpected or to avoid predictability (such as role-playing games). Scripted AI is also often used in games that make a benefit of predictability, where the challenge is for the user to learn what the AI will do and then counter it.

One other use of scripted AI which is applicable to training simulations is to have a high level AI which is responsible for overall decision-making, but which selects scripts that handle implementing the behavior that it selects. GAIA supports simple scripts of this sort.

Finite State Machines

Another classic architecture is the Finite State Machine (FSM) or Hierarchical Finite State Machine (HFSM). In this architecture, states are defined to represent the core things that the character can do, while transitions define the conditions under which the AI will change from one state to another.

An example FSM for an insurgent AI, shown in figure 1, might have states for guarding a position, firing its weapon (when an enemy comes close), reloading, fleeing, dying, and so forth. It might transition from guarding to firing when an enemy is spotted, from firing to reloading when its magazine is empty, from firing to fleeing when most of its buddies are dead, etc.

The fundamental problem with FSMs is that as the number of states grows, the number of possible transitions grows exponentially. Furthermore, they are limited to the behavior changes described by the transitions. If two states don't have a transition between them then there is no way to switch from one to the other. For example, characters using the simple FSM in figure 1 will not die if hit while

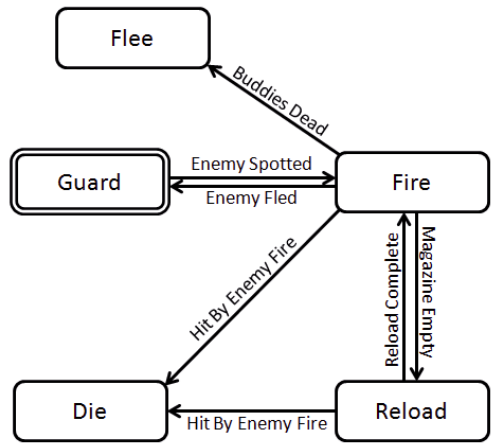

Figure 1: A Simple FSM

guarding or while fleeing, and if most of their buddies die while they are reloading then they will go back to firing before they flee. As a result, while the FSM architecture is quite simple, configurations quickly become complex and difficult to modify as they grow. HFSMs can improve on this by breaking the problem into sub-problems, but at the cost of even more restrictions on the ability to transfer between states.

As with scripts, there are specific situations where FSMs are appropriate. In particular, FSMs are commonly used for animation control. In this case, they closely map to the problem being addressed. Animations can be represented very naturally as states, with the transitions between them—whether animated or blended—represented as FSM transitions. Two of the most popular middleware solutions for animation control take this approach [5], [6].

Academic AI

Another solution that is frequently seen in training simulations—although much less so in games—is to use academic AI. Academia has been wrestling with AI for several decades longer than the game industry, and many of the techniques used in games can trace their roots back to academic AI. In particular, the field of behavior-based robotics has generated numerous innovations which were later adopted or re-invented by the game industry.

As described above, the fundamental goals of academic AI are quite different from those of game AI. Where

games—and training simulations—typically need focused solutions which provide authorial control and simplicity while avoiding artificial stupidity, much of academic AI is more focused on the big hard problems—general purpose problem solvers, large scale autonomy, optimal or near-optimal solutions, and ultimately human level intelligence. This research is tremendously fascinating and important, but not necessarily applicable to the game industry's short term needs.

In other words, scripting and FSMs give too *little* control to the AI, making it difficult to get sufficient reactivity and resulting in high costs, difficult-to-change configurations, and inappropriate behavior when an unforeseen situation occurs. Academic AI, on the other hand, often gives too *much* control to the AI, resulting in difficult-to-eliminate moments of artificial stupidity and/or behavior that doesn't match the author's intent.

Modern Game AI Alternatives

Ten years ago the vast majority of games used either FSMs or scripted AI, and machine learning approaches were viewed as the most exciting upcoming technology. Over the last decade, however, FSMs and scripted AI have become much more niche solutions, and machine learning has largely been abandoned for use in games—despite the fact that it does very well in other domains. In their place, two solutions have risen to prominence.

Behavior Trees

Behavior Trees (BTs) have become wildly popular in the Game AI community and have largely replaced HFSMs, particularly for games which don't require as much autonomy. The architecture grew out of the behavior-based robotics community, such as the work of Kaelbling [7] and Nilsson [8]. The term "Behavior Tree" is believed to have been coined by Damian Isla to describe the architecture that he built for Halo 2 [9].

A BT consists of a hierarchy of *selectors*, each of which chooses among several options. These options can either be concrete (i.e., something the character will actually do), or they can contain another selector with its own options. Control works its way down through the tree of selectors until it arrives at a concrete option.

BTs have several major benefits, which make them easier to configure and more flexible than previous approaches.

Hierarchy: When configuring an AI, one has to consider the relative importance of each pair of options that might be selected. The number of such pairs is the square of the number of options, so the difficulty of tuning the AI can be exponential on the number of options that it contains. If one splits decision-making into multiple separate steps, each of which selects from among a fraction of the options, configuration becomes dramatically easier. In other words, $x \bullet (\frac{n}{x})^2 = \frac{1}{x} \bullet n^2$, so breaking the selection from among n options into x steps reduces the complexity of configuration to (roughly) $\frac{1}{x}$ what it would otherwise be.

One way to accomplish this sort of subdivision is to build a hierarchy of decisions, each of which focuses on the big picture and defers the implementation details to a lower place in the hierarchy. Thus, the top-level selector makes only the big picture decision, picking the main action that the AI should be doing. Implementation of the selected option can then be delegated to a sub-selector, which makes the highest level decision as to how to proceed and delegates non-trivial implementation details.

Focused Complexity: In addition to subdividing the problem, each selector can use a different decision-making algorithm. This is significant because different decisions are more tractable to different algorithms. Thus, increasing overall simplicity by using the type of selector allows each decision to be expressed in the most elegant way possible.

Traditionally, BTs use very simple selectors, typically employing purely Boolean logic or random selection [9]. However, there is nothing inherent in the architecture that prevents the creation of selectors that use more complex approaches. Allowing more complex selectors achieves focused complexity. That is, using simple approaches wherever possible for the reasons discussed above, but using more complex algorithms only where that complexity is necessary to create the desired experience for the users. The result is a best-of-both-worlds mix of complexity where it is necessary, and simplicity everywhere else.

Modularity: Subtrees are modular, which is to say that a given subtree can be referenced from multiple places in the tree. This prevents the need to re-implement

functionality every place that it is used, and creates the possibility of at least limited reuse within the scope of a game or scenario—significant work still needs to be done in order to allow reuse across multiple games or simulation engines.

Utility-Based AI

Most of the approaches presented so far tend toward purely Boolean decision-making—when they reach a branching point they have a check that returns a clear yes or no answer. In an FSM for example, one either takes a transition or not—FSMs are usually implemented such that you take the first valid transition found.

In contrast, utility-based AI uses a heuristic function to calculate the goodness (i.e., the utility) of each option, and then that utility is used to drive decision-making. This is typically done by taking the option with the highest utility (absolute utility selection), or by using the utility as a weight when selecting from among options (weight-based random selection). More recently, architectures have been developed that use two utility values, one of which is an absolute utility value while the other is used for weight-based random selection [2].

The benefit of utility-based AI is that it allows the AI to take the subtle nuance of the situation into account when making a decision, as opposed to picking at random or simply taking the first option that it finds. In situations where more than one option is valid, utility-based AI will base its decision on an evaluation of the relative appropriateness and/or importance of each option.

As an example, imagine the AI for a character in combat. Perhaps there are bullets being fired in the vicinity, a hand grenade somewhere nearby that is about to explode, and an allied combatant who has been hit and is in need of immediate first aid. A purely Boolean approach would evaluate the possible actions in some order and take the first which is valid. For example, it might always respond to hand grenades if there are any in the area. If no hand grenades are present then it might always respond to bullets, and only when there are neither bullets nor hand grenades would it consider helping the wounded teammate.

This sort of AI is not only far too black-and-white to be realistic, it is also highly predictable and easily exploitable by the trainee. A real human in this situation would have a tremendous number of factors that might affect his decision. For example: How close are the bullets? Do I have cover? Do I know of any hostile flanking forces? How close is the hand grenade? Am I in the kill radius? Am I wearing a flak vest? Is my teammate threatened by the hand grenade? How badly is he wounded? Is he somebody that I know well (i.e., how willing am I to risk my life for him)?

Using a utility-based approach, developers build heuristic functions which evaluate the answers to each of those questions, and quantify the relative value of each possible response. As a result, the final decision will depend on a detailed evaluation of the situation. Furthermore, if a similar situation occurs in the future, or if the user runs through the scenario a second time, the result will probably be different because the details of the situation are unlikely to be exactly the same. If more variability is needed, one can select randomly from among reasonable responses, making the AI even less predictable while still ensuring that the selected action makes sense. For example, utility-based AI can be used to create an AI that will usually seek self-preservation, but that still has a small chance to decide to be heroic and run into hostile fire to save the buddy, or to dive on top of the hand grenade.

Utility-based approaches aren't new to either academic or game AI. One common complaint is that they can be challenging to configure, particularly for an inexperienced developer. This gets easier with practice, however, and techniques for subdividing the problem and reusing partial solutions (such as hierarchy and modularity) can help dramatically as well. In general, the end result is worth the effort for applications that require deeper, more nuanced decision-making. As a result, utility-based AI has been widely used in those types of games which have significant variance in the breadth of situations that can occur. For example, most strategy games (e.g., the Empire Earth [10] or Sid Meier's Civilization [11] series) and sandbox games (e.g., The Sims [12] or Zoo Tycoon series) use utility-based AI. In recent years, as games have become larger and more complex, more and more games have found utility to be a useful tool in the creation of AI behavior, either as the primary decision-making architecture, or in conjunction with some other architecture (e.g., embedded in a BT or HFSM).

For those interested in learning more about the craft of building utility functions, *Behavioral Mathematics for Game AI* is an excellent place to begin [13].

The Game AI Architecture

The goal of the GAIA effort is to build an AI architecture which is highly extensible, allowing developers to quickly create new configurations or modify configurations which already exist. In addition, the architecture should enable reuse of configurations within a particular scenario, across multiple scenarios, and even between scenarios built on entirely different simulations engines. This section describes the architecture's core decision-making modules.

The GAIA architecture draws heavily from the BT architecture's modular, hierarchical structure. The core decision-making logic consists of four types of components: reasoners, options, considerations, and actions. Reasoners are responsible for the actual decision-making. They select from among options. The options have considerations, which guide the reasoner in its deliberations, and actions, which are responsible for making appropriate things happen in the simulation.

Each of these components has a base class which defines its interface. Numerous subclasses are defined within the GAIA layer, and simulation-specific subclasses can be created as well. We have a factory system which takes an object definition in extensible markup language (XML) and constructs the appropriate subclass, configured appropriately. Thus an AI configuration is created by defining the top-level reasoner and all of its components, including subreasoners, in XML.

Reasoners

One key realization exposed by the BT architecture is that different approaches to decision-making are appropriate for different decisions. Thus, multiple types of selectors exist. Reasoners fill the same role in GAIA as selectors in a BT, except they are not limited to simple Boolean or random selection. This allows use of a complex reasoner for specific decisions where that level of complexity is appropriate, while retaining simplicity everywhere else.

With this philosophy in mind, the reasoner interface (shown in figure 2) can allow any approach to decision-making to be implemented as a reasoner. To date we have implemented a scripted reasoner (the Sequence Reasoner) and several different utility-based reasoners: the Simple Priority Reasoner, the Weighted Random Reasoner, and the Dual Utility Reasoner. FSMs and teleo-reactive programs are envisioned as likely next steps.

Options

As figure 2 suggests, reasoners contain a set of options and function by selecting an option for execution. Options don't have much functionality in their own right. They are primarily just containers for considerations and actions,

```
// Enable/Disable the reasoner. Called when the containing action is selected
// or deselected, so as to start or stop decision-making.
virtual void        Enable(AIContext* pContext);
virtual void        Disable(AIContext* pContext);

// Suspends/Resume the reasoner. When the reasoner is suspended, its internal
// state is maintained so that it picks up where it left off when it resumes.
virtual void        Suspend(AIContext* pContext);
virtual void        Resume(AIContext* pContext);

// Pick an option for execution, suspend or deselect the previous option, and
// update the selected option so that its actions can execute
virtual void        Think(AIContext* pContext);

// Find out whether the reasoner has anything selected, and if so, what.
bool                HasSelectedOption() const;
AIOptionBase*       GetSelectedOption();
```

Figure 2: The Reasoner Interface

although they do have a flag which specifies whether they should suspend or deselect the previously executing option when they are selected. Their interface is shown in figure 3.

```
// Called when the option starts/stops execution.
virtual bool    Select(AIContext* pContext);
virtual void    Deselect(AIContext* pContext);

// Suspend/Resume the option.
virtual void    Suspend(AIContext* pContext);
virtual void    Resume(AIContext* pContext);

// If true then the reasoner should suspend the previously executing option
// when this option is selected, rather than deselecting it.
virtual bool    PushOnStackWhenSelected();

// Called every frame while we're selected. Executes our actions.
virtual void    Update(AIContext* pContext);

// Returns true if all of our actions have completed, false otherwise.
bool            IsDone(AIContext* pContext);
```

Figure 3: The Option Interface

Considerations

Considerations are responsible for evaluating the situation. Each type of consideration evaluates a particular aspect of the situation, and then those evaluations are combined together to indicate the overall validity of the option. The consideration interface is shown in figure 4.

```
// Called once per cycle, evaluates the situation and stores the result.
virtual void    Calculate(AIContext* pContext);

// Return the results of Calculate().
virtual float   GetBaseWeight() const;
virtual float   GetMultiplier() const;
virtual float   GetForce() const;

// Certain considerations need to know when we are selected or deselected.
virtual void    Select(AIContext* pContext);
virtual void    Deselect(AIContext* pContext);
```

Figure 4: The Consideration Interface

To give a few examples, the *Should Take Cover* consideration evaluates whether shots have been fired within some radius of a specified position. The *Is Hit* consideration evaluates whether or not the character has been hit by hostile fire. The *Message* consideration evaluates whether a particular message has been received from the simulation (messages may be generated when the operator sends a command to the character, for example).

In addition to these external considerations, which query information from the simulation, there are internal considerations which track the AIs internal state. For example: the Is Done consideration checks whether all of the associated actions have finished execution; the Timing consideration checks how long the option has (or has not) been executing; and the Time Since Failure consideration checks how long it has been since the option failed to execute when selected by the reasoner. Finally, the Tuning consideration returns fixed values specified in XML, and can be used to set up a default indication of the option's validity.

The above considerations are among the more commonly used, but countless other examples exist. Information that is expected to have an impact on decision-making needs to be expressed as a consideration. In the combat example with the hand grenade, hostile fire, and wounded ally, one might have considerations for evaluating the distance to the grenade from a given position (i.e., from our position or the position of the wounded ally), the distance to the bullet impacts from a given position, whether we have cover from the shooter(s), the angle between known hostile units (to determine flanking units), the current medical condition of the wounded ally, and so on.

There are many ways in which a particular consideration could affect the evaluation of an option. For example, there might be an option which is a really good choice when under fire. On the other hand, a different option might

be an absolutely horrible choice while under fire, even though it is normally pretty good. In both of these cases one might use a *Should Take Cover* consideration, but the configurations would be different. Thus, each would return the appropriate values given the actual situation.

Considerations return their evaluation in the form of a force, a base weight, and a multiplier. The force for the option is calculated by taking the maximum of the forces returned by the considerations, while the option's weight is calculated by first adding up all of the base weights, and then multiplying the resulting value by all of the multipliers. This is discussed in more detail in [2].

AI developers typically use the option's force as absolute utility, while using the option's weight for weight-based random selection. However, each reasoner implementation can use the considerations however it chooses, including not using them at all. For example, the sequence reasoner doesn't evaluate its options but just executes each one in order. If at some point in the future there is a need to add complexity to the considerations—such as adding support for exponents or polynomial curves—this can be done as long as default values are provided in the base class that ensure all current considerations continue to function as designed.

The key advantage of considerations is that they allow reuse of the evaluation code. For instance, many options should not be reselected for a certain period of time after they are deselected so as to avoid obvious and unrealistic repetition. Thus, a *Timing* consideration is used to apply a cooldown. Similarly, many options should only be selected if shots have been fired nearby, or if a particular message has been received from the simulation, or if they have not failed to begin execution recently. One can configure the AI's decision-making simply by specifying the considerations to apply to each option in XML. This can be done more rapidly and far more safely than we could write C++ code for the same decisions. This consideration-based approach was a key factor to rapidly create the AI for both Iron Man and Angry Grandmother.

Actions

Actions are the output of the reasoning architecture—they specify what should happen if their option is selected. Their interface is shown in figure 5.

```
// Called when the action starts/stops execution.
virtual void      Select(AIContext* pContext);
virtual void      Deselect(AIContext* pContext);

// Suspends/Resume the action.
virtual void      Suspend(AIContext* pContext);
virtual void      Resume(AIContext* pContext);

// Called every frame while we're selected.
virtual void      Update(AIContext* pContext);

// Check whether this action is finished executing. Not all actions finish.
virtual bool      IsDone(AIContext* pContext);
```

Figure 5: The Action Interface

Options can have more than one action, which allows creation of separate actions for separate subsystems. For example, a single option could contain separate actions to set a character's expression, gesture animation, and lower body animation, as well as an action that specifies a line of dialogue to play, all executing simultaneously. However, parallel actions need to be used with caution, as different simulation engines may or may not be able to support them.

There are two types of actions: *concrete* actions and *subreasoners*. Concrete actions are hooks back into the simulation code and cause the character under control to do something (e.g., play an animation, fire a weapon, move to a position, play a line of dialogue, etc.). Subreasoners contain another reasoner which may be of the same type or a different type from the action's parent reasoner. Thus, hierarchy is created by having a *top level reasoner* which contains options with one or more subreasoners.

Reusability

Most aspects of simulations are reused extensively. There are simulation engines, such as Virtual Battle Space 2 (VBS2), Real World, or Unity, which are used for many simulations. There are terrain databases and libraries of character models and animations that can be carried from simulation to simulation, even across different simula-

tion engines. There are even AI architectures, such as AI.Implant, SOAR, or Xaitment, that see reuse. To date however, little work has been done to find ways to reuse the AI configurations.

In other words, if one creates a compelling character for a particular scenario, the character model, animations, and dialogue can be reused, but there is no easy way to reuse the AI configuration which specifies behavior. Instead, every new training simulation requires that a new set of AI configurations be implemented, even for behavior that is very similar to that which has come before. Occasionally reuse occurs by way of copy and pasting from one configuration to the next, but this is at best ad hoc and not sustainable over the long term. Configuring the AI typically takes far more time than implementing the architecture, and yet the vast majority of that work is not reused! The result is a dramatic increase in the cost of scenario creation, as well as a limit to the level of AI quality that can be achieved.

The game industry has no answers. The conventional wisdom among game developers is that games are too different for behavior from one game to be useful in another. If one looks at the end result, there are core behaviors which are the same across a great many games, many of which are also needed for training simulations. For example, many first-person shooters and squad-level infantry training simulations feature behaviors such as fire and maneuver, use of cover, call-for-fire, use of improvised explosive devices, sniper behavior, ambushes, suicide bomber behavior, breaking contact, and so forth. If a library existed containing configurations like these then each new project could start with fully functional behaviors, rather than having to build basic competence from scratch. In some cases developers might need to modify their reused behaviors to fit the specifics of the scenario being developed, but this iteration would need to be performed whether it started from existing behavior or not.

Simulation standards such as the High Level Architecture (HLA) and Distributed Interactive Simulation (DIS) are proof that this sort of reuse is possible. While the information that passes between the simulation and the AI is not the same as what those standards contain, it is similar in scope and type. If simulation data can be standardized, then it should be possible to standardize AI data as well.

The SENSE–THINK–ACT Loop

The SENSE–THINK–ACT model is a standard representation of the AI process, and is widely used in both games and simulations. Using this model, each decision-making cycle begins by sensing the state of the world—that is, gathering up all of the data needed for decision-making. Next, the AI thinks, which is to say that it processes both this sensory data and its internal state, and selects appropriate responses. Finally, it acts, which means that it sends commands back into the simulation which cause the selected responses to be executed. This decision-making cycle typically occurs quite frequently (often 30-60 times a second).

Examining this model, the portion of the AI available for reuse is the decision-making process—that is, the "think" step. If developers wrap that step using clean interfaces for the sensory data (its inputs) and actions (its outputs), then they can encapsulate the logic that defines AI behavior in a simulation-agnostic way.

Toward that end, virtual parent classes have been created at the GAIA level. The simulation layer is expected to implement child classes which provide the simulation-side functionality, as well as factory classes which allow those children to be created and configured from XML. Thus on the sensory side, the GAIA layer defines the member variables and query functions which the AI will use, while relying on the simulation layer to populate those member variables with data. On the action side, the GAIA layer defines the control data which specifies how the action is to be executed (e.g., the *Fire* action includes the target to shoot at, as well as data describing the timing of the shots, the number of shots per burst, and the number of bursts to fire), while relying on the simulation layer to provide the implementation which will appropriately execute the action by making simulated bullets fly.

Of course, it is unavoidable to make assumptions about the simulation engine when creating these interfaces. Since every new engine is different, the interfaces are unlikely to be a perfect fit. Thus, the process of integration often includes implementing simulation-level functionality that GAIA assumes to exist, and may also include ignoring GAIAs decisions in certain cases where the simulation has its own system for handling some aspect of the AI. For example, the VBS2 integration includes limited path-

planning capabilities because the built-in path planner is insufficient. It also ignores actions that raise or lower the character's weapon, and instead lets the AI in VBS2 handle that aspect of the character's performance.

Integration to a new engine is a time-consuming process, but it is still only a subset of the work that would be needed to implement a new AI architecture. Any new AI would have to include all of the integrated functionality as well.

Data Representation

Abstracting the AI's decision-making logic away from the simulation is one of the greatest challenges when finding a simulation-agnostic representations for the data. This section will discuss some of the representations that have been chosen. While there is not sufficient space to be comprehensive, other data representations typically mimic those discussed here.

Characters: The AI will typically need to know a variety of information about each character in the simulation to include both AI-controlled characters and those controlled by trainees. This includes details such as the character's name, role, and side, as well as its position, orientation, and velocity. All of this information is wrapped within the `AICharacterData` structure. It is expected that the simulation will provide data for each character and update it regularly.

The Blackboards: One easy way to share information between decoupled classes is to provide a shared memory structure which both classes can see. With that in mind, GAIA includes a *global blackboard* that specifies much of the information that the AI needs to know. For example, the global blackboard holds all of the character data, as well as a list of shots fired and where they landed. The simulation is expected to implement some mechanism for populating that information and keeping it up to date. Typically this is done using a child class.

In addition to the global blackboard, each character has a local blackboard which holds character-specific data.

Targets: There are a great number of considerations and actions which need a target position, orientation, or both. For example, the *Move* action needs to know where to move, the *Turn* action needs to know what direction to face, and the *Fire* action needs to know who to shoot. Given the broad use of this concept, building an architecture to support it consists of a base class and factory following the same pattern as the core AI components (i.e., the considerations, actions, options, and reasoners). Thus, one can have targets that represent the position of the camera, the closest trainee, a particular character by name, or just an XML-specified position or orientation.

Ranged Values: When configuring AI behavior, it is often useful to be able to specify a range of valid values. For example, one might want to have an option that is valid when shots are being fired between 5-15 meters away. One might want to have a character fire between 3 and 5 rounds per burst. One might want to perform a particular behavior for 10-15 seconds before selecting something new. Again, the wide-spread use of this concept is supported through a templatized ranged value class, which can support storage and input from XML of the min and max values, as well as random selection of values within the specified range.

Time: GAIA contains two classes for representing time. `AITime` represents absolute time (i.e., the current clock time, or the elapsed time since the simulation was started), while `AITimeDelta` represents elapsed time (i.e., the difference between two `AITimes`). For example, storing the time when a particular option was most recently selected requires an `AITime`. On the other hand, a *Timing* consideration that prevents an option from executing for more than 13 seconds requires an `AITimeDelta`.

In addition, the `AITimeManager` is a singleton which keeps track of the current time in the simulation. By default it uses the `clock()` function from `time.h`, but the simulation can, and probably should, replace this generic implementation with their own time manager. This allows the AI to respect features such as pausing the simulation or speeding up/slowing down execution.

Strings: Strings are an extremely convenient way to represent configuration data, particularly within XML, because they are easily human readable. However, they are wasteful of memory and expensive to compare. Consequently, GAIA provides the `AIString` and `AIStringTag` classes. Both of these compute a hash value using the djb2 algorithm

[15], which is inexpensive to compute and allows for cheap, constant-time comparison. `AIStringTag` discards the original string to conserve memory, while `AIString` retains it for later use.

Results

The GAIA architecture inherits the advantages of the BT architecture in that it is hierarchical and modular. Like the BT, it allows the most appropriate reasoner to be used at each point in the hierarchy, but it also supports much more complex reasoners. This allows one to use complex approaches where they are necessary while limiting that complexity to only the decisions that require it. In addition, considerations provide modularity at the level of individual decisions, which enables the rapid creation of logic for evaluating each option.

As discussed above, the ideas of hierarchy, modularity, and focused complexity have been used with success on several past projects. In particular, hierarchy and focused complexity allow developers to iterate much more quickly and safely, while the decision-level modularity provided by the considerations enables them to create significantly complex AI much more rapidly than previously possible.

By far the most ambitious goal of this program is the desire to create reusable behavior, which has had good initial success. Scenarios have been implemented for IITSim—the simulation engine used to control mixed reality characters at the Marine Corps' Infantry Immersion Trainer, at Camp Pendleton, CA—and ported to VBS2. This resulted in the same scenarios running in both engines using identical configuration files and AI libraries, but different terrain and character models.

This result is particularly hopeful since the underlying simulation engines are quite different. IITSim is an engine with source code access and direct control of the AI, whereas the VBS2 integration sits on top of that engine's scripting interface and existing AI. Of course, these behaviors are quite simple. They are a good first test case, but further work will need to be done in order to extend this work to more complex characters.

Conclusion

This paper presented the Game AI Architecture, which is an approach to AI for training simulations that embraces hierarchy, modularity, and focused complexity in order to provide AI behavior that is highly extensible and reusable. The architecture's extensibility has been demonstrated through multiple extremely successful past projects, but the reusability remains a work in progress, though early results are encouraging. One key requirement for success will be the definition of clean interfaces which describe the interactions between the AI and the underlying simulation engine.

Acknowledgements

The author would like to thank the U.S. Army Research, Development, & Engineering Command (RDECOM) and the U.S. Marine Corps Warfighting Laboratory (MCWL) for their generous support of this work.

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Author's Biography

Mr. Kevin Dill

Mr. Kevin Dill is a Staff Software Engineer at the Lockheed Martin Advanced Simulation Center and the Chief Architect of the GAIA program. He is a recognized expert on Game AI and a veteran of the game industry, with seven published titles under his belt. He was the technical editor for *Introduction to Game AI and Behavioral Mathematics for Game AI*, and a section editor for *AI Game Programming Wisdom 4*. He has taught classes on game development and game AI at Harvard University, Boston University, and Worcester Polytechnic Institute.

This paper was originally published as 12S-SIW-046 in Proceedings of the 2012 Spring Simulation Interoperability Workshop (SIW). Copyright 2012, by the Simulation Interoperability Standards Organization, Inc.

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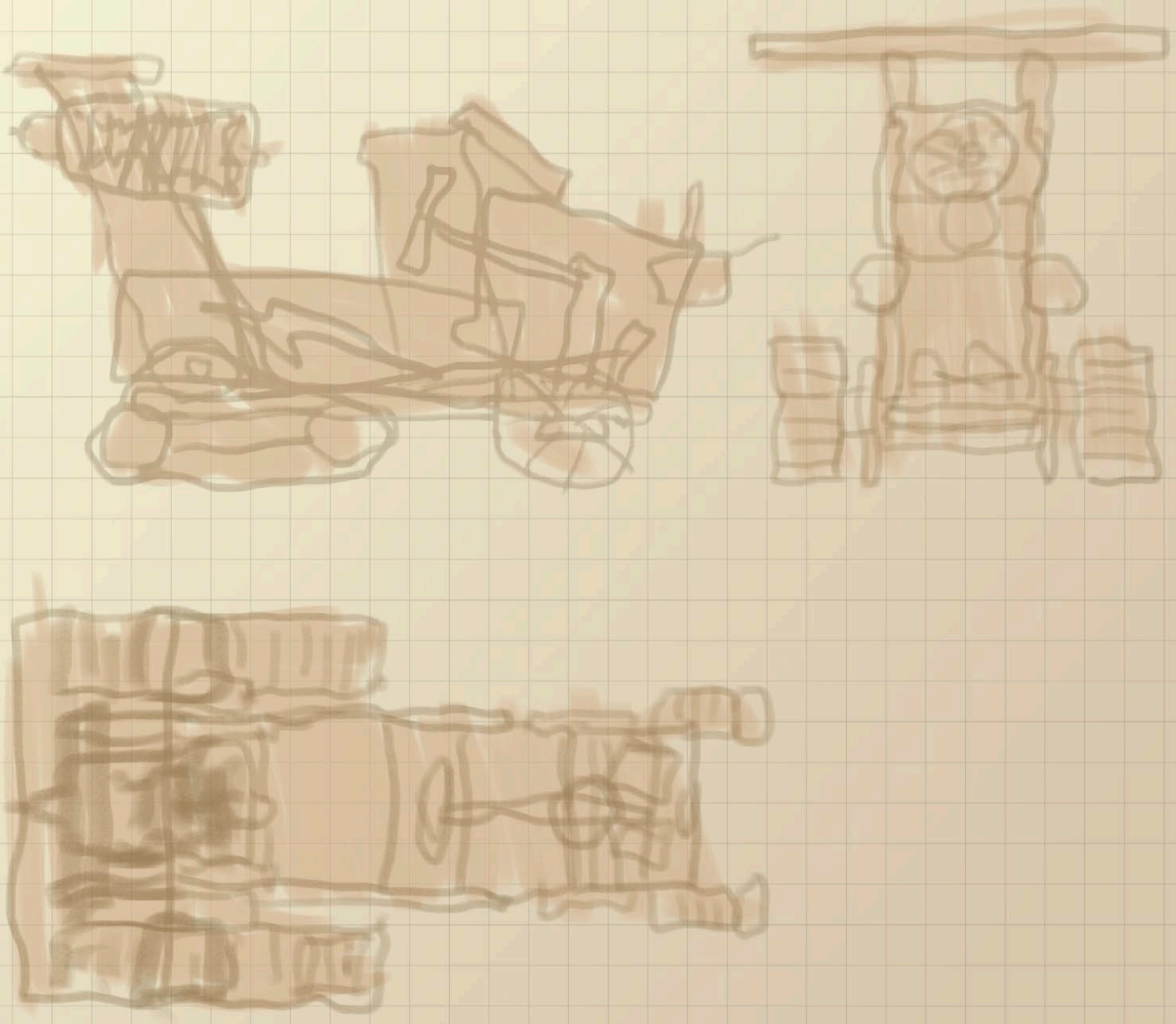

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Fall Edition 2013
Volume 8 Issue 3

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