

Foundations '02 Executive Summary

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The *Workshop on Foundations for Modeling and Simulation (M&S) Verification and Validation (V&V) in the 21st Century*, better known as **Foundations '02**, was held October 22-24, 2002 in the Kossiakoff Conference and Education Center at the Johns Hopkins University Applied Physics Laboratory in Laurel, Maryland (USA). This Executive Summary describes the Foundations '02 vision (including its background), identifies what Foundations '02 leadership (Program Co-chairs and General Chair) believe were its initial principal findings, presents key future challenges for M&S V&V, and lays out current follow-on plans for Foundations '02. These follow-on plans show how insights from Foundations '02 can be shared with the M&S community, matured into greater completeness, and evolve toward a roadmap of specific actions to support significant technical advances in M&S V&V.

The Vision -- Foundations '02 was designed to address four significant issues related to modeling and simulation verification and validation (M&S V&V):

1. need for articulation (at the college textbook level) of the current state of the M&S V&V art – textbook level M&S V&V material does not exist except in the computational science and engineering arena;
2. need for an up-to-date comprehensive bibliography of M&S V&V materials – the last comprehensive bibliography was nearly a decade old;
3. need for a coherent and extensive (if not comprehensive) synopsis of M&S V&V research needs; and
4. improvement in communications about V&V across various M&S community boundaries with an eye toward exchange of lessons learned and leveraging opportunities to encourage broader use of best practices.

The crucial nature of these issues is evidenced by the fact that twenty-eight organizations endorsed the Foundations '02 Workshop and agreed to serve as sponsors (see Table ES-1 at the end of this Executive Summary). Sponsors come from a broad spectrum of M&S and software communities, representing both domestic and international interests. Ten of the sponsors are government organizations; eight are academic institutions; six are professional societies concerned about M&S; and four are from industry.

The Approach -- The Foundations '02 approach to establishing V&V state of the art (issue 1 above) was to identify key V&V application areas and to have a substantive paper (at the college textbook level) developed by acknowledged experts in the field. The paper provided a technical basis for informed discussion of the topic which allowed identification of potential caveats, alternative perspectives, etc. The resulting product -- the combination of the paper, its briefing, and its discussion -- basically articulates the state of M&S V&V art in that area. Foundations '02 structured its agenda with adequate time for substantial presentation of these invited papers and in-depth discussion of their topics. In addition to the invited paper sessions designed to formulate the state of the art in V&V, Foundations '02 had sessions on eight special interest topics of M&S V&V significance (see Table ES-2 for a listing of invited paper and special interest topics).

Papers prepared for Foundations '02 pointed clearly to the state of V&V art, and having competent V&V practitioners participating in paper discussions ensured that balanced and comprehensive perspectives were obtained. The 198 Foundations '02 participants provided the expertise necessary to achieve Foundations '02 objectives. The participants came from many different M&S communities, providing both breadth and depth to the discussions; their distribution was approximately:

- 40% from the U.S. Defense community (both government and supporting contractors)
- 15% from other U.S. government organizations (i.e., Department of Energy, NASA, FAA, NIST)
- 25% from academia (many of whom support various government activities)
- 10% from other industry organizations
- 10% from outside the U.S. (Belgium, Canada, France, Germany, and the United Kingdom).

The diversity of participants was so much greater than that for most M&S V&V meetings that a substantial beginning was made to improve communications about V&V across M&S community boundaries, facilitating the sharing of insights and best practices from outside one's immediate associations (issue 4 above). Moreover, the ability to look at M&S V&V practices from such a broad spectrum of M&S experience allowed a more comprehensive assessment of the state of the V&V art than would have been possible otherwise.

Another product resulting from Foundations 02 is an up-to-date M&S V&V bibliography (issue 2 above). It was primarily drawn from contributions provided by Foundations '02 participants. The Foundations '02 V&V Bibliography contains more than 600 entries, most of which date from the mid-1990s to the present.

Initial Statement of Principal Findings -- A number of themes were repeated frequently by Foundations '02 participants in plenary sessions and in discussion synopses. These themes constitute some of the initial principal findings from Foundations '02, elaboration of which will come from continued consideration of material in the Foundations '02 proceedings:

- The primary motivation for M&S V&V is risk reduction, i.e., to ensure that the simulation can support its user/developer objectives acceptably. This provides the benefit side for cost-benefit concerns about V&V, which is the core issue in the question of how much V&V is needed.
- Effective communication is a problem because there continues to be differences in the details about terminology, concepts, and V&V paradigms among various M&S communities – and excessive use of acronyms makes it difficult to communicate easily across community boundaries.
- Advances in M&S framework/theory can enhance V&V capabilities, and is essential for increasing automated V&V techniques.
- Limitation in items required for effective V&V (required data and detailed characterization of associated uncertainties and errors, simulation/software artifacts, etc.) have to be faced and addressed, with many of the management processes for coping with them being common in many areas of simulation application.
- Cost and resource requirements for M&S V&V are not as well understood as they need to be because meaningful information about such is not widely shared within M&S communities, and much more information about cost and resource requirements needs to be collected and made available to facilitate development of more reliable estimation processes.
- Many areas of M&S V&V need to employ more formal (repeatable and rigorous) methods to facilitate better judgments about appropriateness of simulation capabilities for intended uses.

A synopsis of M&S V&V research needs (issue 3 above) was developed from papers prepared for Foundations '02, their discussion, and suggestions from Foundations '02 participants. The M&S V&V community is faced by two very different kinds of challenges. One set of challenges relate to M&S management (or implementation): *how to do what we know how to do*. The other challenges have a research flavor: *areas that we need to understand better in order to find viable technical solutions*. We discuss both below.

Management Challenges: Three management (implementation) challenges stand out: *qualitative assessment*, appropriate and effective *use of formal assessment processes*, and M&S/V&V *costs/resources* (accounting, estimation, benefit). The challenge is how to ensure that “best practices” are employed where they exist and are pertinent.

- 1) **Qualitative Assessment.** Qualitative assessment involves human judgment in assessment: “peer review,” “subject matter expert (SME)” evaluation, face validation, etc. Often people involved in qualitative assessments are selected and perform their assessments without appropriate credentials and/or formal processes. Methods exist, which if used, can increase qualitative assessment objectivity and consistency.
- 2) **Formal Assessment.** Formal assessment, whether statistical in nature or following some other rigorous mathematical approach, can be difficult to employ fully. The management challenge is development of appropriate “light-weight” variants of the processes which can be more easily employed in M&S V&V to enhance the quality of formal assessments.
- 3) **Costs/Resources.** Correct estimation of resources needed is a primary challenge in any M&S application. Inadequate information is currently available for reliable estimation of M&S V&V costs/needed resources. The management challenge is to collect and organize appropriate cost and resource information (from case studies and other sources), making it available to the M&S community so robust methods for M&S/V&V cost/resource estimation can be developed.

Research Challenges: Four research challenges stand out: *inference*, coping with *adaptation*, *aggregation*, and *human involvement/representation*.

- 1) **Inference.** Data availability to support assessment of simulation “predictions” is a fundamental problem, especially for the test and evaluation community on the operational side and the experimental community on the science side. Comparison of simulation results with the available data can be described statistically and data-simulation result relationships can be specified in terms of accuracy, error, resolution, etc. for the region of the application domain for which data exist; *but no scientifically rigorous methods currently exist for making inferences about relationships between simulation results (“predictions”) and elsewhere in the application domain*.
- 2) **Adaptation.** Advances in technology have led to a new genre of computational programming, termed adaptive programming. Techniques employed in adaptive programs include artificial intelligence (AI), expert systems, genetic algorithms, fuzzy logic, machine learning, etc. As adaptive processes become more capable and more widely incorporated in

M&S, the V&V challenge is clear: the M&S performance can differ from instance to instance and therefore presents fundamental challenges to the prediction and assessment of performance. *No scientifically rigorous methods currently exist to ensure future M&S performance involving adaptive programming will be as good as or better than past performance.*

- 3) **Aggregation.** Elements and interactions of a simulation can be represented in varying levels of detail. As simulations become more complex, especially in the case of distributed simulations which may use more than one level of resolution for the same kind of element or interaction, better methods for determining the potential impact on simulation results from such variation in levels of detail are required to minimize potential misuse of simulation results. *Present theory and assessment processes related to this topic are embryonic.*
- 4) **Human Involvement/Representation.** Representation of human behavior in simulations is widely recognized as being critical; the complexity of representing the variety of human behavior in an automated way that appropriately reflects impacts of the simulated situation on human decision making and performance is a major challenge. The critical stumbling block is uncertainty about influences of factors and processes involved for many kinds of simulation applications. Although better understanding exists about simulation V&V when people are involved for education/training purposes or to represent human behavior in the simulated situation, there are still many significant research issues concerning interactions among simulation characteristics, the people involved, and appropriate simulation uses.

The V&V research challenges for these four areas are to develop clear and coherent definition of expected M&S performance under various conditions. Other important research challenges for M&S V&V are also identified in the Foundations '02 proceedings, such as those involving the theoretical foundation for M&S V&V and aspects of visualization in M&S V&V.

Follow-on – We now turn our attention to what lies ahead, both immediately and in the longer term. The first step is publication of the Foundations '02 proceedings so that others may use insights from Foundations '02 to advance M&S V&V capabilities. The next step is to ensure that the M&S community is aware of insights from Foundations '02 and how they can be helpful; otherwise some will not avail themselves of this resource. The third step is to interact with others in M&S communities to mature and evolve Foundations '02 insights into specific plans of action that will enhance our ability to determine that M&S have adequate correctness to fully support their intended uses. Each of these steps is discussed briefly below. Their consequences are also addressed.

- **Proceedings:** *V&V State of the Art: Proceedings of Foundations '02, a Workshop on Model and Simulation Verification and Validation for the 21st Century* will be published by The Society for Modeling and Simulation International/Society for Computer Simulation (SCS) in December 2002 on CD. The CD will contain all papers, presentations, and discussion synopses of Foundations '02 plus the V&V bibliography and Foundations '02 background material. Basically the same material will be available to the public via the Defense Modeling and Simulation Office (DMSO) website from mid-November 2002 for about a year.
- **Awareness:** Presentations based upon insights from Foundations '02 are currently planned for Interservice Industry Training, Simulation and Education Conference (I/ITSEC, December 2002), the Spring and Fall Simulation Interoperability Workshops (SIWs, March & September 2003), the Military Operations Research

Society Symposium (MORSS, June 2003), and the Summer Computer Simulation Conference (SCSC, July 2003). Papers drawing upon Foundations '02 insights are also expected at conferences sponsored by the U.S. Association of Computational Mechanics (USACM), American Institute of Astronautics and Aeronautics (AIAA), American Society of Mechanical Engineers (ASME), and Joint Army Navy NASA Air Force (JANNAF) Interagency Propulsion Committee. This Executive Summary and appropriate briefings will be provided for Foundations '02 sponsors and related organizations.

- **Research Funding:** Specific M&S V&V research suggestions will be developed in adequate detail for funding agencies to consider seriously. Basic ideas contained in the Foundations '02 proceedings will be matured and focused through interactions with M&S V&V community members, and then targeted for appropriate agencies.
- **Increased Professionalism:** This has two different thrusts: one educational and the other related to normal procedures employed by V&V practitioners.
 - It is expected that the academic community will begin to incorporate M&S V&V more explicitly and extensively into various curricula and that some will even take material in the Foundations '02 proceedings and elaborate it into textbooks related to specific V&V application areas.
 - It is also expected that various organizations and professional societies will produce “best practices” and other V&V guides (using the Foundations '02 material as a starting point).
- **Increased Communication Across Community Boundaries:** Many at Foundations '02 discovered insights in different M&S communities that could improve their capabilities. Some will communicate individually with those in other communities. This will be very helpful, but it will not have the community-wide impact needed to benefit all. Structured interaction is necessary for that. Part of the structure needed for communication across community boundaries can occur through established professional societies. Because M&S V&V is only a small part of such societies (even of those focused on M&S), this is unlikely to stimulate the substantial cross-community communication needed. Also, most professional society meetings do not usually support the kind of in-depth V&V exploration that happened at Foundations '02. Numerous suggestions were made during Foundations '02 and since about the potential value of holding a workshop similar to Foundations '02 every 2-3 years to continue articulation of the advancing state of M&S V&V art and to facilitate cross-community communications.

This Executive Summary addresses *initial* findings of Foundations '02. It does not contain the more detailed ideas and plans that we expect in the future from Foundations '02 stimulated insights. Those who participated in Foundations '02 and others who are exposed to insights in Foundations '02 materials are expected to develop the V&V art beyond where we are at present, benefiting all M&S communities. We believe that these improvements in M&S V&V will be substantial and will result from various influences.

- The Foundations '02 V&V bibliography will broaden the knowledge base of many V&V practitioners.
- Some improvements will result because more of the M&S community will become aware of what we know how to do, our current state of the V&V art.
- Some improvements will result from more insistence upon best practices as these become more widely known in M&S communities through developing standards and guides so that V&V practitioners more often do what we know how to do, and do it well.
- Some improvements will result from increased V&V instruction in academic programs and in the workplace, from progress in particular V&V research areas, and from computational advances.

The consequence of these improvements will be better simulations and better awareness of simulation capabilities so that they are more likely to be used appropriately and more fully support their application objectives.

Table ES-1

Foundations '02 Sponsors

(28 organizations which endorse addressing the Foundations '02 objectives)

- Association for Computational Machinery (ACM) Transactions on Modeling & Computer Simulation (TOMACS)
- Aegis Technology Group, Inc.
- American Society of Mechanical Engineers (ASME) Applied Mechanics Division (AMD)
- Arizona Center for Integrative Modeling & Simulation (ACIMS)
- Boeing Phantom Works
- Center for Economic Research (CentER), Tilburg University (Netherlands)
- Clemson University
- **Defense Modeling and Simulation Office (DMSO) – primary initiating sponsor**
- Federal Aviation Administration (FAA) Flight Standards Service
- Gesellschaft für Informatik (Bonn, Germany)
- Illgen Simulation Technologies
- Innovative Management Concepts, Inc. (IMC)
- **Johns Hopkins University/Applied Physics Laboratory (JHU/APL) – facility provider**
- Joint Accreditation Support Activity (JASA)
- **Modeling and Simulation Subcommittee of the Joint Army Navy NASA Air Force (JANNAF) Interagency Propulsion Committee – initiating sponsor**
- McLeod Institute of Simulation Sciences -- California State University (CSU), Chico
- Ministry of Defence (UK) Synthetic Environment Coordination Office
- Modeling & Simulation Information Analysis Center (MSIAC)
- NASA Ames Research Center
- National Institute of Standards and Technology (NIST)
- **National Training Systems Association (NTSA) – hosting sponsor**
- Office of Naval Research (ONR)
- Shodor Education Foundation, Inc.
- Simulation Interoperability Standards Organization (SISO)
- Survivability/Vulnerability Information Analysis Center (SURVIAC)
- The Society for Modeling and Simulation International (SCS)
- United States Association for Computational Mechanics (USACM)
- University of Central Florida Institute for Simulation and Training (UCF/IST)

Table ES-2

Invited Paper & Special Interest Topic Session Topics

- A1: Verification Technologies
- A2: Validation Methods and Technologies
- A4: SME Use in M&S V&V
- A5-T5 combined session: Formal Methods in V&V
- A6: M&S Foundations
- B1: Computational Science/Engineering V&V
- B2: V&V for HWIL/System in Loop M&S
- B3: V&V of M&S with People or HBR
- B4: Estimating V&V Resource Requirements
- B5: V&V of M&S with Adaptive Processing
- B6: V&V of Multi-Resolution M&S
- T1: V&V Education in Academia
- T2: Managing V&V
- T3: V&V Research
- T4: V&V Issues re M&S Reuse
- T6: V&V Tools, Templates, and Resources
- T7: V&V Policies, Guides, Standards
- T8: V&V Education in the Workplace