

A Vision for Modeling and Simulation at APL

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APL's Science and Technology (S&T) Vision calls on the Laboratory to be "an excellent practitioner" in modeling and simulation (M&S), while looking to others to lead in this area. In fact, APL has made significant M&S contributions to sponsor programs throughout its existence. Because of the rapid advances in computing and networking technologies over the past two decades, being an excellent practitioner demands maintaining cognizance of the rapidly advancing state of the art and practice in M&S in order to ensure that the high-technology military and civilian programs that APL supports can capitalize on these advances. This article provides a brief overview of the state of the practice of M&S at the Laboratory and describes a vision and strategy for APL to maintain its role in this area.

INTRODUCTION

Modeling and simulation (M&S), in general usage, refers to the process of representing an entity and its behavior. Although the terms *model* and *simulation* have varying definitions in the technical literature, this article uses the definitions adopted by DoD (Ref. 1; also a good source for definitions of other M&S-related terms used in this article):

- *Model*: A physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process
- *Simulation*: A method for implementing a model over time

There are many ways of categorizing models and simulations (see Ref. 2 for one such example), but no generally accepted complete taxonomy. This article adopts a method, adapted from Ref. 3, that defines four *views* by which such a categorization can be done:

1. *Application domain*—The problem area addressed by the model or simulation, such as transportation, space physics, or various military warfare areas
2. *Resolution level*—The amount of detail or degree of aggregation employed in the model or simulation used (different application domains often represent this as a "pyramid" of levels, such as those shown in Fig. 1)
3. *Role*—The general function with which the model or simulation is associated (e.g., DoD roles such as analysis, training, acquisition, or experimentation)
4. *Technique*—The particular distinctive method(s) used by the model or simulation to accomplish its purpose (static or dynamic, deterministic or stochastic, continuous or discrete, time-stepped or event-driven, distributed, hardware-in-the-loop, etc.)

A single model or simulation will generally have one or more characteristics in each of these views.

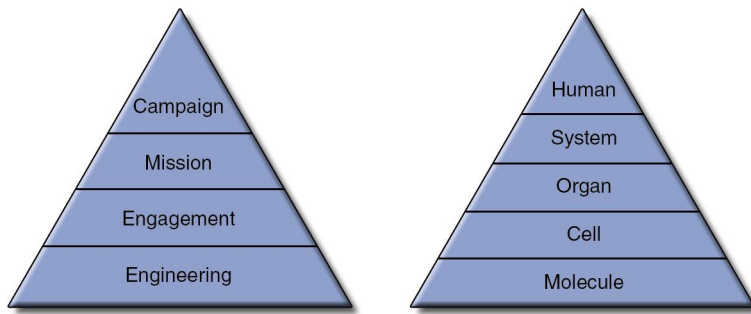


Figure 1. Examples of M&S resolution levels: (left) military simulations and (right) physiological models.

Providing a comprehensive review of all M&S activities at APL is not the intent of this article; to do so would require a much lengthier treatment. Rather, the intent is to outline a vision and strategy for APL to remain an M&S excellent practitioner in the future. In keeping with the intent, this article provides only a brief overview of the state of the practice of M&S at APL, using the above views as a means of characterizing and distinguishing the nature of the M&S work performed at the Laboratory. Several (but certainly not all) areas of APL M&S expertise are highlighted, and a few examples of our M&S activities are cited. (For more detailed information on M&S use at APL, see Refs. 4–6.)

THE STATE OF THE PRACTICE OF M&S AT APL

M&S has been a key technology area since APL's inception in the early 1940s and continues to be pervasive, as evidenced by program documentation (models and simulations are being used in every Laboratory business area and department), by continuing professional interest (e.g., over 60 internal M&S seminars have been held since 1997), and by anecdotal information (abundant mentions of M&S use appear in APL staff resumes, etc.).

As noted in the *APL Science & Technology Vision*,⁷ the Laboratory intends to “be an excellent practitioner, but will look to others to lead in” the M&S area of science and technology (S&T). As noted therein, in addition to the pervasiveness cited above, a small cadre of APL staff forms a niche element of DoD M&S leadership, and innovative APL M&S practitioners provide critical contributions to ongoing Laboratory activities in a number of areas. Moreover, because of the rapid advances in computing and networking technologies over the past two decades, being an excellent practitioner demands maintaining cognizance of the rapidly advancing state of the art and practice in M&S to ensure that the high-technology military and civilian programs that APL supports take advantage of these advances.

A TAXONOMY OF M&S USE AT APL

By combining the four views of models and simulations cited earlier with representative characteristics that can be used to describe models and simulations according to those views, an attempt can be made to define a taxonomy of models and simulations used at APL. The taxonomy is not purely hierarchical, but rather descriptive, with one or more characteristics within each of the views being used to describe

any individual model or simulation. Figure 2 shows this potential taxonomy, with the characteristics shown under each view being an APL-oriented subset of all the characteristics that might be used in each view for all models and simulations in existence.

In the application domain view, APL M&S activities can be characterized quite well simply by using the taxonomy of current Laboratory business areas. For example, just as many of APL's “traditional” business areas map to warfare areas (e.g., Air and Missile Defense, Undersea Warfare [USW], Precision Engagement, Strategic Systems), a significant portion of APL's M&S expertise and applications map to these same application domains. Similarly, APL's M&S expertise in the space science and satellite engineering application domains is traceable to the work performed in the Civilian Space and National Security Space business areas.

In the resolution level view, one has to first use the application domain as context. For example, using the military simulation pyramid shown in Fig. 1 as a reference, and recognizing that there is not always a clear line of demarcation between levels of resolution, one can characterize APL's military simulation work as having components across all levels (although campaign-level work is relatively limited). The Laboratory's considerable engineering and engagement simulation expertise tends to be concentrated in the departments associated with systems engineering in individual warfare areas. Expertise in mission-level simulations tends to be broadest in the National Security Analysis Department, where multiwarfare analysis requires a variety of such simulations, but mission-level simulations for specific mission areas are also employed in several other departments.

In the role view, M&S use follows the historical roles that APL has had for its major sponsors—principally in the areas of system development/acquisition, analysis (including operations research), and test and evaluation activities. Nevertheless, there are niche areas of M&S expertise at the Laboratory in other M&S roles, including such areas as the training of system operators, the

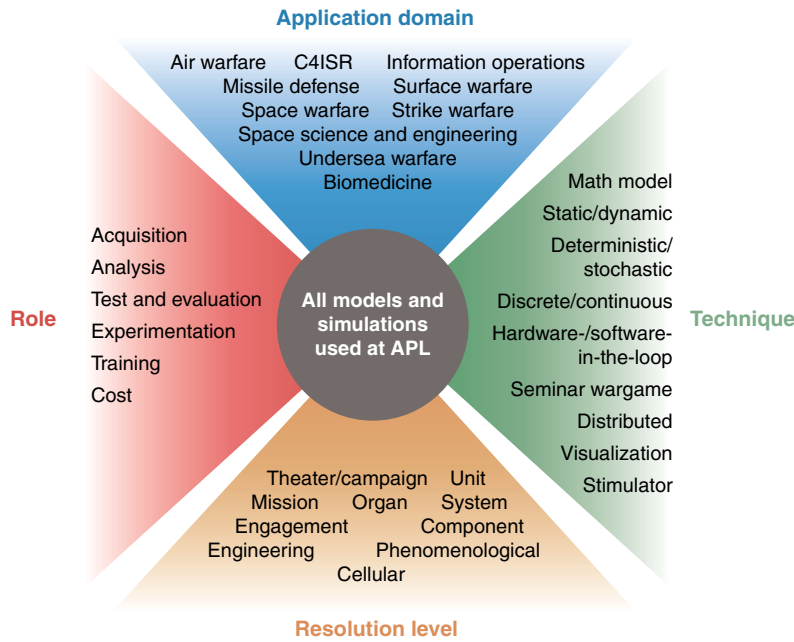


Figure 2. A potential taxonomy for models and simulations used at APL: four views and sample characteristics. (C4ISR = command, control, communications, computers, intelligence, surveillance, and reconnaissance.)

modeling of jamming systems, and cost analysis for system development and use.

In the technique view, APL has made significant use of constructive simulations (simulations involving simulated people [or none at all] operating simulated systems) across multiple levels of the military simulation pyramid, involving both deterministic and stochastic methods as well as both continuous and discrete time management, depending on the application. But there are also significant examples of hardware- and software-in-the-loop simulations (e.g., the Guidance System Evaluation Laboratory [GSEL] and the Wrap-Around Simulation Program [WASP]); stimulators (hardware/software that injects signals into the sensor system(s) of operational equipment to imitate the effects of entities or the environment); static mathematical models; specialty-area uses of distributed simulations; and what may be referred to as complex adaptive systems (e.g., agent applications and genetic algorithms).

AREAS OF APL M&S EXPERTISE

Given the breadth of the M&S activities cited previously, it is difficult to rank with any degree of confidence the relative levels of competence that APL possesses in all of these areas. Nevertheless, it is possible to cite several areas in which many observers would characterize APL as having notable M&S expertise. These areas might be characterized as *broad*, *specialty*, and *emerging*. Within each area, it is possible to identify one or

more specific efforts that illuminate that expertise. Once again, however, it is not possible here to enumerate all areas of APL M&S expertise or even to provide a comprehensive treatment in the areas mentioned. The reader is again referred to previous issues of the *Technical Digest* for more detailed discussions in specific areas of individual interest.³⁻⁵

Broad Areas

In view of its longstanding history working in Navy fleet defense areas, APL has a broad area of expertise in *ship and missile system engagement simulation*. This area, while focusing on the engagement level of resolution in the taxonomy of Fig. 2, spans the application domains of missile defense as well as air, surface, strike, and undersea warfare. It has historically focused on the acquisition, analysis, and test and evaluation roles and has involved most of the special simula-

tion techniques shown in Fig. 2. Just a few of the many examples from this area are the AN/SPY-1 FirmTrack simulation, the Standard Missile family of six-degrees-of-freedom (6-DOF) simulations, the Ship Self-Defense System simulation, the GSEL hardware-in-the-loop simulation, the WASP for the Cooperative Engagement Processor, the Trident II 6-DOF trajectory simulation, and several Tomahawk Missile simulations.

Another area of recognized broad APL M&S expertise is *environmental modeling*, spanning the environments of the ocean, the atmosphere, and space. Radar propagation over the open ocean and in littoral environments has significant effects on ship-based sensor systems, and APL has needed to develop an understanding of these effects. One example of APL model development in this area is the Tropospheric Electromagnetic Parabolic Equation Routine electromagnetic propagation simulation. In conjunction with the emerging interest in more complex urban environments, APL's Research and Technology Development Center is also researching 3-D electromagnetic propagation codes. In the space science and engineering application domain, environmental effects on APL spacecraft, as well as characteristics of the space environment itself and effects on the Earth, have long been studied using models and simulations in APL's Space Department.

In addition, because of its longstanding involvement in USW for the Navy, APL has developed a significant capability in acoustic propagation modeling, supported by a variety of codes. This capability has been extended

to permit normally computationally intensive representations of environmental effects to be represented in lower-resolution computer simulations using cluster analysis to categorize the range of environmental effects over the parameter space of interest. This technique, developed in the Multi-resolution Interaction Validity project (Fig. 3), has been more recently used to develop acoustic environment inputs for DoD's Joint Warfare System campaign-level simulation.

A third broad area of APL M&S expertise is *naval mission modeling*, particularly in those areas where the Laboratory also has the technical underpinning of higher-resolution models, such as in air warfare, missile defense, and USW. This mission modeling has been used significantly in force-level analysis and also to support acquisition system decision making. Examples of APL-developed simulations in this area include the Battle Force Engagement Model (BFEM), used primarily for anti-submarine warfare modeling; the Object-oriented Rule-Based Interactive System (ORBIS), used primarily (but not exclusively) in the USW area; and the Surface Anti-Air Warfare Multi-ship Simulation (SAMS), used primarily for Navy fleet anti-air warfare analysis. APL also uses other mission-level simulations developed elsewhere in the DoD M&S community, including the Extended Air Defense Simulation (EADSIM), Suppressor, the Joint Integrated Mission Model, and the Naval Simulation System (NSS), among others. APL has also recently become significantly involved in the Office of the Chief of Naval Operations' "World-Class Modeling" initiative, which is an effort to improve models and simulations used for decision making, with significant emphasis on simulations at the mission and campaign levels.

Selected Specialty Areas

In the area of *operations research*, groups in several APL departments use a variety of M&S tools in combination with experimental design and stochastic optimization techniques. Such techniques can be used to reduce the number of model or simulation executions necessary to understand and analyze the solution spaces of various problems. A detailed treatment of stochastic

methods can be found in Ref. 8. A number of APL staff members have been, and continue to be, involved in leadership capacities and as presenters in the Military Operations Research Society, which sponsors periodic conferences and symposia on the application of operations research techniques to military problems.

APL also has expertise in survivability and vulnerability M&S and in the modeling of jamming effects. Survivability/vulnerability modeling has been performed for the Tomahawk program and for the Multi-mission Maritime Aircraft (MMA), for example. In the latter case, the Enhanced Surface-to-Air Missile Simulation (ESAMS) was used to perform RF survivability analysis.⁹ More generally, APL is actively involved in improving modeling tools through interactions with the Survivability/Vulnerability Information Analysis Center. Some applications in the modeling of jamming systems have included simulations to predict the performance of strategic communication links in jamming environments and to predict the performance of turbo codes in jamming environments for the Navy and Air Force.

With advances in computer networking over the past 10–15 years, the specialty area of *interoperable simulation engineering* has emerged, which falls under the distributed technique of Fig. 2. This area is one in which APL has a very credible capability as well as a leadership role in the development of standards. With the publication of the first DoD M&S Master Plan in 1995,¹⁰ the Defense Modeling and Simulation Office (DMSO) embarked upon the creation of the High Level Architecture (HLA) standard for simulation interoperability. APL has had a significant role throughout the development of the HLA and its associated Federation Development and Execution Process, including its migration to become the IEEE Standard 1516. APL staff members currently have prominent roles in the evolution of this standard. (See Ref. 11 for a description of one Laboratory contribution to this.) In addition, APL now serves as a trusted agent for DMSO in verifying that each implementation of commercially produced HLA RunTime Infrastructure implementations conforms to the HLA standards prior to their use by DoD customers.

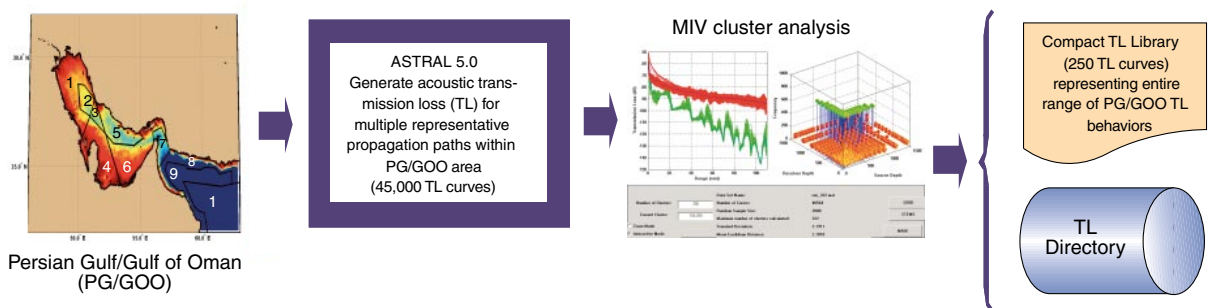


Figure 3. Development of Global 2001 war game acoustic TL Library using Multi-resolution Interaction Validity (MIV).

The Laboratory has also produced several HLA simulation federations, both under internal funding and for directly funded programs. Two directly funded efforts are the APL Remote TBM Engagement Missile/Ship (ARTEMIS) simulation, a high-fidelity integrated end-to-end Navy Ballistic Missile Defense simulation,¹² and the Human Exercise Federation, a physiological simulation of an astronaut exercise protocol developed for the National Space Biomedical Research Institute.¹³ More recently, under internal funding, APL has federated five of the simulations mentioned in the previous section (BFEM, NSS, EADSIM, ORBIS, and SAMS) to form the APL Integrated Multi-warfare Simulation (AIMS). Techniques from the initial AIMS development effort were subsequently applied by APL in the development of the Modeling and Simulation Acquisition Support Environment for the Navy's MMA program.

Improving the credibility of defense models and simulations is a challenge that requires not only technical capability, but also a process, which has become known as *verification, validation, and accreditation (VV&A)*.¹⁴

- *Verification*—The process of determining that a model implementation and its associated data accurately represent the developer's conceptual description and specifications
- *Validation*—The process of determining the degree to which a model and its associated data provide an accurate representation of the real world from the perspective of the intended uses of the model
- *Accreditation*—The official certification that a model, simulation, or federation of models and simulations and its associated data are acceptable for use for a specific purpose

The development of VV&A processes and the application of those processes to ensuring the credibility of specific models and simulations are also areas of expertise in which APL has played a leadership role. The Laboratory has provided a staff member to serve as the Technical Director for VV&A at DMSO since 1997 with responsibility for drafting and coordinating DoD VV&A policy¹⁴ and for leading the development of the DoD M&S VV&A Recommended Practices Guide, a web-based source of accepted VV&A practices used throughout the DoD M&S community. APL has performed a leading role in Tomahawk simulation management for over a decade, which is heavily focused on ensuring the validity of simulations used for that system. APL has also performed a variety of VV&A projects, most often focused on validation and accreditation assessment of models and simulations, for several Navy organizations, joint commands, and DoD agencies.

Selected Emerging Areas

With the increasing emphasis on network-centric systems, both for warfighting and for the gathering and

processing of intelligence, APL is increasing its expertise in *network modeling*. Although communications modeling is a key element of this, it also includes the "softer" cognitive aspects of command and control and intelligence analysis. In the communications area, APL has made significant use of OPNET, which has become a *de facto* standard for modeling communications at the engineering level, to model traditional communications systems, various concepts for such network-centric communications architectures as those envisioned for the Army's Future Combat Systems, and elements of information operations such as defense against network attacks. Looking to the future, APL is also performing research and development using M&S of fundamental network construction concepts applicable to the Global Information Grid (GIG) and has explored the use of process modeling tools as a means of representing and evaluating the performance of systems with architectures defined according to the DoD Architecture Framework (DoDAF).

As military systems become more complex, the need to ensure that the operators of those systems can run them effectively becomes even more important. Although training has not historically been a primary role for APL, in the last decade or so, a specialty area of expertise in *PC-based training simulation* has emerged. The first documented APL application in this area was the Ship Control Training Program, a series of ship control simulators built to replicate the systems and instrumentation in submarine control centers,¹⁵ which built upon the Laboratory's experience with Trident submarine system evaluation. This work later evolved into larger-scale multi-year training simulation efforts, including the trainer for the Advanced SEAL Delivery System (Fig. 4). APL has also constructed PC-based simulators for the law enforcement community¹⁶ and for training military chaplains in selected aspects of their activity. This work led to the spin-off of a new company, SIMmersion, LLC, in 2002.

A VISION AND STRATEGY TO REMAIN AN EXCELLENT M&S PRACTITIONER

Simply stated, APL's vision for its M&S S&T area is

To remain an excellent practitioner in M&S, sought after by its sponsors to bring established and emerging M&S capabilities to bear in supporting APL's contributions to its sponsors' critical challenges.

For APL to achieve this vision demands a multi-element strategy with the following four pillars (Fig. 5):

Pillar 1—Stay Strong in, and Build upon, Broad Areas of Expertise

Staying strong in, and building upon, broad areas of expertise, although ostensibly the easiest of the four elements to achieve, nevertheless requires attention.



Figure 4. Prototype of the Navy SEAL combatant submersible simulator.

APL’s business base in its traditional areas is likely to be healthy for the foreseeable future, so there is clearly the opportunity to remain strong in ship and missile system engagement simulation, environmental modeling, and Navy mission modeling (and several other areas). Nevertheless, each of these areas can be expected to advance in the larger M&S community, and maintaining APL’s recognized expertise will require some effort. Although direct funding may often permit the improvement of modeling techniques and simulation tools, there are likely to be some areas where maintaining expertise and tools, as well as M&S development and analytic processes, will require the application of internal investment funds.

Pillar 2—Seek Opportunities to Contribute in Specialty Areas

In many specialty areas of APL M&S expertise, such as the aforementioned interoperable simulation

engineering and VV&A, there tends to be a smaller market and less continuity in direct funding on a yearly basis, with efforts likely to be a succession of projects rather than a stable long-term program. In these areas, including any APL M&S specialty areas that could emerge over the next several years, the strategy needs to be one of actively seeking additional opportunities in which to contribute. This involves “staying connected” in the segments of the M&S community that require such expertise and showing how the successful performance of past efforts is applicable to new problems as they emerge.

Pillar 3—Apply Existing Expertise to Grow in Identified Emerging Areas

APL’s ability to apply its existing M&S expertise to grow in identified emerging areas, such as network modeling and PC-based training simulations, is in many cases linked to the sustained importance of the emerging application areas for the M&S capability. For example, network modeling has grown in importance with the emergence of the DoDAF for describing systems and the plans for the implementation of the GIG. As long as network-centricity remains a key concept in defense planning, network modeling to support this concept will continue to be important, and APL can apply its existing M&S expertise to grow in this area. Similar arguments could be made for models and simulations to support capability-based planning, in conjunction with the still-evolving Joint Capabilities Integration and Development System.

Pillar 4—Stay Attuned and Contribute to Technology/Process Advances

Staying attuned and contributing where possible to M&S technology and process advances requires both staying connected to and “being a player” in the broader M&S community. This necessitates participation in M&S conferences and workshops, particularly those associated with M&S applications in APL’s business areas, and seeking leadership positions both in those activities and in special M&S studies and panels when opportunities arise (e.g., the aforementioned OPNAV World-Class Modeling initiative). Just as *simulation interoperability* emerged as a key M&S technology area a decade ago, model and simulation *component interoperability* (which refers to the ability to compose existing model and simulation

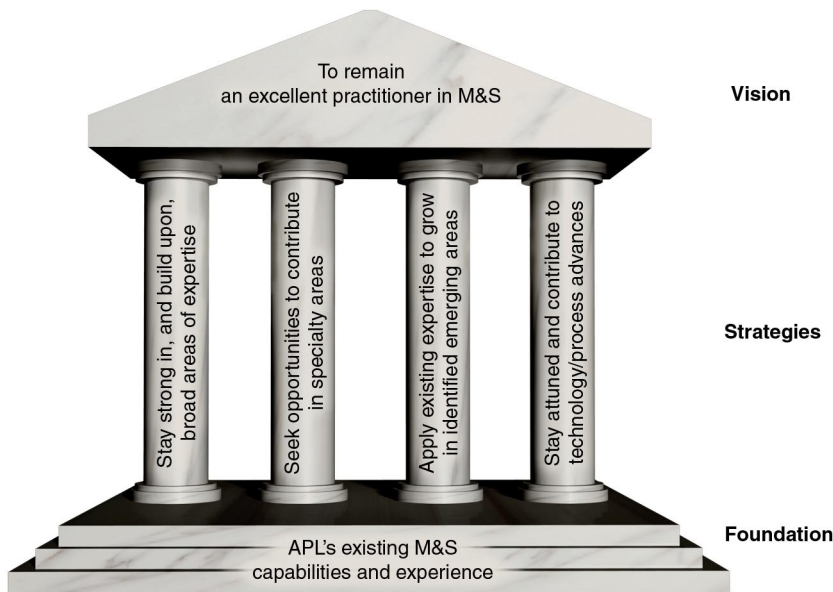


Figure 5. Achieving APL’s S&T vision in M&S.

components, and involves semantic as well as syntactic issues) seems to be emerging as a key M&S technology area that deserves APL attention.

CONCLUSION

Modeling of systems and their components and simulation of their behavior over time have been an important part of APL's work since its inception 60 years ago. As computer and information technology has advanced, APL's capabilities in M&S have increased accordingly, enhancing the ability to provide significant contributions to many sponsored programs and solidifying APL's reputation as an excellent practitioner in M&S.

Achieving the vision of remaining in that role requires far more than maintaining current capabilities. It requires continued attention to evolving the existing capabilities, seeking opportunities in special areas of strength, applying expertise to emerging areas, and being aware of and participating in the advancement of M&S technology. APL's future in the application of models and simulations to challenging defense, security, and scientific problems remains bright, but will require both management attention and technical contributions to achieve the vision.


ACKNOWLEDGMENTS: The characterization of models and simulations using four views presented in this article is based on one devised by Dr. Dale K. Pace. Dr. Pace has been a recognized contributor, and a prolific author, in the M&S community for a significant period of time, particularly and most recently in the area of VV&A process and recommended practice development. With his retirement from APL in

February 2005, APL and the M&S community at large will miss his many valued contributions.

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