Arizona Center for Integrative Modeling & Simulation

University of Arizona

Arizona State University

3rd Revision, Jan. 2002

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Preamble

In the recent past, modeling and simulation (M&S) tools have reached the market place that are oriented toward particular application disciplines and enable a wide spectrum of knowledge workers to formulate and effectively develop solutions to their current problem sets. However, due to the rise of increasingly multifunctional and interacting systems that include both natural and artificial elements, the multidisciplinary nature of the emerging problems defies existing approaches and techniques. This new breed of problems require concepts and tools that support both generic, as well as domain-specific, representations, in collaborative and distributed M&S environments. The Arizona Center for Integrative Modeling and Simulation (ACIMS) will be devoted to research and instruction that advance the use of M&S as means to integrate disparate partial solution elements into coherent global solutions to multidisciplinary problems. To do this, the Center will bring together the facets shown in Figure 1, advancing the concepts, tools, and methodology of M&S so that it can make the enormous computation power on the horizon applicable to emerging problems requiring multidisciplinary solutions.

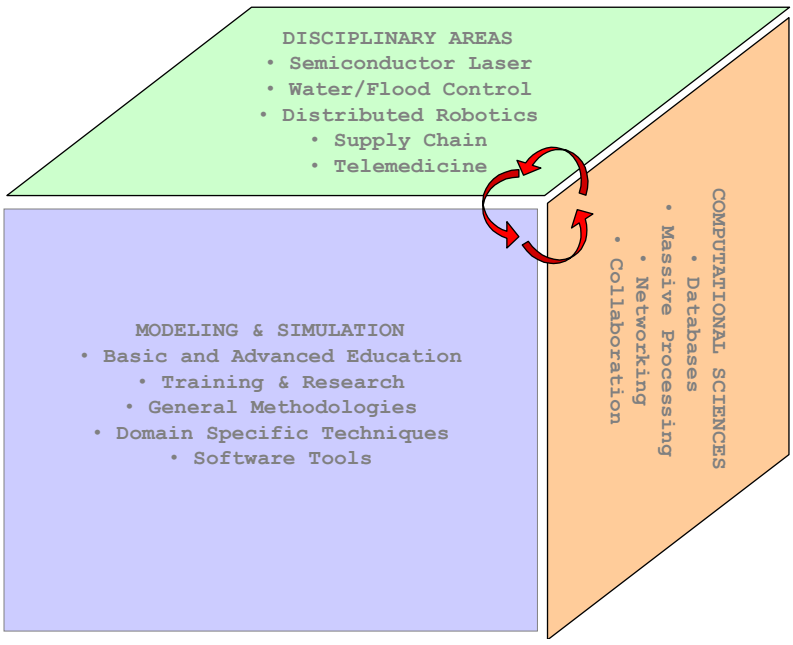

Figure 1: Integrating the facets: Computational Sciences, M&S, Multidisciplinary Problems

As shown in Figure 2, the aim of the proposed Center is to bring together a variety of researchers across various colleges at the three Universities of State of Arizona in integrative modeling and simulation. The kinds of projects are best illustrated by some examples in which ACIMS, or its progenitor faculty, have taken part.

- Development of a high-performance parallel simulation environment with applications to ecological landscape modeling combined faculty from Electrical and Computer Engineering, School of Renewable Natural Resources, and Computer Sciences. It was supported by the National Science Foundation (1993-1996) and was the progenitor of later projects sponsored by the US Air Force, Army, and the Defense Advanced Research Projects Agency.

- Scientific Discovery through Advanced Computing (SciDAC) Center for Supernova Research provides funding to two national labs and two universities. (Los Alamos and Livermore National Labs; University of California at Santa Cruz and University of Arizona) to carry out a program of research aimed at solving the problem of how core collapse occurs in thermonuclear supernovae. This is a very comprehensive and ambitious project, with many steps. It is one of fifty-one SciDAC projects that will receive a total of approximately $200 million in three years to develop scientific computing software and hardware infrastructure to advance fundamental research in areas related to the Department of Energy's missions. The SciDAC program will help create a new generation of scientific simulation codes and improved mathematical and computing systems software that will allow these codes to use modern terascale parallel computers effectively. The strategy is to support coordinated efforts by the scientists working to solve complex problems in physics, chemistry and biology, and the applied mathematicians and computer scientists working to develop the computational tools required for that research.

- Sponsored by NSF, the "Workshop on Modeling and Simulation of Ultra-Large Networks: Challenges and New Research Directions" brought some thirty invited participants to Tucson Arizona in November, 2001. Top-flight researchers from different areas related to communication network design, analysis, modeling and simulation, they were charged with the task of with elucidating the unknowns of ultra-large networks (such as the evolving Internet) and with new directions of research that can address these unknowns. The results were a set of specific findings of gaps in our knowledge of the behavior of ultra-large networks and how to deal with their design, management, and control. The outcome helped to formulate significant and compelling research directions for consideration in future NSF funding priorities.

In each of these cases the core research involves extending the capabilities of integrative modeling and simulation software environments in concert with the core objectives of the Center. Such research can only be done by multidisciplinary teams that provide expertise in supporting research areas such as intelligent computing, flexible heterogeneous networking, and temporal databases.

Other M&S Centers

Recognizing the need for integrative modeling and simulation tools, a number of universities have established centers concentrating on modeling and simulation [. Two such M&S centers that have been in existence for several years are the Institute for Simulation and Training (IST) at the University of Central Florida (Kincaid, 2001) and Virginia Modeling Analysis and Simulation Center (VMASC) centered at Old Dominion University (Rogers, 2001). IST primarily focuses on applied research for military training in support of Department of Defense and government subcontractors. The driving objectives of VMASC are to transfer proven modeling and simulation techniques and tools to industry, to provide a vehicle for university/industry research projects, and to promote economic development. In contrast to IST and VMASC, the proposed Center objectives are primarily focused on basic research in modeling and simulation as well as applied research in a variety of application areas.

The Georgia Institute of Technology and Naval Post Graduate School have established centers in M&S in the past year. From the point of view research, Georgia Tech Modeling & Simulation Research and Education Center (MSREC) seeks to promote modeling and simulation along specific domain and technology thrusts (Fujimoto, 2001). Its educational objectives of developing degree programs in M&S are similar to those of ACIMS. The Naval Post Graduate School Modeling, Virtual Environments and Simulation (MOVES) approach is to bring together existing courses and associated research activities under one umbrella (MOVES, 2001).

From the educational standpoint, all centers are pursuing similar objectives – i.e., offering graduate degree programs both at Masters and Ph.D levels, although ACIMS has also been advocating the importance and the need for infusing modeling and simulation courses as part of required undergraduate curriculum especially for engineering and science students.

What really distinguishes ACIMS from other new and existing M&S centers is its emphasis on the need for sustained and continued development of the theoretical and conceptual foundations of Modeling and Simulation. ACIMS is in a solid position to promote such development on the basis of its past and ongoing integrative M&S research activities (Zeigler, 2001; Sarjoughian and Zeigler, 2001). The projects that ACIMS will seek to take on are characterized by being strategically and tactically ingrained in the foundations of M&S. We believe that only such firm grounding will provide reliable methodologies and software for solving the challenging multidisciplinary problems that are foreseeable on the horizon. Moreover, only such an approach can contribute to the long-term development of the theoretical foundations once a particular applications project has terminated.

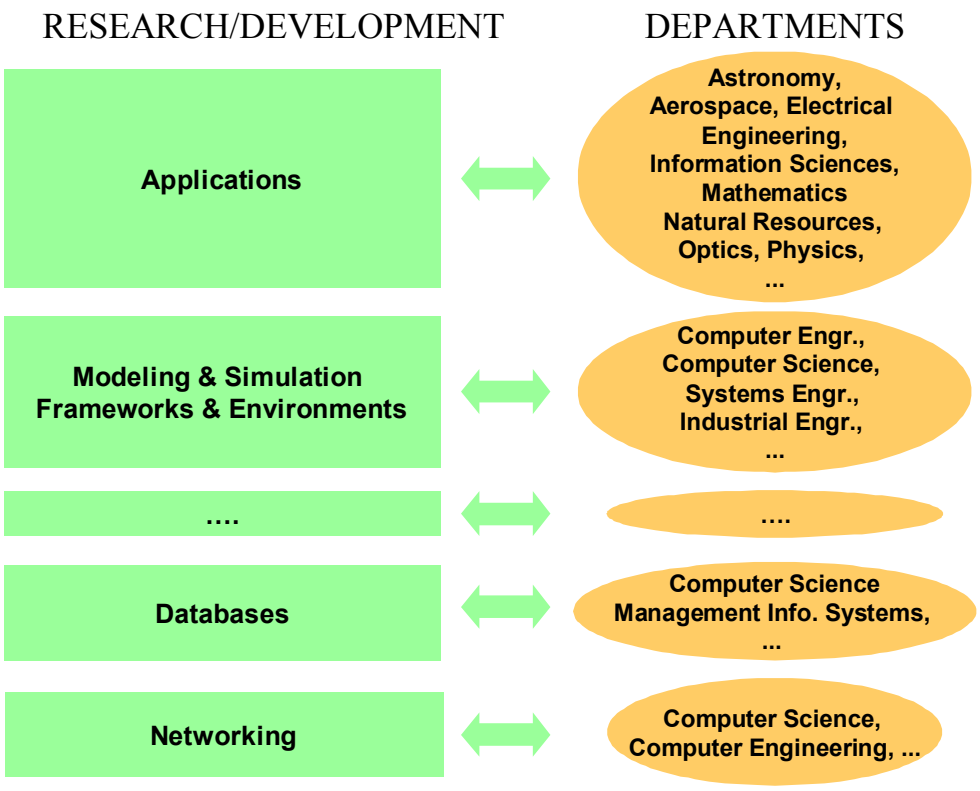

Figure 2: Activities supporting integrative M&S research`

National Demand for M&S Professionals

An indication of the timeliness of the above stated mission of the Center is the urgent need for M&S professionals that has developed in recent years. The emerging, highly interwoven systems and technologies thrive on collaborations of knowledge workers such as educators, scientists, engineers, and others. M&S supplies a common — and essential — framework that supports coordination of such multidisciplinary knowledge-work. In two formative workshops, a strong consensus emerged among individuals from industry, government, and academia that there is a demand for M&S professionals which is exploding as all sectors of the economy increasingly shift their basis for design and decision-making over to model-based simulation (NSF Workshop 1998; Rogers 1997). However, these workshops independently concluded that the majority of education and training offered in modeling and simulation lacks a pedagogical setting and is not founded on a firm programmatic foundation. It was hard to avoid the prediction that the undersupply of qualified graduate with solid education and training in M&S will continue to get worse unless government and industry intervene to support rigorous education and training in M&S as a discipline [M&SPCC, 2001]. In the meantime, employers are adopting an ad hoc solution to this national problem. They seek to hire students from a variety of specialty areas (e.g., aerospace engineering, computer science, and physics) in the hope that capable students with these kinds of disciplinary backgrounds can be sufficiently well trained

on-site in the required M&S skills over a period of one or two years. While such job-oriented training may have advantages for the employer, it is unlikely to provide the well-conceived grounding in generic skills that are required for true M&S professionals and is not likely to produce the number of such professionals needed in the long run. The research, education and training objectives of the Center are driven by the burgeoning national demand for graduating students who are well educated and trained in the integrative M&S discipline the Center will provide.

Over the last decade the research budgets for U.S. land management agencies and the Department of Defense have been shrinking. With fewer dollars available, field experiments and developmental testing have been drastically reduced. It has become evident that there is a greatly increased role for Modeling and Simulation (M&S) in planning, design, experimentation, testing, and training functions. However, this increased reliance on M&S methods and technologies assumes an accumulated knowledge base which, unfortunately, may not be up to the demands being made of it.

The main reason is that while M&S is not new to any of these government agencies, funding has almost always been application driven, with research and development only a side benefit of an application effort (falling in federal 6.02 or 6.03 rather than 6.01 budget classes). In contrast to computer science (or even to other sub-disciplines such as Artificial Intelligence and computer networking), modeling and simulation has not been recognized as a high priority by the National Science Foundation, the major source of support for such disciplinary research. There is excellent research being done at various university, federal and industrial R&D labs in the area of M&S. There is little directional planning, however, that would coordinate such activities or compound their individual contributions into a cumulative knowledge base that would serve as a reliable resource for future applications.

There are signs that this is beginning to change. Within the Department of Defense, a joint services coordinating office has been established (Defense Modeling and Simulation Office, DMSO), and after several years is starting to include basic research and development in its thinking. Much of this is driven by the developments centered around the proposal for a high level architecture (HLA) that would enable models at globally dispersed locations to be coupled together. It is recognized that although technological hurdles are significant, when they are overcome, there will remain difficult methodological solutions that are needed to assure reliable results especially in system design applications. Moreover, as mentioned above, through the SciDAC initiative, the Department of Energy has recognized the need to develop scientific computing software and hardware infrastructure to advance fundamental research in areas related to missions. The stated strategy is to support coordinated efforts by the scientists working to solve complex problems in physics, chemistry and biology, and the applied mathematicians and computer scientists working to develop the computational tools required for that research.

The need for more fundamental research and its codification motivates the establishment of a center devoted to integrative modeling and simulation. Such a center will serve to promote the development and dissemination of the knowledge base in M&S methodology and technology. It will itself contribute to the advancement of the field, but more than that, serve as an access point for other researchers and users.

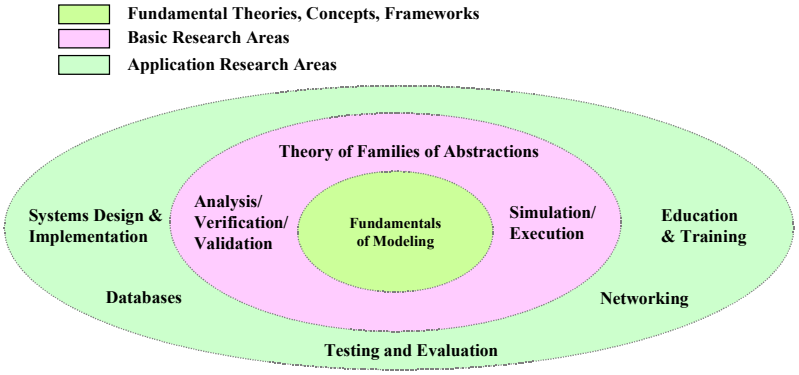

Figure 3: Major Components Underlying M&S Education and Training

The Center will foster both long term and short-term research. Long term-oriented research has as its primary goal the examination of fundamental "facts" or "laws" about M&S. Short-term research seeks to draw the implications of current fundamental knowledge for more immediate practice. Of course such distinctions represent the extremes of a wide spectrum of research activities, where the interaction between basic and applied is necessary for the advancement of each. However, as indicated above, the under-support for the longer-term orientation in the past needs to be rectified.

The impact that modeling and simulation will have on our lives in the next century will be significant. For example, the development of models to predict floods or droughts in specific areas, or the effect of new medical treatments will require extensive computer resources and a vast collection of verified and validated models. The Center will be the national focus for the development and use of M&S in all aspects of human endeavor.

Recent advances in the methodology and technological underpinning of M&S have addressed the elements in Figure 1. Such advances include object and event-oriented modeling approaches, use of multiple modeling abstractions, and support for collaborative and distributed M&S activities. The next generation of scientists and engineers will need to have at their fingertips the particular skills needed to adopt and exploit such advances (refer to Figure 4). However, these advanced concepts have not entered into the mainstream of undergraduate or graduate education.

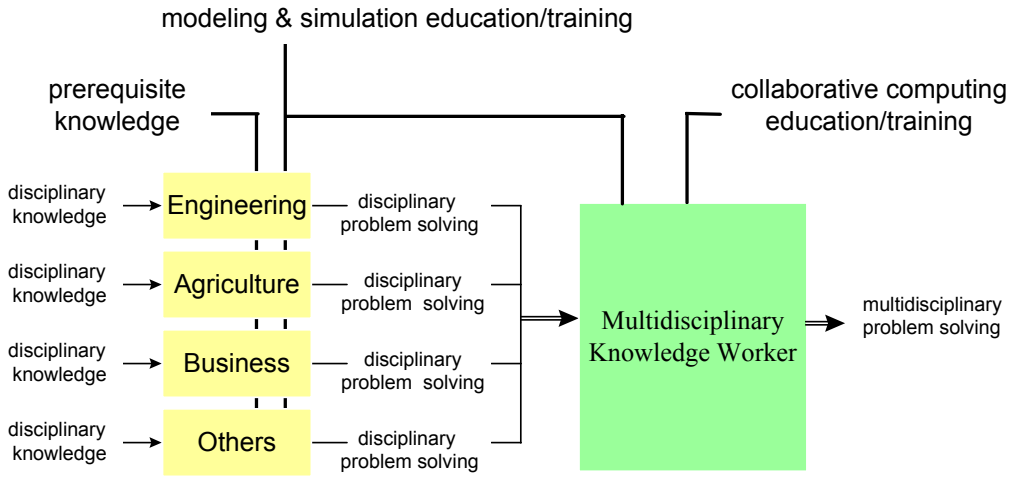

Figure 4: Unifying Disciplinary/Non-Disciplinary Knowledge For M&S Professionals

I. Description of the Center for Modeling & Simulation

A. The Center will be a multidisciplinary unit with participation of faculty and students from Agriculture, Engineering, Science and Social and Behavioral Sciences. Its organizational structure will be as follows:

(1) **Director:** The Director of the ACIMS will be a faculty member at The University of Arizona with a strong and active research interest in modeling and simulation. The Director will have a joint appointment with the ACIMS and his/her home college. The Director will be appointed to a renewable five-year term by the Dean of the college of Engineering & Mines on the recommendation of the Executive Committee (see below) and will report to the College Dean.

Duties and Responsibilities:

a. coordinates the administration of the ACIMS and its resources;
b. represents the ACIMS to The University Administration and provides liaison with the faculties of the University;
c. chairs the Executive Committee and the Scientific and Faculty memberships of the ACIMS;
d. implements the long-term research strategy and the policies formulated be the Executive Committee;
e. prepares and submits an annual report to the University Administration and to the Executive Committee.

(2) **Associate Director:** The Associate Director will be a faculty member at The University of Arizona with a strong and active research interest in modeling and simulation. The Associate Director will have a joint appointment with the ACIMS and his/her home college. The Associate Director will be appointed to a renewable five-year term by the Dean of the College of the Engineering & Mines on the recommendation of the Executive Committee (see below) and will report to the Director of the ACIMS.

Duties and Responsibilities:

a. assists the Director in the administration of the Center and represents the Center when the Director is unavailable;
b. implements the short term application strategies of the ACIMS;
c. studies and evaluates the Center's position in M&S as it relates to the national interests;
d. prepares and submits an annual report to the Executive Committee on the Center's effectiveness at meeting its short and long term goals and its response to the needs of the research and user communities;

(3) **Executive Committee:** The Executive Committee will be comprised of the Director, the Associate Director, two faculty of the ACIMS, and Dean. The Dean will represent the interests of the Colleges from which the ACIMS faculty hold their primary appointments and this responsibility will rotate among the participating colleges every two years. The faculty representatives will be appointed to renewable three-year by the Dean of

College of Engineering & Mines on the basis of nominations from the ACIMS Faculty.

Duties and Responsibilities:

a. oversees administration of the ACIMS and its resources;
b. uses information supplied by the Director and Associate Director to articulate the scientific goals and long range plans of the ACIMS;
c. solicits, evaluates, and approves applications for appointments to Scientific and Faculty status in the ACIMS, and reviews these appointments annually on the basis of research activity and funding, contributions to the programs and missions of the ACIMS;
d. reviews and approves the budget of the ACIMS;
e. establishes procedures for the review of research proposals.

(4) **Scientific Members:** All qualified scientists associated with universities or governmental agencies in the United States and Canada, and actively pursuing research in the area of M&S and/or teaching at an advanced level in the area, may apply to become Scientific Members. Among these scientists will be regular and research faculty, postdoctoral associates, graduate students, and visiting faculty, lecturers, and scholars. Applications for membership will be solicited, evaluated, and approved by the Executive Committee, and all such appointments will be reviewed annually by the Executive Committee.

(5) **Faculty:** The Faculty of the ACIMS will comprise regular and research faculty members of the University of Arizona who fulfill all of the following criteria:

a. are Scientific Members of the ACIMS;
b. devote a major part of their research effort to M&S;
c. have significant records of research activity, funding, achievement, and publications relevant to M&S;
d. have expressed an interest in joining the Faculty of the ACIMS and a willingness to participate actively and appreciably in its programs;
e. have been approved for appointment to the Faculty of the ACIMS by the Executive Committee and the Deans of College of Engineering & Mines.

(6) **Industrial and Government Participants:** The ACIMS will initially seek support for its programs from a number of corporations and government agencies. Each of these Participants will:

a. provide substantive financial support for the ACIMS on a recurrent basis;
b. delegate a representative to membership for the ACIMS on the Scientific Advisory Committee of the ACIMS (see below);
c. have opportunities to involve members of the its scientific staff in collaborative research with ACIMS (although research within the ACIMS will be open, and any arrangements concerning freedom of inquiry, open discussion, and publication will conform to current

University policies and procedures, these operating principles do not preclude confidential consulting and research-cooperation agreements between corporations and individual ACIMS scientists);

d. be welcome to send members of its scientific staff to the ACIMS for technical training.

(7) **Scientific Advisory Committee:** The Scientific Advisory Committee will comprise the following individuals, one of whom will be asked by the Dean of College of Engineering & Mines to serve as Chair person of the Committee:

a. three distinguished academic scientists from universities outside of Arizona who have contributed substantially to the understanding of modeling and simulation;
b. one representative from each Industrial Participant in the ACIMS;
c. one distinguished researcher from a Federal Government Agency (optional).

Duties and Responsibilities:

a. to meet annually in Tucson for two days for:
    1. a one-day Annual Symposium presented by the ACIMS Scientific Members, to which Industrial and Government Participants could send any number of conferees, and
    2. a meeting on the second day to review the activities of the ACIMS and to make recommendations to the Executive Committee and the University Administration;
b. to review and to respond *ad lib* to the ACIMS Annual Report.

B. ACIMS is a new unit.

II. Purpose and Activities of the ACIMS

Fundamentals of Modeling and Simulation

Modeling and Simulation (M&S) is the set of activities related to constructing models of real phenomena and studying them by means of computer simulation. The number of disciplines that employ one form or another of M&S is large and growing larger, so that almost every facet of engineering, science, and business makes use of the technology. One of the factors in the growth of M&S is the increasing availability of data. That data comes in the form of geographic information systems which store vast quantities of data concerning all aspects of physical and cultural information about the earth. GIS databases have become the de facto standard for handling data concerning such diverse information as topography and soils, political boundaries, population statistics for cities, and information dealing with the understanding of ancient cultures. More importantly, many of the problems arising in the information age are multi-disciplinary in nature and will require the collaboration of experts from across the disciplines for their solution. The ACIMS will assist in the delineation of the fundamental aspects of the development of M&S as an interdisciplinary activity and not as a task that simply requires domain specific knowledge. The ACIMS will use its expertise to: research the development and use of GIS technology; establish the fundamentals of M&S; develop computer tools and concepts to support GIS and M&S activities; and foster the application of these tools and concepts to a broad spectrum of multi-disciplinary applications.

Research supported by such agencies as NSF, NASA and DARPA has over a thirty year period has supported the development and extension of fundamental frameworks, concepts, theories, and generic software for modeling and simulation. Abstractions and families of abstractions, such as relating to discrete event representations, are intended to help penetrate to underlying structures determining complicated behaviors and represent these structures in a clear and precise manner. The developed theories and supporting software arose, were tested and refined, in a variety of challenging application contexts including computer, communication, transportation and manufacturing systems. Research directions include:

New Modeling Approaches: Such approaches can be distinguished along at least two dimensions: how they treat passage of time (stepped vs event-driven) and how they treat coordination of component elements (synchronous vs asynchronous). Recent event-based approaches enable more realistic representation of loosely coordinated semi-autonomous processes, while older methods implicitly impose strict global coordination of components. Event-based approaches offer conceptual alternatives to address complex organizational issues in natural phenomena such as face recognition by biologically plausible neural networks or team behavior in business environments. They are also the basis for distributed simulation environments that employ multiple computers exchanging data and synchronization signals through message passing.

Multiple Model Abstractions: Use of a family of abstractions has become essential in system design, each abstraction responding to a different, and isolated, set of issues. However, simplifications that were useful and spurred development initially may no longer prove adequate later on. A case in point is the breakdown in the digital logic

abstraction that has enabled the rapid evolution of digital computing in the last half century. Models of logical behavior must be combined with models of the (continuous) electromagnetic signal transmission early in the design of ultra-high density, high functionality chips. Frameworks were developed to support integration and interoperation of such abstractions and for reasoning about the relationships among the properties represented by individual models.

Integrative Distributed Simulation Frameworks: Due to lack of integrative frameworks and prevalence of overwhelming complexity constraints, models and simulation have been fragmented. To develop policies for managing traffic flow to reduce pollution, data and models maintained by city, state, and government agencies such as the Environmental Protection Agency. Unfortunately, although many of the component simulations exist in such applications, they have not been designed to work together as they are expressed in single purpose, non-modular packages, in disparate modeling languages, and usually designed for single machine processing. Standardized, multi-platform, distributed simulation environments have been developed that support interfacing of legacy software as components within larger simulation models.

Collaborative Distributed Modeling and Simulation: Collaborative modeling and simulation environments enable multiple modelers to share each other's knowledge and to more effectively build well-structured models of large, complex, multifaceted systems. For example, problems such as shipment of commodities can no longer be modeled and understood by understanding the inner working of the shipping company alone. Instead, subject matter experts from the shipping company as well as others from the Airline Company, Telephone Company, etc. must join forces to understand the complexity and intricacies of an entire shipping process. Collaborative distributed modeling tools require high bandwidth wide-area networking capabilities to interconnect subject experts independently of their physical locations and time zones.

Educational Objectives

The use of modeling and simulation requires more knowledge than is generally available. Although books have been written about various aspects of M&S, few authors have had much success discussing the large issues raised above. The ACIMS will have as a long-term goal the following educational components: (a) Development of new course materials for use in graduate instruction, undergraduate, and K-12; (b) retraining of engineers in M&S through individual, graduate programs of study; (c) training in computer-based tools; (d) on/off campus workshops, seminars, and training; (e) visiting scholars program; (f) assessments of M&S field and its impacts on science, government, and industry; and (g) technical support to industrial and governmental participants.

ACIMS will develop a generic approach to modeling and simulation that, when integrated with disciplinary knowledge, will better prepare graduates for solving problems within their chosen disciplines (see Figure 4). Its educational objectives will be realized through the introduction of a specialization in M&S within the curriculum offerings in the ECE Department. Possible core courses for this specialization are shown in green in Figure 5. Courses already available will be employed whenever possible to form this specialization. Undergraduates in

Computer Engineering Bachelors degree program will be able to take a new course in discrete event modeling and simulation as an elective. This will allow them to obtain a package of capabilities needed for technical (as opposed to managerial or research) levels of M&S in industry and government. The package consists of the concepts and skills taught by the new course together with the background supplied by courses already available (e.g., object oriented program and continuous system modeling).

In addition to the above university wide courses, specialized short courses, seminars, and tutorials are needed for professionals in industry and government. Such short courses can be tailored for specific class of audience and furthermore delivered on site.

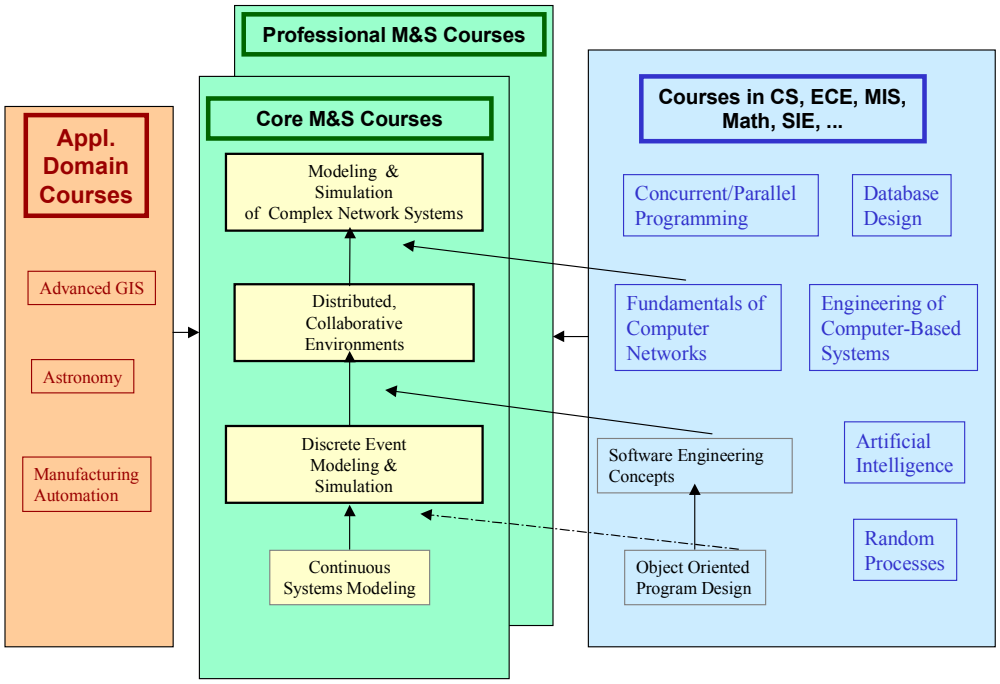

Figure 5: Proposed Sequence of Course in the M&S Specialization (green) in the context of current courses

For the graduate level, two new courses — Distributed Collaborative Environments and Modeling and Simulation of Complex Network Systems — are devised to replace a current course in discrete event modeling and simulation. These courses will benefit from the existence of courses shown in blue in Figure 5 that supply background material and challenging application areas. As suggested by the arrows in Figure 5, the prerequisite course structure for the M&S specialization will be devised to so that appropriate background will be available to students at the appropriate stages in their study.

Facilities, Equipment, and Other Resources

The Arizona Center for Integrative Modeling and Simulation (ACIMS) is located at the University of Arizona and at the Arizona State University. Its lab facility offer state-of-the-art hardware and software technologies to support parallel and distributed modeling and simulation and software development in a controlled setting. The lab offers a cluster of some 25 dedicated computers (Sun Ultra 30, SGI, PCs and laptops, and high-end server) running Unix-based (Solaris and Linux) and a variety of Windows Operating Systems. These computers and various peripherals are networked through two 24 port 100 mbps switches. Software development tools include popular programming languages and debugging environments, and middleware environments such as Borland VisiBroker Java and C++ supporting CORBA 2.3 specification, ACE-TAO, and HLA/RTI. The laboratory owns software engineering tools such as Rational Rose, JBuilder, network enabled Software Configuration Management, InstallAnywhere, Oracle Database, Optimize It, and JTest. ACIMS provide space for nearly 30 graduate students, visiting scholars, and faculty

In addition to its own resources, ACIMS faculty and students have access to several related laboratories. For example:

The High Performance Distributed Computing (HPDC) Lab (www.ece.arizona.edu/~hpdc). Located in the Electrical & Computer Engineering (ECE) department at the University of Arizona, the HPDC lab offers an environment of computing and network resources that duplicates three key aspects of the Internet environment. To emulate Internet routing behavior, the lab has a network topology that utilizes three CISCO 7000 routers, Gigabit Ethernet and three ATM switches. The ATM switches (IBM 8260 and MMAC-Plus) provide 155 Mbps ATM connections for the workstations and PCs which are also connected to the ECE network through a 10/100 Mbps Ethernet LAN. For web server emulation the lab has a cluster of 4 Linux high performance servers, each with 4 processors, that are inter-connected by a gigabit Ethernet switch. In addition, To emulate customer call response, the lab has a network of 40 dedicated PCs that can be configured to offer various multimedia service loads. These three emulation facilities provide a rich environment for testing and evaluating large-scale systems in the context of technologies and applications to efficiently and cost-effectively exploit the emerging high speed networks, high performance computers, and internet technologies.

The RAPTOR Lab (Real-time Algorithms, Performance Testing and Operations Research) (http://www.sie.arizona.edu/SPEED-CS/raptormore/raptor/index.html) offers a laboratory testbed emulating an Open Pit Mine. The main goal of this testbed is to provide an environment in which decision-making algorithms can be rapidly developed and integrated within simulations. The testbed consists of both *physical* vehicles and *virtual* vehicles that allow investigation of "what-if" scenarios at different levels of abstraction.

Funding

The majority of funding for the unit will come from research grants, training programs, and the participation of government and industrial partners. The scope of ACIMS modeling & simulation research and education is shown in Figure 3. Emergence of new applications/prototypes (e.g., lightweight agents) enabled by Discrete Event System Specification (DEVS) theory (e.g., Dynamic Structure Theory) provides the basis for developing commercial software (e.g., Complex Network System Modeling.) In turn, market dynamics provide vital knowledge for alternative and new applications. Similarly, based on lessons learned in the prototypes and applications, the M&S theory explores new territories, providing concepts and methodologies to extend the foundation of modeling and simulation capabilities. Figure depicts existing and future funding sources. Basic research is mostly funded through federal government agencies such as National Science Foundation, DARPA and Office of Naval Research (ONR), Sponsoring of application-oriented research is mostly through agencies such Department of Defense Modeling and Simulation Organization (DMSO), US Army and Air Force, and Department of Energy (DOE). Prototypes and proof of concept studies are sponsored by multinational companies such as Lockheed Martin, Raytheon, and IBM. Startups that commercialize ACIMS developed software for bringing services and products to market are a future potential source of "feedback" funding as their products mature and need further enhancement to remain viable.

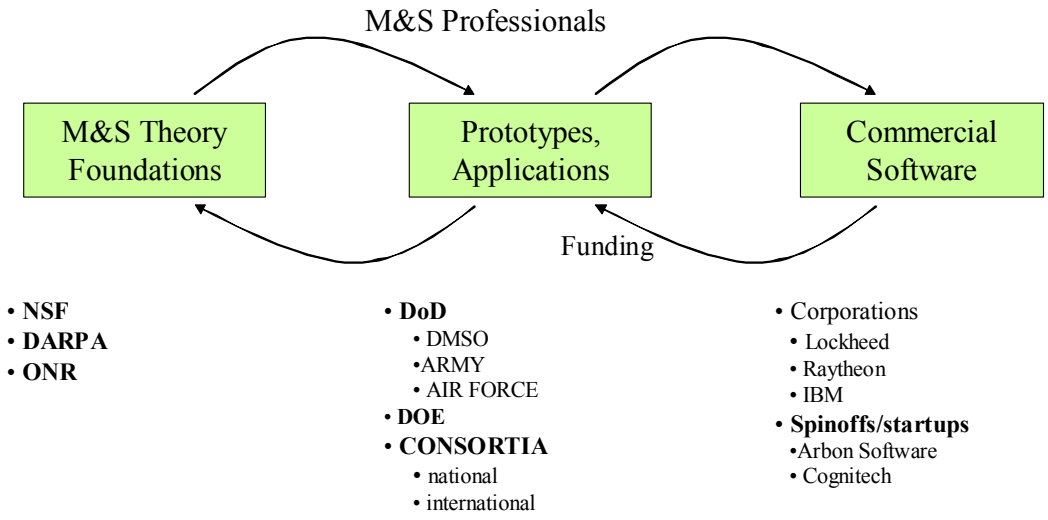

Figure 6: Funding Sources related to Research and Development

References

Fujimoto, R., (2001). The Georgia Tech Modeling and Simulation Research and Education Center, SCSC, 2001, Orlando, Fl. http://www.msrec.gatech.edu

Kincaid, J.P., D. McBride, T. Clarke, C. Reilly, (2001). The New Modeling and Simulation Ph.D. Program at the University of Central Florida, SCSC, 2001. http://www.ist.ucf.edu

M&SPCC, (2001), Modeling and Simulation Professional Certification Program, http://www.simprofessional.org

NPS Modeling, Virtual Environment, & Simulation, (2001). http://movesinstitute.org/

Rogers, R. V., Ed., (1997). What Makes a Modeling and Simulation Professional. Workshop, N. S. E. Enhancing Teaching Simulation to Computer Science Majors.

Rogers, R.V., (2001). Virginia Modeling Analysis and Simulation Center, SCSC, Orlando, FL, http://www.vmasc.odu.edu

Sarjoughian, H.S., B.P. Zeigler, (2001). Fostering an Integrated Approach to Modeling and Simulation Research, Education, and Training, SCSC, 2001, Orlando, FL, http://www.acims.arizona.edu

Zeigler, B.P., (2001). Newly Established Center for Integrative Modeling & Simulation, Simulation Technology Magazine, http://www.sisostds.org/webletter/siso/iss_78/art_365.htm