P

rogress in science and engineering is increasingly driven by advances and applications of information technology (IT). When ISIS was founded in 1998, it was on a seemingly unstoppable winning streak stemming from the profound transformation of society by the Internet. It has become so pervasive that the established structure of computer science and engineering research has changed significantly. For example, the tight integration of physical and information processes in cyber-physical systems has inspired the development of a new systems science, which is simultaneously computational and physical.

The fusion of information with physical and social sciences creates convergence across disciplines. The deep integration of computational, physical, and human aspects of engineered systems has spurred the development of cross-disciplinary approaches that are yielding new methods and curricula in science and engineering design and education.

Since its inception, ISIS has been at the forefront of these IT revolutions. Our name—Institute for Software-Intensive Systems—captures the essential driver of the ongoing changes: the integrative role of IT in modern software-reliant system development and application. Our research focuses on the foundations and technologies that place rigorously defined models and frameworks, their analysis, optimization, and transformation at the center of software-reliant systems development and assurance methods.

In addition to being actively involved in all aspects of the academic research enterprise via scholarly publications and teaching, the impact of ISIS is amplified by making our results accessible to both peers and practitioners. ISIS’s unique strengths thus stem from our ability to produce not only solid theories and foundations, but also methods and high-quality, open-source tools and toolkits that allow academia and industry to access and apply our research results. For example, our Model Integrated Computing toolsuite—together with a rich set of software for analysis, distributed real-time and embedded middleware frameworks, and design patterns/artifacts—have been adopted by researchers worldwide and have transitioned to many production projects and systems.

The multifaceted strengths of ISIS are appreciated by our many sponsors, who need to demonstrate high return on their R&D investments in a highly competitive funding landscape. The center of software-reliant systems development and assurance methods.

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WHo IS ISIS anD WHat Do We Do?

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We work on the science and engineering of (QoS)-enabled networking, middleware, systems, and virtualization. In addition to advancing the forefront of science and engineering, our research has profound impacts on many domains, ranging from health care to transportation, defense, cyber-security, and the environment.

As a leader in the intersection of systems science, computer science, and engineering for over a decade, ISIS is the primary center for multiple, large, long-term projects of national significance. Some projects have applications in mission-critical and national strategic areas, such as advanced manufacturing; air traffic safety; cyber-security; intelligence; transportation, defense, cyber-security, and privacy.

Our research directions and impact build upon work in the environment. As a leader at the intersection of systems science, computer science, and engineering for over a decade, ISIS will set the future course for science and technology in the United States, while providing mechanisms to protect our science and privacy.

One reason ISIS makes such substantial impacts is that we create game-changing platforms and tools and follow-up on work that began more than 25 years ago, based on the theoretical foundations—along with empirically-grounded innovations available to everyone. We also produce solid technology innovations. We also learn about our long-term investments and results in model-integrated computing and middleware for distributed real-time and embedded systems. In addition to pushing the boundaries of science and engineering, we create technologies and tools that solve real-world problems that improve our daily activities and quality of living. Equally important, we are also training our students to supply the intellectual capital that supports the twenty-first century workforce. We look forward to working together with you to invent the future of IT through ISIS.

Tedd Kugay
Model-based design, middleware, mobile, distributed systems

Grace Draven
Modeling and analysis of software systems, model-based design, fault-tolerance, secure computing, wireless networks, sensor networks

Adelchi Griba
Model-driven engineering, distributed computing, middleware, mobile, embedded
distributed systems

Liam Howard
Model-based design, middleware, autonomous technologies

Gabor Karsai
Model-based visualization environments, model transformations, system synthesis, intelligent learning environments, cyber-physical systems, distributed real-time and embedded systems

Nathan Dobrzalek
Model-integrated cyber-physical systems, sensor networks, wireless networks

Mike Laddage
Model-integrated computing, wireless sensor networks, real-time systems, game theoretic modeling

Ender Koç
Distributed real-time and embedded systems, software patterns and frameworks, model-driven engineering

Steve Pipino
Computational economics, network science, simulation, machine learning

Jules White
Mobile security, mobile augmented reality, cloud computing, wireless systems

Yau Ho
Networking and distributed systems, wireless networks, network security
By building computer models, we are better able to understand the complexity and interaction of different cyber-physical components and to divide big problems into smaller problems so their solutions become more tractable and affordable.

—XENOFON KOUTSOUKOS

As vehicles and other cyber-physical systems become increasingly complex, there’s a critical need for better methods of predicting the behavior of the physical processes and ensuring that the integrated computational processes for cyber-physical systems, which deliver advanced capabilities in airplanes, cars, spacecraft, and smartphones, and even smart power grids. Although their use is ubiquitous—with well over 90 percent of all microprocessors now used for cyber-physical systems—it’s historically been hard to validate and verify these systems due to the lack of theoretical foundations and automated tools for testing tightly integrated computational and physical systems. To address the challenges of cyber-physical system verification and validation, the Institute for Software Integrated Systems (ISIS) is creating model-integrated computing tools in an open tool ecosystem that includes workshops, invited talks, plenary sessions, an advisory board, and increased collaboration amongst research groups around the world.

Professor of Engineering, are leading the Science of Integration for Cyber-Physical Systems, funded by the National Science Foundation (NSF). This project is creating model-integrated computing techniques, which enable the design, analysis, and integration of complex cyber-physical systems using automated tools. This work will enable incremental validation and verification of key system properties, such as functional correctness, safety, and stability, so these systems need not be retested and redelivered from scratch to accommodate every change. This project is also focusing on how to combine disparate computational tools into an open tool integration framework that cyber-physical system practitioners and engineers can apply to develop and sustain complex systems more rapidly and reliably throughout their lifecycles, Koutsoukos said. These integrated tools are essential to aid in building and assuring safety and mission-critical cyber-physical applications, such as autonomous air and ground vehicles.

“By building computer models, we are better able to understand the complexity and interaction of different cyber-physical components and to divide big problems into smaller problems so their solutions become more tractable and affordable,” said Koutsoukos.

The second platform is a group of quadrotor helicopters that perform collaborative tasks, such as formation flying. More flexible than conventional drones, these helicopters have many potential applications, such as in search-and-rescue operations, training simulators, and controlling vehicle traffic. Cyber-physical system innovators like these have huge implications for the way vehicles are made and how they move around. There are also many potential applications for devices in other cyber-physical domains, such as insulin pumps or pacemakers in the medical field. ISIS has long been a leader in the field of model-integrated computing, pioneering domain-specific modeling languages, formal models and model transformations, and integrated tools to support simulation, analysis, and quality assurance, explained Koutsoukos. The modeling techniques and tools developed at ISIS as part of the NSF Science of Integration for Cyber-Physical Systems project helps predict and evaluate how different vehicle hardware and software components will interact.

“By building computer models, we are better able to understand the complexity and interaction of different cyber-physical components and to divide big problems into smaller problems so their solutions become more tractable and affordable,” said Koutsoukos.

“Building computer models, we are better able to understand the complexity and interaction of different cyber-physical components and to divide big problems into smaller problems so their solutions become more tractable and affordable,” said Koutsoukos.

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“The hope is that all of these technologies will be able to improve cyber-physical system safety and reliability with fewer retests,” Koutsoukos said. “Our model-integrated computing tools aim to minimize such problems when developing cyber-physical systems. It’s the future and it’s here to stay.”
In the study of cyber-physical systems, the next generation of scientists and engineers. This recently funded Education Working Group has as its goal the wide dissemination of materials for cyber-physical systems education, including course outlines, modules for insertion into other courses, new degree program development, and integration into K-12 science, technology, engineering, and mathematics (STEM) programs. The group serves as a clearinghouse for publishing recent research results and will tackle the complex task of assembling an array of modules to provide a variety of curricula for instructors to integrate into their teachings. In addition, the CPS-VO is home to several research conferences and workshops focusing on cyber-physical systems, including:
- The NSF Cyber-Physical System Program's National Principal Investigator Meeting;
- The High Confidence Software and Systems Conference, which focuses on new scientific and technological foundations that can enable entirely new generations of engineered designs that are becoming essential for effectively operating life-, safety-, security-, and mission-critical systems; the Principal Investigator Meeting;
- The Workshop on Medical Device Innovation Using Cyber-Physical Systems, providing new directions for research on technology for time-critical systems, including:
- The National Workshop on the New Clockwork for Time-Critical Systems, providing new directions for research on technology for time-critical systems; and
- The National Workshop on the New Clockwork for Time-Critical Systems, providing new directions for research on technology for time-critical systems; and
- The Workshop on Medical Device Innovation Using Cyber-Physical Systems, providing new directions for research on technology for time-critical systems; and
- The National Workshop on the New Clockwork for Time-Critical Systems, providing new directions for research on technology for time-critical systems; and
- The NSF Cyber-Physical System Program's National Principal Investigator Meeting;
FRACTIONATING SATELLITES TO BOOST R&D, COMMERCIAL, AND DEFENSE CAPABILITIES

It’s hard enough to get busy humans to stay connected, but what about a constellation of communicating satellites hurtling at high speed through orbit miles apart? Gabor Karsai, professor of electrical engineering and institute associate director of ISIS, is leading a team creating just such a network in the sky called “fractionated spacecraft,” which is a cluster of independent small satellites that work together to perform coordinated missions.

One of the crucial social and engineering challenges in creating fractionated satellites is the robust information system architecture. Of the eight groups competing for the software portion of the System F6 project, the Vanderbilt ISIS team won with a unique ability to integrate every piece of the puzzle to invent an entirely new and comprehensive software platform for fractionated spacecraft during the project’s initial phase, according to Karsai.

After the initial design phase, ISIS was tapped to oversee the completion of the System F6 information architecture platform. Additional members of the distributed team building this system include Kestrel Institute from Palo Alto, California; Object Computing Inc., from St. Louis, Missouri; Kestrel IT from the Netherlands; and Sattelite Systems from Indianapolis, Indiana.

“System F6 is an example of the new networking world in which one small task better than a single satellite. That kernel of an idea expanded to the concept of networking many small satellites together to perform multiple tasks. A fractionated architecture offers more flexibility and robustness than traditional design during mission operations, as well as during design and procurement. In particular, fractionation enhances space system adaptability and survivability, while shortening development timelines and reducing the barrier-to-entry for participants in the space industry. "The big problem with single satellites is that everything goes wrong, you have a very expensive piece of space junk," Karsai said. “With the System F6 model, you have many smaller satellites, with every one doing part of the work. You have plenty of spares so that when something does go wrong—one can fail and failures do— the network survives.”

Cubical technology—often used to fly educational payloads—could be brought into a network. "The System F6 project experiments must be flexible for use in a range of different topics and missions," Karsai said. Hence, the system puts into practice the full span of complex computer science problems and topics. Eventually, the goal is for the System F6 system to grow into a self-sustaining, self-motivating ecosystem populated with contractors, problem solvers, and those in need of solutions. The spin-offs resulting from the System F6 project have the potential to perform many complex research projects by pointing sensors in any direction—toward space, the atmosphere, the oceans, earth’s crust—taking constant measurements and sending back data to help scientists better understand how the world works. It could have taken a very narrow design view and just focused on the software. But we have to worry about how the software interacts with the spacecraft and how faults on the spacecraft will impact the software. That’s not something a typical computer scientist does," Karsai said. He obviously relishes the challenge and likens the current task to the early pioneering days of the Internet, which was likewise funded by the government, starting in the late 1960s and early 1970s. Those inventors could scarcely imagine the scope and impact of the Internet today.

"Our goal is to create an open standard where any vendor can build a satellite that can fully participate in a fractionated satellite cluster," Karsai said. Similarly, the open-source information architecture platform allows inventors to develop all kinds of applications, creating myriad spin-off opportunities. The System F6 software can be used to implement commercial applications, as well. The System F6 operating package under development by ISIS could one day be integrated into existing satellites, bringing them into a System F6 cluster without having to build new spacecraft, Karsai explained. Even the insomniac space junk," Karsai said. “With the System F6 model, you can build a satellite that can fully participate in a fractionated satellite cluster.”
Institute for Software Integrated Systems

"FACE takes a much deeper, science-based approach, focusing on compositionality and cooperation platforms, which are important research thrusts of ISIS. This holistic approach balances key business, managerial, and technical success drivers at scale."

—DOUGLAS C. SCHMIDT

STANDARD SOFTWARE PLATFORMS ENHANCE EFFICIENCY, COST, AND ACCESSIBILITY

Modern military systems, particularly avionics, are increasingly dominated by software, which is driving the urgent need for technologies being developed at ISIS that permit the Department of Defense (DoD) to build and update mission-critical software systems for aircraft better, faster, and cheaper.

A consortium of industry, academic, and government entities known as the Future Airborne Capability Environment (FACE) is helping to develop standard software for military avionics systems.

Currently, DoD-selected contractors often build everything from the ground up, including the bulk of the software. When it’s time for a system upgrade or update, the thing from the ground up, including the bulk of the software acquisition for military avionics systems.

"FACE takes a much deeper, science-based approach, focusing on compositionality and cooperation platforms, which are important research thrusts of ISIS," Schmidt said.

"FACE is an effort to open up the process and ensure software components across multiple platforms can be solved with standards and discipline alone. "FACE takes a much deeper, science-based approach, focusing on compositionality and cooperation platforms, which are important research thrusts of ISIS," Schmidt said.

"FACE is a standard that has no teeth unless you can enforce it effectively more than traditional closed-source approaches. FACE will lower total ownership costs, achieve better economic environment.

Successful integration of the FACE open-source software will require a modular and well-articulated software architecture, with precisely specified interfaces and technical success drivers at scale."

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Detecting and accurately locating snipers has been an elusive goal of the armed forces and law enforcement agencies for many years. Prior counter-sniper efforts at ISIS and elsewhere focused on special-purpose hardware and software that displayed the location of enemy shooters. ISIS engineers have recently invented a next-generation counter-sniper mobile app for commodity Android smartphones that has reached the final testing phase.

Called the Shooter Localization with Mobile Phones (SOLOMON), this mobile app collects sound waves through microphones mounted on soldiers’ headsets. These measurements are then used to determine precise enemy shooter location data that are displayed on the soldiers’ phones via Google Maps. The system can also determine the precise trajectory of the bullet, as well as the type of rifle that fired it.

The human ear is easily fooled by echoes. For example, soldiers in urban environments or in rocky, mountainous terrain often cannot tell the direction of incoming fire until they actually see the enemy. A system like SoloMon can determine the source of the very first shot, enabling a quick reaction. A fast response can mean the difference between life and death, explained Akos Ledeczi, associate professor of computer engineering and senior research scientist at ISIS. Ledeczi, together with research scientists Peter Volgyesi and Janos Sallai, comprised the ISIS team that developed the SOLOMON application under DARPA funding.

“The novel ideas behind SOLOMON allowed placing fewer and smaller microphones on headsets already worn by soldiers to communicate with each other and their operating base,” Ledeczi explained. The smartphones are networked together so data can be fused from multiple units, filtering out echoes and other unrelated sounds. Location data is then processed and displayed directly on the phones.

A small company has licensed the technology and is preparing the system for production and sale, according to Ledeczi. The key element of the SOLOMON technology—namely, that it is the first system to rely on the duration of the boom from supersonic rifle shots, and not just the arrival time, to determine shooter location—has also been patented.

While the SOLOMON technology can save soldiers’ lives on the battlefield, the innovative ideas behind the project also have implications for civilian safety. ISIS engineers are testing ways to use ultrasonic waves from vibrations to determine when a structure—a bridge, for example—may need repairs. Such early detection methods could potentially save major disasters with minor repairs.

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Working closely with Honeywell engineers, ISIS researchers are mining regional airline data to build the Vehicle Integrated Prognostic Reasoner (VIPR), which uses knowledge derived from advanced data mining and machine-learning techniques to diagnose and detect potential problems in an airplane before an accident or emergency landing.

The VIPR project aims to find evolving faults in aircraft systems, such as the engine and the avionics, and detect potential problems in an airplane before an adverse event occurred. They consider mitigating factors, such as weather conditions, degrading equipment, and pilot error, and look for sequences of events that might have been overlooked, such as an evolving degradation in a fuel injection system that caused an engine to overheat and eventually shut down. More recently, they’ve generalized their approach to exploration methods that search for anomalies in terabytes of flight data.

“We found that in many cases, you could reliably detect the likelihood of a particular problem occurring by thorough and careful analysis of available data,” Biswas said.

The ISIS team’s activities go beyond conventional diagnostic knowledge that can yield potential innovations and safety features. For example, ISIS researchers working with Honeywell experts have discovered new monitors and more accurate diagnostic knowledge to detect faults in fuel supply lines, the fuel injection systems, and the engines themselves. Their results show that faults can be detected more quickly and accurately, allowing the initiation of maintenance actions in a timely manner to avoid compromising aircraft safety.

“Our task is to find ways to help experts do what they do better,” Biswas said.

Biswa and Koutsoukos came into the VIPR project with extensive experience in analyzing complex cyber-physical systems. “It is the interaction between software and hardware that really determines how the system behaves,” said Biswas. “The depth of our expertise—combined with years of experience in the field—enables us to analyze interactions between different parts of the system and understand how these systems behave.”

“Winning this award was particularly gratifying because ensuring flight safety has such a broad impact on both individuals and society,” Biswas said.

The data mining technologies developed by ISIS may also help inform training methods, improve software integrated design, and find systematic ways of analyzing the vast reams of data the FAA requires airlines to collect to inform decisions, rather than relying on current ad hoc methods for identifying problems.

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“Winning this award was particularly gratifying because ensuring flight safety has such a broad impact on both individuals and society,” Biswas said.
WHAT IS UNIQUE TO VANDERBILT IS THIS COMBINATION OF EXCELLENT, PRACTICAL MEDICAL CARE PLUS THE AVAILABILITY OF ADVANCED SOFTWARE AND INFORMATION TECHNOLOGY, WHICH CREATES A STRONG FOUNDATION FOR RAPID PROGRESS.”

YUAN XUE

INSTITUTE FOR SOFTWARE INTEGRATED SYSTEMS

“THE GOAL OF ISIS RESEARCHERS IS TO UNDERSTAND THE FUNDAMENTAL ISSUES THAT CAUSE CYBER VULNERABILITIES AND TO DEVELOP MODEL-BASED METHODS AND TOOLS TO HELP PREVENT PROBLEMS BEFORE THEY OCCUR.”

Sztipanovits

YUAN XUE

THE PRIVACY PRESERVING RECORD LINKAGE PROJECT, LED BY THAD OAHA, ASSOCIATE PROFESSOR OF BIOMEDICAL INFORMATION AT VANDERBILT UNIVERSITY MEDICAL CENTER, IS YET ANOTHER SHARPS PROJECT THAT ALLOWS THE SECURE INTEGRATION OF MEDICAL RECORDS FROM MULTIPLE SOURCES, INCLUDING MULTIPLE HOSPITALS AND EHR SYSTEMS.

VANDERBILT UNIVERSITY SCHOOL OF ENGINEERING
When engineers build safety-critical cyber-physical systems, such as medical devices, cars, or airplanes, they start with extensive computer modeling to ensure critical system components, such as software in pacemakers, traction controllers, or autopilots, operate properly in the full-scale design.

—JANOS SZTIPANOVITS

A good example of ISIS’s impact on safety-critical system development is the recently completed ISIS-led Model-based Design of High Confidence Systems project. This Air Force Office of Scientific Research (AFOSR)-funded project generated powerful model-integrated computing techniques and tools for software platforms that underlie many complex cyber-physical systems used by humans.

“When engineers build safety-critical cyber-physical systems, such as medical devices, cars, or airplanes, they start with extensive computer modeling to ensure critical system components, such as software in pacemakers, traction controllers, or autopilots, operate properly in the full-scale design,” explained Janos Sztipanovits, ISIS director and E. Bronson Ingram Distinguished Professor of Engineering.

Cyber-physical systems have become so complicated that it’s neither practical nor affordable to build them without first testing the joint behavior of the physical and computational system by using precise-scale computer models.

“High confidence means not only that there are no faults in your system, but you can also prove that your system works even under adverse conditions. Model-based design is about closing that loop ever tighter,” he said.

After verification of the integrated system is complete, engineers create tools to automate the creation of its software components.

“Projects like Model-based Design of High Confidence Systems create natural springboards to new projects and new challenges,” said Sztipanovits. “We welcome and enjoy these challenges. It’s all about turning science and engineering concepts into reality.”

As a case in point, Sztipanovits pointed out that many methods and tools created for the Model-based Design of High Confidence Systems project became the building blocks for the next generation of ISIS model-integrated computing efforts, such as the META portion of the DARPA Adaptive Vehicle Make (AVM) program that aims to radically alter the way military vehicles are built (see page 22). “ISIS is at the forefront of the cyber-physical system revolution due to our strong focus on the foundations of model-based design and model-integrated computing,” Sztipanovits said. These foundations include model-based design automation for software, model transformations and model management, model-based verification of tools and systems, design-space exploration, and semantic foundations for models and modeling.

In addition to its many contributions to the foundations of model-based design via model-integrated computing, ISIS also has an impressive track record of rapidly transitioning research results into action, as happened with the recently completed Model-based Design of High Confidence Systems project and the ongoing AVM project. This transition success has become increasingly important to funding agencies, which expect significant and timely returns on their R&D investments.

ISIS has likewise created many open-source, model-integrated design and computing tools over the past two decades. Since these tools are available to anyone, they have created an ecosystem for rapid innovation and economic growth throughout the cyber-physical R&D community.

“Open source is essential for research visibility and impact,” said Sztipanovits. “It accelerates technology transfer and broadens the global reach of our design technologies and tools.”

While ISIS has thrived at the critical juncture in the cyber-physical systems revolution, there are growing pains. Sztipanovits expressed concern about the availability of scientists and engineers for the future. Although computer science enrollments at Vanderbilt and other universities are growing again after the dot-com bubble burst, the nearly decade-long gap has left the nation with a critical need to attract more students to the intersection of computer science and engineering. That’s why ISIS is focusing on engaging increasing numbers of students—not just at the graduate level but undergraduates as well (see page 27).
An innovative ISIS project, the Android Mobile Military Middleware Objects (aMMo), is developing lightweight middleware software platforms that connect standard smartphones and mobile apps into secure military and disaster recovery communications devices. Presently deployed with more than 2,000 troops overseas, the aMMo project provides the ideal confluence of these two technologies,” Schmidt explained. The flexible middleware and agile development methods applied on aMMo have allowed for several hardware revisions already. Neema said, “One problem that ISIS addressed was the need for lower level hardware to integrate with a radio, which required alternative to the cables they did not interfere with radio frequencies. The latter modification was forced by ISIS research scientist James “Bubba” Davis, who explains why the DARPA Transformative Apps Hardware now includes “bubba cables.”

“Middleware provides the glue to make the smartphone work efficiently and securely within this environment,” explained Bapty. Mobile devices used with aMMo middleware makes modern smartphone apps accessible to war fighters.”

“Smartphone-based technologies—especially open-source projects like Android and aMMo—are a key driver of future innovation for research, education, and industry,” said Schmidt. “ISIS’s goal is to develop a microcosm of exciting things to come.”

“The work on aMMo spans from high-level, Java-based middleware research to the lower level hardware and software stack,” Schmidt explained, “and when things go wrong, you have to reason through many complex interactions. You need people who can go across multiple levels and are not afraid to challenge assumptions.”

“Anything can go wrong at any layer of the entire hardware and software stack,” Neema said, “and when things go wrong, you have to reason through many complex interactions. You need people who can go across multiple levels and are not afraid to challenge assumptions. One problem that ISIS addressed was the need for lower level hardware to integrate with a radio, which required alternative to the cables they did not interfere with radio frequencies. The latter modification was forced by ISIS research scientist James “Bubba” Davis, who explains why the DARPA Transformative Apps Hardware now includes “bubba cables.”

“ISS and Vanderbilt are leaders in DRE middleware and military software apps, so the aMMO project provides the ideal confluence of these two technologies.”

—DOUGLAS C. SCHMIDT

Vanderbilt School of Engineering
ISIS IS LEADING EFFORTS TO REVOLUTIONIZE MILITARY VEHICLE DESIGN

Designing a complex system in one fell swoop is the revolutionary concept behind the Adaptive Vehicle Initiative (AVI) research program, a flagship initiative funded by DARPA with heavy involvement by ISIS. This ambitious program seeks to drive innovation in design automation and manufacturing and intends to completely revamp the way the DoD supplies vehicles to the nation’s troops.

In the conventional model, a contractor creates a military vehicle from the ground up, from design to manufacturing. This process is open to anyone, even student groups at the K–12 level. The vehicleFORGE collaboration portal (see page 24) will allow diverse teams to work together without geographic limitations.

The AVI will lay the groundwork for a new industrial model that will actually build the vehicle. ISIS played an integral part in the development of Foundry, a next-generation design suite of tools that was created as part of the AVI initiative. Foundry is the heart of the AVI ecosystem, providing a shared design platform for all stakeholders in the AVI program.

The AVI is an ambitious program that seeks to drive innovation in design automation and manufacturing and intends to completely revamp the way the DoD supplies vehicles to the nation’s troops. The AVI is funded by DARPA with heavy involvement by ISIS.

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SanDeep Neema

The potential impact of our research on manufacturing is huge. Being able to create a design rapidly and have it built quickly has immense potential. That’s the model of manufacturing that the U.S. needs to evolve toward.

SanDeep Neema
Institute for Software Integrated Systems

ISIS senior research scientist and research associate professor of electrical engineering and computer science.

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22 Institute for Software Integrated Systems

23 Vanderbilt School of Engineering
DESIGNING VEHICLES IN THE CLOUD THROUGH AN INNOVATIVE COLLABORATION PORTAL

The VehicleFORGE portion of the DARPA-funded Adaptive Vehicle Make (AVM) project creates an innovative cloud-based platform that integrates a wide range of model repository, design collaboration, and user management capabilities into a collaboration portal and testing ground for the competition portion of AVM.

VehicleFORGE includes many traditional collaboration tools, such as Web-based infrastructure for discussions, design submissions, and brainstorming sessions. However, the system has the ability to integrate computer-aided design (CAD) models and other structural and behavioral simulations of an adaptive cyber-physical system. It also has the capability to quickly discern differences between models as the design process progresses.

Contenders in the AVM competition, called the Fast Track Next-Generation Ground (fANg) Vehicle, are using collaboration tools to create and validate their work as they compete DARPA’s challenge to design an amphibious ground vehicle, said Larry Howard, ISIS senior research scientist and principal investigator for VehicleFORGE.

“Generally, these kinds of virtual communities only exist for the lifetime of a grant or program. Once the funding stops, everything disappears except a final report that documents what transpired on the project. Innovations like VehicleFORGE will enable new kinds of long-term collaborations between researchers and practitioners. We also expect it will become a platform for facilitating future scientific and engineering innovations,” Howard said.

For the AVM project, VehicleFORGE will support DARPA’s goal of leveraging open innovation. This innovation will occur via collaborative model development by teams from diverse organizations that compete to build the best design. By demonstrating the innovation process, DARPA plans to engage several orders of magnitude more talent than current industry models.

“In today’s world, you have just a few highly specialized contractors who compete for this kind of work,” Howard said. “The government often doesn’t see the value of the software tools themselves. There are so many brilliant engineering minds out there. The government needs to make great things, but for some other purpose besides national security.”

Howard predicted. He added, “The challenge will be to interest and educate a new generation of engineers, entrepreneurs, and investors in these emerging technologies.”

“VehicleFORGE is part of the next generation of engineering design, representing a shift to a modeling and simulation approach, which will become a dominant paradigm in engineering, not just a fleeting technological fad,” Howard explained. “There will be many things that happen afterward. It’s all contingent on the value of the demonstration. The AVM concept is vital to the DoD’s ability to sustain and improve capabilities in the future. There are so many brilliant engineering minds out there. Unless the military finds ways to engage them in building the things they need, those engineers will continue to make great things, but for some other purpose besides national security.”

“The whole point is to design a vehicle and produce evidence of the quality of that design without ever having built a prototype and with high enough confidence to send it to the factory.”

—LARRY HOWARD

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“We’re right on the cusp of a really big change if projects like AVM and VehicleFORGE pay off,” Howard explained. “There will be many things that happen afterward. It’s all contingent on the value of the demonstration. The AVM concept is vital to the DoD’s ability to sustain and improve capabilities in the future. There are so many brilliant engineering minds out there. Unless the military finds ways to engage them in building the things they need, those engineers will continue to make great things, but for some other purpose besides national security.”

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An exciting component of the DARPA-funded Adaptive Vehicle Make (AVM) project at ISIS is an undergraduate design contest, called the Model-Based Amphibious Racing Challenge (MBARC), which marked the first official test of the AVM design methods. Using early components of the OpenMETA design tools developed as part of the AVM project, students from participating universities validated the computational methods and the specific tools, all while making a small amphibious vehicle.

"With Vanderbilt a key player in the AVM program, we are uniquely positioned to test and validate the tools that we are creating, as well as to demonstrate these tools to other institutions and ultimately increase their adoption in practice," says Tom Withrow, assistant professor of the practice of mechanical engineering.

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As the nation faces a growing need to improve science, technology, engineering, and math (STEM) education, a critical question must be addressed: Is it possible to create a more engaging STEM learning atmosphere in K–12 classrooms while instilling deeper understanding of the material? The answer is “yes” with help from the right kinds of computer learning tools.

Institute for Software Integrated Systems (ISIS) is rolling out these new technologies at an opportune time. The state of Tennessee is mandating the creation of more STEM high schools as part of the “Race to the Top” initiative. There is also a growing shortage of American university students in STEM disciplines. "As systems used by humans become more complex, scientists and engineers need to build computational models to design and analyze these systems. It therefore makes sense to introduce ideas of computational thinking beginning as early as elementary school," said Gaulam Biswas, professor of computer science and computer engineering.

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Biswas is leading the development of two educational software projects: SimSelf (Simulation Environment Designed to Model and Scaffold Learners’ Self-regulatory Skills to Optimize Complex Science Learning) and CT Sim (Computational Thinking with Scientific Modeling and Simulation). Both projects seek to improve student understanding of science and increase their interest in STEM disciplines by building computer-based models that explain how things work.

"Science and mathematics help us understand and navigate the real world, whether you’re a lifeguard watching fish swim in a tank, a middle school student who faces traffic congestion problems when driven to school, or a software engineer working to design a better aircraft monitoring system," Biswas said. "We use the knowledge gained from computer-aided, in-class exercises to solve problems, and we do this in a way that makes the learning task engaging and relevant." The SimSelf program focuses on teaching better learning strategies and self-regulation skills as preparation for life-long learning. For example, students might be asked to explain the causes and effects of global warming or the regulation of human body temperatures. If the program detects that a student is relying too much on trial and error methods to build a model, the program guides him or her to develop more effective learning strategies through conversations with automated computer agents.

CT Sim focuses on teaching middle and high school students computational thinking skills to support modeling and simulation. It guides students to realize that many behaviors in the real world can be explained by a sense-and-act model. For example, if an animal is hungry (sense) it looks for food (act). Moreover, CT Sim reinforces the idea that people constantly make conditional decisions, such as deciding to take a different route when the traffic on the current route is heavy. "We’ve constructed a visual language that helps students model the behavior of agents, like a car or a fish, using computational constructs,” Biswas explained. "When modeling a fish, a student needs to learn to model computationally how the fish gains and loses energy as well as how the fish impacts its surrounding ecosystem. Students can then use these modeling questions and solve problems, such as how to build a better fish tank.”

At the end of each day, SimSelf and CT Sim generate reports for classroom teachers. “We’re not building systems to replace teachers, but instead we are using technology to make teachers more effective. It’s hard for teachers to follow in detail the progress of 25+ students in their classes. Through our software programs, we collect data to provide a summary on individual students, as well as overall class performance for teachers at the end of the day. Teachers can use this information to make decisions on where to focus their teaching the next day,” Biswas said.

Four high school teachers in Chattanooga and Nashville are working with Biswas’ team to develop their own curricula. Pilot projects in Nashville schools help students learn about the causes and effects of global warming and then apply what they’ve learned to solve real-world problems, such as how to streamline long drop-off lines at school. Another project helps middle school students model and learn about an ecosystem and use what they have learned to build and sustain an eco-column, which is an aqueous ecosystem built into a large terrarium. Biswas works closely with researchers at the nation’s top education school, Vanderbilt University’s Peabody College, including teaching and learning faculty members Pratim Sengupta and Doug Clark. While Peabody researchers understood how the education system works, ISIS engineers understood the practical constraints of converting ideas into technological solutions. Said Biswas, “It’s a natural partnership.”

Vanderbilt School of Engineering
“Even though our DRE middleware work has been going on for over twenty years, new results are emerging because the needs of our sponsors keep changing.”

—ANDY GOKHALE

### MIDDLEWARE INNOVATION DELIVERS INTEGRATED SOLUTIONS

Distributed real-time and embedded (DRE) middleware is computer software that integrates diverse programming languages, operating systems, networks, and hardware as an important building block for many projects at ISIS. The motivation for this middleware sprawled from the realization that companies and laboratories were constantly rewriting software from scratch to handle complex distributed systems programming problems, such as interprocess communication, demultiplexing, concurrency, synchronization, fault tolerance, and security concerns. DRE middleware provides common software infrastructure that can be reused and adapted for diverse functions in a variety of operating systems.

Even though our DRE middleware work has been going on for over twenty years, new results are emerging because the needs of our sponsors keep changing.” —Andy Gokhale

**Institute for Software Integrated Systems**

In the early 1990s, Schmidt took his first faculty position at Washington University in St. Louis, attracting Gokhale, now associate professor of electrical engineering and computer science, and an ISIS senior research scientist at Vanderbilt, was one of the first people Schmidt and Gokhale hired to work on open-source DRE middleware innovation cycle and discovered many foundational patterns underlying the design of various middleware systems. This focus has driven us to seek partners and do things that have a broad impact at ISIS make their work especially gratifying. That’s why we’ve been fortunate to work with many really bright researchers and take it in new directions. We’ve been able to write software that runs seamlessly across different operating systems, such as Windows and Linux. ISIS’s DRE middleware has also been used in building collaborative educational tools “to support the idea that a group of students can all contribute and together they collaboratively work—even when they are geographically and spatially distributed—on real problems that will help them further strengthen their STEM concepts,” Gokhale said.

“Even though our DRE middleware work has been successful in many foundational areas, the latest cutting-edge research, one of the roles we increasingly play is the role of research integrators,” Schmidt said.

“Even though our DRE middleware work has been ongoing open-source DRE middleware as a graduate student at the University of California at Irvine in the early 1990s, and it became the subject of his Ph.D. thesis. “together we pioneered the open-source DRE middleware innovation cycle and discovered many foundational patterns underlying the design of various middleware systems. This focus has driven us to seek partners and do things that have a broad impact at ISIS make their work especially gratifying. That’s why we’ve been fortunate to work with many really bright researchers and take it in new directions. We’ve been able to write software that runs seamlessly across different operating systems, such as Windows and Linux. ISIS’s DRE middleware has also been used in building collaborative educational tools “to support the idea that a group of students can all contribute and together they collaboratively work—even when they are geographically and spatially distributed—on real problems that will help them further strengthen their STEM concepts,” Gokhale said.

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typically create model-based frameworks built around GME that make it easier to solve not only the original problem, but a whole class of related problems.

The idea behind model-integrated computing is that we pull information in from many tools and try to abstract out what is common to these tools. We then define a set of models for the common parts, and regenerate the software using the GME tools, rather than re-implementing the same artifacts from these models. We then separate the common parts from the domain-specific parts.

Related tools can also analyze how well a design will work and whether the model will stand up to the expected load and/or configure large portions of the application code and supporting software infrastructure. The general idea behind model-integrated computing is that we pull information in from many tools and try to abstract out what is common to these tools. We then define a set of models for the common parts, and regenerate the software using the GME tools, rather than re-implementing the same artifacts from these models. We then separate the common parts from the domain-specific parts.

“GME is not only one of our flagship research tools at ISIS, but it is also used worldwide, in industry and academia.” says Karasi. “It represents a paradigm shift that has far-reaching impact on both software professionals and domain experts alike.”

The key advantage of the model-integrated computing approach is that it supports execution application evolution in a seamless manner. End users of a GME-based environment need not be software engineers/programmers. They can simply modify the models as requirements change and regenerate the application without having to write a single line of lower-level code.

Model-integrated computing aids in building a wide range of engineered systems, including commercial and physical components, as well as addressing problems of integration with surrounding systems (e.g., the hardware infrastructure), while allowing the system to evolve seamlessly. It is a key part of the new, rapidly evolving Web-based GME.

Web-based GME is a key part of the new, rapidly evolving Web-based model-integrated computing tools. The Web-based GME provides access to the computing environment from any platform, including Windows, Mac, Linux, and even tablets, without the need to install any software. It also supports online collaboration, similar to Google Docs. This new tool will be a significant step forward, as it will run on any platform, including Windows, Mac, Linux, and even tablets, without the need to install any software.

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ACRONYMS

ACE . . . . . . . ADAPTIVE Communications Environments
AMMO . . . . . . Android Mobile Military Middleware objects
AMR . . . . . . . Adaptive Wiki Make
APSIR . . . . . . Air Force Office of Scientific Research
CMCL . . . . . . Component, Context, and Manufacturing Model Library
CAD . . . . . . . Computer-Aided Design
CIAO . . . . . . Component-Integrated ACE ORB
COM . . . . . . . Component Object Model
CORBA . . . . . . Common Object Request Broker Architecture
CSS-VoD . . . . . Cyber-Physical Systems-Virtual Organizations
CTSM . . . . . . Computational Thinking with Scientific Modeling and Simulation
DARPA . . . . . . Defense Advanced Research Projects Agency
DDS . . . . . . . Data Dissemination Service
DoD . . . . . . . Department of Defense
DRE . . . . . . . Distribute Real-time and Embedded
EMR . . . . . . . Electronic Medical Record
FACE . . . . . . . Future Airborne Capability Environment
FANG . . . . . . . Fast Adaptable Non-Generation Ground
FCS . . . . . . . Future Combat Systems
HIPAA . . . . . . Health Insurance Portability and Accountability Act
NKH . . . . . . . National Institute of Health
IRAB . . . . . . . Instantly Recoverable Adaptive through Bots
ISIS . . . . . . . Institute for Software Integrated Systems
MBRAC . . . . . . Model-Based Amphibious Racing Challenge
MURI . . . . . . . Multidisciplinary University Research Initiative
NASA . . . . . . . National Aeronautics and Space Administration
NSF . . . . . . . National Science Foundation
R&D . . . . . . . Research and Development
SHARP . . . . . . Strategic Health Care IT Advanced Research Projects on Security
SimSelf . . . . . . Simulation Environment Designed to Model and Scaffold Learners’ Self-regulatory Skills to Optimize Complex Science Learning
SOLARION . . . . . Shooter Localization with Mobile Phones
TAO . . . . . . . The ACE ORB
TRUST . . . . . . Team Research in Trusted Ubiquitous Security Technologies
VIFR . . . . . . . Vehicle-Integrated Prognostic Reasoner

ABOUT VANDERBILT AND NASHVILLE

A private research university, Vanderbilt was founded in 1873 and named for Cornelius Vanderbilt, who provided the school its initial $1 million endowment. Vanderbilt enrolls 12,000+ students from all 50 U.S. states and over ninety foreign countries in its four undergraduate and six graduate and professional schools. In its 2013 ranking of universities, U.S. News and World Report ranked Vanderbilt 17th among national universities in the United States. Vanderbilt is located in the beautiful and historic city of Nashville, which offers a full range of cultural amenities, two major professional sports franchises (the Nashville Predators and the Tennessee Titans), an abundance of parks and outdoor recreation, a temperate climate, and a reasonably low cost of living. 
SIS is an academic/professional research institute established by the Vanderbilt University School of Engineering in 1998 and located just off campus on Nashville’s Music Row. Our work focuses on systems, with deeply integrated software that are networked, embedded, and cyber-physical.

Annual funding is $20+ million, and there are active projects with dozens of academic and industry collaborators at Vanderbilt, other leading universities, and companies in the U.S. and around the world. ISIS employs 80+ research scientists and staff engineers, 11 electrical engineering/computer science faculty, six administrative staff members, and 40+ graduate students.

We conduct cutting-edge, world-class research on real-world problems in the following areas:

**Model-Integrated Computing**
- Model-based design automation for software
- Modeling techniques and tools—visual and textual
- Model transformations and model management
- Model-based verification of systems and software
- Design-space exploration, generative design
- Model and tool integration
- Semantic foundations for models and modeling

**Distributed Real-Time and Embedded Systems**
- Adaptive and reconfigurable middleware
- Model-based integration technology
- Secure and fault-tolerant middleware
- Middleware for mobile devices

**Wireless Sensor Networks**
- Operating software for wireless sensor networks
- Radio-interferometric sensor localization
- Applications: shooter location, infrastructure monitoring, and many others

**Model-Based Design of Cyber-Physical Systems**
- Design of systems where classical engineering meets computing: vehicles, robots, etc.
- Verification and high-confidence design
- Model-based manufacturing
- Model-based system integration of CPS

**Systems Security and Privacy**
- Privacy-aware health information systems
- Foundations for resilient systems design
- System security co-design
- Secure control systems for industry and society

Learn more about all ongoing ISIS projects at www.isis.vanderbilt.edu.

ISIS conducts cutting-edge research on next-generation technologies essential to developing and assuring mission- and safety-critical, software-reliant systems. Our dynamic research environment provides a creative atmosphere that offers many opportunities for creating, applying, and evaluating novel methods, techniques, and tools in multiple domains, including cyber-physical systems, health care, cyber-security, and manufacturing automation.

ISIS funds dozens of post-doctoral, graduate, and undergraduate intern positions from a wide range of sponsors, including NSF, HHS, DARPA, DOG, DOD, NIH, NASA, AFRL, Boeing, GM, BAE Systems, Raytheon, and many others. ISIS research assistants receive a competitive stipend, a tuition scholarship, and full health insurance coverage. There are also many opportunities for travel to conferences worldwide, as well as to work with our partners at top universities and research institutes around the country and globe.

Opportunities for post-doc and undergraduate internship positions are listed regularly on our website at www.isis.vanderbilt.edu. Graduate students working at ISIS can enroll in programs on the Vanderbilt campus, ranging from computer science, electrical engineering, and mechanical engineering to medical informatics and others.

To find out more about graduate research opportunities at ISIS and the application process, please contact Professor Xenofon Koutsoukos at xenofon.koutsoukos@vanderbilt.edu.

**World-class, interdisciplinary research with global impact.**
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