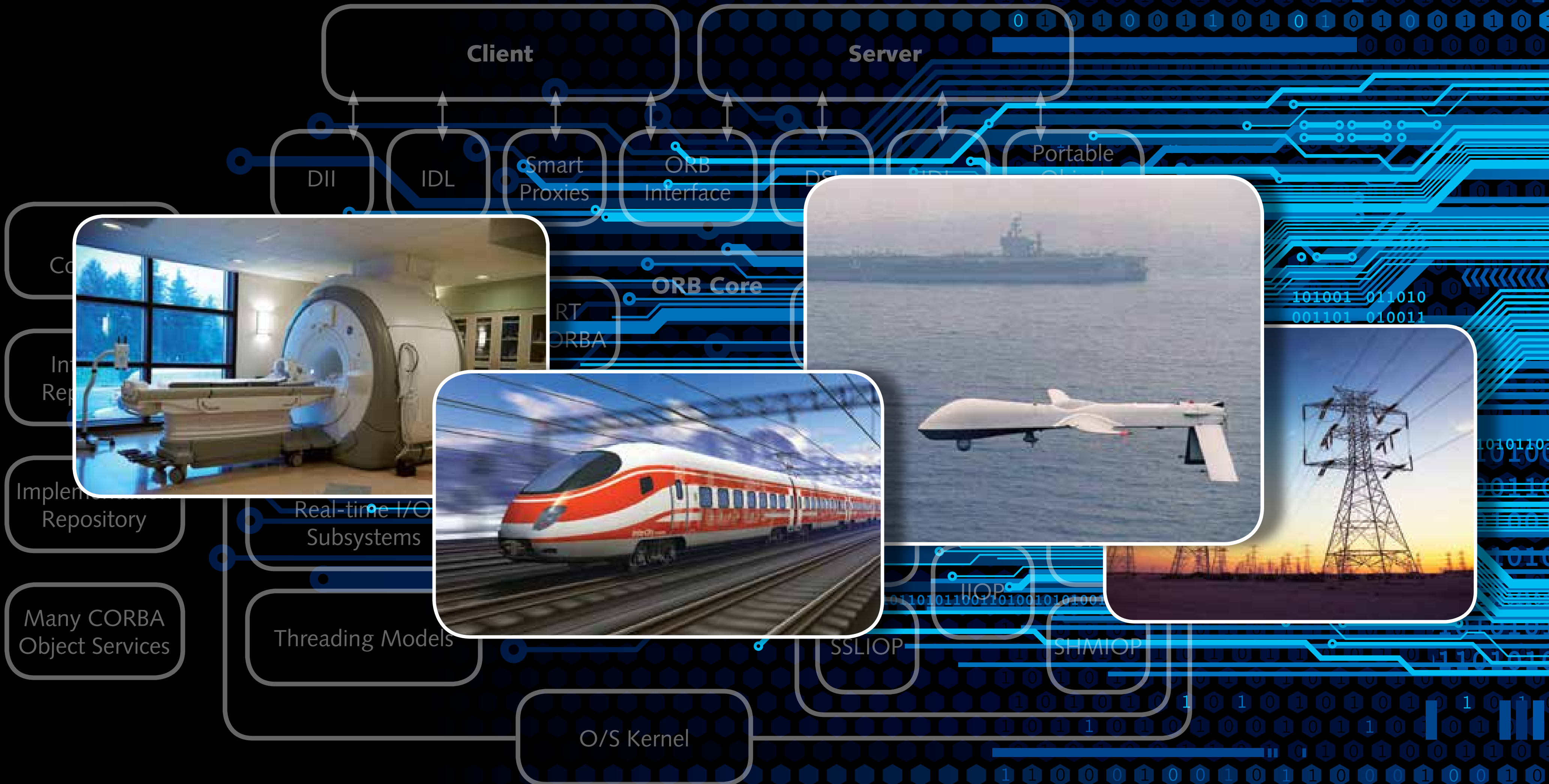
INNOVATIONS 2013



VANDERBILT UNIVERSITY

ISIS Institute for Software Integrated Systems

15th Anniversary Edition 1998-2013

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FROM OUR DIRECTOR

Progress 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 Revolution. It became clear over time, however, that this first wave of IT revolutions was just one element of a much broader and deeper paradigm shift fueled by the pervasive and multidisciplinary application of IT in science, technology, and society.

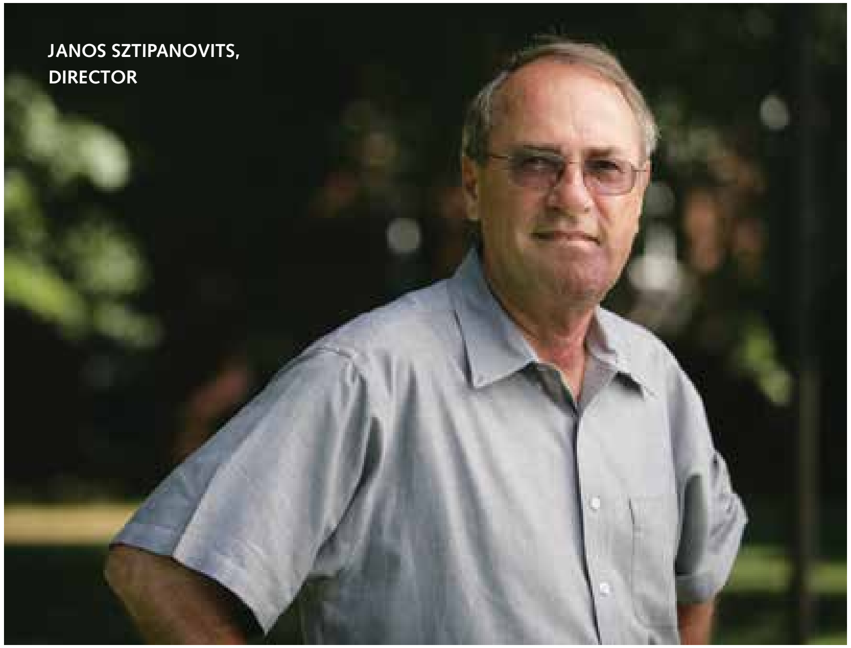
The multidisciplinary research and development activities stemming from the second wave of the IT revolution have proceeded in multiple synergistic directions, with the following profound effects:

The most exciting developments occur at the wavefront, that is, at the intersection of IT with physical, biological, and engineering sciences. There are many examples for science and technology fields and industrial sectors, such as cyber-physical systems, health care, cyber-security, and manufacturing automation, where this intersection has yielded disruptive technologies that create new industries and rearrange the status quo in entire economic sectors.

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 Integrated 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.



JANOS SZTIPANOVITS, DIRECTOR

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 environment. In recent years ISIS has become a national hub for cyber-physical systems. We also lead and/or are major partners in an NSF S&T Center on cyber-security; Multidisciplinary University Research Initiatives (MURIs) in autonomous systems; national centers in health IT addressing security and privacy; major projects focusing on mobile computing, common operating platform environments, and fractionated spacecraft; along with other high-impact areas. Our vision is to continue extending our track record of success as an internationally recognized center of excellence and innovation in the exciting, ongoing transformation of science and engineering by advanced IT research and transition.

WHO IS ISIS AND WHAT DO WE DO?

We work on the science and engineering of software-reliant systems that are all around us—in vehicles, hospitals, design shops, space systems, and factories—to name just a few. There is an enormous variety of software and the same is true for our work. With more than 120 faculty, staff, and students, as well as over 60 active projects, it's hard to report everything we do. Our goal, therefore, is to provide a sampling that showcases the impact we are making as a prominent leader in driving and shaping the enormous effect of and changes in software-reliant systems developed and encountered by humans.

At ISIS, we focus on software-reliant systems that are networked, computational, and physical. At the core of our work are systems science and engineering foundations, such as the fundamentals of composition in heterogeneous systems, tools for agile software and systems engineering, assured system integration, model-integrated computing, quality-of-service (QoS)-enabled networking, and middleware and virtualization. In addition to advancing the frontiers of science and engineering, our research has profound impacts on many domains, ranging from health care to education to transportation, defense, cyber-security, and the environment.

As a leader at 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 nationally strategic areas, such as advanced manufacturing; airline safety; cyber-security; intelligent transportation; and science, technology, engineering, and mathematics (STEM) education. Most projects build on our prior results in model-integrated computing, distributed real-time and embedded middleware, network resource management, and software patterns. Nearly all projects are highly technical—many with deep theoretic foundational issues—and have far-reaching implications that are not yet fully realized.

Many of our projects are at the cutting edge of software-reliant systems: secure and privacy-preserving health care systems, revolutionary system design tools for vehicles, and distributed operating systems software for satellite clusters. What is clear is that the research and transition activities being conducted at ISIS will set the future course for science and technology in the United States, while providing mechanisms to protect our security and privacy.

Our research directions and impact build upon work that began more than 25 years ago, based on the foundations and applications of model-based design in software and systems. This ongoing work has become a critical component of U.S. competitiveness as progress in modern science, engineering, and product development is increasingly driven by the application of advanced information

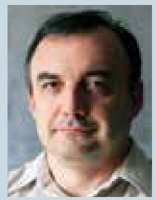
ISIS Faculty and Senior Researchers

Ted Bapty
Model-based avionics systems, cyber-physical systems, parallel and distributed systems

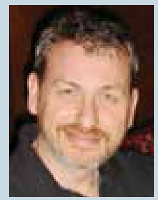
Gautam Biswas
Modeling and analysis of embedded systems; model-based diagnosis; fault-adaptive control intelligent learning environments; planning, scheduling, and resource allocation for distributed systems

Aniruddha Gokhale
Model-driven engineering, distributed computing middleware, model-driven middleware

Larry Howard
Design technologies, adaptive learning technologies



Gabor Karsai
Model-based visual programming environments, model transformations and system synthesis, integrated software and systems engineering, complex systems and their formal models



Xenofon Koutsoukos
Hybrid and embedded systems, cyber-physical systems, sensor networks

technology (IT) in support of software-reliant systems. Distributed real-time and embedded systems, cyber-security, health IT, cloud computing, autonomous systems, and manufacturing technology are some of the many areas where emerging technologies are disrupting the status quo in entire industrial sectors. ISIS has been at the forefront of this revolution for over a decade, and we continue to expand our role as a leader and partner in key science and technology innovations.

One reason ISIS makes such substantial impacts is that we create game-changing platforms and tools and follow an open-source distribution model that makes these innovations available to everyone. We also produce solid theoretical foundations— along with empirically-grounded methods and high-quality, model-based tools and middleware platforms—that foster rapid transition of new technology to both academia and industry.

The success of ISIS—particularly after its recent migration to new facilities on Nashville's vibrant and creative Music Row—has solidified Vanderbilt University's position as a premier research institution. Our success has also had broader implications: by recruiting and training the best faculty, staff, and students in the fields of cyber-physical systems, distributed real-time and embedded middleware, intelligent learning environments, model-integrated computing, software engineering, and trustworthy computing, we are cultivating a high-technology cluster ecosystem in Middle Tennessee and beyond.

The role of IT in engineering practice has greatly influenced innovation, and ISIS has been a key part of that radical transformation. The traditional conservatism of engineering, with its empirical foundations built up over time through the study of fielded artifacts (particularly their failures), is yielding to more integrated, theoretical design understanding applied through modeling, simulation, and emulation at scale. This change to the process of design for complex software-reliant artifacts is more fundamental and significant than many other impacts of IT and is at the heart of what lies ahead.

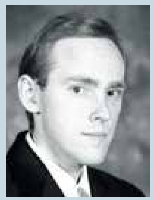
The articles in this brochure offer you a taste of our current flagship projects in the domains of common operating platform environments, cyber-physical systems, data mining and machine learning, STEM education, systems security and privacy, and wireless sensor networks. You'll also learn about our 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.

Akos Ledeczi
Model-integrated computing, wireless sensor networks, medical information technology

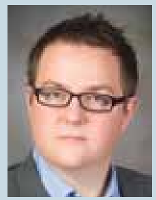
Sandeep Neema
Model-based system design, middleware for mobile devices, complex system design, space exploration

Douglas C. Schmidt
Distributed real-time and embedded middleware, software patterns and frameworks, model-driven engineering

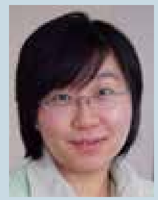
Janos Sztipanovits
Embedded software, cyber-physical systems, model-integrated computing



Yevgeniy Vorobeychik
Computational economics, game theoretic modeling of security, simulation, machine learning



Jules White
Mobile security, mobile augmented reality, cyber-physical security, mobile/cloud cyber-physical systems



Yuan Xue
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

BY LAND, SEA, AIR, OR SPACE: CREATING COMPLEX SYSTEMS TO FUNCTION SEAMLESSLY

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 components obey physical world constraints, such as control laws for flight surfaces or anti-lock brakes. That’s where ISIS is playing a major role in advancing solutions.

Among the hardest problems facing researchers and engineers are those associated with producing robust and secure integration of physical and computational processes for cyber-physical systems, which deliver advanced capabilities in airplanes, cars, spacecraft, 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.

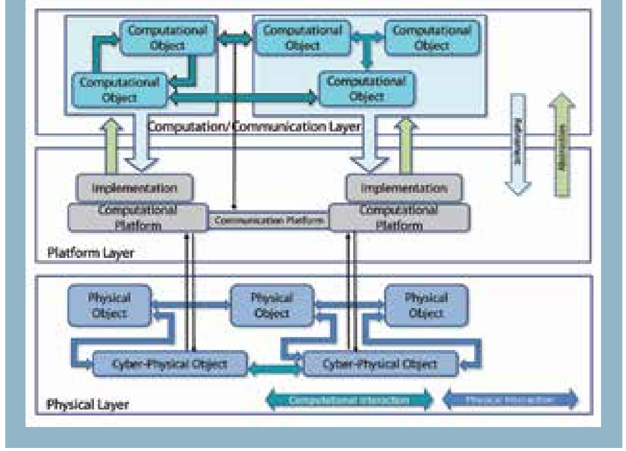
To address the challenges of cyber-physical system validation and verification, Xenofon Koutsoukos, associate professor of computer science and computer engineering, and Janos Sztipanovits, ISIS director and E. Bronson Ingram Professor of Engineering, are leading the Science of Integration for Cyber-Physical 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. These tools will enable incremental validation and verification of key system properties, such as functional correctness, safety, and stability, so these systems need not be built and retested from scratch to accommodate every change.

This project is also focusing on how to combine disparate model-integrated computing 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 life cycles, Koutsoukos said. These integrated tools are essential to aid in building and assuring future safety and mission-critical cyber-physical applications, such as autonomous air and ground vehicles.

Together with General Motors (GM), the University of Maryland, and the University of Notre Dame, Koutsoukos, Sztipanovits, and their ISIS team are building two platforms. The first is an experimentation platform consisting of a commercial simulator used by GM to design and test automotive functionality, such as adaptive cruise control and lane change warning. The network and the processors are real, but the car is simulated.

“This method allows us to address key implementation effects, such as network delays and processor failures, before designing the system,” Koutsoukos says. “In the same way that operating system and application software in a computer or smartphone must be updated regularly, auto companies like GM must update car software. The moment that happens, we must ensure that everything



continues to work without creating unforeseen problems." A key challenge is accommodating such updates while keeping the system safe, Koutsoukos added.

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 assisting in search-and-rescue operations, tracking smugglers, and controlling vehicle traffic.

Cyber-physical system innovations 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 Sztipanovits. 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.

Understanding how to transform cyber-physical system integration from a "black art" into an engineering discipline based on sound theoretical foundations and scalable tools is the lofty goal of much ongoing cyber-physical system work at ISIS. Model-integrated computing is the future of complex cyber-physical systems, such as aircraft, spacecraft, and cars, Sztipanovits said.

When modern companies design an aircraft or a car, they buy computing devices and processors they plan to use for the lifetime of the product, all integrated after significant testing, which is expensive and time-consuming. "The moment anything is changed, all the testing is invalidated," he added. "That's the problem we're trying to address—how not to do it from scratch over and over again."

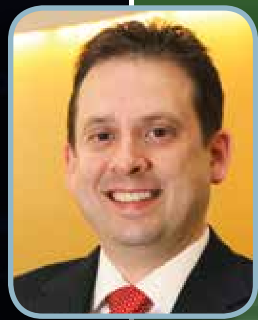
Educational activities associated with the NSF-funded project are yielding new courses at Vanderbilt and new curricula for the cyber-physical systems field. "We must produce much new and revamped course material to educate the next generation of engineers needed to support rapid innovation," Koutsoukos said. At least one ISIS graduate student on the project team spent a summer working at GM.

Another goal of the project is to disseminate research results and foster an international community around cyber-physical systems. This ecosystem includes workshops, invited talks, plenary sessions, an advisory board, and increased collaboration amongst research groups around the world.

"The hope is that all of these technologies will be able to improve cyber-physical system safety and reliability with fewer recalls," 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."

"Significant progress in the study of cyber-physical systems requires lowering the disciplinary boundaries between computer science and more traditional, 'physical' fields of engineering, as the solutions necessitate a systems-oriented approach."

—CHRIS van BUSKIRK



CREATING COMMUNITIES TO TACKLE GRAND "CHALLENGES" IN CYBER-PHYSICAL SYSTEMS

Researchers, industry, and government agencies studying cyber-physical systems are working collaboratively to share ideas, problems, and solutions quickly in the Web portal of the Cyber-Physical System Virtual Organization (CPS-VO), built and operated by ISIS.

"The CPS-VO provides a collaboration platform for cyber-physical system stakeholders," said Chris van Buskirk, principal investigator for the NSF-funded project and ISIS research scientist.

The immediate goal of CPS-VO is to disseminate emerging research rapidly among stakeholders, increasing the impact and effectiveness of the ongoing work, and reducing time to transition it to practitioners. But the broader goal focuses on helping communities form to tackle the "grand challenges" of cyber-physical system science and engineering.

Cyber-physical systems, the next generation of engineered systems, merge the physical world with computation and are generally software-driven, with multiple applications from aerospace to automobiles to civil engineering and medicine.

"Significant progress in the study of cyber-physical systems requires lowering the disciplinary boundaries between computer science and more traditional, 'physical' fields of engineering, as the solutions necessitate a systems-oriented approach," explained van Buskirk.

The CPS-VO includes participants from the broad cyber-physical systems research community and is assisted by a collaboration-enabling platform consisting of a community website, a repository, a source of educational materials, and a social networking facility. The Web-based interactions are augmented by conferences, seminars, and workshops that foster in-person interactions.

The CPS-VO provides the primary source of information about cyber-physical systems research. The services it provides to members are essential for nurturing a scientific community, including opportunities for publication, a merit-based peer-review system, a source for interesting research challenge problems, discussion forums, and an independent technology review system geared towards facilitating technology transition, van Buskirk said.

The goal of the CPS-VO is to encourage communities that come together through cyber-physical systems research initiatives funded by NSF, the National Security Agency (NSA), and other sponsors to tackle common challenges arising in their fields, ranging from devices to solving larger problems, such as how to improve traffic flow and prevent accidents.

"There's a huge social aspect to this," van Buskirk explained. "We have lots of small communities with their own expertise, but there's not as much cross-disciplinary interaction as we need to solve significant and pervasive cyber-physical systems problems."

Launched in 2011, the CPS-VO immediately yielded productive connections between participants with common interests, including a new group that is developing education curriculum to teach CPS concepts to the next generation of scientists and engineers. This recently founded Education Working Group has as its goal the

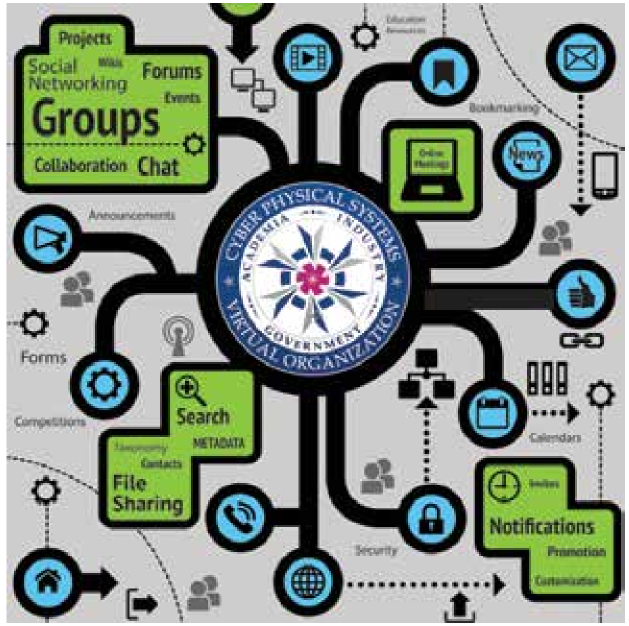
wide dissemination of materials for cyber-physical systems education, including course outlines, modules for insertion into other courses, new degree program development, and integration into K-12 science, technology, engineering, and mathematics (STEM) programs. The group serves as a clearinghouse for publicizing 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 now 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 National Workshop on the New Clockwork for Time-Critical Systems, providing new directions for research on technology for time-critical systems;
- The National Security Agency's Science of Security Community Meeting;
- The Workshop on Medical Device Innovation Using Cyber-Physical Systems, and
- The Secure and Trustworthy Cyberspace Program of the NSF.

In addition, the CPS-VO serves as an important tool for the DARPA Adaptive Vehicle Make Program (see page 22), which uses the site to distribute research results and prototype toolsets for the design, manufacture, integration, and verification of air and ground vehicles of substantial complexity.

"We've just begun to scratch the surface of cyber-physical system capabilities," said van Buskirk. "It's exciting to consider the possibilities that will emerge from the energy of the groups that are forming under the auspices of the CPS-VO."



FRACTIONATING SATELLITES TO BOOST R&D, COMMERCIAL, AND DEFENSE CAPABILITIES

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

The System F6 program is a cooperative effort of government, academia, industry, and nonprofit entities funded by DARPA with NASA acting as technical supervisor. The goal of the program is to demonstrate the feasibility and benefits of a fundamentally new satellite architecture. In this architecture, the functionality of a traditional "monolithic" spacecraft is delivered by a cluster of wirelessly interconnected modules capable of sharing their resources elsewhere in the cluster. The first flight test of a System F6-based fractionated spacecraft is set for 2015.

The original idea behind the System F6 program sprang from the notion that many small satellites can perform a single 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 satellite 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 if something 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—any one can fail and failures do occur—the network survives."

One of the crucial scientific 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; Remedy IT from the Netherlands; and Saffire Systems from Indianapolis, Indiana.

"This project is not only about designing and writing a new networked operating system," Karsai explained. "We have to create complex security safeguards that prevent different software programs from interfering with each other. We have to quickly handle faults that appear all the time in a complex system such as this. We have to manage the network that is subject to drastic degradations and data loss. All these problems must be solved and addressed together. You can't address them one by one in isolation."

ISIS has the critical mass to tackle such complex problems because it can quickly bring together a diverse team, he said. "We were able to put together a team that not only has experience with design, but also with building software and doing complex systems engineering. We 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.

DARPA is taking a similar approach to the System F6 program, envisioning these networked satellites as a Space Global Commons. Industry standards (such as the Internet Protocols) and open-source platform technologies (such as the Linux operating system and CORBA and DDS middleware) form the basis of the network, creating the building blocks for future space applications. In particular, the ACE, TAO, and CIAO open-source middleware (see page 30) used on System F6 have been guided by Douglas C. Schmidt, professor of computer science and senior research scientist at ISIS, and Aniruddha Gokhale, associate professor of computer science and senior research scientist at ISIS.

"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 inexpensive

CubeSat technology—often used to fly educational payloads—could be brought into a network.

"The System F6 system software 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 wheat grows or how to site an archeological dig, for example. As Karsai said, "It's hard to imagine all of the possibilities for growth. We're literally building a business incubator for R&D in the sky."

"Our goal is to create an open standard where any vendor can build a satellite that can fully participate in a fractionated satellite cluster."
—GABOR KARSAI

> " FACE takes a much deeper, science-based approach, focusing on compositionality and composition 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 Capabilities Environment or FACE™ is helping to achieve that DoD goal by defining a common operating platform environment. That operating platform is comprised of a set of new standards, recommendations, reference implementations, and conformance tools to help reduce the cost of software acquisition 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 program office is forced to go back to the original contractor because those systems are often unique or protected by proprietary interfaces. As a result, the military has created many redundant "point-solutions" that are prohibitively expensive to develop, certify, and sustain, explained Ted Bapty, research associate professor of electrical engineering and computer science and senior research scientist at ISIS.

But what if these systems were based on constantly improved and updated software that used open, standard interfaces? Common functions that apply to multiple systems would then become accessible to all defense contractors. Large and small businesses could participate in these projects, greatly expanding the talent pool available to the program offices. That's part of what FACE seeks to do, added Bapty.

"FACE is an effort to open up the process and ensure contractors use a common set of interfaces, procedures, and requirements," he said. "The government can then incorporate pieces from other contractors to leverage their efforts and have more portability and interoperability of acquired software components across multiple platforms."

Reusing software applications and infrastructure services that work for multiple military systems decreases costs, spurs innovation, and increases acquisition and operational performance, said James "Bubba" Davis, a research scientist with ISIS.

"The military has traditionally developed software from scratch. But with the component-based design paradigm provided by FACE, if multiple defense avionics programs have the same needs or goals, they can use the same software from related projects," Davis said. So that means that software created for an Apache helicopter, for example, could conceivably be used in another type of aircraft.

Earlier attempts at systematic software reuse for the DoD often ended with failure, said Douglas C. Schmidt, professor of computer science and a senior research scientist at ISIS. One reason for these failures was that system integration has traditionally been viewed as an interoperability problem that can be solved with standards and discipline alone.

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

ISIS is developing a reference implementation and associated model-integrated computing software toolkit

FACE is a trademark of The Open Group.

as part of FACE. This software will be available in open-source form to anyone building avionics systems for the DoD. The resulting FACE ecosystem will help reduce the barriers to adoption of the standard. Rapid adoption of FACE will lower total ownership costs, achieve better performance, field innovations more rapidly, and leverage existing government and defense contractor workforce more effectively than traditional closed-source approaches to fielding software.

Successful integration of the FACE open-source software will require a modular and well-articulated software system architecture, with precisely specified interfaces and safety and security profiles. "What you're allowed to use and not allowed to use (when building software) is clearly defined," Bapty said. "In addition, FACE will enable full disclosure of design specifications to contractors, including competitors and small businesses."

The ISIS team of ten professionals is partnering with a team from Georgia Institute of Technology under a contract with the U.S. Navy to provide technical assistance, software development, and inputs to the standards. The Open Group-managed consortium of government, industry, and academic participants is helping define and ratify the standards. An initial draft standard already is in place, but it will take some time to reach full penetration into the military avionics marketplace.

The ISIS team is building a set of conformance tools to ensure that software developed by contractors will meet the FACE standards. They are also working to develop a conformance verification process.

"A standard has no teeth unless you can enforce it and is not viable these days unless you can enforce it cost effectively," Bapty explained. Advancing and fine-tuning the conformance tools is another area for potential research growth, he said, adding that the FACE initiative should create multiple opportunities for contractors who excel in different aspects of software creation and who realize that government purchasing policies must adapt to the changing economic environment.

"The FACE project has a huge potential to jump-start many different research and development areas," said Bapty. Moreover, by fostering competition and innovation through open business practices, FACE enables the development and sustainment of software and hardware components by different contractors over the life cycle.

"The cost efficiencies driven by FACE and related common operating platform environments that ISIS is involved with are invaluable in helping the United States ensure our national security at a price we can afford," said Schmidt.

The FACE Architecture

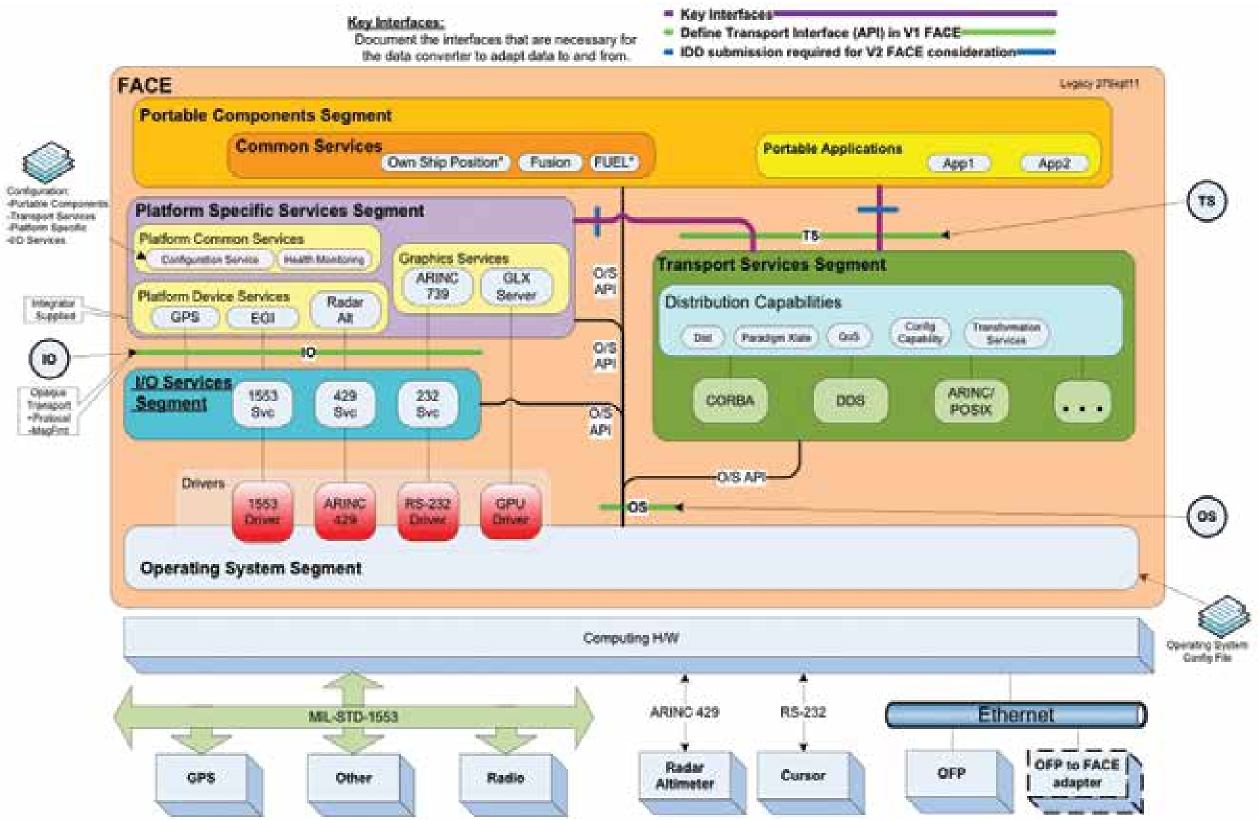


Figure 16 from "Future Airborne Capability Environment (FACE) Reference Architecture, Edition 1.0" is used with permission from The Open Group.

"ISIS is the ideal location for developing innovative technologies due to the critical mass of researchers and engineers working on similar problems."
—AKOS LEDECZI

SHOOTER LOCALIZATION MOBILE APP PINPOINTS ENEMY SNIPERS

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.

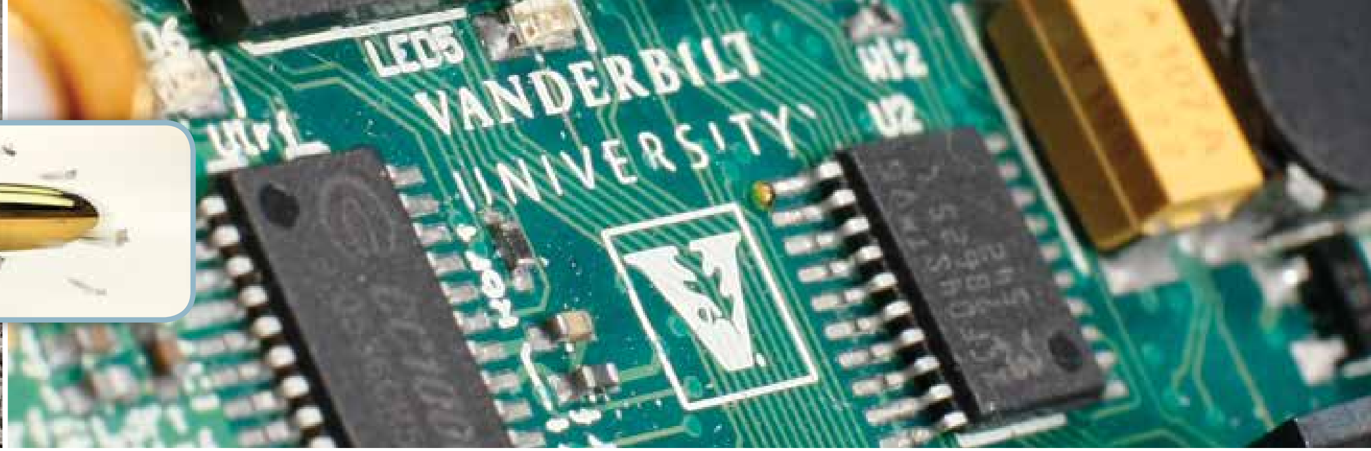
The human ear is easily fooled by echoes. For example, soldiers in urban environments or in rocky, mountainous terrain often cannot tell the direction of incoming fire until they actually see the enemy. A system like SOLOMON can determine the source of the very first shot, enabling a quick reaction. 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 avert major disasters with minor repairs.

The SOLOMON shooter location system is just one of many technologies under development in the wireless sensor network group at ISIS. For example, a novel software-defined radio is being developed under NSF funding that allows researchers to experiment with novel wireless communication protocols that consume considerably less power than conventional radios. Currently, comparable equipment requires wall power or large batteries that would still run out of power in an hour. The new technology makes it possible to run outdoor experiments for hours using conventional AA batteries.

The group is also working on a novel, GPS-based localization technology that provides much higher accuracy than what is feasible today. The underlying idea is to allow nearby GPS receivers, such as mobile phones, to share their GPS data with each other and then use that data to cooperatively compute the ranges between the receivers. The goal is to determine the relative locations of the mobile devices at centimeter-scale accuracy to enable such applications as collision avoidance or platoon control for driverless cars, distributed mobile sensor arrays, or an urban guidance system for the visually impaired. The approach will come in handy for the SOLOMON project as well. This research is sponsored by NSF and a 2012 Google Research Award.

"We are truly honored to have received this award from Google. They get thousands of submissions each year from around the world but fund only a handful of them," explained Ledeczi. "ISIS is the ideal location for developing innovative technologies due to the critical mass of researchers and engineers working on similar problems."

Just steps away from his office are other engineers who can assist in hammering out solutions to hard problems, such as how to distinguish echoes from line-of-sight sounds. He explained, "This is not just engineering in theory—we are creating things that never existed before."

MACHINE LEARNING BOOSTS HUMAN EXPERTISE TO PREVENT PLANE CRASHES

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 system, as well as anomalies that occur due to pilot actions and unusual environmental conditions, such as inclement weather or the orientation of a runway in a particular airport.

"We are one of the first projects that has taken this data and tried to apply intelligent analysis to help isolate, detect, and prevent adverse events," said Gautam Biswas, professor of computer science and computer engineering, who leads the NASA-funded VIPR project.

Even though plane crashes are rare, the growing complexity of aircraft systems has increased the chances for unexpected occurrences; hence the need to combine machine-driven exploration with human expertise to understand these situations, said Biswas.

"We're reaching limits in terms of how effectively human experts can analyze unusual situations," he said. "We must therefore find ways to use all our resources—human expertise and research in data mining and machine learning—to enhance existing knowledge. Analyzing the huge amounts of operational data that we have collected over the years will improve decision-making during flight operations, maintenance, scheduling, and overall airline management. The most important goal is improved airline safety and efficiency."

VIPR uses advanced data mining and machine-learning techniques to explore and analyze large amounts of flight data to derive new and useful knowledge. Human experts then use that knowledge to improve diagnostic monitors and reasoning systems available on today's aircraft.

Biswas, graduate student Daniel Mack, and associate professor of computer science and computer engineering Xenofon Koutsoukos sift through the data collected by numerous sensors and monitors for up to fifty flights 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 have reliably detected 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 machine learning. Two sets of experts—aircraft engineers from both Honeywell and NASA—are presented with diagnostic knowledge that can yield potential innovations and safety features. For example, ISIS researchers working

"It is the interaction between software and hardware that really determines how the system behaves. The depth of our expertise—combined with years of experience in this field—enables us to analyze interactions between different parts of the system and understand how these systems behave."

—GAUTAM BISWAS

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.

Biswas said real airline disasters and averted disasters alike motivate his work. For example, data analysis of Air France Flight 447—en route from Rio de Janeiro to Paris when it crashed into the Atlantic Ocean in 2009—indicated a junior pilot failed to understand sensor data and alarms that went off in the aircraft. On the other hand, the now famous Captain Sully had the experience and training to safely crash-land a U.S. Airways flight in the Hudson River that same year with no casualties.

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.

Biswas 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 this field—enables us to analyze interactions between different parts of the system and understand how these systems behave."

Phase one of VIPR received top honors in the 2011 Associate Administrator Awards for Technology and Innovation by NASA's Aeronautics Research Mission Directorate. "Receiving 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

COMBINING WORLD-CLASS HEALTH CARE WITH SECURE PATIENT RECORDS

Our society faces a growing threat from misuse of information in cyber-systems. The cost of intellectual property theft to U.S. companies alone tops $250 billion a year, and it is estimated that $1 trillion was spent globally to address problems caused by cyber-breaches. As cyber-security has become a national priority, ISIS has focused a great deal of work on the science of security, including ensuring privacy for the next generation of information systems, such as electronic medical records (EMRs).

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. Among the projects on that front are Team Research in Trusted Ubiquitous Security Technologies (TRUST) project, which is a Science and Technology Center funded by the NSF, and the Strategic Health Care IT Advanced Research Projects on Security (SHARPS), which is funded by the Department of Health and Human Services.

TRUST is the umbrella for multiple projects led by Janos Sztipanovits, ISIS director and E. Bronson Ingram Distinguished Professor of Engineering, in partnership with researchers from University of California at Berkeley, Carnegie Mellon University, Cornell University, and Stanford University. In this project, ISIS focuses on creating trustworthy health information systems that, by design, are aware of and enforce privacy constraints." If you model policies correctly, you can compute the proper behavior," Sztipanovits explained. "You need precise modeling that applies logic and reasoning."

In the SHARPS project, ISIS works with researchers at the Vanderbilt University Medical Center to develop modeling tools for privacy policies and technology tools to integrate privacy models in the exchange of health information. SHARPS leverages the expertise built up from TRUST to specifically target health care applications. Partners with Vanderbilt on SHARPS are University of California-Berkeley, Carnegie Mellon University, Dartmouth University, Harvard University, Johns Hopkins University, New York University, Stanford University, University of Illinois at Urbana-Champaign, and University of Washington.

EMRs are an aspect of TRUST and SHARPS that has become a national priority as the government strives to normalize and institutionalize EMRs nationwide to improve access and reduce cost. The complexity of EMRs stems from the need to integrate multiple, software-reliant systems—some commercial, some produced in-house—in a manner that satisfies the rapidly changing (and often conflicting) demands of medical innovations, clinical procedures, and insurance and government regulations, explained Yuan Xue, assistant professor of electrical engineering and computer science and an integral part of TRUST and SHARPS.

EMRs are connected to an array of systems that support health care business operations, including clinical documentation, laboratory reports, radiology services, pharmaceutical dispensing, and billing. Patient data security and compliance with regulations, such as Health Insurance Portability and Accountability Act (HIPAA) requirements, present complexities, as does the fact that most EMR systems are connected to Web portals, exposing them to continual Internet attacks.

"We've developed techniques to build an architecture that protects the EMR system and the Web portal," Xue said. The system works like a firewall that's intelligent enough to recognize intended information and updates so the entire system need not be shut down for every change. This approach is typical for ISIS researchers—getting multiple systems to work together and to detect and prevent anomalies. "We really enjoy these complex multidisciplinary challenges," added Sztipanovits.

Another collaborative project within the TRUST program is CareNet, which supports remote patient monitoring by using sensor technologies to send data to medical personnel. CareNet allows home monitoring of patients with chronic diseases, such as heart conditions or diabetes, improving patient comfort and reducing medical costs.

Sztipanovits also leads an ISIS team in a collaborative TRUST project with the Vanderbilt University Medical Center and the Department of Biomedical Informatics of the School of Medicine to develop a patient management system for sepsis treatment. Triggered by bacteria invasion through wounds or IV lines, sepsis causes the body to literally attack itself. The rapid sepsis detection and patient management system, currently in clinical trial, integrates with an automated decision support system to help hospital personnel navigate successfully through the complex treatment process. The success of the sepsis program is an exemplar for other such model-based, decision support systems to normalize treatment plans, said Sztipanovits.

The Privacy Preserving Record Linkage project, led by Brad Malin, associate professor of biomedical informatics at Vanderbilt University Medical Center, is yet another SHARPS

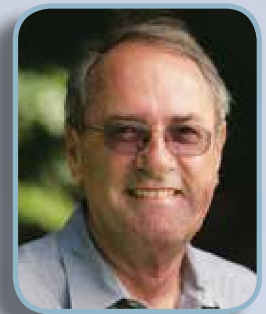
and TRUST offshoot that allows the secure integration of medical records from multiple sources, including multiple treatment facilities or ancillary services, such as radiology or pathology. It also enhances research opportunities by allowing third parties, such as the National Institute of Health (NIH), to collect a large number of records for research while protecting individual patient's identities in accordance with HIPAA regulations.

Vanderbilt was a natural choice for TRUST and SHARPS due to the combination of ISIS and a world-class medical center, said Xue. "The Vanderbilt University Medical Center has long applied new technologies to facilitate better patient care, while ISIS has been a leader in developing secure, robust technologies for health care and other mission- and safety-critical domains," she 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."

Most software tools and platforms developed at ISIS are open-source, making the results of ISIS research widely accessible. The availability of open-source tools enables rapid adaptations to cyber-security needs and opens the field to small- and mid-sized companies' participation in the competitive process, Sztipanovits said. Multiple spin-off opportunities from TRUST and SHARPS are emerging as the need increases to secure health care platforms and protect patient privacy.

"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."

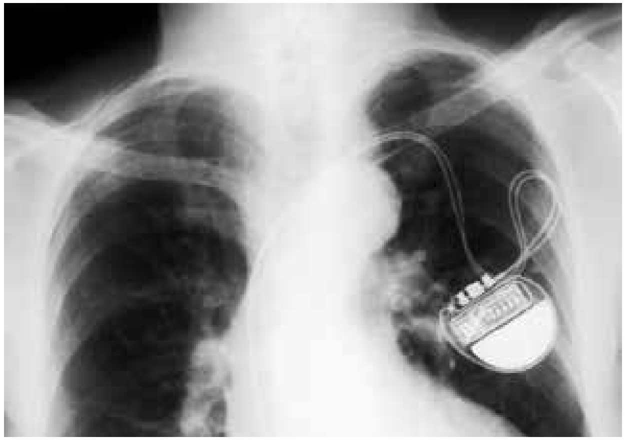
—JANOS SZTIPANOVITS



DEPEND ON IT: RELIABILITY OF COMPLEX SYSTEMS A KEY FOCUS FOR ISIS

Whether you realize it or not, your life may depend on model-based software design principles and tools. Systems today—everything from pacemakers to remotely piloted aircraft to the power grid—are complex, and the processes used to build the software platforms that make them work are surprisingly creative. More important, these processes leverage decades of R&D on innovative tools and methods—the kind of advanced software design work going on at ISIS every day to ensure software and hardware integrate together successfully.

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).

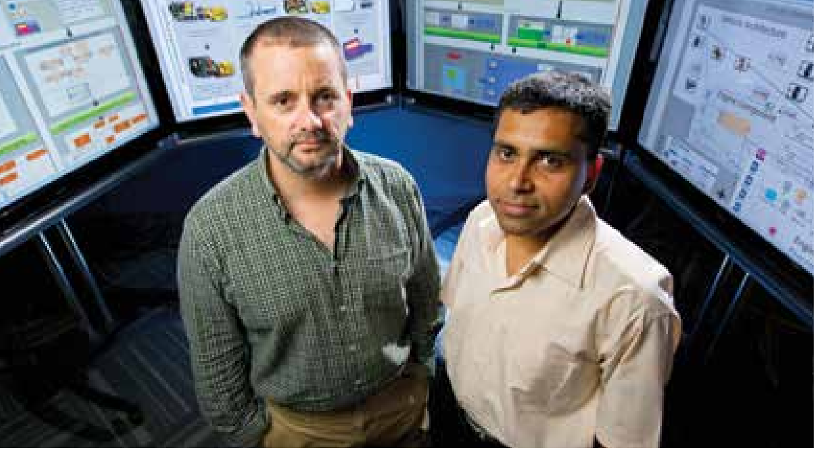
"ISIS is at the forefront of the cyber-physical system revolution due to our strong focus on the foundations of model-based design and model-integrated computing," Sztipanovits said. These foundations include model-based design automation for software, model transformations and model management, model-based 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).



> "ISIS and Vanderbilt are leaders in DRE middleware and mobile software apps, so the AMMO project provides the ideal confluence of these two technologies."
>
> —DOUGLAS C. SCHMIDT

THERE'S AN APP FOR THAT: TURNING SMARTPHONES INTO TOOLS FOR TROOPS

An innovative ISIS project, the Android Mobile Military Middleware Objects (AMMO), is developing lightweight middleware software platforms that convert standard smartphones and mobile apps into secure military and disaster recovery communications devices. Presently deployed with more than 2,000 troops overseas, the DARPA-funded AMMO project is geared to help soldiers avoid firing on friendly troops, navigate back to base in unfamiliar territories, avoid potential ambush points, and protect civilians traveling with the troops.

Middleware developed at ISIS provides the building blocks to allow smartphone apps to replace and expand the functions of the traditional tactical radios used by the military. Numerous military-relevant software apps developed by the DARPA program already are in the field, with more under development.

"What's great about AMMO is that DARPA has deployed it to soldiers who are actually using it through the apps, giving it rave reviews, and ensuring its continued upgrades meet their needs," said Sandeep Neema, ISIS senior research scientist, research associate professor of electrical engineering and computer science, and principal investigator (PI) for AMMO.

"DARPA's goal with Transformative Apps (the DARPA program under which AMMO is being developed) is to achieve maximum impact quickly in the field," said co-PI Ted Bapty, ISIS senior research scientist and research associate professor of electrical engineering and computer science. "Soldiers in Afghanistan are using AMMO software. DARPA's agile research and development approach focuses on getting this software and hardware out there quickly to help them, see what they like, and then iterating. Some of the best ideas come from soldiers using the apps and providing rapid response feedback."

He continued, "When soldiers get out there, and they're looking in the sun with all this heavy equipment on and someone's shooting at them, that's a vastly different environment than we experience here in the lab at ISIS, so thorough user testing in the field is critical."

Converting commercially available smartphones for use in a constrained battlefield environment requires flexibility and serious problem-solving acumen. Often, the underlying infrastructure expected by a smartphone used in the USA—on a 3G or WiFi network, for example—is not readily accessible, nor is the requisite security available since conventional mobile phones are easily hacked or jammed in combat situations. The AMMO smartphones must therefore be made tamper-proof and function with existing tactical radios in Army units.

"Middleware provides the glue to make the smartphone work efficiently and securely within this environment," explained Bapty. Middleware delivers a software communication layer to enable the operating system and the apps to work together with tactical radios. "The tactical environment is where the AMMO middleware shines. This middleware makes modern smartphone apps accessible to war fighters."

While traditional tactical radios are used primarily for voice or data transmission, the smartphone apps hosted atop AMMO provide additional functions, such as mapping for dynamic positioning, sharing photos that might help identify enemy troops or transmitting information about an improvised explosive device (IED) explosion that requires medical assistance for troops. Translator apps allow more rapid communication with the local population. Twitter-like apps allow quick communication, with multimedia attachments. The SOLOMON shooter location technology developed by ISIS engineers (see page 12) is building on some of the Android-based middleware technology developed for the AVM project.

AMMO's data relay capability provides important functionality as well, according to Bapty. For example, it allows soldiers to relay information back to base from troops farther afield or from those blocked by dense vegetation.

Vanderbilt was the natural environment for AMMO, which emerged in part from the research tools and applied work of ISIS on a previous Army-sponsored project called Future Combat Systems (FCS). Among the tools ISIS created for FCS was a student-built robot controlled by a smartphone and equipped with a camera to identify certain objects. ISIS researchers realized some of those innovations could be applied to mobile phones, and DARPA fast-tracked the ideas for use in the battlefield.

"Our work on AMMO spans from high-level, Java-based programming abstractions down to cable wire soldering. The cross-disciplinary nature of the team and the experience we've built across the board makes us the right team," Neema said. "We have both the people and the technology."

Among those people is co-PI Douglas C. Schmidt, professor of computer science and a senior research scientist at ISIS, who has worked extensively on middleware technologies for distributed real-time and embedded (DRE) systems (see page 30). "ISIS and Vanderbilt are world leaders in DRE system middleware and mobile software apps, so the AMMO project provides the ideal confluence of these two technologies," Schmidt explained.

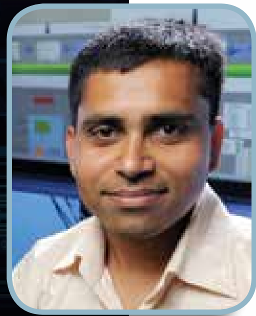
The flexible middleware and agile development methods applied on AMMO have allowed for several hardware revisions already, Neema said. One problem that ISIS addressed was the need for lower level hardware to integrate with a radio, which required alterations to the cables so they did not interfere with radio frequencies. The latter modification was finessed by ISIS research scientist James "Bubba" Davis, which explains why the DARPA Transformative Apps hardware now includes "Bubba cables."

"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 and debug problems, and that's what we have here at ISIS." R&D projects sometimes fail, he said, because of researchers' tendency to focus only on a small area of expertise rather than supporting the broader project objectives. "For the end users, the entire system—smartphone hardware, radios, cables, operating system, middleware, applications—has to work or nothing works. At ISIS, we've never shied away from dealing with the whole technology spectrum."

AMMO started in 2010 with $500,000 in seed money from DARPA and has scaled up considerably since then, with a recent $17 million dollar award to ISIS as the prime contractor. This increased funding has allowed ISIS to create undergraduate research opportunities with as many as five interns per academic year. Some graduates who interned at ISIS while undergraduates at Vanderbilt have taken their technology expertise to commercial jobs in Nashville, broadening the AMMO technology transition impact.

"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, "so ISIS's success with the AMMO project is a microcosm of exciting things to come."

> "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



ISIS IS LEADING EFFORTS TO REVOLUTIONIZE MILITARY VEHICLE DESIGN

Designing a complex vehicle in one-fifth the time is the revolutionary concept behind the Adaptive Vehicle Make (AVM) 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. DARPA's open AVM approach will allow multiple vendors to compete at multiple levels throughout the acquisition process, saving time and money, as well as creating economic opportunities for more participants.

"This is the kind of innovation that allows separation of design from fabrication, a model that revolutionized the VLSI industry. Right now, the design can only be done by a shop that has the integrated capability to do a complete production run. The idea is to detangle the design houses from manufacturing houses and make the entire process more open, innovative, and competitive," said Sandeep Neema, ISIS senior research scientist and research associate professor of electrical engineering and computer science.

In the AVM project, ISIS is creating tools through model-integrated computing and cyber-physical systems engineering processes and methods. These processes, methods, and tools will allow rapid reconfiguration and analysis of the whole vehicle design. Vehicle components can be combined, added, or modified quickly, creating powerful capabilities for designers.

"We should be able to apply these concepts and tools to a variety of vehicles, though the current focus is on amphibious vehicles," said Neema, who along with Ted Bapty, ISIS senior research scientist and research associate professor of electrical engineering and computer science, led the initial AVM design phase, called "META." They are now leading teams of ISIS research scientists and engineers, creating an open-source, fully integrated toolsuite for the broader AVM project.

Through AVM, DARPA is harnessing creativity and activity of unconventional design and manufacturing entities including small companies and self-organized teams of collaborating experts to yield a more open vehicle design process. A competition portion of the AVM program feeds into the ultimate goal: the democratization of vehicle design. 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 major components of AVM that ISIS is leading or participating in are:

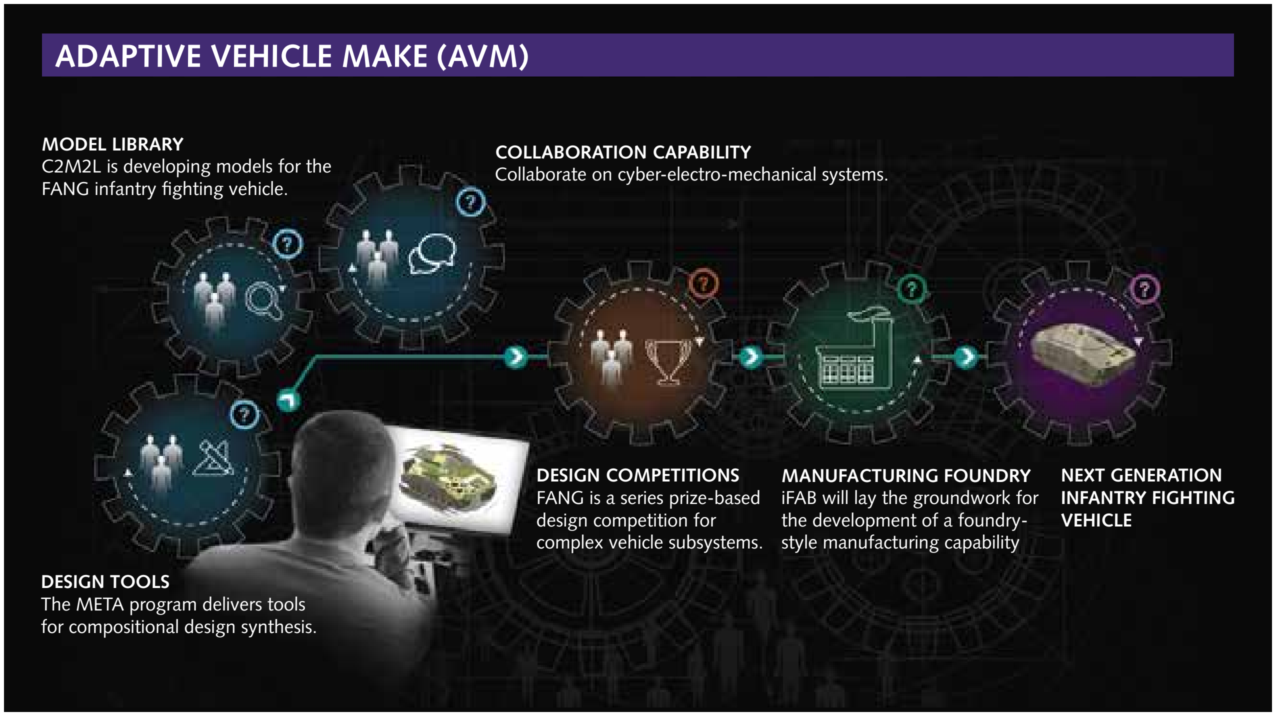
- META, which was the initial design automation portion of AVM. It began with concept exploration and small-scale demonstration of the tools supporting the design process. After the year-long initial phase, ISIS was selected as the main "integrator" for the open-source design tool chain OpenMETA and has begun the process of specifying and implementing capabilities that will be ultimately used in the competition phase of AVM. Bapty and Neema are the PIs for OpenMETA. Collaborating with the lead team from ISIS are groups from Georgia Tech University, MIT, Oregon State University, Palo Alto Research Center, Smart Information Flow Technologies, and Stanford Research Institute.

- The Component, Context, and Manufacturing Model Library (C2M2L, pronounced "camel") portion of AVM is developing computer models that are used as building blocks in the design, verification, and manufacturing of vehicles. ISIS is responsible for the integrity and compliance of the component models to accepted and standardized interfaces. More than twenty undergraduate interns helped with the curation of these components. C2M2L will be conducted in phases beginning with the vehicle drivetrain and mobility subsystems. Neema is the PI for C2M2L.
- The Fast Adaptable Next-Generation Ground (FANG) Vehicle portion of AVM sets the rules for competition and defines how that process will be conducted. FANG is run by Ricardo, a Detroit-based engineering and technical consulting company, with ISIS providing training materials, curating all tools, and operating a help desk as a main subcontractor. Bapty is the PI for Vanderbilt's FANG effort.
- The Model-Based Amphibious Racing Challenge (MBARC) is the educational component of AVM (see page 26). MBARC is a student-led design competition that teaches students about model-based vehicle design, the META process, and how to evaluate the AVM design tools. It has a smaller scope than FANG and is performed by student teams from MIT, University of California at Berkeley, and Vanderbilt. Tom Withrow, assistant professor of the practice of mechanical engineering, is the lead for the Vanderbilt MBARC team.
- VehicleFORGE (see page 24) is a cloud-based collaboration hub where AVM designs are submitted, tested, and validated. It includes the creation of a central website to engage several orders of magnitude more talent than is available in the current industry model. Larry Howard, ISIS senior research scientist, is the PI for VehicleFORGE.
- Foundry, as the name implies, is the portion of AVM that will actually build the vehicle. ISIS played an integral part in the precursor to Foundry, instant Foundry Adaptive through Bits (iFAB), which was responsible for the Foundry design. Gabor Karsai, professor of electrical engineering and computer science and associate director of ISIS, was the iFAB PI.

Computer software, hardware, and scads of physical components must integrate seamlessly to meet DARPA's goals for AVM. "We cut across the spectrum of engineering skills to achieve these goals," said Bapty. "The main idea is to drive innovation in design and manufacturing."

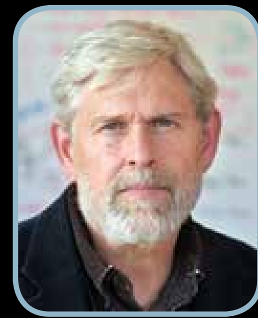
"The potential impact of our research on manufacturing is huge," Neema added. "Being able to create a design rapidly and have it built quickly has immense potential. That's the model of manufacturing that the U.S. needs to evolve toward." The success of AVM could yield better products that can adapt to markets faster, with more products rolling out more efficiently and frequently, he said.

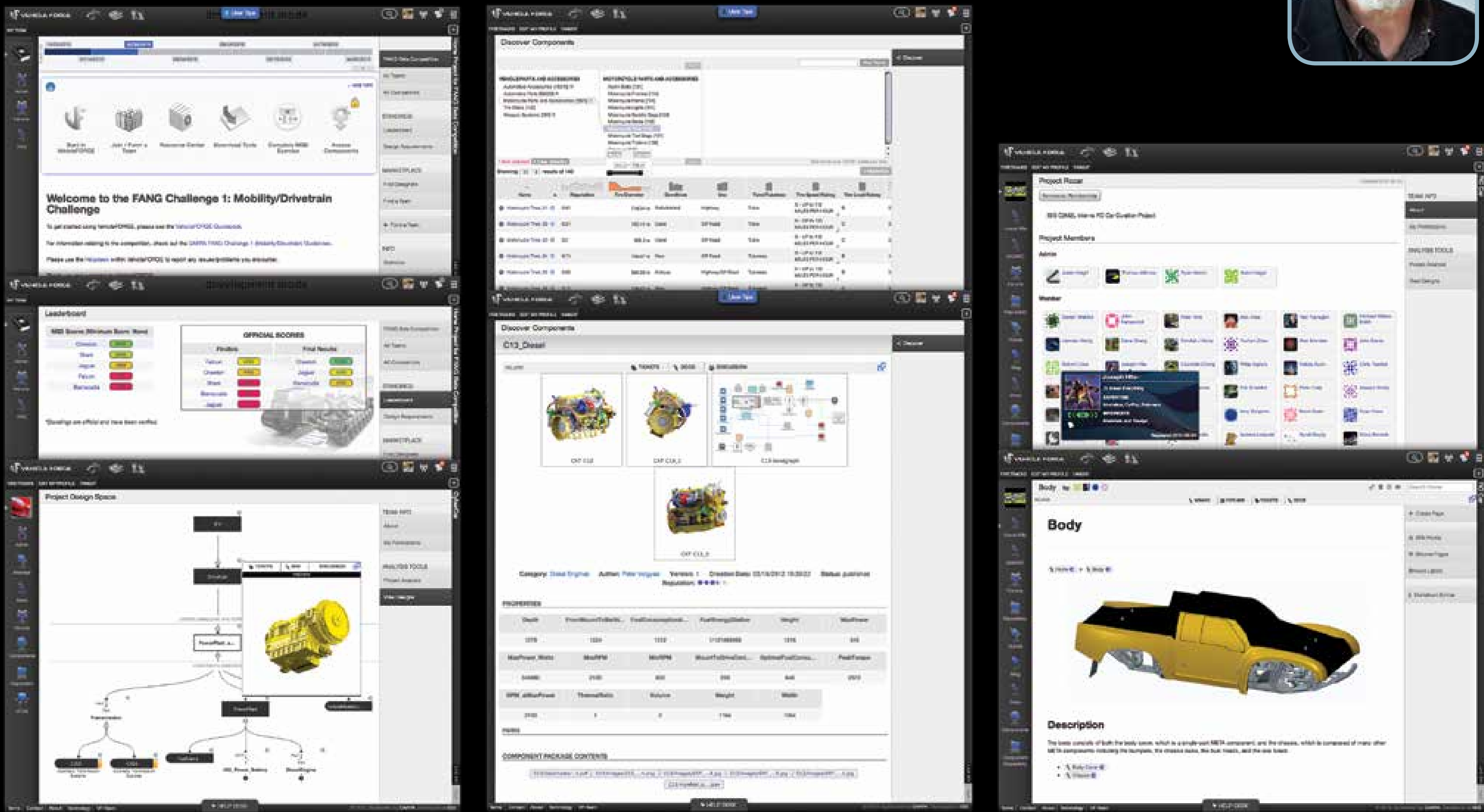
META and the other AVM projects represent the culmination of many previous ISIS projects, from designing tools for space station systems to automobile manufacturing information systems. "Having done that process over and over again, we are well suited to meet the AVM challenge. We have the core set of concepts already in place," said Bapty. "Our technology and people base is broad and deep."



“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





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 solutions to design problems, with an important addition: The system has the ability to integrate computer-aided design (CAD) models and other structural and behavioral representations of design found in cyber-physical systems modeling. It also has the capability to quickly discern differences between models as the design process progresses.

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

The success of VehicleFORGE will help demonstrate the viability of cloud-based deployment of complex analysis tools and create the foundation for new types of collaboration within the cyber-physical system community. "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 longer-lived collaborations between researchers and practitioners. We also expect it will become a platform for incubating 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 democratizing 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. "So, the government often doesn't see much variety of responses in solicitations and, therefore, they don't get much design diversity or innovation. The way to accomplish that goal is to decompose the method by which systems are acquired and increase competition by an order of magnitude using cloud-based collaboration tools like VehicleFORGE."

Using collaboration methods based on the successes of open-source software communities, Howard's team selected the code base of SourceForge.net as a starting point for VehicleFORGE. "To build VehicleFORGE, we had to reinterpret software forges for a very different domain: cyber-physical systems. Designs here are dominated by material and physical concerns, which are strongly reflected in the ways designers represent and analyze these systems," he said.

The work was completed rapidly—in a year's time—to have VehicleFORGE in place for the first AVM design challenge: designing a drive train for the FANG amphibious vehicle.

"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 sufficient confidence to send it to the foundry," Howard said. Successful designs will take into account the entire supply chain equation to reduce cost. "If I have to special order a part from one place on the planet, and it just had an earthquake, then I can't put this vehicle in the field," he explained. The manufacturability of the design is another key component in the AVM competition.

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

"We're right on the cusp of a really big change if projects like AVM and VehicleFORGE pan out," 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."

"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."

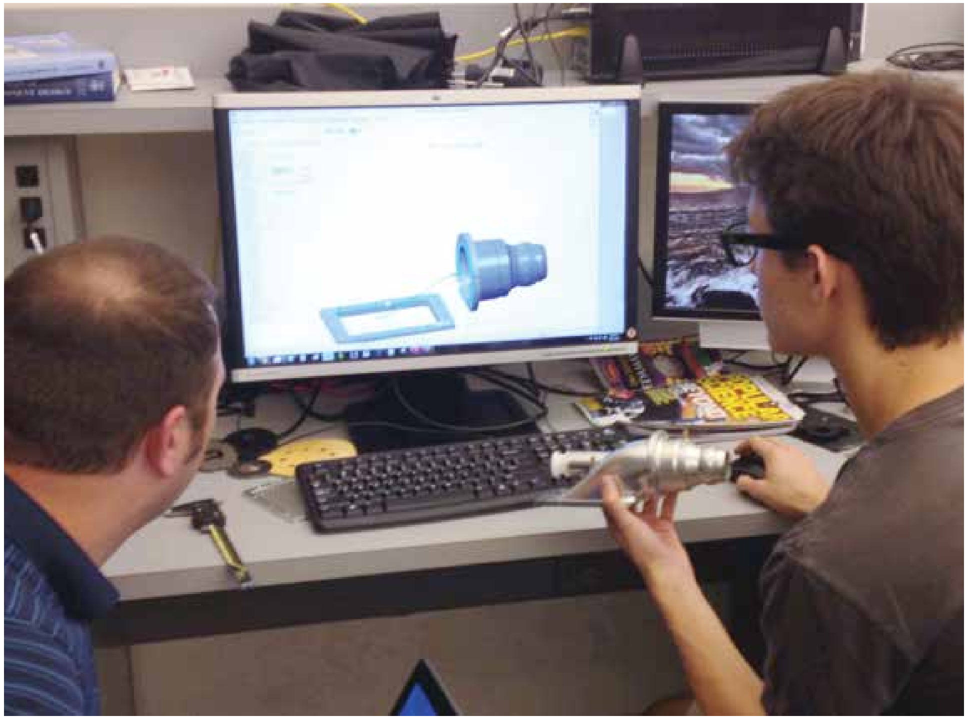
—TOM WITHROW

UNDERGRADUATE STUDENTS ARE CREATING SMALL-SCALE AMPHIBIOUS VEHICLES AT ISIS

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.

Using model-integrated computing methods, the MBARC students are challenged to come up with truly novel designs that can be fabricated quickly. This first year included participants from three universities—Vanderbilt, MIT, and the University of California at Berkeley—with plans to expand to more universities next year.

"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.



The META tools are meant to create a complex design in a shorter time frame. The initial focus is military applications, but the longer-term goal is dual use for civilian projects. The challenge from DARPA is to create tools to eliminate multiple iterations of the design-build-test-redesign cycle.

At Vanderbilt, the MBARC design project takes place in a class where undergraduate students learn about the cyber-physical systems design methods being created at ISIS, explains Withrow, who is running the Vanderbilt project design team. Sandeep Neema, ISIS senior research scientist and research associate professor of electrical engineering and computer science, is principal investigator for MBARC.

The AVM project has already inspired significant student participation at Vanderbilt. In summer 2011, four undergraduate students from Vanderbilt's School of Engineering collaborated on the initial cyber-physical systems modeling of an armored personnel carrier. During the 2011/12 school year, fifteen students worked on creating the first full-featured prototype using system-based architecture. This electromechanical vehicle was a 1:5 scale, radio-controlled car formed in the CyPhy laboratory on the Vanderbilt campus in Featheringill Hall. Forty more undergraduate students from multiple universities furthered these efforts during 2012 at ISIS.

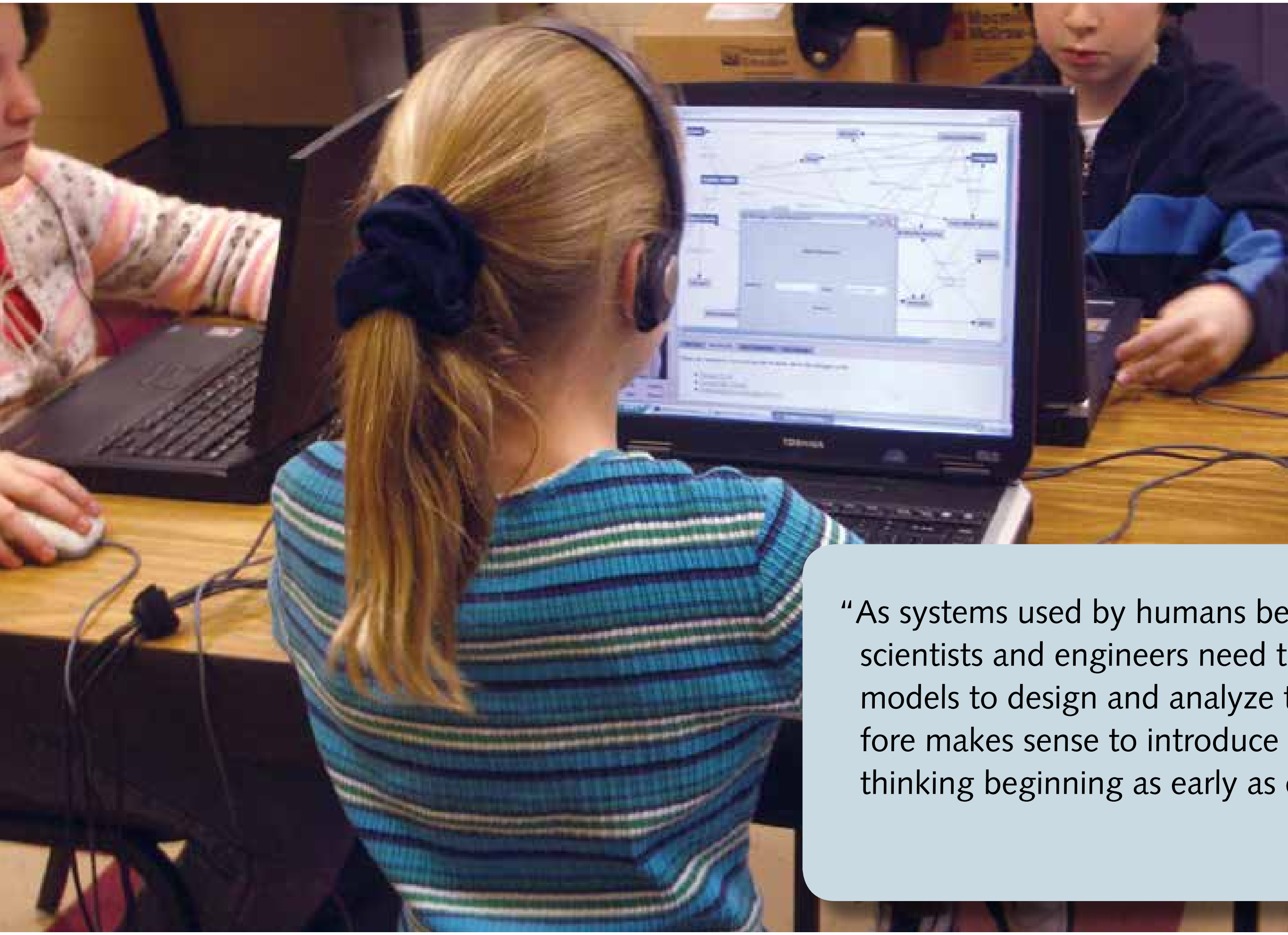
"What we've done is model an industrial setting in the midst of an academic environment so that students get real-world engineering experience. MBARC is enabling effective cross-pollination of interdisciplinary research," explains Ryan Wrenn, an ISIS staff engineer who works with the undergraduates.

The real-world experience was the hook for Phil Ingram, a mechanical engineering undergraduate from Denver, Colorado, who took a job at OSIsoft in San Leandro, California, after graduating from Vanderbilt in 2012. He jumped at the chance to spend more time with computer modeling in the spring of his senior year "learning a subset of skills that we can apply to future jobs," Ingram said.

The hope is that undergraduates will be inspired by the work to join the next generation of manufacturing and design innovators. "This kind of multi-systems engineering is the future of engineering," Withrow said, "and these undergraduates at Vanderbilt are an integral part of the design process."

EDUCATION MODELING TOOLS BOOST STEM TEACHING IN K–12 SCHOOLS

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 encouraging deeper understanding of the material? The answer is: "Yes," with help from the right kinds of computer learning tools.



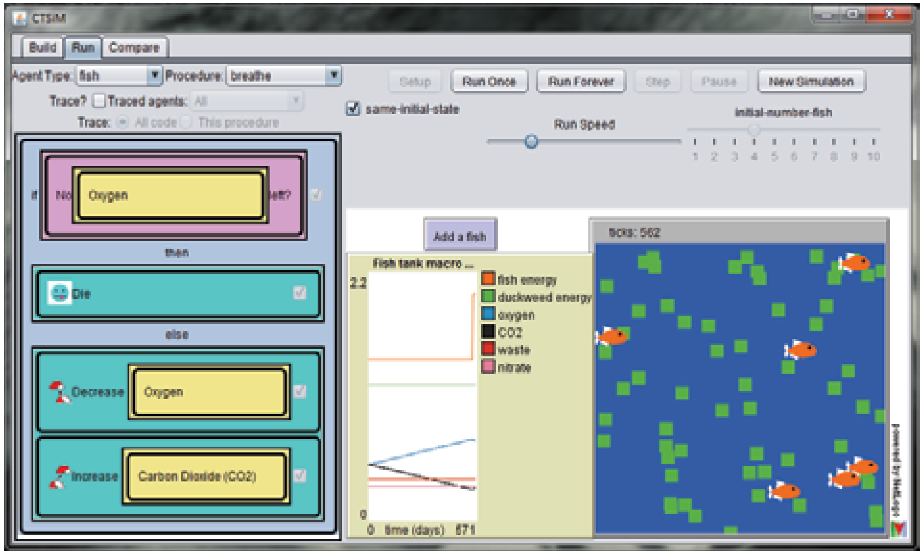
These new computer learning tools—already under development at ISIS and being tested in some Tennessee schools—allow students to explore, build, analyze, and reflect as they learn by modeling science phenomena. The students, in turn, use the modeling tools to answer relevant questions about the world around them, such as how to design a better fish tank, analyze traffic flow in crowded cities, or teach basic ecology concepts that describe the function of a pond ecosystem.

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 Gautam Biswas, professor of computer science and computer engineering.

"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."

—GAUTAM BISWAS



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 CTSiM (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 kindergartner 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.

CTSiM focuses on teaching middle and high school students computational thinking skills to support modeling and analysis. 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, CTSiM reinforces the idea that people constantly make conditional decisions, such as deciding to take a different route when 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 their model to answer questions and solve problems, such as how to build a better fish tank."

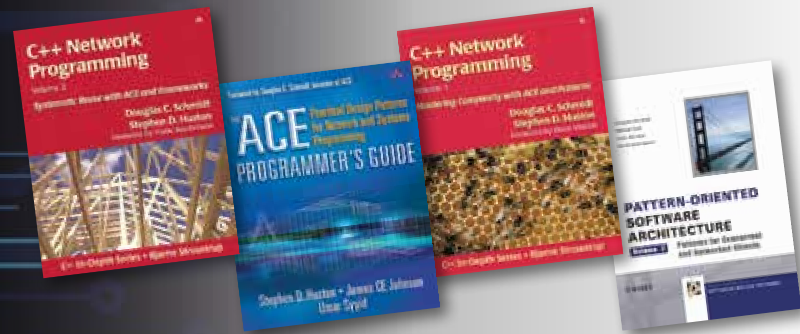
At the end of each day, SimSelf and CTSiM generate reports for classroom teachers. "We're not building systems to replace teachers, but instead we are using technology to make teachers more effective. It's hard for teachers to follow in detail the progress of 25+ students in their classes. Through our 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 curricular units. Pilot projects in Nashville schools help students learn about the causes and effects of global warming and then apply what they've learned to solving real 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 inside a two-liter soft drink bottle.

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 understand how the education system works, ISIS engineers understand the practical constraints of converting ideas into technological solutions. Said Biswas, "It's a natural partnership."

"Even though our DRE middleware work has been going on for over twenty years, newer and better 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 and serves as an important building block for many projects at ISIS. The motivation for this middleware sprang 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.

Douglas C. Schmidt, professor of computer science and an ISIS senior research scientist, began developing 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. When Schmidt took his first faculty position at Washington University in St. Louis, Aniruddha Gokhale, now associate professor of electrical engineering and computer science and an ISIS senior research scientist at Vanderbilt, was one of his first graduate students. "Together we pioneered the open-source DRE middleware innovation cycle and discovered many foundational patterns underlying the design of flexible and optimized DRE middleware," said Schmidt.

Schmidt and Gokhale led the development of the influential middleware packages ACE (ADAPTIVE Communications Environments) and TAO (The ACE ORB), which are popular open-source, pattern-oriented frameworks. They have been used successfully by thousands of companies and projects worldwide in many mission-critical application domains, including national defense and security, datacom/telecom, financial services, air transportation management, and medical engineering. ACE and TAO formed the basis for CIAO (Component Integrated ACE ORB), which they developed after joining ISIS at Vanderbilt to extend ACE and TAO. CIAO provides powerful component-based abstractions using advanced deployment and validation techniques based on the ISIS GME (Generic Modeling Environment) toolsuite (see page 32).

"We're the ones who made open-source DRE middleware widely accessible and adoptable by the mainstream for mission-critical application domains where the right answer delivered too late becomes the wrong answer," Schmidt said. For example, the response time of an anti-locking braking system coming seconds later, instead of within a fraction of a second, can lead to catastrophic consequences, despite the response being functionally correct.

ACE, TAO, and CIAO are important components of key ISIS projects, including System F6, which is building a network of orbiting satellites in the sky called "fractionated spacecraft" (see page 8) and Android Mobile Military Middleware Objects (AMMO), which is a lightweight middleware platform that converts standard smartphones and mobile apps into secure military and disaster recovery communications devices (see page 20).

At its basic level, DRE middleware shields operating system differences so that specific applications can operate in any kind of system. It keeps proprietary commands or functions from interfering with application portability, while still ensuring end-to-end, quality-of-service properties, such as low latency, dependable timing, data confidentiality, and high throughput.

The importance of open-source DRE middleware like TAO increased after the dot-com bubble burst, Schmidt explained, because many companies had difficulty finding ways to thrive due to their large investments in proprietary middleware. "They had a large and growing customer base, but a decreasing revenue stream due to lack of investors and shrinking stock prices. They began to adopt the open-source DRE middleware technology we'd developed and deployed it into their code bases," he said.

The open-source DRE middleware developed at ISIS provides a sound technical solution to an otherwise prohibitively expensive problem. "A number of companies sprung up to support the open-source work that we had been doing at ISIS," Schmidt said. "An ecosystem evolved in response to our leadership in revolutionizing the open-source DRE middleware space."

The middleware community at Vanderbilt has brought in over $20 million in research funding in the past decade, yielded a half-dozen books and hundreds of technical publications, and helped graduate more than 25 doctoral and master's students, Gokhale added.

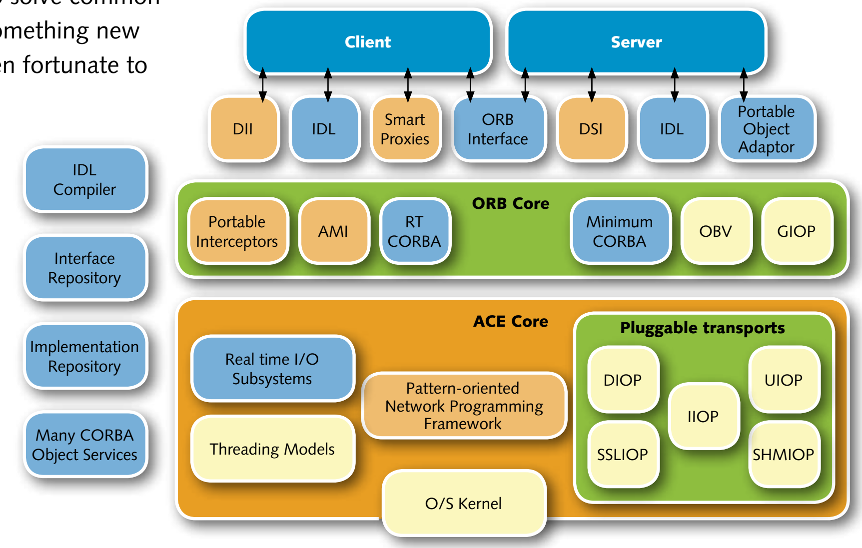
"DRE middleware is a perfect example of the way researchers at ISIS combine fundamental research with applied research to solve real problems," said Schmidt. "It comes from a combination of a deep understanding of the research principles plus awareness of the challenges faced by practitioners. We have many research collaborations and partner with other top universities, too. In addition to our cutting-edge research, one of the roles we increasingly play is the role of research integrator."

The beauty of centering the open-source DRE middleware work at an academic institution is the ability to bring together people from around the world working in various capacities and time zones and for diverse purposes—from industry to government to institutes—to solve common problems. "Our goal is to always find something new and take it in new directions. We've been fortunate to work with many really bright researchers and developers along the way," Schmidt said.

"Even today, twenty years later, we're finding a new purpose in the System F6 project," Gokhale said. The System F6 project (see page 8) is using a completely new system called System F6OS in which ISIS DRE middleware is infused into a new operating system, in part to make the system more secure.

AMMO (see page 20) uses ACE as a portability layer, making it easier to write software that runs seamlessly across different operating systems, such as Windows and Linux. ISIS's DRE middleware also has been used in building collaborative educational tools "to support the idea that a group of school kids can come together and then 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 going on for over twenty years, newer and better results are emerging because the needs of our sponsors keep changing," Gokhale said. For example, ISIS is teaming with industry on a Small Business Technology Transfer (STTR) project funded by the Air Force Research Lab that uses ACE, TAO, and GME to provide a real-time computing cloud over multicore and distributed-core hardware platforms.



Schmidt and Gokhale both said the collegiality and dedication to world-class, interdisciplinary research with global impact at ISIS make their work especially gratifying. "What you find at ISIS are people who look at problems from many different perspectives," Gokhale said. "We're all about outreach and collaboration. That's why we've been so successful at middleware, since it's fundamentally an integrative technology that makes it easier to build DRE systems out of collaborative components. This focus has driven us to seek partners and do things that have a broad impact, rather than just limited point solutions."

GENERIC MODELING ENVIRONMENT: BUILDING TOOLS THAT BUILD TOOLS

The motto of model-integrated computing and its main tool—the Generic Modeling Environment (GME)—could be the old saying: "Give a man a fish and you feed him for a day. Teach a man to fish and you feed him for a lifetime." Instead of providing a point solution to a given engineering or scientific problem, ISIS engineers 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.

While model-integrated computing is the overall scientific and engineering approach to building such integrated systems, GME is a modeling toolkit that implements that approach, explained Akos Ledeczi, associate professor of computer engineering and senior research scientist at ISIS.

GME is a model-integrated, program synthesis tool for creating domain-specific models, which support higher-level abstractions than general purpose programming languages (such as C++/C and Java) and general-purpose modeling languages (such as UML), so they require less effort and fewer low-level details to develop a given system. GME also allows users to define new modeling languages using metamodels, which describe the rules, constraints, and concepts applicable and useful for modeling a class of problems.

The main advantage of the model-integrated computing approach is that it supports 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 computational and physical components, as well as addressing problems of integration with surrounding systems (including middleware infrastructure), while allowing the system to evolve. Related tools can also analyze how well a design will work and often synthesize and/or configure large portions of the application code and supporting software infrastructure.

"The general idea behind model-integrated computing is that we just don't sit down and write software to solve a particular problem," Ledeczi said. "We look at that problem and a set of related problems and try to abstract out what can be generalized. We model the system, and we generate part of the software and other design and manufacturing artifacts from these models. It's easier to change the models and regenerate the software using the GME tools, rather than having programmers write new code manually."

The entire model-integrated computing program was initially developed at ISIS under the leadership of Janos Sztipanovits, ISIS director and E. Bronson Ingram Professor of Engineering, and Gabor Karsai, professor of electrical engineering and computer science and ISIS associate director. Ledeczi became involved with the GME tool as a graduate student under Sztipanovits' tutelage.

The original GME toolkit was written for Microsoft computers using the Component Object Model (COM) for integration. GME is easily extensible, and external components can be written in any language that supports COM (including C++, Visual Basic, C#, Python, etc.). The upcoming Web-based GME is a key part of the new, rapidly evolving generation of technology that will make model-integrated computing accessible to anyone with a Web browser. 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. It will also support online collaboration, similar to Google Docs.

The computer models created with the ISIS model-integrated computing tools allow projects to move forward more rapidly and at a lower cost by discovering potential problems earlier. In each project, the modeling language is adapted to fit the thinking and tools of the practitioner. Moreover, ISIS engineers often don't use just one modeling language, but instead create different languages within

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

—GABOR KARSAI

domains or individual disciplines. "It's not one size fits all," Ledeczi explained.

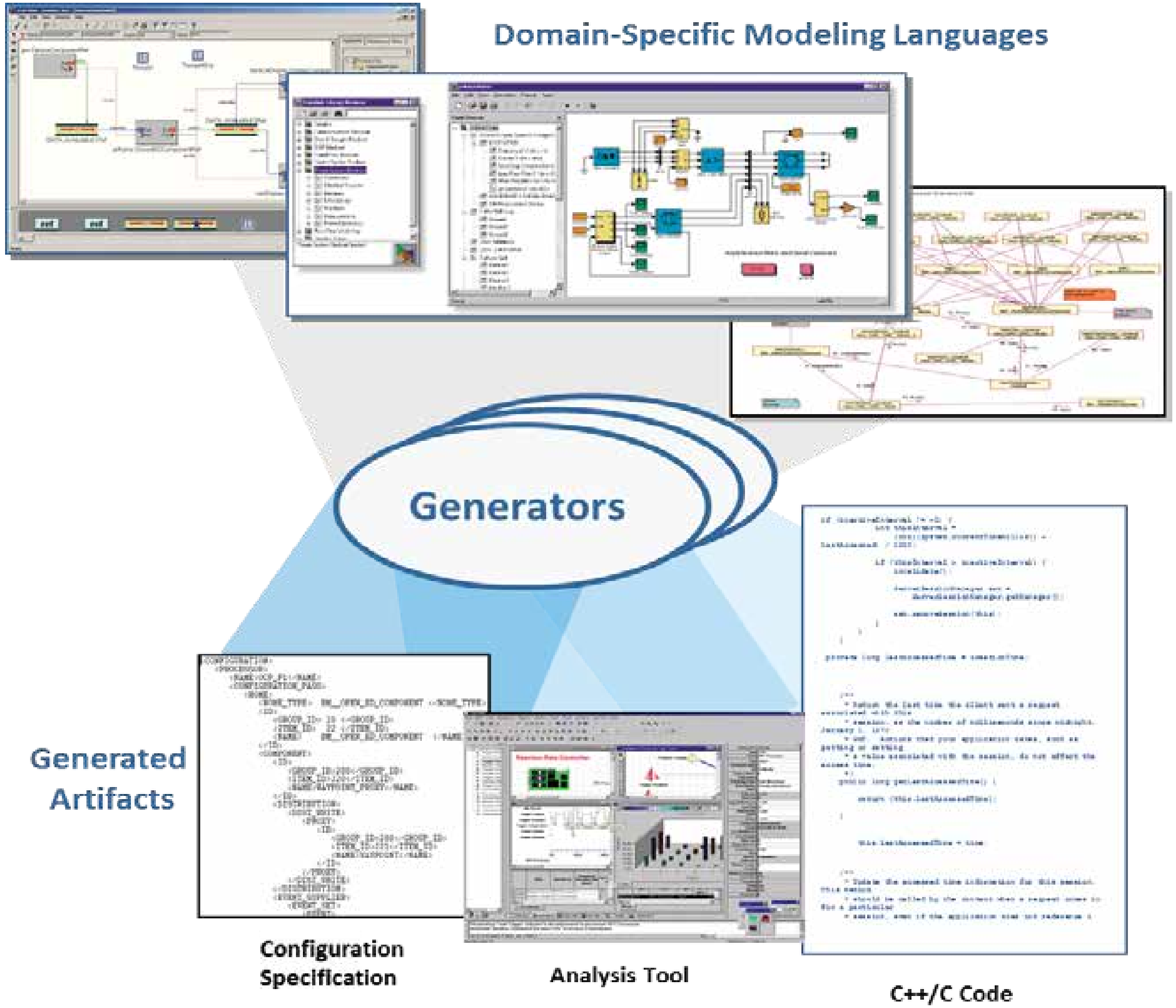
GME is the most popular model-integrated computing toolkit for current projects at ISIS. "Whenever you see model-based design at ISIS, ninety percent of the time we are using GME in one way or another," Ledeczi said, "GME is well regarded for its adaptability and is easy to extend. Anybody can add software tools in many different programming languages to expand its functionality. What we have created are baseline tools for many actual and possible projects."

Earlier projects using GME included the development of a complex system for General Motor Corp.'s former Saturn plant in Spring Hill, Tennessee, to produce a production flow monitoring application. The modeling reflected how production was supposed to work, allowing the system to quickly locate problems even before the human operators realized problems existed. Porting the application to a different plant involved only building models. No lower-level software changes were needed.

Boeing used previous versions of model-integrated computing technology and tools when designing and building the International Space Station, including its fault detection, isolation, and recovery system.

There are medical applications of GME as well. This technology helped model the treatment protocols for a clinical decision support system currently used in multiple intensive care units, a joint project between the Vanderbilt University Medical Center and ISIS.

Current projects include the META portion of the extensive Adaptive Vehicle Make (AVM) project centered at ISIS (see page 22), as well as tools used by the Future Airborne Capability Environment (FACE) (see page 10) to test conformance to the FACE standard reference architecture.



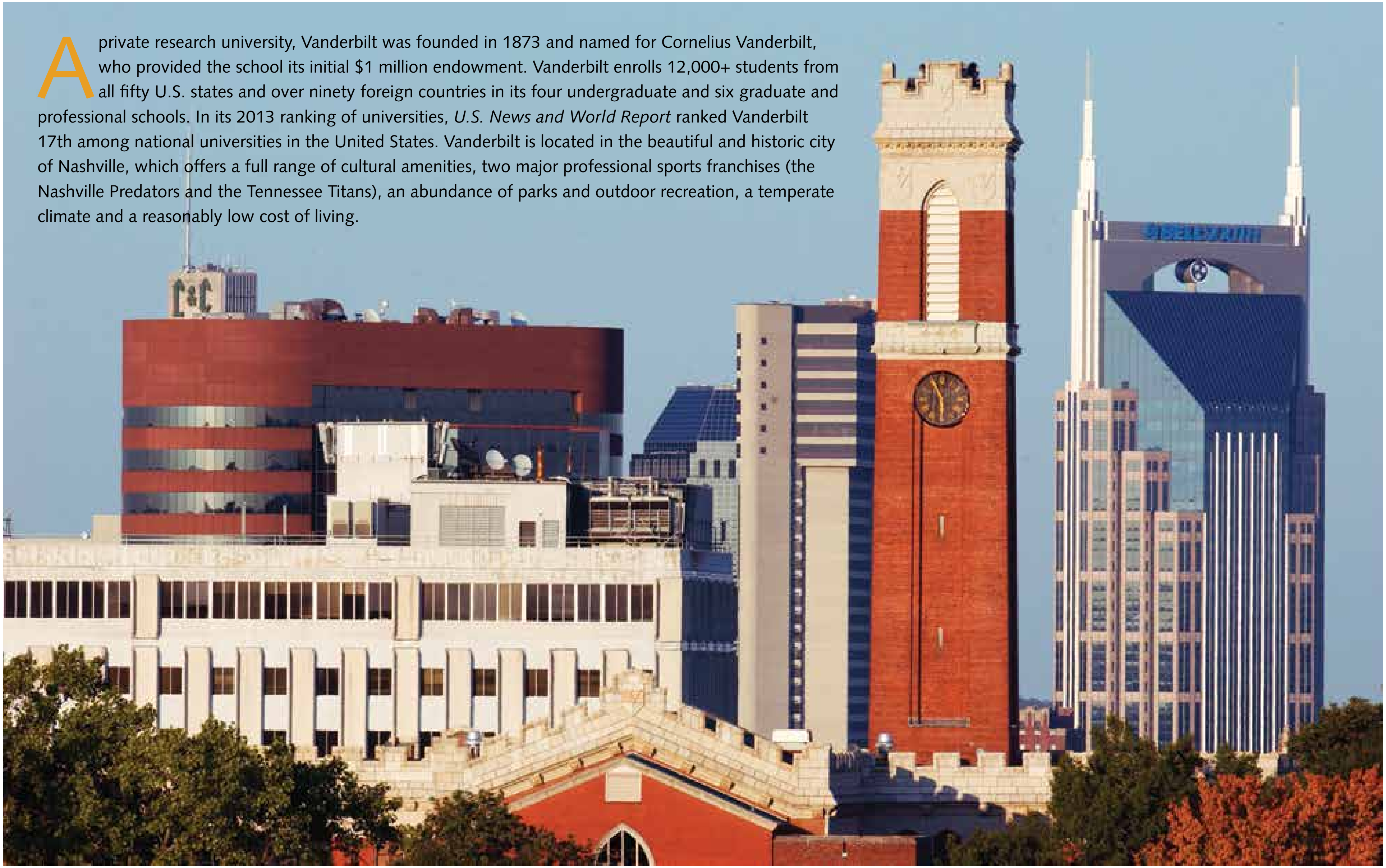
Likewise, the Component-Integrated ACE ORB (CIAO) project at ISIS (see page 30) uses GME to generate the XML-based descriptor files it uses for deploying and configuring application components for the System F6 project (see page 8).

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

ACRONYMS

ACE . . . . ADAPTIVE Communications Environments
AMMO . . . . . Android Mobile Military Middleware Objects
AVM . . . . . . Adaptive Vehicle Make
AFOSR . . . . . Air Force Office of Scientific Research
C2M2L . . . . . 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
CPS-VO. . . . . Cyber-Physical Systems-Virtual Organization
CTSiM . . . . . 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 Capabilities Environment
FANG . . . . . Fast Adaptable Next-Generation Ground
FCS . . . . Future Combat Systems
HIPAA . . . . . Health Insurance Portability and Accountability Act
NIH . . . . National Institute of Health
iFAB . . . . . . instant Foundry Adaptive through Bits
ISIS . . . . Institute for Software Integrated Systems
MBARC . . . . . 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
SHARPS. . . . . 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
SOLOMON . . . Shooter Localization with Mobile Phones
TAO . . . . . . The ACE ORB
TRUST . . . . . Team Research in Trusted Ubiquitous Security Technologies
VIPR . . . . . . Vehicle Integrated Prognostic Reasoner

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 fifty 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.



ABOUT ISIS

ISIS 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 reflective 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**

OPPORTUNITIES FOR CONDUCTING RESEARCH AT ISIS

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, DOD, DOE, 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 posted regularly on our website at **www.isis.vanderbilt.edu/jobs**. 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**.

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