Coordinated Science Lab Newsletter
ENGINEERING AT ILLINOIS

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Connect

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ILLINOIS
Coordinated Science Lab
COLLEGE OF ENGINEERING

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Director's Message | Klara Nahrstedt

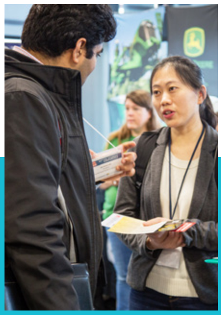
In this issue of Connect, you'll learn about a new CSL initiative that is transforming modern military operations. The $25 million Internet of Battlefield Things (IoBT REIGN), led by CS Professor Tarek Abdelzaher, will develop an interconnected system of humans, machines, and networks working together to enhance defensive capabilities.

The multi-organizational consortium, funded by the Army Research Laboratory, is perhaps our largest effort in the Internet of Things space, but it is far from the only one. In these pages, you'll also read about the SONIC Center, which has come to a close after five productive years. SONIC produced foundational work in shifting the computing paradigm, enabling robust and energy-efficient computing for nanoscale devices. This work will be critical in shaping the IoT of the future. CSL researchers are also pushing new advancements in smart cities, programmable electronic embedded systems, and security issues related to IoT.

In addition, CSL continues to actively promote women in engineering and computer science. The Lab sponsored the Grad Society of Women Engineers conference this winter and has also hosted a number of lunches with female faculty in CSL and ITI. In honor of Women in Engineering Week, held in February, we introduced the Women of CSL video and social media series, which addresses challenges and opportunities that women face in this field, while also highlighting CSL faculty and students who serve as role models for future generations. We also welcomed Dina Katabi of MIT as our R.T. Chien Lecture Series speaker this spring.

Please take a few minutes to look at these stories and all the other exciting things underway CSL!

CSL Highlights



Eric Horvitz, Technical Fellow & Director, Microsoft Research Labs

CSL Student Conference

The 2018 CSL Student Conference had a record-breaking year, with 835 registrants from 54 different disciplines. The conference highlighted the breadth of research from CSL students, from artificial intelligence to information processing, and offered a job fair, poster session, robotics demos, and more.

Across the three days, there were 26 presentations, including 17 CSL students, four invited student talks, four keynote speakers, and Eric Horvitz, director of Microsoft Research Labs, as the plenary speaker. There were 21 poster presentations, 12 robotics demonstrations, and at the job fair, there were 18 companies and 150 graduate students. Thanks to this year's co-chairs, Tarek Sakakini and James Schmidt, as well as the rest of organizing committee and the CSL staff who helped make the conference a tremendous success.

Speculative Futures

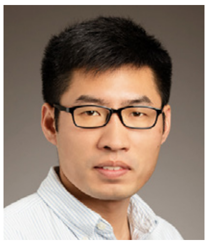
Speculative Futures, a series of events in November 2017 and organized by CSL and Illinois Program for Research in the Humanities, examined where the worlds of humanities, science, and engineering collide. Drawing on Illinois' world-famous technological legacy, Speculative Futures brought together artists, writers, and technology innovators into conversation with one another in order to spark new creative projects.

Events included a talk featuring creative writers and artists discussing the role of technology and the creative imagination; a reception and interactive demonstrations at the National Center for Supercomputing Applications (NCSA); a workshop for students grades 6-12 to learn about writing science fiction; pecha kucha style presentations from English undergraduates telling stories inspired by their engineering counterparts' research; and a panel with the featured speakers discussing how the interaction of science, engineering, and the humanities serves to motivate, inspire, and facilitate their work.

CSL Highlights

Four new faculty join CSL

CSL welcomed four new faculty members to our team last semester: Jian Huang (ECE), Aleksandr Stolyar (ISE), Ruoyu Sun (ISE), and Vadim Zharnitsky (Math).



Jian Huang is a member of CSL's Reliable and High Performance Computing research group, and his research focuses on building practical, reliable, secure, and high-performance systems, and to bridge all layers of systems stack from hardware platforms to applications.

Aleksandr Stolyar is one of the world's top queueing theorists, specializing in analysis and control of stochastic networks. He joined CSL's Decision and Control group.

Ruoyu Sun's work focuses on data analytics. His research interests focus on large-scale optimization and its application in machine learning, data analysis, and signal processing. At CSL, he works with the Signals, Inference, and Networks group.

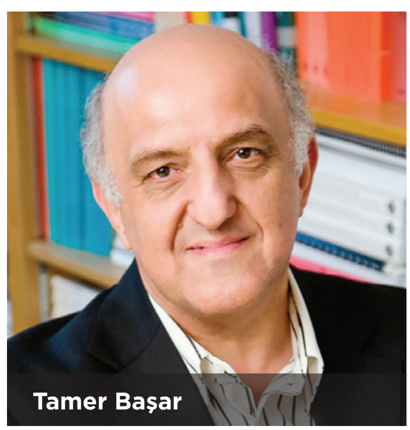
Vadim Zharnitsky has also joined CSL as a member of the Decision and Control group. Zharnitsky's research interests center around dynamical systems and differential equations, nonlinear waves, and Hamiltonian dynamics.

CSL faculty in leadership

Andreas Cangellaris, the former dean of the College of Engineering and CSL faculty member, was selected by Chancellor Robert Jones to be the campus's vice chancellor for academic affairs and provost.


Andreas Cangellaris

Tamer Başar, CSL faculty member, director of the Center for Advanced Study, and professor of electrical and computer engineering at Illinois, was named the interim dean of the campus's College of Engineering.


Tamer Başar

Internet of Battlefield Things connects soldiers with advanced technology

On the battlefields of tomorrow, humans and technology will work together in a seamless, cohesive network, giving soldiers a competitive edge and keeping troops and civilians out of harm's way.

CSL researchers are leading a $25 million initiative to develop the scientific foundations of a next-generation Internet of Battlefield Things (IoBT), designed to enable new predictive battlefield analytics and services. The "Alliance for IoBT Research on Evolving Intelligent Goal-driven Networks (IoBT REIGN)," funded by the Army Research Lab, includes collaborators from ARL, Carnegie Mellon University, University of California, Berkeley, University of California, Los Angeles, University of Massachusetts, University of Southern California, and SRI International. The funding covers the first five years of a potential 10-year effort.

In the future, military operations will rely less on human soldiers and more on interconnected technology, leveraging advancements in unmanned systems and machine intelligence in order to achieve superior defense capabilities. The IoBT will connect soldiers with smart technology in armor, radios, weapons, and other objects, to give troops "extra sensory" perception, offer situational understanding, endow fighters with prediction powers, provide better risk assessment, and develop shared intuitions.

This effort to understand and exploit the unique capabilities of networked battlefield systems is an interdisciplinary problem that brings together researchers in cyber-physical computing, information theory, security, formal methods, machine learning, networking, control, and cognitive science, among other disciplines.

An integral part of the alliance is the collaboration between ARL and the academic and industry researchers.

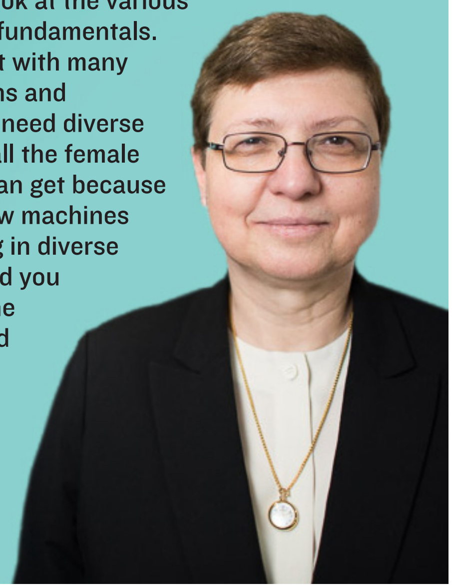
"This award enables a true collaboration between researchers at ARL and researchers in academia and industry to change the status quo in smart battlefield services," said Tarek Abdelzaher, the academic lead of the Alliance and a professor of computer science at Illinois. "Through ARL's Collaborative Research Alliance model, we can change our fundamental understanding of what's possible when computers, sensors, data, weapons, soldiers, wearables, and media analytics are networked to empower new defense capabilities."

Women of CSL

Engineering is a growing and diverse field. Yet women are still a minority. During the month of March, we introduced Women in CSL, an online intitiative highlighting the amazing female leadership, faculty, and students we have in our unit. This effort aims to break down barriers and encourage more women to pursue engineering and sciences. Below are what CSL women have to say about life in engineering and the importance of getting more women into the field.

"Coming from India, women are a minority in engineering, or any higher education. When I came to America, I was expecting it to be very different here, because this is a first world country and there are many opportunities. But I saw that the proportions were not any different, and that surprised me. And I said, maybe there is something that I can do. I am pretty hopeful that these numbers will change in the coming decade or so."

SUMA BHAT
Research Assistant Professor, ECE, CSL



"Engineering is a fantastic area to be in. The amount of inventions that are here or are coming will absolutely need women to look at the various applications and fundamentals. I truly believe that with many of these inventions and applications, you need diverse teams. We need all the female researchers we can get because many of these new machines will be interacting in diverse environments, and you can't just have one sex build that kind of environment."

KLARA NAHRSTEDT
Director, CSL

"There is an imbalance between the number of males and females in the engineering field. One factor is the social expectation and stereotype of women, which discourages females to choose engineering as a career. . .the most effective way to diminish and eventually remove this stereotype is to get more women into engineering and prove that it is wrong."

WEI ZUO
PhD Student, ECE

"I believe it is important to have more females so as to inspire younger female generations, who can see women in engineering as role models. In addition, by increasing the number of women in engineering we will no longer see it as a 'male' degree, which will potentially lead to motivate more women towards studying engineering."

IDOIA OCHOA
Assistant Professor, ECE

SONIC: Breaking the barrier between memory and processing

When DARPA and the Semiconductor Research Corporation funded the SONIC (Systems on Nanoscale Information fabriCs) Center in 2013, the goal was simple and revolutionary at the same time: to transform computing as we know it. During the past five years, SONIC has done exactly that, achieving major breakthroughs in deep-memory architecture and vertically integrated research methodology.

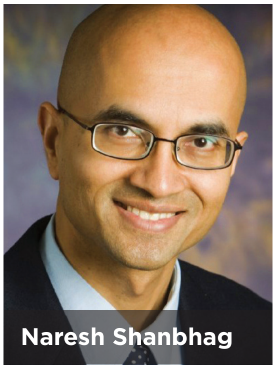
Now at SONIC's end, Connect reflects on the impact the center has had on the field of computing.

Deep In-Memory Architecture: DIMA

SONIC's research was motivated by the observation that today's computers have begun to approach and sometimes exceed human performance in performing specific cognitive tasks such as recognition. Yet these successes have come at a power consumption cost, with computers expending significantly more energy than the human brain to conduct the same task.

Thus, SONIC research was driven by one fundamental question: How can one design intelligent machines that can proactively interpret and learn from data, and solve unfamiliar problems using what has been learned, all while operating with the energy efficiency of the human brain?

SONIC researchers addressed this question by leveraging ideas from neuro-inspired and Shannon-inspired communication theory at the system level. They translated the powerful insights from these domains into realizable architectures and circuits. In a typical von Neumann computing system, the memory and processor are separate.


Naresh Shanbhag

In the past, it has been difficult to bring these two close to each other inside a system. Using Shannon theory, SONIC researchers created a DIMA chip that brings the processor next to the memory by turning computation from digital into analog, while still preserving accuracy.

“DIMA is able to operate on low signal-to-noise ratio fabrics while generating reliable system outputs,” explains Shanbhag, the Jack S. Kilby Professor of Electrical and Computer Engineering.

By breaching the memory wall, their DIMAs and deep in-sensor architectures (DISAs) achieved energy savings ranging from 10× to 113×, which are throughput gains of up to 6×, as well as an energy-delay product reduction of 52× to 162× over traditional von Neumann computing architecture.

As part of this process, SONIC researchers established a statistical foundation for computing in the nanoscale era.

Vertically Integrated Research

SONIC researchers published more than 600 papers in top conferences and filed 11 patents, demonstrating their unique systems-to-devices research portfolio.

SONIC’s research outcomes were a direct consequence of deep collaboration among an outstanding group of faculty and students with expertise spanning neuroscience, coding theory, machine learning, microarchitecture, integrated circuit design, and devices. Their collaboration was nurtured by SONIC’s unique vertically integrated center organization and research agenda that encompassed systems-to-devices in a holistic manner.

“It was ambitious. We urged top minds in our center to think outside their own disciplines,” said Shanbhag.

SONIC researchers evangelized their unique approach to semiconductor research at various forums including a Semiconductor R&D organized by the White House Office of Science and

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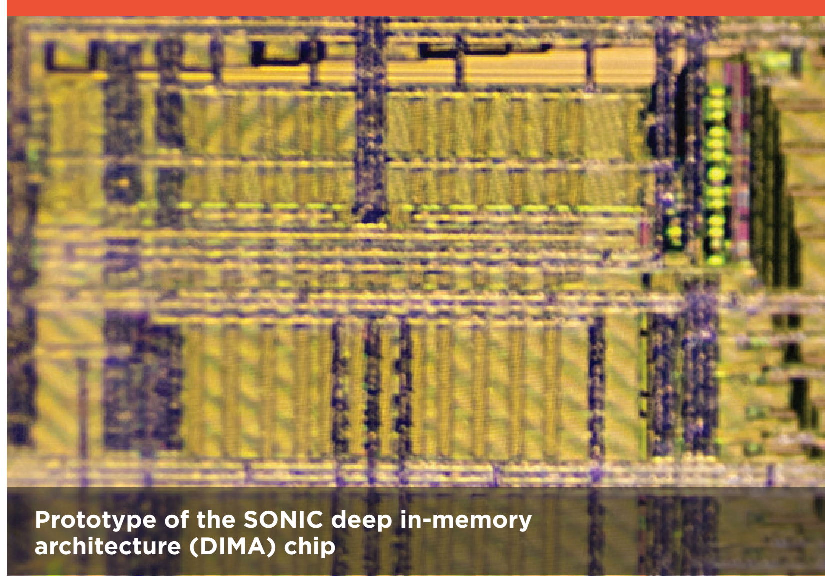
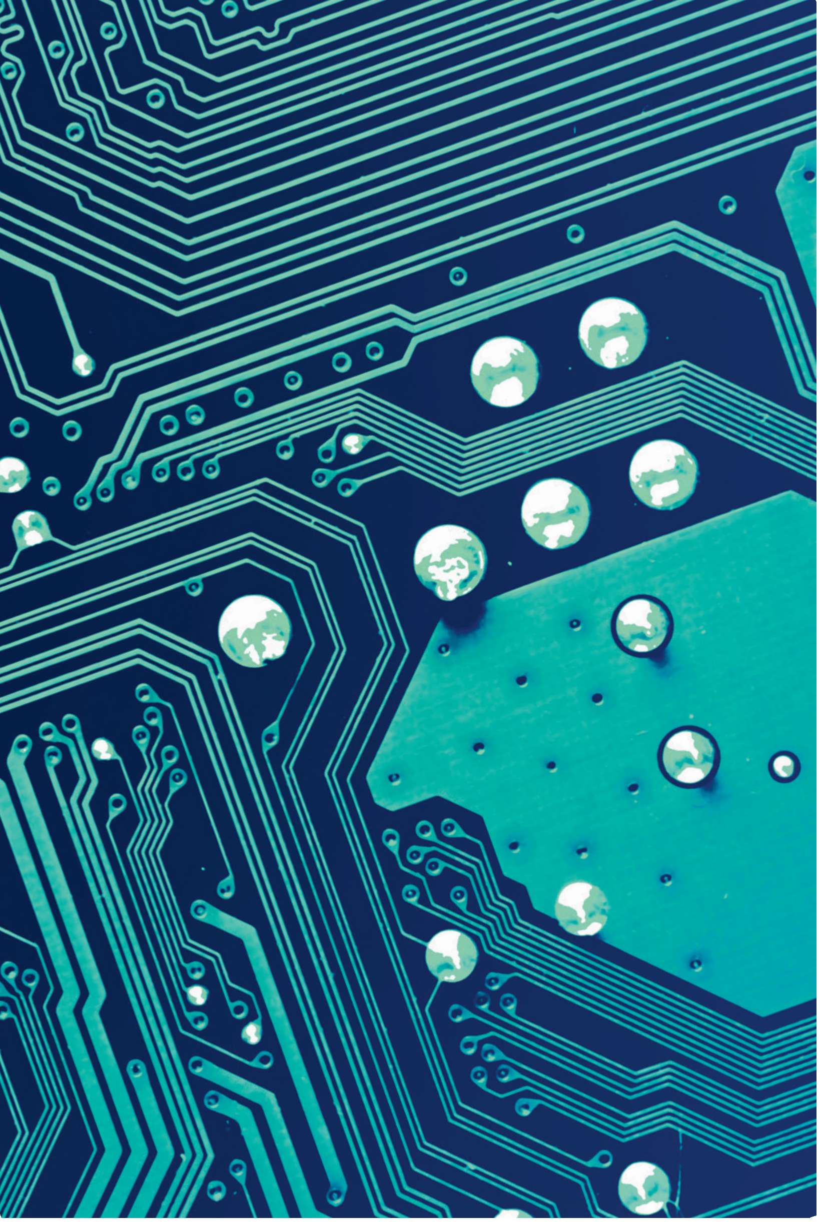
How can one design intelligent machines that can proactively interpret and learn from data, and solve unfamiliar problems using what has been learned, all while operating with the energy efficiency of the human brain?

NARESH SHANBHAG


Prototype of the SONIC deep in-memory architecture (DIMA) chip



Technology Policy. There, they met with CTOs from major semiconductor companies to brainstorm.

"We talked about ways for the U.S to fund researchers so that as a nation we have a semiconductor sector that remains competitive with the rest of the world," said Shanbhag.

As a result, SONIC's vertically integrated research agenda has become the standard for recent advanced semiconductor research programs. The Joint University Microelectronics Program (JUMP) sought to establish four (out of six) SONIC-style vertical centers. Key SONIC concepts such as Shannon-inspired computing, algorithmic noise-tolerance, and in-memory architectures were called out as key areas for future research. DARPA's Electronics Resurgence Initiative (ERI) similarly has a vertically integrated structure geared to translate outcomes from STARnet and JUMP. Furthermore, nanoelectronic COmputing REsearch (nCORE), funded by SRC, also embraces the SONIC philosophy of providing systems pull on device research.

"SONIC's structure was inspired by how we work in CSL. We have system researchers, architects, and circuit designers working closely together," said Shanbhag. "It's not new for us. We have a wonderful staff to support us. CSL was the right place for SONIC to be born."

History of SONIC

The SONIC Center, led by the University of Illinois at Urbana-Champaign, was an innovative research team established in 2013 to take a new look at computing systems.

Funded by DARPA and the Semiconductor Research Corporation, SONIC was led by CSL and ECE Professors Naresh R. Shanbhag and Andrew Singer. They brought together 27 faculty and 104 graduate students from 10 renowned universities.

CSL and Mayo Clinic team up to develop improved method to identify seizure-causing regions in the brain

Epilepsy—a condition that affects an estimated 65 million people worldwide—can be a difficult condition to treat. A team at CSL and Mayo Clinic has developed a method with the potential to significantly improve the accuracy and reduce the cost and time needed to identify regions of the brain causing epilepsy.

Using probabilistic modeling and artificial intelligence techniques based on real data from patients suffering from epilepsy, Yogatheesan Varatharajah and Mayo Clinic neurologist Dr. Greg Worrell developed a model to identify seizure generating brain regions using only non-seizure data. The new approach has the potential to decrease the time of an epilepsy procedure from days or weeks to just a couple of hours.

It has been long appreciated that the epileptic brain regions responsible for seizures generate abnormal activity even when a patient is not having a seizure. It is similar to the sparks that occur before a fire ignites. Worrell and Varatharajah investigated this further.

"When we looked at the data the doctors were collecting, we examined the abnormal activity and using sophisticated machine learning techniques, we were able to actually predict where the seizures were coming from," said Varatharajah, a CSL PhD student in electrical and computer engineering advised by CSL and ECE Professor Ravishankar Iyer.

"This gave us the idea of utilizing our probabilistic modeling expertise in epilepsy procedures to identify the seizure-generating regions without having to look at the brain activity during the seizures," he said.

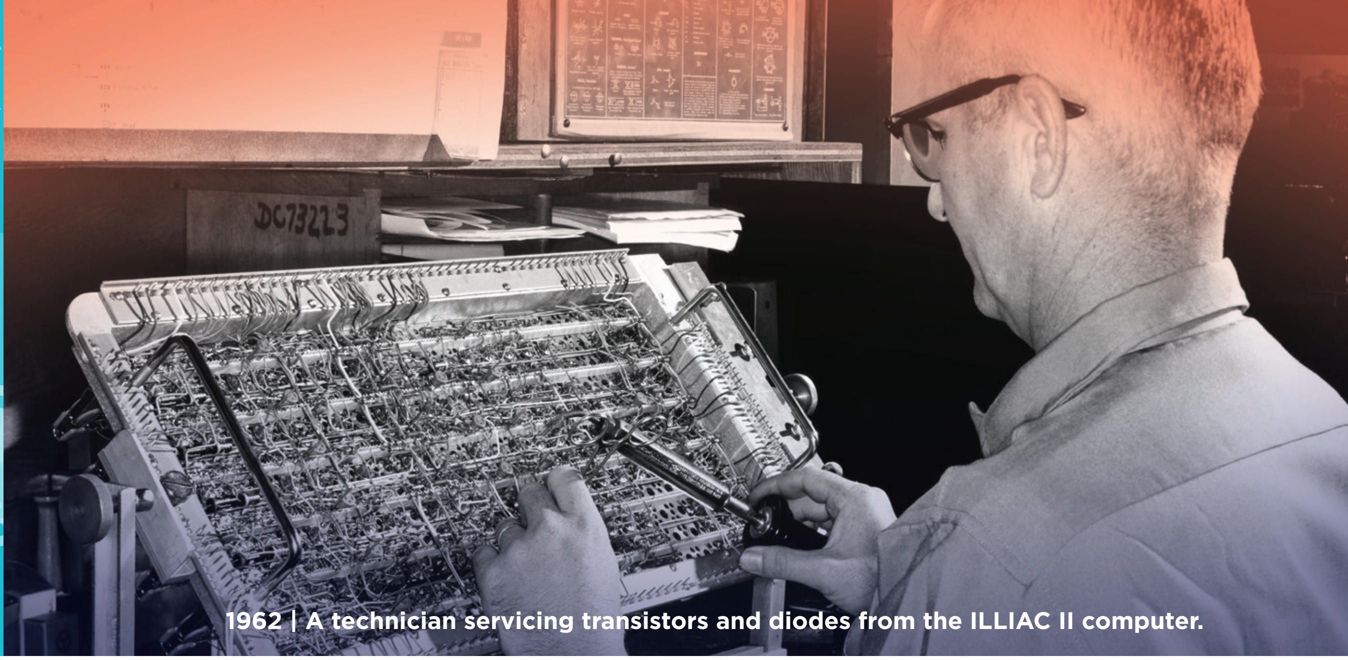
As many as 30 percent of people who suffer from epilepsy don't respond to any kind of drug treatment. For those people, surgery to remove the area of the brain causing the seizures is one of their only solutions.

To locate the seizure-generating brain region, surgeons typically implant sensors directly on the brain to monitor the brain activity during seizures. The problem is that this procedure requires patients to have seizures—and it may take days or weeks for one to occur.

Varatharajah and his colleagues have proposed a vastly difference experience. Using electroencephalography (EEG) data from the brain sensors, the team analyzed non-seizure activity from 80 patients with epilepsy. To test their accuracy, they compared their results to the seizure EEG data and surgery outcomes from patients.

If approved for clinical use, patients would undergo surgery to place electrodes on the brain, and then—during the same procedure—the team's algorithms would collect and analyze EEG data for just two hours to determine the seizure-inducing brain region, allowing the doctors to evaluate results and make a decision about removing the area.

The technology, which the team is continuing to develop, is being patented by Mayo Clinic, and they are evaluating the possibility of using it in clinical practice. This collaborative work was made possible by the Illinois-Mayo Alliance.



1962 | A technician servicing transistors and diodes from the ILLIAC II computer.

Top innovations in CSL's history

With more than 65 years of rich history in science and technology innovation, CSL has paved the way in tackling hard problems to solve the world's challenges and shape the future of society.

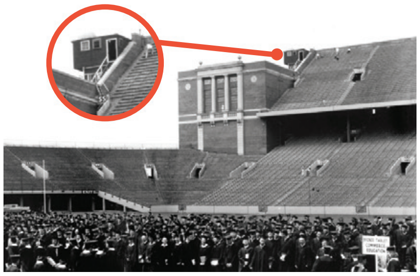
As Brian Dear aptly put in *The Friendly Orange Glow*, "CSL was no ordinary laboratory. They relished hard problems. Impossible problems. Problems nobody else would or could take on."

Take a look at some of our most notable achievements from the first two decades of CSL's commitment to doing the impossible.

SECRET SHACK

The birthplace of new radar technology

Memorial Stadium housed more than football in the 1950s. In the southwest corner of the stadium, a wooden shack was perched near the upper-level seats. Only a select group of CSL scientists knew that the shack was being used to conduct top-secret radar research for the military. Formed in 1951 near the start of the Korean War, the Secret Shack was used to improve weaponry and other combat equipment, enhance defense systems, and contribute to new reconnaissance technology.



A portable radar

The MTI (moving target indicating) sentry radar was small enough for soldiers in Korea to carry on their backpacks and set up anywhere. This was the first radar to produce a sound instead of a visual image, so sentries did not have to watch a screen. Used in combat in Korea, the sentry radar was especially effective in maintaining vigilance at known traffic points under zero-visibility conditions. It could locate and recognize a man walking or crawling, as well as the movement of groups or vehicles, for a range of up to five miles.

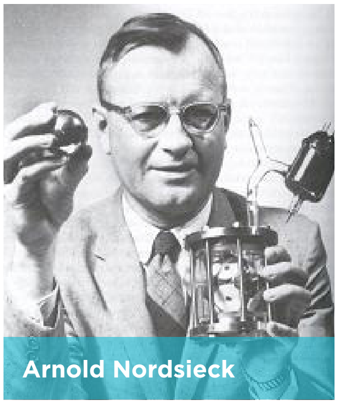
Peeking through the Iron Curtain

CSL's side-looking airborne radar was used in Germany to peer across the Iron Curtain. This thin, 18-foot antenna was mounted along the side of an aircraft, permitting the plane to fly parallel to a border and peer into enemy territory for a 40-mile range.

SUPER COMPASS

An interdisciplinary project

As an interdisciplinary lab, CSL is uniquely positioned to champion projects not possible in more traditional disciplinary settings. One of the earliest examples of this commitment to interdisciplinary research was the invention of the electrostatic vacuum gyroscope—a "super compass" as some called it.



Arnold Nordsieck

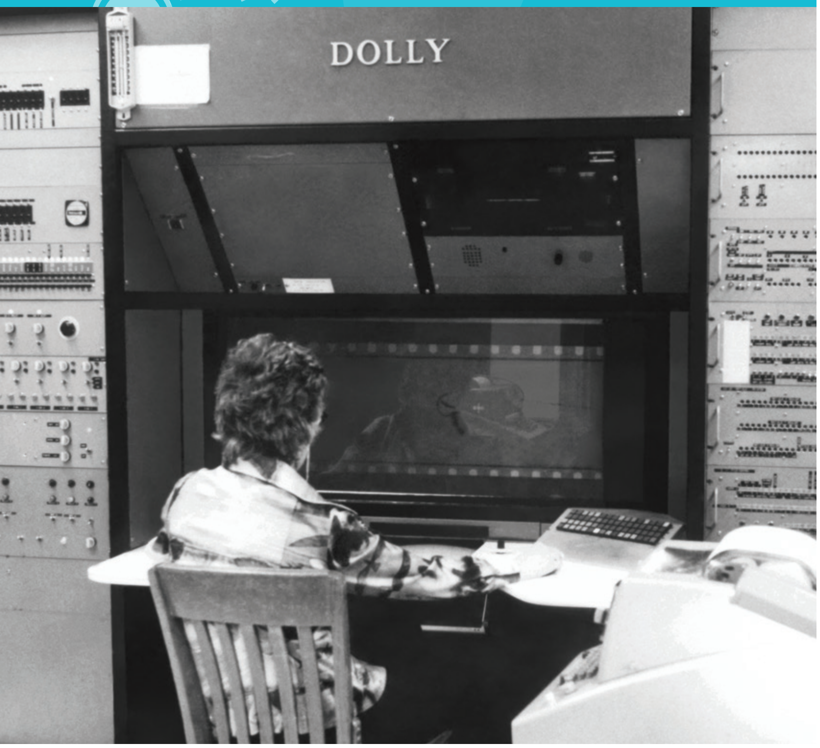
Navigation for months underwater

Yet Arnold Nordsieck, leading the project, argued, "This project is tailor-made for us. I believe that if it can be built anywhere, it can be built here." In the early 1950s, the first nuclear submarine paved the way for a new future of naval warfare. Unlike diesel-powered boats, which had to surface to recharge batteries, nuclear submarines could stay submerged for months. But they were still limited by primitive navigational aids, which required surfacing to recalibrate. CSL researcher Arnold Nordsieck, a physicist, had the solution: an electrostatic vacuum gyroscope. This gyroscope would support the rotor with magnetic fields to prevent friction of mechanical ball bearings, resulting in increased accuracy and improved reliability.

Accurate and reliable navigation

The electrostatic vacuum gyroscope became the central component of the inertial navigation system, which made it possible for nuclear submarines to navigate the seas of the world while immersed for months.

> ***"CSL was no ordinary laboratory. They relished hard problems. Impossible problems. Problems nobody else would or could take on."***
>
> **BRIAN DEAR,**
> *THE FRIENDLY ORANGE GLOW*



ILLIAC

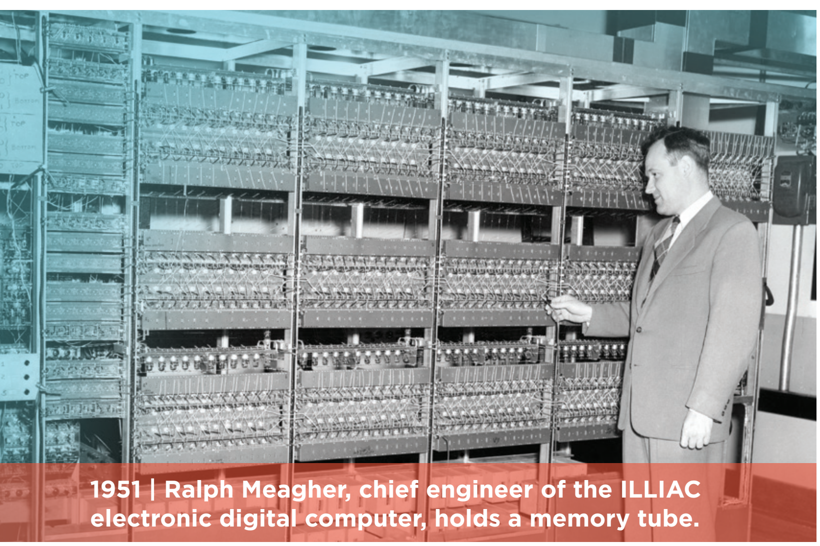
Building a reliable foundation

In the 1940s, computers were extremely rare, but researchers at CSL were leading the way in the foundations of reliable computing. During this time, the University of Illinois tried to purchase a computer commercially, but it couldn't be delivered. This setback led to a remarkable project—researchers at the University of Illinois, led by CSL physicist Ralph Meagher, decided to build a general purpose computer of their own. In 1952, a multidisciplinary group constructed ILLIAC (ILLInois Automatic Computer). It was the first computer in the world created and owned entirely by an educational institution.

What ILLIAC could do

It was the sole-service computer at the university for many years. Because it was built by CSL researchers, they had priority access to the computer, and it helped solve a wide variety of scientific problems, including for homework, recalled CSL emeritus professor Jose Cruz. It also:

- Calculated the exact orbit of Sputnik, two days after its launch
- Processed student registrations and records
- Analyzed structural damage caused by atomic bombs
- Computed stresses in highway bridges
- Composed music
- Performed calculations for satellites



1951 | Ralph Meagher, chief engineer of the ILLIAC electronic digital computer, holds a memory tube.

> *ILLIAC was the first computer in the world created and owned entirely by an educational institution."*

PLATO

First computer-based educational system in the world

CSL has the distinction of creating the first computer-assisted instructional system in the world. Its name: PLATO, or Programmed Logic for Automatic Teaching Operations.

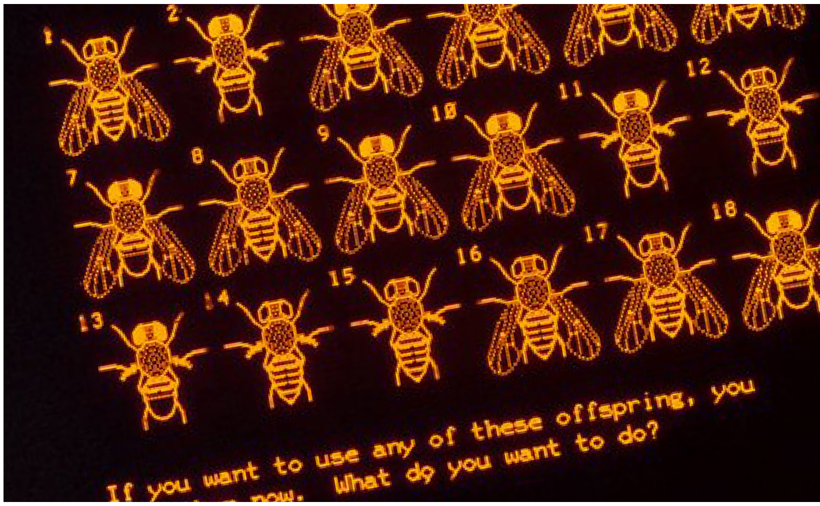
Long before Microsoft and Apple were founded—before the Internet as we know it existed and when massive computers took up entire rooms—there was PLATO, a computer-based educational program that grew to something much more: a robust online community that led to the first instant messages, chatrooms, emoticons, virtual goods and economics, and more.

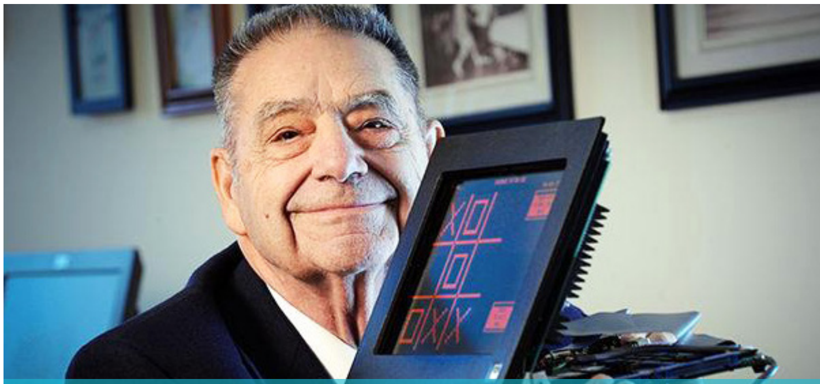
PLATO was a project designed to see if a computer could teach a student as well if not better than a human could. Over the course of four decades, a confluence of people and ideas contributed to PLATO's growth, and it all began with a few core CSL faculty leadership, in the original CSL building, an attic space dubbed the Physics "penthouse."

CSL: A hub of innovation

With the advent of ILLIAC—the first computer built for an educational institution in the world—CSL leadership began talking about creating a "book with feedback." The CSL director at the time, Dan Alpert, pegged a newly minted electrical engineering PhD named Donald Bitzer to head the project.

Bitzer stated, "Illinois was the perfect place to accomplish such an interdisciplinary project. The technology for computers, communications, and input-output to the student did not exist and had to be invented and constructed from scratch. The software did not exist either. We started slowly with only three of us working on the project which eventually grew to more than 100 people. It took the support of [College of Engineering] Dean William Everitt and the foresight of CSL Director Daniel Alpert to help make this possible."





Donald Bitzer, a former CSL researcher largely regarded as the "Father of PLATO".

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