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Keeping Track of Time in Cyber-Physical Systems

New five-year, $4-million NSF Frontier award to improve time in networked physical systems

The National Science Foundation today announced a five-year, $4 million "Frontier" award to tackle the challenge of time in cyber-physical systems (CPS)—engineered systems that are built from and depend upon the seamless integration of computational algorithms and physical components. Frontier awards constitute NSF's largest single investments in CPS. The grant brings together expertise from five universities and establishes a center-scale research activity to improve the accuracy, efficiency, robustness and security with which computers maintain knowledge of physical time and synchronize it with other networked devices on the emerging "Internet of Things."

Clockwise from top left: UCLA's Mani Srivastava and Sudhakar Pamarti; UCSD's Rajesh Gupta; Carnegie Mellon's Ragunathan Rajkumar and Anthony Rowe; UC Santa Barbara's João Hespanha; and Thomas Schmid from the University of Utah.

Time has always been a critical issue for science and technology. From pendulums to atomic clocks, the accurate measurement of time has helped drive scientific discovery and engineering innovation. For example, advances in distributed clock synchronization technology enabled Global Positioning System (GPS) satellites to precisely measure distances. This, in turn, created new opportunities and even entirely new industries, enabling the development of mobile navigation systems. However, many other areas of clock technology are still ripe for development.

Time presents a particular fundamental challenge in emerging applications of CPS, which connect computers, communication, sensors and actuator technologies to objects and play a critical role in our physical and network infrastructure. Cyber physical systems depend on precise knowledge of time to infer location, control communication, and accurately coordinate activities. CPS are critical to real-time situational awareness and control of a broad and growing range of applications, including autonomous cars and aircraft autopilot systems, advanced robotic devices, medical devices, energy-efficient buildings, advanced manufacturing and modern agriculture, among others.

The Frontier award from NSF will support a project called Roseline that seeks to develop new clocking technologies, synchronization protocols, operating system methods, as well as control and sensing algorithms. The project is led by faculty from the University of California, Los Angeles (UCLA) Henry Samueli School of Engineering and Applied Science, and includes electrical engineering and computer science faculty from the University of California, San Diego, Carnegie Mellon University, the University of California, Santa Barbara and the University of Utah.

"The National Science Foundation has long supported research to integrate cyber and physical systems, and have supported the experimentation and prototyping of these systems in a number of different sectors – from transportation and energy to medical systems," said Farnam Jahanian, head of the NSF directorate for Computer and Information Science and Engineering. "As the 'Internet of Things' become more pervasive in our lives, precise timing will be critical for these systems to be more responsive, reliable and efficient."

"Through the Roseline project, we will drive cyber-physical systems research with a deeper understanding of time and its trade-offs, and advance the state-of-the-art in clocking circuits and platform architectures," said UCLA professor Mani Srivastava, principal investigator on the project.

Today, most computing systems use tiny clocks to manage time in a relatively simplistic and idealized fashion. For example, software in today's computers has little visibility into, and little control over, the quality of time information received from its underlying hardware. At the same time, the clocks have little, if any, knowledge of the quality of time needed by the software, nor an ability to adapt to it. This leaves computing systems that are dependent on time vulnerable to complex and catastrophic disruptions.

The Roseline team will address this problem by rethinking and re-engineering how the knowledge of time is handled across a computing system's hardware and software.

"Roseline will drive accurate timing information deep into the software system," said University of California, San Diego computer science and engineering chair Rajesh Gupta, a co-principal investigator on the project. "It will enable robust distributed control of smart grids, precise localization of structural faults in bridges, and ultra-low-power wireless sensors."

The research will have a broad impact across many sectors, including smart electrical grids, aerospace systems, precision manufacturing, autonomous vehicles, safety systems and infrastructure monitoring.

In addition to Srivastava and Gupta, the Roseline team includes Sudhakar Pamarti of UCLA; João Hespanha of UC Santa Barbara; Ragunathan Rajkumar and Anthony Rowe of Carnegie Mellon University; and Thomas Schmid of the University of Utah.

Beyond the research and testing of components, project leaders plan to integrate CPS and timing components into graduate and undergraduate course materials, and engage pre-college students in outreach efforts, including the Los Angeles Computing Circle, which focuses on teaching real-world applications of computer science to students from local high schools.

"Measurement, distribution, and synchronization of time have always been a critical issue in science and technology, and there is a long history of new time-related technologies revolutionizing society," said David Corman, NSF program director for CPS. "As computation becomes embedded in physical systems around us, it becomes all the more important that computers be able to know time accurately, efficiently, and reliably. I am excited to see the Roseline team undertake this challenging and important task."

Roseline constitutes a key component of NSF's long-standing support for CPS research and education, for which investments have spanned nearly $200 million during the last five years.

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