Implementing Next-Generation Embedded Systems with Functional Reactive Programming and Real-Time Virtual Resources

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LECTURE ABSTRACT

The use of sophisticated digital systems to control complex physical components in real-time has grown at a rapid pace. These applications range from traditional stand-alone systems to highly-networked cyber-physical systems (CPS), spanning a diverse array of software architectures and control models. Examples include city-wide traffic control, robotics, medical systems, autonomous vehicular travel, green buildings, physical manipulation of nano-structures, and space exploration. Since all these applications interact directly with the physical world and often have humans in the loop, we must ensure their physical safety. Obviously, the correctness of these embedded systems and CPSs depends not only on the effects or results they produce, but also on the time at which these results are produced. For instance, in a CPS consisting of a multitude of vehicles and communication components with the goal to avoid collisions and reduce traffic congestions, formal safety verification and response time analysis are essential to the certification and use of such systems.

The benefits of using the functional (reactive) programming (FRP) over the imperative programming style found in languages such as C/C++ and Java for implementing embedded and real-time software are several. The functional programming paradigm allows the programmer to intuitively describe safety-critical behaviors of the system and connect its components, thus lowering the chance of introducing bugs in the design phase. Its stateless nature of execution does not require the use of synchronization primitives like mutexes and semaphores, thus reducing the complexity in programming on parallel and multi-core platforms. Hence, FRP can potentially transform the way we implement next-generation embedded systems and CPS. However, accurate response time analysis of FRP-based controllers remains a largely unexplored problem. The first part of this talk will introduce a framework for accurate response time analysis, scheduling, and verification of embedded controllers implemented in FRP.

Real-time resource partitioning (RP) divides hardware resources (processors, cores, and other components) into temporal partitions and allocates these partitions as virtual resources (physical resources at a fraction of their service rates) to application tasks. RP can be a layer in the OS or firmware directly interfacing the hardware, and is a key enabling technology for virtualization and cloud computing. Open embedded systems make it easy to securely add and remove software applications as well as to increase resource utilization and reduce implementation cost when compared to systems which physically assign distinct computing resources to run different applications. The second part of this talk will describe ways based on the Regularity-based Resource Partition Model (RRP) to maintain the schedulability of real-time tasks as if they were scheduled on dedicated physical resources and increase the utilization of the physical multi-resources.

SPEAKER BIOSKETCH

Albert M. K. Cheng is a Full Professor of Computer Science and of Electrical and Computer Engineering (joint appointment), and former interim Associate Chair of the Computer Science Department at the University of Houston. His research interests center on the design, specification, modeling, scheduling, and formal verification of real-time, embedded, and cyber-physical systems, green/power/thermal-aware computing, software engineering, and real-time machine learning and decision systems. He is the founding Director of the UH Real-Time Systems Laboratory, a U.S. Department of State Fulbright Specialist (2019-2022), and an ACM Distinguished Speaker (2020-2023). Prof. Cheng received the B.A. with Highest Honors (summa cum laude) in Computer Science, graduating Phi Beta Kappa at age 19, the M.S. in Computer Science with a minor in Electrical Engineering at age 21, and the Ph.D. in Computer Science at age 25, all from The University of Texas at Austin, where he held a GTE Foundation Doctoral Fellowship. He has served as a technical consultant for a number of organizations, including IBM and Shell, and was also a Visiting Professor in the Departments of Computer Science at Rice University and at the City University of Hong Kong. Dr. Cheng is the author/co-author of over 250 refereed publications in leading journals (including IEEE Transactions on Computers, IEEE Transactions on Software Engineering, and IEEE Transactions on Knowledge and Data Engineering) and top-tier conferences (including RTSS and RTAS). He is the Local Organization Chair of the 41st IEEE Real-Time Systems Symposium (RTSS) to be held in Houston, Texas, in December 2020. His recent awards include the Outstanding Leadership Award as Track Chair and the Outstanding Leadership Award as Keynote Speaker at IEEE ICESS 2014, the 2015 University of Houston's Lifetime Faculty Award for Mentoring Undergraduate Research for his "Exceptional efforts in demonstrating a lasting commitment to undergraduate research," and the 2016 Faculty Excellence Award. His recent work titled "Multi-Mode P-FRP Task Scheduling" received an Outstanding Paper Award at the 20th IEEE International Symposium on Real-time Computing (ISORC), May 2017.

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