Research@CSE Computer Engineering

Computer Engineering research at the University of Michigan is conducted mainly within the Computer Engineering Laboratory (CE Lab), which comprises a multidisciplinary group of researchers working in the primary areas of chip design, computer architecture, embedded systems, interactions between hardware and software, scalable computing, and secure, trustworthy and reliable digital systems.

Computer Engineering researchers explore theoretical, experimental, and applied aspects of computer design within a broad spectrum of areas ranging from digital logic and VLSI design, to architecture, design automation and validation, reliable and secure design, up to compilers and operating systems.

RESEARCH CENTERS:

ada
Led by Prof. Valeria Bertacco

ARM
Led by Prof. Trevor Mudge

KEY RECOGNITIONS:

#1
U-M is #1 in hardware pubs (Architecture, CAD) for the past decade+

68,000
Over 68,000 citations since 2014

KEY FACULTY AWARDS:

- **NSF CAREER Awards:** Austin, Bertacco, Chen, Das, Dick, Fu, Mahlke, Mars, Narayanasamy, Wenisch
- **ACM SIGARCH Maurice Wilkes Award:** Austin
- **ACM-IEEE Eckert-Mauchly Award:** Mudge
- **Sloan Fellows:** Austin, Das, Fu
- **IEEE TTTC Lifetime Contribution Medal:** Hayes
- **ACM-SIGDA Pioneering Achievement Award:** Hayes
- **IEEE TCCA Young Computer Architect Award:** Dreslinski
- **CoE Research Excellence Award:** Austin, Chen, Mudge
- **U-M Faculty Recognition Award:** Bertacco
- **CRA-W Borg Early Career Award – Das**
- **ISCA Hall of Fame – Austin, Davidson, Mahlke, Mars, Mudge, Narayanasamy, Tang, Wenisch**
- **MICRO Hall of Fame – Austin, Das, Mahlke, Mudge**
- **Computer Aided Verification Award - Sakallah**

PROFESSIONAL SOCIETY FELLOWS:

- **ACM Fellows:** Chen, Hayes, Mudge, Sakallah
- **IEEE Fellows:** Austin, Bertacco, Chen, Fu, Hayes, Mahlke, Mazumder, Mudge, Sakallah

TECH TRANSFER:

ambiq micro Intelligent Energy-Efficient ICs

clinc

Parabricks

AGITA LABS

SimpleScalar LLC

Sequal

COMPUTER SCIENCE AND ENGINEERING
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ACCELERATORS AND HETEROGENEOUS ARCHITECTURES

Faculty: Todd Austin, Valeria Bertacco, Reetuparna Das, Ron Dreslinski, Scott Mahlke, Jason Mars, Trevor Mudge, Satish Narayanasamy, Lingjia Tang, Thomas Wenisch

Moore's law is ending soon, signaling a tectonic shift in the industry roadmap. Global Foundaries, a leading semiconductor manufacturer, recently halted the development of 7nm process technology and beyond. Demand for computing, however, continues unabated. Application or domain-specific customization is the most promising approach to sustain growth in the post-Moore's law world. Another key driver for customization stems from the growing popularity of domains such as deep learning that produce classes of "killer apps" for specialized chips. Touted as the accelerator "golden age", the last few years have already witnessed commercial accelerator products from Tech giants. CELab researchers are at the forefront of this paradigm and are developing acceleration solutions for several high-value domains: data analytics, deep learning, graph processing, image processing, and precision health.

COMPILERS/OS - SYNERGY WITH ARCHITECTURES

Faculty: Todd Austin, Peter Chen, Scott Mahlke, Jason Mars, Satish Narayanasamy, Lingjia Tang

Computer engineering researchers are exploring a wide range of topics that utilize compiler and operating systems to optimize computing systems. For example, Prof. Mahlke's group is concerned with the design of customized processors, accelerators, and systems that deliver higher performance, lower power, and more reliability. Their approach is to increase the efficiency of designs by customizing the hardware to the software that will run on the system. The focus is on building programmable systems, thus new compiler technology is required to automatically map applications onto the new hardware. Profs. Mahlke and Narayanasamy work on domain specific architectures and compilers, GPGPUs, medical imaging, etc. Profs. Chen and Narayanasamy explore problems at the interface of architecture, operating systems and program analysis, to help programmers write and maintain reliable parallel software. Specific projects include support for tolerating concurrency bugs, memory consistency models and deterministic replay.

COMPUTER-AIDED DESIGN

Faculty: Todd Austin, Valeria Bertacco, Robert Dick, John Hayes, Pinaki Mazumder, Karem Sakallah

Research on computer-aided design (CAD) and very large-scale integrated (VLSI) circuits is conducted in the Computer Engineering Laboratory and the Solid-State Electronics Laboratory (ECE). Researchers have made seminal contributions in the areas of timing analysis and optimization, verification, reliable design, automatic test generation, and low-power design. Maintaining one of the largest CAD and VLSI research programs in the nation, The Computer Engineering Lab researchers are spearheading the exploration of novel design methodologies for trust-worthy and energy-efficient electronic systems in the nanometer regime.

COMPUTER ARCHITECTURE

Faculty: Todd Austin, Valeria Bertacco, Reetuparna Das, Ron Dreslinski, Scott Mahlke, Jason Mars, Trevor Mudge, Satish Narayanasamy, Lingjia Tang, Thomas Wenisch

Research in this space addresses a broad range of issues of parallel systems: coherency protocols and memory consistency models, design for programmability and software reliability, GPGPUs, low power design, reliability, effective validation, and deterministic behavior. The faculty have already developed a number of key projects in this space and deployed their ideas in complex processor prototypes.

A few examples include the post-silicon validation techniques for multi-core processors developed in Prof. Bertacco's group, Prof. Narayanasamy's deterministic replay techniques for parallel systems, multicore memory systems developed in Prof. Wenisch's group. Prof. Mudge's group is working on building a massively parallel low-power system with hundreds of layers of interconnected 3D stacked silicon.

DATA CENTER ARCHITECTURE

Faculty: Valeria Bertacco, Peter Chen, Reetuparna Das, Ron Dreslinski, Scott Mahlke, Jason Mars, Trevor Mudge, Lingjia Tang, Thomas Wenisch

Today in the United States, data centers account for close to 3% of total US electricity consumption — more the entire transportation manufacturing industry. Our department has several efforts underway to improve data center energy efficiency, reliability, availability, and manageability. Specific research topics include novel energy-efficient processor architectures; system, cluster, and room-level power and thermal management; enterprise application benchmarking and performance analysis; memory and storage energy efficiency; virtualization and server consolidation; data-center-wide resource provisioning; capacity management; and system-level reliability.

EMBEDDED, NETWORKED, AND WIRELESS SYSTEMS

Faculty: Robert Dick, Ron Dreslinski, Scott Mahlke, Z. Morley Mao, Alanson Sample

Embedded systems are computers within devices not generally considered to be computers, e.g., vehicles, medical devices, smartphones, sensor networks, etc. The embedded systems market is growing 50% faster than that for general-purpose computing. Embedded system designers frequently face the problem of designing compact, complex, high-performance, inexpensive, low-power, real-time, reliable, secure, and wireless devices within a relatively very short time to market. Computer engineering research in this area covers the entire "stack," from transistors and circuits to operating system and applications.

EMERGING TECHNOLOGIES

Faculty: John Hayes, Wei Lu (ECE), Pinaki Mazumder, Yaoyun Shi, Duncan Steel (ECE), Zhengya Zheng (ECE)

Exciting new physical techniques and design methodologies for computation are emerging that promise dramatic improvements in performance, scaling, energy use, and reliability. These technologies are often characterized as nanoelectronic (scaled well below current electronic circuits) or neuromorphic (capable of advanced, brain-inspired computing), and they address such challenging problems as machine learning. Research in the CE Lab and other Michigan laboratories (Physics) is at the forefront of all these areas. Topics being investigated include quantum information processing, stochastic computing, and physical devices such as memristors, quantum dots, and trapped ions.

LOW POWER DESIGN

Faculty: Todd Austin, Ron Dreslinski, Pinaki Mazumder, Trevor Mudge, Alanson Sample, Thomas Wenisch

Over the past decade, computer engineering researchers at Michigan have created some of the lowest-power designs. To name a few examples, the Razor project has won the Microprocessor Report's Innovator of the Year Award and is deployed commercially, the subliminal processor design, which was the lowest power microprocessor ever developed when it first appeared, is the first practical energy-recovery circuitry with sub-CV2 power consumption.

Research in low-power circuits and architectures continues strong, spanning the entire spectrum from ultra-low-power subthreshold devices for deeply embedded applications to high-performance energy-recovery circuitry for multi-GHz processors. Furthermore, new explorations are underway in the space of data center architectures.

RUNTIME CORRECTNESS

Faculty: Todd Austin, Valeria Bertacco, Satish Narayanasamy

The ability to guarantee the functional correctness of digital integrated circuits and, in particular, complex microprocessors, is a key task in the production of secure and trusted systems. Unfortunately, this goal remains today an unfulfilled challenge, as evidenced by the long errata lists available for commercial microprocessors that list latent bugs not found during the design verification process.

To address the challenges of verification, Computer Engineering researchers are turning toward the design of introspective systems capable of recognizing and correcting their errant ways. They are exploring and developing "patching" techniques that can repair these escaped bugs directly at the customer site, practically making hardware as malleable as software. In addition, they investigate low-cost techniques to validate computation at runtime, in particular techniques that are provably capable of preventing incorrect results. Work in this area draws heavily from the computer architecture and computer-aided design fields.

SECURE, RELIABLE AND TRUSTWORTHY COMPUTING

Faculty: Todd Austin, Valeria Bertacco, Kevin Fu, John Hayes, Scott Mahlke, Satish Narayanasamy

The continued scaling of silicon fabrication technology has led to significant reliability concerns which are quickly becoming a dominant design challenge. Design integrity is threatened by complexity challenges in the form of immense designs defying complete verification, and physical challenges such as silicon aging and soft errors, which impair correct system operation, not to mention security side-channels that can be perpetrated by exploiting the hardware design.

Computer engineering researchers are addressing these key challenges through synergistic research vectors, which range from near-term reliability stress reduction techniques to improve the quality of today's silicon, to longer-term technologies to detect, recover, and repair faulty systems. Computer engineering researchers are also working on hardware security assurance solutions to protect computer systems against hardware and software attacks by means of hardware protection techniques.

These efforts are supported and complemented by strong focus on functional verification methodologies. The overarching goal is to provide highly effective and low-cost solutions to ensure security, correctness and reliability in future designs, thereby extending the lifetime of silicon fabrication technologies.

VALIDATION AND TESTING

Faculty: Valeria Bertacco, John Hayes, Pinaki Mazumder, Karem Sakallah

The computer engineering lab includes one of the largest and broadest Electronic Design Automation research programs in the nation. Research efforts span VLSI design, logic design, testing, and verification and validation. Our faculty have made seminal contributions in the areas of timing analysis and optimization, formal verification and automatic test generation. The group has an exceptional publication record, including numerous best paper awards at the most prestigious conferences and journals in the field. Among several other contributions, computer engineering researchers have made numerous key contributions in domain including the breakthrough satisfiability solver GRASP and the runtime correctness architecture DIVA. Current research is focusing on new directions in software verification, silicon piracy, and hardware security assurance.

VLSI AND SILICON DESIGN

Faculty: Todd Austin, Valeria Bertacco, Reetuparna Das, Ronald Dreslinski, Scott Mahlke, Pinaki Mazumder, Trevor Mudge

This area covers a wide range of topics and mixes applied research, supported by test chips and measurement results, with far reaching conceptual projects. In particular, the major topics currently under investigation include low-power design techniques, nanoscale CMOS mixed-signal design, and the exploration of evolving packaging technologies. One of the key goals of the research in this space is to streamline the design flow from application to silicon system, optimizing time-to-market, performance and power, and seamlessly leveraging heterogeneous silicon components. Technologies among those being explored include self-assembled and discoverable systems, chiplet-based design, high-level synthesis flows from app to chip, and software defined hardware to support course grained reconfigurability.

Research@CSE Computer Engineering

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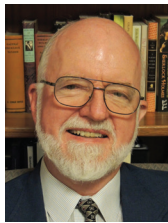Arthur F. Thurnau
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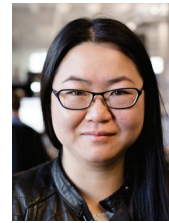of Engineering
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