# Embedded System Design and Modeling

**ECE382N.23, Unique 17800, Fall 2024**

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**Lectures**: TTh 12:30-2:00pm, ECJ 1.318

**Instructor**: Andreas Gerstlauer <gerstl@ece.utexas.edu>
Office hours: TTh 11:00am-noon, EER 5.882

**Class webpage**: http://www.ece.utexas.edu/~gerstl/ece382n_f24/

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## Background and Objectives

High-performance embedded and edge computing systems that have to satisfy high computing demands while often operating under stringent correctness, real-time, energy or other resource constraints are ubiquitous in areas such as robotics, edge machine learning and autonomous intelligence. Coupled with a typically limited and known desired functionality, this provides both a need and the opportunity to optimize their hardware/software implementation across the compute stack. At the same time, with the end of traditional semiconductor scaling and the associated rise of energy efficiency as a primary design concern, application- or domain-specific computer architectures and systems-on-chip (SoCs) incorporating a large number of heterogeneous accelerators and other hardware/software optimizations have become prevalent in a wide range of areas, e.g. neural network training/inference or video processing in the cloud.

The programming and design of such specialized, heterogeneous and accelerator-rich computer systems, however, poses significant challenges, e.g. in exploring large design spaces to find optimized solutions across multiple design objectives. This creates a need for automated methods and tools to support design- and run-time optimization. In particular, recent trends have leveraged advances in machine learning (ML) for system compilation and synthesis. The basis for any such automation of the design process are, however, first and foremost well-defined formalizations of design models and methods that allow computer-aided algorithms to be applied.

In this research-focused course, we will cover theory and practice of system-level design of application- or domain-specific embedded, edge and high-performance computing systems. With an emphasis on the formal modeling foundations and specifically ML solutions for design automation, the course will present methods and techniques for application specification, energy/performance modeling, synthesis and compilation, and optimization and design space exploration at the system level. We will discuss the traditional methods, recent research results and trends as well as new ideas for advancing state-of-the-art.

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## Catalog Description and Course Topics

Formal methods and design automation techniques for specification, modeling, synthesis, and electronic system-level (ESL) design of embedded and application-/domain-specific systems:

- Application models and Models of Computation (MoCs), concurrency and time: finite state machines (FSMs), process networks, dataflow, task graphs;
- Domain-specific and system-level design languages (DSLs/SLDLs) and methodologies;
- System energy/performance modeling and refinement: virtual platform prototyping and SoC simulation, transaction-level modeling (TLM), and ML-based predictive modeling.
- System-level compilation, synthesis and optimization: algorithms and ML methods for application mapping, partitioning, scheduling, design space exploration, and embedded hardware and software synthesis;
- Heterogeneous system compilers and system-level synthesis tools, examples and case studies.

**Prerequisites**

- Fundamentals of embedded systems and hardware/software co-design (ECE445L Embedded System Design Lab, ECE445M Embedded & Real-Time Operating Systems, or equivalent);
- Fundamentals of computer architecture and computer system design (ECE460N Computer Architecture, or equivalent);
- Working knowledge of C/C++, algorithms and data structures (ECE360C Algorithms, or equivalent);
- Fundamentals of digital hardware design and hardware description languages (ECE460M Digital System Design using HDLs, or equivalent).

**Textbooks**

None required, paper readings and notes will be provided. Recommended for background reading:

1. D. D. Gajski, S. Abdi, A. Gerstlauer, G. Schirner, *Embedded System Design: Modeling, Synthesis, Verification*, Springer, 2009.
2. P. Marwedel, *Embedded System Design: Embedded Systems, Foundations of Cyber-Physical Systems, and the Internet of Things*, Fourth Edition, Springer, 2021.
3. E. A. Lee, S. A. Seshia, *Introduction to Embedded Systems: A Cyber-Physical Systems Approach*, Second Edition, MIT Press, 2017.

**Grading and Academic Dishonesty Policies**

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|---|---|
| Homework and reading assignments: | 35% |
| Class participation: | 15% |
| Class project: | 50% |

Late submissions will not be accepted. Oral discussion of homework and reading assignments is encouraged but make sure to submit your own individual and independent solution. Projects should be done in teams. Collaboration and teamwork on projects is highly encouraged. Copying of any part of a solution without explicit reference to its source is plagiarism and considered cheating.

**Outline and Schedule (Tentative)**

| Week | Dates | Topic |
|---|---|---|
| **1** | Aug 27, 29 | Introduction, System-level design methodologies |
| **2** | Sep 3, 5 | Application specification, Models of Computation (MoCs) |
| **3** | Sep 10, 12 | Workload modeling and forecasting |
| **4** | Sep 17, 19 | System-level design languages, LLMs for system design |
| **5** | Sep 24, 26 | System energy/performance modeling and estimation |
| **6** | Oct 1, 3 | Analytical and simulation-based SoC modeling |
| **7** | Oct 8, 10 | Machine learning (ML)-based predictive modeling |
| **8** | Oct 15, 17 | **Project review presentations** |
| **9** | Oct 22, 24 | System synthesis, optimization, design space exploration (DSE) |
| **10** | Oct 29, 31 | Optimization heuristics, evolutionary DSE algorithms |
| **11** | Nov 5, 7 | Reinforcement and other learning-based DSE methods |
| **12** | Nov 12, 14 | System-level design tools and case studies |
| **13** | Nov 19, 21 | Review, advanced topics and project discussions |
| **14** | Nov 26, 28 | *Fall break* |
| **15** | Dec 3, 5 | **Final project presentations** |

**Sharing of Course Materials**

Sharing of course materials is prohibited. No materials used in this class, including, but not limited to, lecture hand-outs, videos, assessments (quizzes, exams, papers, projects, homework assignments), in-class materials, review sheets, and additional problem sets, may be shared online or with anyone outside of the class unless you have my explicit, written permission. Unauthorized sharing of materials promotes cheating. It is a violation of the University's Student Honor Code and an act of academic dishonesty. I am well aware of the sites used for sharing materials, and any materials found online that are associated with you, or any suspected unauthorized sharing of materials, will be reported to Student Conduct and Academic Integrity in the Office of the Dean of Students. These reports can result in sanctions, including failure in the course.

**Class Recordings**

Class recordings are reserved only for students in this class for educational purposes and are protected under FERPA. The recordings should not be shared outside the class in any form. Violation of this restriction by a student could lead to Student Misconduct proceedings.

**Electronic Mail Notification Policy**

In this course e-mail will be used as a means of communication with students. You will be responsible for checking your e-mail regularly for class work and announcements. The complete text of the University electronic mail notification policy and instructions for updating your e-mail address are available at http://cio.utexas.edu/policies/university-electronic-mail-student-notification-policy.

**Use of Canvas and Class Web Site**

This course uses the class web page and Canvas to distribute course materials, to communicate and collaborate online, to submit assignments and to post solutions and grades. You will be responsible for checking the class web page and the Canvas course site regularly for class work and announcements. As with all computer systems, there are occasional scheduled downtimes as well as unanticipated disruptions. Notification of disruptions will be posted on the Canvas login page. Scheduled downtimes are not an excuse for late work. However, if there is an unscheduled downtime for a significant period of time, I will make an adjustment if it occurs close to the due date.

**Students with Disabilities**

The University of Texas at Austin provides upon request appropriate academic adjustments for qualified students with disabilities. For more information, contact Disability and Access (D&A), Student Services Building (SSB), 471-6259, http://disability.utexas.edu.

**Religious Holidays**

Religious holy days sometimes conflict with class and examination schedules. If you miss an examination, work assignment, or other project due to the observance of a religious holy day you will be given an opportunity to complete the work missed within a reasonable time after the absence. It is the policy of The University of Texas at Austin that you must notify each of your instructors at least fourteen days prior to the classes scheduled on dates you will be absent to observe a religious holy day.

**Counseling and Mental Health**

Do your best to maintain a healthy lifestyle this semester by eating well, exercising, avoiding drugs and alcohol, getting enough sleep and taking some time to relax. This will help you achieve your goals and cope with stress. All of us benefit from support during times of struggle. You are not alone. There are many helpful resources available on campus and an important part of the college experience is learning how to ask for help. Asking for support sooner rather than later is often helpful. If you or anyone you know experiences any academic stress, difficult life events, or feelings like anxiety or depression, we strongly encourage you to seek support. The Counseling and Mental Health Center (CMHC) provides counseling, psychiatric, consultation, and prevention services that facilitate students' academic and life goals and enhance their personal growth and well-being: https://healthyhorns.utexas.edu/cmhc/. You can also talk to the CARE Counselor in the College of Engineering, who has drop-in office hours in EER.

**Title IX Reporting**

Title IX is a federal law that protects against sex and gender-based discrimination, sexual harassment, sexual assault, sexual misconduct, dating/domestic violence and stalking at federally funded educational institutions. UT Austin is committed to fostering a learning and working environment free from discrimination in all its forms where all students, faculty, and staff can learn, work, and thrive. When sexual misconduct occurs in our community, the university can:

1. Intervene to prevent harmful behavior from continuing or escalating.
2. Provide support and remedies to students and employees who have experienced harm or have become involved in a Title IX investigation.
3. Investigate and discipline violations of the university's relevant policies.

Faculty members and certain staff members are considered ``Responsible Employees" or ``Mandatory Reporters," which means that they are required to report violations of Title IX to the Title IX Coordinator at UT Austin. The instructors (myself and the TAs) are Responsible Employees and must report any Title IX related incidents that are disclosed in writing, discussion, or one-on-one. Before talking with me, the TAs, or any faculty or staff member about a Title IX related incident, be sure to ask whether they are a responsible employee. If you want to speak with someone for support or remedies without making an official report to the university, email advocate@austin.utexas.edu. For more info about reporting options and resources, visit https://titleix.utexas.edu/campus-resources or contact the university's Title IX Office via email at titleix@austin.utexas.edu.

**Classroom Evacuation and Emergency Preparedness**

All occupants of university buildings are required to evacuate a building when a fire alarm and/ or an official announcement is made indicating a potentially dangerous situation within the building. Familiarize yourself with all exit doors of each classroom and building you may occupy. Remember that the nearest exit door may not be the one you used when entering the building. If you require assistance in evacuation, inform your instructor in writing during the first week of class. For evacuation in your classroom or building:

1. Follow the instructions of faculty and teaching staff.
2. Exit in an orderly fashion and assemble outside.
3. Do not re-enter a building unless given instructions by emergency personnel.

Emergency evacuation route information and emergency procedures can be found at http://www.utexas.edu/emergency and https://preparedness.utexas.edu.