

System-on-Chip (SoC) Design

ECE382M.20, Unique: 17090, Fall 2021

Lectures: TTh 12:30-2:00pm, ECJ 1.318 and online (Zoom)

Instructor: Andreas Gerstlauer <gerstl@ece.utexas.edu>, Office hours: TTh 2-3pm, online (Zoom)

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Class website: Canvas and http://www.ece.utexas.edu/~gerstl/ece382m_f21/

Description

With technological advances that allow us to integrate complete multi-processor systems on a single die, Systems-on-Chip (SoCs) are at the core of most embedded computing and consumer devices, such as smart phones and automotive, aerospace, robotics or medical electronics. This course will provide an understanding of the concepts, issues, and process of designing highly integrated SoCs following systematic hardware/software co-design & co-verification principles. Specifically, the class project involves taking public domain C++ code for a machine learning based visual object detection application utilizing a deep/convolutional neural network (DNN/CNN) and mapping it to an ARM-based virtual and FPGA prototyping platform using state-of-the-art synthesis and verification tools and design flows.

Goals

This course is designed for students to learn and be able to:

- Model and specify embedded systems at high levels of abstraction.
 - Analyze the functional and nonfunctional performance of the system early in the design process to support design decisions.
 - Analyze hardware/software tradeoffs, algorithms, and architectures to optimize the system based on requirements and implementation constraints.
 - Analyze tradeoffs and explore architecture and micro-architecture design spaces to develop and synthesize custom hardware accelerators.
 - Understand hardware, software, and interface synthesis.
 - Understand issues in interface design.
 - Use co-simulation to validate system functionality.
 - Describe examples of applications and systems developed using a co-design approach.
 - Appreciate issues in system-on-chip design associated with co-design, such as intellectual property, reuse, and verification.
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Course Description and Course Topics

Methodologies and tools for System-on-Chip (SoC) and hardware/software co-design and co-verification:

- Hardware/software co-design: partitioning, real-time scheduling, hardware acceleration;
 - Virtual prototyping: electronic system-level languages and hardware/software co-simulation;
 - High-level synthesis: allocation, scheduling and binding algorithms for C-to-RTL synthesis;
 - SoC integration: SoC communication architectures, IP interfacing, verification and test;
 - FPGA prototyping of hardware/software systems.
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Prerequisites

- Working knowledge of C and C++, including software development and debugging (e.g. ECE322C Data Structures, or equivalent);
- Embedded real-time system design and hardware/software interfacing (e.g. ECE445M Embedded & Real-time Operating Systems, or equivalent);
- Digital hardware design and hardware description languages (e.g. ECE460M Digital System Design using Verilog, or equivalent);
- It is helpful to have some basic knowledge of advanced linear algebra and machine/deep learning algorithms.

Textbooks

No required textbook. Optional textbooks:

- P. Marwedel, [*Embedded System Design: Embedded Systems Foundations of Cyber-Physical Systems, and the Internet of Things*](#), Fourth Edition, Springer, 2021.
- D. C. Black, J. Donovan, B. Bunton, A. Keist, [*SystemC: From the Ground Up*](#), Second Edition, Springer, 2010.
- S. Pasricha, N. Dutt, [*On-Chip Communication Architectures \(System on Chip Interconnect\)*](#), Morgan Kaufman, 2008.
- G. De Micheli, [*Synthesis and Optimization of Digital Circuits*](#), McGraw-Hill, 1994.

Grading

Homework:	15%
Exam:	20%
Labs:	30%
Project:	35%

Late penalty: 20% per day (24 hours).

Oral discussion of homework problems is encouraged but solutions have to be submitted individually and independently. Labs and the final project will be done in teams. Copying of any part of a homework, lab or project solution without explicit reference to its source is plagiarism and considered cheating.

Tentative Course Outline and Schedule

Week	Lecture Topic
1 (Aug 26)	Class and Project Overview
2 (Aug 31/Sep 2)	System-Level Design Methodology and SystemC Language
3 (Sep 7/9)	Virtual Platform Prototyping, Transaction-Level Modeling (TLM) in SystemC
4 (Sep 14/16)	HW/SW Co-Design
5 (Sep 21/23)	Application Mapping and Scheduling
6 (Sep 28/30)	Hardware Accelerator Architectures and Interfacing
7 (Oct 5/7)	C-to-RTL High-Level Synthesis (HLS)
8 (Oct 12/14)	HLS Operation Scheduling and Resource Binding
9 (Oct 19/21)	HLS Design Space Exploration

10 (Oct 26/Oct 28)	System Integration and SoC Communication Architectures
11 (Nov 2/4)	Review, Exam
12 (Nov 9/11)	Emulation and FPGA Prototyping
13 (Nov 16/18)	SoC Verification and Test
14 (Nov 23/25)	System Metrics, <i>Thanksgiving</i>
15 (Nov 30/Dec 2)	Project Design Reviews
Finals (Dec 11)	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.

Online Learning Resources

This course may be offered in a format to which you are unaccustomed. If you are looking for ideas and strategies to help you feel more comfortable participating in our class, please explore the resources available here: <https://onestop.utexas.edu/keep-learning/>.

Students with Disabilities

The University of Texas at Austin provides upon request appropriate academic accommodations for qualified students with disabilities. For more information, contact the Services for Students with Disabilities (SSD) at 471-6259, <http://diversity.utexas.edu/disability>.

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: <http://cmhc.utexas.edu/>.

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 Title IX Office 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>.

COVID-19 Guidance

While we will post information related to the contemporary situation on campus, you are encouraged to stay up-to-date on the latest news as related to the student experience at <https://protect.utexas.edu/students>.

To help preserve our in-person learning environment, the university recommends the following to help protect yourself, your friends and family, as well as the community (especially those who can not protect themselves, e.g. children who can not be vaccinated) in Austin in general:

- [Vaccinations are widely available](#), free and not billed to health insurance. The vaccine will help reduce the transmission of the virus to others and reduce serious symptoms in those who are vaccinated.
- Adhere to university [mask guidance](#) as well as [CDC guidelines](#) and [City of Austin guidelines](#) and wear a face covering (over nose and mouth) while indoors, including during class and even when you are vaccinated (vaccinated people can carry the virus, albeit for a much shorter time and at reduced rates). I cannot enforce this, but highly encourage you to. Properly fitted and high-quality (K)N95 masks can significantly reduce transmission. There is lots of info on the web about the best masks for people at all ages.
- [Proactive Community Testing](#) remains an important part of the university's efforts to protect our community. Tests are fast and free.

To help keep everyone at UT and in our community safe, it is critical that students report COVID-19 symptoms and testing to [University Health Services](#), and faculty and staff report to the [HealthPoint Occupational Health Program](#) (OHP) as soon as possible. Please see this [link](#) to understand what needs to be reported. In addition, to help understand what to do if a fellow student in the class (or the instructor or TA) tests positive for COVID, see this [University Health Services link](#).