Electrical & Computer ENGINEERING

Carnegie Mellon

Course Syllabus

18-648: Embedded Real-Time Systems

Fall 2016

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Course Description:

Real-time embedded systems pervade many aspects of modern life ranging from household appliances, transportation and motion control systems, medical systems and devices, robotics, multimedia and mobile communications, video-games, energy generation/distribution/management, to aerospace and defense systems. This course has three complementary goals. One, it will cover the core concepts and principles underlying these systems, including resource management, scheduling, dependability and safety. Implications to multi-core platforms, SoCs, networks communication buses and energy management will also be discussed. Mathematical models and analysis techniques will be presented. Two, the course will offer hands-on experience with implementing real-time embedded systems on realistic platforms. This will be facilitated by detailed discussions of hardware-software interfaces, concurrency and communications. Finally, application-level

concepts such as signal processing, image processing, computer vision, sensor fusion and feedback control will complete an overview of the breadth and depth of real-time embedded systems. Knowledge of the C programming language, basic computer architecture and an assembly language will be assumed.

Students can expect to learn how to program with the embedded computing architecture that is ubiquitous in cell-phones, portable gaming devices, robots, PDAs, etc. Students will then go on to learn and apply real-time principles that are used to drive critical embedded systems like automobiles, avionics, medical equipment, planetary rovers, etc. Topics covered include embedded architectures (building up to modern 16/32/64-bit embedded processors); interaction with devices (buses, memory architectures, memory management, device drivers); concurrency (software and hardware interrupts, timers); real-time principles (multi-tasking, scheduling, synchronization); implementation trade-offs, profiling and code optimization (for performance and memory); embedded software (exception handling, loading, mode-switching, programming embedded systems). Through a series of laboratory exercises with state-of-the-art embedded processors and popular development tools, students will acquire skills in the design/implementation/debugging of core embedded real-time functionality.

Number of Units: 12

Pre-requisites: 18-213 *and* 18-345 *and* 18-447
(Grade of D or higher is required in the prerequisites)

Course Designation: Breadth, Depth, Coverage.

Course Area: Software Systems and Computer Networking

Class Schedule:

- **Lecture**:
  Monday and Wednesday *10:30am – 12:20pm* PH 125C

- **Recitation (only when announced)**:
  Thursday *7:00pm – 8:50pm* GHC 4307

Required Textbook:
None.

Other Supplemental Materials: Any required handouts will be made available.

Brief List of Topics Covered: Please see lecture schedule.

Course Blackboard:
To access the course blackboard from an Andrew Machine, go to the login page at: http://www.cmu.edu/blackboard. You should check the course blackboard daily for announcements and handouts.

Course Wiki:
Students are encouraged to use the ECE wiki to provide feedback about the course at: http://wiki.ece.cmu.edu/index.php.

Grading Algorithm:

20%	Quizzes (5) – The lowest quiz score will be dropped
60%	Labs Projects (4) – Expected project weights: 10%, 16%, 16%, and 18%
20%	Final Exam

Relative grading will be used to assign the final letter grades.

Tentative Course Calendar:

Date	Day	Class Activity	Notes
August			
29	Mon.	Course Overview	Classes Begin
31	Wed.	Embedded Real-Time Systems	
September			
5	Mon.	Labor Day; No Classes	No Classes
7	Wed.	Uniprocessor Scheduling – I	
12	Mon.	Uniprocessor Scheduling – II	Lab #1 Handout
14	Wed.	Device and Memory Management	
19	Mon.	Linux and RT-Extensions	
21	Wed.	Performance Optimization	Quiz #1
26	Mon.	Resource Reservations	
28	Wed.	Resource Sharing – I	Lab #2 Handout
October			
3	Mon.	*cont'd*	
5	Wed.	Resource Sharing – II	Quiz #2
10	Mon.	Power-Aware Scheduling – I	
12	Wed.	Power-Aware Scheduling – II	Lab #3 Handout
17	Mon.	Aperiodics – Fixed-Priority Servers	
19	Wed.	Aperiodics – Dynamic-Priority Servers	Quiz #3
24	Mon.	Multiprocessor Scheduling - I	
26	Wed.	Multiprocessor Operating Systems	
31	Mon.	Power-Aware Multiprocessor Scheduling	
November			
2	Wed.	Real-Time Communications	Quiz #4
7	Mon.	Overload Management	Lab #4 Handout
9	Wed.	Hierarchical Scheduling	
14	Mon.	Case Studies – I	
16	Wed.	Case Studies – II	Quiz #5
21	Mon.	Feedback Control Theory	
23	Wed.	Thanksgiving Holiday; No Classes	Have a good break!
28	Mon.	Signal Processing	
30	Wed.	System-Level Considerations	
December			
5	Mon.	Advanced Topics – I	
7	Wed.	Advanced Topics - II	Dec 9: Last Day of Classes
12-16		Final Exam Period	Exam Date & Time Picked By Registrar

Education Objectives (Relationship of Course to Program Outcomes):

(a) an ability to apply knowledge of mathematics, science, and engineering:

Real-time scheduling theory is based on sound mathematical principles. A deep understanding of core theorems is necessary to do well in the course (in in-class quizzes and in the final exam).

(b) an ability to design and conduct experiments, as well as to analyze and interpret data:

High-level lab project requirements can be satisfied in multiple ways and appropriate/efficient implementations must be chosen.

(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability:

Timing constraints of real-time applications must be satisfied while energy considerations are also being taken into account.

(d) an ability to function on multi-disciplinary teams:

Each lab project will be carried out by a team of 3 persons and appropriate partitioning of work and skills is required for successful completion of projects.

(g) an ability to communicate effectively:

Each lab project must be accompanied by a written report.

(j) a knowledge of contemporary issues:

The platform chosen for the lab projects represent modern artifacts used widely throughout the world.

(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice:

An understanding of modern software development tools is required.

Usage of Mobile Phones and Laptops During Class

As research on learning shows, unexpected noises and movement automatically divert and capture people's attention, which means you are affecting everyone’s learning experience if your cell phone, pager, laptop, etc. makes noise or is visually distracting during class. For this reason, you are allowed to take notes on your laptop, but you must turn the sound off so that you do not disrupt other students' learning. If you are doing anything other than

taking notes on your laptop, please sit in the back row so that other students are not distracted by your screen.

Mobile phones must be turned off or be in "vibrate" mode.

Recording of Class Sessions
Classroom activities may be taped or recorded by a student for the personal, educational use of that student or for all students presently enrolled in the class only, and may not be further copied, distributed, published or otherwise used for any other purpose without the express written consent of the instructor, Professor Raj Rajkumar. All students are advised that classroom activities may be taped by students for this purpose.

ECE Academic Integrity Policy
(http://www.ece.cmu.edu/programs-admissions/masters/academic-integrity.html**):**

The Department of Electrical and Computer Engineering adheres to the academic integrity policies set forth by Carnegie Mellon University and by the College of Engineering. ECE students should review fully and carefully Carnegie Mellon University's policies regarding Cheating and Plagiarism; Undergraduate Academic Discipline; and Graduate Academic Discipline. ECE graduate student should further review the Penalties for Graduate Student Academic Integrity Violations in CIT outlined in the CIT Policy on Graduate Student Academic Integrity Violations. In addition to the above university and college-level policies, it is ECE's policy that an ECE graduate student may not drop a course in which a disciplinary action is assessed or pending without the course instructor's explicit approval. Further, an ECE course instructor may set his/her own course-specific academic integrity policies that do not conflict with university and college-level policies; course-specific policies should be made available to the students in writing in the first week of class.

This policy applies, in all respects, to this course.

CMU Academic Integrity Policy (http://www.cmu.edu/academic-integrity/index.html**):**

In the midst of self-exploration, the high demands of a challenging academic environment can create situations where some students have difficulty exercising good judgment. Academic challenges can provide many opportunities for high standards to evolve if students actively reflect on these challenges and if the community supports discussions to aid in this process. It is the responsibility of the entire community to establish and maintain the integrity of our university.

This site is offered as a comprehensive and accessible resource compiling and organizing the multitude of information pertaining to academic integrity that is available from across the university. These pages include practical information concerning policies, protocols and best practices as well as articulations of the institutional values from which the policies and protocols grew. The Carnegie Mellon Code, while not formally an honor code, serves as the foundation of these values and frames the expectations of our community with regard to personal integrity.

This policy applies, in all respects, to this course.

The Carnegie Mellon Code

Students at Carnegie Mellon, because they are members of an academic community dedicated to the achievement of excellence, are expected to meet the highest standards of personal, ethical and moral conduct possible.

These standards require personal integrity, a commitment to honesty without compromise, as well as truth without equivocation and a willingness to place the good of the community above the good of the self. Obligations once undertaken must be met, commitments kept.

As members of the Carnegie Mellon community, individuals are expected to uphold the standards of the community in addition to holding others accountable for said standards. It is rare that the life of a student in an academic community can be so private that it will not affect the community as a whole or that the above standards do not apply.

The discovery, advancement and communication of knowledge are not possible without a commitment to these standards. Creativity cannot exist without acknowledgment of the creativity of others. New knowledge cannot be developed without credit for prior knowledge. Without the ability to trust that these principles will be observed, an academic community cannot exist.

The commitment of its faculty, staff and students to these standards contributes to the high respect in which the Carnegie Mellon degree is held. Students must not destroy that respect by their failure to meet these standards. Students who cannot meet them should voluntarily withdraw from the university.

This policy applies, in all respects, to this course.

Carnegie Mellon University's Policy on Cheating
(http://www.cmu.edu/academic-integrity/cheating/index.html) states the following:

According to the University Policy on Academic Integrity, cheating "occurs when a student avails her/himself of an unfair or disallowed advantage which includes but is not limited to:

- Theft of or unauthorized access to an exam, answer key or other graded work from previous course offerings.
- Use of an alternate, stand-in or proxy during an examination.
- Copying from the examination or work of another person or source.
- Submission or use of falsified data.
- Using false statements to obtain additional time or other accommodation.
- Falsification of academic credentials."

This policy applies, in all respects, to this course.

Carnegie Mellon University's Policy on Plagiarism (http://www.cmu.edu/academic-integrity/plagiarism/index.html) states the following:

According to the University Policy on Academic Integrity, plagiarism "is defined as the use of work or concepts contributed by other individuals without proper attribution or citation. Unique ideas or materials taken from another source for either written or oral use must be fully acknowledged in academic work to be graded. Examples of sources expected to be referenced include but are not limited to:

- Text, either written or spoken, quoted directly or paraphrased.
- Graphic elements.
- Passages of music, existing either as sound or as notation.
- Mathematical proofs.
- Scientific data.
- Concepts or material derived from the work, published or unpublished, of another person."

This policy applies, in all respects, to this course.

Carnegie Mellon University's Policy on Unauthorized Assistance (http://www.cmu.edu/academic-integrity/collaboration/index.html) states the following:

According to the University Policy on Academic Integrity, unauthorized assistance "refers to the use of sources of support that have not been specifically authorized in this policy statement or by the course instructor(s) in the completion of academic work to be graded. Such sources of support may include but are not limited to advice or help provided by another individual, published or unpublished written sources, and electronic sources. Examples of unauthorized assistance include but are not limited to:

- Collaboration on any assignment beyond the standards authorized by this policy statement and the course instructor(s).
- Submission of work completed or edited in whole or in part by another person.
- Supplying or communicating unauthorized information or materials, including graded work and answer keys from previous course offerings, in any way to another student.
- Use of unauthorized information or materials, including graded work and answer keys from previous course offerings.
- Use of unauthorized devices.
- Submission for credit of previously completed graded work in a second course without first obtaining permission from the instructor(s) of the second course. In the case of concurrent courses, permission to submit the same work for credit in two courses must be obtained from the instructors of both courses."

This policy applies, in all respects, to this course.

Carnegie Mellon University's Policy on Research Misconduct
(http://www.cmu.edu/academic-integrity/research/index.html) states the following:

According to the University Policy for Handling Alleged Misconduct in Research, "Carnegie Mellon University is responsible for the integrity of research conducted at the university. As a community of scholars, in which truth and integrity are fundamental, the university must establish procedures for the investigation of allegations of misconduct of research with due care to protect the rights of those accused, those making the allegations, and the university. Furthermore, federal regulations require the university to have explicit procedures for addressing incidents in which there are allegations of misconduct in research."

The policy goes on to note that "misconduct means:

- fabrication, falsification, plagiarism, or other serious deviation from accepted practices in proposing, carrying out, or reporting results from research;

- material failure to comply with Federal requirements for the protection of researchers, human subjects, or the public or for ensuring the welfare of laboratory animals; or

- failure to meet other material legal requirements governing research."

"To be deemed misconduct for the purposes of this policy, a 'material failure to comply with Federal requirements' or a 'failure to meet other material legal requirements' must be intentional or grossly negligent."

To become familiar with the expectations around the responsible conduct of research, please review the guidelines for Research Ethics published by the Office of Research Integrity and Compliance.

This policy applies, in all respects, to this course.

Take care of yourself.

Please 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. Counseling and Psychological Services (CaPS) is here to help: call 412-268-2922 and visit their

website at http://www.cmu.edu/counseling/. Consider reaching out to a friend, faculty or family member you trust for help getting connected to the support that can help.

If you or someone you know is in danger of self-harm (including suicidal thoughts), please call someone immediately, day or night:

CaPS: 412-268-2922

Re:solve Crisis Network: 888-796-8226

If the situation is life-threatening, call the police:

On campus: CMU Police: 412-268-2323

Off campus: 911

If you have questions or concerns about this or your coursework, please let your instructor know.