

## **EE445M Final Exam Study Guide (Spring 2018):**

### **Instructions:**

- Open book and open notes.
- No electronic devices (all cell phones off).
- Please be sure that your answers to all questions (and all supporting work that is required) are contained in the space (boxes) provided.
- *Anything outside the boxes will be ignored in grading.*
- For all questions, unless otherwise stated, find the most efficient (time, resources) solution.

### **Lecture notes: Lectures 1-12**

Skip Lecture 9, slides 8-14, no noise

Skip Lecture 9, slides 17-18, no analog filter

Skip Lecture 11, slides 48-61, no fuzzy logic

Skip Lecture 11, slides 62-69, no odometry

Skip Lecture 13, slides 2-9, no other OS

### **Labs: Labs 1-7, important topics**

Lab 1: Interrupts, Cortex M architecture, FIFOs, serial port, ADC

Lab 2: Real time OS, semaphores, critical sections, synchronization, communication

Lab 3: Priority scheduling, blocking semaphores, debugging

Lab 4: File system, SPI, SD cards

Lab 5: Memory & process management, process loading & linking

Lab 6: CAN, sensor interfacing, and distributed systems

Lab 7: PWM, control, and abstraction

### **Book: Chapters 1-10**

#### **1. Computer Architecture**

1.1. Introduction to Real-Time Operating Systems

1.1.1. Real-time operating systems

1.1.2. Embedded Systems

1.2. Computer Architecture

1.2.1. Computers, processors, and microcontrollers

1.2.2. Memory

1.3. Cortex-M Processor Architecture

1.3.1. Registers

1.3.2. Stack

1.3.3. Operating modes

1.3.4. Reset

1.3.5. Clock system

1.4. Texas Instruments Cortex-M Microcontrollers

1.4.1. Introduction to I/O

1.4.2. Texas Instruments TM4C123 LaunchPad I/O pins

~~1.4.3. Texas Instruments TM4C1294 Connected LaunchPad I/O pins~~

~~1.4.4. Texas Instruments MSP432 LaunchPad I/O pins~~

- 1.4.5. Interfacing to a LaunchPad
- 1.5. ARM Cortex-M Assembly Language
  - 1.5.1. Syntax
  - 1.5.2. Addressing modes and operands
  - 1.5.3. List of twelve instructions
  - 1.5.4. Accessing memory
  - 1.5.5. Functions
  - 1.5.6. ARM Cortex Microcontroller Software Interface Standard
  - 1.5.7. Conditional execution
  - 1.5.8. Stack usage
  - ~~1.5.9. Floating point math~~
  - ~~1.5.10. Keil assembler directives~~
- 1.6. Pointers in C
  - 1.6.1. Pointers
  - 1.6.2. Arrays
  - 1.6.3. Linked lists
- 1.7. Memory Management
  - 1.7.1. Use of the heap
  - 1.7.2. Simple fixed-size heap
  - 1.7.3. Memory manager: malloc and free
- 1.8. Introduction to debugging

## **2. Microcontroller Input/Output**

- 2.1. Parallel I/O
  - 2.1.1. TM4C I/O programming
  - ~~2.1.2. MSP432 I/O programming~~
- 2.2. Interrupts
  - 2.2.1. NVIC
  - 2.2.2. SysTick periodic interrupts
  - 2.2.3. Periodic timer interrupts
  - 2.2.4. Critical sections
  - 2.2.5. Executing periodic tasks
  - 2.2.6. Software interrupts
- 2.3. First in First Out (FIFO) Queues
- 2.4. Edge-triggered Interrupts
  - 2.4.1. Edge-triggered interrupts on the TM4C123
  - ~~2.4.2. Edge triggered Interrupts on the MSP432~~
- 2.5. UART Interface
  - 2.5.1. Transmitting in asynchronous mode
  - 2.5.2. Receiving in asynchronous mode
  - 2.5.3. Interrupt-driven UART on the TM4C123
  - ~~2.5.4. Interrupt driven UART on the MSP432~~
- 2.6. Synchronous Transmission and Receiving using the SSI
- 2.7. Input Capture or Input Edge Time Mode
  - 2.7.1. Basic principles
  - 2.7.2. Period measurement on the TM4C123
  - ~~2.7.3. Period measurement on the MSP432~~

- 2.7.4. Pulse width measurement
- 2.7.5. Ultrasonic distance measurement
- 2.8. Pulse Width Modulation
  - 2.8.1. Pulse width modulation on the TM4C123
  - ~~2.8.2. Pulse width modulation on the MSP432~~
- ~~2.9. Analog Output~~
- 2.10. Analog Input
  - 2.10.1. ADC Parameters
  - 2.10.2. Internal ADC on TM4C
  - ~~2.10.3. Internal ADC on MSP432~~
  - 2.10.4. IR distance measurement
- 2.11. OS Considerations for I/O Devices
  - 2.11.1 Board Support Package
  - 2.11.2 Path Expression
- 2.12. Debugging
  - 2.12.1. Functional Debugging
  - 2.12.2. Performance Debugging (FFT analysis)
  - 2.12.3. Debugging heartbeat
  - 2.12.4. Profiling

### **3. Thread Management**

- 3.1. Introduction to RTOS
  - 3.1.1. Motivation
  - 3.1.2. Parallel, distributed and concurrent programming
  - 3.1.3. Introduction to threads
  - 3.1.4. States of a main thread
  - 3.1.5. Real-time systems
  - 3.1.6. Producer/Consumer problem using a mailbox
  - 3.1.7. Scheduler
- 3.2. Function pointers
- 3.3. Thread Management
  - 3.3.1. Two types of threads
  - 3.3.2. Thread Control Block (TCB)
  - 3.3.3. Creation of threads
  - 3.3.4. Launching the OS
  - 3.3.5. Switching threads
  - 3.3.6. Profiling the OS
  - 3.3.7. Linking assembly to C
  - 3.3.8. Periodic tasks
- 3.4. Semaphores
- 3.5. Thread Synchronization
  - 3.5.1. Resource sharing, nonreentrant code or mutual exclusion
  - 3.5.2. Condition variable
  - 3.5.3. Thread communication between two threads using a mailbox
- 3.6. Process Management
- 3.7. Dynamic loading and linking

## 4. Time Management

- 4.1. Cooperation
  - 4.1.1. Spin-lock semaphore implementation with cooperation
  - 4.1.2. Cooperative Scheduler
- 4.2. Blocking semaphores
  - 4.2.1. The need for blocking
  - 4.2.2. The blocked state
  - 4.2.3. Implementation
  - 4.2.4. Thread rendezvous
- 4.3. First In First Out Queue
  - 4.3.1. Producer/Consumer problem using a FIFO
  - 4.3.2. Little's Theorem
  - 4.3.3. FIFO implementation
  - 4.3.4. Three-semaphore FIFO implementation
  - 4.3.5. Two-semaphore FIFO implementation
  - 4.3.6. One-semaphore FIFO implementation
  - 4.3.7. Kahn Process Networks
- 4.4. Thread sleeping
- 4.5. Deadlocks
- 4.6. Monitors
- 4.7. Fixed Scheduling

## 5. Real-time Systems

- ~~5.1. Data Acquisition Systems~~
  - ~~5.1.1. Approach~~
  - ~~5.1.2. Performance Metrics~~
  - ~~5.1.3. Audio Input/Output~~
- 5.2. Priority scheduler
  - 5.2.1. Implementation
  - 5.2.2. Multi-level Feedback Queue
  - 5.2.3. Starvation and aging
  - 5.2.4. Priority inversion and inheritance on Mars Pathfinder
- 5.3. Debouncing a switch
  - 5.3.1. Approach to debouncing
  - 5.3.2. Debouncing a switch on TM4C123
  - ~~5.3.3. Debouncing a switch on MSP432~~
- 5.4. Running event threads as high priority main threads
- ~~5.5. Available RTOS~~
  - ~~5.5.1. Micrium uC/OS-II~~
  - ~~5.5.2. Texas Instruments RTOS~~
  - ~~5.5.3. ARM RTX Real Time Operating System~~
  - ~~5.5.4. FreeRTOS~~
  - ~~5.5.5. Other Real Time Operating Systems~~

## **6. Digital Signal Processing**

- 6.1. Basic Principles
- 6.2. Multiple Access Circular Queue
- 6.3. Using the Z Transform to Derive Filter Response
- 6.4. IIR Filter Design Using the Pole-Zero Plot
- 6.5. Discrete Fourier Transform
- 6.6. FIR Filter Design
- 6.7. Direct Form Implementations.
- 6.8. Exercises

## **7. High-Speed Interfacing**

- 7.1. The Need for Speed
- 7.2. High-Speed I/O Applications
- 7.3. General Approaches to High-Speed Interfaces
  - 7.3.1. Hardware FIFO
  - 7.3.2. Dual Port Memory
  - 7.3.3. Bank-Switched Memory
- 7.4. Fundamental Approach to DMA
  - 7.4.1. DMA Cycles
  - 7.4.2. DMA Initiation
  - 7.4.3. Burst versus Single Cycle DMA
  - 7.4.4. Single Address versus Dual Address DMA
  - 7.4.5. DMA programming on the TM4C123
- 7.6. Exercises

## **8. File system management**

- 8.1. Performance Metrics
  - 8.1.1. Usage
  - 8.1.2. Specifications
  - 8.1.3. Fragmentation
- 8.2. File System Allocation
  - 8.2.1. Contiguous allocation
  - 8.2.2. Linked allocation
  - 8.2.3. Indexed allocation
  - 8.2.4. File allocation table (FAT)
- 8.3. Solid State Disk
  - 8.3.1. Flash memory
  - 8.3.2. Flash device driver
  - 8.3.3. eDisk device driver
  - 8.3.4. Secure digital card interface
- 8.4. Simple File System
  - 8.4.1. Directory
  - 8.4.2. Allocation
  - 8.4.3. Free space management
- 8.5. Write-once File System
  - 8.5.1. Usage

- 8.5.2. Allocation
- 8.5.3. Directory
- 8.5.4. Append
- 8.5.5. Free space management
- 8.6. Readers-Writers Problem
- 8.7. Exercises

## **9. Communication Systems**

- 9.1. Fundamentals
  - 9.1.1. The network
  - 9.1.2. Physical Channel
  - ~~9.1.3. Wireless Communication~~
  - 9.1.4. Radio
- 9.2. Controller Area Network (CAN)
  - 9.2.1. The Fundamentals of CAN
  - 9.2.2. Texas Instruments TM4C CAN
- 9.3. Embedded Internet
  - 9.3.1. Abstraction
  - 9.3.2. Message Protocols
  - 9.3.3. Ethernet Physical Layer
  - ~~9.3.4. Ethernet on the TM4C1294/MSP432E401Y~~
- 9.4. Internet of Things
  - 9.4.1. Basic Concepts
  - 9.4.2. UDP and TCP Packets
  - 9.4.3. Web server
  - ~~9.4.4. UDP communication over WiFi~~
  - ~~9.4.5. Other CC3100 Applications~~
- ~~9.4. Bluetooth Fundamentals~~
  - ~~9.4.1. Bluetooth Protocol Stack~~
  - ~~9.4.2. Client-server Paradigm~~
- ~~9.5. CC2650 Solutions~~
  - ~~9.5.1. CC2650 Microcontroller~~
  - ~~9.5.2. Single Chip Solution, CC2650 LaunchPad~~
- ~~9.6. Network Processor Interface (NPI)~~
  - ~~9.6.1. Overview~~
  - ~~9.6.2. Services and Characteristics~~
  - ~~9.6.3. Advertising~~
  - ~~9.6.4. Read and Write Indications~~
- ~~9.7. Application Layer Protocols for Embedded Systems~~
  - ~~9.7.1. CoAP~~
  - ~~9.7.2. MQTT~~
- 9.8. Exercises

## **10. Robotic Systems**

- 10.1. Introduction to Digital Control Systems
- 10.2. Binary Actuators

- 10.2.1. Electrical Interface
- 10.2.2. DC Motor Interface with PWM
- ~~10.3. Sensors~~
- ~~10.4. Odometry~~
- 10.5. Simple Closed-Loop Control Systems.
- 10.6. PID Controllers
  - 10.6.1. General Approach to a PID Controller
  - 10.6.2. Design Process for a PID Controller
- ~~10.7. Fuzzy Logic Control~~
- 10.8. Exercises

### **Past exams:**

#### **Real time OS, semaphores, critical sections, synchronization, communication**

- Spring 2001, Quiz2, Question 2, Sleep primitive
- Fall 2001, Quiz2, Question 4, Priority scheduler, deadlock
- Spring 2002, Quiz1, Question 3, Dynamic thread allocation, thread Kill
- Fall 2002, Quiz2, Question 2, application of semaphores
- Fall 2002, Final, Question 4, use of semaphores
- Fall 2002, Final, Bonus questions 1,2,6, assembly language used in OS programming
- Fall 2003, Quiz1, Question 2, use of semaphores
- Fall 2003, Quiz1, Question 3, changing the TCB
- Fall 2003, Quiz1, Question 4, definition of time jitter
- Fall 2003, Quiz1, Question 5, implementation of OS\_Wait
- Fall 2003, Final, Question 14, definitions of OS concepts/terms
- Fall 2004, Quiz2, Question 2, Three thread rendezvous
- Fall 2004, Quiz2, Question 3, Binary semaphore
- Fall 2004, Final, Question 9, Path expression
- Fall 2005, Quiz2, Question 4, Reader/writer problem
- Fall 2005, Quiz2, Question 5, Cooperative thread scheduler
- Fall 2006, Quiz2, Question 9, Fork
- Fall 2006, Quiz2, Question 5, Resource allocation graph
- Fall 2006, Final, Question 5, Exponential Queue or multi-level feedback queue scheduling
- Spring 2008, Quiz2, Question 4, use of semaphores
- Spring 2008, Final, Question 2, Effect of OS on time-jitter while sampling an ADC
- Spring 2008, Final, Question 5, Critical section, design new instruction
- Spring 2009, Quiz 2, Question 4, Critical section
- Spring 2009, Quiz 2, Question 5, Fork and join
- Spring 2009, Final, Question 5, kill threads that finish executing
- Spring 2010, Quiz 1, Question 2, word bank
- Spring 2010, Quiz 1, Question 4, alternate words for signal and wait
- Spring 2010, Quiz 1, Question 5, what happens if an ISR calls OS\_Wait
- Spring 2010, Quiz 1, Question 6, implementing mutual exclusion
- Spring 2010, Quiz 1, Question 7, application of semaphores
- Spring 2011, Quiz 1, Question 4, definitions
- Spring 2011, Quiz 1, Question 5, application of semaphores

Spring 2011, Quiz 1, Question 6, new implementation of semaphores  
Spring 2011, Quiz 1, Question 7, priority scheduler (the 2011 class did horrible on this question because they parroted their lab solution without reading the question)  
Spring 2010 Final, Question 5, definitions d, i, j  
Spring 2011 Final, Question 8, bounded waiting  
Spring 2011 Final, Question 9, real time OS, minimizing latency  
Spring 2011 Final, Question 11, FIFO with semaphores  
Spring 2011 Final, Question 12, implementing semaphores in a Dual core processor  
Spring 2011 Final, Question 16, implementing a thread scheduler on a 16-core processor  
Spring 2012 Quiz 1, Question 4, Two SPs.  
Spring 2012 Quiz 1, Question 5, OS definitions.  
Spring 2012 Quiz 1, Question 7, Monitor and deadlocks.  
Spring 2012 Quiz 1, Question 8, OS\_AddThread and OS\_Kill.  
Spring 2012 Quiz 1, Question 9, Use OS to debounce a switch.  
Spring 2012 Final, Question 3, is a real-time scheduler possible?  
Spring 2012 Final, Question 5, How does paging provide for security?  
Spring 2012 Final, Question 6, Mailbox  
Spring 2012 Final, Question 10, Wait\_For\_Events  
Spring 2013 Quiz 1, Question 1, Priority.  
Spring 2013 Quiz 1, Question 3, OS definitions.  
Spring 2013 Quiz 1, Question 5, using semaphores.  
Spring 2013 Quiz 1, Question 6, Assembly language thread switch.  
Spring 2013 Final, Question 3, How does MSP/PSP provide for security?  
Spring 2013 Final, Question 6, FIFO with semaphores  
Spring 2013 Final, Question 11, PendSV to implement cooperation

### **General questions**

Fall 2004, Quiz2, Question 4, Time-jitter  
Fall 2004, Quiz2, Question 5, Definitions and a word bank  
Fall 2005, Quiz2, Question 6, Time-jitter  
Fall 2006, Final, Question 4, Critical section  
Spring 2009, Quiz 2, Question 3, FIFO implementation  
Spring 2011, Quiz 1, Question 1, time jitter  
Spring 2011, Quiz 1, Question 2, reentrant, parameter passing, LR  
Spring 2011, Quiz 1, Question 3, bit-banded I/O eliminates critical section, which registers are pushed on the stack during an interrupt context switch, what is LR during an ISR  
Spring 2010 Final, Question 1, Cortex M3 interrupt context switch (answer for TM4C123)  
Spring 2011 Final, Question 2, Cortex M3 interrupt context switch  
Spring 2012 Quiz 1, Question 3, Harvard architecture.  
Spring 2012 Quiz 1, Question 6, Reentrancy.  
Spring 2012 Final, Question 1, Definitions  
Spring 2013 Quiz 1, Question 2, Control and observability.  
Spring 2013 Quiz 1, Question 4, Critical section  
Spring 2013 Final, Question 1, Definitions  
Spring 2013 Final, Question 7, Time-jitter  
Spring 2014 Final, Question 7, Profiling



## **File System**

Fall 2006, Quiz1, Question 2, Bit vector free space  
Fall 2006, Quiz1, Question 3, File system  
Spring 2008, Quiz1, Question 1, File translation table  
Spring 2008, Quiz1, Question 2, Block size  
Spring 2009, Quiz1, Question 1, Contiguous Allocation  
Spring 2010, Quiz2, Question 4, File system logger  
Spring 2010, Quiz2, Question 5, High reliability File system  
Spring 2011, Quiz2, Question 5, Wear leveling disk system  
Spring 2011, Quiz2, Question 6, Disk clustering  
Spring 2011, Final, Question 7, FAT file system  
Spring 2012, Quiz2, Question 4, File system in flash EEPROM  
Spring 2012, Final, Question 8, Indexed file system  
Spring 2013, Quiz2, Question 4, File system file table  
Spring 2013, Final, Question 9, FAT file system  
Spring 2014, Quiz2, Question 4, File system with an index table  
Spring 2014, Final, Question 11, File system with FAT

## **CAN**

Fall 2005, Final, Question 4, CAN bandwidth  
Fall 2005, Final, Question 5, CAN latency (although the solution for this question is specific to the 9S12, it could be asked in general, or in specific for the STM32)  
Fall 2006, Final, Question 3, CAN Id  
Spring 2008, Final, Question 1, Noise  
Spring 2008, Final, Question 7, Fifo queue  
Spring 2009, Final, Question 1, General concepts, ACK  
Spring 2011, Final, Question 6, Half duplex and differential drive  
Spring 2012, Final, Question 7b), CAN error recovery  
Spring 2014, Final, Question 3, purpose of the 120 ohm resistors  
Spring 2014, Final, Question 6, Is CAN synchronous or asynchronous?  
Spring 2014, Final, Question 12, CAN synchronization

## **DMA**

Spring 2011 Final, Question 5, Cycle steal versus burst DMA  
Spring 2014 Final, Question 8, Cycle steal versus burst DMA

## **Fuzzy Logic**

Spring 2014 Final, Question 9, Fuzzy Logic math  
Book questions 10.3-10.4, 10.5, and 10.8

## **Motor & Control Questions**

Fall 2005, Final, Question 8, Design of a PID controller  
Fall 2006, Final, Question 1, Tach interface  
Fall 2006, Final, Question 2, Measure motor current  
Fall 2006, Final, Question 6, Design of a PID controller

~~Spring 2008, Final, Question 3, Motor interface~~  
~~Spring 2008, Final, Question 4, PWM and motor control~~  
~~Spring 2009, Final, Question 3, Motor interface~~  
~~Spring 2009, Final, Question 7, Measure motor current~~