CSCI E-92, Fall 2025: Principles of Operating Systems

Prof. James L. Frankel
Harvard University

Version of 6:34 PM ET 23-Sep-2025

Zoom

- You are encouraged to turn on your video feed
  - This allows the course staff to better determine if students seem puzzled and/or have questions

- Class and section meetings are recorded
  - Students who are unable to attend a meeting for any reason are able to view recordings later
  - It's still better to participate in the live session so that questions can be asked and answered
  - Many students find that reviewing material later to fully appreciate the details presented during class – even if they participated in the live class – is very helpful

First Class Meeting on 9/2/2025

- Our **class website** is located at URL: **https://cscie92.dce.harvard.edu/fall2025/**
  - The slides that I use in each class are available at https://cscie92.dce.harvard.edu/fall2025/index.html#onlinedocs-slides

- Please participate in the live stream and ask questions verbally using **Zoom** available in **Canvas** (**https://canvas.harvard.edu/courses/164146**) under the **Zoom** menu
- In addition, questions may be asked textually using **Zoom's Chat facility**

Staff Introductions

- Professor
  - James “Jamie” Frankel
- Teaching Assistant
  - Stephen Benjamin

Quick Polls

- Class Enrollment (Multiple Choice)
- Class Participation
- Section Participation
- Class Expectations (Multiple Choice)

- You can choose to answer the polls anonymously

Student Introductions

- Please tell us a little about yourself
  - Where you're located
  - What you do when you're not at Harvard
  - Your technical background
  - Your out-of-work/school hobbies

Tour of Class Web Site

- At the top there are alerts
- Links for streaming and videos
- Info about midterm exam, prerequisites, overview, bibliography, instructors and section, Ed Discussion wiki/forum, Say Hello!, your location, git & GitHub, grading, accessibility, plagiarizing, publishing course materials, outline/approximate schedule, hardware-related information, agenda for the upcoming class, slides used in class, questionnaire & problem sets, assorted links, papers discussed in class, link to the section home page

Meeting Times

- Section meets on Tuesdays in Room L01, 53 Church Street, Harvard Square, Cambridge, Massachusetts from 6:45 PM to 7:45 PM Eastern Time (ET) and in Zoom using the **Section**: HELIX Classroom room
  - This is immediately before class meets

- Class meets on Tuesdays in Room L01, 53 Church Street, Harvard Square, Cambridge, Massachusetts from 8:00 PM to 10:15 PM Eastern Time (ET) and in Zoom using the **Class**: HELIX Classroom room
  - Elongated class meeting time

- I will attempt to include a break during the class meeting *(but no guarantee because of scope of material to be presented)*

Section

- Very important (and required)
  - Discusses concepts & issues that are not covered in class
  - Often gives a sketch of algorithms and approaches to be used in solving the problem sets
  - Adds enrichment on topics discussed in class/lecture
  - Great forum for a more interactive dialog
  - Is live streamed and also recorded

Syllabus Review

- Questions?
  - Questions are always welcomed
    - Any questions now?
  - If there is limited time to answer questions, I'll let you know

- Review of Syllabus
  - Midterm exam
  - Prerequisites
  - Overview
  - Required and optional books
  - The daily agenda (these slides) and all slides used in class

- Order book, if you have not already done so
  - Modern Operating Systems, 5/e by Tanenbaum & Bos
    - The 4/e is also acceptable

  - Somewhat limited online access is available to all of our books through our Library Reserves link in Canvas
    - All of our books (except for those concerning Git) are currently available for online access

Required Readings

- Refer to the Approximate Schedule section of the course website for required readings to be completed before each class meeting

Say Hello!, Student Locations, Harvard Key, Using cscie92.dce.harvard.edu

- Submit a video in Canvas under **Discussions** as a reply to my “Say Hello!” topic
- Please post your primary location using **Student Locations** facility in Canvas
- Ensure that your **Harvard Key** is established
- Ensure that you are able to VPN into Harvard using **vpn.harvard.edu** and **Cisco AnyConnect/Secure Client**
- Ensure that you have an account on our cscie92.dce.harvard.edu AWS instance
  - Once your VPN connection is established, login to cscie92.dce.harvard.edu using SSH/SFTP (SecureCRT & SecureFX) with your HarvardKey NetID as your login name and your HarvardKey password as your password
  - If you are unable to login to cscie92.dce.harvard.edu, you may need to synchronize your HarvardKey password by using a browser to visit https://key.harvard.edu/manage-account and then clicking on “Synchronize Password >” and following the instructions on the next screen

g.harvard.edu e-mail Address

- If you're interested, you can get a g.harvard.edu account that will give you an e-mail address and access to Google Apps for Harvard
  - Get started at http://g.harvard.edu/
  - Note: Please be aware that when you claim your g.harvard account that g.harvard will become your primary Harvard e-mail address. All official communication from Harvard will be sent to your new g.harvard address and your g.harvard account will become your HarvardKey login name.

Class Discussion Group: Ed Discussion

- Ask all non-personal questions in Ed so the whole class can benefit from the answers
  - Ed can be found in Canvas by following the Ed Discussion link (https://canvas.harvard.edu/courses/164146/external_tools/115899?display=borderless)
  - Students are welcome to answer questions there, too
  - Personal questions should be sent to the course staff via e-mail
    - If general, all three course staff members should be included in e-mails to allow the fastest reply
  - All registered students should already be in our Ed group

NXP ARM K70 Hardware

- Show class the hardware
  - Students should order the NXP TWR-K70F120M hardware now
    - If available, the **TWR-K70F120M-KIT** includes the TWR-K70F120M (which includes **TWR-K70F120M, TWR-SER, TWR-ELEV**).
    - Sold by Mouser, Digi-Key, Newark, Arrow, Verical, Future, Avnet, ebay, etc.
    - Purchasing the **TWR-K70F120M** may be difficult or impossible
  - In addition to NXP/Freescale board, order the **Adafruit USB to TTL Serial Cable - Debug / Console Cable for Raspberry Pi, P/N 954**
    - Available from adafruit.com https://www.adafruit.com/product/954 and also from Amazon
  - If needed, order necessary cables or adapters
  - Order **microSDHC card**(s) for exclusive use during this class
    - https://cscie92.dce.harvard.edu/fall2025/index.html#hwrefs-microsdhccard
  - If needed, order an SD card reader for your usual computer
  - Possible **static dissipative devices**: mat, strap, ground point

- For any interested students in the US (or elsewhere) who are unable to procure the TWR-K70F120M, we will lend you that board for the semester
  - The NXP TWR-K70F120M is in short supply
  - All borrowed hardware must be returned at the end of the semester

NXP ARM TWR-K70F120M Hardware

- Any students interested in borrowing the TWR-K70F120M for the duration of the semester should send e-mail to **all course staff**
  - Include your **name** and **full mailing address**
  - Include your **phone number**
  - Include a statement that you will “return the NXP TWR-K70F120M board at the conclusion of the semester”

- Keep in mind that you are still responsible for purchasing all the other necessary hardware

Problem Set and Term Project Overview

- Problem Set 0: the course questionnaire, fix-this-program & word-count
- Problem Set 1: textbook problems & simple shell including conversion of microseconds since the Unix epoch to printable form
- Problem Set 2: memory management: malloc & free, K70 LED flashing program, shell enhancements
- Problem Set 3: textbook problems & device independent I/O for LEDs, pushbuttons, and a FAT32 file system on microSDHC, shell enhancements, must use UART serial input & output for all shell interactions
- Problem Set 4: K70 enhancements: faster clock, off-chip SDRAM, supervisor calls, serial I/O added to device independent I/O, (optional LCD display), A-to-D input, and touch sensors, unprivileged mode, shell enhancements
- Term Project Proposal for term project features
- Problem Set 5: FlexTimer for time and date, interrupt-driven serial I/O, user timer, shell enhancements
- Problem Set 6: SysTick for multiprocessing, processes
- Term Project Presentation: Advanced OS features – as approved for each student

Problem Set 0

- Complete Problem Set 0
  - Establish a GitHub account
  - Install git as described on the section web site (https://cscie92.dce.harvard.edu/fall2025/section/index.html)
  - Modify the course questionnaire with your personal answers
  - Fix warnings and errors in fix-this-program on the cscie92 instance
  - Write the word count program
  - Create a branch named “problem-set-0”, create a merge request, add the appropriate comment
- Due this coming Sunday night, September 7th, 2025 at midnight ET

Problem Set 1

- Present **Problem Set 1**
  - Due at midnight ET on Sunday night, September 21st, 2025

- Presentation of Problem Set 1 is delayed to next week

Lying to Students

- I will lie to you this semester

Lying to Students

- I will lie to you this semester
  - There are too many details to give the whole truth
  - That is the only way we can make reasonable progress through the material

- By the end of the semester, all lies will be fully corrected

Non-academic Class Activities

- Encourage a student community

- If interested, students are welcome to gather with us after each class for dinner in Harvard Square
  - Opportunity for students to socialize in an informal setting outside of class
  - Discussion/conversation/sharing after class
  - Need not be class related

- Ski trip during the winter (usually between the Fall and Spring semesters)
- Sailing trip(s) during the summer

Class Break

- Let’s take a 5 minute break
- I have the textbooks and hardware available in class
- You’re welcome informally interact during the break (whether you’re here in person or remotely)

New Material for this Week

- Cover new slides
  - **Review of the C Programming Language** through the **Associativity (§7.2.1)** slide #15

Second Class Meeting on 9/9/2025

Second Class Meeting Agenda

- Questions and Comments
- Class Website & Canvas, Zoom links
- Administrivia
  - K70 Hardware
  - Midterm Exam
  - Student actions: Order textbook(s), Say Hello!, Student Locations
- Problem Set 1
- Review of the C Programming Language (continued)
- Devices, Abstractions Provided, OS Structure
- Processes

Questions or Comments

- From section immediately before class tonight
- Last week's section
- Last week's class
- Problem Set 0
- Access to the class cscie92.dce.harvard.edu instance & other logistics
- Readings
- Anything else

Class Website, Canvas, Zoom Links

- Our **class website** is located at URL: **https://cscie92.dce.harvard.edu/fall2025/**
  - The slides that I use in each class are available at https://cscie92.dce.harvard.edu/fall2025/index.html#onlinedocs-slides

- Please participate in the live stream and ask questions verbally using **Zoom** available in **Canvas** (**https://canvas.harvard.edu/courses/164146**) under the **Zoom** menu
- In addition, questions may be asked textually using **Zoom's Chat facility**

NXP ARM K70 Hardware

- NXP ARM K70 Hardware
  - **All students should have already ordered the NXP TWR-K70F120M hardware**
    - If available, the **TWR-K70F120M-KIT** includes the TWR-K70F120M (which includes **TWR-K70F120M, TWR-SER, TWR-ELEV**).
    - Sold by Mouser, Digi-Key, Newark, Arrow, Verical, Future, Avnet, ebay, etc.
    - Purchasing either the **TWR-K70F120M** or the **TWR-K70F120M-KIT** may be difficult or impossible, *but see below*
  - **Now is the time to order the remaining required hardware**
  - (1) In addition to NXP/Freescale board, order the **Adafruit USB to TTL Serial Cable - Debug / Console Cable for Raspberry Pi, P/N 954**
    - Available from adafruit.com https://www.adafruit.com/product/954 and also from Amazon
    - The Adafruit USB to TTL Serial Cable is terminated with a USB Standard-A plug
  - If needed, order necessary cables or adapters
    - (2) Cable from USB mini-B J13 on the TWR-K70F120M to an appropriate USB connector for your development environment (probably USB Standard-A or USB-C)
    - (3) A powered USB hub
      - Example: SABRENT HB-UMP3 4-Port USB 3.0 Hub with Individual LED Lit Power Switches, Includes 5V/2.5A Power Adapter; connects to computer via USB-A
    - (4) Order at least a couple **microSDHC card**(s) for exclusive use during this class and an SD adapter
    - https://cscie92.dce.harvard.edu/fall2025/index.html#hwrefs-microsdhccard
  - (5) If needed, order an SD card reader for your usual computer
    - Examples:
    - (a) Anker USB-C SD Card Reader, 2-in-1 USB-C Memory Card Reader with Dual Slot for SDXC, SDHC, SD, MMC, RS-MMC, Micro SDXC, MicroSD, Micro SDHC Card, and UHS-I Cards
    - (b) Anker USB-A 3.0 SD Card Reader, 2-in-1 SD Card Reader for SDXC, SDHC, MMC, RS-MMC, Micro SDXC, Micro SD, Micro SDHC, UHS-I Cards
    - (c) Cable Matters 202058-BLK USB-A 3.0 to microSD, SD, SDHC & SDXC Card Reader
    - (d) Apple USB-C to SD Card Reader
  - (6) Possible **static dissipative devices**: mat, strap, ground point
    - See class website at Static dissipative devices used in the lab
  - (7) If developing on an Apple M-Series Mac (processor is an M1, M2, or M3), then a Segger J-Link EDU Mini is also required and a Windows VM
    - See https://shop-us.segger.com/product/j-link-edu-mini-8-08-91/ and https://www.adafruit.com/product/3571

- For any interested students in the US (or elsewhere) who are unable to procure the TWR-K70F120M, we will lend you that board for the semester
  - The NXP TWR-K70F120M is in short supply
  - All borrowed hardware must be returned at the end of the semester

NXP ARM TWR-K70F120M Hardware

- Any students interested in borrowing the TWR-K70F120M for the duration of the semester should send e-mail to all course staff ASAP
  - Include your name and full mailing address
  - Include your phone number
  - Include a statement that you will “return the NXP TWR-K70F120M board at the conclusion of the semester”
- If you are attending class in person, you must pick up the board during class
- Keep in mind that you are still responsible for purchasing all the other necessary hardware

Midterm Exam

- Our midterm exam will be available starting at 8:00 PM ET on October 21, 2025
  - The exam must be started within 24 hours of the date & time above
  - The exam is three hours in length
  - The exam will be administered under Proctorio
- Section will be held before class that evening, but that section meeting will not cover any material or answer any questions relevant to the midterm exam – in fairness to distance students who may be travelling to their proctored exam

Textbooks

- If not already done, order
  - Modern Operating Systems, Fifth Edition; Andrew S. Tanenbaum and Herbert Bos; Prentice-Hall, 2023, 2014, 2008; ISBN-13 978-0-13-761887-3
- Or, if the updated and preferred Fifth Edition is not accessible:
  - Modern Operating Systems, Fourth Edition; Andrew S. Tanenbaum and Herbert Bos; Prentice-Hall, 2015, 2008; ISBN-13 978-0-13-359162-0
- Recommended C Language Reference Manual:
  - C: A Reference Manual, Fifth Edition; Samuel P. Harbison and Guy L. Steele, Jr.; Prentice Hall, 2002; ISBN-13 978-0-13-089592-9

Say Hello!, Student Locations

- Submit a video in Canvas under **Discussions** as a reply to my “Say Hello!” topic

- Please post your primary location using **Student Locations** facility in Canvas

Problem Set 1

- Present **Problem Set 1**
  - Due at midnight ET on Sunday night, September 21st, 2025

Five Free Late Days

- Please don’t use any of your five free late days early in the class
- Because the later problem sets are built upon earlier problem sets, the free late days are more valuable later in the semester
- Also, the larger problem sets are worth more points and take much more time to complete

Today's New Material

- Continue covering **Review of the C Programming Language** slides beginning with **Associativity Examples** slide #16
- Cover **Devices, Abstractions Provided, OS Structure** slides
- Cover **Processes** slides through the **Thread Usage (2) – Web Server** slide #25

Third Class Meeting on 9/16/2025

Third Class Meeting Agenda

- Questions and Comments
- Administrivia
  - K70 Hardware Distributed During Break
  - **Everyone needs to have ordered all necessary hardware by now!**
  - Mandatory software development environment
  - Install CodeWarrior and build sample programs
- Problem Set Status
- Present the DataSizes, FlashLED, and Pushbuttons Projects
  - CodeWarrior Usage
  - Hardware Background
  - Interacting with the Hardware in C Code
- Introduction to details of the K70 Hardware and Low-Level Programming

Questions or Comments

- From section immediately before class tonight
- Last week's section
- Last week's class
- Problem Set 0 & 1
- Logistics
- Readings
- Anything else

NXP ARM K70 Hardware

- NXP ARM K70 Hardware
  - All students should have already ordered the NXP TWR-K70F120M hardware
  - **Now is the time to order the remaining required hardware**
  - (1) In addition to NXP/Freescale board, order the **Adafruit USB to TTL Serial Cable - Debug / Console Cable for Raspberry Pi, P/N 954**
    - Available from adafruit.com https://www.adafruit.com/product/954 and also from Amazon
    - The Adafruit USB to TTL Serial Cable is terminated with a USB Standard-A plug
  - If needed, order necessary cables or adapters
    - (2) Cable from USB mini-B J13 on the TWR-K70F120M to an appropriate USB connector for your development environment (probably USB Standard-A or USB-C)
    - (3) A powered USB hub
      - Examples: SABRENT HB-UMP3 4-Port USB 3.0 Hub with Individual LED Lit Power Switches, Includes 5V/2.5A Power Adapter; connects to computer via USB-A
    - (4) Order at least a couple **microSDHC card**(s) for exclusive use during this class and an SD adapter
    - https://cscie92.dce.harvard.edu/fall2025/index.html#hwrefs-microsdhccard
  - (5) If needed, order an SD card reader for your usual computer
    - Examples:
    - (a) Anker USB-C SD Card Reader, 2-in-1 USB-C Memory Card Reader with Dual Slot for SDXC, SDHC, SD, MMC, RS-MMC, Micro SDXC, MicroSD, Micro SDHC Card, and UHS-I Cards
    - (b) Anker USB-A 3.0 SD Card Reader, 2-in-1 SD Card Reader for SDXC, SDHC, MMC, RS-MMC, Micro SDXC, Micro SD, Micro SDHC, UHS-I Cards
    - (c) Cable Matters 202058-BLK USB-A 3.0 to microSD, SD, SDHC & SDXC Card Reader
    - (d) Apple USB-C to SD Card Reader
  - (6) Possible **static dissipative devices**: mat, strap, ground point
    - See class website at Static dissipative devices used in the lab
  - (7) If developing on an Apple M-Series Mac (processor is an M1, M2, or M3), then a Segger J-Link EDU mini is also required and a Windows VM
    - See https://shop-us.segger.com/product/j-link-edu-mini-8-08-91/ and https://www.adafruit.com/product/3571
  - (8) NEW: A nicer ribbon cable solution is available for the Segger J-Link EDU mini from 1BitSquared
    - See 1BitSquared JTAG SWD 10pin to 20pin IDC Cable on the class website

NXP TWR-K70F120M to be Mailed

- If you have requested to borrow the NXP TWR-K70F120M board and to have it mailed to you…
  - Please be certain that you have completed all of the requirements for me to send you a board
    - Include your name and full mailing address
    - Include your phone number
    - Include a statement that you will “return the NXP TWR-K70F120M board at the conclusion of the semester”
- Keep in mind that you are still responsible for purchasing all the other necessary hardware

K70 Software Development Environment

- We are now requiring all students to use CodeWarrior Version 11.1
- All students need either a Windows 10 or 11 native OS or a Windows 11 virtual machine
- The Segger J-Link EDU mini is not required, but it is strongly recommended
  - The Segger J-Link EDU mini is required with Apple Silicon M-Series Macintosh

Additional CodeWarrior Information

- When adding .c files to the Sources folder, it is fine to import the files either by selecting “Copy files” or “Link to files”

- When adding header files to the Project_Headers folder, always select “Copy files”
  - There seems to be a bug in CodeWarrior that doesn’t allow it to access header files through a link (not sure if this is still present in Version 11.1)

Install CodeWarrior, Build Sample Programs

- Before next week's class meeting
  - Install CodeWarrior
  - Install Device Drivers
  - Connect Hardware Devices
  - Build Sample Programs Covered in Class Today

Problem Set 1

- Problem Set 1
  - Due this coming Sunday night, September 21st, 2025 at midnight ET

Problem Set 2

- Due at midnight ET on Sunday night, October 5th, 2025

- Three questions about memory management and page replacement
- Implement your own malloc & free replacements
- Additional shell commands: malloc, free, memorymap, memset & memchk
- Convert your shell to use your malloc & free
- On the NXP K70 ARM, implement LED flash program with pushbutton debouncing

- Implementation of malloc & free is significantly more work than PS1
  - Start early and test your implementation
  - At the end of PS2, you will be using your implementation of malloc & free rather than the system functions

- Present an overview of Problem Set 2

Hardware Precautions, Serial Adapter Need, J-Link EDU

- Be careful with static electric charges
- Be careful with the USB connector on the TWR-K70F120M and keeping the hardware equipment from falling

- Remember to order Adafruit 954 Serial to USB adapter – not needed yet
- J-Link EDU mini is a better debug probe to use with our hardware, but is not required

- Everyone: static dissipative devices are helpful

Creating a CodeWarrior Project and Running It on the K70

- Quite a few different hardware configurations
  - Use the straight-forward configuration (*i.e.,* no Tower Elevators for now even if you have them)
  - I'll be using the Segger J-Link EDU mini, but using OSJTAG is also possible
- Follow the directions on how to connect the hardware components together
- Follow these directions on how to install CodeWarrior
- Follow these directions on how to build a new project using CodeWarrior
- Follow these directions on how to run a project under CodeWarrior
  - Don't install any software updates to CodeWarrior

Hardware is Pretty Cool!

- I hope you’re excited to be using raw hardware!

Get Hardware Working before Next Week's Class Meeting

- For next week,
  - Everyone should have installed CodeWarrior 11.1
  - Build and run the DataSizes, FlashLED, and Pushbuttons projects

Present C Code for K70 Hardware

- Present the DataSizes, FlashLED, and Pushbuttons Projects
  - CodeWarrior Usage
  - Hardware Background
  - Interacting with the Hardware in C Code

- Create a brand new project for DataSizes and explain all the code in DataSizes
- Present the FlashLED project and run it
- Present the Pushbuttons project and run it

Fourth Class Meeting on 9/23/2025

Fourth Class Meeting Agenda

- Questions and Comments
- Administrivia
- Review of Current Status
- Comments on Programming Solutions
- Basic Electronics
- Details of the K70 Hardware and Low-Level Programming
- Processes (continued)
- Memory Management

Questions or Comments

- Remaining questions from today's section meeting
- Previous section meetings
- Previous class meetings
- Problem Set 0, 1, or 2
- Readings
- Any other questions or issues

Administrivia

- In Ed, to enable e-mail notifications of all new threads…
  - Go to Account -> Settings (in the upper right)
  - Then, in the left menu, click on Notifications
  - Under New Thread Digests, turn on “Instant” for this course

Any Issues Getting Hardware Working?

- For today,
  - Everyone should have installed CodeWarrior 11.1
  - If you have the TWR-K70F120M, then you should have built and run the DataSizes, FlashLED, and Pushbuttons projects

  - Try building and running the InputAndOutput project
  - Reading **Application Note 1 is crucial** for understanding details about performing Console I/O on the K70 under CodeWarrior

Other Hardware Devices

- If you have the Primary and the Secondary Elevators and you have either or both the TWR-SER and the TWR-LCD-RGB board(s), then you should purchase the Segger J-Link EDU mini
  - This will allow you to power the entire Tower assembly through the elevators
  - If you have the TWR-SER board, you will be able to use the serial port on that board in addition to the serial port provided by the Adafruit 954
    - To use this additional serial port, you will need the Tripp-Lite Keyspan Serial Adapter and the serial cable

Problem Set 1

- Problem Set 1
  - Was due this past Sunday night, September 21st, 2025 at midnight ET

Problem Set 2

- Due at midnight ET on Sunday night, October 5th, 2025

- Three questions about memory management and page replacement
- Implement your own malloc & free replacements
- Additional shell commands: malloc, free, memorymap, memset & memchk
- Convert your shell to use your malloc & free
- On the NXP K70 ARM, implement LED flash program with pushbutton debouncing

- Implementation of malloc & free is significantly more work than PS1
  - Start early and test your implementation
  - At the end of PS2, you will be using your implementation of malloc & free rather than the system functions

Problem Set 3

- PS3 is the most time-consuming of any of the problem sets in this course
- Please complete PS2 on time so that you have as much time as possible for PS3

Comments on Programming Solutions (1 of 3)

- Document and comment your code
- Keep up to date with posts in Ed
- In addition to class, attend section and office hours, if possible
- All malloc'ed memory should be free'd
  - Memory for a command: free'd at end of command's execution
  - Memory for your shell/OS: explicitly free'd at end of the program's execution
- Use valgrind or a similar program to check for memory leaks and invalid memory accesses
- Check return codes from all functions/system call that you use
  - This includes malloc!
  - Refer to the man pages
  - Of course, check return codes from your functions, too

Comments on Programming Solutions (2 of 3)

- strcpy, etc. deal with NUL-terminated strings
- strncpy, etc. deal with maximum length NUL-terminated strings
- memcpy, etc. deal with length-counted memory
- malloc'ed memory is *not* initialized – it may contain arbitrary values
  - Don't count on it being zero filled
  - Don't initialize all malloc'ed memory to zero unless absolutely necessary
    - That is a time-consuming operating
- Be extremely careful to avoid off-by-one errors that are very common
  - For example, if a buffer must be able to hold 256 chars and will be NUL-terminated, it must be 257 chars in size

Comments on Programming Solutions (3 of 3)

- As we move forward, the course Application Notes become important
  - At this point, only AN1, AN3, AN15, and AN16 are relevant
- Writing clear and efficient code matters
  - Don’t repeatedly malloc, then malloc and copy, then free unless necessary
    - malloc and free are expensive operations
  - If the size can be relatively easily determined up front, that’s a much better solution
- C has call-by-value semantics on parameters to functions
  - Pass a pointer to a parameter that a function needs to modify
  - Don’t pass a pointer to a parameter if a function is only reading the parameter

Today’s New Material: Basic Electronics

- Cover **Basic Electronics** slides
- Describe how pushbuttons work
  - Pull-up resistor
- Describe how LEDs work
  - Ohm's law
  - Current limiting resistor
- Extremely important: Exercise care with the USB connectors; They cannot take any force applied to them; If force is applied, they will break off the board in an irreparable way

Let’s Start to Deal with the K70 ARM Hardware!

- A great deal of documentation
  - Manuals for our processor
    - ARM processor
      - ARM®v7-M Architecture Reference Manual
    - Cortex M4
      - Cortex M4 Technical Reference Manual
    - Our K70 chip
      - K70 Sub-Family Reference Manual
  - Schematics for our boards
    - TWR-K70F120M Quick Start Guide
    - TWR-K70F120M User Manual
    - TWR-K70F120M Schematics
- Software

Hardware Information on the Class Website

- Source code for examples
- Application Notes

- More…

Hardware Documentation

- Refer to the **TWR-K70F120M Schematics**
- Refer to the **K70 Sub-Family Reference Manual**

Continue to Present C Code for K70 Hardware

- Explain all the code in
  - FlashLED: main.c, delay.h, delay.c, led.h, led.c
  - Pushbuttons: main.c, pushbutton.h, pushbutton.c
  - InputAndOutput: main.c, util.h, util.c
    - Talk about our CSCI E-92 Application Notes in general and AN1 in specific
- Cover the references to the **TWR-K70F120M Schematics**
  - Page 9 of 11: determination of port and bit numbers for each LED
- Cover the references to the **K70 Sub-Family Reference Manual**

Today's New Material: Processes

- Continue covering **Processes** slides beginning with the **Thread Usage – Dispatcher and Workers** slide #26 through the **unknown** slide #
  - The **Mutual Exclusion through Strict Alternation** and **Mutual Exclusion through Peterson's Solution** slides were not covered in any depth

Today’s New Material: Memory Management

- Cover the **Memory Management** slides