CSUN | CALIFORNIA STATE UNIVERSITY NORTHRIDGE

COMP 122

DR JEFF SOFTWARE
INDIE APP DEVELOPER

COMP122

Fall 2023 Rev 8-27-23

Computer Arch &

ASSEMBLY Programming

Syllabus

Dr Jeff Drobman

website ➡ *drjeffsoftware.com/classroom.html*

email ➡ *jeffrey.drobman@csun.edu*

Index

Section

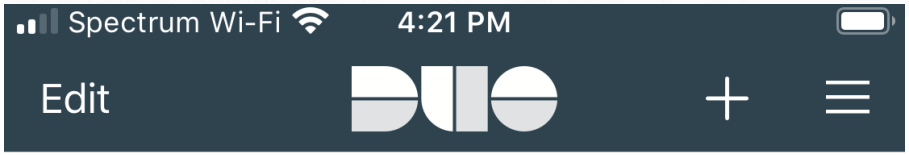
Admin

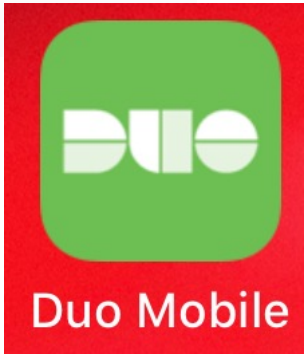
Login MFA

Duo Multi-Factor Authentication

What is Multi-Factor Authentication?

Multi-factor authenticationadds a second layer of security to your online accounts. Verifying your identity using asecond factor(like your phone or other mobile device) prevents anyone but you from logging in, even if they know your password. CSUN uses Duo multi-factor authentication for *any* application that stores or processes Level 1 Confidential information.





Add/Drop & Waitlist

- Week 1
  - Enrollment: Open (class full)
  - Waitlist: must attend all classes
- Week 2
  - Enrollment: Closed
  - Waitlist: will be given permissions
- Week 3
  - Enrollment: last week to DROP
  - Waitlist: last week to use permissions
- Week 4+ → no changes
  - Enrollment: Closed + NO DROPS
  - Waitlist: permissions expired

Permissions

Lecture

Un-Used Permission Numbers

General Info | Comments

	Permsn #	Expire On	Issued	Iss
1	811944	09/14/2019	☐	
2	461550	09/14/2019	☐	
3	343914	09/14/2019	☐	
4	109620	09/14/2019	☐	
5	965448	09/14/2019	☐	
6	943711	09/14/2019	☐	

Lab

Un-Used Permission Numbers

General Info | Comments

	Permsn #	Expire On	Issued	Is
1	134907	09/14/2019	☐	
2	758814	09/14/2019	☐	
3	100237	09/14/2019	☐	
4	111795	09/14/2019	☐	
5	378000	09/14/2019	☐	
6	738900	09/14/2019	☐	
7	187320	09/14/2019	☐	

CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE

COMP122

Class Website

http://drjeffsoftware.com/classroom.html

slides PDF files

DR JEFF SOFTWARE
INDIE APP DEVELOPER

DR JEFF'S *CLASSROOM* WEB PAGE

COMMON FILES

LAST UPDATE-- AUG 20, 2020

History of Technology part 1: Computers part 2: Chips part 3: Software & Networks	drobman-tech_history-pt1.pdf Download File drobman-tech_history-pt2.pdf Download File drobman-tech_history-pt3.pdf Download File
Introduction to Technology	drobman-tech_intro.pdf Download File
HPC (Hi-Perf Computing)	drobman-tech-hpc.pdf Download File
Quantum Computing	drobman-tech-qc.pdf Download File
Cryptography	csun-cs-crypto.pdf Download File
Tech News	csun-cs-news.pdf Download File
Funnies	csun-cs-funnies.pdf Download File
UCLA *Internet-50*	csun-ucla-i50.pdf Download File

CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE

COMP122

Class Website

http://drjeffsoftware.com/classroom.html

DR JEFF SOFTWARE
INDIE APP DEVELOPER

slides PDF files

DR JEFF SOFTWARE
INDIE APP DEVELOPER

HOME PRODUCTS SERVICES LICENSING MORE...

TECH HISTORY >

CLASSROOM

Dr Jeff's CSUN class COMP122/222 Portal

LAST UPDATE: AUG 17, 2020

Course 122 SYLLABUS doc + Syllabus Slides

Course 222 SYLLABUS doc + Syllabus Slides

MARS--MIPS Sim

Lab Form (122)

Project 1 Form (122)

Project Form (222)

REFERENCE MANUALS

mips_instruction_set.pdf
Download File

arm_isa_qref.pdf
Download File

CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE

COMP122

Class Website

http://drjeffsoftware.com/classroom.html

slides PDF files

LECTURE SLIDES (122)

csun-cs122-keyslides.pdf Download File
csun-cs122-isa-mips.pdf Download File
csun-cs122-isa-x86.pdf Download File
csun-cs122-lecture1.pdf Download File
csun-cs122-isa-arm.pdf Download File
csun-cs122-isa-2900.pdf Download File
csun-cs122-lecture2.pdf Download File
csun-cs122-isa-mcs8.pdf Download File
csun-cs122-isa-r5.pdf Download File
csun-cs122-lecture-logic_nums.pdf Download File
csun-cs122-isa-pic18.pdf Download File
csun-cs122-patterson.pdf Download File

LECTURE (222)

csun-cs222-lecture.pdf Download File
csun-cs222-gpu.pdf Download File

LAB SLIDES (122)

csun-cs122-lab0.pdf Download File
csun-cs122-lab1.pdf Download File
csun-cs122-raspi.pdf Download File

Section

Assignments

CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE

DR JEFF SOFTWARE
INDIE APP DEVELOPER

Subject Schedule

COMP122

Labor Day
- Sep 4

Week	1	2	3	4	5	6	7	8
Topic	Data MARS	CPU, IC History	Com Org Models	ISA MIPS ARM	ISA x86 FP	Memory	System Ints	Review Exam
MIPS Ch.	1-2	2	2, 3	7, 3/4		5		
ARM Ch.								

Midterm

←Logic→

Week	9	10	11	12	13	14	15
Topic	**Logic** BB's	**Logic** Comb'l	**Logic** Seq'l	ICU Pipes FSM	Perf Sec	Arch CPU	Final Prep

Final

Thxgvg
- Nov 23

subject to change

CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE

COMP122

Lab Assignments/Exams

WEEK	1	2	3	4	5	6	7	8
	Lab 1	Lab 2	Lab 3	Lab 4	Lab 5	Lab 6	Lab 7	Lab 8
Wt	2	3	3	3	3	3	3	Midterm

Labor Day
- Sep 4

Oct 18/19

9	10	11	12	13	14	15	16
Lab 8	Lab 9	Lab 9	Proj 1	Proj 1	Proj 2	Proj 2	
5	5		7	Thxgvg	7		FINAL

- Nov 23

Dec 14/18

- All assignments must be submitted by Dec 10

FINAL

My Exam Schedule > Fall Semester 2023 > CSU Northridge Personalize |

Class	Class Title	Exam Date	Exam Time	Exam Room
COMP 122-02 (16511)	COMP ARCH ASSEM (Lecture)	12/14/2023, Thursday	3:00PM - 5:00PM	Jacaranda 1618
COMP 122-04 (16685)	COMP ARCH ASSEM (Lecture)	12/18/2023, Monday	3:00PM - 5:00PM	Jacaranda 2221

Lab Programs

1. "Hello World": I/O in MIPS & ARM
2. Number systems and radix conversion
3. BCD on LED
4. Moving data (memory <-> GR< -> FPU <-> CP0)
5. "Hello World" extended: loops, macros, functions/subroutines
6. Computation 1: Fibonacci (add, overflow)
7. Computation 2: Factorials (mult, overflow)
8. Bit-wise operations (bit masks, shifts); example: tic-tac-toe
9. Interrupt/Exception handler

10. Project 1: LED (MMIO, delay loops, speed slider)
11. Project 2: ISA design (logic design & sim new instructions)

2	3	3	3	3	3	3	5	5	7	8
LAB	LAB	LAB	LAB	LAB	LAB	LAB	LAB	LAB	Proj	Proj
1	2	3	4	5	6	7	8	9	1	2

CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE

COMP122

Canvas Grades

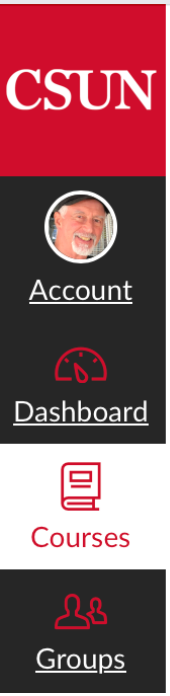
CSUN

COMP 122-16685-FA2023 › Grades

Lab 8 Out of 100	Lab 9 Out of 100	Project 1: LED Out of 100	Project 2: ISA Out of 100	Final Exam Out of 50	Final Score Out of 100
–	–	–	–	–	–
–	–	–	–	–	–
–	–	–	–	–	–
–	–	–	–	–	–
–	–	–	–	–	–

CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE
COMP122

Canvas Files



AMD64 refman.pdf

ComOrg TOC.pdf

ComOrg Vol1-Ch1.pdf

ComOrg Vol1-Ch2.pdf

CS122 syllabus-Fa23.pdf

CSUN-CS122-Week1.pdf

CSUN-CS122-Week2.pdf

DRJ_Genesis-article.pdf

LAB FORM-Fa23.docx

Lab1D-ARM.asm


Lab1D-sim.PNG

Lab1Hello122.java

Lab9.asm

Section

Textbooks

CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE
COMP122

ChatGPT Picks Book

There are several excellent textbooks on computer architecture, and the choice of the best one can depend on your specific needs and background. However, I can recommend a widely acclaimed textbook that is often considered one of the best in the field:

Title: "Computer Organization and Design: The Hardware/Software Interface"
Authors: David A. Patterson and John L. Hennessy

This textbook is commonly referred to as the "Patterson and Hennessy" book or simply "COD." It provides a comprehensive introduction to computer architecture and covers a broad range of topics, including digital logic, instruction set architecture, pipelining, memory hierarchy, and parallelism. The book is well-structured, accessible to beginners, and offers in-depth explanations along with real-world examples.

It is worth noting that computer architecture is a rapidly evolving field, and new editions of textbooks are released periodically to incorporate the latest advancements. As of my knowledge cutoff in September 2021, the fifth edition of "Computer Organization and Design" was the most recent one. However, I recommend checking for newer editions or alternative textbooks to ensure you have the most up-to-date information available.

CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE
COMP122

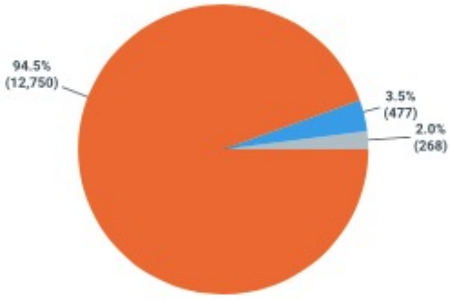
eBook: zyBook

zyBooks
A Wiley Brand

Why zyBooks? Catalog Success Stories Instructors Students Blog Sign In

Fall 2019 Student Survey

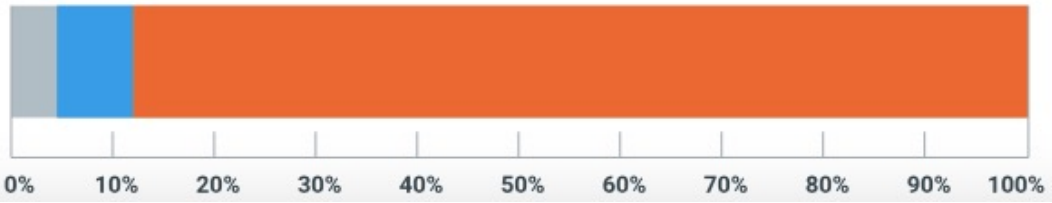
Student Feedback is vital to creating an effective learning experience. We survey all students at the end of every semester to gauge student satisfaction and to benchmark how we compare to other tools they use—so that we can keep improving. Below are the results from the November 2019 survey.



94.5% report that zyBooks helps them learn.

zyBooks **helped** my learning. Neutral Hinderance

88.3% agree that zyBooks is easy to use.



CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE
COMP122

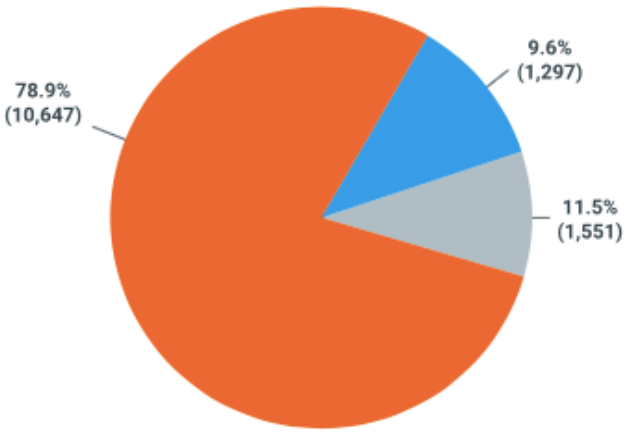
eBook: zyBook

zyBooks A Wiley Brand | Why zyBooks? | Catalog | Success Stories | Instructors | Students | Blog | Sign In

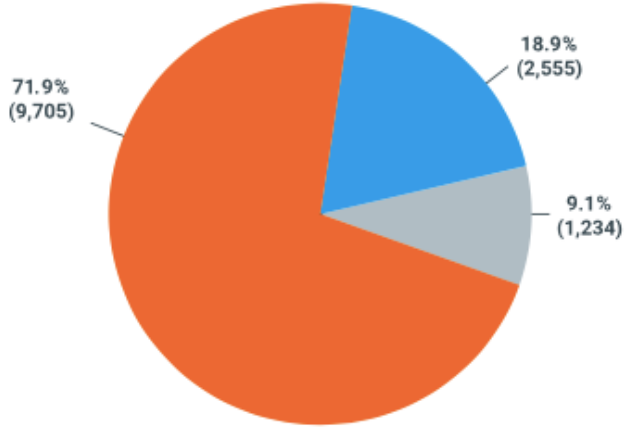
Students **prefer using zyBooks** over traditional textbooks or digital alternatives.

- Interactive ***Participation Activities***

How students feel about zyBooks vs. traditional textbooks



How students feel about other digital learning solutions

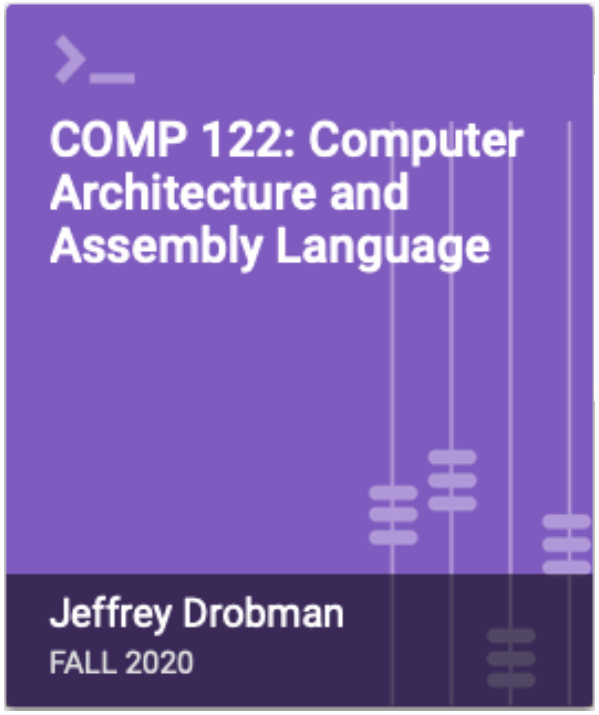


CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE

COMP122

Textbook: zyBook

recommended eBook



1. Sign in or create an account at learn.zybooks.com
2. Enter zyBook code

   CSUNCOMP122DrobmanFall2020
3. Subscribe

❖ To Buy/Subscribe ($72)

A subscription is **$72**. Students may begin subscribing on Aug 10, 2020 and the cutoff to subscribe is Dec 01, 2020. Subscriptions will last until Dec 29, 2020.

❖ To Use

https://learn.zybooks.com/zybook/CSUNCOMP122DrobmanFall2020

CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE

COMP122

Computer Architecure

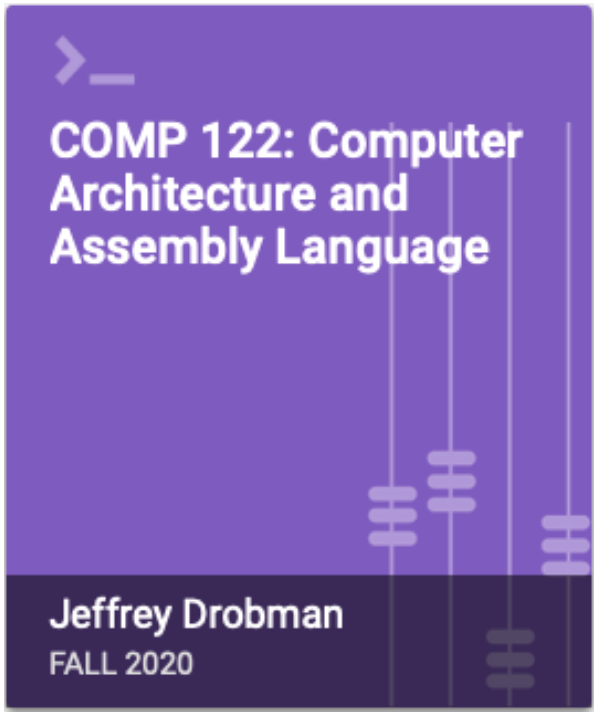
Patterson & Hennessy

MIPS

zyBooks My library > Computer Organization and Design

Table of contents

About this material



zyBook

1. Computer Abstract / Tech
2. Instructions
3. Arithmetic for Computers
4. The Processor
5. Memory Hierarchy
6. Parallel Processors
7. Appendix A — MIPS
8. Appendix B — Logic
9. Appendix C — GPU's
10. Appendix D — Control Units
11. Appendix E — Compare ISA's

7. Appendix A

- 7.1 Introduction
- 7.2 Assemblers
- 7.3 Linkers
- 7.4 Loading
- 7.5 Memory usage
- 7.6 Procedure call convention
- 7.7 Exceptions and interrupts
- 7.8 Input and output
- 7.9 SPIM
- 7.10 MIPS R2000 assembly language

CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE

COMP122

P/H ToC

COMP 122: Computer Architecture and Assembly Language
Spring 2020

Table of contents

About this material

1. Computer Abstract / Tech
2. Instructions
3. Arithmetic for Computers
4. The Processor
5. Memory Hierarchy
6. Parallel Processors
7. Appendix A — Assembly/SPIM/***Exceptions***
   Sec 7.7 — ***Interrupts***
8. Appendix B — Logic/Clocks
9. Appendix C — FPU/GPU/threads
10. Appendix D — ICU
11. Appendix E — ISA: MIPS v ARM v others

CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE

COMP122

Textbook: zyBook

About this material

COMP 122: Computer Architecture and Assembly Language

zyBook ISBN: 978-1-394-00640-3

Please refer to the catalog page for the default section/chapter ordering.

Authors

Authors of Computer Organization and Design (5th ed)	**David A. Patterson** / Professor of Computer Science / University of California, Berkeley **John L. Hennessy** / Professor of Electrical Engineering / Stanford University

Contributors and interactive version release information

Contributors	Frank Vahid, Susan Lysecky, Nkenge Wheatland, Alex Edgcomb: Extended into interactive version.
Additional contributors	Lorraine Diaz, John Dixon, Daniel Fox, Sirina Nabham: Converted into digital version.
Release date	November 2016 29 original sections replaced by interactive sections (Translating and starting a program; A C sort example to put it all together; Arrays versus pointers; Advanced material: Compiling C and interpreting Java; Real stuff: ARMv7 (32-bit) instructions; Real stuff: x86 instructions; Real stuff: The rest of the ARMv8 instruction set;

Patterson

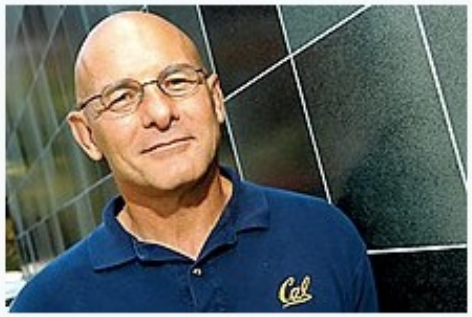
David Patterson (computer scientist)

David Andrew Patterson (born November 16, 1947) is an American computer pioneer and academic who has held the position of Professor of Computer Science at the University of California, Berkeley since 1976. He announced retirement in 2016 after serving nearly forty years, becoming a distinguished engineer at Google.[3][4] He currently is Vice Chair of the Board of Directors of the RISC-V Foundation,[5] and the Pardee Professor of Computer Science, Emeritus at UC Berkeley.

Patterson is noted for his pioneering contributions to RISC processor design, having coined the term RISC, and by leading the Berkeley RISC project.[6]As of 2018, 99% of all new chips use a RISC architecture.[7][8] He is also noted for leading the research on RAID storage together with Randy Katz.[9]

His books on computer architecture (co-authored with John L. Hennessy) are widely used in computer science education. Along with Hennessy, Patterson won the 2017 Turing Award for their work in developing RISC.

David Patterson



Born	November 16, 1947 (age 71) Evergreen Park, Illinois
Nationality	American
Alma mater	UCLA
Known for	RISC RAID Network of Workstations
Awards	Turing Award (2017) Eckert–Mauchly Award[1] (2008) ACM Distinguished Service Award (2007) Computer History Museum Fellow (2007) National Academy of Engineering Member National Academy of Sciences Member AAAS Fellow ACM Fellow (1994) IEEE Fellow Karl Karlstrom Outstanding

- UCB → ACM → RISC-V → Google

- ACM Turing award

Hennessy

John L. Hennessy

From Wikipedia, the free encyclopedia

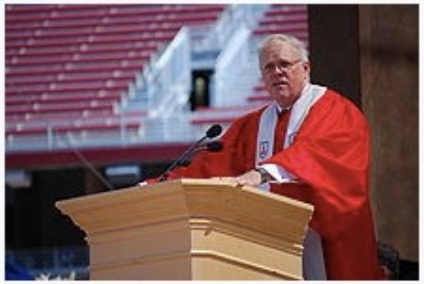
John Leroy Hennessy (born September 22, 1952) is an American computer scientist, academician, businessman, and Chair of Alphabet Inc.[5] Hennessy is one of the founders of MIPS Computer Systems Inc. as well as Atheros and served as the tenth President of Stanford University. Hennessy announced that he would step down in the summer of 2016. He was succeeded as President by Marc Tessier-Lavigne.[6] Marc Andreessen called him "the godfather of Silicon Valley."[7]

Along with David Patterson, Hennessy won the 2017 Turing Award for their work in developing the reduced instruction set computer (RISC) architecture, which is now used in 99% of new computer chips.[8]

❖Stanford → MIPS → Google

- ACM Turing award
- *Godfather* of Silicon Valley

John Hennessy

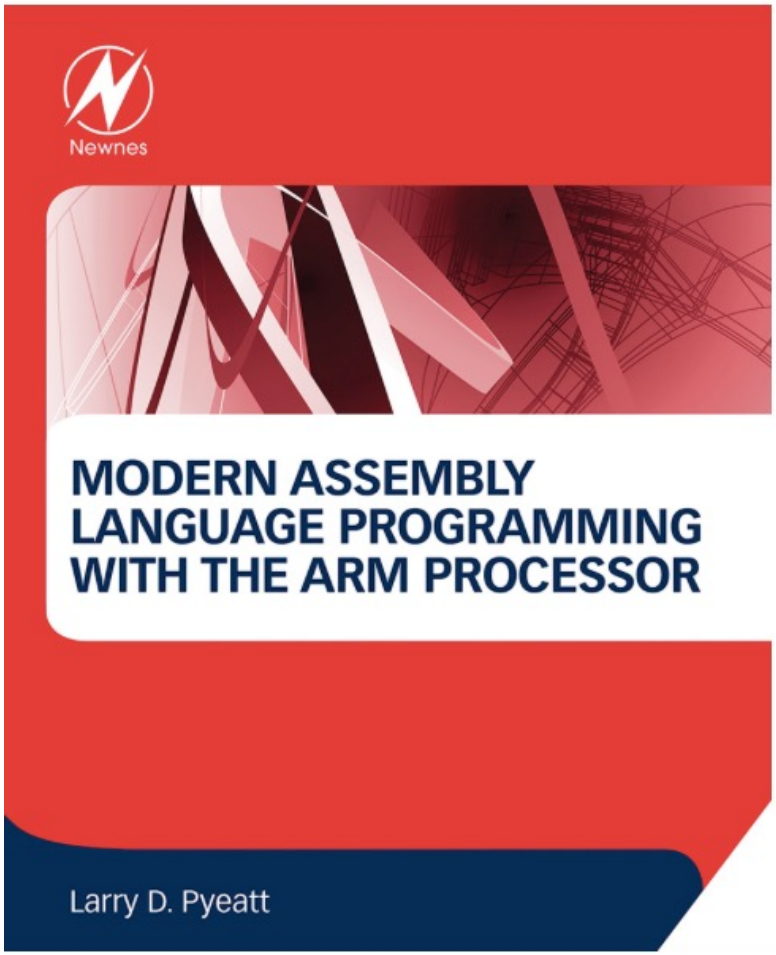


10th President of Stanford University	
In office	2000–2016
Preceded by	Gerhard Casper
Succeeded by	Marc Tessier-Lavigne
11th Provost of Stanford University	
In office	1999–2000
Preceded by	Condoleezza Rice
Succeeded by	John Etchemendy

CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE
COMP122

ARM Assembly

FREE Access



❖ Chapters 3-4

CHAPTER 3

Load/Store and Branch Instructions

CHAPTER 4

Data Processing and Other Instructions

CHAPTER OUTLINE

CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE

COMP122

ARM Assembly

FREE Access

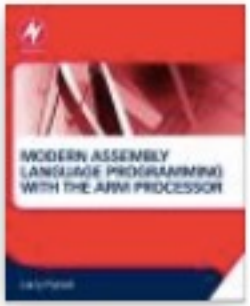
https://csun-primo.hosted.exlibrisgroup.com/primo-explore/fulldisplay?docid=TN_els_book_whole9780128036983&context=PC&vid=01CALS_UNO&search_scope=EVERYTHING&tab=everything&lang=en_US

https://tinyurl.com/CSUN-ARM-book

CSUN | OneSearch

LIBRARY HOME | DATABASES | LIBGUIDES

Search anything



BOOK

Modern Assembly Language Programming with the ARM Processor

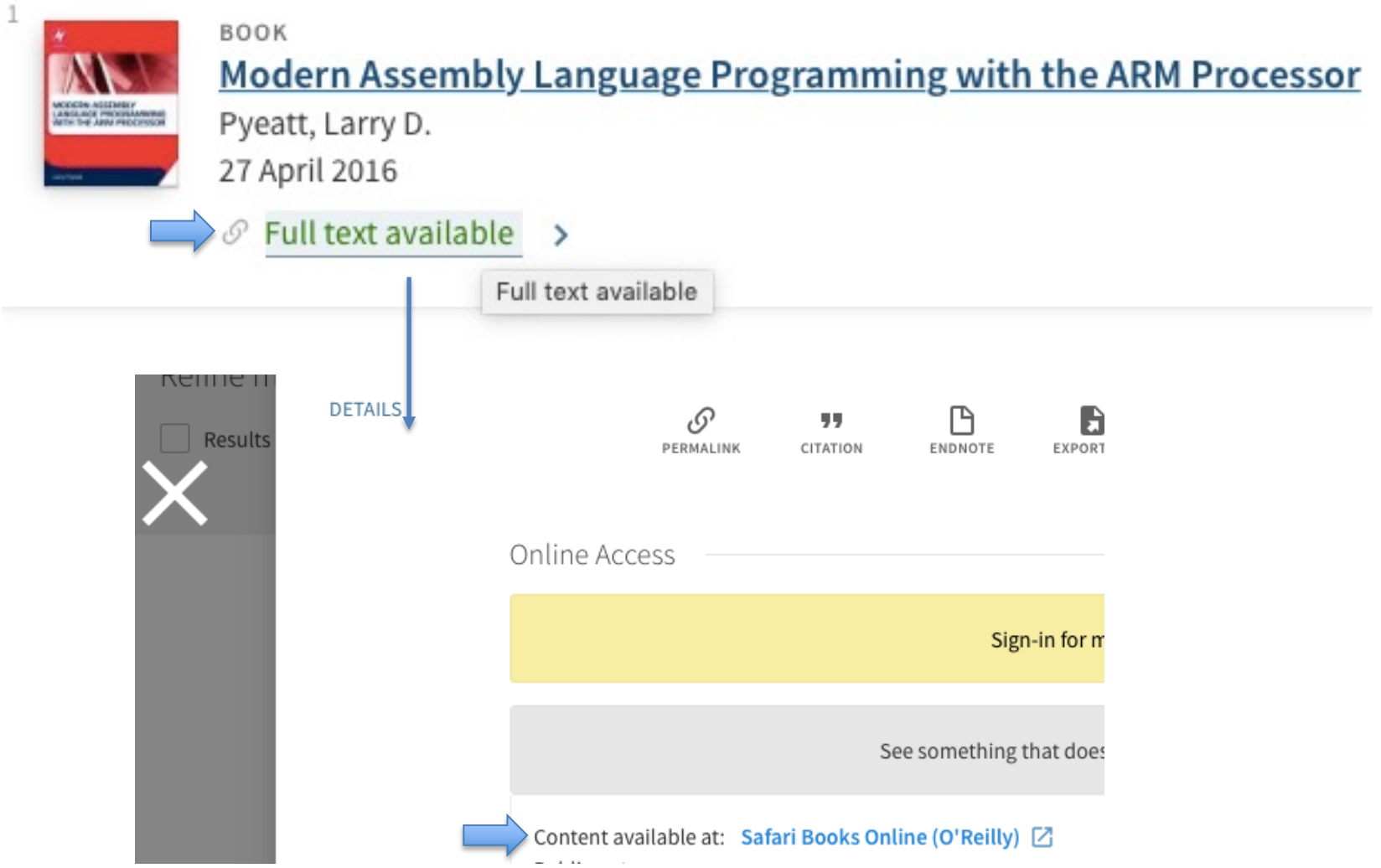
Pyeatt, Larry D.

27 April 2016

CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE
COMP122

ARM Assembly

FREE Access



CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE

COMP122

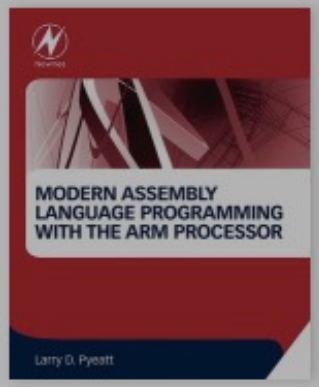
ARM Assembly

FREE Access

O'REILLY®

Safari

Search... Enterprise Pricing



Modern Assembly Language Programming with the ARM Proces

by Larry D. P

Publisher: Newn

Release Date: Ma

ISBN: 978012803

View table of

Book Description

Modern Assembly Language Progr
presents the concepts of assembly l
embedded systems.

O'REILLY Safari

Welcome to the O'Reilly Learning Platform!

Your institution provides you free access to our 35K+ books, 30K+ hours of video, curated learning paths, case studies, interactive tutorials, audio books, and O'Reilly conference videos!

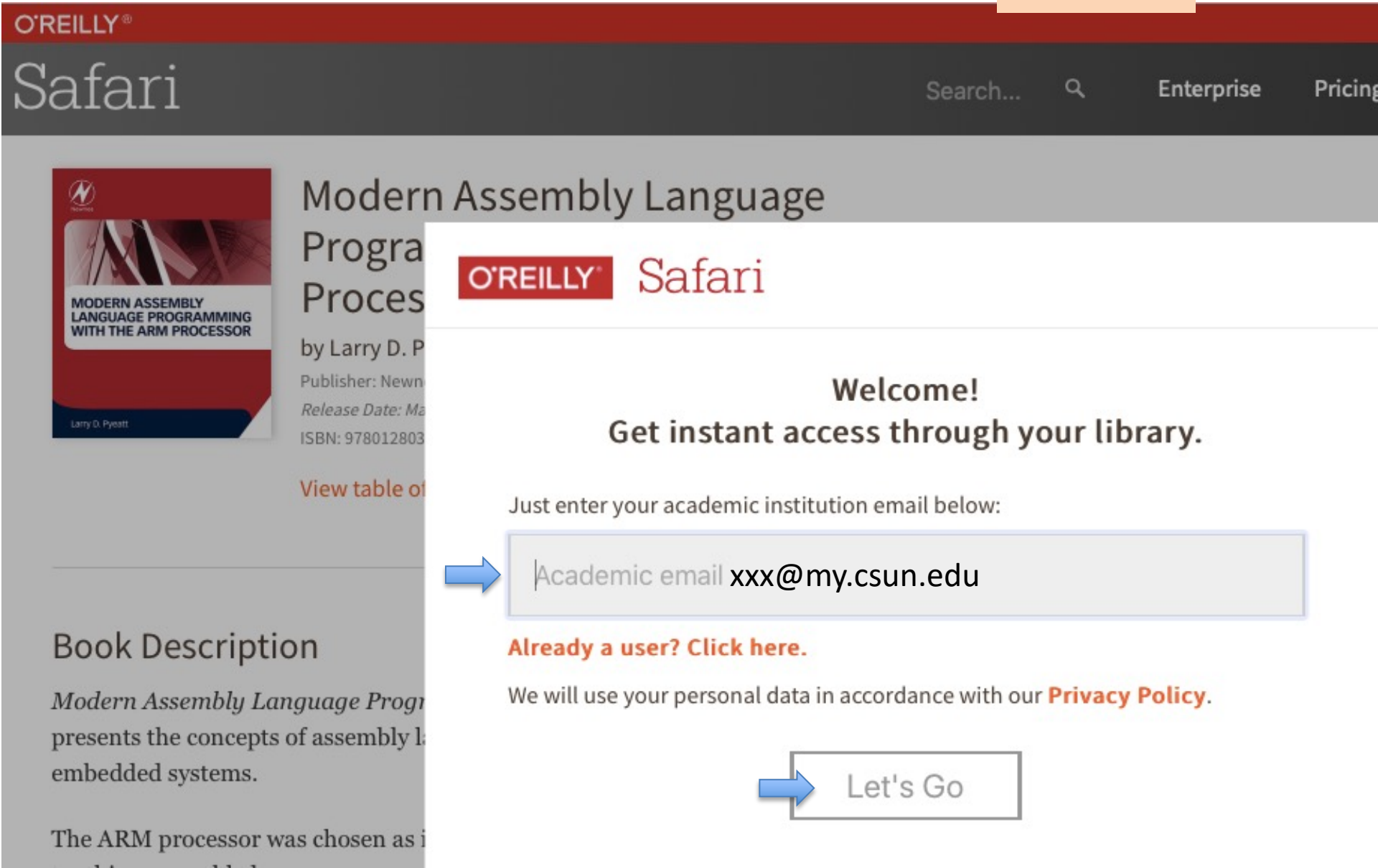
Got It

CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE
COMP122

ARM Assembly

DR JEFF SOFTWARE
INDIE APP DEVELOPER

FREE Access



CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE

COMP122

ARM Assembly

FREE Access

Details

Title	Modern Assembly Language Programming with the ARM Processor
Author	Pyeatt, Larry D. >
Subjects	Assembly >
	Hardware >
	Computer Science >
Notes	Modern Assembly Language Programming with the ARM Processor is a tutorial-based book on assembly language programming using the ARM processor. It presents the concepts of assembly language programming in different ways, slowly building from simple examples towards complex programming on bare-metal embedded systems. The ARM processor was chosen as it has fewer instructions and irregular addressing rules to learn than most other architectures, allowing more time to spend on teaching assembly language programming concepts and good programming practice. In this textbook, careful consideration is given to topics that students struggle to grasp, such as registers vs. memory and the relationship between pointers and addresses, recursion, and non-integral binary mathematics. A whole chapter is dedicated to structured programming principles. Concepts are illustrated and reinforced with a large number of tested and debugged assembly and C source listings. The book also covers advanced topics such as fixed and floating point mathematics, optimization, and the ARM VFP and NEONTM extensions. PowerPoint slides and a solutions manual are included. This book will appeal to professional embedded systems engineers, as well as computer engineering students taking a course in assembly language using the ARM processor. Concepts are illustrated and reinforced with a large number of tested and debugged assembly and C source listing Intended for use on very low-cost platforms, such as the Raspberry Pi or pcDuino, but with the support of a full Linux operating system and development tools Includes discussions of advanced topics, such as fixed and floating point mathematics, optimization, and the ARM VFP and NEON extensions
Publisher	Elsevier Science
Creation Date	27 April 2016
Language	English
Identifier	**ISBN:** 9780128036983
Source	ScienceDirect (Elsevier B.V.)

ACM Library

Languages, and more with the wealth of online books, courses, videos and other life-long learning resources found in ACM's online Learning Center, such as:

Books

- Computer Architecture, 5th Edition (O'Reilly)
- Computer Architecture and Organization (O'Reilly)
- Digital Design and Computer Architecture (ScienceDirect)
- Domain-Specific Languages in R: Advanced Statistical Programming (O'Reilly)
- The Essentials of Computer Organization and Architecture, Fourth Edition (Skillsoft)
- Inside the Machine (O'Reilly)
- Microcontroller Theory and Applications with the PIC18F, Second Edition (Skillsoft)
- Microprocessor 8085, 8086 (Skillsoft)
- Multiprocessor Systems-on-Chips (ScienceDirect)
- Sustaining Moore's Law (O'Reilly)
- The Technical Foundations of IoT (Skillsoft)

Full-Length Courses and Videos

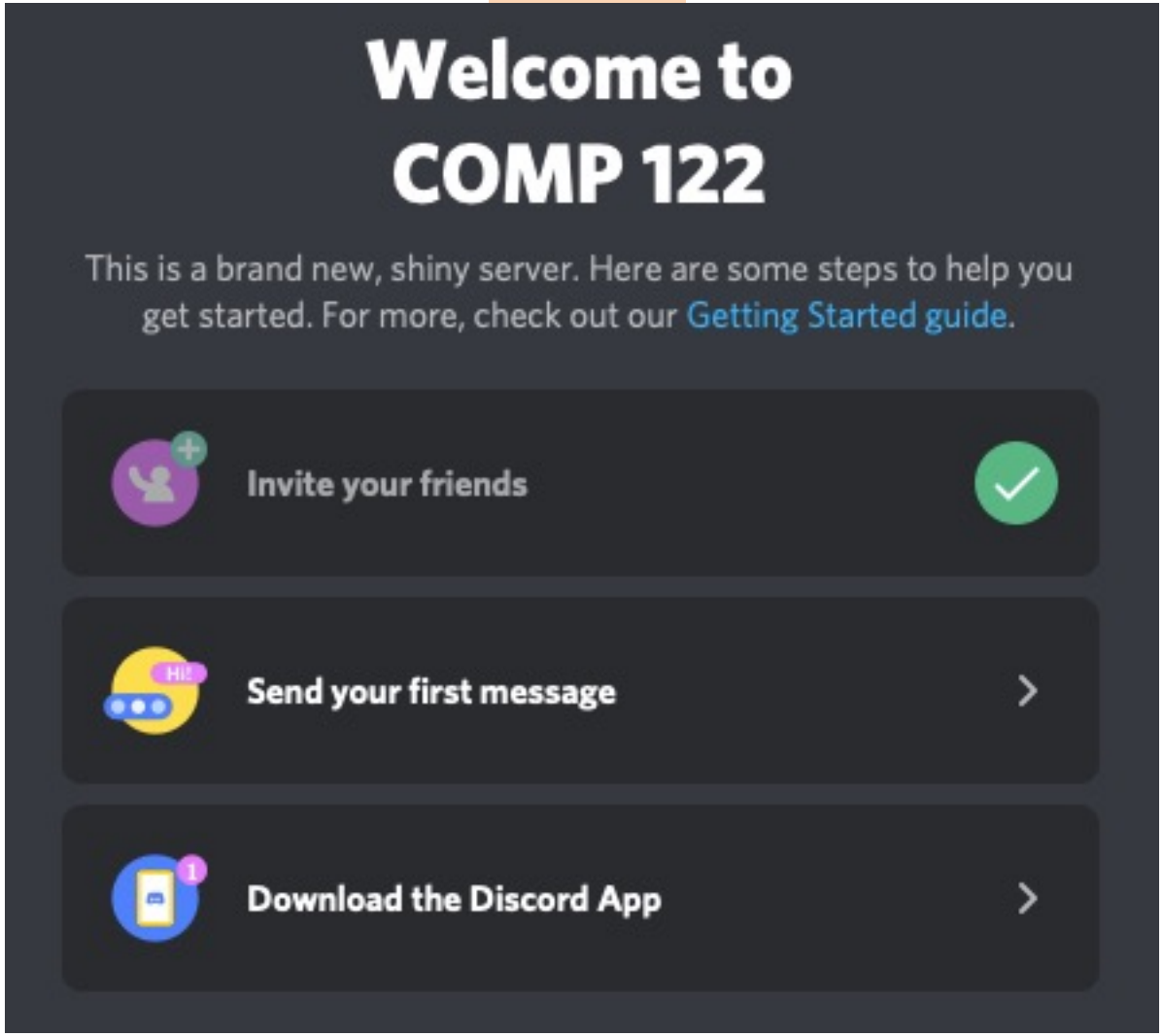
- Computer Science: An Interdisciplinary Approach (O'Reilly)
- Data Analytics and Machine Learning Fundamentals (O'Reilly)
- Getting Started with Google Cloud Platform LiveLessons (O'Reilly)
- High Performance Scientific Computing with C (O'Reilly)
- Internet of Things Hardware (Skillsoft)
- Learn Artificial Intelligence with Tensor Flow (O'Reilly)

Tutorials, Learning Paths, Live Lessons, Short Videos, and More

- SHORT VIDEO: Computer Science Retrospective (O'Reilly)

Discussion Groups

Discord



Project A: MIPS ISA

MIPS 32

- List all these instructions in *MIPS32* (as in MARS)
  - Loads
  - Branches
  - Primitives & Pseudos* (flag with asterisk)

Loads:
lw, lui, …

Branches:
b, beq, …

- Note: these classes involve an ***Effective Address (EA)*** calculation

Project A: ISA's

1. Compare ISA's of MIPS and ARM by instruction <Class.sub.instr>: ex. <ALU.add>. Use the given slide as the baseline by identifying missing and extra instructions.

2. List instruction Formats (R, I, J) for each instruction class

3. Compare "Load" instructions of MIPS and ARM in detail (explain what each instruction does and whether it is a *primitive* or *pseudo-op*:

MIPS: lb, lh, lw, la, li, lui

ARM: ??

CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE
COMP122

Baseline Instruction Set

Rev Aug 2021

Computation

- ALU
  - ADD
  - SUB
  - AND
  - OR
  - XOR
  - NOT
- MULT/DIV [opt]
- BIT
  - SET/CLR
  - TEST
- COMPARE
  - CMP
- SHIFT
  - SHIFT (A, L)
  - ROTATE

Memory

- Reg-Reg
  - MOV
- Reg-Mem
  - LOAD
  - STORE
  - MOV

RISC

- Mem-Mem
  - MOV

CISC

- Stack
  - PUSH
  - POP

Program Control

- JUMP
  - JUMP/GOTO
- BRANCH
  - BRA
  - BRCC
  - LOOP
- CALL
  - CALL/CALR/JAL
  - RET/RETFIE
- NOP

System Control

- Reset
  - RESET
- Power
  - SLEEP/HALT

I/O

- I/O
  - IN
  - OUT

OLD

- Mem Mapped
  - MOV PORT
  - LOAD/STORE

NEW

CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE
COMP122

Project 1

- Logic simulators
  - MIPS
  - ARM
    - Embest board

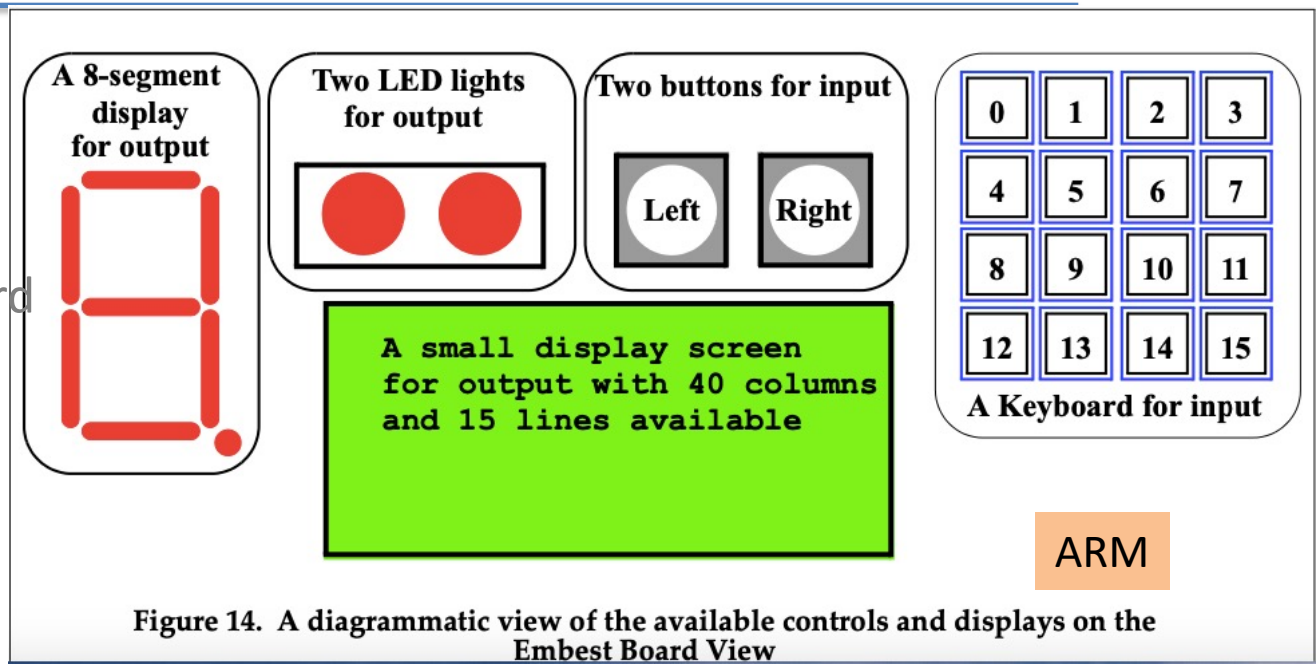
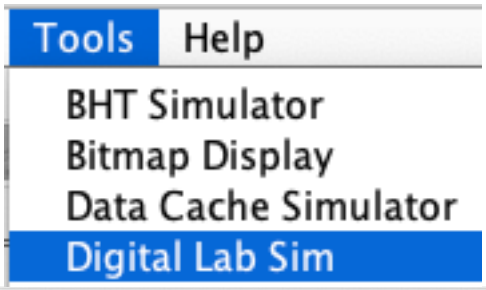
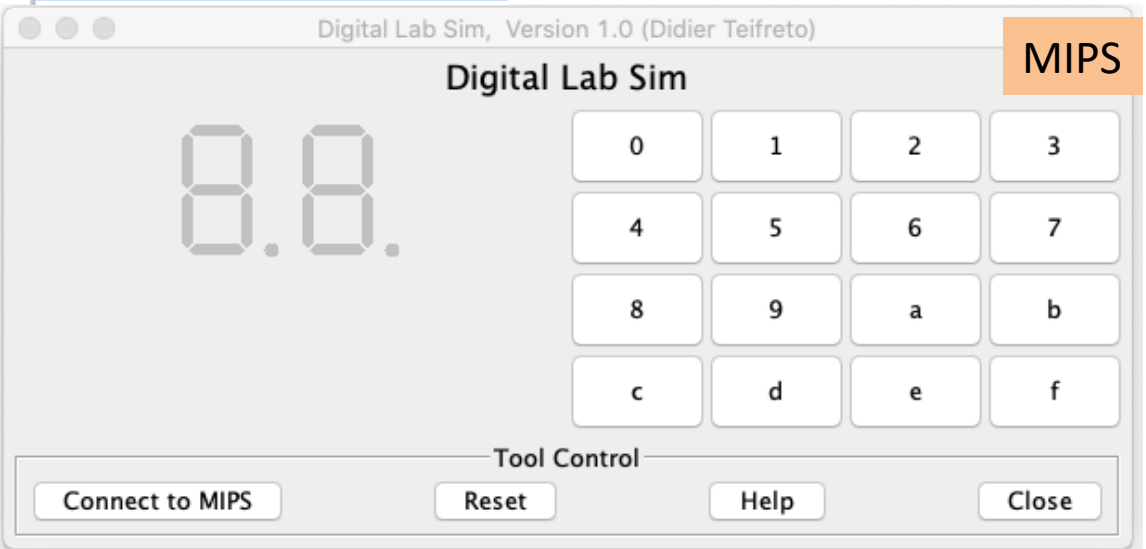


Figure 14. A diagrammatic view of the available controls and displays on the Embest Board View





Project 1

- Logic simulators
  - MARS *Digital Lab Sim* tool

MIPS

- Functions (on LEDs)
  - I=Initial(s)
  - B=Blink (*all* on/off)
  - F=Flash (Initials-*sequential* on/off)
  - Z=Zero Flash (0-*sequential* on/off)
  - C=Counter
  - Q=Quit
  - Calculator (hex keypad – bonus)
- Use *Jump Table*
  - Input letter for Command
  - Test & Branch (beq)
  - Add Handlers as subroutines

- Command Interpreter
  - I
  - B
  - F
  - Z
  - C
  - Q

Section

Syllabus

CPU ISA's

Main

Focus

- MIPS
- ARM
  - **Apple**
  - Qualcomm
  - Samsung

Mobile

Desktop

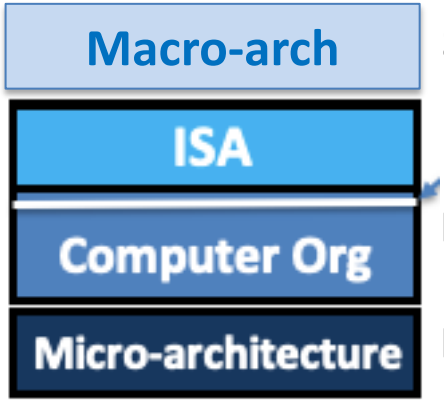
- x86
  - Intel
  - AMD

CSUN CALIFORNIA STATE UNIVERSITY NORTHRIDGE

COMP122

Course Description (122)

- **Computer Architecture/Organization (COMP122/ 222)**
  - **CPU, FPU, GPU org** (ALU, registers, addressing)
  - **ISA's: MIPS, ARM, x86**
  - **Memory models**
    - MLM- caches
    - Virtual memory
  - CPU status (PSW) & clock sync
  - Interrupts, Exceptions, Syscall
  - Cores & Threads
  - Pipelines (ICU)
  - *Microprogramming (Am2900)*
  - Logic & State Machines (FSM)
  - CPU performance/benchmarks
- **Computer Arithmetic (COMP222)**
  - **ALU**: Full adder
  - Mult/Div (Booth's algorithm)
  - Error codes (ECC, CRC, parity)
- **Parallel & *Micro* Architecture (COMP222)**
  - Multi-core, Multi-threading, *superscalar*
  - SIMD/MIMD/SPMD



System arch – *Cores*

Instructions (Primitives)

***Software** Interface*

Execution Units
- ALU, ICU, Reg

Low-level execution
- Pipelines, threads
- scheduling
- branch prediction

(COMP122)

- Software Tools
  - IDE's/Assemblers
  - OS, RTOS, ***Monitors***
  - ***Simulators***
- Debug Tools
  - ICE/Logic Analyzers
  - *Disassemblers*

CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE
COMP122

Computer Science Sub-Fields

- Problem solving and Algorithms
- Programming (OOP)
- Software Engineering (SDLC, IPO, structured design, design patterns)

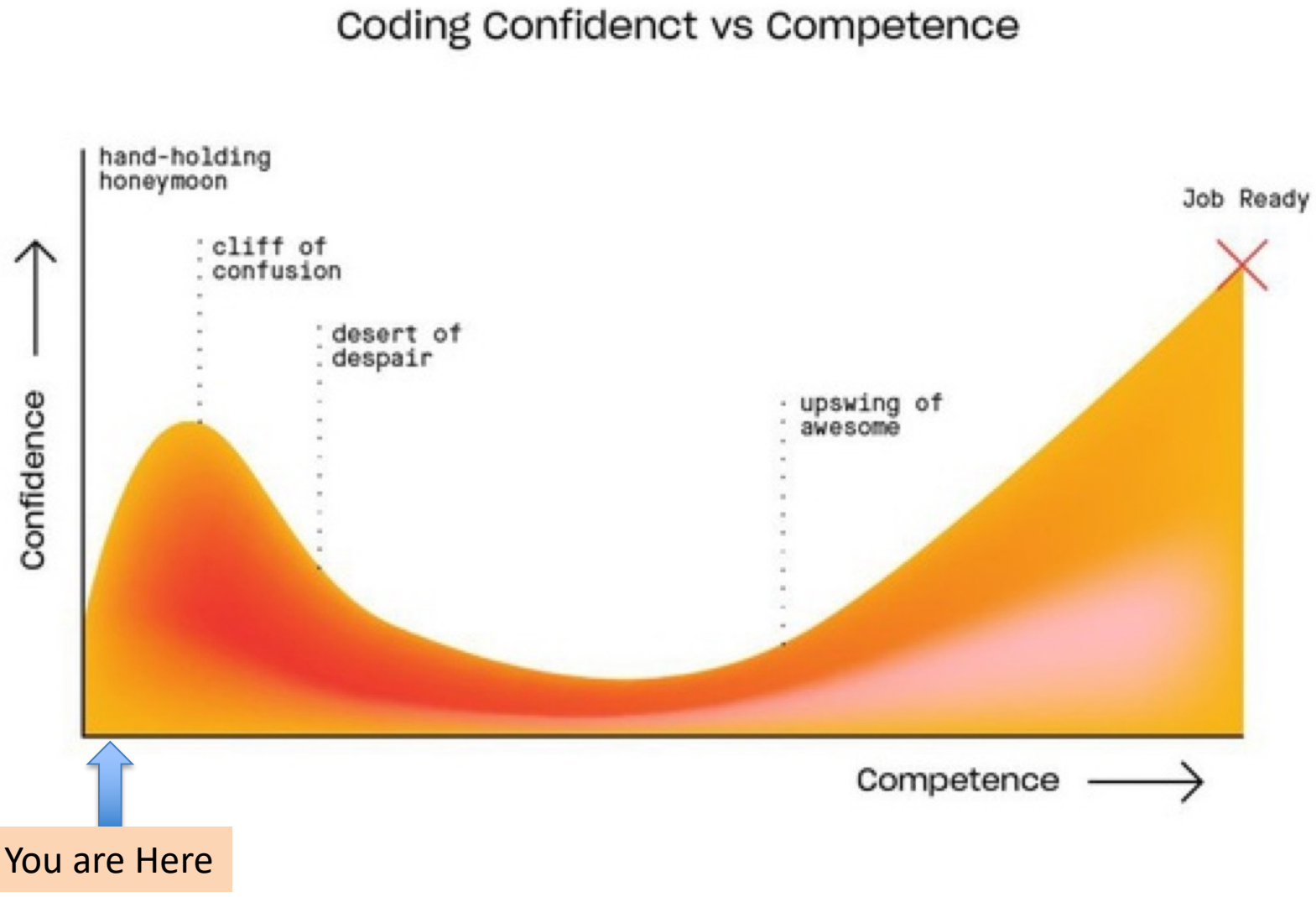
1st course
- Desktop

- Automata theory
- Systems programming
  - OS (shell, kernel, I/O)
  - Compiler construction
- Data
  - Database management & models (DBMS)
  - Data science & Mining
- Graphics (gaming, VR, animation)
- AI
  - Game playing with Heuristics
  - Machine learning (Deep learning) & robotics
  - Pattern recognition (fingerprints, facial, etc.)
- Cryptography & Cybersecurity
- Simulation & Modeling
  - Queueing theory
- Digital System design (logic design)
- Computer Architecture (ISA, SIMD, caches, multi-threading)
- Numerical Analysis & Control (DNC), CAM
- Information Technology (IT/CIT)

Application Realms
- Desktop
- Mobile
- Website
- Embedded

Computer Engineering

Programmer Proficiency



CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE

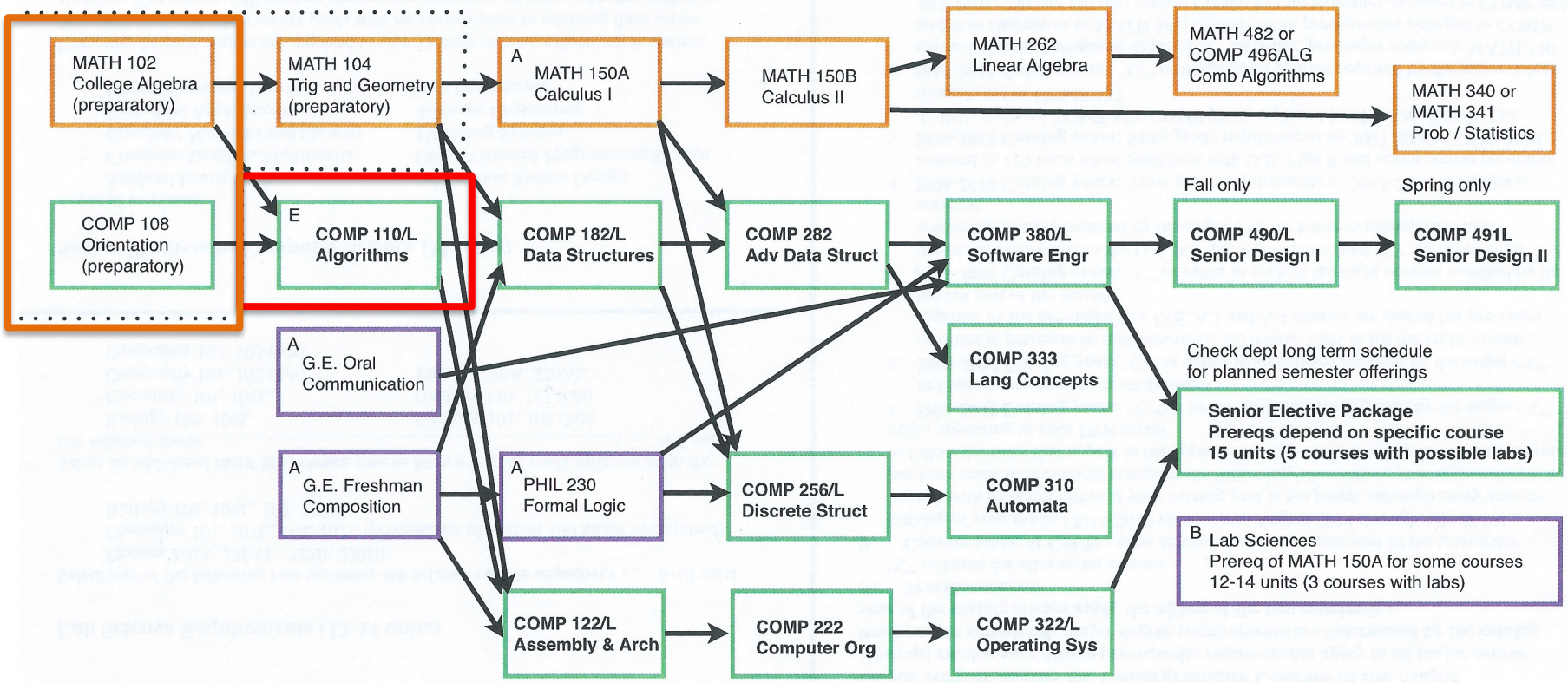
COMP122

Curriculum-CS

CSU Northridge, Computer Science Department

COMPUTER SCIENCE MAJOR

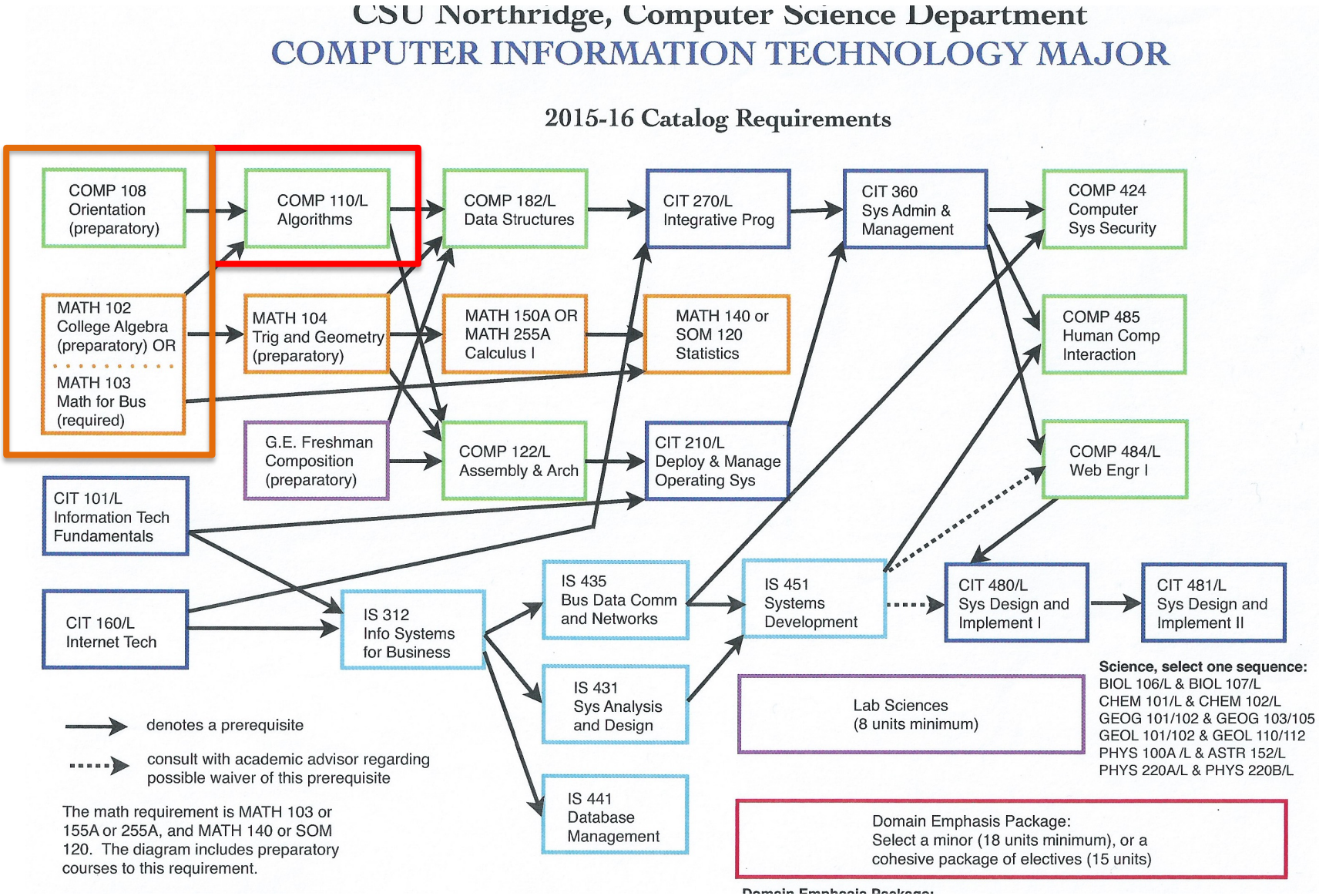
2015-16 Catalog Requirements



CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE

COMP122

Curriculum-IT

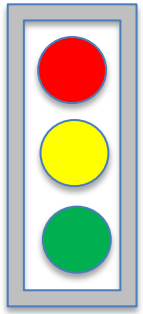


CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE
COMP122

Grading – Scale

Grade	Pct	Interpret
A+	98	VERY good
A	**92**	
A-	90	
B+	88	PRETTY good
B	**82**	
B-	80	
C+	78	BARELY good
C	**72**	
C-	70	
D+	68	substandard
D	**62**	
D-	60	
F	<60	failed

color coding



Grading – Weights

Single COMBINED GRADE

- **45%** Lab Assignments
- **10%** Lab Midterm Exam
- **10%** Lecture Midterm Exam
- **15%** Lab Final Exam
- **20%** Lecture Final Exam

Category	Weight
Labs (9)	**32**
Projects (2)	**13**
Midterm	**20**
Final	**35**

Lab + home

Programming
45

Testing
55

In-class

2	3	3	4	4	4	4	4	4	6	7
LAB	LAB	LAB	LAB	LAB	LAB	LAB	LAB	LAB	Proj	Proj
1	2	3	4	5	6	7	8	9	1	2

Quizzes/Exams

- Midterm
  - Mid course (8th week) – W/Th Oct 18/19
- Final
  - 16th week – Dec 14/18

- Canvas
- Multiple choice
- All exams ***open book*** (notes, PC, Internet)

Section

Tools

Ref: COMP122 ***Lab0*** slide set

CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE

COMP122

MARS

MARS (MIPS Assembler and Runtime Simulator)

Missouri State UNIVERSITY

courses.missouristate.edu

Mac Desktop

https://courses.missouristate.edu/KenVollmar/MARS/download.htm

Download MARS 4.5 software! (Aug. 2014)

Note: Is your MARS text unreadably small? Download and use a new release Java 9, which contains a fix to automatically scale and size AWT and Swing components for High Dots Per Inch (HiDPI) displays on Windows and Linux. Technical details.

MARS features overview: (List of features by version)

- GUI with point-and-click control and integrated editor
- Easily editable register and memory values, similar to a spreadsheet
- Display values in hexadecimal or decimal
- Command line mode for instructors to test and evaluate many programs easily
- Floating point registers, coprocessor1 and coprocessor2. Standard tool: bit-level view and edit of 32-bit floating point registers (screenshot).
- Variable-speed single-step execution
- "Tool" utility for MIPS control of simulated devices. Standard tool: Cache performance analysis tool (screenshot).
- Single-step backwards

MARS

MARS (MIPS Assembler and Runtime Simulator)

MARS - Mips Assembly and Runtime Simulator

Release 4.5

August 2014

Introduction

MARS, the **M**ips **A**ssembly and **R**untime **S**imulator, will assemble and simulate the execution of MIPS assembly language programs. It can be used either from a command line or through its integrated development environment (IDE). MARS is written in Java and requires at least Release 1.5 of the J2SE Java Runtime Environment (JRE) to work. It is distributed as an executable JAR file. The MARS home page is **`http://www.cs.missouristate.edu/MARS/`**. This document is available for printing there.

As of Release 4.0, MARS assembles and simulates 155 basic instructions of the MIPS-32 instruction set, approximately 370 pseudo-instructions or instruction variations, the 17 syscall functions mainly for console and file I/O defined by SPIM, and an additional 22 syscalls for other uses such as MIDI output, random number generation and more. These are listed in separate help tabs. It supports seven different memory addressing modes for load and store instructions: `label`, `immed`, `label+immed`, `($reg)`, `label($reg)`, `immed($reg)`, and `label+immed($reg)`, where `immed` is an integer up to 32 bits. A setting is available to disallow use of pseudo-instructions and extended instruction formats and memory addressing modes.

Our guiding reference in implementing the instruction set has been *Computer Organization and Design, Fourth Edition* by Patterson and Hennessy, Elsevier - Morgan Kaufmann, 2009. It summarizes the MIPS-32 instruction set and pseudo-instructions in Figures 3.24 and 3.25 on pages 279-281, with details provided in the text and in Appendix B. MARS Releases 3.2 and above implement all the instructions in Appendix B and those figures except the delay branches from the left column of Figure 3.25. It also implements all the system services (syscalls) and assembler directives documented in Appendix B.

CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE

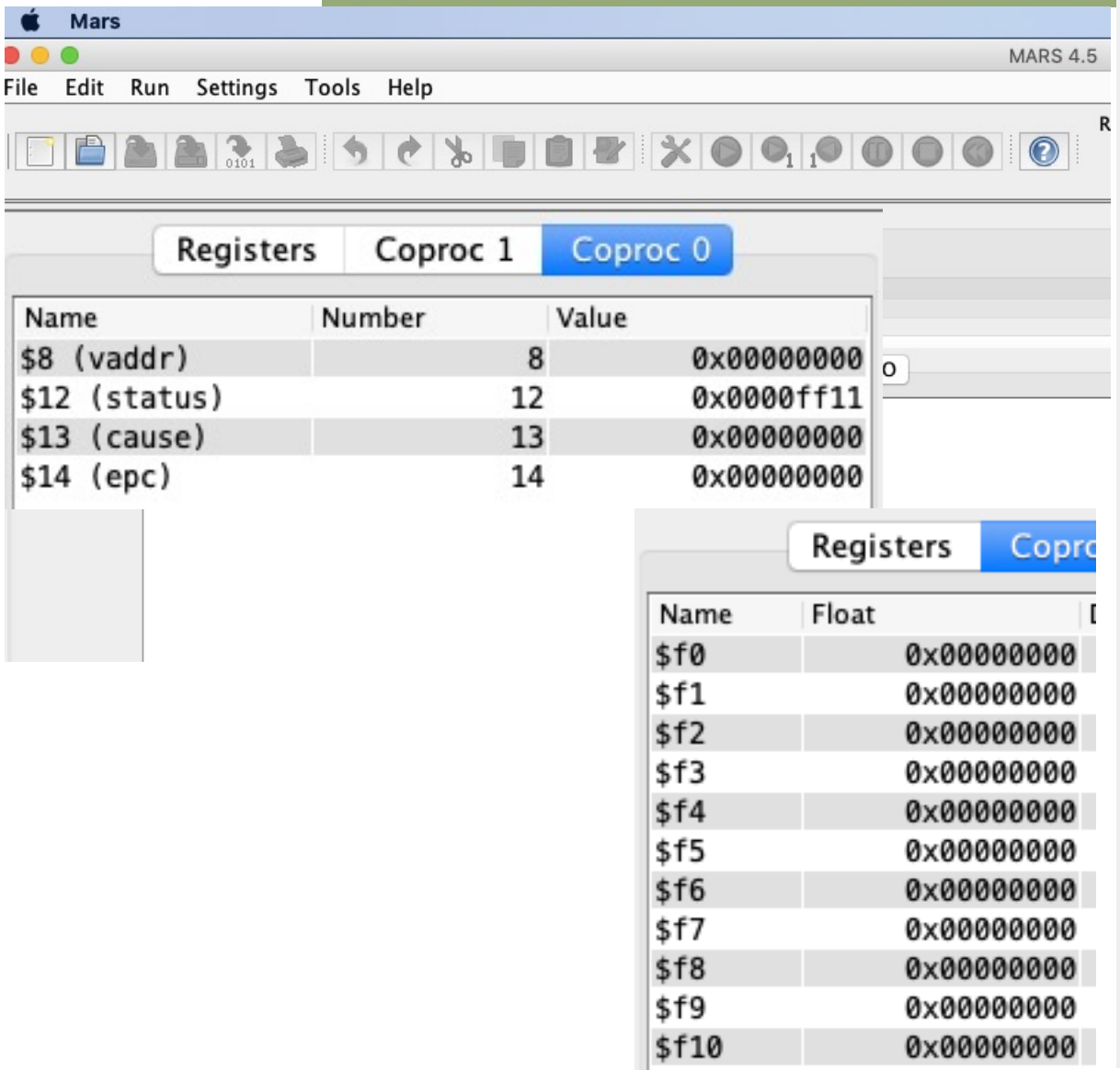
COMP122

MARS

DR JEFF SOFTWARE
INDIE APP DEVELOPER

MARS (MIPS Assembler and Runtime Simulator)

Registers

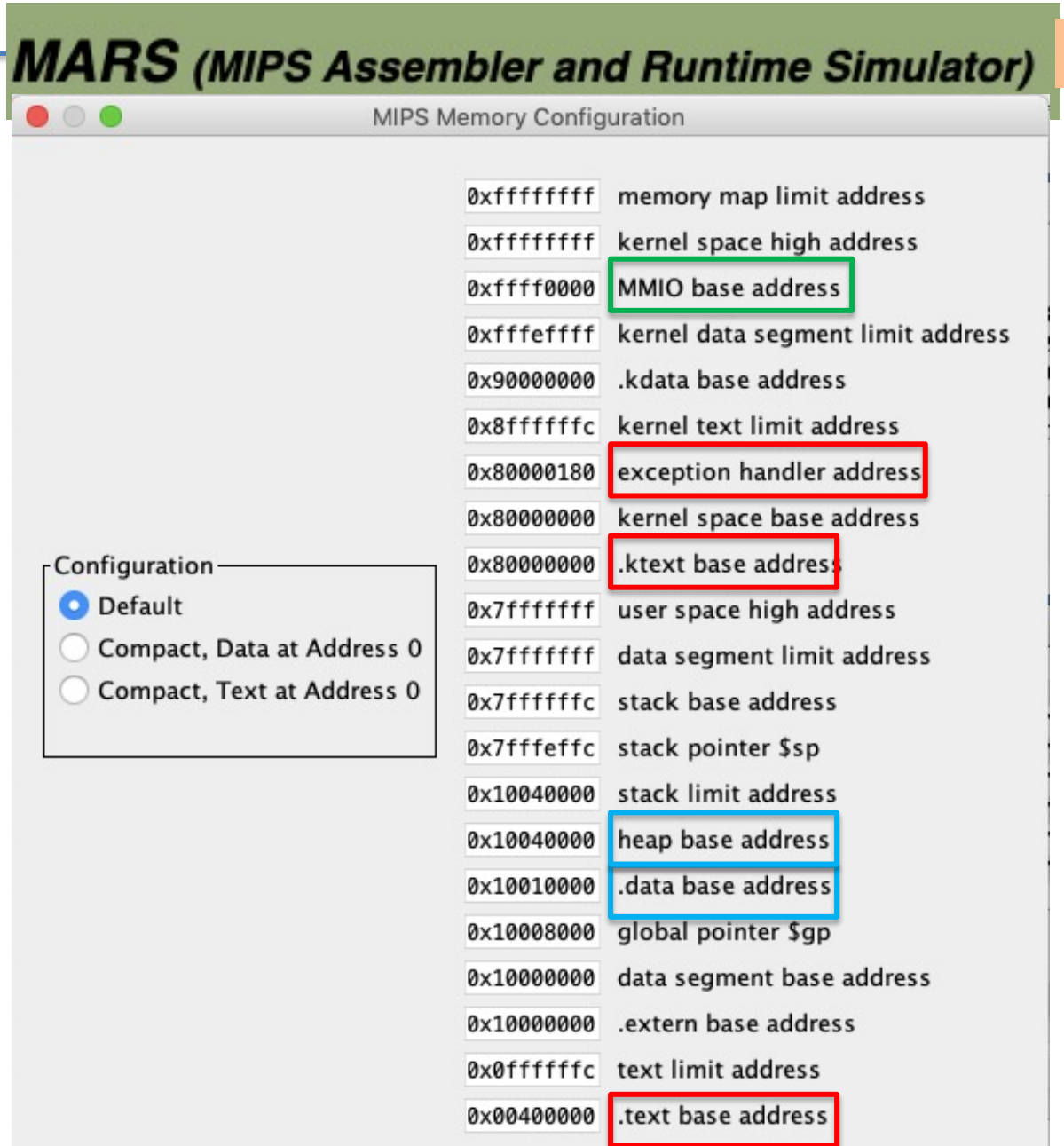


Registers | Coproc 1 | Coproc 0

Name	Number	Value
$zero	0	0x00000000
$at	1	0x00000000
$v0	2	0x00000000
$v1	3	0x00000000
$a0	4	0x00000000
$a1	5	0x00000000
$a2	6	0x00000000
$a3	7	0x00000000
$t0	8	0x00000000
$t1	9	0x00000000
$t2	10	0x00000000
$t3	11	0x00000000
$t4	12	0x00000000
$t5	13	0x00000000
$t6	14	0x00000000
$t7	15	0x00000000
$s0	16	0x00000000
$s1	17	0x00000000
$s2	18	0x00000000
$s3	19	0x00000000
$s4	20	0x00000000
$s5	21	0x00000000
$s6	22	0x00000000
$s7	23	0x00000000
$t8	24	0x00000000
$t9	25	0x00000000
$k0	26	0x00000000
$k1	27	0x00000000
$gp	28	0x10008000
$sp	29	0x7fffeffc
$fp	30	0x00000000
$ra	31	0x00000000
pc		0x00400000
hi		0x00000000
lo		0x00000000

MARS

Memory Map



Section

Stats

Class Years/Majors

Distributions

Year	Major	Sex	Ethnic
4	CIT	F	Arm
4	CIT	F	Asian
4	CIT	F	Asian
4	CIT	M	Asian
4	CIT	M	Asian
3	CIT	M	Asian
3	CIT	M	Asian
3	CS	M	Hisp
3	CS	M	Hisp
3	CS	M	Hisp
3	CS	M	Hisp
3	CS	M	Hisp
3	CS	M	Hisp
3	CS	M	Hisp
3	CS	M	Hisp
3	CS	M	Hisp
3	CS	M	ME
2	CS	M	ME
2	CS	M	ME
2	CS	M	W
2	CS	M	W
2	CS	M	W
2	CS	M	W
2	CS	M	W
2	CS	M	W
2	CS	M	W
2	EE	M	W
2	ME	M	W

- Majors:
  - 3 CIT
  - 25 CS
  - 1 CE, X
- Years:
  - 5 seniors
  - 21 juniors
  - 4 sophs
- Sex:
  - 25 M
  - 5 F

= 17% → CECS = 15% F

CS Dept
- BS CS = 1185
- BS CIT = 362
- BS CE = 337
- MS CS = 43
- MS SWE = 22

CSUN
CALIFORNIA
STATE UNIVERSITY
NORTHRIDGE
COMP122

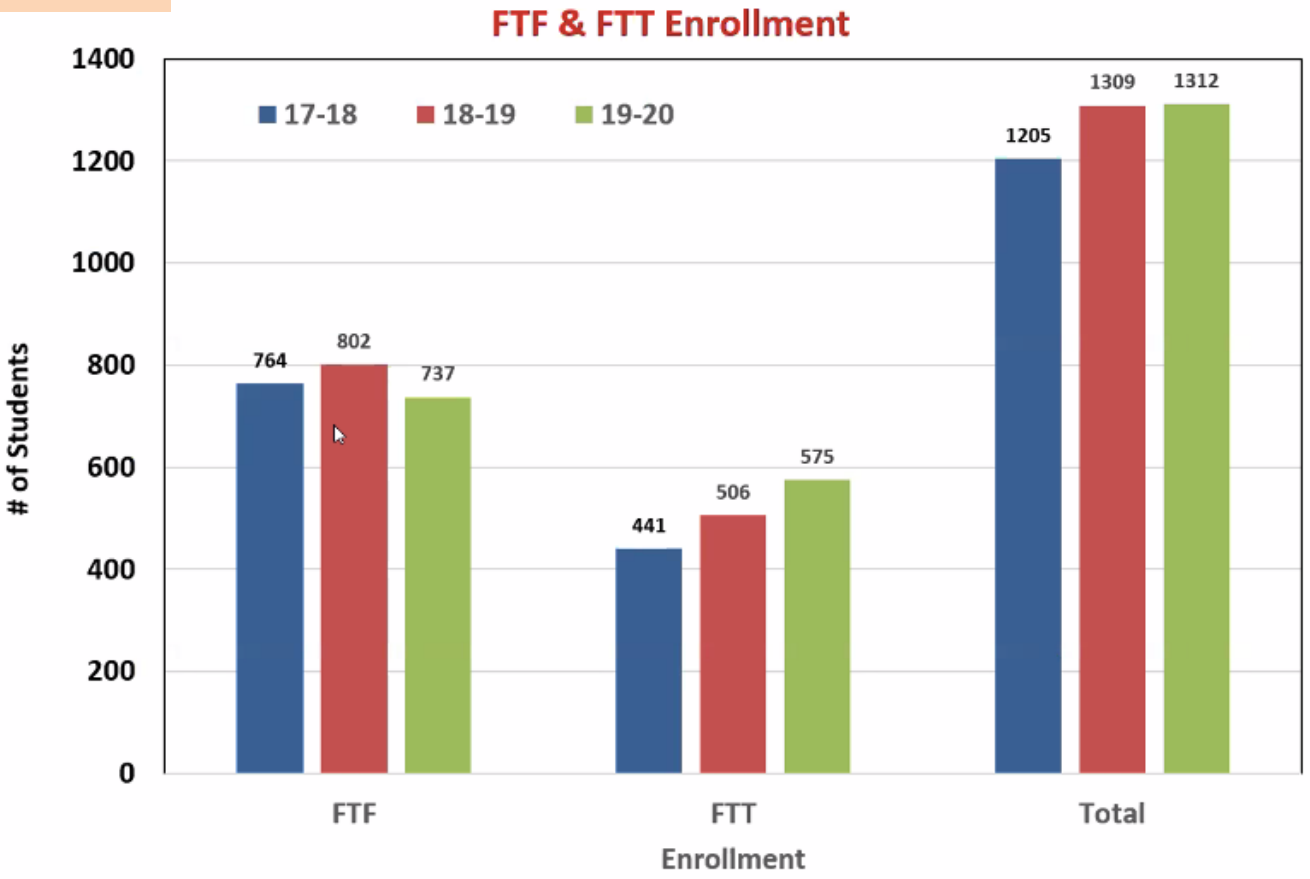
CSUN CECS Enrollment

DR JEFF SOFTWARE
INDIE APP DEVELOPER

CSUN | CALIFORNIA STATE UNIVERSITY NORTHRIDGE

CECS Updates

15% Female



CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE
COMP122

Comp Sci/CIT Majors

Academic Year	Fall Enrollment By Year				Total BSCS Enrollment	BSCS Degrees Awarded
	Fr	So	Jr	Sr		
2019-20	276	246	230	563	1185	
2017-2018	273	137	232	297	939	
2016-2017	215	118	193	247	773	106
2015-2016	217	87	193	198	695	67
2014-2015	109	61	153	162	485	69
2013-2014	99	55	118	174	446	67

CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE

COMP122

Comp Engr Majors

Academic Year	Fall Enrollment By Year				Total BSCompE Enrollment	BSCompE Degrees Awarded
	Fr	So	Jr	Sr		
2019-20	91	71	50	98	337	
2017-2018	129	69	67	98	363	
2016-2017	122	58	67	103	350	41
2015-2016	162	61	63	93	379	24
2014-2015	140	50	59	90	339	21
2013-2014	117	51	63	76	307	17

CS Dept Stats

- Graduates
  - **1-2%** of all BS CS grads in US & Canada!
  - Grad rates
    - 4-year = 7.6%
    - 6-year = 42%
- Jobs – Pay (2 years out, annual)
  - BS = $60K
  - MS = $80K

About CSU

About the California State University

The California State University is the largest system of four-year higher education in the country, with 23 campuses, 52,000 faculty and staff and 482,000 students. Half of the CSU's students transfer from California community colleges. Created in 1960, the mission of the CSU is to provide high-quality, affordable education to meet the ever-changing needs of California. With its commitment to quality, opportunity, and student success, the CSU is renowned for superb teaching, innovative research and for producing job-ready graduates. Each year, the CSU awards more than 127,000 degrees. One in every 20 Americans holding a college degree is a graduate of the CSU and our alumni are 3.8 million strong. Connect with and learn more about the CSU in the CSU NewsCenter.

CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE

COMP122

CSUN Rankings

Money Magazine

Money | Best Colleges For Your Money 2019 | Build Your Own Rankings | Popular Rankings | Search for a college | SEARCH

Rank	College Name	Median SAT/ACT score	Est. price 2019-20 without aid	Est. price 2019-20 with avg. grant	% of students who get any grants	Average student debt	Early career earnings
24	Houston, TX	1540/34	$66,000	$25,800	61%	$11,200	$69,200
25	**Massachusetts Maritime Academy** Buzzards Bay, MA	1120/23	$26,800	$15,500	48%	$26,930	$67,200
26	**Washington and Lee University** Lexington, VA	1420/32	$68,900	$26,700	57%	$19,920	$63,200
27	**Georgia Institute of Technology** Atlanta, GA	1310/32	$30,000	$16,900	62%	$23,750	$70,800
28	**The University of Texas at Austin** Austin, TX	1340/30	$26,600	$15,300	50%	$21,500	$59,100
29	**California State University-Northridge** Northridge, CA	1020/20	$23,100	$6,400	70%	$13,830	$49,600
30	**University of California-Santa Barbara** Santa Barbara, CA	1300/31	$37,700	$17,200	62%	$16,300	$57,300
30	**University of Notre Dame** Notre Dame, IN	1450/33	$72,500	$29,300	62%	$21,430	$64,700

CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE
COMP122

CSUN Rankings

Money Magazine

Money Magazine 2019-20 "Best College Value" ranking:

1 **UCI**,, 2 CUNY, 3 Princeton, 4 **UCLA**, 5 **UCD**, 6 Stanford, 7 MIT, 8 Michigan, 9 **UCSD**, 10 Virginia, 11 **UCB**, 12 **UCR**, 13 **CSULB**, 14 Harvard, 15 Vanderbilt, 16 CalTech, 17 Yale, 18 Texas A&M, 19 Duke, 20 Illinois, 21 Florida, 22 **CSUF**, 23 Washington, 24 Rice, 25 Mass. Maritime, 26 Washington & Lee, 27 Georgia Tech, 28 Texas, 29 **CSUN**, 30T **UCSB**, 30T Notre Dame, 32 Penn, 33 Binghamton, 34 Virginia Poly, 35 CUNY Brooklyn, 36 **CSULA**, 37 Swarthmore, 38 Bates, 39 Williams, 40 No. Carolina State, 41 **California Poly** Pomona, 42 Connecticut, 43T Maryland, 43T Holy Cross, 45 William & Mary, 46 Wisconsin, 47 Stony Brook, 48 New Jersey, 49 VMI, 50 Rutgers, 51 **CSU** Fresno, 52 No. Carolina, 53 CUNY John Jay, 54 Colgate, 55 Purdue, 56 **CSU** Chico, 57 James Madison, 58 Union College, 59 Michigan State, 60 Pomona, 61 Georgetown, 62 Northwestern, 63 **CSU** Monterey Bay, 64T George Mason, 64T Amherst, ... 68 **CSU** Stanislaus, ..., 70 **CSU** San Bernardino, ..., 72 Brown, ..., 74 **CSU** San Diego, 75 **California Poly** SLO, 77 U of Chicago, 78 Clemson, 79 Boston College, 81 Columbia, 91 Cornell, 93 **CSU** CI, 95 Dartmouth, 96 **CSU** Dominguez Hills, 97 Indiana, 98 Wake Forest, 99 Buffalo, 100 CUNY Queens, 101 Claremont McKenna, 102 Florida State, 103 **UCSC**, 104 **CSU** San Jose, ..., 120 Carnegie Mellon, 125 Johns Hopkins, 131 **USC**, 136 Harvey Mudd, 138 Wash. State, 144 **CSU** San Francisco, 150 **CSU** Sacramento

score: UC = 6/12 + 8/103, CSU = 16/150

Forbes "Top Colleges"

Below are the top ten winners of this year's #MyTopCollege competition:

1. California State University, Fullerton
2. Widener University
3. Sweet Briar College
4. Otterbein University
5. California State University, Northridge
6. California State University, Fresno
7. Saint Francis University
8. Stony Brook University
9. California State University, Long Beach
10. California State University, Chico

Section

Student Success

Success

Success =

Aptitude

+

Attitude

- Aptitude
  - Math/Logic
  - Computing/programming
  - Problem solving
  - Algorithms
  - Pattern recognition
- Attitude
  - ***Show up***
    - Physically
    - Mentally
  - ***Effort***
    - Work hard
    - Submit ALL assignments
  - ***Prepare***
    - Exams

➢ Effort!

Aptitude Assessment: Math

- Algebra
  - Functions
  - Formulas/ equations
- Arrays
  - Vectors (1D)
  - Matrices (2D)
- Number systems (radix)
  - Radix (base): Decimal, Binary & Hex
  - Powers and logs (e.g., $2^{10} = 1024$)
- Data types
  - Integers vs. Floating-point
  - Non-numeric (e.g., characters)
  - Logic (Boolean)
- Codes
  - ASCII

Aptitude Assessment: Coding

- X = X + 1
  - → Understand this?
- Algorithms
- Hierarchical models
  - Nesting
  - Precedence
  - Trees (“B-trees”)
- Strings
  - Character strings
- Arrays
  - Vectors (1D) –> x[ ]
  - Matrices (2D) -> x[ ] [ ]

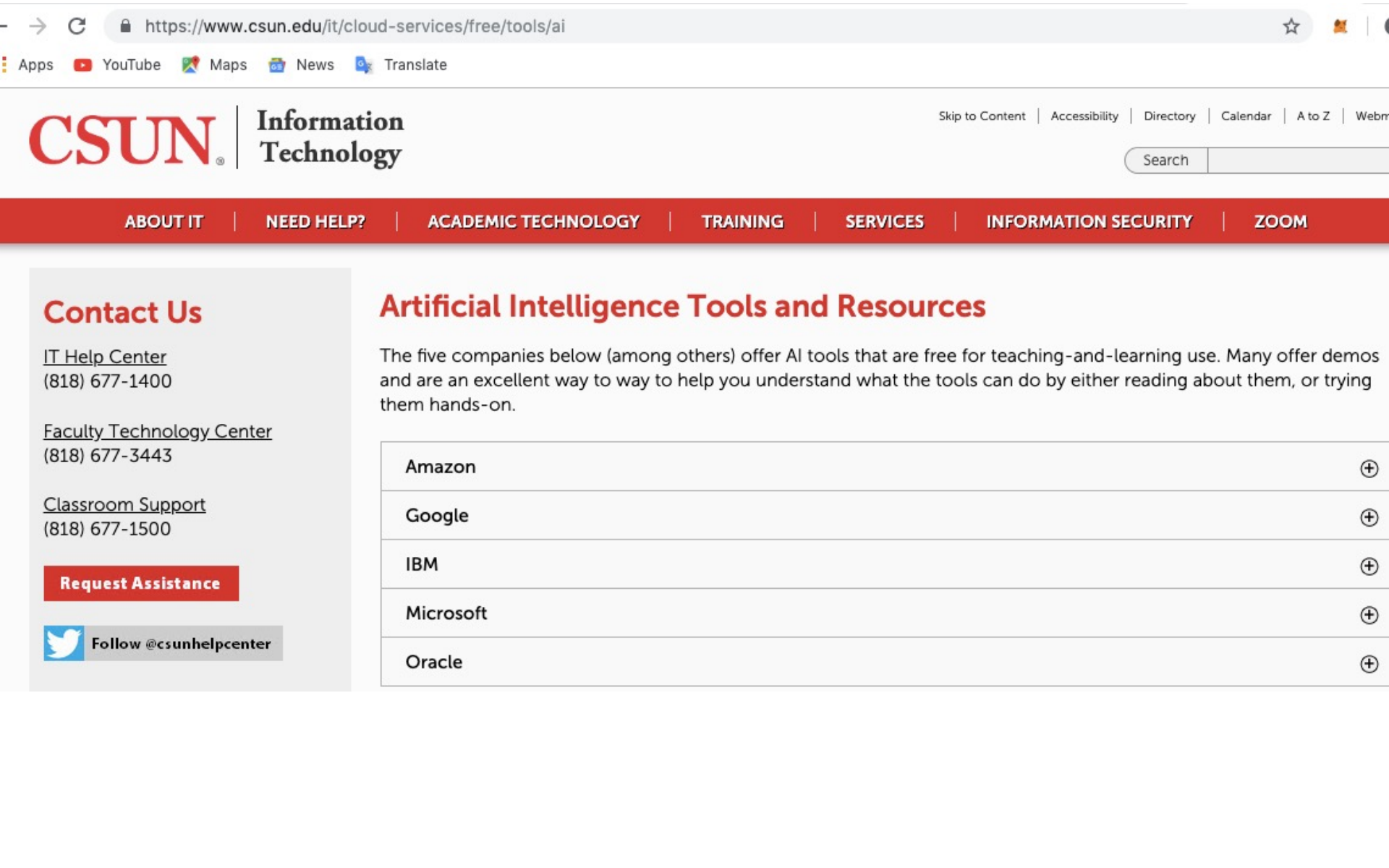
Section

AI Tools

CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE
COMP122

Blockchain Tools (AI)

DR JEFF SOFTWARE
INDIE APP DEVELOPER



CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE
COMP122

CSUN IT -- AI Tools

DR JEFF SOFTWARE
INDIE APP DEVELOPER

Artificial Intelligence Tools and Resources

The five companies below (among others) offer AI tools that are free for teaching-and-learning use. Many offer demos and are an excellent way to way to help you understand what the tools can do by either reading about them, or trying them hands-on.

Amazon

- Amazon Recognition Image - Deep learning-based image analysis
- Amazon Recognition Video - Deep learning-based video analysis
- Amazon Lex - Build chatbots to engage customers
- Amazon Comprehend - Discover insights and relationships in text
- Amazon Translate - Fluent translation of text
- Amazon Transcribe - Automatic speech recognition
- Amazon Polly - Natural sounding text to speech

CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE
COMP122

CSUN IT -- AI Tools

Artificial Intelligence Tools and Resources

The five companies below (among others) offer AI tools that are free for teaching-and-learning use. Many offer demos and are an excellent way to way to help you understand what the tools can do by either reading about them, or trying them hands-on.

Amazon ⊕

Google ⊖

Train Custom Machine Learning Models - Train machine learning models through transfer learning and neural architecture search

Large Scale Machine Learning Service - Build machine learning models

Job Search and Discovery - Provide intuitive job search that anticipates what job seekers are looking for

Create conversational experiences - Build conversational interfaces for websites, mobile applications, messaging platforms, and IoT devices.

Video Analysis - Make videos searchable and discoverable; search every moment of every video file

Image Analysis - Understand the concept of an image

Speech Recognition - Convert audio to text by applying neural network models

Text Analysis - Reveal the structure and meaning of text

Dynamic Translation - Translate an arbitrary string into any language

CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE

COMP122

CSUN IT -- AI Tools

Artificial Intelligence Tools and Resources

The five companies below (among others) offer AI tools that are free for teaching-and-learning use. Many offer demos and are an excellent way to way to help you understand what the tools can do by either reading about them, or trying them hands-on.

- Amazon ⊕
- Google ⊕
- IBM ⊖

  - Conversation - Build and deploy chatbots and virtual agents
  - Discovery - Uncover connections in data by combining automated ingestion with advanced AI functions
  - Speech to Text (STT) - Easily convert audio and voice into written text for quick understanding of content
  - Text to Speech (TTS) - Convert written text into natural-sounding audio in a variety of languages and voices
  - Language Translator - Dynamically translate news, patents or conversational documents
  - Natural Language Classifier - Interpret and classify natural language with confidence
  - Natural Language Understanding - Analyze text to extract metadata from content such as concepts, entities and sentiment
  - Visual Recognition - Tag, classify and search visual content using machine learning
  - Tone Analyzer - Analyze emotions and tones in written content
  - Personality Insights - Predict personality characteristics, needs, and values through written text

CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE
COMP122

CSUN IT -- AI Tools

DR JEFF SOFTWARE
INDIE APP DEVELOPER

Microsoft

Computer Vision - Distill actionable information from images

Face Detect - Detect, identify, analyze, organize, and tag faces in photos

Content Moderator - Automated image, text, and video moderation

Emotion Recognition - Personalize user experiences with emotion recognition

Custom Vision Service - Customize your own computer vision models for your unique use case

Video Indexer - Unlock video insights

Recommendations - Predict and recommend items your customers want

Academic Knowledge Discovery - Tap into a wealth of academic content in the Microsoft Academic Graph

Knowledge Exploration Service - Enable interactive search experiences over structured data via natural language inputs

Question and Answer Maker - Distill information into conversational, easy-to-navigate answers

Entity Linking Intelligence Service - Power your app's data links with named entity recognition and disambiguation

Custom Decision Service - A cloud-based, contextual decision-making API that sharpens with experience

Language Understanding - Teach your apps to understand commands from your users

Text Analytics - Easily evaluate sentiment and topics to understand what users want

Spell Check - Detect and correct spelling mistakes in your app

Translator Text - Easily conduct machine translation with a simple REST API call

CSUN IT -- AI Tools

Microsoft

Web Language Model - Use the power of predictive language models trained on web-scale data

Linguistic Analysis - Simplify complex language concepts and parse text with the Linguistic Analysis API

Translator Speech - Conduct real-time speech translation with a simple REST API call

Speaker Recognition - Use speech to identify and authenticate individual speakers

Speech Conversion - Convert speech to text and back again to understand user intent

Custom Speech Service - Overcome speech recognition barriers like speaking style, background noise, and vocabulary

Autosuggest - Give your app intelligent auto-suggest options for searches

Image Search - Search for images and get comprehensive results

News Search - Search for news and get comprehensive results

Video Search - Search for videos and get comprehensive results

Web Search - Get enhanced search details from billions of web documents

Custom Search - An easy-to-use, ad-free, commercial-grade search tool that lets you deliver the results you want

Entity Search - Enrich your experiences by identifying and augmenting entity information from the web

CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE
COMP122

CSUN IT -- AI Tools

Artificial Intelligence Tools and Resources

The five companies below (among others) offer AI tools that are free for teaching-and-learning use. Many offer demos and are an excellent way to way to help you understand what the tools can do by either reading about them, or trying them hands-on.

- Amazon ⊕
- Google ⊕
- IBM ⊕
- Microsoft ⊕
- Oracle ⊖

  Create chatbots - use a range of tools to create bots that can interact

  Create a custom component - using these specialized tools

Section

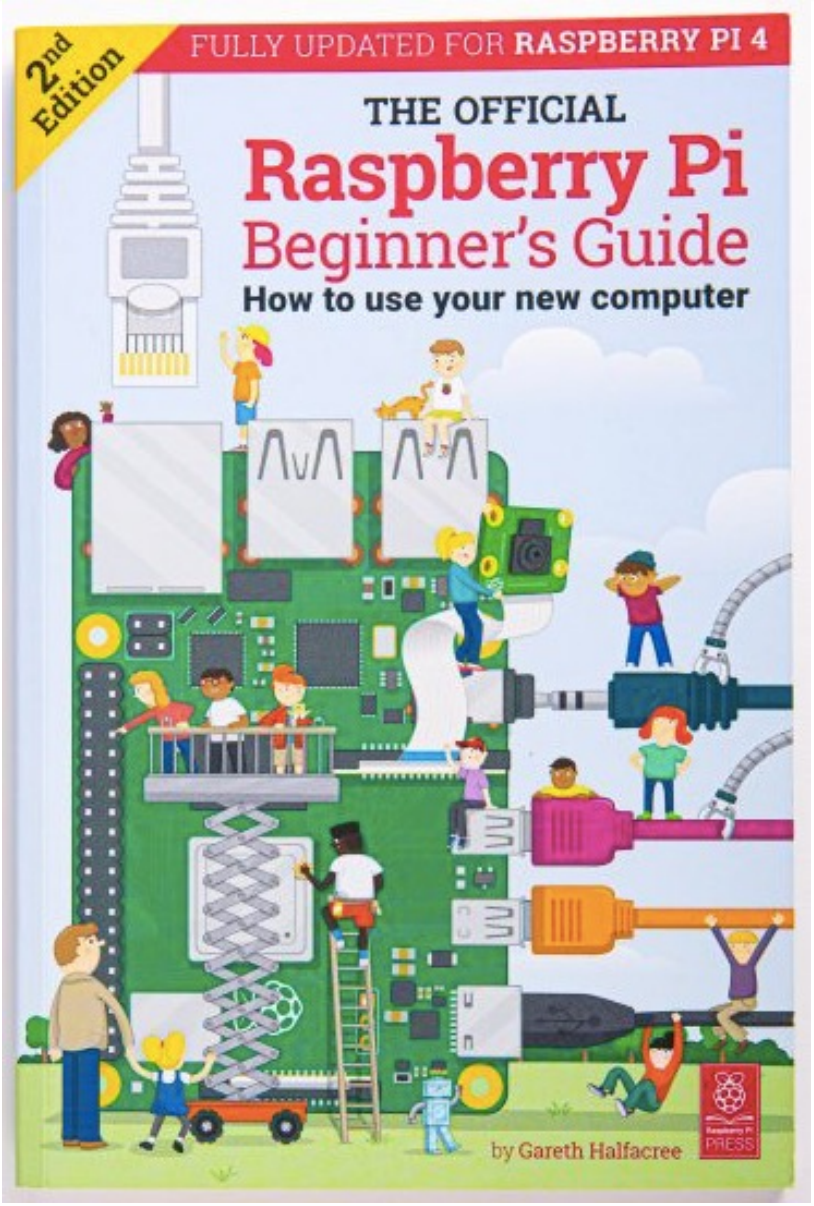
Pi

Books

CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE
COMP122

Pi Book

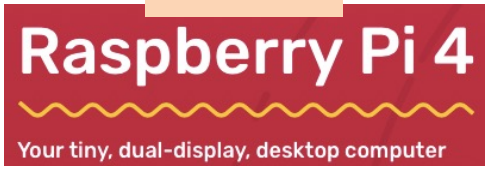
Amazon

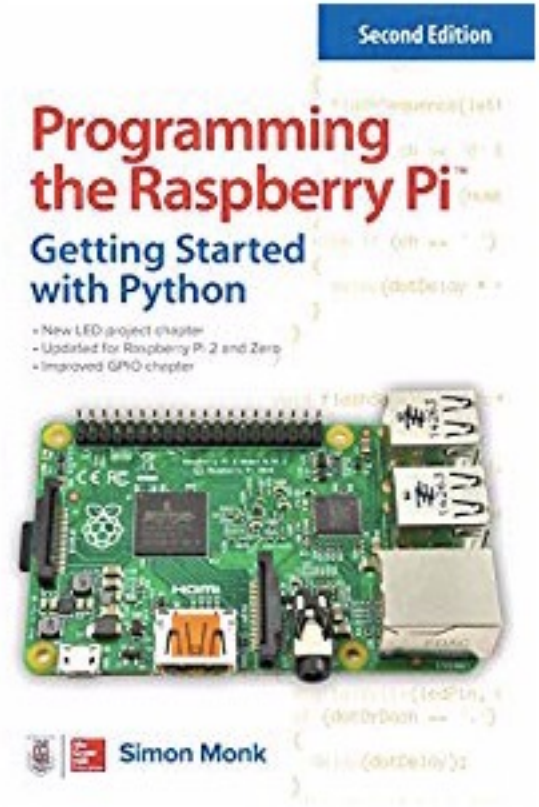


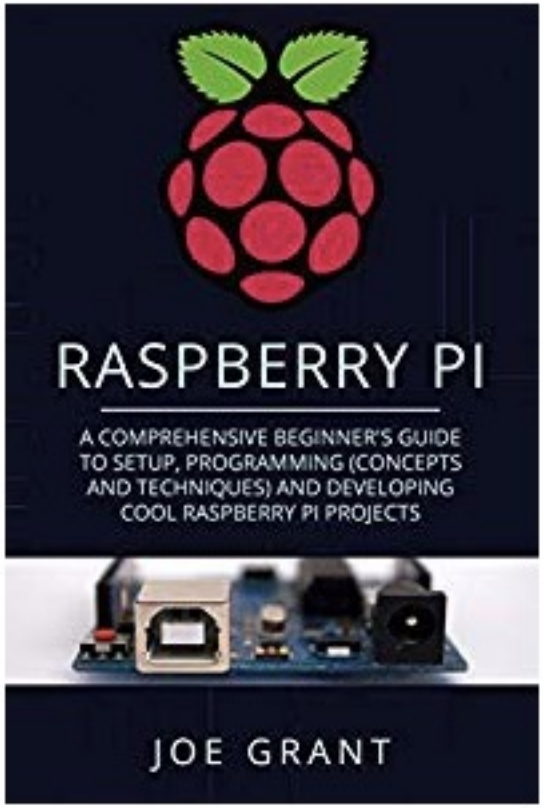
CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE
COMP122

Pi 4 Books

Amazon

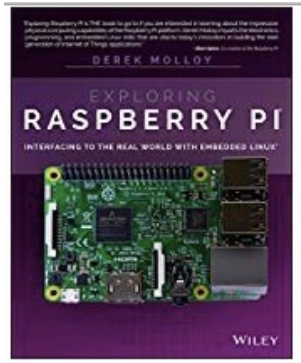






Pi 4 Books

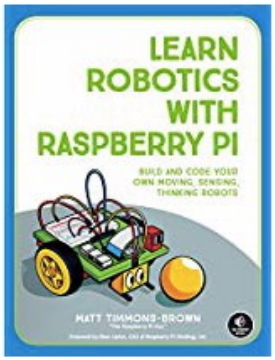
Amazon



Exploring Raspberry Pi: Interfacing to the Real World with Embedded...

$20.74

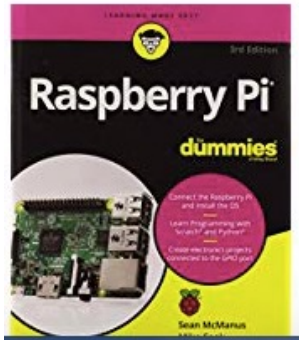
Shop now



Learn Robotics with Raspberry Pi: Build and Code Your Own Moving,...

$16.34

Shop now



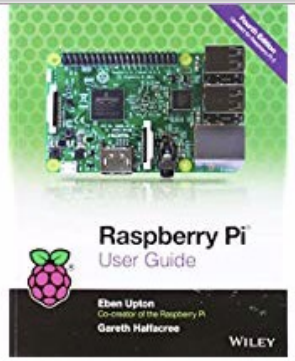
Raspberry Pi For Dummies, 3rd Edition

$18.02

Shop now

Pi 4 Books

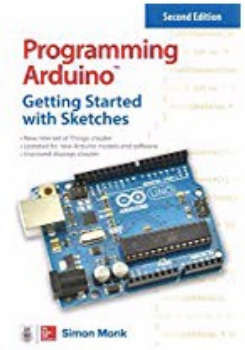
Amazon



Raspberry Pi User Guide, 4th Edition

$16.74

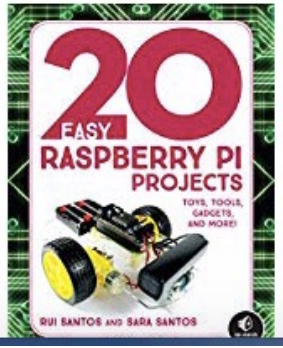
Shop now



Programming Arduino: Getting Started with Sketches, Second Edition...

$11.69

Shop now



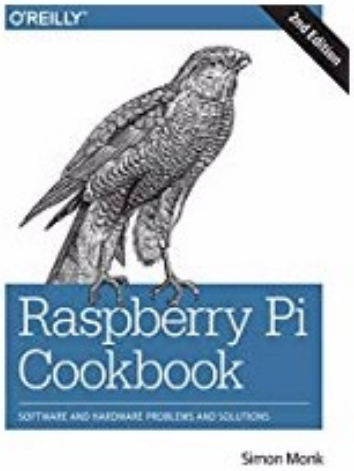
20 Easy Raspberry Pi Projects: Toys, Tools, Gadgets, and More!

$16.96

Shop now

Pi 4 Books

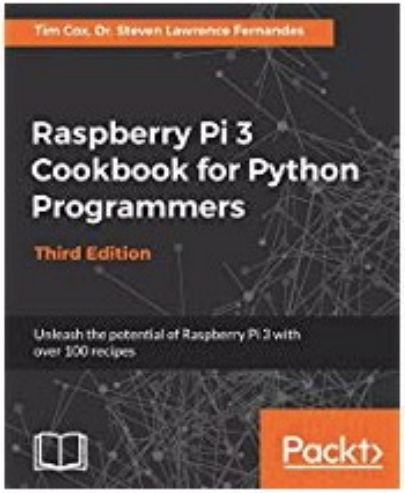
Amazon



Raspberry Pi Cookbook
Hardware Problems and

$31.72

Shop now



Raspberry Pi 3 Cookbook for Python Programmers: Unleash the...

$34.99

Shop now

CSUN
CALIFORNIA STATE UNIVERSITY NORTHRIDGE
COMP122

Pi 4 More

DR JEFF SOFTWARE
INDIE APP DEVELOPER

Raspberry Pi 4
Your tiny, dual-display, desktop computer

Raspberry Pi Weekly
Stay connected with the Raspberry Pi community

Future Learn Categories Courses Using FutureLearn Search online co

Raspberry Pi Foundation