General Information for Computer Engineering (CpE) PhD Qualifying Exam
(revised in August 2022)

The Computer Engineering (CpE) Qualifying Exam is administered in <u>two parts: a written exam and an oral exam</u>. The objective of the <u>written exam is to determine the students' understanding of the fundamentals of CpE subjects and to ensure solid theoretical background to start research</u>. The objective of the <u>oral exam is to evaluate the students' ability for critical thinking, problem-solving and communication required to conduct research independently</u>. The oral exam will be administered only for the students who passed the written exam. Every PhD student is required to pass the Qualifying Exam, both written and oral exams, by the end of the second semester after completion of the M.S. degree or by the end of the fifth semester after completion of the B.S. degree.

Students who fail the Qualifying Exam on their first attempt will be given a second opportunity to pass the exam when it is given in the following semester. Students who fail the exam once and do not take the exam in the subsequent semester will no longer be considered PhD degree candidates in the ECE department. A student who fails the Qualifying Exam on two consecutive semesters may file a written petition with the ECE Graduate Studies Committee for a third attempt. The petition must include at least three faculty recommendations, documentation of academic and research progress, and documentation of extenuating circumstances. The committee will vote, by simple majority, to approve or deny the petition. If the petition is approved, it will be forwarded to the Office of Graduate Studies as a request to administer the last attempt.

A. Written exam (WE) Policy and Procedures

Overall Procedure

The written exam will be normally held on the third weekend of each spring and fall semester. The written exam session is <u>three hours long</u>. Each student, when they register for the exam, will select <u>four specialization areas</u> for the written exam.   Students will only be provided problems for the areas selected. Possible specialization areas that can be chosen include all emphasis areas of CpE (Computational Intelligence; Computer Architecture and Embedded Systems; Integrated Circuits and Logic Design; Networking, Security, and Dependability) and <u>no more than one single emphasis area in electrical engineering</u>.

The written exam problems are selected to cover fundamental materials in CpE. As a general rule, basic material from undergraduate and fundamental subjects from 5xxx-level courses will be covered. The problems are designed so that each problem should take approximately 15-20 minutes to work. The student is required to work <u>any eight of the sixteen problems (no more than three per area)</u>. The sixteen problems will consist of four problems from each of the four areas selected. Written exam subjects and associated study guides are available in a later section.

Reference Material

The Fundamentals of Engineering (FE) Reference Handbook (NCEES, version 9.2, 2013, http://www.engineering.uco.edu/~aabuabed/index_files/FE_Handbook.pdf) will be available to each student at the exam. Only several selected sections will be provided including: Units, Conversion Factors, Mathematics, Probability/Statistics. <u>Note that this is intended to provide only the general</u>

information including fundamental formulae, constants and mathematical tables, etc. The authors of exam problems may not utilize this Reference Handbook when they design the problems. No other reference material is allowed. The only items students are allowed to bring to the exam are pencils, pens, erasers, and calculators (without network connectivity). Extra answer sheets will be provided by the exam proctor upon request. Extra calculator batteries or other supplies will not be available from the exam proctor. In order to keep track of the amount of time remaining during the exam, each student should bring his or her own watch.

Grading Policy

Each problem on the exams will be graded by the faculty member who wrote the problem. Generally, partial credit is given. A score based on the 4.0 - 0.0 scale including all intermediate scores, e.g. 3.6, 2.7, etc., (4.0, 3.0, 2.0 and 1.0 being equivalent to the letter grades "A", "B", "C" and "D", respectively), is given for each of the eight problems. The average score is determined by averaging the eight scores, respectively.

An average score of 3.0/4.0 is typically required for passing the written exam. Exam scores for each student will be reviewed by the ECE Graduate Studies Committee. The committee will determine if each student passes or fails the written exam. Students will be notified of the results of the exam, indicating "pass" or "fail", approximately one week after the exam is given.

A student may review the graded answers only in the presence of the graduate secretary, without taking pictures, making notes nor taking the answers with the student. If the student has any question on the solution of a particular problem, it should be done in writing in the presence of the graduate secretary within one week after the results are announced. The secretary forwards the writing and the student's answer sheet to the problem author without revealing the student's identity. The author provides the secretary with an anonymously written explanation to be forwarded to the student by the secretary. The faculty member may choose to meet the student instead of writing.

B. Oral exam (OE) Policy and Procedures

Overall Procedure

Within five weeks of passing the written exam, the student's oral exam, an oral presentation (typically one hour, but no longer than two hours), must be scheduled. The advisor must form the student's tentative PhD graduate committee (at least three including the advisor) immediately after passing the written exam. Then, the student will notify the graduate secretary of the possible exam date/time after consulting with the committee members.

Two weeks (and no sooner) prior to the oral exam, the student will be given an assignment comprised of two journal articles relevant to the student's potential research topic, as agreed upon by the PhD committee. During the oral exam, the student will be required to summarize and critique these articles. The student will be given no more than 15 minutes per article to give a complete overview of its technical contents. Subsequently within the next 30 minutes, the student will be required to properly place the novelty, shortcomings, how the student's future research fits within or builds upon the works in these articles and other pertinent issues. Each examinee is required to prepare their oral presentation material. The required format for the presentation and the evaluation items are available in a later section.

The committee will be present during the oral exam to ask questions, discuss nuances and observe student's ability to engage in technical discussions, student's potential for performing independent research, etc. All committee members are required to physically attend the oral exam. Under unavoidable circumstance, the committee member may join the session remotely with permission from the Graduate Coordinator. At least half of committee members must be physically attending. The advisor should not speak on behalf of the student during the exam.

Assignment Handling

The PhD graduate committee will select two journal articles suggested by the student's advisor. Each article must be directly relevant to the potential research topic of the student and an original scholarly research paper (excluding review articles) conducted by third party researchers and published by professional societies and/or academic publishers with perceived authority (e.g. IEEE, Elsevier, etc.).

Two weeks before (and no sooner) the oral exam, the advisor must deliver the two selected articles to the student to be used for the oral exam. The committee (including the advisor) must not provide the student with any information related to this assignment nor discuss any technical issue directly related to the assignment during the entire period of exam administration.

Grading Policy

The PhD graduate committee will prepare a one-page Pass/Fail evaluation report before leaving the oral exam location. This report is comprised of an evaluation rubric and, if necessary, obligatory remedial action items that the student must meet to proceed to, or along with, planning the dissertation. An average score of 4.0 (in 5.0 – 1.0 scale), averaged from three rubric items available in a later section (Knowledge, Critical Thinking and Communication Skill) is typically required to pass the oral exam. The advisor is responsible for making sure that the required remedial actions are completed before the Comprehensive Exam is scheduled.

Students who fail the oral exam on their first attempt will be given a second opportunity during the following semester. It is at committees' discretion whether to use the same articles at the second attempt as during the first exam, or use different articles.

C. Study guides

Written Exam (WE)

The following material, broken down by area, is intended to provide you with more information on the exam. Previous PhD Qualifying Exam problems are posted on the department web site.

Computational Intelligence

The written exam covers basic concepts and problems related to computational intelligence related areas from 5xxx level courses. Such topics are covered in courses including: CpE 5310/EE 5310/ Sys Eng 5211-Computational Intelligence and CpE 6310 – Markov Decision Processes.

Topics include:

1. Artificial Neural Networks (ANNs):
   The Artificial Neuron; Supervised Learning Neural Networks; Unsupervised Learning Neural Networks; Radial Basis Function Networks. This part will be introductory in nature since most of the course involves EC, SI, and FS methods for training and developing ANN structures.
2. Evolutionary Computing (ECs):
   Genetic Algorithms (GAs), Genetic Programming (GP), Evolutionary Programming (EP), Evolutionary Strategies (ESs). Applications of these algorithms (GAs, ESs) to train neural networks will be emphasized.
3. Artificial Immune Systems (AIS):
   The biological immune system is a highly parallel and distributed adaptive system. It uses learning, memory, and associative retrieval to solve recognition and classification tasks. Artificial Immune Systems is a new computational approach for the CI community. It is an excellent tool for solving engineering problems. The design of robust controllers using AIS will be covered among other applications.
4. Swarm Intelligence (SI):
   Particle Swarm Optimization (PSO); Ant Colony Optimization; Cultural Evolution. Applications of PSO to train neural networks will be emphasized. The integration of Swarm and Cultural evolution will be discussed.
5. Fuzzy Systems (FS):
   Fuzzy Systems; Fuzzy Interference Systems; Fuzzy Controllers; Rough Sets.
6. Hybrid Systems:
   The integration of these CI paradigms in the development of hybrid systems for solving engineering problems. For example, the application of CI in optimal digital circuits design, mapping and routing on hardware, in design of identifiers and controllers for nonlinear systems, image and signal processing, etc.

Computer Architecture and Embedded Systems

Topics covered in the Architecture and Embedded Systems exam are covered primarily in CpE 3150 – Digital Systems Design – and in CpE 5110 - Principles of Computer Architecture.

Specific topics from CpE 3150, Digital Systems Design, include:
1. Address decoding
   ● Determine the address range of RAM/ROM devices with respect to a target microprocessor
2. Microprocessor instruction set design
   ● Identify addressing modes used in assembly language instructions for the instruction set architecture
   ● Determine the machine code for specified assembly language instructions
3. Microprocessor instruction and program timing
   ● Determine the execution time of an assembly language subroutine or program given the instruction machine cycle and microprocessor execution parameters
   ● Write an assembly language subroutine that executes in a specified time
   ● Use architecture timers to generate specified time delays
4. Microprocessor instruction execution
   ● Describe the fetch, decode, and execute components of instruction execution for specified microprocessor instructions

- Describe the fetch, decode, and execute components of instruction execution based on the microprocessor architecture (Von Neumann, Harvard)
5. Microprocessor code conversion
    - Convert an assembly language subroutine or program to the C language
    - Convert a C language subroutine or program to assembly language
6. Microprocessor interrupt sources
    - Identify interrupt sources and interrupt source vector addresses from a microprocessor interrupt vector table
    - Write an assembly language interrupt service routine for the different interrupt sources (timers, external interrupts, USART, etc.)
    - Interpret assembly language interrupt service routine code to identify interrupt source and operations performed
    - Determine interrupt source priority based on microprocessor interrupt architecture
7. Describe and build a task scheduler. Describe the basis behind existing real-time operating systems (RTOS) and implement simple programs with these systems.

Specific topics from CpE 5110, Principles of Computer Architecture, include:
1. Have an understanding about the flow of operations and control in a computer,
    - Instruction cycle,
    - Interrelationship between assembly (machine) instructions and micro-instructions
    - Role of major components of a simple computer
        - Control Unit (CU)
        - Arithmetic Logic Unit (ALU)
        - Memory unit
        - I/O unit
2. ALU
    - How to design an ALU
    - Fast ALU
        - Fast addition
        - Fast multiplication
        - Fast division,
3. Memory System
    - Address accessible memory
        - Classification
        - Access gap:
            - Definition
            - Architectural solutions to reduce the access gap
                - Interleaved memory
                - Cache memory
                - Memory hierarchy
        - Size gap
            - Definition
            - How to reduce the size gap
                - Segmentation
                - Paging
        - Content addressable memory

- Definition, design, classification
- Associative algorithm

4. Concurrency and different classes of concurrent systems,
    - Definition, Flynn's and extended Flynn's classification
        - Array of processors
        - Vector processor
        - Multiprocessor
        - Pipelining
5. Design challenges of concurrent system,
    - Hazards
    - Cache coherency
6. Advanced architectures
    - Superscalar architecture
    - Super pipeline system
    - Very Long Instruction Word (VLIW) architecture
    - Multicore systems

Integrated Circuits and Logic Design

Topics covered in this exam are covered primarily in CpE 2210 and CpE 5220 and include the following. Items marked with afterwards (general knowledge) indicates that only general knowledge of the topic is required.

Digital Logic and Digital Circuit Design:
1. Logic function simplification using K-maps (up to 6 variables)
2. Using digital components (mux, demux, decoder, comparators, half-adder, full-adder, etc.) for digital circuit design and implementation
3. 2^s complement, sign magnitude, and unsigned formats (addition, subtraction, multiplication, division)
4. Mealy and Moore state machines using D, SR, JK flip-flops
    - Interpreting circuits (state variables, state table, state transition diagram, state reduction, state machine implementation)
    - State machine design and implementation from problem specifications
5. Logic function implementation using logic array components
6. Logic function implementation using static CMOS complementary logic

Digital System Modeling:
1. Calculating circuit delay parameters, given component delay information (e.g., calculate minimum clock period given component propagation delays and flip-flop setup and hold times)
2. Hardware Description Language digital design (for both combinational and synchronous circuits) for digital component and digital system design
    - Behavioral, structural, and dataflow models
    - Concurrent and sequential language elements
    - Use of testbenches
3. Digital component and system design tradeoffs based on size, area, power, speed considerations

Networking, Security and Dependability

The basic concepts and problems are related to networked systems. Such topics arecovered in courses including CpE 5410 (Introduction to Computer Communication Networks) and CpE5420 (Introduction to Network Security) CpE 5510 Fault-Tolerant Digital Systems including the following topics:

1. Understand network architectures.
2. Describe an overview of communication networks, explaining the general principles governing the transport, network, medium access control, data link, and physical layers in a layeredarchitecture.
3. Describe how these layers operate and interact, and how the major functions of each layer are affected by network speed and user requirements.
4. Identify protocols commonly used for provision of fundamental network services, and compare and contrast alternatives.
5. Investigate the limitations of current networks, such as the Internet, Ethernet, ATM, and wireless LANs.
6. Evaluate the performance of a network, and suggest improvements employing new technologies.
7. Discuss basic security and reliability challenges in networking, as well as solutions commonly employed to address these challenges.
8. Describe the basic notions of confidentiality, authentication, integrity, and non-repudiation
9. Discuss each of the following threats: man-in-the-middle attack, meet-in-the-middle attack, replay attack.
10. Describe each of the attacks on information flow: interruption, interception, modification, and fabrication, with examples of each.
11. Describe the typical "life-cycle" of a virus.
12. Explain the differences between security policies, mechanisms, and services.
13. Describe the functioning of a firewall and/or a Virtual Private Network (VPN).
14. Describe advantages of fault-tolerant systems and basic approaches.
15. Describe redundancy and voting techniques.
16. Describe recovery and rollback techniques.
17. Given input, determine MTTR, MTBF, MTTF.
18. Error detection/correction codes
19. Self-checking logic circuit design techniques
20. Generate a fault tree analysis from data.
21. Describe common probability distributions associated with reliability analysis.
22. Mathematically relate reliability, system life time, and failure rate.
23. Differentiate reliability from availability.
24. Describe basic graph-theoretic terms such as, node, link, average degree, betweenness, and usageof them for modeling network performance.

Recommended references:
- Computer Networks, Andrew Tanenbaum and David Wetherall, Fifth Edition, Prentice Hall, 2011. (ISBN-10: 0132126958; ISBN-13: 9780132126953)
- Data and Computer Communications, William Stallings, Tenth Edition, Pearson, 2014. (ISBN-10: 0133506487; ISBN-13: 9780133506488

- Network Security: Private Communication in a Public World, Charlie Kaufman, Radia Perlman, and Mike Speciner, Second Edition, Prentice Hall, 2002. (ISBN-10: 0130460192; ISBN-13: 9780130460196)
- Cryptography and Network Security: Principles and Practice, William Stallings, Sixth Edition, Pearson, 2014. (ISBN-10: 0133354695 • ISBN-13: 9780133354690)
- Charlie Kaufman, Radia Perlman, and Mike Speciner, *Network Security: Private Communicationin a Public World*, 2nd edition, Prentice Hall, 2002. Fault-Tolerant Systems, by Israel Korean and C. Mani Krishna, Morgan Kaufmann
- Network Security Essentials, 3rd Edition, Stallings, Prentice-Hall
- Security Engineering, Anderson, Wiley
- Probability and Statistics with Reliability, Queuing, and Computer Science Applications, 2nd edition, Kishor S. Trivedi, John Wiley and Sons, 2001, ISBN: 978-0-471-33341-8
- Charlie Kaufman, Radia Perlman, and Mike Speciner, *Network Security: Private Communicationin a Public World*, 2nd edition, Prentice Hall, 2002.

Electrical Engineering

Please refer to the guidelines for the EE Qualifying exam for additional information about these topics.

Oral Exam (OE)

All examinees are required to prepare their oral presentation material with respect to the following policy.

Presentation format (no more than 40 PowerPoint slides)

The suggested format for the presentation are as follows:
1. Article#1 (no more than 10 slides for 15 min)
   - Motivation and rationale of article #1
   - Complete overview of the technical contents of article #1
2. Article#2 (no more than 10 slides for 15 min)
   - Motivation and rationale of article #2
   - Complete overview of the technical contents of article #2
3. Critique on article#1 (no more than 10 slides for 15 min)
   Critical analysis and discussion on:
   - Novelty
   - Shortcomings
   - Pertinent issues related with the examinees's own future research (e.g. how does the own research fit within article #1 and/or what common components does the own research share with article #1, etc.)
   - Pertinent issues related with the examinees's own future research (e.g. how article #1 can be improved and/or what advances can be made by the own research to build upon article #1, etc.)
   - Other pertinent issue if any
4. Critique on article#2 (no more than 10 slides for 15 min)
   Critical analysis and discussion on:

- Novelty
- Shortcomings
- Pertinent issues related with the examinees's own future research (e.g. how does the own research fit within article #1 and/or what common components does the own research share with article #2, etc.)
- Pertinent issues related with the examinees's own future research (e.g. how article #2 can be improved and/or what advances can be made by the own research to build upon article #2, etc.)
- Other pertinent issue if any

Evaluation rubric

The committee members will observe the students' ability required to conduct research independently. It will be evaluated based on the items in the rubric shown below. Therefore, the presentation material and the delivery of presentation should be prepared accordingly.

	Unsubstantiated (1)/ Developing (2)	**Marginal (3)**	**Acceptable (4)/ Proficient (5)**
Knowledge: an ability to apply knowledge of subject matter within their field of study	Does not reflect understanding of subject matter and associated literature	Reflects understanding of subject matter and associated literature	Reflects mastery of subject matter and associated literature
	Demonstrates limited understanding of theoretical concepts	Demonstrates understanding of theoretical concepts	Demonstrates superior understanding of theoretical concepts
	Limited evidence of comprehension	Some evidence of comprehension	Significant evidence of comprehension
	Limited expansion upon previous research	Builds upon previous research	Greatly extends previous research
Critical Thinking: an ability to engage in productive critical thinking within their field of study	Demonstrates rudimentary problem-solving skills	Demonstrates average problem-solving skills	Demonstrates mature problem-solving skills
	Demonstrates limited originality	Demonstrates adequate originality	Demonstrates significant originality
	Displays limited creativity and insight	Displays creativity and insight	Displays significant creativity and insight
Communication: an ability to communicate effectively within their	Presents reasonings incorrectly, incoherently or faulty	Presents reasonings coherently and clearly	Presents reasonings in a superior manner
	Defines objectives poorly	Defines objectives clearly	Defines objectives thoroughly

field of study	Contains numerous grammatical and spelling errors	Contains some grammatical and spelling errors	Contains no grammatical or spelling errors
	Organization is poor	Organization is logical	Organization is excellent

D. Appendix

List of written exam (WE) subjects: revised (effective Fall 2018) and previous tables

Revised subject list of CpE PhD qualifying exam (effective in Fall 2018)

1. Computational Intelligence

C1 – C4	Single subject or combined subjects from: CpE 5310 Computational Intelligence SysEng 5211 Computational Intelligence EE 5370 Introduction to Neural Networks and Applications

2. Computers and Architecture and Embedded Systems

C5 – C8	Single subject or combined subjects from: CpE 3110/5110 Computer Organization and Design, Principles of Computer Architecture CpE 3150/5120 Intro to Microcontrollers and Embedded System Design, Digital Computer Design CpE 5151 Digital Systems Design Laboratory

3. Integrated Circuits and Logic Design

C9 – C12	Single subject or combined subjects from: CpE 2210 Introduction to Digital Logic CpE 5210 Introduction To VLSI Design CpE 5220 Digital System Modeling

4. Networking, Security and Dependability

C13 – C16	Single subject or combined subjects from: CpE 5410 Introduction to Computer Communication Networks CpE 5420 Introduction to Network Security CpE 5510 Fault-Tolerant Digital Systems

Previous subject list of CpE PhD qualifying exam (before Fall 2018)

1. Computers and Architecture

CM1 – 4	CpE3110 Computer Organization and Design
	CpE5110 Principles of Computer Architecture
	CpE5120 Digital Computer Design
CA1 – 4	All courses for CM1 – 4
	CpE6110 Advanced Computer Architecture I

2. Integrated Circuits and Logic Design

CM5 – 8	CpE2210 Introduction to Digital Logic
	CpE5210 Introduction To VLSI Design
	CpE5220 Digital System Modeling
CA5 – 8	All courses for CM5 – 8
	CpE6210 Digital Logic

3. Embedded Computer Systems

CM9 – 12	CpE3150 Introduction to Microcontrollers and Embedded System Design
	CpE5151 Digital Systems Design Laboratory
	CpE5170 Real-Time Systems
	CS3800 Introduction To Operating Systems
CA9 – 12	CpE3150 Introduction to Microcontrollers and Embedded System Design
	CpE5151 Digital Systems Design Laboratory
	CpE5170 Real-Time Systems
	CS3800 Introduction To Operating Systems

4. Computational Intelligence

CM13 – 16	CpE/EE5310 Computational Intelligence
	SysEng5211 Computational Intelligence
	EE5370 Introduction to Neural Networks and Applications
CA13 – 16	All course for CM13-16
	CpE6320 Adaptive Dynamic Programming
	CpE6330 Clustering Algorithms
	CpE6310 Markov Decision Processes

5. Networking

CM17 – 20	CpE5410 Introduction to Computer Communication Networks
	CpE5420 Introduction to Network Security
CA17 – 20	CpE5410 Introduction to Computer Communication Networks
	CpE5420 Introduction to Network Security

6. Security and Reliability

CM21 - 24	CpE5510 Fault-Tolerant Digital Systems
	CpE5410 Introduction to Computer Communication Networks
	CpE5420 Introduction to Network Security
CA21 - 24	All course for CM21 – 24
	CpE6440 Network Performance Analysis
	CpE6510 Resilient Networks