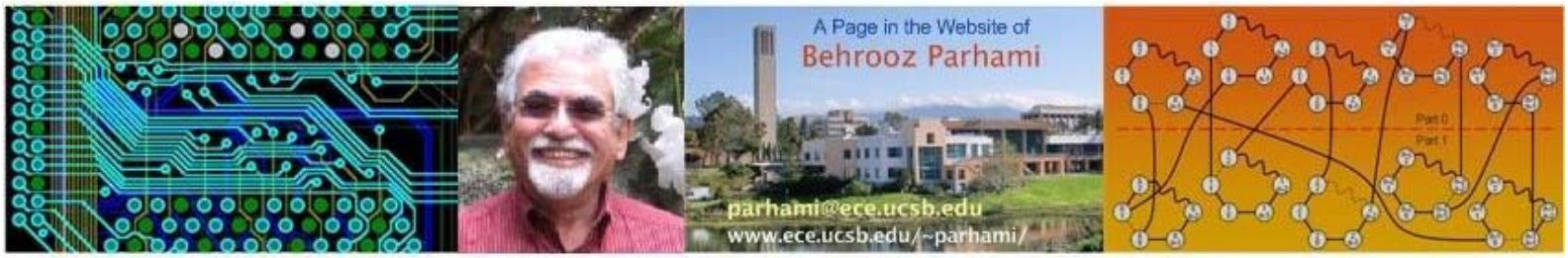

Behrooz Parhami's ECE 257A Course Page for Fall 2016

Fault-Tolerant Computing

Page last updated on 2016 December 11

Enrollment code: 12708
Prerequisite: ECE 154 (or equivalent)
Class meetings: MW 10:00-11:30, Phelps 1431
Instructor: Professor Behrooz Parhami
Open office hours: M 12:00-2:00, W 4:30-5:30; HFH 5155
Course announcements: Listed in reverse chronological order
Course calendar: Lecture, homework, and exam schedules
Homework assignments: Four assignments, worth a total of 30%
Exams: Open-book midterm, worth 30%
Research paper: Required in lieu of final exam, worth 40%
Research paper guidlines: Brief guide to format and contents
Poster presentation tips: Brief guide to format and structure
Policy on academic integrity: Please read very carefully
Grades: Statistics for homework and exam grades
References: Textbook and other sources (**Textbook's web page**)
Lecture slides: Via the textbook's Web page
Miscellaneous information: Motivation, catalog entry, history

Course Announcements

2016/12/11: The fall 2016 offering of ECE 257A is officially over and grades are ready for reporting to the Registrar's Office. Feedback about your research paper grade will be sent to you early tomorrow. Hope your winter break and holidays are pleasant. See you in 2017!
2016/12/08: I have now received all the 9 research papers for ECE 257A and will begin evaluating them this afternoon. I should be able to report the paper and course grades and provide feedback to students by Monday 12/12.

2016/12/01: I have just finished sending feedback to each of you about your poster presentation. The final paper (PDF file sent as e-mail attachment) will be due no later than 12:00 noon on Thursday, 2016/12/08. This slightly extended deadline is firm and cannot be further extended, given the extent of time I need to read and evaluate the papers.

I was generally impressed by the amount of work you put into composing and designing your posters. I list here a few common problems that I saw in multiple posters and presentations. Lettering and diagrams should be large enough to be seen from a few feet away, which is how a poster is normally viewed by the audience. You should not block your poster by standing between the poster and the audience or read directly from the text on the poster. The poster is not meant to contain your entire study and its results. Rather, it should serve as an introduction to the problem studied and some key observations and result, in effect serving as an invitation to the viewer to ask questions and to read the full paper.

2016/11/23: The statement of Problem 25.1, which is missing from the on-line version of the textbook, has been added to the homework area below.

2016/11/13: Homework assignment #4 has been posted to the homework area below. All students now have their research topics assigned. Preliminary references are due by M 11/14, per our course schedule, but if you need 1-2 extra days, I will accept your list via e-mail until W 11/16. Please prepare your list using standard journal format, as exemplified by end-of-chapter references in our textbook.

2016/11/10: Several research topics have been assigned to those who requested them. Three students have not yet proposed an acceptable research topic and must do so immediately (it is way past deadline). Statements

Personal
- Blog & books
- Favorite quotations
- Poetry
- Pet peeve
- Virtual retirement

CE Program

ECE Department

UCSB Engineering

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of Problems 16.6 and 19.3, which are missing from the posted version of the textbook, have just been included as part of HW#3 below.

2016/11/01: Homework assignment #3 has been posted to the homework area below. The research section is now up to date, and the deadline for selecting your research topic has been extended to W 11/9. Midterm exam has been postponed to M 11/7, replacing a previously cancelled lecture. Instead, the lecture on W 11/9 is cancelled. All these changes have been applied to the course schedule below. A final note: Part b of problem 10.2 was apparently not included in the on-line textbook file. For this reason, everyone lost 10 points for not solving that missing part. In effect, HW2 was graded from 90, instead of 100.

2016/10/15: Homework assignment #2 has been posted to the homework area below. The research section will be updated by Tuesday 10/18, giving you 6 days to choose your research topic by the 10/24 deadline.

2016/10/01: Homework assignment #1 has been posted to the homework area below. The course schedule has been updated with research milestones and deadllines. Students who have not sent me the completed take-home survey please do so no later than Monday, 10/03.

2016/09/25: I look forward to meeting all enrolled students tomorrow, M 9/26, in class. As of today, 9 students have enrolled and there is room for others to join.

2016/05/17: Welcome to the ECE 257A web page for fall 2016. Signing up for the course has not yet begun. There are 24 seats in this class, with the first pass on Gold beginning on M 5/23. There will be minimal updates to the lecture slides and textbook chapters during fall 2016.

Course Calendar

Course lectures, homework assignments, and exams, have been scheduled as follows. This schedule will be strictly observed. In particular, no extension is possible for homework due dates. Please begin work on your assignments early. Each lecture corresponds to topics in 1-2 chapters of the instructor's forthcoming textbook on dependable computing. Chapter numbers are provided in parentheses, after day & date.

Day & Date (book chapters) Lecture topic [Homework posted/due] {Special notes}

M 09/26 (0-1) Background and motivation
W 09/28 (1-2) Dependability attributes

M 10/03 (3) Combinational modeling [HW1 posted, chs. 1-4]
W 10/05 (4) State-space modeling

M 10/10 (5, 7) Defect avoidance; Shielding and hardening
W 10/12 (6, 8) Defect circumvention; Yield enhancement [HW1 due]

M 10/17 (9, 11) Fault testing; Design for testability [HW2 posted, chs. 5-12]
W 10/19 (10, 12) Fault masking; Replication with voting

M 10/24 (13, 15) Error detection; Self-checking modules {Research topic specified; extended to W 11/9}
W 10/26 (14, 16) Error correction; Redundant disk arrays [HW2 due]

M 10/31 (17, 19) Malfunction diagnosis; Standby redundancy
W 11/02 (18, 20) Malfunction tolerance; Robust parallel processing [HW3 posted, chs. 13-20]

M 11/07 (1-12) Midterm exam, open-book/notes, 10:00-11:45 (note the extended time)
W 11/09 No lecture {Instructor away for attending a conference} {Extended research topic deadline}

M 11/14 (21, 23) Degradation allowance; Resilient algorithms [HW3 due] {Preliminary reference list due}
W 11/16 (22, 24) Degradation management; Software redundancy [HW4 posted, chs. 21-28]

M 11/21 (25, 27) Failure confinement; Agreement and adjudication
W 11/23 (26, 28) Failure recovery; Fail-safe systems {Abstract and final references due}

M 11/28 Brief survey of current research in the field [HW4 due] {Instructor and course evaluations}
W 11/30 Research poster presentations

R 12/08 {Research paper, submitted as PDF file attached to an e-mail message, due by 12:00 noon}

W 12/14 {Course grades due by midnight}

Homework Assignments

-Turn in solutions in class before the lecture begins.
-Because solutions will be handed out on the due date, no extension can be granted.
-Use a cover page that includes your name, course name, and assignment number.
-Staple the sheets and write your name on top of each sheet in case they are separated.
-Although some cooperation is permitted, direct copying will have severe consequences.

Homework 1: Dependability and its modeling (ch. 1-4, due W 2016/10/12, 10:00 AM)
Do the following problems from the textbook: 1.6, 1.23 (given below), 2.9, 3.15, 4.12
1.23 Risks of automation Read the paper [Neum16] by Peter G. Neumann, moderator of the "Inside Risks" forum, write a half-page abstract for it, and answer the following questions:
a. What is total-system safety? (Provide a definition.)
b. Which area needs more work in the coming years: aviation safety or automotive safety?
c. What is the most important risk associated with the Internet of Things (IoT)?
d. Why are the requirements for security and law enforcement at odds?
[Neum16] Neumann, P. G., "Risks of Automation: A Cautionary Total-System Perspective of our Cyberfuture," *Communications of the ACM*, Vol. 59, No. 10, pp. 26-30, October 2016.

Homework 2: Defects and faults (ch. 5-12, due W 2016/10/26, 10:00 AM)
Do the following problems from the textbook: 5.4, 6.2, 8.4, 9.2, 10.2, 12.5

Homework 3: Errors and malfunctions (ch. 13-20, due M 2016/11/14, 10:00 AM)
Do the following problems from the textbook: 13.2, 14.3, 16.6 (given below), 17.8, 19.3 (given below), 20.5
16.6 RAID 5 with different parity group sizes We have 11 identical disks and want to build a RAID system with an effective capacity equivalent to 8 disks. Discuss the pros and cons of the following schemes (both using the RAID 5 architecture) in terms of data loss probability and ease/latency of data reconstruction.
a. Nine disks are used as a single parity group and 2 disks are designated as spares.
b. Ten disks are arranged into two separate parity groups of 5 disks each and 1 disk is designated as spare.
19.3 Optimal number of spare modules A detailed study of a standby sparing system, with one active module and s spare modules, has determined that $s = 2$ is the most cost-effective choice for the number of spare modules, with $s = 3$ being a close second choice. Deduce the shape of the reliability curve as a function of the number s of spares and discuss the contribution of the coverage factor to these conclusions.

Homework 4: Degradations and failures (ch. 21-28, due M 2016/11/28, 10:00 AM)
Do the following problems from the textbook: 21.4, 23.3 (given below), 24.4, 25.1 (given below), 27.4, 27.5
23.3 Quantifying the reliability of programs Carbin et al. [Carb16] have suggested that reliability of programs under soft errors in the underlying hardware can be quantified by estimating the probability of correctness for variable values and verifying that they exceed predefined thresholds. Discuss the method proposed in the paper with regard to the following.
a. How realistic it is to determine the desired correctness probabilities or lower bounds for them.
b. The fraction of all program failures that can be attributed to soft errors of the kinds considered.
c. Options for corrective actions should the estimated correctness probabilities be unacceptable.
d. Whether the methods proposed might be adaptable to cover other causes of program failures.
[Carb16] Carbin, M., S. Misailovic, and M. C. Rinard, "Verifying Quantitative Reliability for Programs that Execute on Unreliable Hardware," *Communications of the ACM*, Vol. 59, No. 8, pp. 83-91, August 2016.
25.1 MTTF for disk pairs The solution to Example 21.valid (should be 25.valid, as it is in Chapter 25) ends with the suggestion that the model can be better matched to reality by including a transition from state 2 to state 0, with an appropriate rate that reflects coverage. Derive the latter rate to bring to the MTTF close to the observed value of 1371 yr.

Sample Exams and Study Guide

The following sample exam problems are meant to indicate the types and levels of problems, rather than the coverage (which is outlined in the course calendar). Students are responsible for all sections and topics in the textbook and class handouts that are not explicitly excluded in the study guide that follows each sample exam, even if the

material was not covered in class lectures.

Sample Midterm Exam (105 minutes)
Problems 3.12, 4.4, 9.4, and 12.1 from the textbook.

Midterm Exam Study Guide
Study Chapters 1-12 and review the problems in homework assignments 1-2. The following textbook sections are excluded: 6.6, 7.6, 8.6, 9.4, 9.6, 11.6

Sample Final Exam (120 minutes) (Not applicable to fall 2016 offering)
Problems 15.5, 17.1, 21.2, and 27.3 from the textbook.

Final Exam Study Guide (Not applicable to fall 2016 offering)
Study Chapters 13-28 and review the problems in homework assignments 3-4. The following textbook sections are excluded: 13.6, 14.6, others TBD

Research Paper and Presentation


Each student will review a subfield of dependable computing or do original research on a selected and approved topic. A preliminary list of research topics is provided below (new topics, and new references for the current topics, may be added later). However, students should feel free to propose their own topics for approval. To propose a topic, send via e-mail a one-page narrative, including 2-3 key references, to the instructor.

A publishable report earns an "A" for the course, regardless of homework and midterm grades. See the course calendar for schedule and due dates and **Research Paper Guidlines** for formatting tips.

This year's suggested research topics for ECE 257A are built around the theme "Robustness of Interconnection networks." You can get started on each topic by taking a look at the following two common references, plus one topic-specific reference that is provided further down on this page. The two common references are:

[Parh10] Parhami, B., "Robustness Attributes of Interconnection Networks for Parallel Processing," Keynote Lecture at the First Int'l Supercomputing Conf., Guadalajara, Mexico, March 2010. {PPT and PDF slides are available from **B. Parhami's Publications** Web page; see publication [262].}

[Sall12] Salles, R. M. and D. A. Marion Jr., "Strategies and Metric for Resilience in Computer Networks," *Computer J.*, Vol. 55, No. 6, pp. 728-739, June 2012.

1. Effects of Missing Nodes on Network Diameter and Average Distance (Assigned to: Adrian Fiorito)
[Kris87] Krishnamoorthy, M.S. and B. Krishnamurthy, "Fault Diameter of Interconnection Networks," *Computers & Mathematics with Applications*, Vol. 13, Nos. 5/6, pp. 577-582, 1987.

2. Effects of Missing Links on Network Diameter and Average Distance (Assigned to: TBD)
[Kris87] Krishnamoorthy, M.S. and B. Krishnamurthy, "Fault Diameter of Interconnection Networks," *Computers & Mathematics with Applications*, Vol. 13, Nos. 5/6, pp. 577-582, 1987.

3. Synthesis of Interconnection Networks with Maximal Fault Tolerance (Assigned to: TBD)
[Chen09] W. Chen, W. J. Xiao, and B. Parhami, "Swapped (OTIS) Networks Built of Connected Basis Networks are Maximally Fault Tolerant," *IEEE Trans. Parallel and Distributed Systems*, Vol. 20, pp. 361-366, March 2009.

4. Adaptive Schemes for Point-to-Point Communication in Networks (Assigned to: Xuan Wang)
[Ngai91] Ngai, J. Y. and C. L. Seitz, "A Framework for Adaptive Routing in Multicomputer Networks," *Computer Architecture News*, Vol. 19, No. 1, pp. 6-14, March 1991.

5. Adaptive Schemes for Collective Communication in Networks (Assigned to: Prashansa Mukim)

[Pand95] Panda, D. K., "Issues in Designing Efficient and Practical Algorithms for Collective Communication on Wormhole-Routed Systems," *Proc. Int'l Conf. Parallel Processing Workshop on Challenges for Parallel Processing*, 1995, pp. 8-15.

6. Deadlocks in Adaptive Routing and How to Avoid or Detect Them (Assigned to: Fengqiao Sang)
[Dall93] Dally, W. J. and H. Aoki, "Deadlock-Free Adaptive Routing in Multicomputer Networks Using Virtual Channels," *IEEE Trans. Parallel and Distributed Systems*, Vol. 4, No. 4, pp. 466-475, April 1993.

7. Diagnosability of Regular Degree-*d* Interconnection Networks (Assigned to: Sixin Tao)
[Chan05] Chang, G.-Y., G. J. Chang, and G.-H. Chen, "Diagnosabilities of Regular Networks," *IEEE Trans. Parallel and Distributed Systems*, Vol. 16, No. 4, pp. 314-323, April 2005

8. Diagnosability of Hierarchical or Multilevel Interconnection Networks (Assigned to: Nan Wu)
[Xu09] Xu, M., K. Thulasiraman, and X.-D. Hu, "Conditional Diagnosability of Matching Composition Networks Under the PMC Model," *IEEE Trans. Circuits and Systems II*, Vol. 56, No. 11, pp. 875-879, November 2009.

9. Synthesis of Interconnection Networks with Maximal Diagnosability (Assigned to: Yiming Gan)
[Chan05] Chang, G.-Y., G. J. Chang, and G.-H. Chen, "Diagnosabilities of Regular Networks," *IEEE Trans. Parallel and Distributed Systems*, Vol. 16, No. 4, pp. 314-323, April 2005

Topics outside the main theme for the quarter

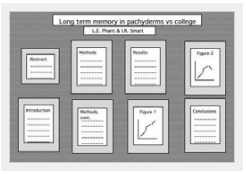
a. Reasoning Under Uncertainly, with Applications to Dependable Computing (Assigned to: TBD)
[IJAR16] *Int'l J. Approximate Reasoning*, Vol. 71, pp. 1-62, December 2016 (Five review articles on 40 years of Dempster-Shafer Theory)

b. Probabilistic Analysis of Program Correctness Under Soft Errors (Assigned to: TBD)
[Carb16] Carbin, M., S. Misailovic, and M. C. Rinard, "Verifying Quantitative Reliability for Programs that Execute on Unreliable Hardware," *Communications of the ACM*, Vol. 59, No. 8, pp. 83-91, August 2016.

c. Effects of Temporal Resistance-State Variation on ReRAM Reliability (Proposed by: Abanti Basak)
[Ref 1] "Modeling Framework for Cross-Point Resistive Memory Design Emphasizing Reliability and Variability Issues"

d. Computation-Oriented Fault Tolerance Schemes for RRAM-Based Systems (Proposed by: Wenqin Huangfu)
[Chen15] Chen, C.-Y., et al., "RRAM Defect Modeling and Failure Analysis Based on March Test and a Novel Squeeze-Search Scheme," *IEEE Trans. Computers*, Vol. 64, No. 1, pp. 180-190, January 2015.

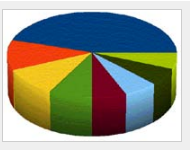
Poster Presentation Tips



Here are some guidelines for preparing your research poster. The idea of the poster is to present your research results and conclusions thus far, get oral feedback during the session from the instructor and your peers, and to provide the instructor with something to comment on before your final report is due. Please send a PDF copy of the poster via e-mail by midnight on the poster presentation day.

Posters prepared for conferences must be colorful and eye-catching, as they are typically competing with dozens of other posters for the attendees' attention. Here is an **example of a conference poster**. Such posters are often mounted on a colored cardboard base, even if the pages themselves are standard PowerPoint slides. In our case, you should aim for a "plain" poster (loose sheets, to be taped to the wall in our classroom) that conveys your message in a simple and direct way. Eight to 10 pages, each resembling a PowerPoint slide, would be an appropriate goal. You can organize the pages into 2 x 4 (2 columns, 4 rows), 2 x 5, or 3 x 3 array on the wall. The top two of these might contain the project title, your name, course name and number, and a very short (50-word) abstract. The final two can perhaps contain your conclusions and directions for further work (including work that does not appear in the poster, but will be included in your research report). The rest will contain brief description of ideas, with emphasis on diagrams, graphs, tables, and the like, rather than text which is very difficult to absorb for a visitor in a very limited time span.

Grade Statistics



All grades listed are in percent, unless otherwise noted.
HW1 grades: Range = [70, 98], Mean = 88, Median = 90
HW2 grades: Range = [65, 88], Mean = 79, Median = 83
HW3 grades: Range = [55, 98], Mean = 77, Median = 76
HW4 grades: Range = [63, 94], Mean = 79, Median = 80
Overall homework grades: Range = [68, 92], Mean = 81, Median = 83
Midterm exam grades: Range = [47, 91], Mean = 70, Median = 73
Research paper grades: Range = [55, 90], Mean = 76, Median = 85
Course letter grades: Range = [B, A+], Mean = 3.6, Median = 3.7

References

Required text: B. Parhami, *Dependable Computing: A Multilevel Approach*, chapters will be posted as they are updated. Please visit the **textbook's web page** for general information. Lecture slides are also available there.

Some useful books (not required):

Koren/Krishna, *Fault-Tolerant Systems*, Morgan Kaufmann, 2007 (ISBN 0-12-088525-5)
Shooman, *Reliability of Computer Systems and Networks*, Wiley, 2002 (ISBN 0-471-29342-3)
Siewiorek/Swarz, *Reliable Computer Systems*, Digital Press, 1992 (ISBN 1-55558-075-0)
Johnson, *Design and Analysis of Fault-Tolerant Digital Systems*, Addison Wesley, 1989 (ISBN 0-201-07570-9)

Research resources:

Proc. IEEE/IFIP Int'l Conf. Dependable Systems and Networks (DSN), formerly known as Fault-Tolerant Computing Symp. (FTCS), annual, since 1971.
IEEE Trans. Dependable and Secure Computing, quarterly journal, published since 2004
IEEE Trans. Reliability, Quarterly journal, published since 1955
IEEE Trans. Computers, monthly journal, published since 1952
UCSB library's electronic journals, collections, and other resources

Miscellaneous Information

Motivation: Dependability concerns are integral parts of engineering design. Ideally, we would like our computer systems to be perfect, always yielding timely and correct results. However, just as bridges collapse and airplanes crash occasionally, so too computer hardware and software cannot be made totally immune to unpredictable behavior. Despite great strides in component reliability and programming methodology, the exponentially increasing complexity of integrated circuits and software systems makes the design of prefect computer systems nearly impossible. In this course, we study the causes of computer system failures (impairments to dependability), techniques for ensuring correct and timely computations despite such impairments, and tools for evaluating the quality of proposed or implemented solutions.

Catalog entry: **257A. Fault-Tolerant Computing. (4) PARHAMI.** *Prerequisites: ECE 154. Lecture, 3 hours*. Basic concepts of dependable computing. Reliability of nonredundant and redundant systems. Dealing with circuit-level defects. Logic-level fault testing and tolerance. Error detection and correction. Diagnosis and reconfiguration for system-level malfunctions. Degradation management. Failure modeling and risk assessment.

History: Professor Parhami took over the teaching of ECE 257A in the fall quarter of 1998. Previously, the course had been taught primarily by Dr. John Kelly, who instituted the two-course sequence ECE 257A/B, the first covering general topics and the second (now discontinued) devoted to his research focus on software fault tolerance. Borrowing from his experience in teaching dependable computing at other universities and based on an extensive survey of the field that he published in 1994, Professor Parhami oriented the course toward an original multilevel view of impairments to computer system dependability and techniques for avoiding or tolerating them. The levels of this models, in increasing order of abstraction, are: defects, faults, errors, malfunctions, degradations, and failures. A textbook based on this multilevel model of dependable computing is in preparation.

Offering of ECE 257A in fall 2016 (PDF file)
Offering of ECE 257A in fall 2015 (PDF file)
Offering of ECE 257A in winter 2015 (PDF file)
Offering of ECE 257A in fall 2013 (PDF file)
Offering of ECE 257A in fall 2012 (PDF file)

Offering of ECE 257A in fall 2009 (PDF file)
Offering of ECE 257A in fall 2007 (PDF file)
Offerings of ECE 257A in 1998 and 2006 (PDF file)
