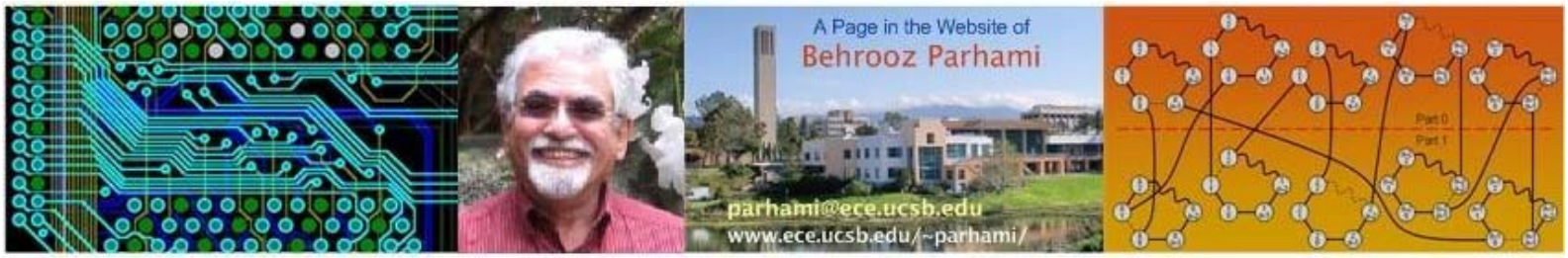

- Home & Contact
- Curriculum Vitae
- Research
  - Computer arithmetic
  - Parallel processing
  - Fault tolerance
  - Broader research
  - Research history
  - List of publications
- Teaching
  - ECE1 Freshman sem
  - ECE154 Comp arch
  - ECE252B Comp arith
  - ECE252C Adv dig des
  - ECE254B Par proc
  - ECE257A Fault toler
  - Student supervision
  - Math + Fun!
- Textbooks
  - Computer arithmetic
  - Parallel processing
  - Dependable comp
  - Comp architecture
  - Other books
- Service
  - Professional activities
  - Academic service
  - Community service
  - Industrial consulting
- Files & Documents
- Useful Links
- Personal

Behrooz Parhami's ECE 257A Course Page for Fall 2015

Fault-Tolerant Computing

Page last updated on 2015 December 10

Enrollment code: 50799
Prerequisite: ECE 154 (or equivalent)
Class meetings: MW 10:00-11:30, HSSB 3202
Instructor: Professor Behrooz Parhami
Open office hours: MW 12:30-2:00; 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%, and final, worth 40%
Research paper: Not applicable to fall 2015
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

2015/12/09: The fall 2015 offering of ECE 257A is officially over. Final exam papers have been graded and course grades have been assigned. After a final review and check tomorrow morning, course grades will be reported to the Registrar's Office by noon. I will be seeing some of you in my graduate course ECE 254B (Advanced Computer Architecture: Parallel Processing) next quarter. My winter 2016 office hours will be the same as this quarter's: MW 12:30-2:00. I wish all of you an enjoyable winter break and a happy holiday season!

2015/11/27: It appears that, due to a misunderstanding, some students thought that our W 11/25 class, rather than the W 12/02 class, is cancelled. Please read the announcement after this one. If you have questions regarding chapters 26 and 28, covered on W 11/25, please see me during my office hours. I have added some material to the text and slides for part VII and reposted them to the textbook's Web page. For HW 4, please note that all IEEE and ACM publications are accessible to you via UCSB Library's Web site, under 'Electronic Journals.'

2015/11/24: Dead week changes: I will move the lecture originally scheduled for W 12/02 to M 11/30 and cancel our class on Wednesday 12/02. However, HW4 is still due on W 12/02. You can slip your paper under my office door up to 12:30 PM (the start of my office hour) on 12/02. No homework will be accepted after 12:30 PM. I will hold extra office hours from 10:00 AM to 12:00 noon on F 12/04 for any last-minute questions before our final exam on M 12/07, 8:30-11:00 AM, in our regular classroom.

2015/11/21: Homework 4 has been posted to the homework area below. Lecture slides and text for chapters 25-28 and the appendix have also been updated for fall 2015. The appendix may undergo more changes, in which case I will announce the updates here in about a week.

2015/11/15: Updated lecture slides and text for chapters 21-24 have been posted to the textbook's Web page. The next updates and HW4 should appear no later than Saturday 11/21.

2015/11/09: While we were discussing RAID storage concepts in class, a question was raised about the relevance of those ideas to new SSD storage options. Even though SSD storage has different failure mechanisms (they contain no moving parts subject to mechanical failure, but suffer from higher error rates and

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limited erase counts), applicable high-level concepts are pretty much the same. Here is a good reference about the issues involved in designing SSD RAIDS.
Jeremic, N., G. Muhl, A. Busse, and J. Richling, "The Pitfalls of Deploying Solid-State Drive RAIDs," *Proc. 4th Int'l Conf. Systems and Storage*, Article No. 14, 2011.
This **on-line article** provides a good overview of the problems and of products available in the market.
2015/11/03: Midterm exam papers have been graded and Homework 3 has been posted to the homework area below. Updated lecture slides and text for chapters 17-20 have been posted to the textbook's Web page.
2015/10/25: Updated lecture slides and text for chapters 13-16 have been posted to the textbook's Web page. The next updates should appear no later than Sunday 11/01.
2015/10/17: Homework 2 has been posted to the homework area below. Updated lecture slides and text for chapters 9-12 have been posted to the textbook's Web page. We are now up to date on all the material needed for our open-book midterm exam, to be held on M 11/02.
2015/10/11: Updated lecture slides and text for chapters 5-8 have been posted to the textbook's Web page. Material for chapters 9-12, as well as HW2, will be posted no later than Sunday 10/18.
2015/10/02: Homework 1 has been posted to the homework area below. If you have not yet e-mailed or turned in the completed introductory survey to the instructor, please do so by class time on M 10/5.
2015/09/23: Welcome to the ECE 257A web page for fall 2015. Thus far, 19 students have signed up for the class and I look forward to meeting you all on Monday 9/28. I will be updating and improving the on-line course textbook and lecture slides as we go through the fall quarter. Please pay attention to the associated posting date when downloading material for the course. The first set of lecture slides for chapters 0-4 will be updated no later than Sunday 9/27.

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 09/28 (0-1) Background and motivation
W 09/30 (1-2) Dependability attributes

M 10/05 (3) Combinational modeling [HW1 posted, chs. 1-4]
W 10/07 (4) State-space modeling

M 10/12 (5, 7) Defect avoidance; Shielding and hardening
W 10/14 (6, 8) Defect circumvention; Yield enhancement [HW1 due]

M 10/19 (9, 11) Fault testing; Design for testability [HW2 posted, chs. 5-12]
W 10/21 (10, 12) Fault masking; Replication with voting

M 10/26 (13, 15) Error detection; Self-checking modules
W 10/28 (14, 16) Error correction; Redundant disk arrays [HW2 due]

M 11/02 (1-12) Midterm exam, open-book/notes, 10:00-11:45 (note the extended time)
W 11/04 (17, 19) Malfunction diagnosis; Standby redundancy [HW3 posted, chs. 13-20]

M 11/09 (18, 20) Malfunction tolerance; Robust parallel processing
W 11/11 Veterans Day holiday; no lecture

M 11/16 (21, 23) Degradation allowance; Resilient algorithms
W 11/18 (22, 24) Degradation management; Software redundancy [HW3 due]

M 11/23 (25, 27) Failure confinement; Agreement and adjudication [HW4 posted, chs. 21-28]
W 11/25 (26, 28) Failure recovery; Fail-safe systems

M 11/30 Catching up and big-picture review {Instructor and course evaluations}

W 12/02 Brief survey of current research in the field [HW4 due]

M 12/07 (13-28) Final exam, open-book/notes, 8:30-11:00
W 12/16 {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 2015/10/14, 10:00 AM)
Do the following problems from the textbook: 1.20, 2.23, 2.25, 3.12, 4.22

Homework 2: Defects and faults (ch. 5-12, due W 2015/10/28, 10:00 AM)
Do the following problems from the textbook: 5.4, 6.8, 8.2, 9.6, 10.2, 12.5

Homework 3: Errors and malfunctions (ch. 13-20, due W 2015/11/18, 10:00 AM)
Do the following problems from the textbook: 13.1, 14.7ab, 16.5, 17.8, 19.2, 20.5

Homework 4: Degradations and failures (ch. 21-28, due W 2015/12/02, 10:00 AM)
Do the following problems from the textbook: 21.4, 23.2, 24.6, 24.10, 27.6, A.2
Here is reference [Sava15] needed for Problem 24.10: Savage, N., "Split Second," *Communications of the ACM*, Vol. 58, No. 9, pp. 12-14, September 2015. [**Link**]

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)
Problems 15.5, 17.1, 21.2, and 27.3 from the textbook.

Final Exam Study Guide
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

[*Not applicable to the fall 2015 offering.*] 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: 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.

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: TBD)
[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: TBD)
[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: TBD)
[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: TBD
[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: TBD)
[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.

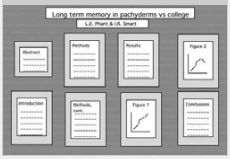
9. Synthesis of Interconnection Networks with Maximal Diagnosability (Assigned to: TBD)
[Chan05] Chang, G.-Y., G. J. Chang, and G.-H. Chen, "Diagnosabilities of Regular Networks," *IEEE Trans. Parallel and Distributed Systems*, Vol. 16, No. 4, pp. 314-323, April 2005

Topics outside the main theme for the quarter

10. Software Fault Monitoring (assigned to: TBD)
[Delg04] Delgado, N., A. Q. Gates, and S. Roach, "A Taxonomy and Catalog of Runtime Software-Fault Monitoring Tools," *IEEE Trans. Software Engineering*, Vol. 30, No. 12, pp. 859-872, December 2004

Poster Presentation Tips

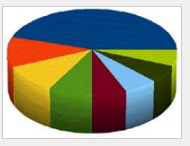
Here are some guidelines for preparing your research poster. The idea of the poster is to present your research results and conclusions thus far, get oral feedback during the session from the instructor and your peers, and to provide the instructor with something



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 = [48, 90], Mean = 71, Median = 72, SD = 12
HW2 grades: Range = [74, 100], Mean = 92, Median = 93, SD = 8
HW3 grades: Range = [51, 89], Mean = 80, Median = 82, SD = 10
HW4 grades: Range = [91, 100], Mean = 96, Median = 95, SD = 3
Midterm exam grades: Range = [50, 97], Mean = 74, Median = 75, SD = 14
Final exam grades: Range = [57, 88], Mean = 76, Median = 78, SD = 8
Course letter grades: Range = [B, A+], Mean = 3.6, Median = A–, SD = 0.4

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 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)