ECE 753 - FAULT-TOLERANT COMPUTING
(Spring 2013-14)

Examination

CLOSED BOOK

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Date: April 15, 2014
Location: Room 1153 Mechanical Engineering
Time: 7:15 PM
Duration: 100 Minutes

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Show your work carefully for both full and partial credit. You will be given credit only for what appears on your exam.

Last Name (Please print): ________________________________
First Name: __________________________________________
ID Number: __________________________________________
1. (15 points) Concepts and Definitions

(a) (2 points) Bathtub curve is often used to describe the relation between failure rate to time and it is divided into three phases. Name these three phases.

(b) (2 points) Briefly explain the distinction between NMR redundancy with spare and self-purging redundancy. Use an example starting with 5 modules. Limit your answer the space provided and be legible.

(c) (8 points) Using data over a number of years, the failure density function of a certain class of electronic components is estimated to be \( f(t) = 0.1250 - 0.0031250t \), where \( t \) is measured in years

i. what is the range for \( t \)?

ii. Calculate the reliability function \( R(t) \) for these components.

iii. Calculate the the hazard function \( z(t) \) for these components.
(d) \textbf{(1.5 points)} What is the latency of fault detection?

(e) \textbf{(1.5 points)} What is an \textit{orphan message}?
2. (9 points) Self Checking

Two bits of data $i_1, i_2$ are to be transmitted from point A to B. For reliability reasons the data is encoded using a (4,2) code and transmitted over four parallel lines. The code used is duplication and complementation of data. The two data bits $i_1, i_2$ are encoded as $i_{1a}, i_{1b}, i_{2a} i_{2b}$. In this $i_{1a} = i_1$ and $i_{1b} = \overline{i_1}$, similarly $i_{2a} = i_2$ and $i_{2b} = \overline{i_2}$. At the destination two possible architectures are under consideration for checking the correctness of the received data. These architectures are shown in Figure 1 (a) and (b). It is assumed that the only faults that can occur are single stuck-at faults. Answer the following:

![Figure 1: Two architectures for a (4,2) code checker](image)

(a) What are the code outputs?

(b) What are the non-code outputs?

(c) Is the checker design self-testing? Explain.

(d) Is the checker design fault-secure? Explain.
In the architecture shown in figure 1(b)

(a) What are the code outputs?

(b) What are the non-code outputs?

(c) Is the checker design self-testing? Explain.

(d) Is the checker design fault-secure? Explain.

(e) Is the checker design totally self-checking? Explain.
3. **(11 points)** Testing and test generation

Consider the combinational circuit of Figure 2 with six inputs and two outputs.

![Circuit Diagram](image)

**Figure 2: Circuit for test generation**

(a) **(2 points)** Which primary inputs may have to be assigned values if we were to find a test for the fault **line 10 stuck-at 0**.

(b) **(1 point)** What assignment at the primary input 2 will excite the fault **line 10 stuck-at 0**.

(c) **(4 points)** List all input combinations that can excite the fault **stuck-at 0 at line 16**. You must show your work.
(d) (2 points) Assuming that the fault **stuck-at 0 at line 14** has already been excited by assigning 0 to input 6 and a 1 to input 9. What additional primary input(s) may have to be assigned values to propagate the effect of this fault to some output. You must show your work and reasoning. You need not find the test yet.

(e) (2 points) Find a test for the fault **stuck-at 0 at line 14**. You must show your work.
4. (12 points) Reliability modeling (Reliability Block Diagram)

Reliability block diagram of a non series parallel system is shown in Figure 3 below. In this diagram the module “b” is a bidirectional module.

![Reliability Block Diagram](image)

**Figure 3: Reliability block diagram of a system**

(a) (8 points) Assume that the reliability of each module is R except the module labeled “b”. Now draw the reliability block diagram of the system in which module “b” is always operational. Thus the block diagram will not have module “b” in it. Now compute the reliability of the system in which module “b” is always operational (never fails). You must show your work. No credit will be given if you do not show your work.
(b) (4 points) Now assume that the reliability of the module “b” is $R_b$. Compute the upper bound on the reliability of the original system give in Figure 3 by first listing all the parallel paths and then writing the reliability expression. You need not simplify the expression.
5. **(14 points) Reliability modeling (Markov Model)**

A fault tolerant system is modeled as in Figure 4. In this model the three states of the system are, *Op, Test, and Rep.*

![Diagram of Markov model of a fault tolerant system](image)

*(a) **(5 points)** Write the three differential equations that must be solved to determine the instantaneous availability of the system.*

*(b) **(2 points)** Write the Matrix A*
(c) (3 points) If the above system is defined as down when it is in state Rep, and it is up otherwise, draw its Markov model for the purpose of computing reliability.

(d) (4 points) Compute the system reliability and MTTF assuming that the initial state of the system is Test.
6. (11 points) System level diagnosis
   Answer the following and be brief.

   (a) (5 points) Show that the system of five units given in Figure 5 is NOT 1-fault one-step diagnosable.

   ![Figure 5: A system with 5 units.](image-url)
(b) (6 points) Consider a sequentially three fault diagnosable system with 8 units shown in Figure 6. The figure also contains a syndrome when a set of three (or fewer) faults are present in this system.

Figure 6: Sequentially diagnosable system with 10 units.

i. Identify as many fault free units as you can in this system. You must give your reason otherwise no points will be awarded.

ii. Identify as many faulty units as you can in this system. You must give your reason otherwise no points will be awarded.
7. (14 points) Error detection and correction coding

(a) (3 points) A linear block code has minimum Hamming distance of 5. Which of the following are true for this code:

- This code can detect 5 errors and correct 0 error
- This code can detect 4 errors and correct 1 error
- This code can detect 4 errors and correct 0 error
- This code can detect 3 errors and correct 2 errors
- This code can detect 3 errors and correct 1 error
- This code can detect 2 errors and correct 2 errors

(b) (4 points) A (9,6) linear block code with six information bits; $i_1, i_2, i_3, i_4, i_5, i_6$; and three parity bits; $p_1, p_2, p_3$; uses the following three equations to realize the three parity bits:

\[
\begin{align*}
p_1 &= \text{even parity over even number information bits} \\
p_2 &= \text{even parity over odd number information bits} \\
p_3 &= \text{even parity over the information bits } i_1, i_2, i_5, i_6
\end{align*}
\]

Write its parity check matrix in systematic form in the following table. For your convenience I have completed the last three columns (identity) part of the matrix.

\[
H = \begin{bmatrix}
i_1 & i_2 & i_3 & i_4 & i_5 & i_6 & p_1 & p_2 & p_3 \\
1 & 0 & 0 & & & & & & \\
0 & 1 & 0 & & & & & & \\
0 & 0 & 1 & & & & & & 
\end{bmatrix}
\]

(c) (1 points) Is the above (9,6) code a single error correcting code? Give reason.
(d) (6 points) The parity check matrix $H$ of a (12,8) linear block code, obtained by shortening a (15,11) Hamming code, is given below:

$$H = \begin{bmatrix}
i_1 & i_2 & i_3 & i_4 & i_5 & i_6 & i_7 & i_8 & p_1 & p_2 & p_3 & p_4 \\
1 & 0 & 1 & 0 & 1 & 0 & 1 & 1 & 1 & 0 & 0 & 0 \\
0 & 1 & 0 & 1 & 0 & 1 & 1 & 1 & 0 & 1 & 0 & 0 \\
1 & 1 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 1 & 0 \\
1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1
\end{bmatrix}$$

Clearly this is a single error correcting code.

i. (2 points) Using this encode the following 8 bit information word into a 12 bits encoded word.

Information word = 1 0 1 1 0 0 1 0

Encoded word =

ii. (2 points) A code word that was obtained by the above (12,8) code was corrupted due a single error and was received as:

Received word = 0 0 0 0 1 1 0 0 0 1 0 1

Compute its syndrome and find the correct code word.

iii. (2 points) A code word that was obtained by the above (12,8) code was corrupted and was received as:

Received word = 0 1 1 0 1 1 0 0 1 1 0 1

Compute its syndrome and deduce the correct code word. If you can not deduce the correct code word, give reason why not.
8. *(14 points)* Checkpointing and recovery

Answer the following.

(a) *9 points* Consider a program that takes 20 hours to complete if no failure occurs during its execution. Now assume that the system suffers from transient failures according to Poisson process and failure rate is 0.005 failures per hour.

i. *(3 points)* What will be the expected execution time for this program with the above failure rate?

ii. *(4 points)* What will be the expected execution time for this program if a checkpoint was taken at 6 hours? Assume that there is no overhead and latency, and recovery is instantaneous.

iii. *(2 points)* Will this time increase or decrease as the checkpoint is moved to a later time? Give your reason(s).
(b) **(3 points)** A system of three processes takes un-coordinated checkpoints as shown in Figure 7. Determine the recovery line if process P2 fails at the point shown.

![Figure 7: Three processes taking checkpoints](image)

(c) **(2 points)** Identify a *useless* checkpoint in the checkpoints shown in Figure 7. Give reason as to why it is a *useless* checkpoint.