Name: ________________________ Student ID: ______________________

National Taiwan Normal University
Department of Computer Science and Information Engineering

CSC0056 - Data Communication
Midterm Exam (Nov. 4, 2019)

(Four group questions; 100 points in total; exam time: 2 hours 50 minutes (9:20am-12:10pm))

1. (25 points) **Error detection code.** Answer the following two questions:
   1a. Using the CRC algorithm with the generator polynomial $g(D)=D^4+D^2+D+1$ and 4 bits for parity check bits, answer the following questions assuming that the data bits are represented as a polynomial $s(D)=D^5+D^4+D^2+1$:
      1.a.1 (5 points) Compute the CRC polynomial c(D), which represents the parity check bits.
      1.a.2 (5 points) Show the code word in terms of polynomial x(D) at the data sending side.
      1.a.3 (5 points) If the data receiving side got the code word 1101011011, will the CRC say that there is an error or will it say that the data is correct? Also, show the quotient polynomial z(D) resulting from the division the CRC performed at the receiving side.
   1b. (10 points) Explain why the minimum distance of a parity check code using "horizontal and vertical parity checks" is 4.

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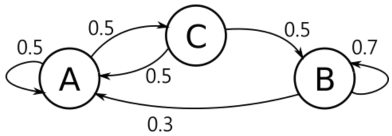
2. (15 points) **Markov chain.** Answer two questions for the following three-state Markov chain:
   2a. (5 points) Create and show the corresponding transition probability matrix.
   2b. (10 points) Compute the stationary distribution for each state.



3. (20 points) **Little's Theorem and Queueing systems.** Consider an Internet-of-Things (IoT) base station which takes 300 independent Poisson data streams from IoT devices and sends all data to a virtual machine in a cloud platform via one communication link. A property of Poisson process states that if multiple independent Poisson processes are merged into a single process, the latter process is Poisson with a rate equal to the sum of the rates of its components. Accordingly, the sending stream of the IoT base station is Poisson with rate λ being the sum of the rates of each data streams from IoT devices. Answer the following two questions:
   3a. (10 points) Using statistical multiplexing, the data link layer and the physical layer in the IoT base station can be modeled as a M/M/1 queueing system. Suppose the transmission times of packets are exponentially distributed with mean 10 milliseconds:
      3.a.1 (4 points) What is the average time a packet spent in this M/M/1 if λ=10 packets/second?
      3.a.2 (3 points) What is the average time a packet spent in this M/M/1 if λ=90 packets/second?
      3.a.3 (3 points) Suppose the propagation delay to the cloud is 30 milliseconds. In order to shorten the overall latency, will you choose to reduce the propagation delay or to improve the service rate in that M/M/1? Give one reason.
   3b. (10 points). Now suppose that we setup the IoT base station to have two communication links to the cloud and we assume that the system becomes a M/M/2 with arrival rate λ=90 packets/second, and the transmission times of packets on each link are exponentially distributed with mean 20 milliseconds, respectively.
      3.b.1 (5 points) What is the probability that the system is empty at a certain given point of time?
      3.b.2 (5 points) What is the average time a packet waited in queue before starting transmission?

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4. (40 points) **Comprehensive understanding.** For each of the following questions, explain as much as you can in no more than five English sentences, and you may use formula and/or drawing whenever you find it helpful:
   - 4a. (5 points) Describe one difference between circuit switching and packet switching.
   - 4b. (10 points) Consider a scenario where one data sender sends data to a data receiver over a physical channel. Give two technical reasons that the data received at the receiving side might differ from the data sent at the sending side, which lead to our conclusion in class that physical channels can be simply regarded as unreliable bit pipes by the higher layer.
   - 4c. (15 points) In our study of the ARQ protocols, each of the stop-and-wait, go-back-N, and selective-repeat ARQs we have covered is a class of algorithms, which means that each of the three has several versions depending on our choice of configuration. Nevertheless, the same core concepts that set the three classes apart from each other remain unchanged. Now, answer the following two questions and explain your answer:
     - 4.c.1 (10 points) In what sense the go-back-N ARQ is better than the stop-and-wait ARQ?
     - 4.c.2 (5 points) In what sense the selective-repeat ARQ is better than the go-back-N ARQ?
   - 4d. (10 points) In our study of queueing systems, we covered both the Poisson process and the exponential distribution as two key elements. Answer the following two questions:
     - 4.d.1 (5 points) Give one reason why the Poisson process is a good and widely used model for describing data arrivals in networks such as those for Internet of Things.
     - 4.d.2 (5 points) Explain the memoryless property in the exponential distribution.

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Summary of results, from the required textbook for this course:

Notation

p_n = Steady-state probability of having n customers in the system

λ = Arrival rate (inverse of average interarrival time)

μ = Service rate (inverse of average service time)

N = Average number of customers in the system

N_Q = Average number of customers waiting in queue

T = Average customer time in the system

W = Average customer waiting time in queue (does not include service time)

$\overline{X}$ = Average service time

Little's Theorem

$$N = \lambda T$$

$$N_Q = \lambda W$$

Poisson distribution with parameter *m*

$$p_n = \frac{e^{-m} m^n}{n!}, \quad n = 0, 1, \ldots$$

$$\text{Mean} = \text{Variance} = m$$

Exponential distribution with parameter λ

$$P\{\tau \le s\} = 1 - e^{-\lambda s}, \qquad s \ge 0$$

$$\text{Density: } p(\tau) = \lambda e^{-\lambda \tau}$$

$$\text{Mean} = \frac{1}{\lambda}$$

$$\text{Variance} = \frac{1}{\lambda^2}$$

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Summary of $M/M/1$ system results

1. Utilization factor (proportion of time the server is busy)
$$\rho = \frac{\lambda}{\mu}$$
2. Probability of n customers in the system
$$p_n = \rho^n(1-\rho), \qquad n = 0, 1, \ldots$$
3. Average number of customers in the system
$$N = \frac{\rho}{1-\rho}$$
4. Average customer time in the system
$$T = \frac{\rho}{\lambda(1-\rho)}$$
5. Average number of customers in queue
$$N_Q = \frac{\rho^2}{1-\rho}$$
6. Average waiting time in queue of a customer
$$W = \frac{\rho}{\mu-\lambda}$$

Summary of $M/M/m$ system results

1. Ratio of arrival rate to maximal system service rate
$$\rho = \frac{\lambda}{m\mu}$$
2. Probability of n customers in the system
$$p_0 = \left[\sum_{k=0}^{m-1} \frac{(m\rho)^k}{k!} + \frac{(m\rho)^m}{m!(1-\rho)}\right]^{-1}, \qquad n = 0$$
$$p_n = \begin{cases} p_0 \dfrac{(m\rho)^n}{n!}, & n \le m \\ p_0 \dfrac{m^m \rho^n}{m!}, & n > m \end{cases}$$
3. Probability that an arriving customer has to wait in queue (m customers or more in the system)
$$P_Q = \frac{p_0(m\rho)^m}{m!(1-\rho)}$$ (Erlang C Formula)
4. Average customer time in the system
$$T = \frac{1}{\mu} + \frac{\rho P_Q}{\lambda(1-\rho)}$$
5. Average number of customers in the system
$$N = m\rho + \frac{\rho P_Q}{1-\rho}$$