Specialized Subjects

15:00-17:30, Monday, August 19, 2019

Instructions

1. Do not open this booklet before the examination begins.

2. This booklet contains five problems. The number of pages is five excluding this cover sheet and blank pages. If you find missing or badly printed pages, ask the proctor for exchange.

3. Answer three problems. You can select any three out of the five. Your answer to each problem should be written on a separate sheet. You may use the reverse side of the sheet if necessary.

4. Fill the top parts of your three answer sheets as instructed below. Before submitting your answer sheets, make sure that the top parts are correctly filled.

専　門　科　目

第　　問

↑ Write the problem No.

受験番号				

↑ Write the examinee No.

5. Submit all the three answer sheets with the examinee number and the problem number, even if your answer is blank.

6. Answer either in Japanese or in English.

7. This booklet and the scratch paper must be returned at the end of the examination.

8. This English translation is supplemental and provided for convenience of applicants. The Japanese version is the formal one.

Problem 1

Consider a circuit of an up-converter, consisting of a constant voltage supply (voltage E), a switch (denoted by SW), a diode (denoted by D), a coil (inductance L), a condenser (capacitance C), and terminals as shown in the figure. Let t be the time, $i(t)$ be the current of the coil, and $v(t)$ be the voltage between the terminals (as for the directions, refer to the figure). Assume that $i(0) = 0$ and $v(0) = E$ at $t = 0$, and that the forward voltage of the diode is negligible. Answer the following questions.

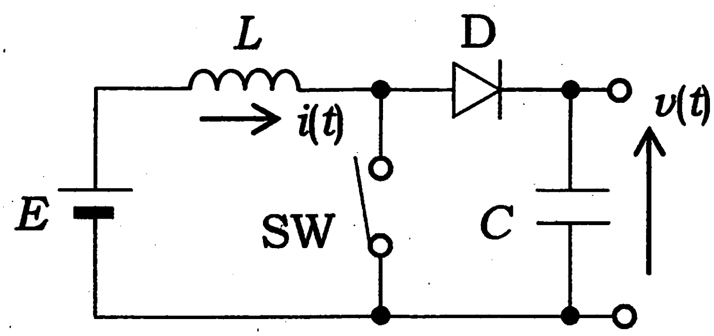
(1) Let us short the switch for duration T_0 from $t = 0$. Find $i(t)$ for $0 \leq t < T_0$.

(2) Let us open the switch at $t = T_0$. We denote by T_1 the duration for $i(t)$ to return to 0. Find $i(t)$ for $T_0 \leq t < T_0 + T_1$, and find T_1.

We repeat the operation described above (short the switch for duration T_0, and then open it for duration T_1) n times from $t = 0$. T_0 and T_1 are constants, and n is an integer larger than or equal to 1.

(3) Describe qualitatively that if $i(T_0 + T_1) = 0$, then $i(n(T_0 + T_1)) = 0$.

(4) Find $v(n(T_0 + T_1))$.



Problem 2

Let us design a circuit that obtains a 4-bit signed integer $Y_{3..0}$ by calculating 4-bit addition/subtraction of a 4-bit signed integer $A_{3..0}$ and a 2-bit signed integer $B_{1,0}$. The integers A, B, and Y are expressed in two's complement. The types of logic gates that you can use are NOT, AND, OR, and XOR, each of which is equipped with as many inputs as the design requires. Answer the following questions.

(1) Show the maximum and minimum values of A and B in decimal form.

(2) Show a circuit that calculates $A + B$ to obtain Y by combining logic gates. Organize the adder as a ripple carry adder. You can use signals from $A_{3..0}$, $B_{1,0}$, supply voltage V_{DD}, and grounding voltage GND as inputs. The output should be $Y_{3..0}$. To simplify the diagram, use the "half-adder" blocks and the "full-adder" blocks after showing gate-level designs of both blocks.

(3) Consider adding an overflow detection mechanism to the circuit designed in (2). Show the overflow detection circuit by combining the logic gates. You can use signals from $A_{3..0}$, $B_{1,0}$, and $Y_{3..0}$ as inputs. The output should be a 1-bit signal named D; it should be '1' when the overflow occurred, or '0' otherwise.

(4) Show a circuit that calculates $A - B$ to obtain Y by combining logic gates. Organize the adder as a ripple carry adder. You can use signals from $A_{3..0}$, $B_{1,0}$, V_{DD}, and GND as inputs. The output should be $Y_{3..0}$. Use the "half-adder" blocks and the "full-adder" blocks in (2).

(5) Show all the input patterns that cause overflows for the calculation designed in (4).

Problem 3

Let A be an N-element array that contains each of the non-negative integers less than $M(\geq 2)$ at least once. Among the subarrays of A, $A_i^j := A[i \mathinner{..} j-1]$ $(0 \leq i < j \leq N)$, that contain each of the non-negative integers less than M at least once, you want to find the shortest one. If there are more than one such subarrays, you obtain the one with the largest start position. For example, given $N = 4$, $M = 2$, and $A = \langle 1, 1, 0, 1\rangle$, you obtain $A_2^4 = \langle 0, 1\rangle$. Answer the following questions.

(1) Consider an algorithm, FIND-SNIPPET, that checks for each subarray of A whether it contains each of the non-negative integer less than M at least once, and then returns the shortest subarray with the largest start position that satisfies the condition.

```
FIND-SNIPPET(N, M, A):
    start = 0
    end = N
    for i = 0 to N − 1 do
        for j = i + 1 to N do
            ┌─────────────┐
            │     (P)     │
            └─────────────┘
    return A_start^end
```

Fill in (P) to complete this pseudocode. Here, you must not exit from for loops using break statements. You can use a function CONTAIN-INTEGERS(M, A, i, j) that checks whether a subarray A_i^j $(0 \leq i < j \leq N)$ contains each of the non-negative integers less than M at least once, and then returns the result as a truth value.

(2) Show the transition of values of i, j, A_{start}^{end}, $start$, and end when the algorithm in (1) is applied to $N = 4$, $M = 2$, and $A = \langle 1, 1, 0, 1\rangle$.

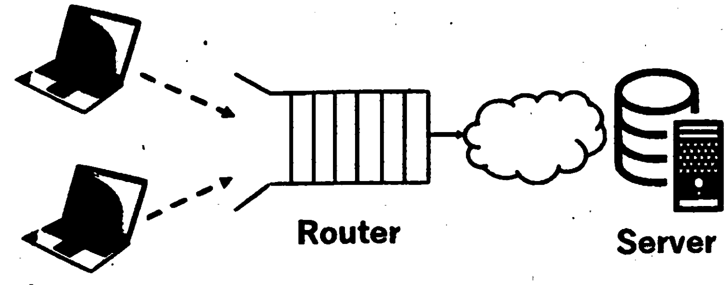
Since FIND-SNIPPET considers all the subarrays of A, it requires the time complexity of $O(N^2)$ and becomes inefficient for large N.

(3) Improve FIND-SNIPPET so that it runs in $O(N)$ and show its pseudocode. Here, you can use CONTAIN-INTEGERS with the assumption that it runs in $O(1)$.

(4) Explain how to realize CONTAIN-INTEGERS that runs in $O(1)$ for the algorithm in (3).

Problem 4

As shown in the figure, IP packets are transferred from two clients to a server. All transferred IP packets are of the same size. The IP packet transmission from the two clients to the router and the IP packet transmission from the router to the server are synchronized, and every IP packet is transmitted in a unit-time T. The router can store N IP packets. When two IP packets arrive at the router and the router cannot store both of them, either of the IP packets is discarded randomly.



(1) The two clients independently generate IP packets with the same probability α $(0 \leq \alpha \leq 1)$. Draw a state transition diagram associated with the number of IP packets buffered in the router.

(2) Obtain the occurrence probability of every state, when $\alpha = 0.5$.

(3) Obtain the IP packet loss probability in (2), when $N = 2$.

(4) Let us change the system so that Client 1 generates and transfers stream-type IP packets (i.e., the IP packets are generated and transferred periodically). In particular, Client 1 transfers one IP packet in every $2T$. Here, the IP packet transmission from Client 2 is the same as (1), and $\alpha = 0.5$ and $N = 2$. Obtain the IP packet loss probability at the router.

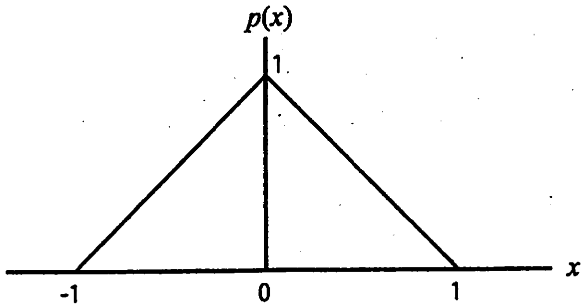
(5) In order to reduce the IP packet loss probability of the stream-type IP packet transmission from Client 1, a forward error correction method is applied. Client 1 generates s redundant IP packets, for the k $(k \geq s)$ IP packets that should be transferred from Client 1 to the server. We assume that the server can correctly decode the k IP packets without IP packet retransmission from Client 1 as long as the number of dropped IP packets in the $k + s$ IP packets sent from Client 1 to the server is smaller than or equal to s.

(a) Obtain the probability, with a formula, that k IP packets from Client 1 are correctly decoded by the server without IP packet retransmission.

(b) Obtain the probability that k IP packets from Client 1 are correctly decoded by the server when $k = 3$ and $s = 1$. Also obtain the probability that k IP packets from Client 1 are correctly received by the server without forward error correction. Here, $\alpha = 0.5$ and $N = 2$.

Problem 5

The output of a discrete-time signal x follows the probability density function $p(x)$ shown in the figure. Answer the following questions. Use $\log_2 3 = 1.58$ and $\log_2 5 = 2.32$.



(1) A quantizer Q_0 quantizes signal x with five levels by uniformly dividing the output range $[-1, 1]$ into five. The quantizer output is represented as q_1, q_2, q_3, q_4, q_5 from the smallest input signal range. Obtain the probability of occurrence of each quantization output.

(2) Obtain the entropy of the quantization output of Q_0.

(3) Obtain a binary code C_0 that is the most efficient in representing the quantization output of Q_0.

(4) Obtain the average code length of C_0.

(5) Obtain the quantization boundaries d_i $(i = 1, 2, 3, 4)$ of the five-level quantizer Q_1 that maximizes the entropy of its output. Quantization operation $Q()$ with the quantization boundaries d_{i-1}, d_i is given by the equation below.

$$Q(d_{i-1} \leq x < d_i) = q_i.$$

Note that $d_0 = -1$ and $d_5 = 1$.

(6) For signal reconstruction, each quantization output q_i is assigned a quantization representative value within its corresponding range. The quantization error is defined as the mean squared error between the values of the original and the reconstruction signals. Show that the quantization representative value $\tilde{x}_i$ which minimizes the quantization error for each quantization output q_i is given by the equation below.

$$\tilde{x}_i = \frac{\int_{d_{i-1}}^{d_i} xp(x)dx}{\int_{d_{i-1}}^{d_i} p(x)dx}.$$

(7) Obtain $\tilde{x}_i$ $(i = 1, 2, 3, 4, 5)$ of the quantizer Q_1.