2012 Summer Entrance Examination

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Creative Informatics

Instructions
1. Do not open this brochure until the signal to begin is given.
2. Write your examinee ID below on this cover.
3. Answer three out of the four problems.
4. Three answer sheets are given. Use a separate sheet for each problem. You may use the backside of the sheet.
5. Write down the examinee ID and the problem ID inside the top blanks of each sheet.
6. Do not take out the sheets and this brochure from this room.

Examinee ID __________________________
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Problem 1

Goods \( G_1, G_2, \ldots, G_n \) have their weights \( a_i \) and value \( c_i \) (\( i = 1, \ldots, n \)), respectively. The problem of packing the maximum total value of goods into a knapsack with a weight limit \( b \) is called the knapsack problem, which can be generally formulated as

[Problem A0]

Maximize \[ c_1x_1 + c_2x_2 + \cdots + c_nx_n \]
Subject to \[ a_1x_1 + a_2x_2 + \cdots + a_nx_n \leq b \]
\( x_i \in \{ 1, 0 \}, \; i = 1, \ldots, n \) (\( x_i = 1 \) when \( G_i \) is packed into the knapsack.)

Here, we specifically consider the following knapsack problem [Problem A1].

[Problem A1]

Maximize \[ 14x_1 + 22x_2 + 30x_3 + 9x_4 + 12x_5 \]
Subject to \[ 2x_1 + 4x_2 + 6x_3 + 2x_4 + 3x_5 \leq 9 \]
\( x_1, \ldots, x_5 \in \{ 1, 0 \} \)

The most straightforward approach to this problem is the enumeration method, in which all the cases are generated and evaluated. Although the number of possible cases in [Problem A1] is \( 2^5 \) and fully within a computable range, this number grows exponentially as the number of possible goods \( n \) increases. Then, we here try to achieve efficient searches through two methods, namely, (1) the branch and bound method and (2) dynamic programming.

(1) Search by the branch and bound method

(1-1) Explain the behavior of the branch and bound method maximizing an objective function, using the following terms:

"branching operation", "sub-problems (child problems)", "incumbent value", "upper bound value", "bounding operation", and "feasible solution"

(1-2) In the knapsack problems, it is convenient if the goods are sorted according to the values per unit weight. In [Problem A1], \( G_1, G_2, \ldots \) are sorted to have higher values per unit weight in this order. A solution of this relaxed problem, where the constraint \( x_i \in \{ 1, 0 \} \) is relaxed to \( 0 \leq x_i \leq 1 \), can be easily obtained with the maximum value \( 14+22+30 \times 0.5 = 51 \) when \( (x_1, x_2, x_3, x_4, x_5) = (1, 1, 0.5, 0, 0) \). This estimate gives an upper bound of the total value for the original knapsack problem with \( x_i \in \{ 1, 0 \} \). Upper bound calculation by employing such relaxed problems can be used also for sub-problems.

In a depth-first search instantiating \( x_1, x_2, \ldots \) to \( \{ 1 \} \) and \( \{ 0 \} \) in this order for [Problem A1], execute a search based on the above branch and bound method to find the solution.

Show the resultant search tree, the goods to be packed into the knapsack \( \{ x_1 \) becoming \( x_1 = 1 \) \) and the maximum total value obtained.
(2) Computation by dynamic programming

We consider here to solve the same knapsack problem by employing dynamic programming. Without a loss of generality, we assume that a_i, b and c in the general problem of [Problem A0] are positive integers. Then we define the following function $F(j,k)$ where j and k are integers with $0 \leq j \leq n$ and $0 \leq k \leq b$.

$F(j,k)$: The maximum total value when limiting the candidates of the goods to $G_1,\ldots,G_j$ which can be packed into the knapsack under the maximum weight constraint $k$.

Apparently, $F(0,k)$ is 0, and in [Problem A1], $F(1,0) = F(1,1) = 0$ and $F(1,2) = F(1,3) = \cdots = F(1,9) = 14$. Eventually, the final answer of the maximum total value for [Problem A1] can be obtained as $F(5,9)$, and the final answer for [Problem A0] can be obtained as $F(n,k)$.


(2-1) Starting from these $F(0,k)$ or $F(1,k)$, we want to get a method of eventually calculating $F(n,b)$ for the general problem of [Problem A0] by incrementing $j$ in sequence. When $F(j-1,k)$ where $0 \leq k \leq b$ are calculated, show a method of calculating $F(j,k)$ as an equation using these $F(j-1,k)$. Here, you can show the equation for convenience by letting $F(j,k) = -\infty$ when $k$ is a negative integer.

(2-2) Using the result of the above question, solve [Problem A1] by calculating cell values of the table shown below in sequence. Show the table with the calculated values $F(j,k)$, goods to be packed into the knapsack, and the maximum total value.

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Table of $F(j,k)$ for [Problem A1]
Problem 2

Packets are transmitted from Host 1 to Host 2, as shown in the figure 1 below. The data packets, sent from Host 1 to Host 2, have identical length, which is M [Bytes]. There are two packet switches (SW1 and SW2) along the transmission path between Host 1 and Host 2. There are not any packets generated by other hosts, nor any packets generated by other applications on Host 1. When a one way packet propagation delay between Host 1 and Host 2 is D[sec] and the transmission bandwidths of three transmission links are B_1, B_2 and B_3 (where B_2 < B_3 < B_1), answer the following questions:

1. In order to achieve error-free data transmission from Host 1 to Host 2, Host 1 transfers data packets to Host 2, while confirming if every data packet is correctly received by Host 2. The following simple algorithm is applied. When a data packet from Host 1 arrives at Host 2, Host 2 sends the acknowledgement packet, called as ACK packet, to Host 1. Here, the size of an ACK packet is m [Bytes], where \( \frac{m}{B_2} < \frac{M}{B_2} \ll D \), so that we can ignore the delay caused by packet transmission/reception at Host 1, Host 2, SW1 and SW2, and Host 1 sends the next data packet right after the reception of an ACK packet from Host 2 with zero latency. Host 2 sends an ACK packet right after the reception of data packet from Host 1 with zero latency. With this system, answer the maximum data transmission throughput from Host 1 to Host 2.

2. In the system described in (1), the data packets are dropped randomly with a probability of \( \rho \). Compute the average latency when the data packet is correctly received by Host 2 after the data packet is sent from Host 1. Here, Host 1 resends the data packet, when Host 1 cannot receive an ACK packet from Host 2, within 3D[sec], and an ACK packet shall not be received by Host 1 after 3D[sec].

3. Before starting data transmission, Host 1 and Host 2 have to perform a data synchronization procedure. Assuming that the synchronized data between the hosts can be transferred with a single packet. Describe the procedure in Host 1 and Host 2 with the state transition diagram or the state transition matrix, when packets can be dropped during packet transmission between them.

4. With the packet transmission algorithm described in (1), we cannot obtain large throughput, when D is large. Propose two methods, so as to improve the throughput, providing their maximum throughput and their required conditions.

![Figure 1](image_url)
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Problem 3

As shown in Figure 1, there is a robot arm which has rotational joints at three points O, E and W, and a two-fingered hand at the end H on an X-Y two-dimensional plane. The position of the hand H is \((h_x, h_y)\) and the orientation of the hand H is \(h_\theta\), the joint angles are \(\theta_1, \theta_2, \) and \(\theta_3\), and the lengths of the links are \(OE = l_1, EW = l_2\) and \(WH = l_3\). Answer the following questions:

1. Write equations for the coordinates \((w_x, w_y)\) of the joint W in terms of the joint angles \(\theta_1\) and \(\theta_2\).

2. As shown in Figure 2, \(\theta(-\pi < \theta \leq \pi)\) is defined as the angle from the axis X to the line OP, where the point P has the coordinates \((x, y)\). Describe the definition of the function \(atan(y, x)\) that calculates \(\theta\) from \((x, y)\) (where \((x, y) \neq (0, 0)\)) using \(\tan^{-1}(a)(-\frac{\pi}{2} \leq \tan^{-1}(a) \leq \frac{\pi}{2})\).

3. Describe the procedure which provides the joint angle \(\theta_1(-\pi < \theta_1 \leq \pi)\) and \(\theta_2(-\pi < \theta_2 \leq \pi)\) from the coordinates \((w_x, w_y)\) of the joint W using \(atan(y, x)\). The procedure should take account of all the constraints on possible values of the joint angles \(\theta_1\) and \(\theta_2\).

4. Write equations for the position \((h_x, h_y)\) and the orientation \(h_\theta\) of the hand H in terms of the joint angles \(\theta_1, \theta_2\) and \(\theta_3\).

5. Describe the procedure which provides the joint angles \(\theta_1(-\pi < \theta_1 \leq \pi), \theta_2(-\pi < \theta_2 \leq \pi)\) and \(\theta_3(-\pi < \theta_3 \leq \pi)\) from the position \((h_x, h_y)\) and the orientation \(h_\theta(-\pi < h_\theta \leq \pi)\) of the hand H.

6. As shown in Figure 3, the hand is located at the point P and two objects are located at Q and R. Explain a method to generate the trajectory of the joint angles of the robot arm to grasp the object Q without colliding with the object R.
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Problem 4

Select four items out of the following eight items concerning information systems, and explain each item in approximately 4～8 lines of text. If necessary, use examples or figures.

(1) Feedback control and feedforward control
(2) Kalman filter
(3) Edge detection methods in image processing (Explain with two examples.)
(4) Monte Carlo method
(5) Learning methods for neural networks (Explain with an example.)
(6) Pipeline hazards (Explain with two examples.)
(7) Microprogram (microcode) control
(8) Merits and demerits of client server systems and P2P systems
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