Specialized Subjects

15:00-17:30, Monday, August 20, 2018

Instructions

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

2. This booklet contains five problems. The number of pages is nine 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

Answer the following questions.

(1) Derive the relationship between the input voltage V_{IN} and the output voltage V_{OUT} of the inverting amplifier circuit in Fig. 1. Here, let us assume that $V_{OUT} = -AV_m$, and the input and the output impedance of the operational amplifier as $R_{IN} = \infty$ and $R_{OUT} = 0$, respectively. Show the derivation process as well.

(2) Derive the relationship between the input voltage V_{IN} and the output voltage V_{OUT} of the circuit in (1) when $A \to \infty$.

(3) In ideal operational amplifiers, we can assume $V_m = 0$ in Fig. 1. Write the technical term for the assumption.

(4) Let us consider a 4-bit digital-analog converter using an ideal operational amplifier (Fig. 2). Derive the resistance of (a)-(c) in the figure when b_3 is the Most Significant Bit (MSB).

(5) Show the output voltage of the circuit in Fig. 2 when the input signal is (b_3, b_2, b_1, b_0), $b_i \in \{0, 1\}$ $(i = 0, \cdots, 3)$.

(6) The circuit in Fig. 3 is also a digital-analog converter. Explain how it works and specify with reasons which switch corresponds to the MSB.

(7) Derive the relationship between R_f and R'_f when the circuits in Figs. 2 and 3 become theoretically equivalent.

(8) Discuss advantages and disadvantages of the circuits in Figs. 2 and 3.

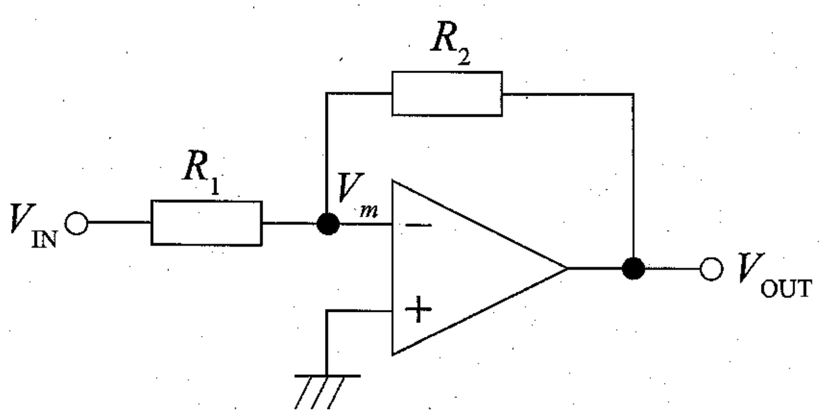


Fig. 1

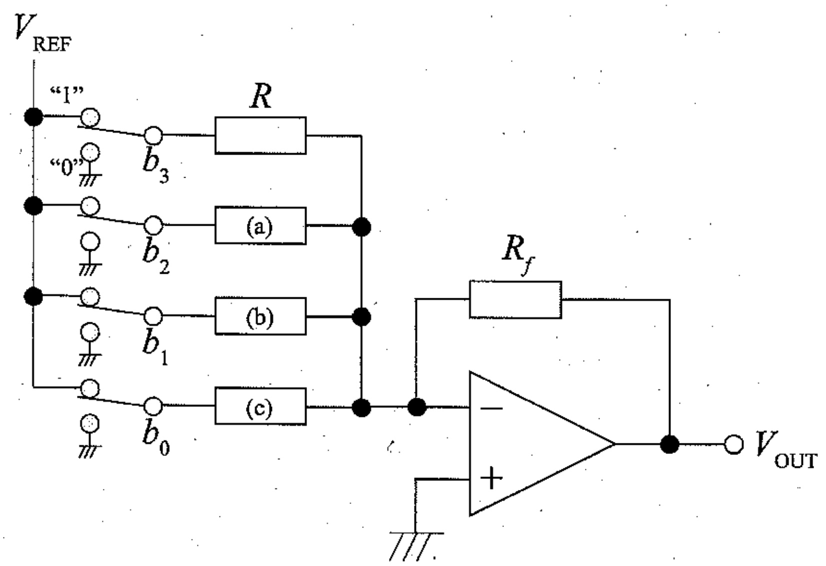


Fig. 2

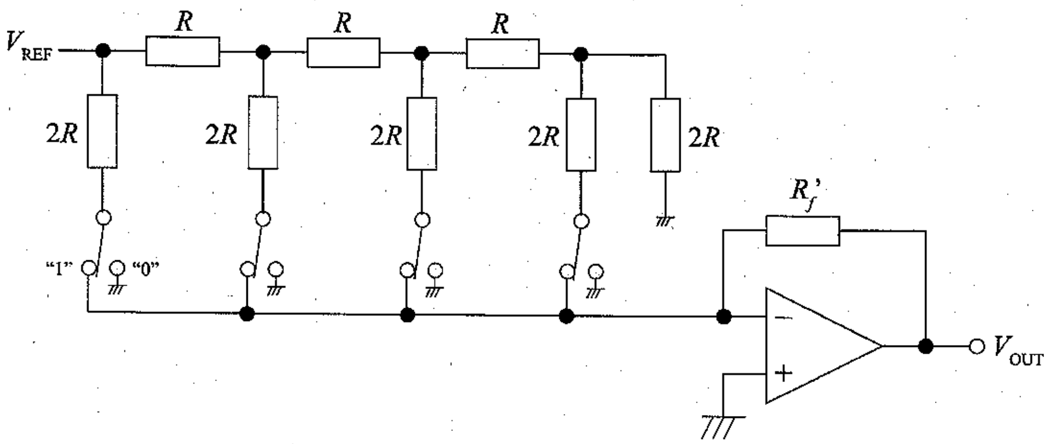


Fig. 3

Problem 2

Virtual memory provides programmers with the illusion that their computers have much larger main memory than physical memory.

Answer the following questions.

(1) Fig. 1 depicts how a page table translates virtual addresses into physical addresses. If an accessed virtual page is not in the main memory (valid bit = 0), a page fault occurs. Give a step-by-step explanation on how the page fault is handled when the accessed virtual page is on the disk and there is no free space in the main memory.

(2) Assume that the page table is implemented with a single array as shown in Fig. 1. Let the size of the virtual address space be 256 TBytes (= 2^{48} Bytes), the size of a page be 4 KBytes (= 2^{12} Bytes), and the size of each entry in the page table be 8 Bytes. Give the size of main memory required for storing the page table.

(3) Explain the problem with the single-array implementation of the page table.

(4) One of the solutions for the problem in (3) is using a multi-level page table (shown in Fig. 2) that constructs the page table in a hierarchical manner. Explain how it solves the problem.

(5) Translation Lookaside Buffer (TLB) works as a cache memory of page table entries. Give a step-by-step explanation on how a TLB miss is handled when the TLB is implemented as a direct mapped cache as shown in Fig. 3.

(6) Assume that the TLB is implemented in hardware. Explain why the number of accesses to the main memory is decreased in the case of a TLB hit compared with the case of a TLB miss. Also explain how the number of accesses to the main memory changes when the multi-level page table is used.

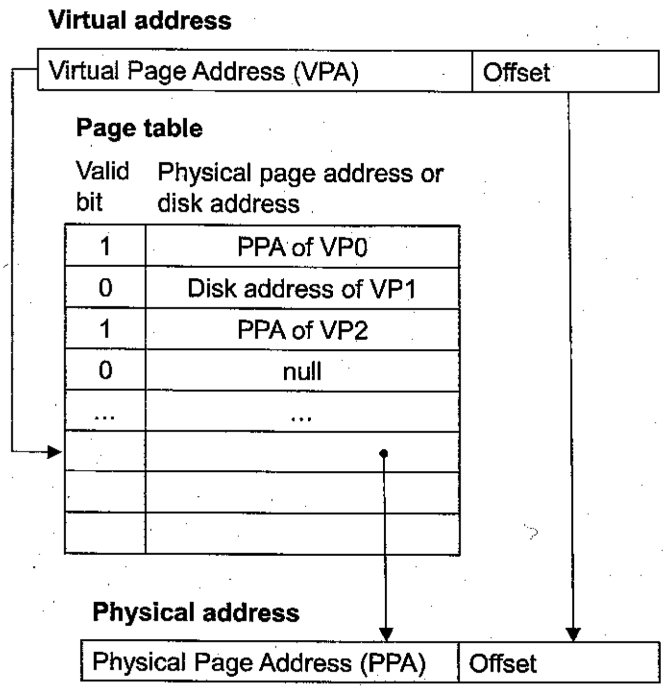

Virtual address
Virtual Page Address (VPA)
Offset
Page table
Valid bit
Physical page address or disk address
1
PPA of VP0
0
Disk address of VP1
1
PPA of VP2
0
null
...
...
Physical address
Physical Page Address (PPA)
Offset

Fig. 1

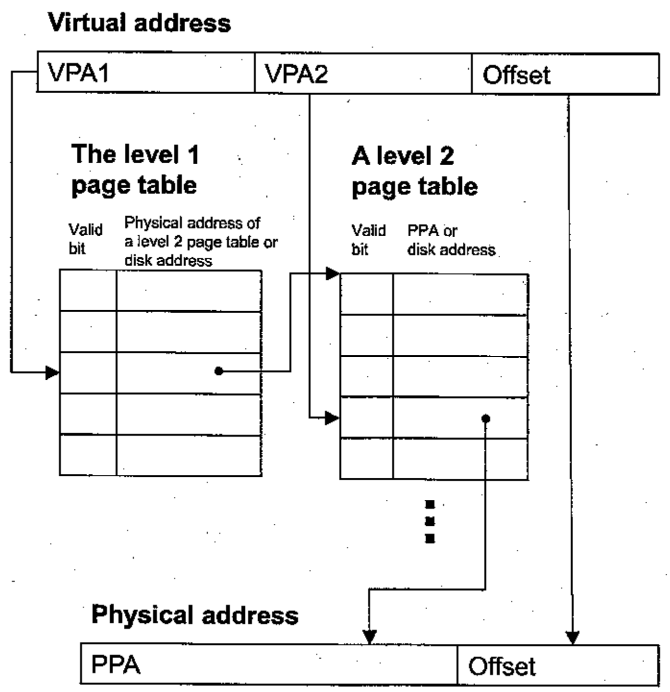

Virtual address
VPA1
VPA2
Offset
The level 1 page table
Valid bit
Physical address of a level 2 page table or disk address
A level 2 page table
Valid bit
PPA or disk address
Physical address
PPA
Offset

Fig. 2

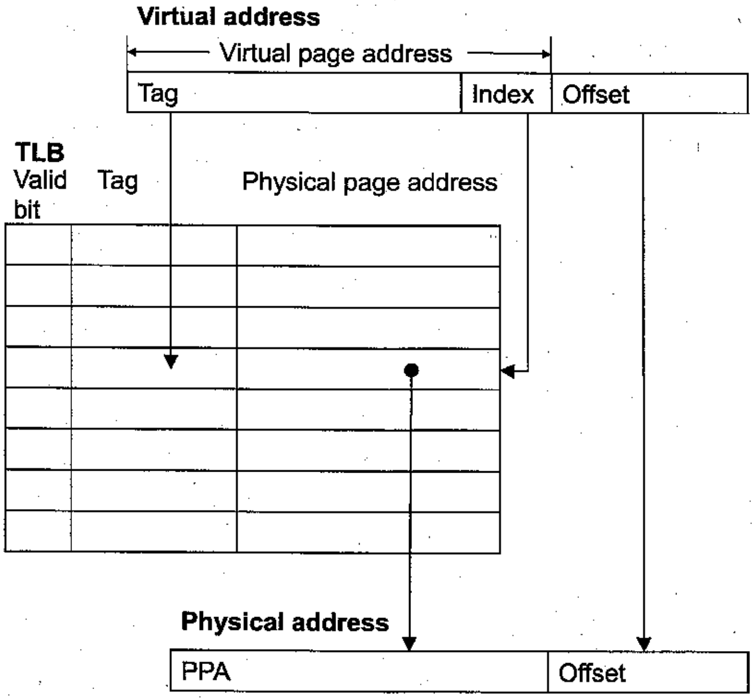
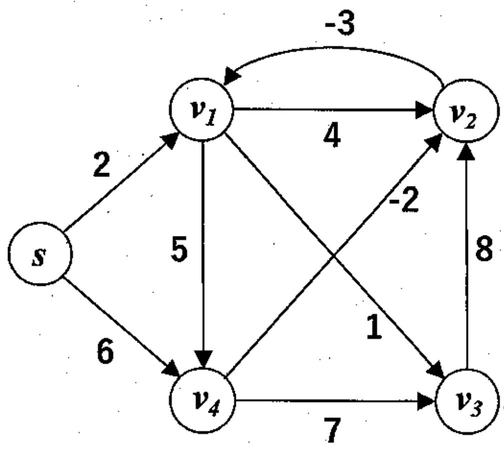

Virtual address
Virtual page address
Tag
Index
Offset
TLB
Valid bit
Tag
Physical page address
Physical address
PPA
Offset

Fig. 3

Problem 3

Given a directed graph $G = (V, E)$ with vertex set V and edge set E, the single-source shortest path problem is the problem of finding the shortest path from the starting point $s \in V$ to each vertex $v \in V$. Here, the shortest path between two vertices is the path that minimizes the sum of the lengths of its constituent edges. Let us consider the single-source shortest path problem when the directed edge from vertex u to vertex v is denoted by (u, v) and the edge length is denoted by d_{uv}. Note that the edge length d_{uv} might be negative, but for any closed path in the graph G, its closed path length shall not be negative. Answer the following questions.

(1) The estimated shortest path length from the starting point s to the vertex v is denoted by $v.d$, where $v.d = \infty$ for all $v \in V - \{s\}$ of the graph G in the initial state of finding the shortest path length. Suppose that the estimated shortest path length $v.d$ is gradually reduced until it becomes the actual shortest path length by relaxing the edges of the graph G one after another. Here, relaxation of the edge (u, v) means to judge whether or not the known shortest path length to the vertex v can be shortened by going through the vertex u and update $v.d$ if shortened. Based on the relaxation of the edges of the graph G, find the shortest path length from the starting point s to each vertex v in the figure below and illustrate its process. Note that each number in the figure represents the corresponding edge length.



(2) The pseudocode of **Algorithm** in the next page describes the algorithm of (1) for solving the single-source shortest path problem. Fill in (A).

(3) Consider not only finding single-source shortest path lengths but also finding the vertex set of each single-source shortest path by using the algorithm of (2). For each vertex $v \in V$ of the graph G, the predecessor vertex of the single-source shortest path is denoted by $v.pre$. Explain what procedure should be added to the pseudocode of (2) to find the vertex set of each single-source shortest path.

(4) Estimate the time complexity using the number of vertices $|V|$ and the number of edges

$|E|$ in a graph when solving the single-source shortest path problem using the algorithm of (2).

(5) Consider applying Dijkstra's algorithm to a graph whose edge lengths are all non-negative. Explain Dijkstra's algorithm using a binary heap as a data structure. Also, estimate the time complexity using the number of vertices $|V|$ and the number of edges $|E|$ in the graph when solving the single-source shortest path problem using the algorithm.

Algorithm

```
for each v ∈ V − {s} do
  v.d = ∞
end for
s.d = 0
for i = 1 to |V| − 1 do
  for each (u, v) ∈ E do
    if v.d > [ (A) ] then
      v.d = [ (A) ]
    end if
  end for
end for
```

Problem 4

Carrier Sense Multiple Access with Collision Detection (CSMA/CD) is a multiple access method used in a wired local area network such as Ethernet.

In CSMA/CD, the *carrierSense* signal is set to ON when a carrier signal is detected on the transmission cable. When a signal from one or more stations is found on the transmission cable, the *collisionDetect* signal is set to ON. A station may transmit a frame after a certain amount of time has passed since the *carrierSense* was turned OFF. If the *carrierSense* is ON, the station must defer the transmission of the frame and wait until the *carrierSense* is set to OFF. When a collision occurs after a station transmits a frame, a bit sequence called jam is sent to inform the other stations of the collisions. After the jam is turned off, the station may retry the transmission after waiting for a random amount of time T.

Answer the following questions.

(1) Suppose that the transmission speed is 10 Mbps, the maximum length of the cable is 2.5 km, and the velocity of propagation of a signal in the cable is 2.0×10^5 km/s. Calculate the minimum frame size required for the CSMA/CD protocol to work properly.

(2) In Ethernet, the binary exponential backoff algorithm is used to determine T. Explain the advantage(s) and disadvantage(s) of the binary exponential backoff algorithm.

(3) Explain how to improve the channel efficiency when many stations exist in the wired local area network using the binary exponential backoff algorithm.

(4) Explain why it is difficult to detect collisions of frames in wireless networks.

(5) Explain the collision avoidance mechanism employed by the IEEE 802.11 standard for wireless local area networks.

Problem 5

Given a signal $f(t)$, we consider converting $f(t)$ to the discrete-time signal at fixed time interval t_s by sampling. An impulse train $\delta_s(t)$ is defined as the sum of impulses $\delta(t)$ shifted at multiples of interval t_s, i.e.,

$$\delta_s(t) = \sum_{i=-\infty}^{\infty} \delta(t - it_s).$$

Then the discrete-time signal $f_s(t)$ of $f(t)$ is calculated as $f_s(t) = f(t) \cdot \delta_s(t)$. Answer the following questions.

(1) Compute the Fourier series expansion of $\delta_s(t)$ by regarding $\delta_s(t)$ as a periodic signal of the periodicity t_s.

(2) Assuming that $\omega_s = \frac{2\pi}{t_s}$, compute the Fourier transform $\Delta_s(\omega)$ of $\delta_s(t)$.

(3) Let $F(\omega)$ and $F_s(\omega)$ be the Fourier transforms of $f(t)$ and $f_s(t)$, respectively. Compute $F_s(\omega)$ by using $F(\omega)$.

(4) Describe the definition of aliasing. In addition, explain aliasing by using the result of (3). Show how to avoid aliasing as the condition of $F(\omega)$ using ω_s.

You can use the following formulae as needed.

Fourier series expansion of periodic signal $x(t)$ with a periodicity of T:

$$x(t) = \sum_{i=-\infty}^{\infty} c_i e^{j\frac{2\pi it}{T}},$$

$$c_i = \frac{1}{T}\int_{T_0}^{T_0+T} x(t) e^{-j\frac{2\pi it}{T}} dt.$$

Fourier transform $X(\omega)$ of the signal $x(t)$:

$$X(\omega) = \int_{-\infty}^{\infty} x(t) e^{-j\omega t} dt.$$

Fourier transform of the signal $x(t) = 1$ is $2\pi\delta(\omega)$.

Convolution of $x_1(t)$ and $x_2(t)$:

$$x_1(t) * x_2(t) = \int_{-\infty}^{\infty} x_1(t') x_2(t - t') dt'.$$

Assuming the Fourier transforms of the signals $x_1(t)$ and $x_2(t)$ to be $X_1(\omega)$ and $X_2(\omega)$, the Fourier transform of $x_1(t) * x_2(t)$ is $X_1(\omega) \cdot X_2(\omega)$.

Similarly, the Fourier transform of $x_1(t) \cdot x_2(t)$ is $\frac{1}{2\pi} X_1(\omega) * X_2(\omega)$.