# Specialized Subjects

9:00〜11:30, Wednesday, August 26, 2009

## Instructions

1. Do not open this booklet before permission is given.

2. This booklet contains 6 problems. The number of pages is eight excluding this cover sheet and blank pages. If you find missing or badly printed pages, ask the attendant for exchange.

3. Answer three problems. You can select any three out of the six. 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 all 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. The three answer sheets must be submitted at the end of the examination, even if they are blank ones.

6. You must answer either in Japanese or in English.

7. This booklet and the preparation sheet must be returned at the end of the examination.

8. This English translation is informal but provided for the convenience of applicants. Japanese version is the formal one.

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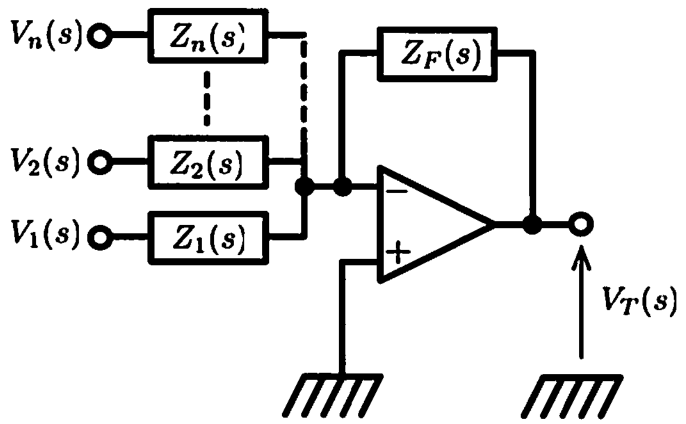
## Problem 1

Answer the questions on the following circuit composed of an ideal operational amplifier and $n+1$ elements of $Z_i(s)(1 \leq i \leq n)$ and $Z_F(s)$. $s$ is a complex number. You can assume that the ideal amplifier has infinite input impedance, zero output impedance, infinite gain, and no delay.




(1) Describe output $V_T(s)$ as a function of input $V_1(s),\ldots,V_n(s)$. When $Z_2(s)$ to $Z_n(s)$ take $\infty$ as their values, describe $V_T(s)$ as a function of $V_1(s)$.

Here, we want to realize the following transfer function as a circuit composed of three ideal operational amplifiers and some resistances and capacitances.

$$H(s) = \frac{V_o(s)}{V_i(s)} = \frac{-5}{s^2 + \sqrt{3}s + 5}$$

(2) The above equation is decomposed as follows.

$$V_o(s) = \left(-\frac{5}{1}\right)\left(-\frac{1}{s}\right)\left\{\left(-\frac{1}{s+\sqrt{3}}\right)V_i(s) + \left(-\frac{1}{s+\sqrt{3}}\right)V_o(s)\right\}$$

Here, $V_A(s)$ is defined as follows.

$$V_A(s) = \left(-\frac{1}{s+\sqrt{3}}\right)V_i(s) + \left(-\frac{1}{s+\sqrt{3}}\right)V_o(s)$$

Show a circuit of this equation, which takes $V_i(s)$ and $V_o(s)$ as input and $V_A(s)$ as output, by using an ideal operational amplifier and several resistances and capacitances.

(3) Realize a circuit which takes $V_i(s)$ as input and $V_o(s)$ as output ($V_o(s) = H(s)V_i(s)$) by using three ideal amplifiers and some resistances and capacitances.

(4) As shown in the figure, an actual operational amplifier is often used with a circuit which feeds the output signal of the circuit back to its input. However, we can find some cases where the amplifier is effectively used with no feedback. Explain an example of applying the amplifier with no feedback. You have to describe a) what kind of function is implemented by that circuit and b) what kind of characteristics of the operational amplifier realize that function.

## Problem 2

A processor performs branch prediction for all the branch instructions, and the branch miss penalty of the processor is $p$ cycles, that is, the execution cycles of a program increases by $p$ cycles per branch misprediction.

The processor executes a program. The total of $n$ instructions are executed and the rate of the branch instructions to them is $b$, that is, the number of executed branch instructions is $b\ n$. And, in an ideal situation where the branch misprediction rate is 0%, the IPC is $i_0$. Here, IPC (Instructions Per Cycle) is the average number of instructions executed in one cycle. Answer the following questions.

(1) The factors that disorder the instruction pipeline of a processor are categorized into structural, data, and control hazards. Explain these three types of pipeline hazards. And explain the relationship(s) between these hazards and branch prediction.

(2) When the branch misprediction rate is 0%, express the execution cycles with $i_0$ and $n$.

(3) When the branch misprediction rate is $\beta$, express the execution cycles with $\beta$, $i_0$, $n$, $b$, and $p$.

(4) Let $i(\beta)$ be the IPC when the branch misprediction rate is $\beta$. Express $i(\beta)$ with $\beta$, $i_0$, $b$, and $p$.

(5) Draw a rough sketch of the graph of $i(\beta)$ under the following condition: $i_0 = 2.0$, $b = 0.2$, $p = 10$. And then, discuss what the graph suggests about the relationship between logical efforts to decrease branch misprediction and the resultant performance improvement.

## Problem 3

Consider the program repeat_union() below, which works as follows.

1. Given $N$ integers $0, 1, \ldots, N-1$, it initially creates $N$ singleton sets each having one of them as its element, namely, $\{0\}, \{1\}, \ldots, \{N-1\}$ (lines 14-15).
2. It then repeats the following "union" operation $M$ times (lines 16-20).

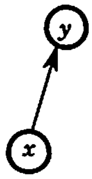
   "union" operation: Pick two elements $x$ and $y$, and merge (compute the union of) the sets they currently belong to (lines 17-19),
3. As a result, it obtains the state of the sets after these operations.

At the step 2 above, the sets $x$ and $y$ originally belong to will disappear, so each element belongs to exactly one set at a time. The following property (∗) holds after the program terminates.

(∗): find($x$) = find($y$) if and only if $x$ and $y$ belong to the same set

```
0:  parents[N]; /* array of integers */
1:  find(x) {
2:    c := x;
3:    while (parents[c] ≠ c)
4:      c := parents[c];
5:    return c;
6:  }
7:  union(x, y) {
8:    a := find(x);
9:    b := find(y);
10:   if (a ≠ b)
11:     parents[a] := b;
12: }
13: repeat_union() {
14:   for x := 0...N − 1
15:     parents[x] := x;
16:   for i := 0...M − 1 {
17:     pick x from 0, ..., N − 1;
18:     pick y from 0, ..., N − 1;
19:     union(x, y);
20:   }
21: }
```

To understand how the algorithm works, let us illustrate the fact parents[$x$] = $y$ by the following figure.

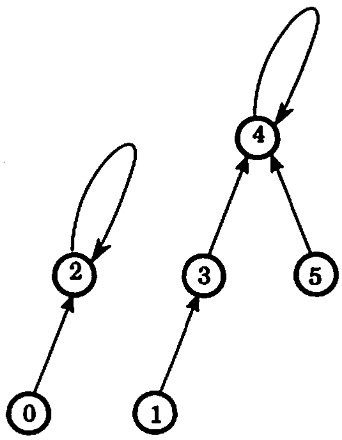



In particular, when $x = y$, we use the following figure.


For example, the state

$$\text{parents}[0] = 2, \quad \text{parents}[1] = 3, \quad \text{parents}[2] = 2,$$
$$\text{parents}[3] = 4, \quad \text{parents}[4] = 4, \quad \text{parents}[5] = 4$$

will be drawn as follows.




(1) Let $N = 6$ and $M = 5$. Assume the following $x$'s and $y$'s are chosen for $i = 0, \ldots, 4$ during the while loop in the lines 16-20. Illustrate the sets after repeat_union() has finished in the way explained above.

| $i$ | $x$ | $y$ |
|---|---|---|
| 0 | 0 | 3 |
| 1 | 2 | 5 |
| 2 | 6 | 1 |
| 3 | 0 | 2 |
| 4 | 4 | 5 |

(2) Execution time of repeat_union() depends on $x$'s and $y$'s chosen in the lines 17 and 18. Show the worst case time complexity of repeat_union(). Express it in terms of $M$ and $N$ ignoring constant factors. Also specify sequences of $x$ and $y$ that attain the worst cases.

(3) We can improve the above worst case performance by slightly modifying union($x$, $y$) and find($x$) (we again ignore constant factors). Describe how to modify it and express the improved time complexity. The improved program must satisfy the property ($*$), of course. Describe the basic idea of the modification and give the details in a pseudo code.

(4) There is an algorithm that finds a minimum spanning tree of an undirectional graph using union and find above. Describe the definition of a minimum spanning tree of an undirectional graph and describe the algorithm briefly.

**Problem 4**

Answer the following questions, related with the transmission system of digital information.

(1) A "modem" is the digital information transmission system using the analogue radio wave or analogue sound. Describe how the "modem" works, while discussing the requirements so that the modem transmission can work.

(2) Describe the operational principle of the following two functions.

(a) CRC(Cyclic Redundancy Check) for error detection. Here, you must refer that the Parity Check belongs to the CRC.

(b) FEC (Forward Error Correction)

(3) We want to transfer the single channel sound, whose frequency is between 20[Hz] to 20[kHz].

(a) Answer the required sampling frequency so as to re-build the original sound information.

(b) Answer the required bandwidth and the number of bits for each sample, when no data compression is applied. Here, we want to achieve 40[dB] dynamic range regarding the sampled data.

(4) Cellular phone e-mail, such as SMS, can be low cost flat rate. On the other hand, the voice communication could not be flat rate, even among the subscribers in same carrier. Discuss the reason above, through the comparison of required number of bits to transfer the eight characters "tokyodai" , using the following two systems; (a) voice (8[kbps] CBR(Continuous Bit Rate) digital transmission) and (b) SMS(e-mail). Here, you do not need to consider any transmission overhead such as training signal or header/trailer.

(5) "Character" is digital information. Since the character is digital information, we can transfer the character with very high transmission efficiency. Explain this reason (i.e., high transmission efficiency), while including the following key words.

Key words; FEC, digitization of analogue information, code space

## Problem 5

(1) Consider a network shown in Fig. 1. In this Figure, let a circle be a node, and let a line be a communication link. We define the shortest path as the path where the minimum number of links are used in a path between nodes. Let us obtain the shortest path from the node A to each of the other nodes. Show an algorithm to obtain the shortest path.

(2) Consider a network shown in Fig. 2, where a cost is assigned to each link. We can calculate the cost of path by summation of link costs along a path. Show an algorithm to obtain the minimum cost path from the node A to each of the other nodes.

(3) Explain an example of such algorithms applied to the Internet.

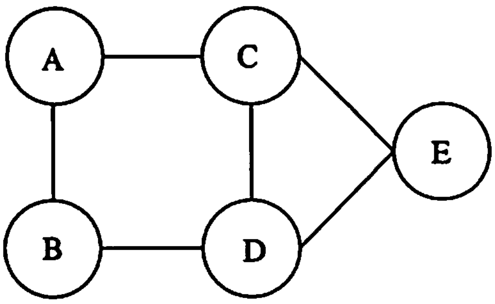



Fig. 1

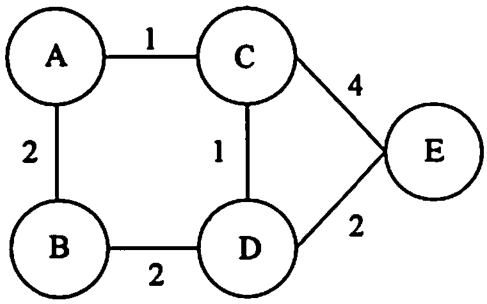



Fig. 2

**Problem 6**

Answer the following questions.

(1) Explain the physical phenomenon of rainbow from the viewpoint of Fourier transform.

(2) Describe to what kind of signals Fourier series expansion and Fourier transform are applicable, respectively.

(3) Derive the Fourier transform $X(f)$ of the following signal $x(t)$, and draw a rough sketch of $X(f)$.

$$x(t) = \begin{cases} E & |t| < \tau/2 \\ 0 & \text{otherwise} \end{cases}$$

(4) Consider the following impulse train $s(t)$.

$$s(t) = \sum_{n=-\infty}^{+\infty} \delta(t - nT_s),$$

where $\delta(t)$ is the delta function, $T_s$ is a sampling period.

Let $x_s(t) = x(t)s(t)$ for a continuous signal $x(t)$. Then, we can obtain the following equation, where $X(f)$ and $X_s(f)$ represent the Fourier transform of $x(t)$ and $x_s(t)$, respectively.

$$X_s(f) = \frac{1}{T_s} \sum_{n=-\infty}^{+\infty} X(f - n\frac{1}{T_s})$$

Explain what you can derive from the above equations.

(5) Consider a set of real data $\{x_n\}(n = 0, \cdots N-1)$. We can expand this data set into regions of $n < 0$ and $n > N-1$. Here we can consider several ways of periodic expansion of the data set. In one way, when the expanded data is transformed into the frequency domain, only cosine components are found. Describe an example of this type of periodic expansion. This is a fundamental of Discrete Cosine Transform (DCT). Explain the reason why DCT is used widely in image compression.

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