1. **(15 points)** Translate the following C segment into MIPS assembly code.

```
while (data[i] == k)
    i = i + j;
```

Assume: Base address of array **data** is in $a0, size of each element in **data** is **4 bytes**, and **i, j, k** correspond to $s0, $s1, $s2 respectively.

(a) **(7 points)** Use both a conditional branch and an unconditional jump in the loop

(b) **(8 points)** Use only one branch or jump in the loop

2. **(12 points)** Explain **structural hazard**, **data hazard** and **branch hazard** in the pipeline design. Give an illustrative example for each of them.

3. **(6 points)** Rewrite -100_{ten} using a 16-bit binary representation. Use

(a) **(2 points)** sign and magnitude representation

(b) **(2 points)** one's complement representation

(c) **(2 points)** two's complement representation

4. **(10 points)** We have the following statistics for two processors M1 and M1 (they have the same classes of instructions):

Instruction class	CPI	Frequency
A	5	25%
B	2	40%
C	3	35%

M1: 200 MHz

Instruction class	CPI	Frequency
A	3	40%
B	3	35%
C	4	25%

M2: 250 MHz

* CPI = clock cycles per instruction, Frequency: occurrence frequency of the instruction class

(a) **(4 points)** Calculate the average CPI for the two processors.

(b) **(4 points)** Calculate the MIPS (Million Instructions Per Second) for them.

(c) **(2 points)** Which machine is faster? How much faster?

5. **(7 points)** Draw the circuit of a 1-bit ALU that performs AND, OR, addition on inputs **a** and **b,** or **a** and $\bar{\mathbf{b}}$. Use the basic AND, OR, Inverter, and Multiplexer gates.

6. **(15 points)** Assume that both the logical and physical address are 16-bits wide, the page size is 1K (1024) bytes, and one-level paging is used.

   a)**(5 points)** How many entries are there in the page table?

   b) **(5 points)** How many bits are occupied by each entry of the page table?

   If the logical address is still 16-bits wide, but the physical address is extended to 20 bits wide.

   c) **(5 points)** In order to do 16->20 mapping, some modification to the original page table is needed. What's it?

7. **(10 points)** Cache is useful and the size of the cache is much smaller than the one of the memory. Virtual memory is also useful. It lets us run a program which size is greater than the size of physical memory.

   What property of a program makes cache and VM useful?

8. **(10 points)** System call is a mechanism through which the user process asks the OS for service. In order to fulfill the request, the OS may call a function to complete the system call.

   Why is system call necessary for protection? (This is equivalent to ask: Can't the user process just call the function inside the OS directly?)

9. **(15 points)** A program handles I/O asynchronously. That is, when it issues a i/o system call, it does not wait the return of system call, but just goes on to do something.

   a) **(10 points)** How does the OS notify this program about the completion of his system call?

   b) **(5 points)** What difficulty must the programmer conquer?