Name: **UID:**

1. What are some optimizations that can be made to the following function?

```
void cs33fun(char* Midterm, char* Grade, int* Final, int n) {
      for (int i = 0; i < (strlen(Midterm)); i++) {
            strcat(Grade, Midterm);
            for (int j = 0; j < n; j++)
                  for (int k = 0; k < i; k++)
                        Final[j] += strlen(Grade);
      }
}
```

2. For the following assembly, draw a data flow graph and identify the critical path.

```
.L1:
      vmulsd      (%rdx), %xmm0, %xmm0
      addq        $8, %rdx
      cmpq        %rax, %rdx
      jne         .L1
```

Given the following table, what is the lowest bound latency to execute n iterations of this loop for integer operations? What about floating point operations?

Latency Table (CPE)	int	double
Arithmetic (except multiply)	1	3
Multiply	2	4
Load/Store	1	1

3. We wish to write a procedure that computes the inner product of two vectors `u` and `v`. An abstract version of the function has a CPE of 14-18 with x86-64 for different types of integer and floating-point data. By doing the same sort of transformations we did to transform the abstract program `combine1` into the more efficient `combine4`, we get the following code:

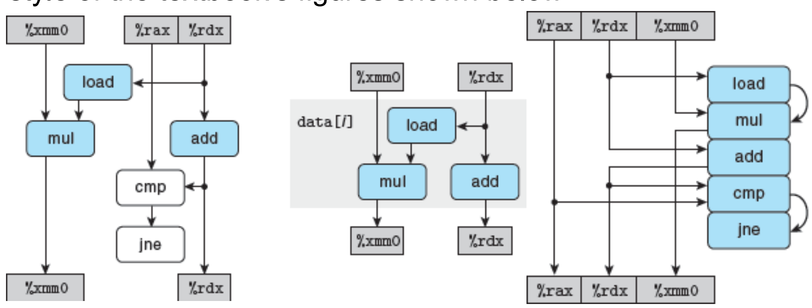
```
/* Inner product. Accumulate in temporary */
void inner4(vec_ptr u, vec_ptr v, data_t* dest) {
      long i;
      long length = vec_length(u);
      data_t *udata = get_vec_start(u);
      data_t *vdata = get_vec_start(v);
      data_t sum = (data_t) 0;
      for (i = 0; i < length; i++) {
            sum = sum + udata[i] * vdata[i];
      }
      *dest = sum;
}
```

Our measurements show that this function has CPEs of 1.50 for `int` data and 3.00 for `double` data. Use the latency table from the previous question for the latencies of operations.

For data type double, the x86-64 assembly for the inner loop is as follows:

```
.L15:                                               ;loop:
  vmovsd  0(%rbp, %rcx, 8), %xmm1                   ; Get udata[i]
  vmulsd  (%rax, %rcx, 8), %xmm1, %xmm1             ; Multiply by vdata[i]
  vaddsd  %xmm1, %xmm0, %xmm0                       ; Add to sum
  addq     $1, %rcx                                 ; Increment i
  cmpq     %rbx, %rcx                               ; Compare i:limit
  jne      .L15                                     ; If !=, goto loop
```

a. Diagram how this instruction sequence would be decoded into operations and show how the data dependencies between them would create a critical path of operations, in the style of the textbook's figures shown below



b. For data type double, what lower bound on the CPE is determined by the critical path?

c. Assuming similar instruction sequences for the integer code as well, what lower bound on the CPE is determined by the critical path for integer data?

d. Explain how the floating-point version can have CPEs of 3.00, even though the multiplication operation requires more than 3 clock cycles.