Problem 1 (25 points)

Consider a system that uses undo logging and produces the following sequence of log records (in exactly this order):

<START>; <T, A, 10>; <T, B, 20>; <T, C, 30>; <T, D, 40>; <COMMIT T>

One possible sequence of actions that leads to these log records is:

Log(A); Log(B); Write(A); Log(C); Write(B); Log(D); Write(C); Write(D); Log(Commit);

In this sequence, Log(X) represents the action that writes to disk the log record for action X, and Write(X) represents the action that updates object X on disk.

Give all possible legal sequences of actions (with undo logging) that satisfy all of the following three conditions:

- the sequence of actions can yield the given log sequence;
- Write(A) is before Log(C);
- Write(B) is before Log(D).

To give the sequences, use the same notation as for the example action sequence.

Problem 2 (30 points)

The following is a sequence of undo-log records written by two transactions T and U:

<START T>; <T, A, 10>; <START U>; <U, B, 20>; <T, C, 30>; <U, D, 40>; <COMMIT U>; <T, E, 50>; <COMMIT T>.

Describe the actions of the recovery manager, including changes to both disk and the log, if there is a crash and the last log record that appears on disk is:

a) <START U>
b) <T, E, 50>
c) <COMMIT T>
Problem 3 (25 points)

Consider a system that uses *redo logging* and produces the following sequence of log records (in exactly this order):

\[
<\text{START}>; <\text{T}, \text{ A}, 10>; <\text{T}, \text{ B}, 20>; <\text{T}, \text{ C}, 30>; <\text{T}, \text{ D}, 40>; <\text{COMMIT T}>
\]

Give all possible legal sequences of actions (with redo logging) that satisfy all of the following three conditions:

- the sequence of actions can yield the given log sequence;
- Write(A) is before Write(C);
- Log(B) is before Log(D).

To give the sequences, use the notation of Problem 1.

Problem 4 (20 points)

Consider the following transaction log from the start of the run of a database system that is capable of running undo/redo logging with checkpointing:

1) \(<\text{START T1}\>
2) \(<\text{T1, A, 50, 10}\>
3) \(<\text{START T2}\>
4) \(<\text{T1, B, 130, 10}\>
5) \(<\text{T1, A, 70, 50}\>
6) \(<\text{T2, C, 20, 10}\>
7) \(<\text{T2, D, 30, 10}\>
8) \(<\text{COMMIT T1}\>
9) \(<\text{START T3}\>
10) \(<\text{T3, E, 60, 10}\>
11) \(<\text{T2, D, 40, 30}\>
12) \(<\text{START CKPT (T2,T3)}\>
13) \(<\text{T2, C, 70, 20}\>
14) \(<\text{COMMIT T2}\>
15) \(<\text{START T4}\>
16) \(<\text{T4, F, 100, 10}\>
17) \(<\text{T4, G, 110, 10}\>
18) \(<\text{COMMIT T3}\>
19) \(<\text{T4, F, 150, 100}\>
20) \(<\text{END CKPT}\>
21) \(<\text{T4, F, 140, 150}\>
22) \(<\text{COMMIT T4}\>

Assume the log entries are in the format

\(<\text{Tid, Variable, New value, Old value}\>

What is the value of the data items \text{A, B, C, D, E, F, and G} on disk after recovery:

a) if the system crashes just before line 10 is written to disk?
b) if the system crashes just before line 15 is written to disk?
c) if the system crashes just before line 16 is written to disk?
d) if the system crashes just before line 19 is written to disk?
e) if the system crashes just before line 22 is written to disk?
f) if the system crashes just after line 22 is written to disk?