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1 Q1

There is a component, call it A at site that initiated the transaction, and components at each of the banks — components B and C. Component B receives the instruction from A. B checks that there is adequate money in the account, and aborts if not. Otherwise, B subtracts 10,000 from the account at B and signals C to deposit 10,000 into the designated account at C. Component C checks that the account exists, and aborts if not. Otherwise, C adds 10,000 to the account and informs A of a successful conclusion. Once A has been informed of the successful conclusion, it reports back to the user of the success.

Due to the presence of time-outs, and since both B and C can send `Abort` back to A, both crashes and failures such as insufficient funds are handled. If B or C crash, the request times out; If there are insufficient funds, then a `Abort` message is sent. The coordinator sends a rollback message to all the participants. Each participant undoes their transactions using the undo log. Each participant sends an acknowledgement to the coordinator. The coordinator undoes the transaction when all acknowledgements have been received.

2 Q2

Consistency: all nodes see the same data at the same time. **Availability:** a guarantee that every request receives a response about whether it was successful or failed. **Partition tolerance:** the system continues to operate despite arbitrary message loss.

The CAP theorem states that you cannot simultaneously have all three; you must make tradeoffs among them. The CAP theorem is sometimes incorrectly described as the choice of picking consistency, availability, and partitioning during **design time**. Really, the theorem allows for databases to choose between these dynamically at **run time**.

When using NoSQL databases, we lose trade-off consistency for a new property called **eventual consistency**. This allows each system to make updates to data and learn of other updates made by other systems within a short period of time, without being totally consistent at all times. For most systems, knowing that it will reach consistency in a short period of time is "good enough", when it allows us to have consistency and availability as well!

3 Q3

- Disk Block size $B = 4096 = 2^1 2\text{bytes/block}$. Main memory is $M = 50\text{MB} = 50 * 2^{20}\text{bytes}$.
- Record R takes $R = 10^7\text{tuples} \times 10^2\text{tuples/byte} = 10^9\text{bytes}$.

- Disk IO is 15 msec.
- Number of blocks needed for relation: $R/B = \frac{10^9 \text{bytes}}{2^{12} \text{bytes/block}} = \frac{10^9}{2^{12}} \simeq 250,000 \text{blocks}$.
- Number of blocks in main memory: $M/B = \frac{50*2^{20} \text{bytes}}{2^{12} \text{bytes/block}} = 50 * 2^8 = 12800 \text{blocks}$.

3.0.1 Q3.1

Since we are reading and storing in random order, we will need around 15msec for each block we are reading. We need to read and write each block of the relation R once. This will take us $15\text{msec} \times 250,000 \times 2 = 7500\text{seconds}$.

3.0.2 Q3.2

The original data may be stored on consecutive cylinders. Each of the 8192 cylinders of the Megatron 747 1 MB on average. We store the initial data (which is 10^3 MB) on 1000 cylinders, and we read 50 cylinders to fill main memory (which is 50MB). Therefore we can read one cylinder with a single seek time. We do not even have to wait for any particular block of the cylinder to pass under the head, because the order of records read is not important at this phase. It takes 6.4 seconds for the transfer of 12,800 blocks. The writing part of phase 1 can also use adjacent cylinders to store the 20 sorted sublists. of records. They can be written out onto another 1000 cylinders. Thus, the writing time for phase 1 is also about 2.15 minutes, or 4.3 minutes for all of phase 1.

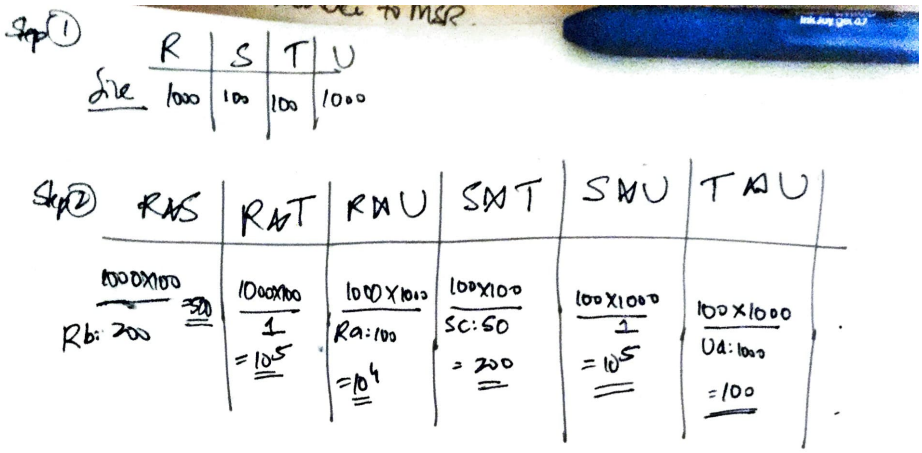
On the other hand, storage by cylinders does not help with the second phase of the sort. Thus, the second phase will still take about 125 minutes.

3.0.3 Q3.3

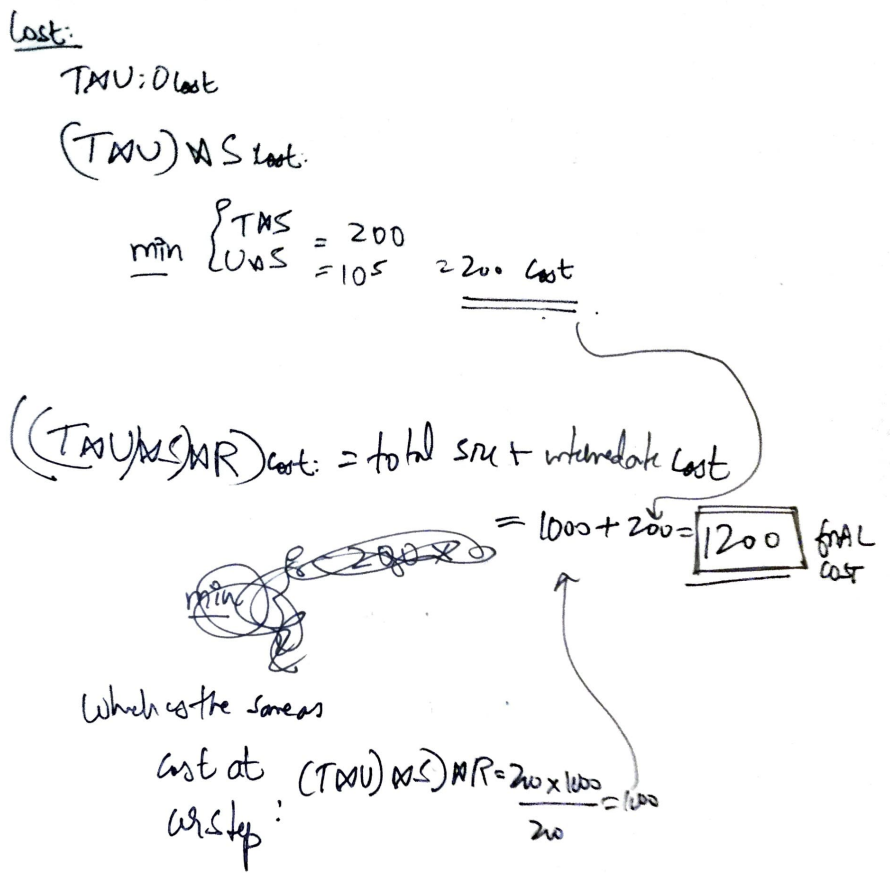
Replacing the disk by 4 disks

4 Q4

4.0.1 Size calculation:



4.0.2 Cost calculation:



5 Q5

5.0.1 Q5.1

After <U, B, 20>, we have transactions T and U active. So, to start the checkpoint, we have to write <START CKPT(T, U)>.

Transaction T is committed after transaction U. So to end, we have to write `<END CKPT>` record after `<COMMIT T>`.

5.0.2 Q5.2

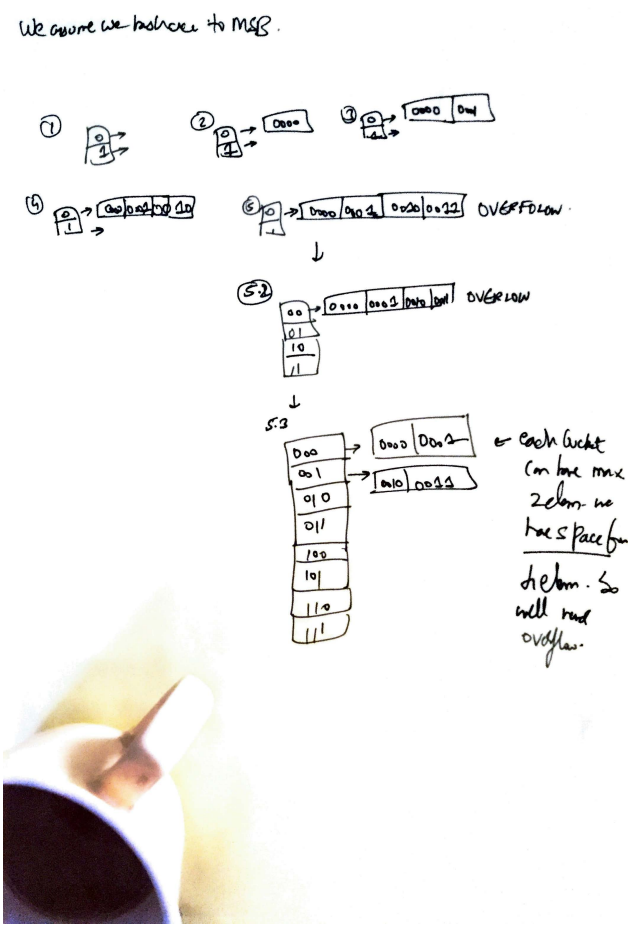
For `<V, B, 80>`, we only need to undo `<V, B, 80>` since we have a `<END CKPT>` checkpoint right before it.

For `<U, D, 40>`, we must look back till `START T` since that is the earliest transaction that we active during the checkpoint.

For `<T, A, 10>`, we must look back till the *previous* checkpoint — not the one being discussed in the question, since it occured even before the current checkpoint started recoding.

6 Q6

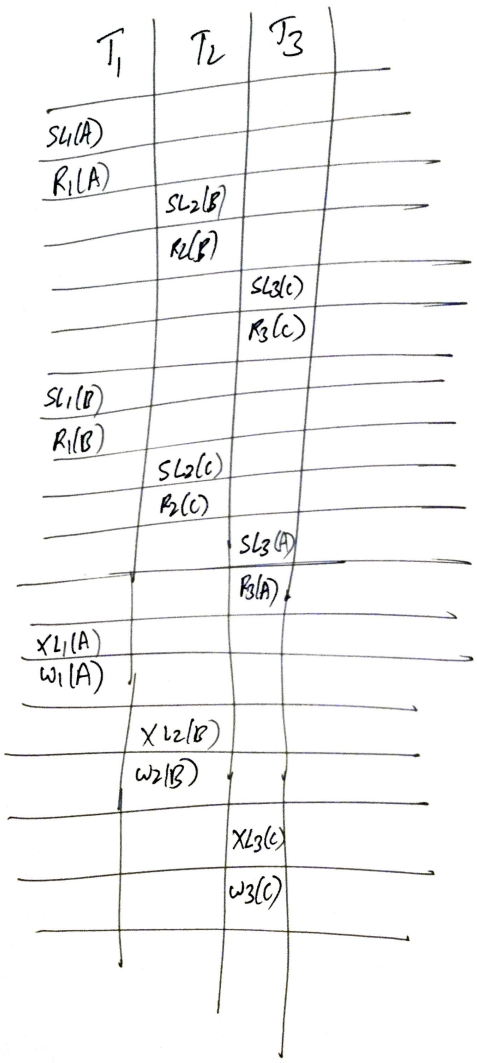
When we insert 0011, there are four records for bucket 0, which overflows. Adding a second bit to the bucket addresses doesn't help, because the first four records all begin with 00. Thus, we go to $i = 3$ and use the first three bits for each bucket address. Now we have space for 4 records in each bucket; however, we can get at maximum 2 records per bucket — we have 4 bit hashes, our buckets are keyed by 3 bits, leaving 1 bit of ambiguity. 1 bit can be 2 records. When 1111 is inserted, we have two records in each bucket.



7 Q7

7.0.1 Q7.1

$SL_x(E)$ for a shared lock by transaction x on elem E. $U_x(E)$ for unlock by transaction x on elem E.



All locks are accepted, since there are no conflicting locks.

7.0.2 Q7.2

Table will be the same as for the above, since we did not have any read action which was followed by a write action of the same element by the same transaction.

7.0.3 Q7.3

8 Q8

$r_1(O_1) \mapsto T_1$ puts $IS(B_1); S(O_1);$ `release`
$r_2(O_2) \mapsto T_2$ puts $IS(B_1); S(O_2);$ `release`
$r_3(O_1) \mapsto T_3$ puts $IS(B_2); S(O_3);$ `release`
$w_1(O_3) \mapsto T_1$ puts $IX(B_2); X(O_3);$ `release`
$w_2(O_4) \mapsto T_2$ puts $IX(B_2); X(O_4);$ `release`
$w_3(O_5) \mapsto T_3$ puts $IX(B_2); X(O_5);$ `release`
$w_1(O_2) \mapsto T_1$ puts $IX(B_2); X(O_3);$ `release`

9 Q9

9.0.1 9.1

In Undo Logging Logging, we need to write all we need to write all modified data to disk before committing a transaction. This may need a large number of disk I/Os. This is unlike the case of Redo logging, which allows changes to be present in-memory; only need to flush changes before committing.

9.0.2 9.2

Selinger optimization improves upon DP approach by keeping for each not only the plan of least cost, but also plans that have higher cost but produce a result that is sorted in an order that may be useful for parent queries.

9.0.3 9.3

View serializable: If a given schedule is found to be view equivalent to some serial schedule. Alternatively, there are no cycles in the dependency graph. Conflict serializable: If there are no cycles in the conflict graph.

Intuitively, view-serializability considers all the connections between transactions T and U such that T writes a database element whose value U reads.

The key difference between view, conflict serializability happens when a transaction T writes a value A that no other transaction reads (since all other transactions later write their own values for A). In this case, the $WT(A)$ action can be placed in certain other positions of the schedule (where A is likewise never read) that would not be permitted under the definition of conflict-serializability. Hence, view serializability is more flexible than conflict serializability.

Therefore, every conflict serializable schedule is indeed view serializable. But there can be some freedom used by the view serializable version that the conflict serializable version cannot use.

9.0.4 9.4

We can use strict 2-phase locking for recoverability. This requires that in addition to the lock being 2-Phase, all Exclusive(X) Locks held by the transaction be released until after the Transaction Commits.

9.0.5 9.5

Database operations are in fact relational algebra operations. These operations are pure mathematical expressions, and are generally reads or writes into disjoint pieces of data. This makes them naturally parallelizable.

Many DB operations such as projections work tuple-at-a-time, which can be parallelized across tuples. If we have the hashes of relations, we can compute union, intersection, and difference all in parallel.

9.0.6 9.6

File system does not generally have multiple readers and writers to a single file. It also does not need to manage structured data. Hence, many of the ACID like concerns simply do not occur in the case of a file system.

9.0.7 9.7

the commit bit for X is true if and only if the most recent transaction to write X has already committed. The purpose of this bit is to avoid a situation where one transaction T reads data written by another transaction U, and U then aborts. This problem, where T makes a "dirty read" of uncommitted data, certainly can cause the database state to become inconsistent, and any scheduler needs a mechanism to prevent dirty reads.

9.0.8 9.8

- Two-phase locking - 2PL.
- General lock based solutions.
- Timestamp ordering.
- Validation based concurrency control.

Increment based locking is good in this case because it allows to add or subtract a constant from an element, which is what most kinds of bank transaactions are. Increment locks on the same element do not conflict with each other.

9.0.9 9.9

The first task of the recovery manager is to divide the transactions into committed and uncommitted transactions. If there is a log record ¡COMMIT T¿, then by undo rule f/2 all changes made by transaction T were previously written to

disk. Thus, T by itself could not have left the database in an inconsistent state when the system failure occurred. However, suppose that we find a ¡START T¿ record on the log but no ¡COMMIT T¿ record. Then there could have been some changes to the database made by T that got written to disk before the crash, while other changes by T either were not made, even in the main-memory buffers, or were made in the buffers but not copied to disk. In this case, T is an incomplete transaction and must be undone.

9.0.10 9.10

all trees of n vertices is n^{n-2}. Number of left-deep trees is $n!$. n^{n-2} is much larger than $n!$.