Fundamentals of Database Systems

Schedules

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Schedule

- A schedule is a *chronological* sequence of instructions from *concurrent* transactions
- If a transaction appears in a schedule, *all* instructions of the transaction must appear in the schedule
- *Order* of instructions within a transaction must be maintained in the schedule
- A transaction finishing successfully will have *commit* as the last instruction
- A transaction not finishing successfully will have *abort* as the last instruction
- Commit and abort statements may be omitted if obvious

Example

- T1 transfers 50 from A to B and then T2 transfers 10% of A to B
- A serial schedule:
  $r_1(A); A := A - 50; w_1(A); r_1(B); B := B + 50; w_1(B);$
  $r_2(A); t := 0.1A; A := A - t; w_2(A); r_2(B); B := B + t; w_2(B);$
- Another schedule:
  $r_1(A); A := A - 50; w_1(A); r_2(A); t := 0.1A; A := A - t;$
  $w_2(A); r_1(B); B := B + 50; w_1(B); r_2(B); B := B + t; w_2(B);$
- This is not a serial schedule but is equivalent
- Yet another schedule:
  $r_1(A); A := A - 50; r_2(A); t := 0.1A; A := A - t; w_2(A);$
  $w_1(A); r_1(B); B := B + 50; w_1(B); r_2(B); B := B + t; w_2(B);$
- This is not a serial schedule and is not equivalent either

Serializability

- Each transaction preserves database consistency
- Hence, a serial schedule also does that
- A schedule is serializable if it is *equivalent* to a serial schedule
- There are different forms of equivalence giving rise to notions of
  - Conflict serializability
  - View serializability
- Operations other than *read* and *write* are ignored
- Instruction I_i of transaction T_i conflicts with I_j of T_j if and only if they access the same data item and at least one of them is a write
- Intuitively, a conflict enforces a logical temporal order of the instructions
- Consequently, if two instructions do not conflict, they can be interchanged

Conflict serializability

- A schedule S is conflict equivalent to another schedule S' if it can be transformed to S' by a series of swaps of *non-conflicting* instructions
- A schedule S is conflict serializable if it is conflict equivalent to a serial schedule
- A serial schedule is conflict serializable, but not vice versa
- If a schedule is conflict serializable, it is correct in the sense that it preserves database consistency

Example

- $S : r_1(a)w_1(a)r_2(a)w_2(a)r_1(b)w_1(b)r_2(b)w_2(b)$
  is conflict serializable as it is conflict equivalent to the serial schedule
  $T_1T_2 : r_1(a)w_1(a)r_1(b)w_1(b)r_2(a)w_2(a)r_2(b)w_2(b)$
  - It is not required to be conflict equivalent to T_2T_1 as well
- $r_1(a)w_2(a)w_1(a)$
  is *not* conflict serializable as it is not conflict equivalent to either of the two serial schedules T_1T_2 and T_2T_1

View serializability

- Two schedules are view equivalent if the reads in them get the same "view", i.e., they read the value produced by the same write operation
- Formally, two schedules S and S' are view equivalent if
  1. For each data item x, if a transaction T reads the initial value of x in S, it reads the same initial value of x in S' as well
  2. For each data item x, if a transaction T writes the final value of x in S, it writes the final value of a in S' as well
  3. If transaction T_i reads the value of data item x produced by write by transaction T_j in S, it must read the value written by T_j in S' as well
- A schedule S is view serializable if it is view equivalent to a serial schedule

Example

- $S : r_1(a)w_1(a)r_2(a)w_2(a)r_1(b)w_1(b)r_2(b)w_2(b)$
  is view serializable as it is view equivalent to the serial schedule
  $T_1T_2 : r_1(a)w_1(a)r_1(b)w_1(b)r_2(a)w_2(a)r_2(b)w_2(b)$
- $r_1(a)w_2(a)w_1(a)w_3(a)$
  is view serializable as it is view equivalent to the serial schedule
  $T_1T_2T_3 : r_1(a)w_1(a)w_2(a)w_3(a)$
- $r_1(a)w_2(a)w_1(a)$
  is *not* view serializable as it is not view equivalent to either of the two serial schedules T_1T_2 and T_2T_1

Relationship between view and conflict serializability

- Every conflict serializable schedule is view serializable, but not vice versa
- Conflict serializability is *stricter* than view serializability
- They are same under the constrained write assumption
- In this assumption, every write of a data item x is constrained by the value of x it has read
  - write(f(read(x)))
- With unconstrained writes (blind writes), a schedule that is view serializable is not necessarily conflict serializable
  - Blind writes: writes to a data item without reading it
- Every view serializable schedule that is not conflict serializable must have blind writes

Other notions of equivalence

- Conflict and view serializable schedules are restrictive in the sense that they aim to guarantee database consistency without analyzing the result
- A schedule S is result equivalent to a schedule S' if it produces the same result as S'
- Consider
  $r_1(A); A := A - 50; w_1(A); r_2(B); B := B - 10; w_2(B);$
  $r_1(B); B := B + 50; w_1(B); r_2(A); A := A + 10; w_2(A);$
- It produces the same result as the serial schedule
  $r_1(A); A := A - 50; w_1(A); r_1(B); B := B + 50; w_1(B);$
  $r_2(B); B := B - 10; w_2(B); r_2(A); A := A + 10; w_2(A);$
  but is not conflict or view serializable
- Determining such equivalence requires *semantic* analysis of operations other than read and write

Testing for serializability

- Create a precedence graph for the schedule
- Directed graph where each transaction is a vertex
- An edge from transaction T_i to T_j exists if
  - $w_i(x)$ precedes $r_j(x)$, or
  - $r_i(x)$ precedes $w_j(x)$, or
  - $w_i(x)$ precedes $w_j(x)$
- A schedule is conflict serializable if and only if its precedence graph is *acyclic*
- *Depth-first search* can detect cycles in $O(n + m)$ time
- *Topological sorting* produces an equivalent serial order
- Testing for view serializability is *NP-complete*
- Practical algorithms
  - Catches all non view serializable schedules
  - But can miss a view serializable schedule

Recoverable schedule

- Conflict and view serializability do not address failures
- Order of commits and aborts are important
- A schedule is called a recoverable schedule if
  - A transaction T_i reads a data item previously written by T_j, and
  - T_j commits *before* T_i commits
- Consider $r_1(a)w_1(a)r_2(a)r_1(b)$
- If T_2 commits just after $r_2(a)$, i.e., if the schedule is $r_1(a)w_1(a)r_2(a)c_2r_1(b)a_1$, then it is *not* recoverable
  - If T_1 crashes, then $w_1(a)$ is undone, but T_2 has already read a wrong value of a and committed
- Therefore, to make it recoverable, the schedule should be $r_1(a)w_1(a)r_2(a)r_1(b)c_1c_2$
  - If T_1 aborts, T_2 can also abort

Cascading rollbacks

- In recoverable schedules, a single transaction failure may lead to a series of rollbacks
- This is called cascading rollbacks or cascading aborts
- Consider $r_1(a)w_1(a)r_2(a)w_2(a)r_3(a)r_1(b)a_1c_2c_3$
- It is recoverable
- However, if T_1 fails, T_2 and T_3 must abort as well
- Not preferable as lot of work is undone

Cascadeless schedule

- Cascading rollbacks are eliminated
- A schedule is called a cascadeless schedule if
  - A transaction T_i reads a data item previously written by T_j, and
  - T_j commits before T_i *reads*
- Consider $r_1(a)w_1(a)r_2(a)r_1(b)a_1c_2$
- It is not cascadeless as T_2 reads a written by T_1 before T_1 commits
- Therefore, to make it cascadeless, the schedule should be $r_1(a)w_1(a)r_1(b)c_1r_2(a)c_2$
- No completed transaction needs to be rolled back
- Every cascadeless schedule is recoverable, but not vice versa

Strict schedule

- Problem of writes remains in the sense that a later transaction may overwrite an uncommitted write
- A schedule is called a strict schedule if
  - A transaction T_i reads or writes a data item previously written by T_j, and
  - T_j commits before T_i *reads* or *writes*
- Consider $r_1(a)w_1(a)w_2(a)r_1(b)a_1c_2$
- It is not strict as T_2 writes a written by T_1 before T_1 commits
- Therefore, to make it strict, the schedule should be $r_1(a)w_1(a)r_1(b)c_1w_2(a)c_2$
- Every strict schedule is cascadeless, but not vice versa

Relationship between schedules