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CONCURRENT SYSTEMS
LECTURE 5

Prof. Daniele Gorla

Software Transactional Memory

- Group together parts of the code that must look like atomic, in a way that is transparent, scalable and easy-to-use for the programmer
- Differently from monitors, the part of the code to group is not part of the definition of the objects, but is application dependent
- Differently form transactions in databases, the code can be any code, not just queries on the DB

Transaction: an atomic unit of computation (look like instantaneous and without overlap with any other transaction), that can access atomic objects.

→ *Assumption*: when executed alone, every transaction successfully terminates.

Program: set of sequential processes, each alternating transactional and non-transactional code (that both access base objects)

STM system: online algorithm that has to ensure the atomic execution of the transactional code of the program.

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Software Transactional Memory

To guarantee efficiency, several transactions can be executed simultaneously (the so called *optimistic execution* approach), but then they must be totally ordered

→ not always possible (e.g., when there are different accesses to the same obj, with at least one of them that changes it)

→ commit/abort transactions at their completion point (or even before)

→ in case of abort, either try to re-execute or notify the invoking proc.

→ possibility of unbounded delay

Conceptually, a transaction is composed of 3 parts:

[READ of atomic reg's] [local comput.] [WRITE into shared memory]

The key issue is ensuring consistency of the shared memory

→ as soon as some inconsistency is discovered, the transaction is aborted

Implementation: every transition uses a local working space

- For every shared register: the first READ copies the value of the reg. in the local copy; successive READs will then read from the local copy
- Every WRITE modifies the local copy and puts the final value in the shared memory only at the end of the transaction (if it has not been aborted)

4 operations:

* $\texttt{begin}_T\texttt{()}$: initializes the local control variables

* $\texttt{X.read}_T\texttt{()}$, $\texttt{X.write}_T\texttt{()}$: as described above

* $\texttt{try\_to\_commit}_T\texttt{()}$: decides whether a non-aborted trans. can commit

A Logical Clock based STM system

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Let T be a transaction; its *read prefix* is formed by all its successful READ before its possible abortion.

An execution is **opaque** if all committed transactions and all the read prefixes of all aborted transactions appear if executed one after the other, by following their real-time occurrence order.

We now present an atomic STM system, called *Transactional Locking 2* (TL2, 2006):

- CLOCK is an atomic READ/FETCH&ADD register initialized at 0
- Every MRMW register X is implemented by a pair of registers XX s.t.
  - XX.val contains the value of X
  - XX.date contains the date (in terms of CLOCK) of its last update
  - It is associated with a lock object (to guarantee MUTEX when updating the shared memory)
- For every transaction T, the invoking process maintains
  - lc(XX) : a local copy of the implementation of reg. X
  - read_set(T) : the set of names of all the registers read by T up to that moment
  - write_set(T) : the set of names of all the registers written by T up to that moment
  - birthdate(T) : the value of CLOCK(+1) at the starting of T

Idea: commit a transaction iff it could appear as executed at its birthdate time

Consistency:

- If T reads X, then it must be that XX.date < birthdate(T)
- To commit, all registers accessed by T cannot have been modified after T's birthdate (again, XX.date < birthdate(T))

A Logical Clock based STM system

```
beginT() :=
    read_set(T), write_set(T) ← ∅
    birthdate(T) ← CLOCK+1

X.readT() :=
    if lc(XX)≠⊥ then return lc(XX).val
    lc(XX) ← XX
    if lc(XX).date ≥ birthdate(T) then ABORT
    read_set(T) ← read_set(T) ∪ {X}
    return lc(XX).val

X.writeT(v) :=
    if lc(XX)=⊥ then lc(XX) ← newloc
    lc(XX).val ← v
    write_set(T) ← write_set(T) ∪ {X}

try_to_commitT() :=
    lock all read_set(T) ∪ write_set(T)
    ∀ X ∈ read_set(T)
        if XX.date ≥ birthdate(T)
        then release all locks
             ABORT
    tmp ← CLOCK.fetch&add(1)+1
    ∀ X ∈ write_set(T)
        XX ← ⟨lc(XX).val , tmp⟩
    release all locks
    COMMIT
```

Remark: to avoid deadlock, there is a total order on the registers and locks are required by respecting this order (the deadlock is avoided as in Solution 1 of the Dining Philosophers)

Virtual World Consistency

Opacity requires a total order on all committed transactions and on all read prefixes of all aborted transactions

→ this latter requirement can be weakened by imposing that the read prefix of an aborted transaction is consistent only w.r.t. its causal past (i.e., its vortual world)

Opacity: total order both on all committed trans.'s and on read prefixes of aborted trans.'s

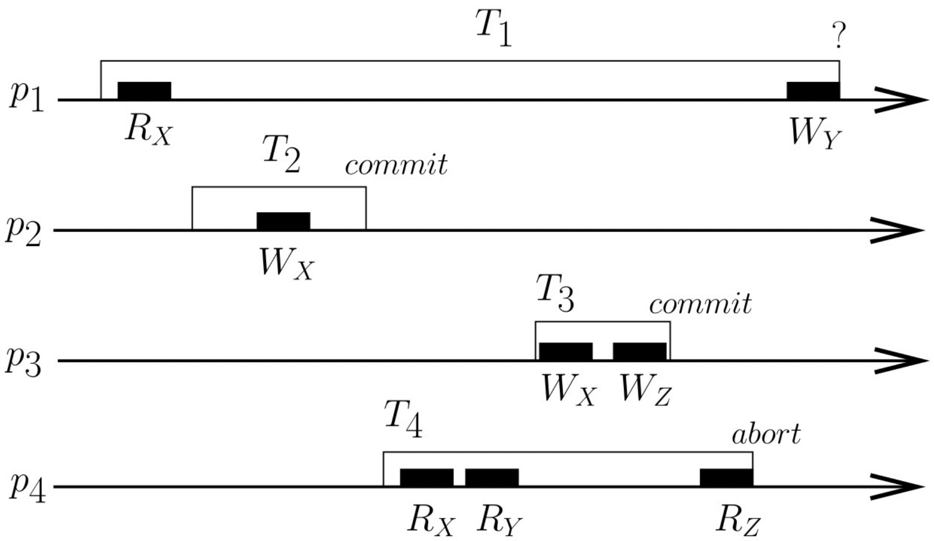
VWC: total order on all committed trans.'s + partial order on committed trans.'s and the read prefixes of aborted trans.'s

The **causal past** of a transaction T is the set of all T' and T'' such that

- T reads a value written by T', and
- T'' belongs to the causal past of T'

VWC allows more transactions to commit → it is a more liberal property than opacity

Virtual World Consistency



Without T4, an opaque execution is

T1 < T2 < T3

and they can all commit.

With T4:

- T4 must abort when reads Z (it cannot be executed atomically: before T3 for reading X and after T3 for reading Z)
- T1 < T2 < r_p(T4) < T3 , where r_p(T4) is {R_X, R_Y} is not opaque because the R_Y in T4 would read the value written by T1, unless also T1 aborts.

  → an aborted trans. leads T1 to abort

  → NOT GOOD!

With VWC we can let T1 commit:

- The total order on committed transactions is T1 < T2 < T3
- The partial order is T2 < r_pref(T4)

A Vector clock based STM system

We have m shared MRMW registers; register X is represented by a pair XX, with:

- XX.val the current value of X
- XX.depend[1…m] a vector clock s.t.
  - XX.depend[X] is the sequence number associated with the current val of X
  - XX.depend[Y] is the sequence number associated with the val of Y on which the current val of X depends from
- There is a starvation-free lock object associated to the pair

We have n processes; process pi has

- For every X, a local copy lc(XX) of the implementation of X
- $p\_depend_i[1…m]$ s.t. $p\_depend_i[X]$ is the seq.num. of the last val of X (directly or undirectly) known by pi

Every transaction T issues by pi has:

- read_set(T) and write_set(T)
- $t\_depend_T[1…m]$ a local copy of p_depend_i (this is used in the optimistic execution, not to change p_depend_i if T aborts)

A Vector clock based STM system

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```
begin_T(i) :=
    read_set(T), write_set(T) ← ∅
    t_depend_T ← p_depend_i

X.read_T(i) :=
    if lc(XX)=⊥ then
        lc(XX) ← newloc
        lc(XX) ← XX
        read_set(T) ← read_set(T) ∪ {X}
        t_depend_T[X] ← lc(XX).depend[X]
        if ∃ Y ∈ read_set(T) s.t.
            t_depend_T[Y] < lc(XX).depend[Y]
        then ABORT
        ∀ Y ∉ read_set(T) do
            t_depend_T[Y] ← max{t_depend_T[Y],
                                lc(XX).depend[Y]}
    return lc(XX).val
```

```
X.write_T(i,v) :=
    if lc(XX)=⊥ then lc(XX) ← newloc
    lc(XX).val ← v
    write_set(T) ← write_set(T) ∪ {X}

try_to_commit_T(i) :=
    lock all read_set(T) ∪ write_set(T)
    if ∃ Y ∈ read_set(T) s.t.
        t_depend_T[Y] < YY.depend[Y]
    then  release all locks
          ABORT
    ∀ X ∈ write_set(T) do
        t_depend_T[X] ← XX.depend[X]+1
    ∀ X ∈ write_set(T) do
        XX ← ⟨lc(XX).val, t_depend_T⟩
    release all locks
    p_depend_i ← t_depend_T
    COMMIT
```