Transaction Concurrency Control via Dynamic Scheduling Based on Static Analysis

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Motivations

Transactional Memory (TM) traditionally employs optimistic concurrency control + contention management.

Advantages of fully pessimistic approaches were recently recognized (Shavit, Matveev WTTM ’11): I/O and system calls, debugging, ...

A lot fewer results are about distributed TMs.
Our work

- **optimistic** locally scoped transactions + replicated objects ⇒ Paxos STM (Euro-TM WDTM ’12),
- **pessimistic** distributed transactions on remote objects ⇒ Atomic RMI (this talk).
Example: “withdraw-deposit” transaction

Below is a program in Atomic RMI, where a and b are remote objects (in the sense of Java RMI):

```java
Transaction t = new Transaction(registry);
t.start();
int balance = a.getBalance();
if (balance < sum) {
    t.rollback();
} else {
    a.withdraw(sum);
    b.deposit(sum);
    t.commit();
}
```
Pessimistic concurrency by versioning

Basic Versioning Algorithm:

- $T_1 \cdot a.w; b.d$
- $T_2 \cdot - - a.w; b.d$
- $T_3 \cdot x.w; y.d$

Supremum Versioning Algorithm:

- $T_1 \cdot a.w; b.d$
- $T_2 \cdot a.w; b.d$
- $T_3 \cdot x.w; y.d$

Static (a priori) scheduling: $T_2$ is temporarily blocked by $T_1$. $T_3$ is not blocked since it accesses other objects.

Both schedules are serializable but $C'_\text{max} < C_\text{max}$.

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1Wojciechowski et al. IPDPS ’04, PPDP ’05
Transaction thread is blocked till transaction commit (◊).

\[ T_1 \]’s rollback causes \( T_2 \) and \( T_4 \) to rollback ⇒
\[ T_2 \]’s commit must be deferred.
\[ T_2 \]’s rollback must cause \( T_4 \) to rollback.
\[ T_3 \] is not affected since it accesses other objects.
Static analysis

When to release an object held by a transaction?

We use 3 methods:

1. The programmer releases an object (simple but not safe!).
2. **Supremum analysis**: Release an object if \# of object calls reached an upper bound (supremum $S$).
3. **Last-use analysis**: If $S$ cannot be inferred, release an object if no more calls can be made by a client (work-in-progress).

We developed a precompiler that instruments Java code after analyzing its translation to Jimple (more suitable than Java bytecode).
Below is our example program, modified by the precompiler:

```java
Transaction t = new Transaction(registry);

a = t.accesses(a, 2); // upper bound = 2
b = t.accesses(b, 1); // upper bound = 1

t.start();
int balance = a.getBalance();
if (balance < sum) {
    t.rollback();
} else {
    a.withdraw(sum);
    b.deposit(sum);
    t.commit();
}
```
Supremum vs. Last-Use Analysis

The object last-use analysis applied:

```java
transaction.start();
for (i=0; i < n; i++) {
    a.m();
    b.m(); // a unnecessary blocked in the last loop
}
::release a, b;
transaction.commit();
```

The object call supremum analysis applied:

```java
transaction.start();
for (i=0; i < n; i++) {
    a.m(); // a will be released in nth iteration
    b.m(); // b will be released in nth iteration
}
transaction.commit();
```
Clients on nodes $i$ ($i = 2..n$):

```c
transaction.start();
a.m();
::release a;
transaction.commit();
```

A method of a remote object $a$ on node 1:

```c
m() {
    ::while (object blocked) {};
    ...
    return res;
}
```

Release of object $a$ by every client requires a network message.
Clients on nodes $i \ (i = 2..n)$:
\[
\text{transaction.start();}
\]
\[
a.m();
\]
\[
\text{transaction.commit();}
\]

A method of a remote object $a$ on node 1:
\[
m() \{
\quad \textbf{while} \ (\text{ticket}(i) - \text{obj.count} > \text{supremum}(i)) \ \{};
\quad \ldots
\quad :\text{obj.count} \leftarrow \text{obj.count} + 1
\quad \text{return} \ res;
\}
\]

Release of object $a$ is a local operation (no network overhead).
Dynamic transaction scheduling - algorithm

1. On transaction start-up, request a globally unique ticket (required by static scheduling of object calls).

2. Sort the queue of ticket requests, either:
   - long transactions first, or
   - short transactions first.

3. Use a simple heuristic: the transaction length is proportional to statically inferred # of object calls.
Micro-benchmark

Designed to check if experimental results match a theoretical schedule (a larger benchmark is an ongoing work):

- four remote objects a, b, c, and d,
- each object has one method “sleep 1 second and return”,
- 4-24 concurrent transactions spawned on 8 network nodes at the same time:
  - 50% short transactions (3 sec.): calls of a, b, and c,
  - 50% long transactions (6 sec.): calls of c, d, c, d, a, and b.

Evaluation environment:

- cluster of nodes: quad-core Xeon X3230 CPU with 4 GB RAM,
- 1Gb network.
Experimental results

**Mean Flow Time**

- **8 Transactions**
  - Atomic RMI
  - Long First
  - Short First
  - BVA
  - Global Lock

- **24 Transactions**
  - Atomic RMI
  - Long First
  - Short First
  - BVA
  - Global Lock

**Throughput**

- **8 Transactions**
  - Atomic RMI
  - Long First
  - Short First
  - BVA
  - Global Lock

- **24 Transactions**
  - Atomic RMI
  - Long First
  - Short First
  - BVA
  - Global Lock
Conclusions and future work

- Pessimistic concurrency by versioning outperforms global lock.
- Static analysis can make this approach efficient and safe.
- Dynamic scheduling of transactions can further improve it for almost null cost at runtime (done in background).
- Upper bounds on calls are used to estimate transaction length.

Future work:

- Problems of distributed deadlock and partial faults.

Project page:

- http://www.it-soa.eu/atomicrmi