# Brief Announcement: Relaxing Opacity in Pessimistic Transactional Memory

Konrad Siek and Paweł T. Wojciechowski

Institute of Computing Science
Poznań University of Technology
60-965 Poznań, Poland
{konrad.siek,pawel.t.wojciechowski}@cs.put.edu.pl

Since in the Transactional Memory (TM) abstraction transactional code can contain any operation (rather than just reads and writes), greater attention must be paid to the state of shared variables at any given time. Thus strong safety properties are important in TM, such as opacity [2], virtual world consistency [3], or TMS1/2 [1]. They regulate what values can be read, even by transactions that abort. In comparison to these, properties like serializability allow inconsistent views, so they are relatively weak. However, strong properties virtually preclude early release as a technique for optimizing TM. Early release is a mechanism that allows transactions to read from other transactions, even if the latter are still live. This can increase parallelism, and it is useful in high contention (see e.g., [4]). Thus, we introduce last-use opacity, a safety property that relaxes opacity.

Opacity consists of three core guarantees: serializability, preservation of real-time order, and consistency. We concentrate on the latter, which stipulates that non-local read operations (i.e. those that read values written by other transactions than the current one) must only read values from committed or commit-pending transactions. *Last-use opacity* relaxes this consistency criterion to only provide last-use consistency [7] and recoverability. Then, a transaction can read from another live transaction, if the latter will no longer access the variable in question. Plus, transactions must commit or abort in the order in which they access shared variables. These conditions are defined as follows:

**Definition 1 (Commit-pending Equivalence).** *Transaction $T_i$ in history $H$ is commit-pending–equivalent with respect to variable $x$ if (a) $T_i$ is live, and (b) there is a read or write operation $op$ on $x$ in $H|T_i$, s.t. for any history $H_c$ for which $H$ is a prefix ($H_c = H \cdot H'$) $op$ is the last read or write on $x$ in $H_c|T_i$.*

**Definition 2 (Last-use Consistent Operation).** *Given a history $H$, a transaction $T_i$ and a read operation $op_r = \mathrm{r}(x)v$ on variable $x$ returning $v$ in subhistory $H|T_i$, we say $op_r$ is last-use–consistent as follows: (a) If $op_r$ is local then the latest write operation on $x$ preceding $op_r$ writes value $v$ to $x$; (b) If $op_r$ is non-local then either $v = 0$ or there is a non-local write operation $op_w$ on variable $x$ writing $v$ in $H|T_k$ ($k \neq i$) where $T_k$ is committed, commit-pending, or commit-pending–equivalent with respect to $x$.*

**Definition 3 (Recoverable Last-use Consistency).** *History $H$ is recoverable last-use–consistent if (a) every read operation in $H|T_i$, for every transaction*

*$T_i$ in $H$ is last-use–consistent, and (b) for every pair of transactions $T_i, T_j$ such that $i \neq j$ and $T_j$ reads from or writes after $T_i$, then $T_i$ aborts or commits before $T_j$ aborts or commit, and if $T_i$ aborts, then $T_j$ also aborts.*

Relaxing consistency necessarily leads to some inconsistent views to be accepted. Hence, while last-use opacity prevents overwriting (releasing $x$ and writing to it afterwards), it does not prevent zombie transactions—ones that view inconsistent state and are forced to abort. This happens if transaction $T_i$ reads from $T_j$ which, for whatever reason, later aborts. Even if $T_i$ eventually aborts, it operates on stale data and, therefore, can behave unexpectedly. However, this can be rendered harmless by, e.g. sandboxing [5], or enforcing invariants.

On the other hand, using last-use opacity yields performance benefits, especially in high contention. In Fig. 1 we compare two variants of the same distributed TM [6]: last-use–opaque LSVA and opaque OSVA. In all benchmarks LSVA is able to process transactions faster, due to its ability to release early.

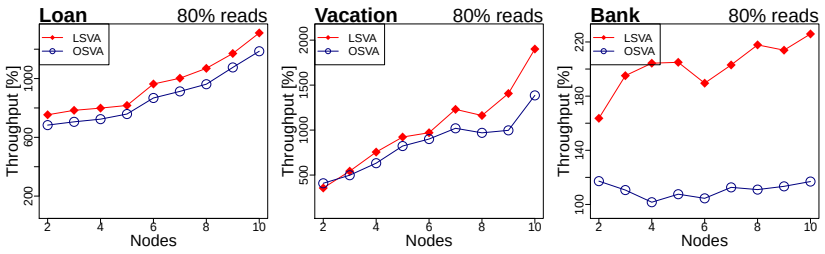


**Fig. 1.** Percentage improvement relative to a lock-based implementation.

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