Script generated by TTT

Title: Petter: Programmiersprachen (23.11.2016)

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Illustrating Transactions

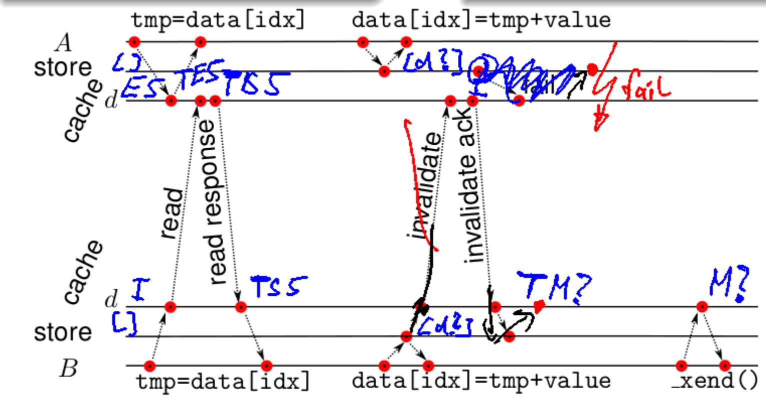
Augment MESI state with extra bit T per cache line. CPU A: E5, CPU B: I

Thread A

```
int tmp = data[idx];
data[idx] = tmp+value;
_xend();
```

Thread B

```
int tmp = data[idx];
data[idx] = tmp+value;
_xend();
```



Common Code Pattern for Mutexes

Using HTM in order to implement mutex:

```
int data[100]; // shared
int mutex;
void update(int idx, int val) {
  if(_xbegin()==-1) {
    if (!mutex>0) _xabort();
    data[idx] += val;
    _xend();
  } else {
    wait(mutex);
    data[idx] += val;
    signal(mutex);
  }
}
```

```
void update(int idx, int val) {
  lock(mutex);
  data[idx] += val;
  unlock(mutex);
}
void lock(int mutex) {
  if(_xbegin()==-1) {
    if (!mutex>0) _xabort();
    else return;
  } wait(mutex);
}
void unlock(int mutex) {
  if (!mutex>0) signal(mutex);
  else _xend();
}
```

- the critical section may be executed without taking the lock (the lock is *elided*)
- as soon as one thread conflicts, it aborts, takes the lock in the fallback path and thereby aborts all other transactions that have read `mutex`

Hardware Lock Elision

Hardware Lock Elision

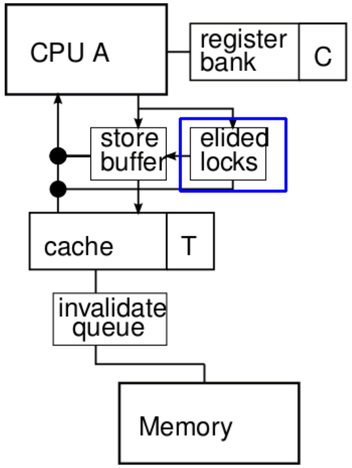
Observation: Using HTM to implement lock elision is a common pattern
⇝ provide special handling in hardware: HLE

- provides a way to execute a critical section without the need to immediately modify the cacheline in order to acquire and release the lock
- requires annotations:
  - instruction that increments the semaphore must be prefixed with `XACQUIRE`
  - instruction setting the semaphore to 0 must be prefixed with `XRELEASE`
  - these prefixes are ignored on older platforms
- for a successful elision, all signal/wait operations of a lock must be annotated

Implementing Lock Elision

Transactional operation:

- re-uses infrastructure for Restricted Transactional Memory
- add a buffer for elided locks, similar to store buffer



- `XACQUIRE` of lock ensures *shared/exclusive* cache line state with $T = 1$, issues `XBEGIN` and stores written value in *elided lock* buffer
- r/w access to a cache line sets T
- like RTM, applying an *invalidate* message to a cache line with $T = 1$ issues `XABORT` analogous for *read* message to a *modified* cache line
- a *local CPU read* from the address of the elided lock accesses the buffer
- on `XRELEASE` on the same lock, decrement C and, if $C = 0$, clear T flags and elided locks buffer and commit to memory

Transactional Memory: Summary

Transactional memory aims to provide `atomic` blocks for general code:

- frees the user from deciding how to lock data structures
- compositional way of communicating concurrently
- can be implemented using software (locks, atomic updates) or hardware

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The devil lies in the details:

- semantics of *explicit HTM* and *STM* transactions quite subtle when mixing with non-TM (*weak* vs. *strong isolation*)
- *single-lock atomicity* and *transactional sequential consistency* semantics
- STM not the right tool to synchronize threads without shared variables
- TM providing *opacity* (serializability) requires *eager conflict detection* or *lazy version management*

Devils in *implicit* HTM:

- RTM requires a fall-back path
- no progress guarantee
- HLE can be implemented in software using RTM

TM in Practice

Availability of TM Implementations:

- GCC can translate accesses in `__transaction_atomic` regions into `libitm` library calls
- ISO Standard to come: *C++ Extensions for Transactional Memory*, introducing `synchronized { }` (preview in GCC 6.1)
- the library `libitm` provides different TM implementations:
  1. On systems with TSX, it maps atomic blocks to HTM instructions
  2. On systems without TSX and for the fallback path, it resorts to STM
- RTM support slowly introduced to OpenJDK Hotspot monitors

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Use of hardware lock elision is limited:

- allows to easily convert existing locks
- `pthread` locks in `glibc` use RTM https://lwn.net/Articles/534758/:
  - allows implementation of back-off mechanisms
  - HLE only special case of general lock
- implementing monitors is challenging
  - lock count and thread id may lead to conflicting accesses
  - in `pthreads`: error conditions often not checked anymore

Outlook

Several other principles exist for concurrent programming:

1. non-blocking message passing (the actor model)
   - a program consists of actors that send messages
   - each actor has a queue of incoming messages
   - messages can be processed and new messages can be sent
   - special filtering of incoming messages
   - example: Erlang, many add-ons to existing languages
2. blocking message passing (CSP, π-calculus, join-calculus)
   - a process sends a message over a channel and blocks until the recipient accepts it
   - channels can be send over channels (π-calculus)
   - examples: Occam, Occam-π, Go
3. (immediate) priority ceiling
   - declare *processes* with priority and *resources* that each process may acquire
   - each resource has the maximum (ceiling) priority of all processes that may acquire it
   - a process' priority at run-time increases to the maximum of the priorities of held resources
   - the process with the maximum (run-time) priority executes

References

D. Dice, O. Shalev, and N. Shavit.
Transactional Locking II.
In *Distributed Computing*, LNCS, pages 194–208. Springer, Sept. 2006.

T. Harris, J. Larus, and R. Rajwar.
Transactional memory, 2nd edition.
Synthesis Lectures on Computer Architecture, 5(1):1–263, 2010.

Online resources on Intel HTM and GCC's STM:

1. http://software.intel.com/en-us/blogs/2013/07/25/fun-with-intel-transactional-synchronization-extensions
2. http://www.realworldtech.com/haswell-tm/4/
3. http://www.open-std.org/jtc1/sc22/wg21/docs/papers/2015/n4514.pdf