Concurrent Systems

Nebenläufige Systeme

XII. Transactional Memory

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— Selbststudium —

Agenda

Preface

Principles
- General
- Characteristic
- Operation

Utilisation
- Abstraction
- Examplification
- Discussion

Summary

Outline

Subject Matter

- discussion on abstract concepts as to facilitation of programming of parallel processes by means of **transactional regions**
  - explicitly versus implicitly transactional approaches
  - hardware (HTM), software (STM), or hybrid (HyTM) solutions

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  - failure of transactions: frequency, reason, alternative measures
  - type of synchronisation: unilateral, multilateral

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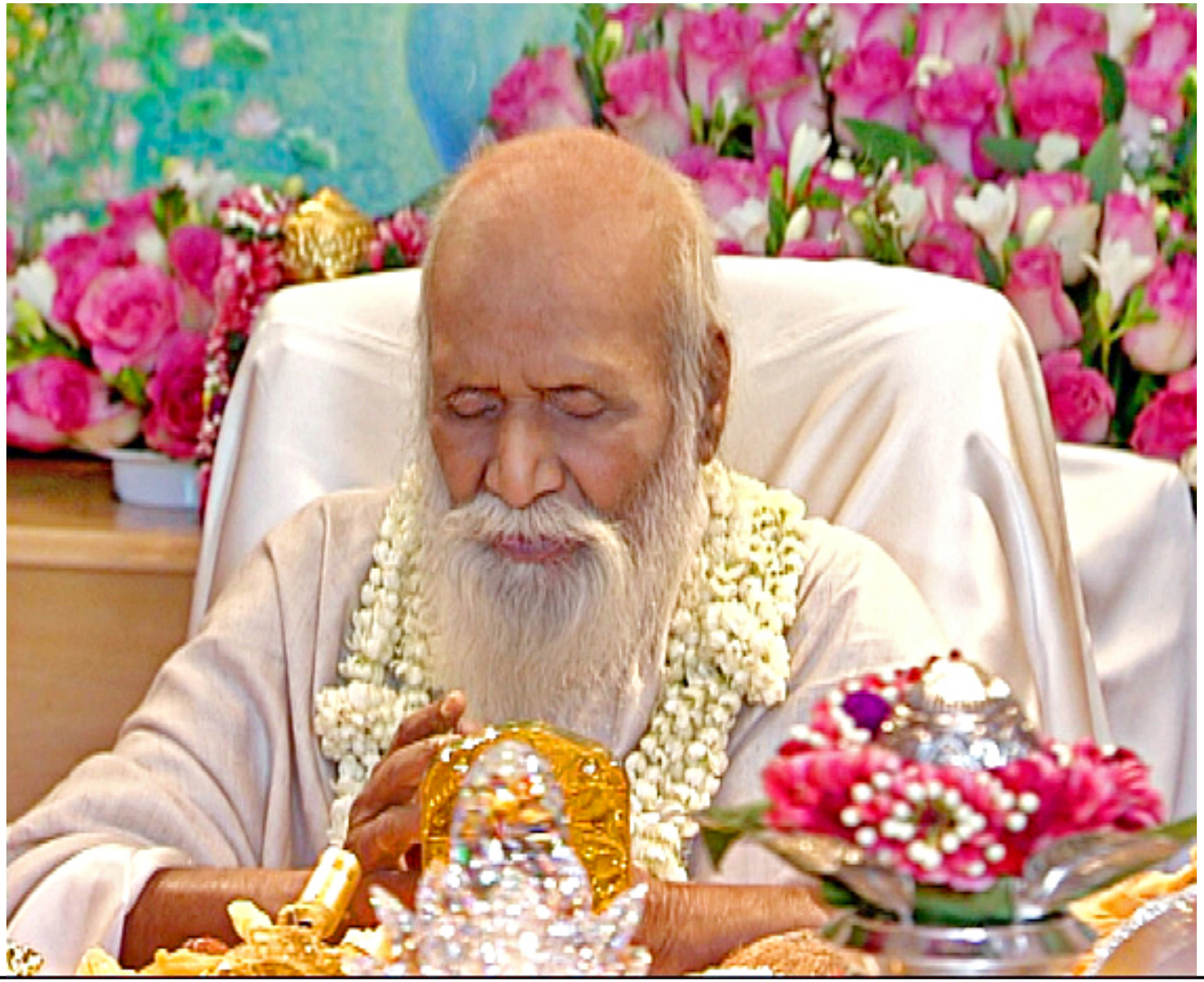
Universal Remedy?

The bigger the critical shared state is, the better TM seems to be. But what about support, overhead, control, and coordination?



Source: http://de.wikipedia.org/wiki/Transzendentale_Meditation

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  - stressless labour, contentment, room for creativity, higher productivity
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- in spite of everything, not run the **risk** of overstating sequential and understating parallel thinking...

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    - technically feasible as "straightforward extensions to multiprocessor cache-coherence protocols" [10]
    - offers a more convenient handling compared to, e.g., a multi-word CAS using (software-implemented CAS-based) LL/SC [14]

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- prone to overhead in case of mindless reuse of external functions or procedures from libraries, for instance
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    - tempt developers of non-sequential programs to see things through rose-coloured glasses
- TM is **a means to an end**—and is far from being a cure-all...

Levels of Abstraction

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HTM
- **hardware** transactional memory [10]

STM
- **software** transactional memory [17]

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- *implicitly transactional* (SLE [16], Rock [18], PPC [7], HLE [12])
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- buffering capabilities limited by (virtual) memory size
- scalability problems [15], significant *metadata* overhead [4]

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HyTM
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- heterogeneous transactions: (1) HTM-based and (2) STM-based
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    - heterogeneous transactions: (1) HTM-based and (2) STM-based
    - (1) gets aborted if in conflict with (2), may be restarted as (2)
- howsoever, **linguistic support** is desirable—but, with or without it, TM is no panacea to solve all non-sequential programming issues

HTM

acc. [8, p. 149/150]

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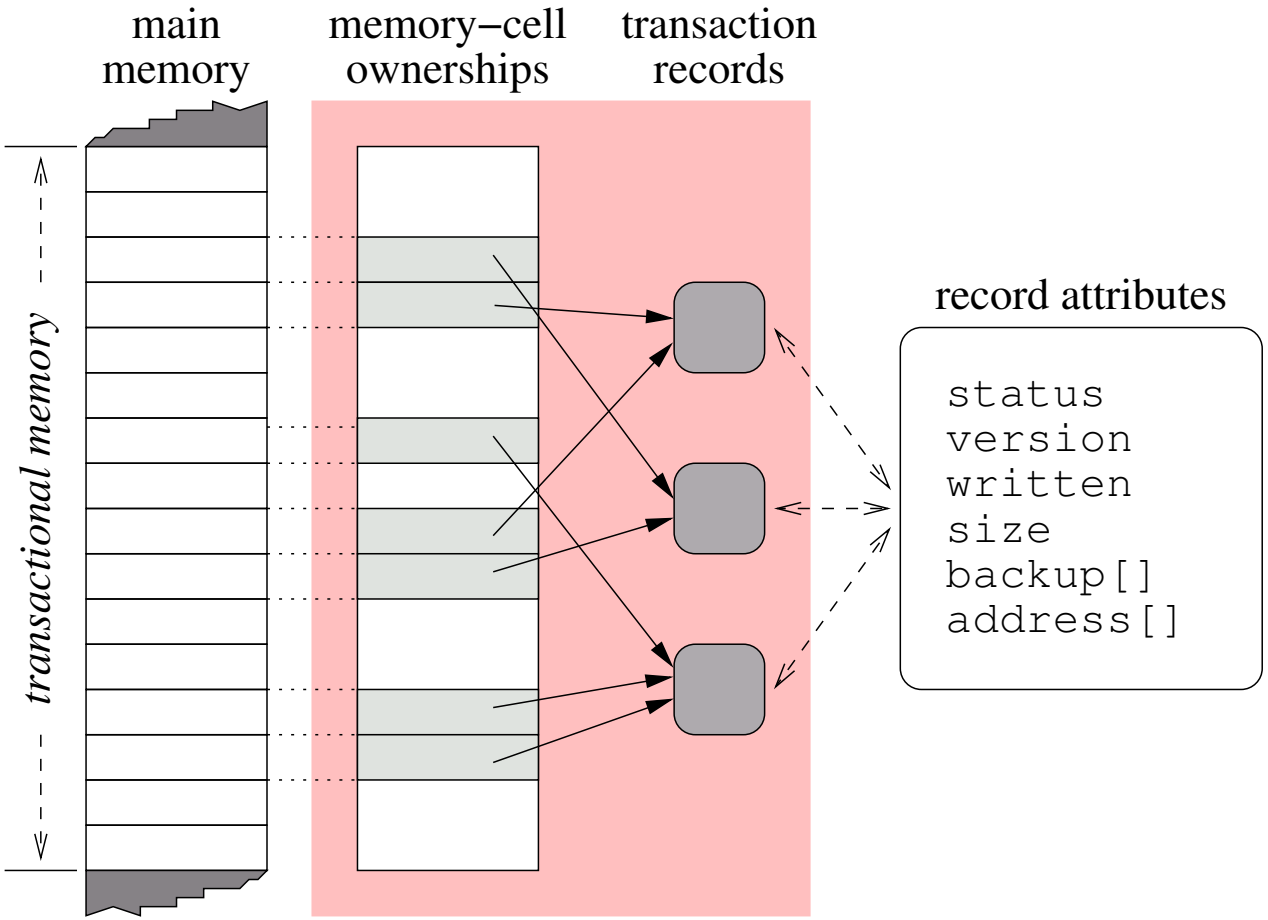
- but, not yet really common in available processors architectures:
  - IBM Blue Gene/Q (PowerPC A2 [7])
    - limited to multi-versioned L2 cache (20 MiB out of 32 MiB, [19, p. 129])
    - "watch granule" is 64 B [11, p. 509], same as cache line size
  - Intel Haswell (TSX [12])[1]
    - transaction size limited to L1 cache (64 KiB), 64 B cache line

[1] Mindless of the TSX bug [13, p. 47], which leaves TSX barred for normal use.

STM: Organisation of the Data Structures acc. [17, p. 103]



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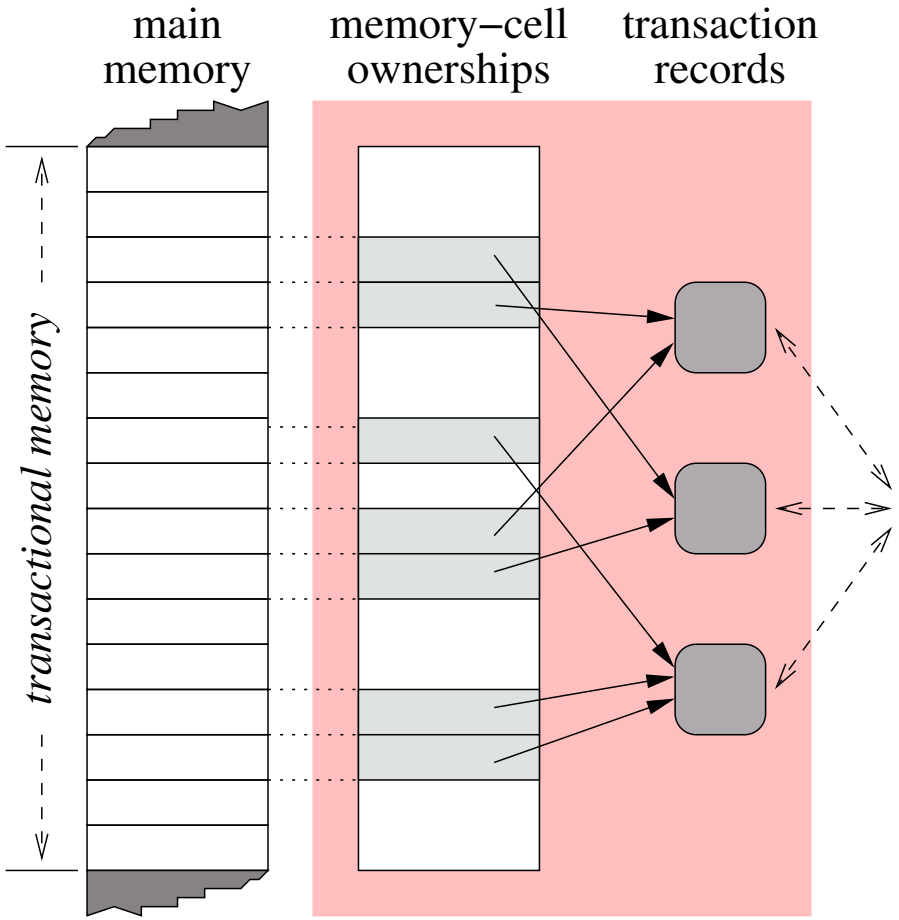

Transaction Data Set

Union of the read- and write-set.

record attributes

```
status
version
written
size
backup[]
address[]
```

Open array of memory locations read/written (`address[]`).

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- a **generation** number (preferable 64-bit) makes a transaction unique
  - additional parameter of steps 1, 2.1, 2.3, and 2.4: needs to be checked

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- an **implicitly transactional** model is assumed, but not the only way
  - by concept, an explicitly transactional approach is feasible as well

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- operations for accessing memory (implicitly or explicitly):
  - *load*
    - transfers a value from shared memory to a private placeholder
    - add the source location to the transaction **read set**
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- further operations are customary, according to circumstances
  - depending on the level of abstraction the TM system is associated with

Positive Thinking I

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  - a **successful commit** seems to be probable, other than abort and retry

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- other **exceptional events**, besides conflicting simultaneous processes
  - originated in the operating-system machine level and below:
    - traps (e.g., page faults) and interrupts (e.g., quantum expiration)
    - context switches (e.g., system calls, process dispatching)
  - originated in the non-sequential program itself:
    - avoidance or resolution of serialisation conflicts

Positive Thinking I

- it is assumed that contention of simultaneous processes is improbable
  - a **successful commit** seems to be probable, other than abort and retry

```
1  extern word_t foo, bar, foobar;
2  do {
3       word_t foo' = load(&foo);
4       word_t bar' = load(&bar);
5       store(&foobar, foo' + bar');
6  } while (!commit());
```

- other **exceptional events**, besides conflicting simultaneous processes
  - originated in the operating-system machine level and below:
    - traps (e.g., page faults) and interrupts (e.g., quantum expiration)
    - context switches (e.g., system calls, process dispatching)
  - originated in the non-sequential program itself:
    - avoidance or resolution of serialisation conflicts
- thus, be aware of reasons and frequency of the failure of transactions
  - if applicable, take care of region-specific **counteractive measures**
  - reflect on alternative concepts/solutions in achieving data consistency

Positive Thinking II

- a more advanced abstraction is to merely declare an **atomic region**
  - at the expense of a loss of control of the extent of the actual data set

```
1 extern word_t foo, bar, foobar;
2 begin(&&dropout);
3       word_t foo' = foo;
4       word_t bar' = bar;
5       foobar = foo' + bar';
6 end();
```

  - unless the compiler knows about critical variables that make up the data set, all variables read or written need to be tracked by the processor
  - this results in unnecessarily larger data sets and increases overhead

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6 end();
```

  - unless the compiler knows about critical variables that make up the data set, all variables read or written need to be tracked by the processor
  - this results in unnecessarily larger data sets and increases overhead
- **retry-loop concealment** is not always an advantageous measure
  - aside from other exceptional events (p. 15), retries are due to contention
  - contention control depends not only on dynamic but also static data
    - i.e., number of contending processes and duration of a single retry
    - whereby the latter is determined by the regions's execution path length
  - *begin*/*end* are unaware of **expectable execution times** of atomic regions

Outline

Operational Interface

```
1  extern void btx(void *);          /* begin */
2  extern void atx();                /* abort */
3  extern bool ctx();                /* commit */
4  extern void etx();                /* end */
5
6  extern long ltx(void *);          /* load */
7  extern void stx(void *, long);    /* store */
```

- in case of STM, it is worth to consider the following **refinements**:
  - upper-bound size of the read- and write-set in `btx`
  - specification of the reason of abort in `abx`
  - declaration of further modes of operation (flags) in `btx`
  - additional (first) parameter indicating `this` transaction in each operation
- however, as (most of) these depend on the program structure of the **transactional region**, determination should be up to the compiler

LIFO-List Revisited I

```
1  inline void push_dos(stack_t *this, chain_t *item) {
2      item->link = this->head.link;
3      this->head.link = item;
4  }
```

LIFO-List Revisited I

```
1  inline void push_dos(stack_t *this, chain_t *item) {
2      item->link = this->head.link;
3      this->head.link = item;
4  }

5  void push_tm_it(stack_t *this, chain_t *item) {
6      btx(0);
7      item->link = this->head.link;
8      this->head.link = item;
9      etx();
10 }
```

LIFO-List Revisited I

```
1  inline void push_dos(stack_t *this, chain_t *item) {
2      item->link = this->head.link;
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9      etx();
10 }
```

`item->link`

Unnecessary data-set member.

LIFO-List Revisited I

```
1  inline void push_dos(stack_t *this, chain_t *item) {
2      item->link = this->head.link;
3      this->head.link = item;
4  }

5  void push_tm_it(stack_t *this, chain_t *item) {
6      btx(0);
7      item->link = this->head.link;
8      this->head.link = item;
9      etx();
10 }

11 void push_tm_et(stack_t *this, chain_t *item) {
12     do {
13         item->link = (chain_t *)ltx(&this->head.link);
14         stx(&this->head.link, (long)item);
15     } while (!ctx());
16 }
```

item->link

Unnecessary data-set member.

FIFO-List Revisited I

```
1  inline void chart_dos(queue_t *this, chain_t *item) {
2      item->link = 0;                /* finalise chain */
3      this->tail->link = item;       /* append item */
4      this->tail = item;             /* set insertion point */
5  }
```

FIFO-List Revisited I

```
1  inline void chart_dos(queue_t *this, chain_t *item) {
2      item->link = 0;                  /* finalise chain */
3      this->tail->link = item;         /* append item */
4      this->tail = item;               /* set insertion point */
5  }
6  void chart_tm_it(queue_t *this, chain_t *item) {
7      item->link = 0;
8      btx(0);
9      this->tail->link = item;
10     this->tail = item;
11     etx();
12 }
```

FIFO-List Revisited I

```
1  inline void chart_dos(queue_t *this, chain_t *item) {
2      item->link = 0;                  /* finalise chain */
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6  void chart_tm_it(queue_t *this, chain_t *item) {
7      item->link = 0;
8      btx(0);
9      this->tail->link = item;
10     this->tail = item;
11     etx();
12 }

13 void chart_tm_et(queue_t *this, chain_t *item) {
14     item->link = 0;
15     do {
16         stx(&this->tail->link, (long)item);
17         stx(&this->tail, (long)item);
18     } while (!ctx());
19 }
```

Both TM variants appear to be equivalent.

LIFO-List Revisited II

```
1  chain_t *wear_dos(stack_t *this) {
2      chain_t *node = this->head.link;
3      this->head.link = 0;
4      return node;
5  }
```

LIFO-List Revisited II

Take a sledgehammer to crack the nut...

```
1  chain_t *wear_dos(stack_t *this) {
2      chain_t *node = this->head.link;
3      this->head.link = 0;
4      return node;
5  }

6  chain_t *wear_tm(stack_t *this) {
7      chain_t *node;
8      do {
9          node  = ltx(&this->head.link);
10         stx(&this->head.link, 0);
11     } while (!ctx());
12     return node;
13 }
```

LIFO-List Revisited II

Take a sledgehammer to crack the nut...

```
1  chain_t *wear_dos(stack_t *this) {
2      chain_t *node = this->head.link;
3      this->head.link = 0;
4      return node;
5  }

6  chain_t *wear_tm(stack_t *this) {
7      chain_t *node;
8      do {
9          node  = ltx(&this->head.link);
10         stx(&this->head.link, 0);
11     } while (!ctx());
12     return node;
13 }

14 chain_t *wear_wfs(stack_t *this) {
15     return FAS(&this->head.link, 0);
16 }
```

Overshoot

Definitely, TM is no magic bullet...

All that Glitters is not Gold...

The TM programming model itself, whether implemented in hardware or software, introduces complexities that limit the expected productivity gains, thus reducing the current incentive for migration to transactional programming and the justification at present for anything more than a small amount of hard- ware support. [4, p. 55]

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- **logical/conditional synchronisation**, e.g. condition variables [6]:
  - waiting on a condition inside a transaction is difficult or impossible
    - difficult, e.g., in case of an I/O operation that cannot be rolled back
    - impossible, if the transactional process is implemented as kernel-level thread[2]

[2] Assuming that TM applies to user-level processes, only—which is usual.

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    - impossible, if the transactional process is implemented as kernel-level thread[2]
  - as a signalling transaction may abort, the stated condition never occurred
    - furthermore, signaller and signallee transactions may happen simultaneously, which is prone to lost-wakeup as the latter may complete before the former

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  - as a signalling transaction may abort, the stated condition never occurred
    - furthermore, signaller and signallee transactions may happen simultaneously, which is prone to lost-wakeup as the latter may complete before the former
- thus, TM is merely an abstraction to **multilateral synchronisation**
  - most attractive semantics is its "single global lock atomicity" [3] ☹

[2] Assuming that TM applies to user-level processes, only—which is usual.

Outline

Résumé

- TM abstractions as to the different rootedness of the implementation
  - HTM: hardware, explicitly/implicitly transactional, hardly available
  - STM: software, lock-less/based solutions, metadata overhead
  - HyTM: hybrid, try HTM first, fall back on STM in critical situations
- principle concepts of TM and functions or instructions, respectively
  - read set, write set, and the union thereof: data set
  - load, store, commit, abort, begin, end—and more...
- examination and discussion of the pros and cons of TM
  - especially limited hardware support still hampers wide use
  - independent thereof, programming introduces other types of complexities
  - also because it merely is an abstraction to multilateral synchronisation
- TM is a means to an end, it has a silver lining but also a demerit...

> *Transactional Memory Should Be an Implementation Technique, Not a Programming Interface. [3]*

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In: *Proceedings of the 21st International Conference on Parallel Architectures and Compilation Techniques (PACT '12)*.
New York, NY, USA : ACM, 2012. –
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Emulation of LL/SC

```
1  typedef struct ref {
2    int *label; /* actual location in (shared) memory */
3    int owner;  /* reservation number: initial anything but -1 */
4  } ref_t;
5
6  inline int ll(ref_t *ref, int key) {
7    int owner, value;
8    do {
9      owner = ref->owner;
10     value = *(ref->label);
11   } while ((ref->owner == -1) || !CAS(&ref->owner, owner, key));
12   return value;
13 }
14
15 inline bool sc(ref_t *ref, int key, int val) {
16   bool done;
17   if ((done = CAS(&ref->owner, key, -1))) {
18     *(ref->label) = val;
19     ref->owner = 0;
20   }
21   return done;
22 }
```

key
- unique transaction number
- advanced when transaction completes

LIFO-List Revisited III

```
1  inline chain_t *pull_dos(stack_t *this) {
2      chain_t *node;
3      if ((node = this->head.link))
4          this->head.link = node->link;
5      return node;
6  }

7  chain_t *pull_tm(stack_t *this) {
8      chain_t *node;
9      do {
10         if ((node = (chain_t *)ltx(&this->head.link)))
11             stx(&this->head.link, (long)node->link);
12     } while (!ctx());
13     return node;
14 }
```

- the implicitly transactional variant would unnecessarily include *node* in the transaction data set...

FIFO-List Revisited II

```
1  inline chain_t* fetch_dos(queue_t *this) {
2      chain_t *node;
3      if ((node = this->head.link)          /* filled? */
4      && !(this->head.link = node->link)) /* last item? */
5          this->tail = &this->head;         /* reset */
6      return node;
7  }
8  chain_t* fetch_tm(queue_t *this) {
9      chain_t *node;
10     do {
11         if ((node = (chain_t *)ltx(&this->head.link))) {
12             stx(&this->head.link, (long)node->link);
13             if (!node->link)
14                 stx(&this->tail, (long)&this->head);
15         }
16     } while (!ctx());
17     return node;
18 }
```

- the implicitly transactional variant would unnecessarily include *node* in the transaction data set...

FIFO-List Revisited III

```
1  inline chain_t *drain_dos(queue_t *this) {
2      chain_t *head = this->head.link;
3      this->head.link = 0;          /* null item */
4      this->tail = &this->head;     /* linkage item */
5      return head;
6  }

7  chain_t *drain_tm(queue_t *this) {
8      chain_t *head;
9      do {
10         head = (chain_t *)ltx(&this->head.link);
11         stx(&this->head.link, 0);
12         stx(&this->tail, (long)&this->head);
13     } while (!ctx());
14     return head;
15 }
```

- the implicitly transactional variant would unnecessarily include *head* in the transaction data set...