Memory Management for Concurrent Data Structures on Hardware Transactional Memory

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Non-blocking Stack (pop)

```
pair<int, bool> pop(Stack::Top& top) {
  Stack* nexttop = nullptr;
  Stack* currtop = top.load();

  do {
    if (currtop == nullptr) return make_pair(0, false);

    nexttop = currtop->next;
  } while (!top.compare_exchange_strong(currtop, nexttop));

  int res = currtop->val;
  delete currtop; // OK?
  return make_pair(res, true);
}
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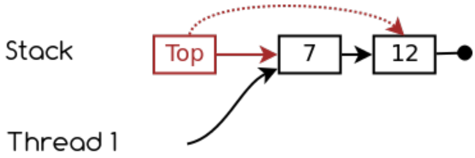

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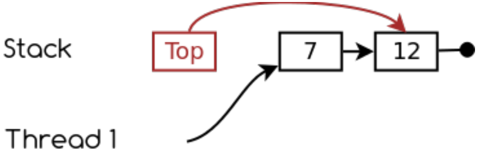

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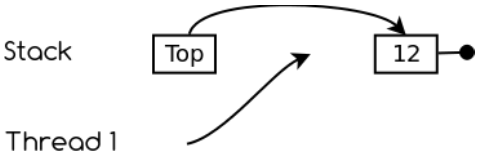


Solutions

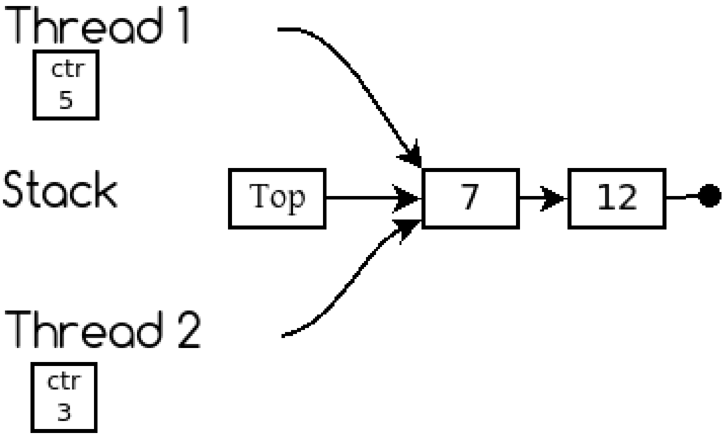
- Garbage collection
- Epochs, Harris (2001)
- Hazard Pointers, Michael (2004)
- Repeated Offender, Herlihy et al. (2004)
- Reference Counting, Gidenstam et al. (2007)
- Optimistic Access, Cohen and Petrank (2015)
- Debra+, Brown (2015)
- QSense, Balmau et al. (2016)

Epochs

Idea

- Record when a thread starts and finishes an operation.
- Record when an object gets removed.
- Delay deletion until threads are past the deletion time or inactive

Epochs



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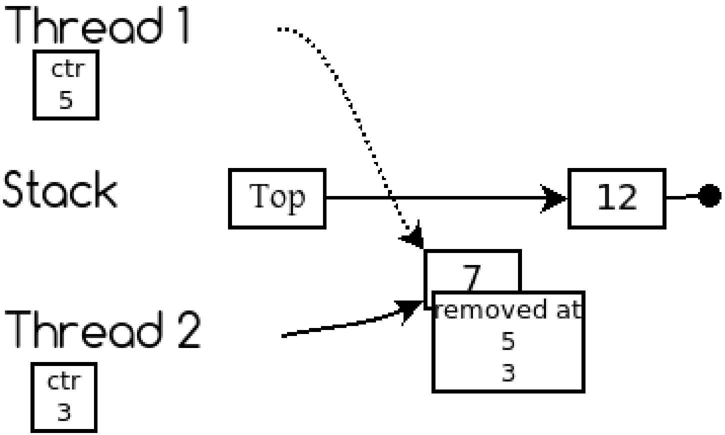

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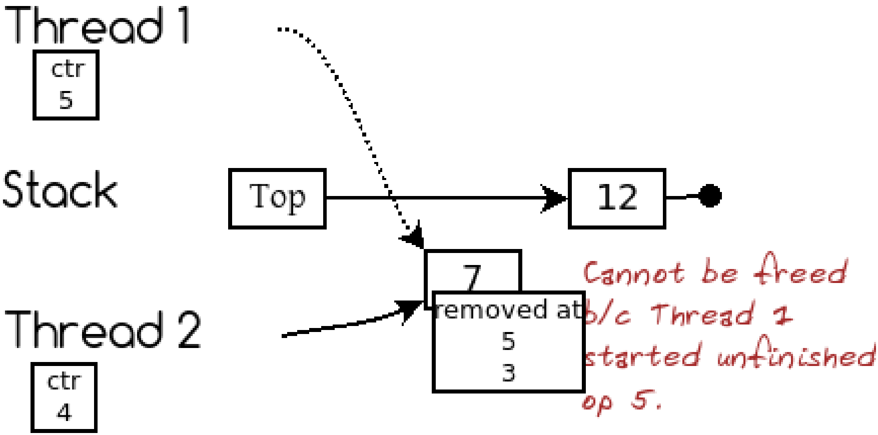
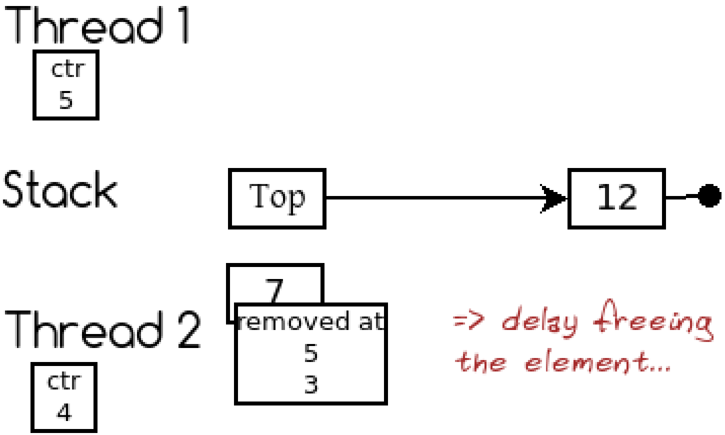


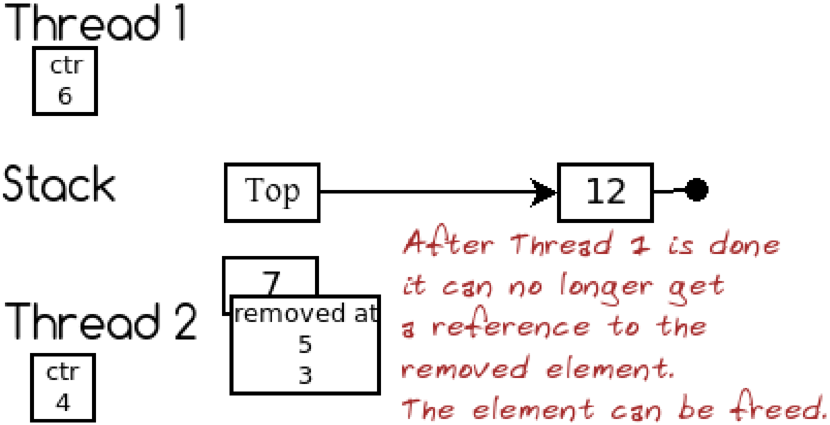
Thread 1
ctr
5
Stack
Top
12
7
removed at
5
3
Thread 2
ctr
4
Cannot be freed
b/c Thread 1
started unfinished
op 5.

Epochs



Thread 1
ctr
5
Stack
Top
12
7
removed at
5
3
Thread 2
ctr
4
=> delay freeing
the element...

Epochs


Thread 1
ctr
6
Stack
Top
12
7
removed at
5
3
Thread 2
ctr
4
After Thread 1 is done
it can no longer get
a reference to the
removed element.
The element can be freed.

Epochs

Benefits

- Low overhead (coarse grain)
- Can bulk free at most every n times, $n > |threads|$

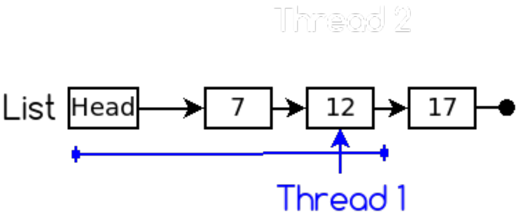
Problems

- What if a thread fails in the middle of an operation?

Hardware Transaction

In principle

HTM makes memory management easy.



Hardware Transaction and Memory Management

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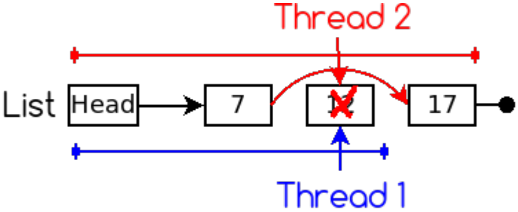

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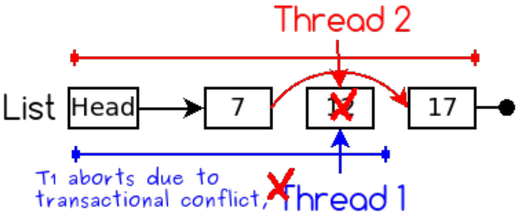
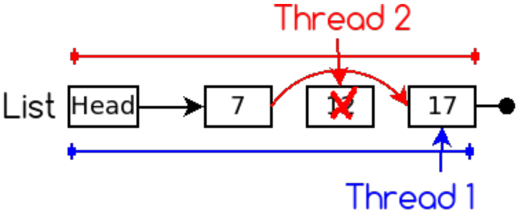


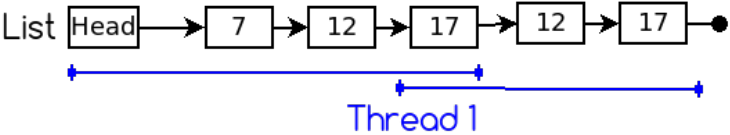
In practice

- Hardware limits transaction size
- It may be undesirable to keep entire data structure in transaction



Partition Access

- Access data structures in partitions.
- Nodes at partition boundaries need to be safe.
- Cost of memory management is reduced greatly.



Partition Size

Benefits of longer transactions

- Memory management is cheap
- Relaxed memory operations
  (Threads sync at begin and end of transaction)
- Amortize cost of transactional overhead over more operations

Drawbacks of longer transactions

- Increases chance of transactional aborts
  - conflict aborts
  - capacity aborts
  - OS aborts

Partition Size

Solution

Compute TX size over rolling average of *n* successful operations.
Dragojević et al., 2011.

Epochs / HTM

Epochs for HTM

Problem

A delayed or failed thread prevents memory from being reclaimed.

Solution

Abort operation executed by delayed thread. (Debra+, Brown (2015)).

HTM

- HTM offers hardware support for aborting operation.
- increment other thread's epoch counter.

Transaction and Epochs

- Start epoch
- Validate epoch in transaction
  - Abort and restart operation if counter is even

Use of Epochs

```
start_epoch();
// transaction partition
if (tx_begin()) {
   ...
   if (!validate_epoch())
      tx_abort();
   ...
   tx_end();
}
end_epoch();
```

Transaction and Epochs

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```

Epochs and Reclamation

Removed Object

- Address to be freed
- Epoch vector when object was removed
- Survival count

Thread Aborts

Abort other threads that prevent object reclamation for *n* times.

Epochs - Implementation Details

- A transaction is tried *n* times before partition size is reduced
- Lock-based fall back path
- HTM and C++ atomics

Abort Delayed Thread

```
void cancel_transaction(size_t threadid, size_t currepoch) {
  epoch_t* epochptr = lookup_thread(threadid);
  epochptr->epoch.compare_exchange_strong(currepoch, currepoch+1);
}
```

Epochs Summary

- Small memory and time overhead
- Operation on a data structure requires transaction

Evaluation

Hazard Pointers for HTM

- Publish needed nodes at end of partition
- Scan other threads for nodes that are referenced
- Storing hazard pointers reduces effective transaction size

  Dragojević et al., 2011.

StackTrack

- Publish beginning and end of pointer array on stack
- \+ No overhead for storing hazard pointers
- Collecting other threads pointers requires TX

Alistarh et al. 2014.

Reference Counting

- Each object has a reference counter
- Increment counter / decrement counter if object is no longer needed

\+ No need to scan other thread's pointers

\- frequent conflicts on counter accesses

\- counters reduce effective transaction size significantly

Dragojević et al., 2011.

Systems

Intel Haswell

- 1 socket
- 4 cores
- 8 threads
- Cache line: 64 bytes
- Level 1: 32K, 8-way
- Level 2: 256K, 8-way
- Max TX (load): 4M
- Max TX (store): 32K
- no progress guarantee

IBM Power 8

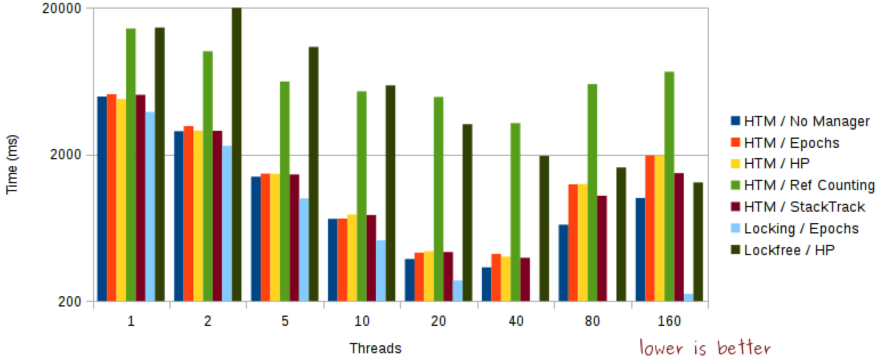
- 2 socket
- 20 cores
- 160 threads
- Cache line: 128 bytes
- Level 1: 64K, 8-way
- Level 2: 512K, 8-way
- Max TX (load): 8K
- Max TX (store): 8K
- no progress guarantee

Evaluation

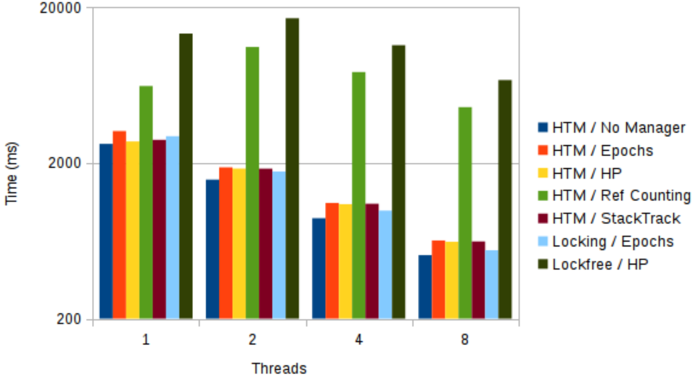
Linked List

- 100K operations (total)
- 10% untimed initial inserts
- alternating insert and erase
- threads access disjoint regions

Evaluation - IBM Power 8



Evaluation - Intel Haswell

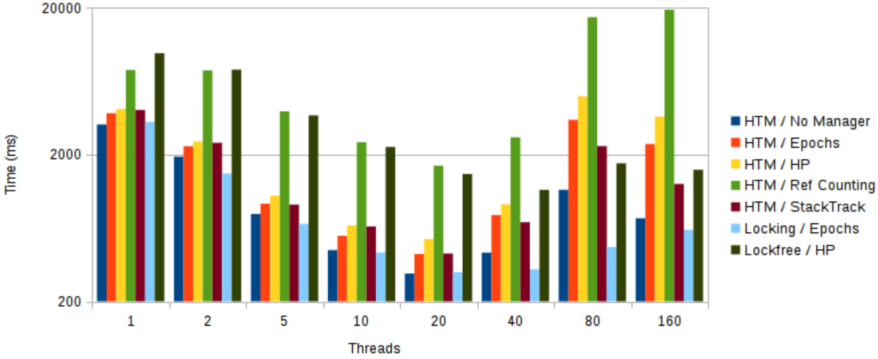


Evaluation

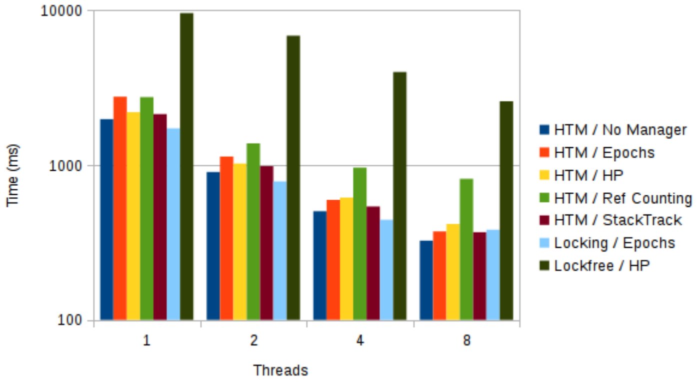
Skip list

- 4M operations (total)
- 10% untimed initial inserts
- alternating insert and erase
- threads access disjoint regions
- Intel: 32 levels, elements in next layer $\frac{1}{2}$
- IBM: 16 levels, elements in next layer $\frac{1}{8}$

Evaluation - IBM Power 8



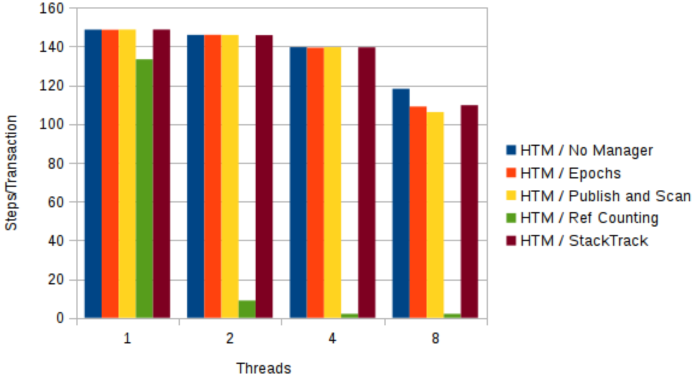
Evaluation - Intel Haswell



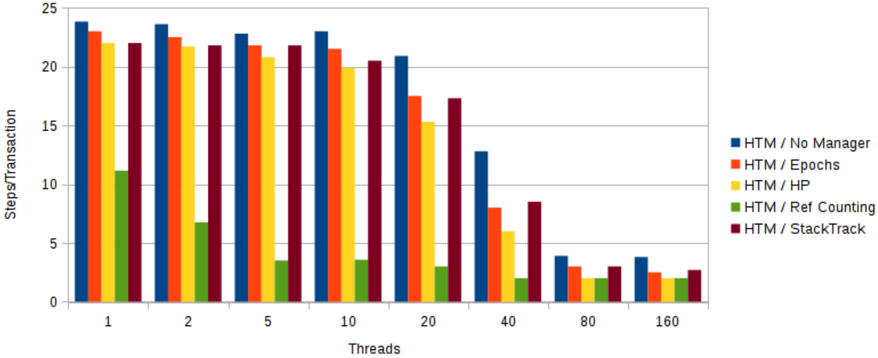
Evaluation

How does the memory management technique impact TX size?

Evaluation - Intel Haswell / Linked list



Evaluation - IBM Power 8 / Skip list



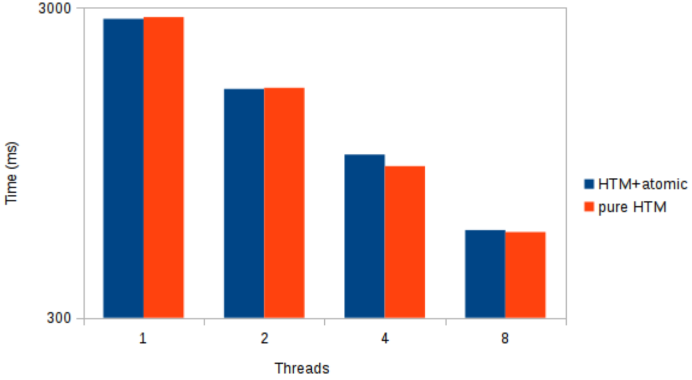
Summary

- Introduced Epochs / HTM
- HTM is a powerful mechanism to speed up common case
- Most memory management techniques perform similarly

- Future Work: Evaluation with other data structures and access patterns

Thank you!

Evaluation - Intel Haswell / Linked list



Evaluation - Intel Haswell / Skip list