TxLinux: Using and Managing Hardware Transactional Memory in an Operating System

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Chip Multi-Processor (CMP)

- Number of cores per chip is rapidly increasing
- As number of cores/threads on a chip increases, importance of parallel programming increases
- Parallel programming is difficult
  - Deadlocks
  - Priority Inversion
  - Lock ordering
- Difficulties lead to a tradeoff between performance and programming complexity

Conventional Locks

- Does not scale well
  - Locks are conservative
    - Locks are “pessimistic”
    - Transactions are “optimistic”
  - Not robust, non-modular
    - If a thread holding a lock is delayed, all threads waiting for that lock must also wait
  - “Losing” wake ups to sleeping threads
    - Problem in large systems
- Synchronization is one of the a great source of bugs in Linux

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Transactional Memory (TM)

- Locks can be difficult to use
  - Small errors can easily result in deadlock
  - Proper implementation can take a lot of planning
- Possible Solution: Transactional Memory
  - Simplifies the atomic process (modular)
    - Programmer denotes atomic sections (e.g. atomic{…})
  - Software Implementations (STM)
    - (Currently) slower than locks
    - (Probably) always slower than hardware
  - Hardware Implementations (HTM)
    - Fast
    - Hardware is limited, difficult to implement

Transactional Memory (TM) cont'd

- Transactions are all or nothing
  - Commit – changes take effect
  - Abort – all changes rolled back to original state and (usually) restarted
- Conflicts
  - Conflicts are dynamically detected (as they happen)
    - When a conflict is detected, one transaction continues
    - Other transaction(s) fail and are restarted
  - TM is optimistic and assumes threads will usually "play nicely" and not interfere with each other

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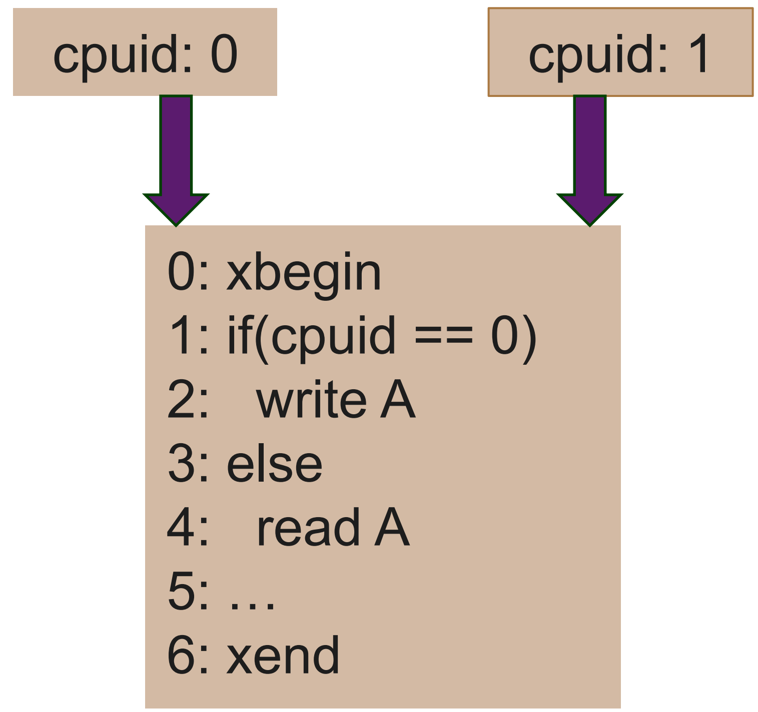
Transactional Memory (TM) cont'd

- Conflict Detection
  - Eager
    - Detect conflicts as they happen
    - May abort when it could have committed
  - Lazy
    - Detect conflicts at time of commit
    - Wastes Computation
- Version Management
  - Eager
    - Immediately puts new values in place
  - Lazy
    - (Temporarily) leaves the old values in place, waiting for them to be committed

HTM Example

- Two cores (0 and 1) simultaneously enter a critical region
  - If cpu0 wins, cpu0 modifies A, cpu1 restarts
  - If cpu1 wins, cpu0 successfully reads and no changes are made to A
- Two concurrent transactions conflict if a write overlaps with another transaction’s read or write



TxLinux's TM Implementation

- TxLinux uses MetaTM
  - MetaTM Primitives
    - xbegin, xend, xretry
    - xpush, xpop (save and restore states of transactions)
    - xgettxid, xtest, xcas
  - Spinlocks can often be safely converted
    - spin_lock() -> xbegin
    - spin_unlock() -> xend
  - Nested transactions are flattened
    - If one fails, the whole transaction fails

Issues with TM

- A few problems
  - Irreversible I/O
  - Issues with using both locks and transactions
    - Sometimes locks are required
  - Larger memory requirements can hurt performance due to support for rollback

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TM & Locks

- Both locks and transactions have advantages/disadvantages
  - Locks
    - Legacy code
    - I/O (cannot be done with transactions because I/O is generally irrevocable)
    - Other (mis)uses (e.g. runqueue, protecting the page table)
  - Transactions
    - Much faster when contention is the exception
    - Problems with larger memory requirements
- Being able to use both is beneficial
  - Let the kernel programmer pick which to use
    - TxLinux

cxspinlock (TM and Locks)

- Cooperative Transactional Spinlock
  - Critical sections can use locks or transactions
    - Programmer doesn't have to make a decision
  - Default to transaction in most cases
    - When I/O (or some operation requiring exclusivity) is detected:
      - Immediately cancel
      - Restart in exclusive mode using locks

cxspinlock API

cx_optimistic: *Use transactions, restart on I/O attempt*	cx_exclusive *Acquire a lock, using contention manager*	cx_end *Release a critical section*

`void cx_optimistic(lock){`
`status = xbegin;`
`if(status==NEED_EXCL){`
`xend;`
`if(gettxid)`
`xrestart(NEED_EXCL);`
`else`
`cx_exclusive(lock);`
`return;`
`}`
`while(!xtest(lock,1));`
`}`
	`void cx_exclusive(lock){`
	`while(1) {`
	`while(*lock != 1);`
	`if(xcas(lock, 1, 0))`
	`break;`
	`}`
	`}`
		`void cx_end(lock){`
		`if(xgettxid) {`
		`xend;`
		`} else {`
		`*lock = 1;`
		`}`
		`}`

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Problems with cxspinlocks

- Reintroduces some problems transactions are meant to eliminate
  - Poor locking can lead to deadlock
  - Combination of transactions and spinlocks can lead to deadlock
    - Flat-nesting of transactions makes the system susceptible to deadlock
- cxspinlocks do require significantly more overhead for spin-lock related functions

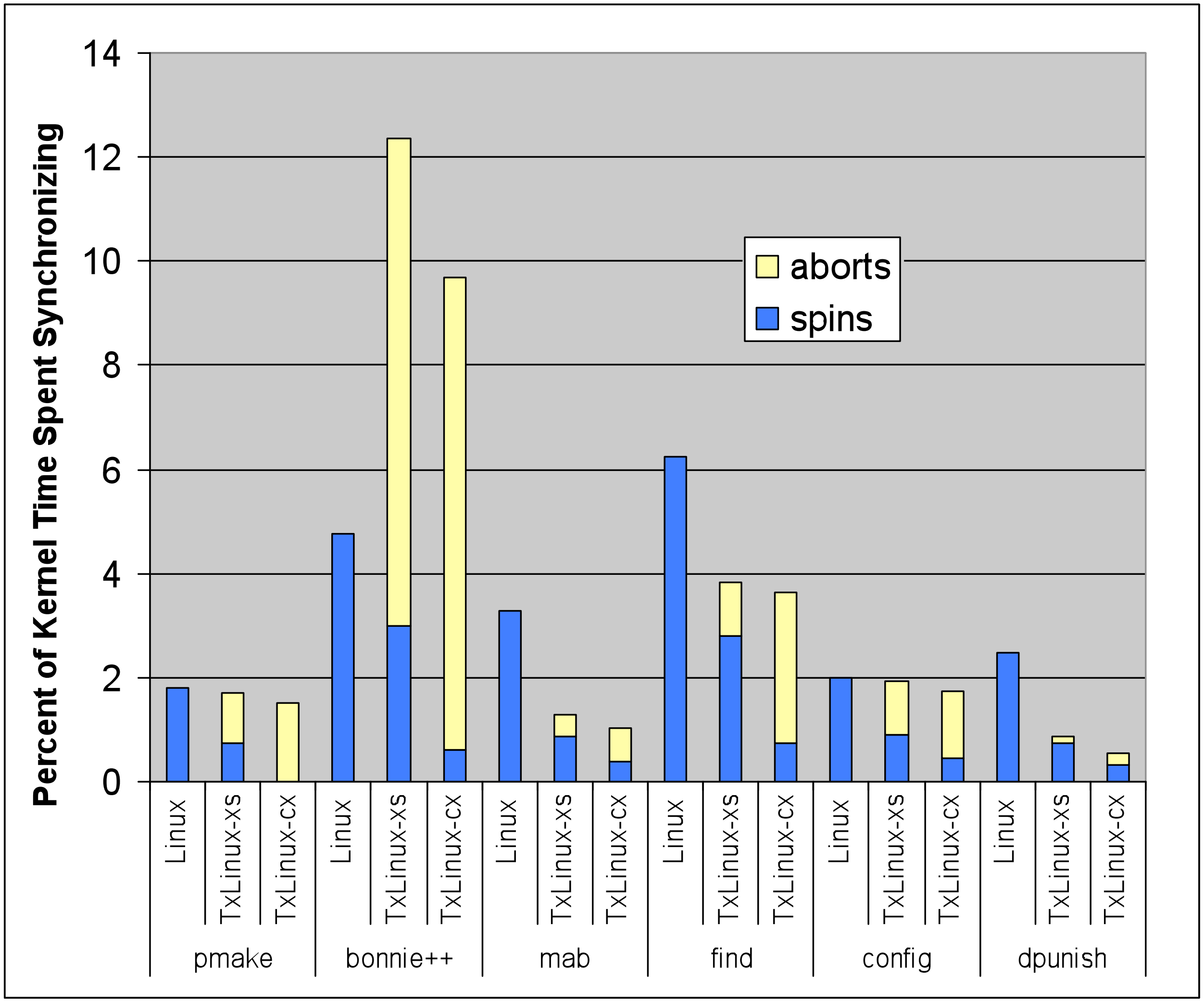
Decoupling I/O from System Calls

- Provide full TM at user level
  - Decouple I/O from system calls
  - Buffer effect of system calls initiated by users in memory without writing to disk
    - Memory requirements might be too high
    - Must kill the process if there are not enough resources
- User retains simpler transactional programming model

TM with Contention Management & Scheduling

- Constantly restarting transactions can waste time
- Contention management and scheduling can help
  - os_prio policy
    - 1. Highest scheduling value
    - 2. SizeMatters
      - Largest transaction size wins, size resets on restart
    - 3. Timestamp
  - Eliminates priority inversion
  - Contention manager favors non-TM threads

Synchronization Overhead



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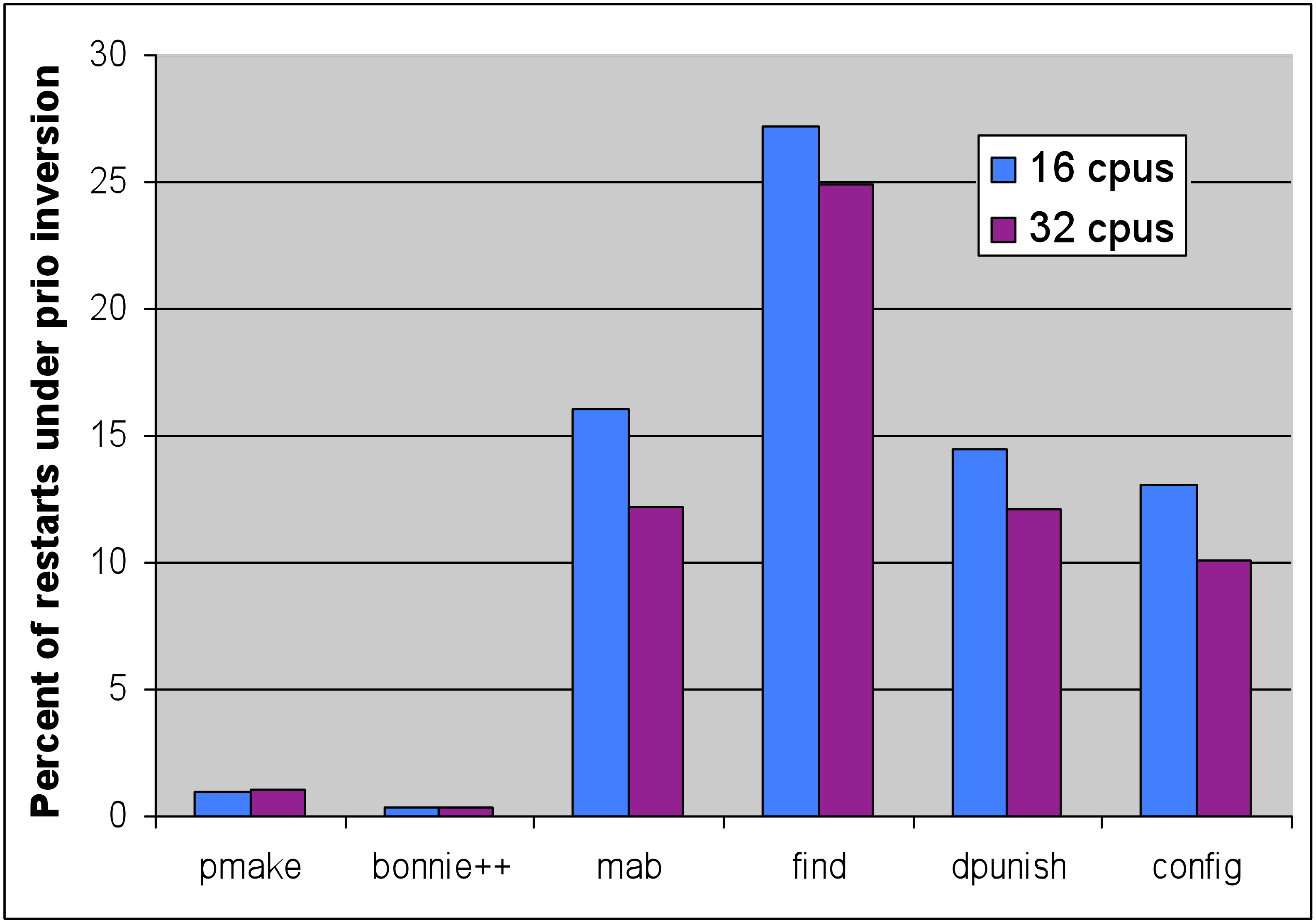
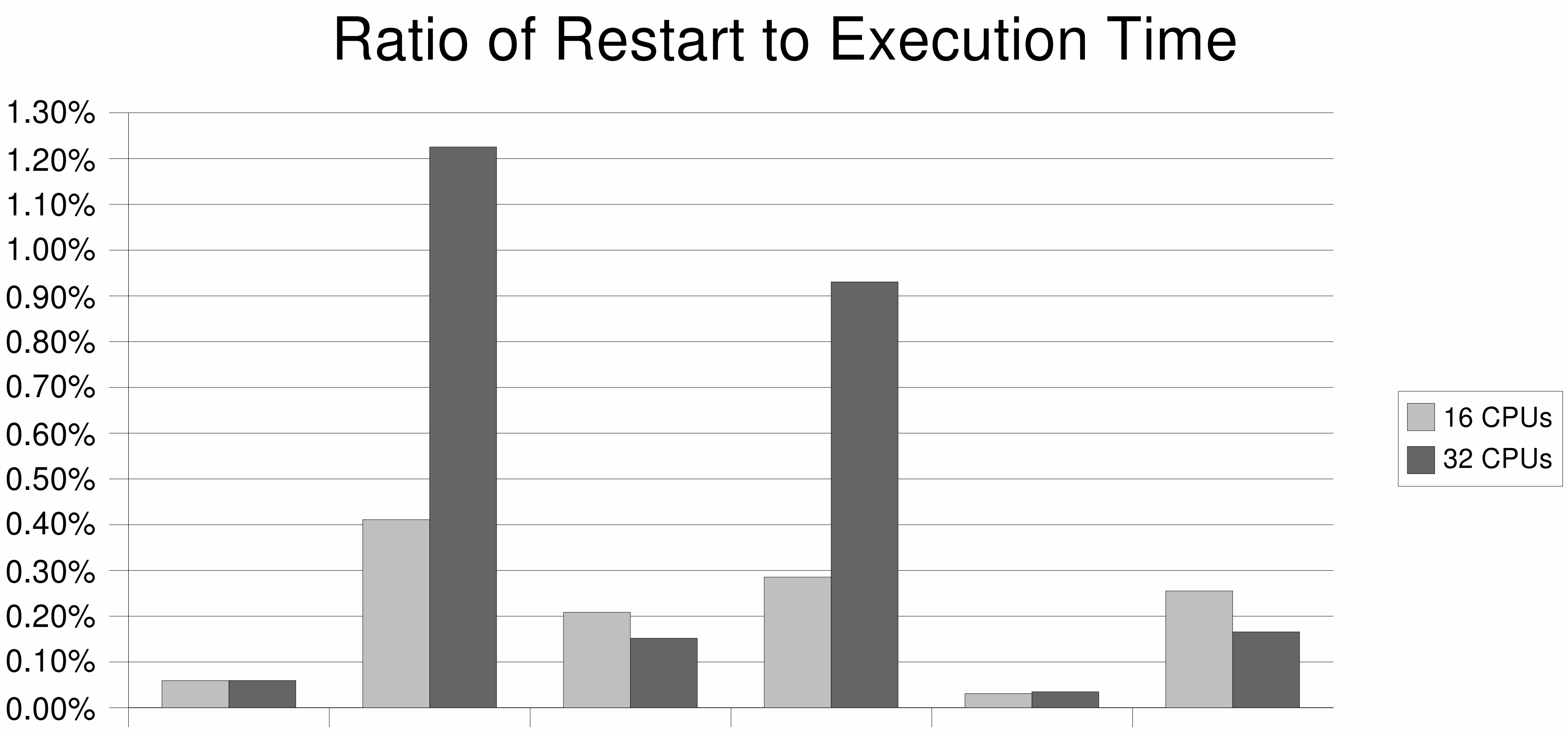
Priority and Policy Inversion in TxLinux



Limits of Performance



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Comments

- Reintroducing problem of deadlocks in a new way
- Passing ownership of locks explicitly does not seem to be possible with TM
- TxLinux always uses eager version management
  - High contention means more aborts
  - More aborts with eager model is more expensive
    - Lazy model simply discards a memo
    - Maybe this would be better?
- cxspinlocks do seem to help simplify the programming model (but not the implementation)
- Priority inversion can be eliminated!!!