Isotope: Transactional Isolation for Block Storage

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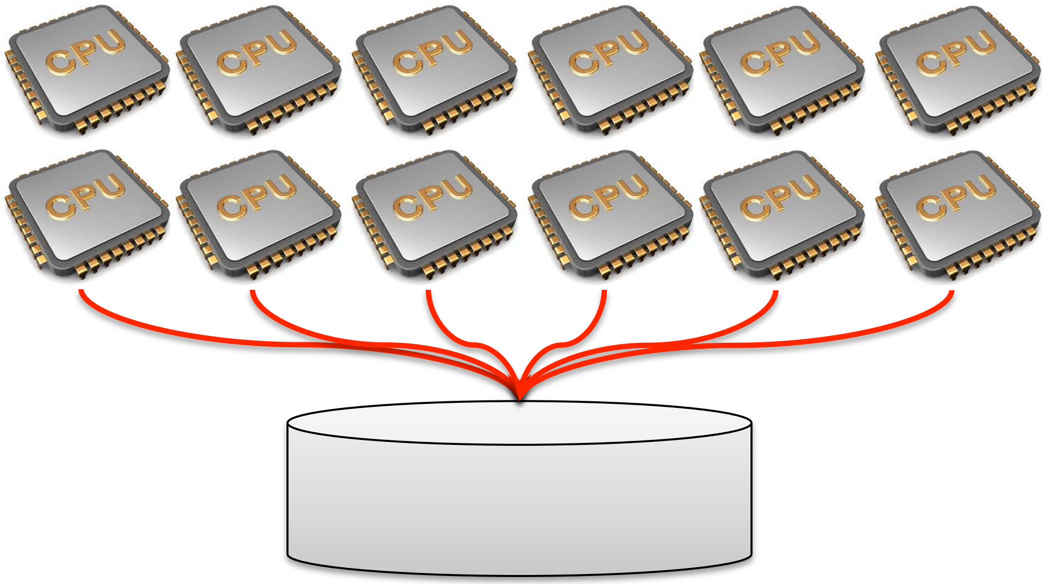
Multicore and Concurrency

- Concurrent access to storage is the norm



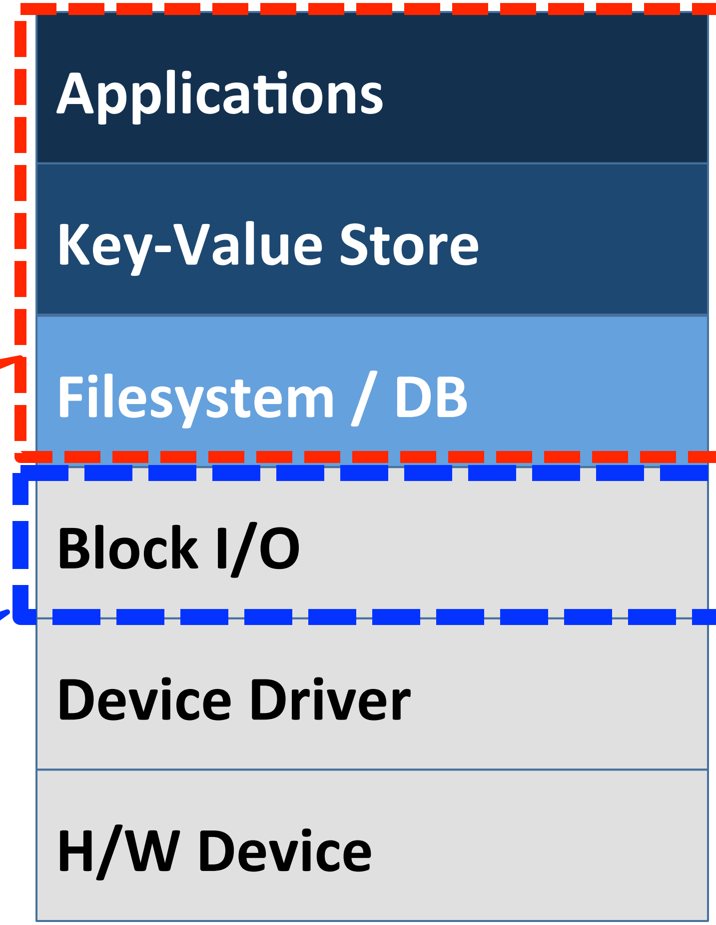
- For safe data access, concurrency control is a must

Concurrency Control in Storage Stacks

- Most modern apps support concurrency control
  - App-specific implementation
  - Typically, locking

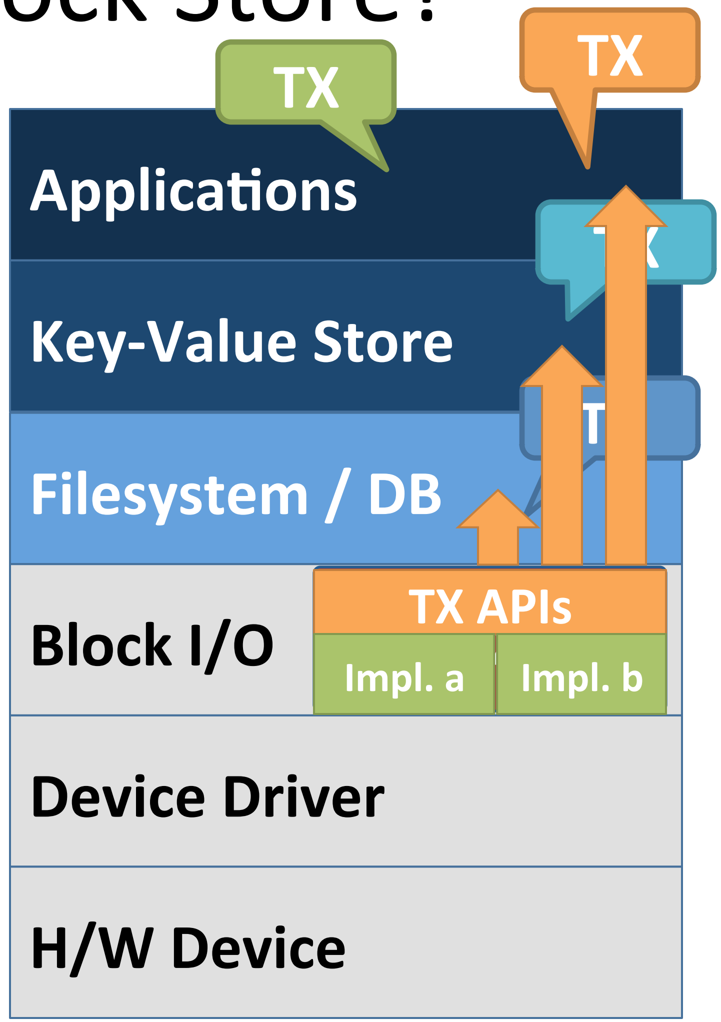
Concurrency Control (+ Atomicity/Durability) Is Difficult

Transactional Block Store (**<u>Isolation</u>** + Atomicity + Durability)



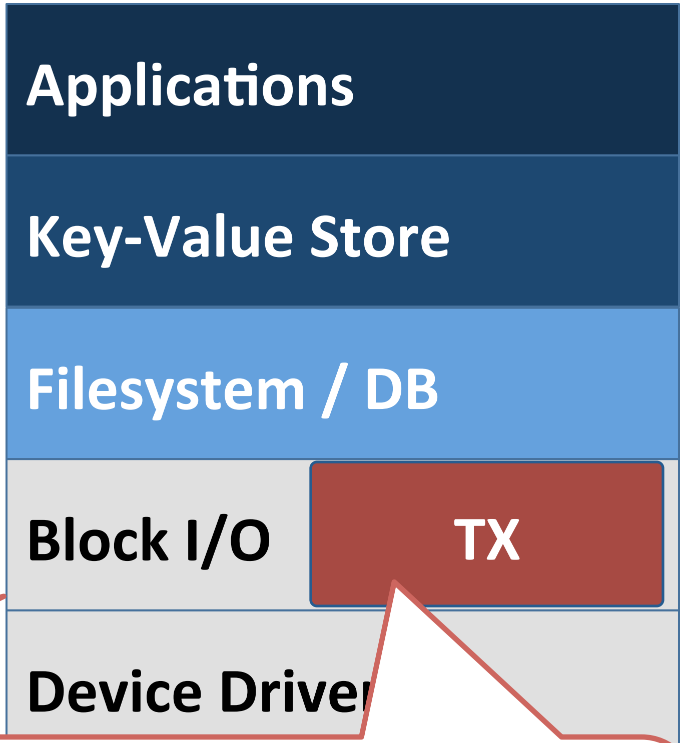
Why Transactional Block Store?

- Simpler applications
  - One common implementation for isolation (and atomicity/durability)
  - TX APIs decouple policy/mechanism
  - TX over application-level constructs (e.g. file, directories, key-value pairs)
  - TX across different applications (e.g. read from file and write to KV store)



End-To-End Argument?

- Application specific functions should be in end-hosts
  - Transactional isolation is general
- Pushed down function should not incur unnecessary overheads
  - Isolation can be implemented efficiently



Many block-level functions, e.g. atomicity, block layer indirection, are already implemented

TX using optimistic concurrency control yields low overhead

How do we design a transactional block store?

Isotope

Is a transactional block store useful?

IsoBT, IsoHT, IsoFS, and ImgStore

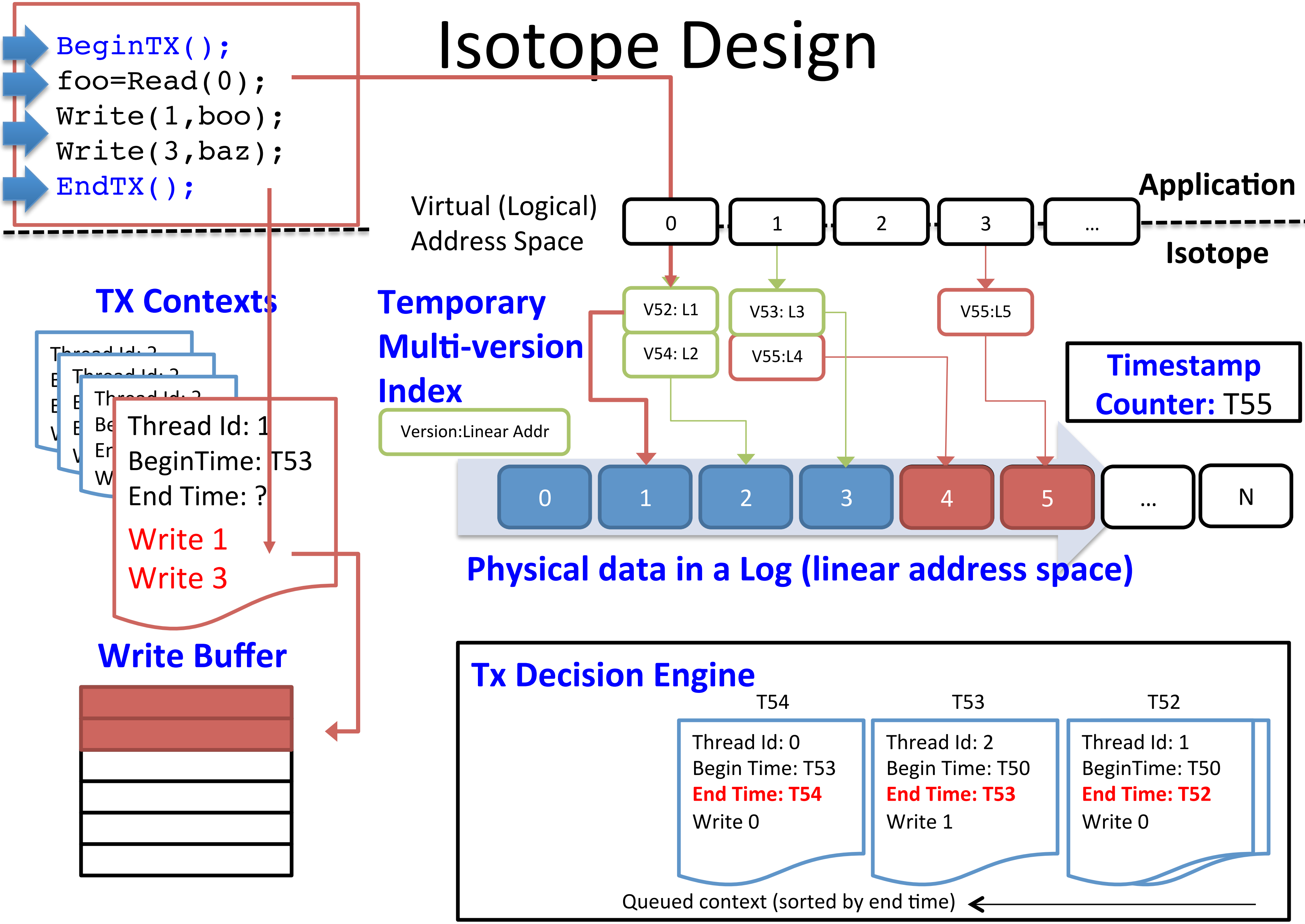
Rest of the Talk

- Isotope
  - Overview
  - Design and APIs
  - Applications
- Performance Evaluation
- Conclusion

Isotope

- The first block store to support TX isolation
  - MARS and TxFlash only supported TX atomicity
- Multi-version optimistic concurrency control
  - Keeps multiple versions of block data
  - Speculatively executes TX until commit time
- One of two semantics supported
  - Strict serializability
  - Snapshot isolation
- Simple APIs
  - BeginTX/EndTX/AbortTX and more

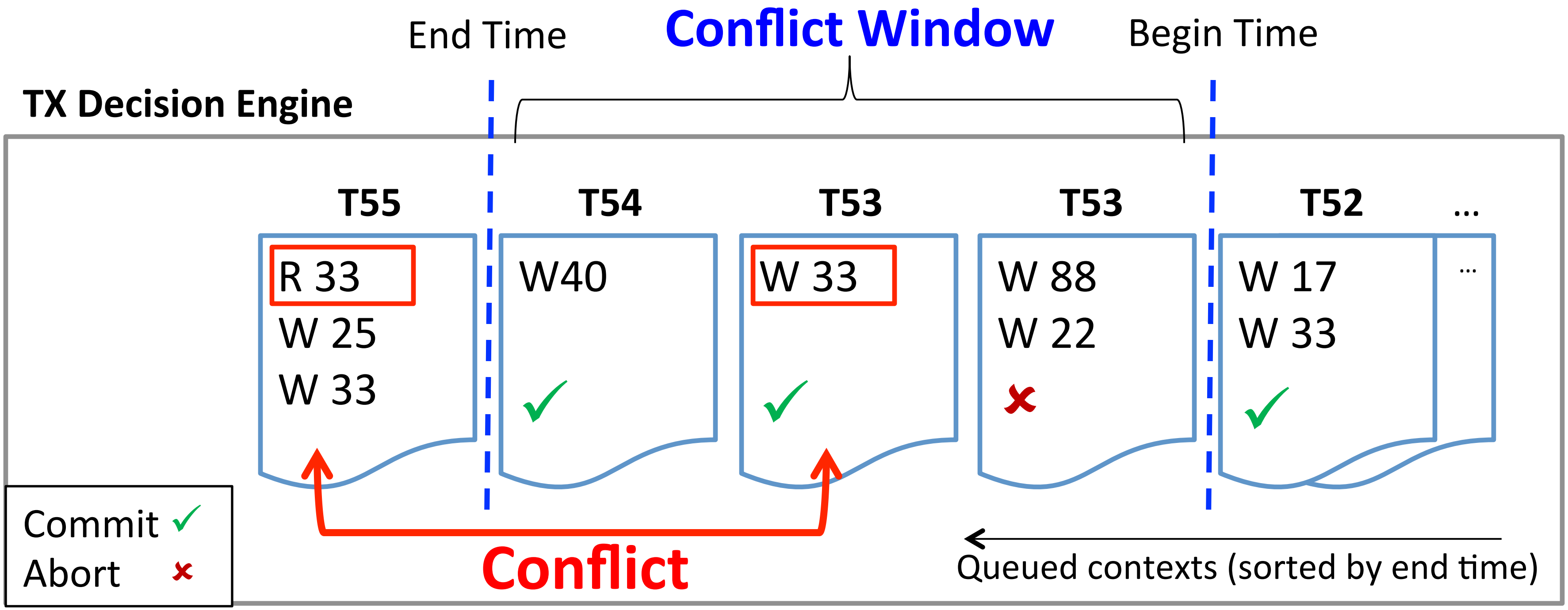
Isotope Design



Deciding Transactions

- Strict serializability based
  - Checks for **read/write conflicts**

```
BeginTX(); // @ T53
foo=Read(33);
Write(25, bar);
Write(33, baz);
EndTX();    // @ T55
```

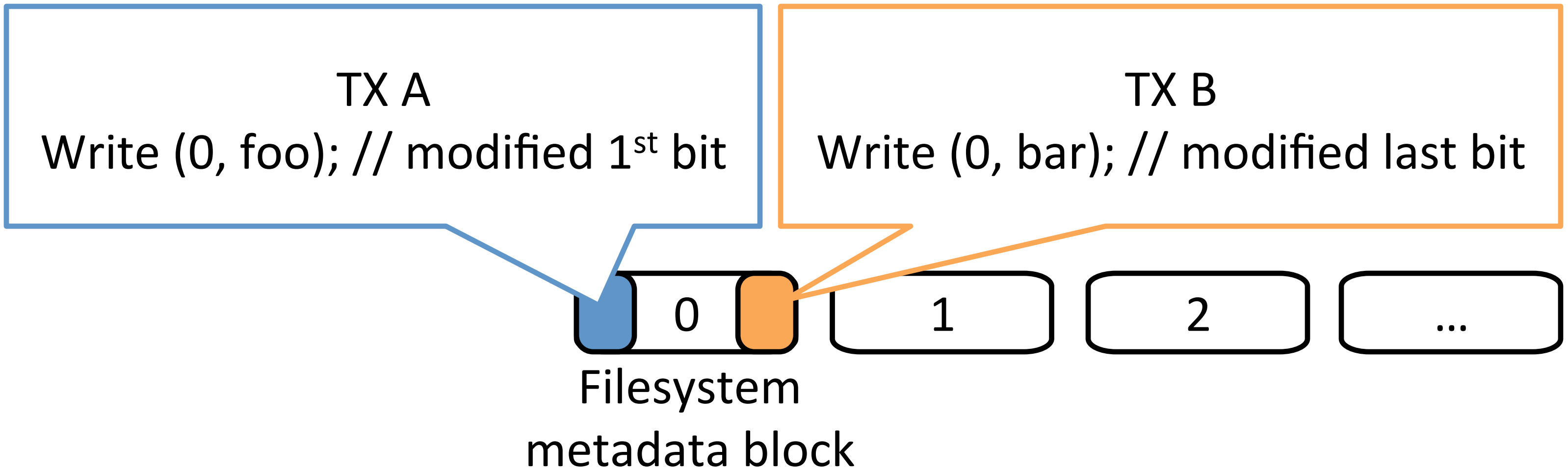


Isotope Challenges and Additional APIs

1. Application must be stateless (no caches)
   - **PleaseCache()**: caches a data block in internal memory cache

2. Mismatching data access granularity (application vs block)
   - **MarkAccessed()**: indicates subblock level data access

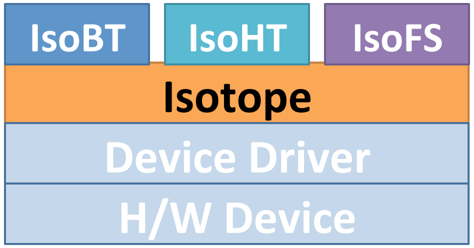
False Conflict



Implementation

- Built as device mapper in Linux kernel
  - Logical block device similar to software RAID or LVM
  - Can run on any block device (Disk, SSD, etc.)
- Log implemented based on Gecko
  - Chain logging design
    (Logs to multiple drives in round robin)
- APIs supported using IOCTL calls
  - BeginTX/EndTX/AbortTX
  - MarkAccessed/PleaseCache
  - ReleaseTX/TakeoverTX

Isotope Applications



- IsoBT and IsoHT
  - C++ library key-value stores
  - Based on persistent B-tree and hashtable
  - ACID Put, Get, Delete, etc.

- IsoFS
  - FUSE based transactional filesystem
  - Executes arbitrary filesystem ops (read, write, rename, etc.) ACID'ly
  - PleaseCache to handle metadata

Ease of Programming

- Lines of code

Example: Get()

```
Lock();                         BeginTX();
If(!ReadMetadata(…)) {          If(!ReadMetadata(…)) {
    Unlock();                       AbortTX();
    return failure;                 return failure;
}                               }
ReadData(…);                    ReadData(…);
Unlock();                       EndTX();
```

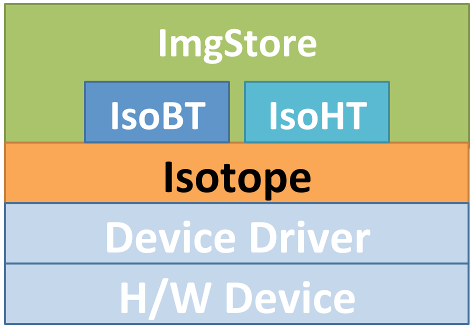
Application	Naïve Lock-Based Isolation	Isotope TX APIs (lines modified)	Isotope Optional APIs (lines added)
IsoHT	591	591 (15)	617 (26)
IsoBT	1,229	1,229 (12)	1,246 (17)
IsoFS	997	997 (19)	1,022 (25)

– Simple replacement of locks to BeginTX/EndTX/AbortTX

– Only few lines of code to add optimizations

Very easy to build transactional applications using Isotope APIs

Composing Applications

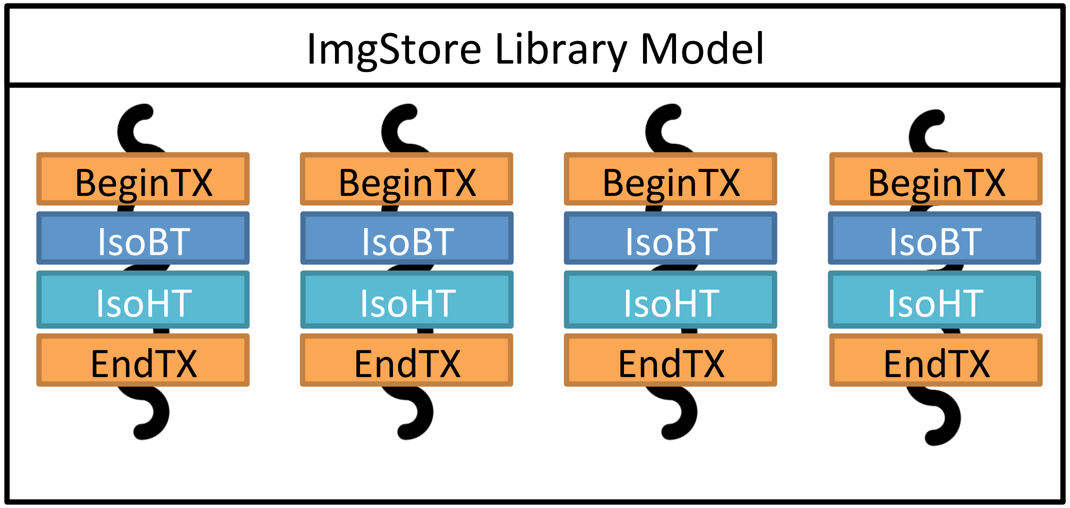


- ImgStore
  - Transactional storage with two subsystems
  - IsoBT for metadata and IsoHT for images

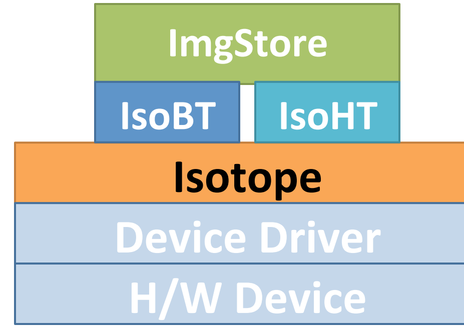
- Case

1. Library

1 process with threads



Composing Applications



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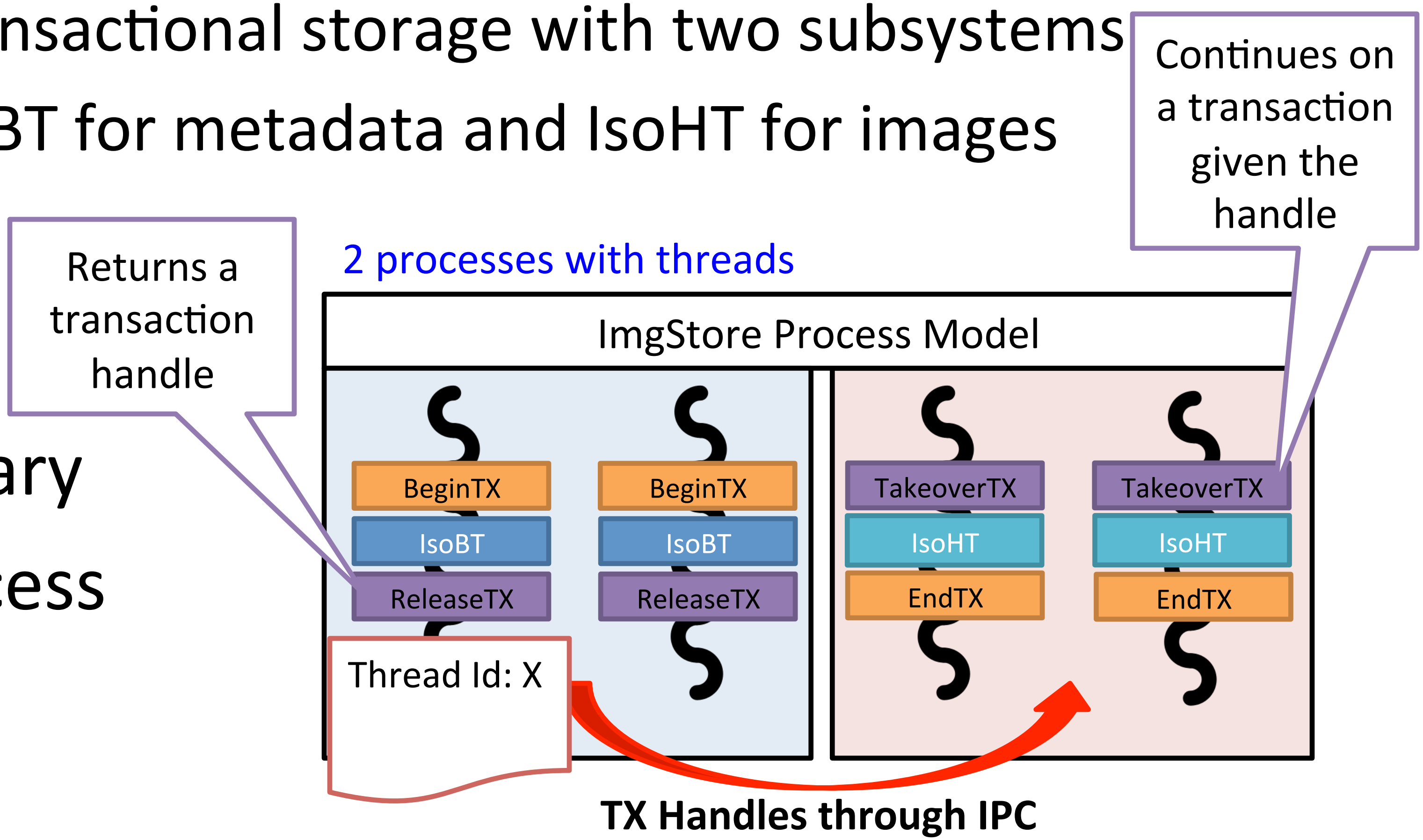
1. Library
2. Process



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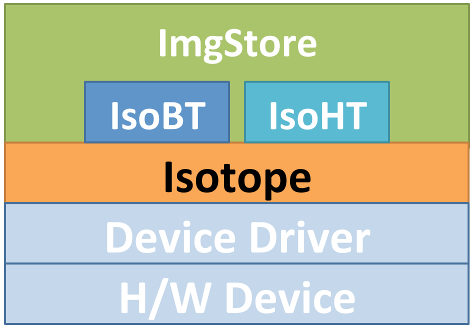

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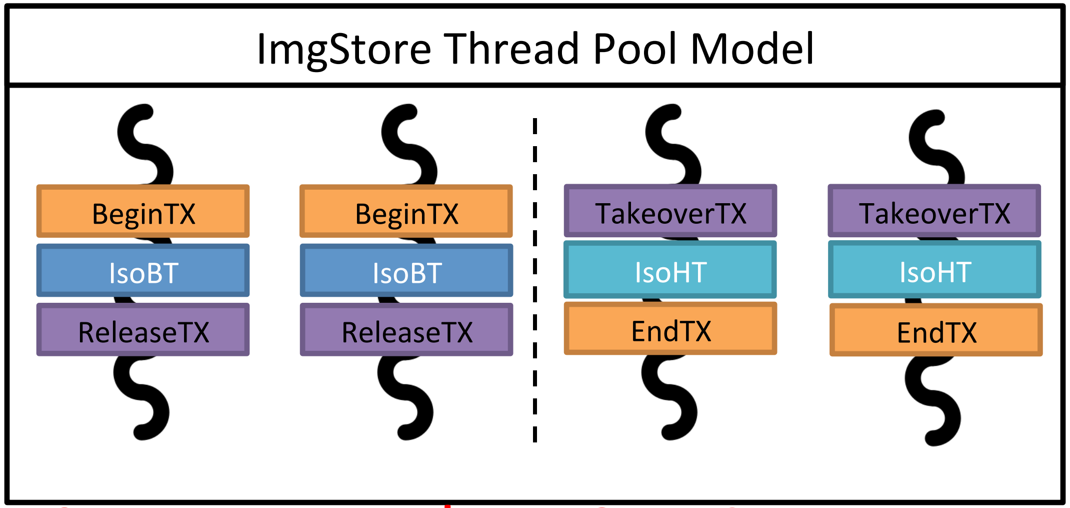
1. Library
2. Process
3. Thread pools

1 process with 2 different thread pools



1. ImgStore was only 150 LoC
2. Easy to build large apps whose TX cross boundaries

Performance Evaluation

1. Micro benchmark
   – Base performance of Isotope?

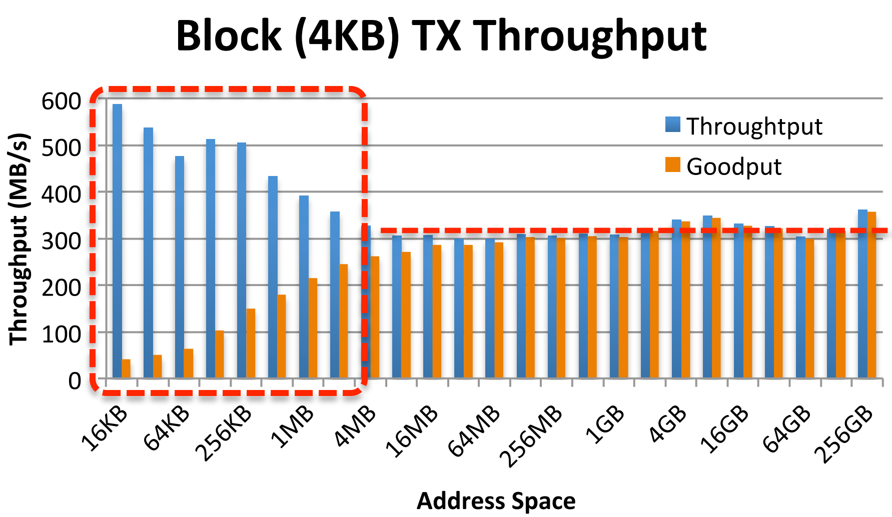
2. Key-value stores
   – Performance of applications built over Isotope?

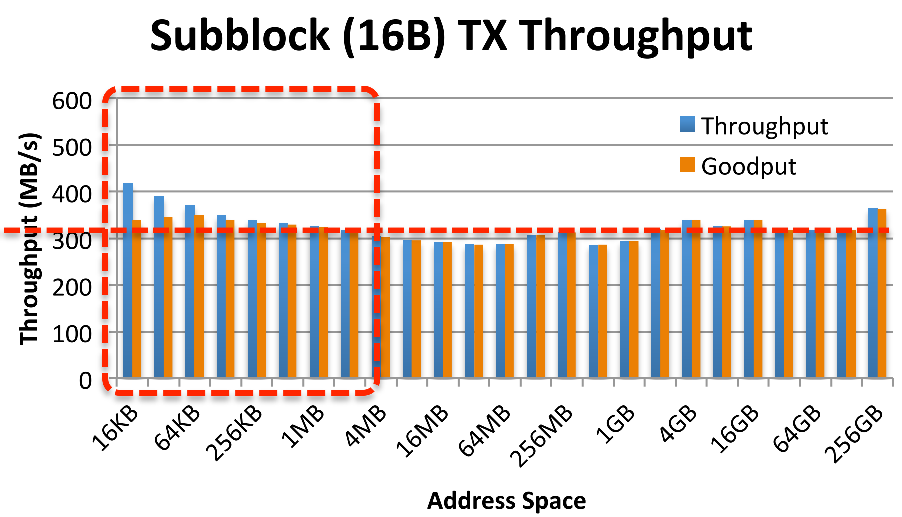
3. Filesystems
   – Performance of new and existing filesystems?

4. ImgStore Composition
   – Performance under different composition?

Micro Benchmark
(Base Performance of Isotope)

- Random 3-4KB-reads-3-4KB-writes TX'es from 64 threads
- Increasing address space (decreasing Tx conflicts)
- Ran on 3-SSD chain

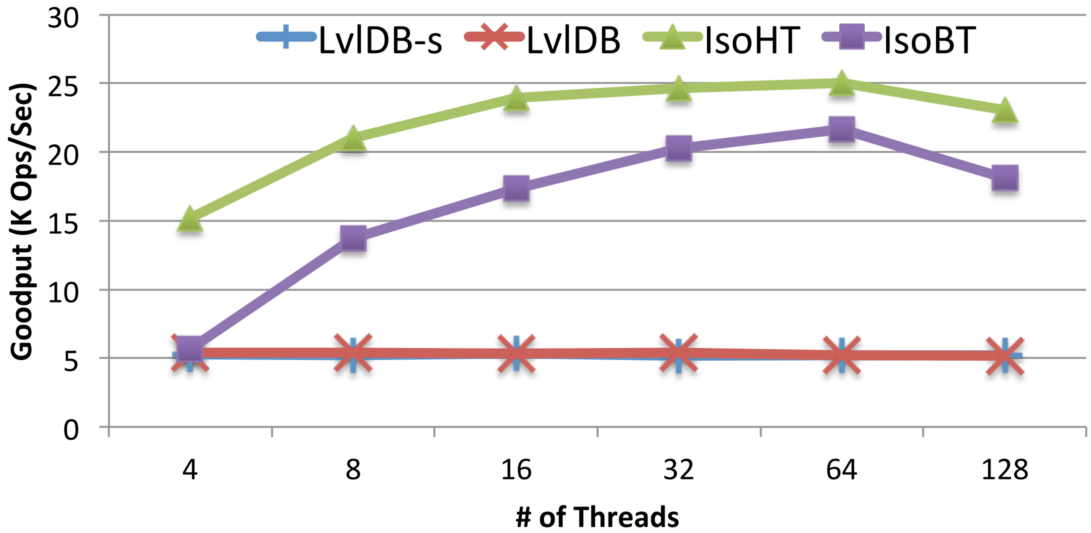




1. Aborts are cheap
2. Subblock TX mechanism has negligible overhead

Key-Value Stores

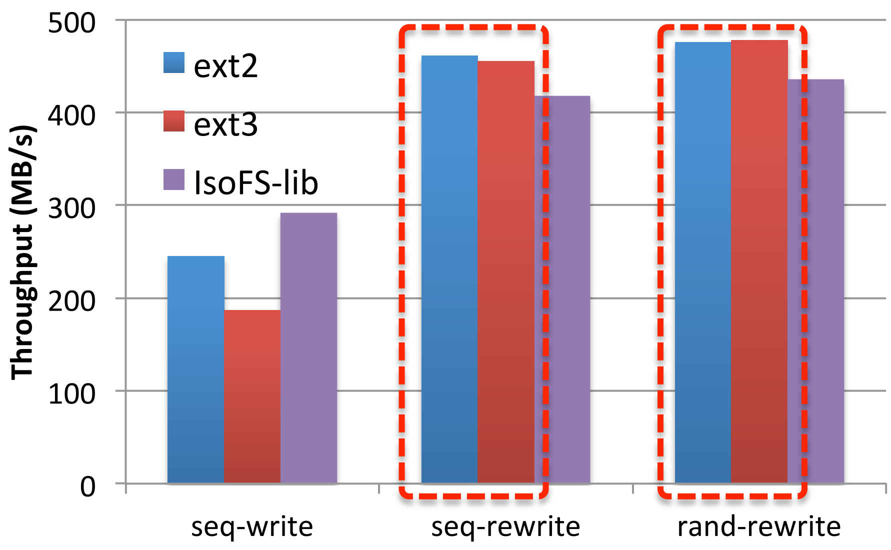
- LevelDB: on RAID0 volume, Sync/Async mode
- Increasing number of threads on 2 SSDs
- 8KB data using YCSB workload-a



Isotope-based applications perform comparable to existing applications and guarantee strong semantics

Filesystems

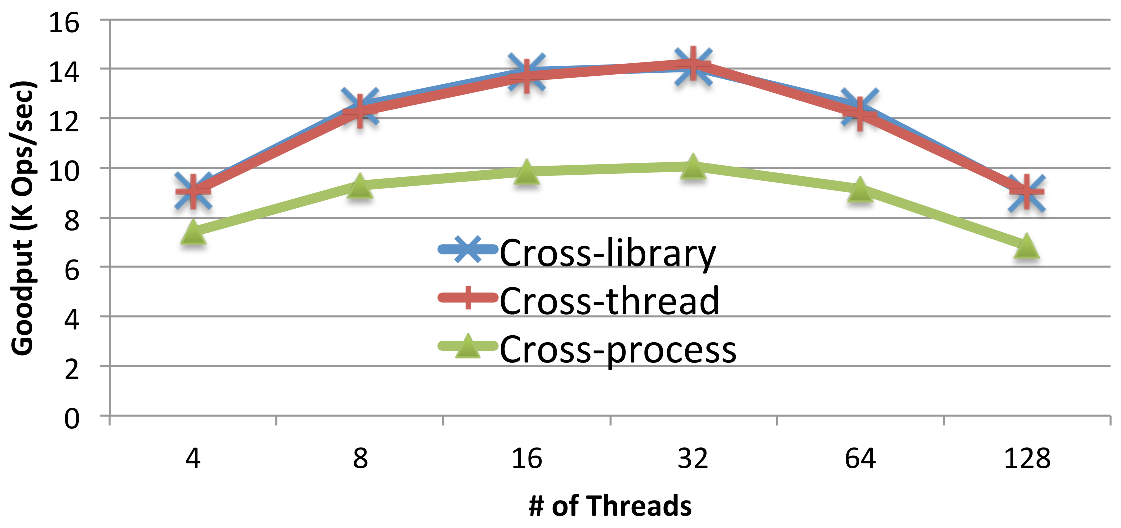
- Ext2 and Ext3 on top of Isotope on SSDs
  - Logging benefit
  - All I/Os as singleton transactions
- IOZone benchmark write/rewrite phase with 8 threads



1. IsoFS performs comparable to ext2/3
2. ext2/3 saturates SSD with no slowdown

ImgStore Compositions

- Different compositions of ImgStore
- YCSB Workload-a
  - 16KB image to/from IsoHT and metadata to/from IsoBT in a TX



1. Small ReleaseTX/TakeoverTX overhead (lib vs thread)
2. Cross process overhead comes from IPC

Conclusion

- First block storage with TX isolation
  - Simple API: BeginTX, EndTX, AbortTX
  - Low overhead design
    (nearly free abort and MVCC)
  - Optimizations for fine grained TX and caching
- Facilitates TX application design
  - 1K LoC transactional KV-stores and filesystem
  - Easy support for composition of TX applications
- Right time to consider pushing Isolation down the I/O stack

Thank you

Questions?