From Crash Consistency to Transactions

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Persistent data is structured; crash consistency hard

- Structured data abstractions built on file system
  - SQLite, BerkeleyDB... -- Embedded DB
  - LevelDB, Redis, MongoDB… -- Key-value store
  - Images, binary blobs... -- Files
- Applications manage storage themselves
  - ...and poorly!
  - The POSIX interface is no longer sufficient

Easy to use & deploy

Data safe on crash

ACID across abstractions

High performance

A transactional file system is the answer

- Structured data uses file system storage
  - Easy management often outweighs high performance
- File system transactions provides API and mechanisms

Easy to use & deploy

Data safe on crash

  - Transactions preserve consistency

High performance

  - Transactions reduce work & syncs
  - Concurrent transactions scalable

ACID across abstractions

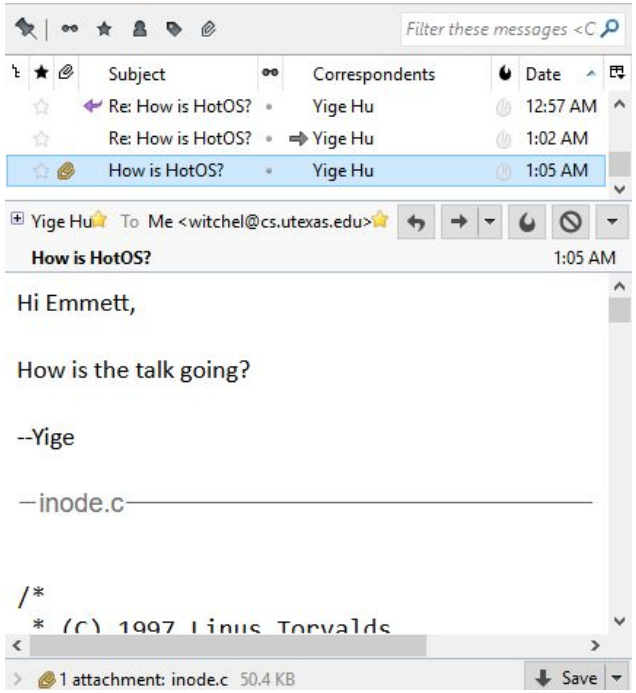
  - Unify different types of updates

We need transactions across storage abstractions

- The Android mail client receives an email with attachment
  - Stores attachment as a regular file
  - File name of attachment stored in SQLite
  - Stores email text in SQLite
- Great work when you can get it, but what can go wrong?
  - Crashes can orphan attachment files
  - Crashes can leave incomplete attachments
  - And this level of crash consistency costs dearly in performance!

How many syncs do you need?

- The Android mail client receives an email with attachment
  - Stores attachment as a regular file (maybe 1 sync?)
  - File name of attachment stored in SQLite
  - Stores email text in SQLite (maybe 1 sync for db? 2 total?)



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  - Stores attachment as a regular file (maybe 1 sync?)
  - File name of attachment stored in SQLite
  - Stores email text in SQLite (maybe 1 sync for db? 2?)
- Requires 6 syncs!
  - If you create/delete a file, sync the parent directory

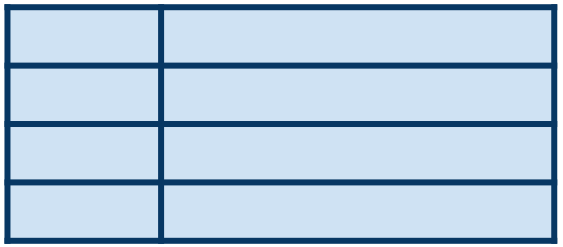
Example: Android mail

Atomically inserting a message with attachment.

Raw files

SQLite

Database file



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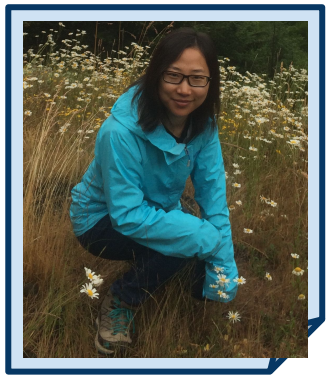

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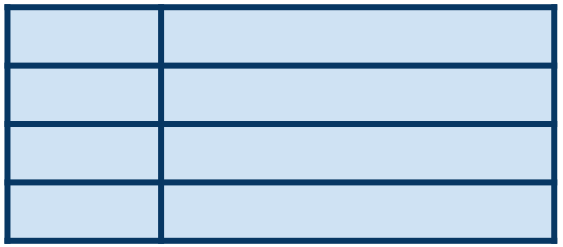

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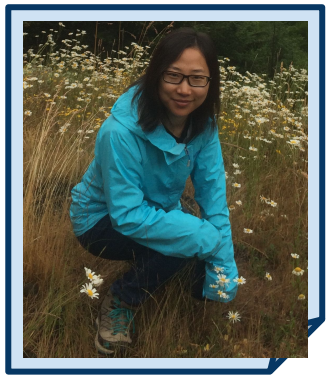

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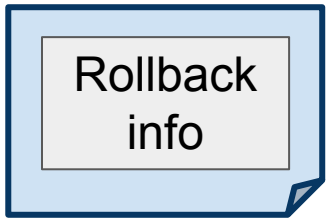
Roll-back log



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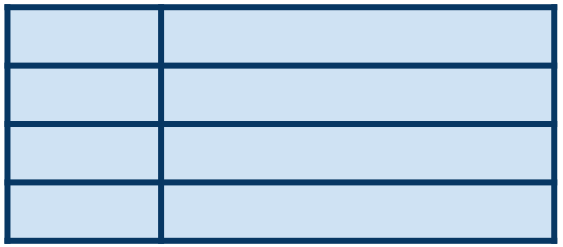

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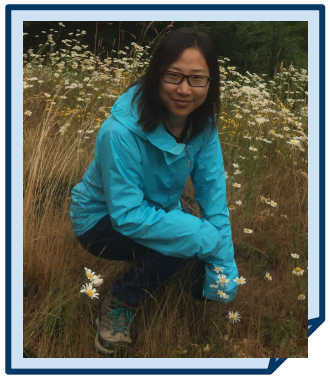

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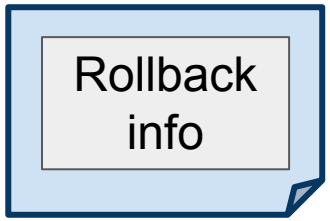

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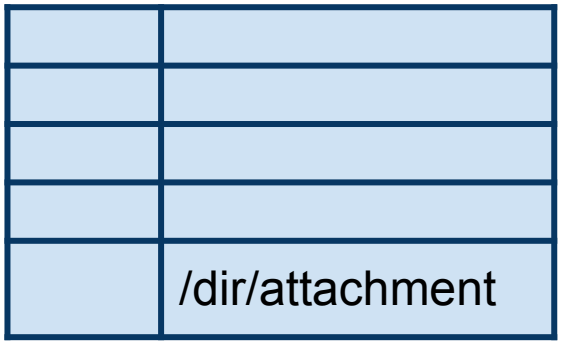

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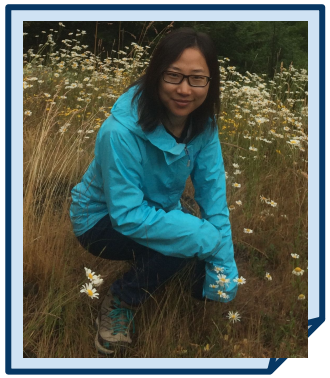

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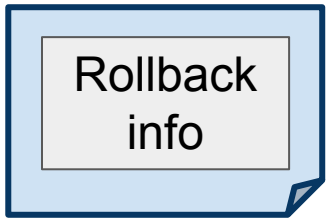

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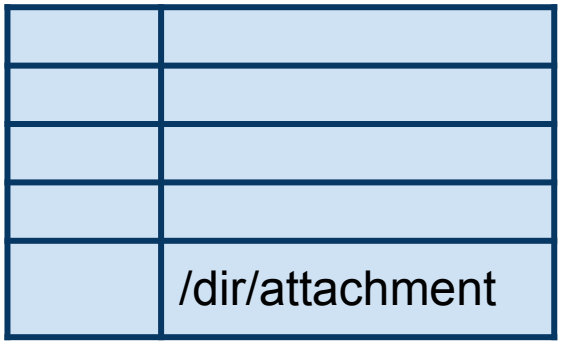

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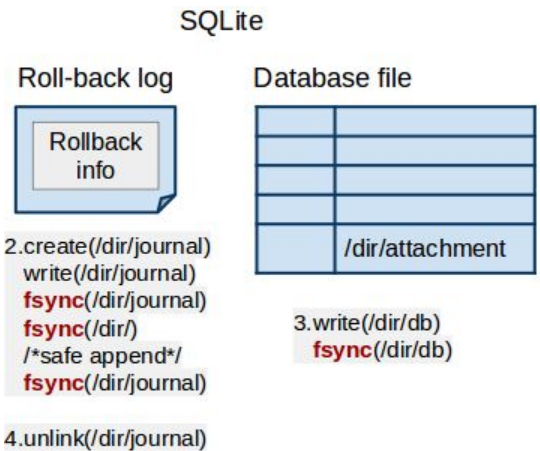
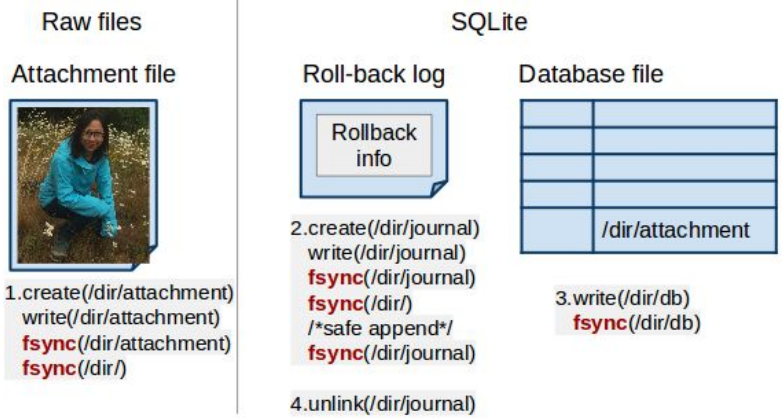
Application consistency using POSIX is slow

- SQLite on ext4: fsync() per transaction (1kB/tx), with FULL synchronization level.

	fsync/tx	
Journal mode	**Insert**	**Update**
Rollback (default)	4	4
Write ahead log (WAL)	5	5
No journal (unsafe)	1	1



System support for crash consistent updates



- Application needs consistent, persistent updates
  - Complicated and ad hoc implementation
  - Crashes can orphan attachment files
  - Crashes can create incomplete attachment files.
- Sync and redundant writes lead to poor performance.
- Need mechanism for cross-abstraction commit

The file system should provide transactional services!

But haven't we tried this before?

Haven’t we seen this movie before?

- Complex implementation
  - Transactional OS: QuickSilver [TOCS 88], TxOS [SOSP 09] (**10k LOC**)
  - In-kernel transactional file systems: Valor [FAST 09]
- Hardware dependent
  - CFS [ATC 15], MARS [SOSP 13], TxFLash [OSDI 08], Isotope [FAST 16]
- Performance overhead
  - Valor [FAST 09] (**35% overhead**).
- Hard to use
  - Windows NTFS (TxF), released 2006 (deprecated 2012)

Windows TxF was hard to use

Modify the following code to use **Windows NTFS (TxF)** transactions.

```
HANDLE hFile = CreateFile(_T("test.file"),
GENERIC_WRITE, 0, 0, CREATE_ALWAYS, 0, 0);
if (hFile == INVALID_HANDLE_VALUE)
{
        cerr << "CreateFile failed" << endl;
        return 1;
}

CloseHandle(hFile);
```

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Modify the following code to use

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```
#include <ktmw32.h>
#pragma comment(lib, "KtmW32.lib")

.....
HANDLE hTrans = CreateTransaction(NULL,0, 0, 0, 0, NULL,
_T("My NTFS Transaction"));
if (hTrans == INVALID_HANDLE_VALUE)
{
        cerr << "CreateTransaction failed" << endl;
        return 1;
}

USHORT view = 0xFFFE; // TXFS_MINIVERSION_DEFAULT_VIEW
HANDLE hFile = CreateFileTransacted(_T("test.file"),
        GENERIC_WRITE,0, 0, CREATE_ALWAYS, 0, 0,
        hTrans, &view, NULL);
if (hFile == INVALID_HANDLE_VALUE)
{
        cerr << "CreateFileTransacted failed" << endl;
        return 1;
}

CloseHandle(hFile);

CommitTransaction(hTrans);
CloseHandle(hTrans);
```

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```

GetFileAttributesTransacted

CopyFileTransacted

DeleteFileTransacted

……

+ 16 new transactional file operations

Windows TxF was hard to use

- Microsoft deprecates TxF (2012)

  “While TxF is a powerful set of APIs, there has been extremely limited developer interest in this API platform since Windows Vista primarily due to its complexity and various nuances which developers need to consider as part of application development.”

Modify the

```
HANDLE hFile = Cr
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if (hFile == INVALI
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CloseHandle(hFile
```

```
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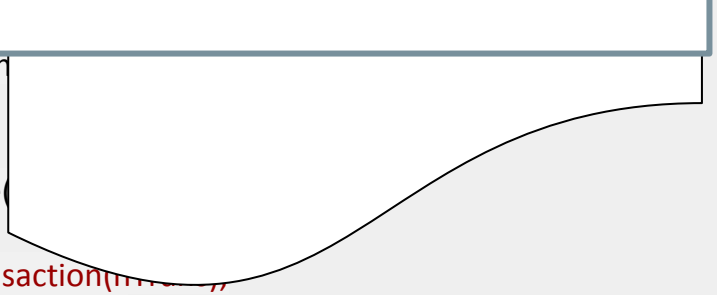

T2FS (Texas Transactional File System)

- Based on Linux ext4
  - Uses file system journal

Data safe on crash

- Simple interface
  - fs_tx_begin, fs_tx_end, fs_tx_abort

Easy to use & deploy

- Usable by any abstraction that stores data in the file system
  - E.g., embedded databases, key-value stores

ACID across abstractions

- Improves performance for structured data
  - Fewer sync calls

High performance

- Increases scalability

Easy to use & deploy

T2FS API

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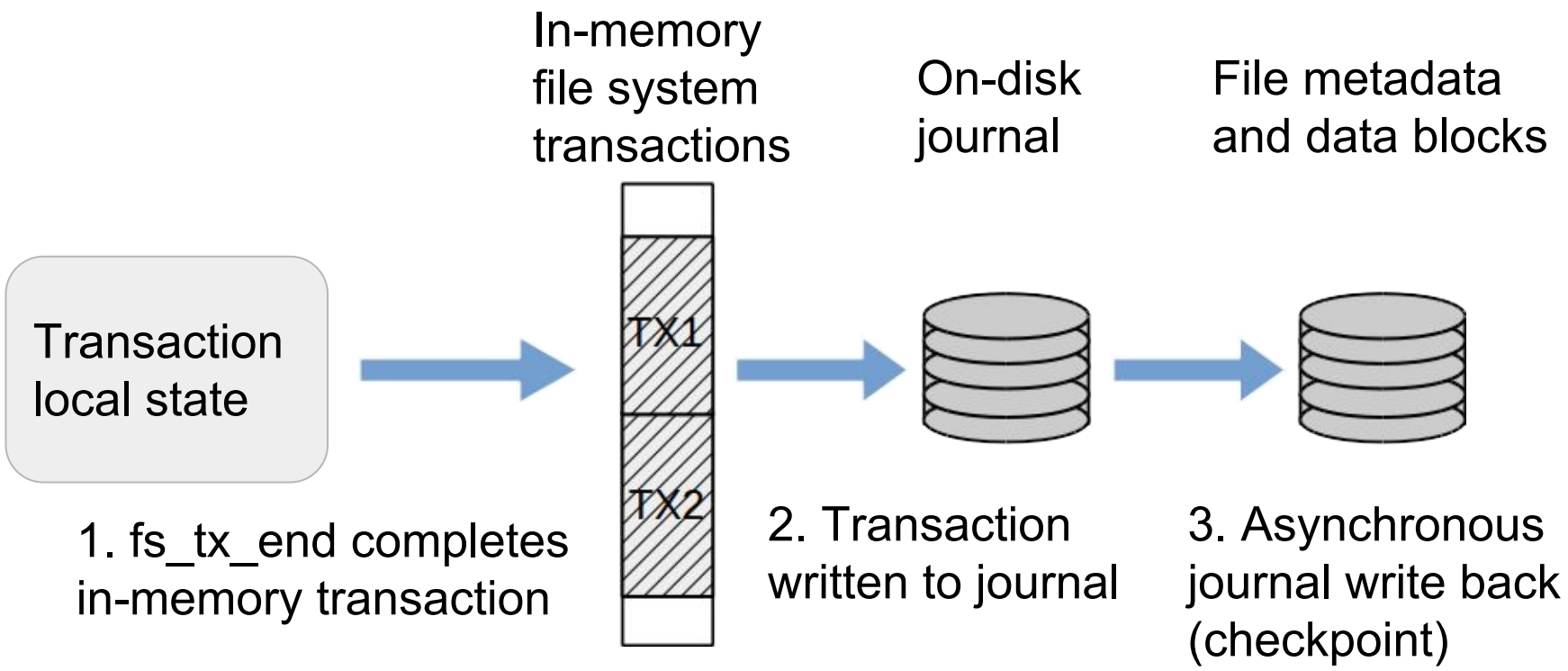
Windows NTFS (TxF) API

Data safe on crash

T2FS managing and persisting transactions

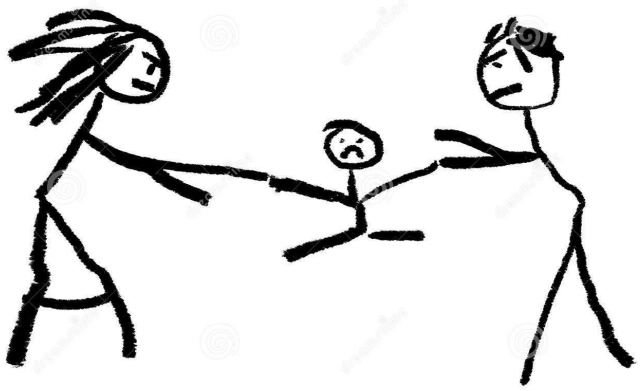
- Decreased complexity: use the file systems' crash consistency mechanism to create transactions.
  - Ext4 journal or ZFS copy-on-write



Data safe on crash

Isolation and Conflict detection

- In-progress writes are all local to kernel thread
- Eager conflict detection on inodes, directory entries
  - Enables flexible contention management
- Fine-grained page locks
  - More scalable than reader/writer lock



ACID across abstractions

T2FS API: Cross-abstraction transactions

Modify the Android mail application to use T2FS transactions.

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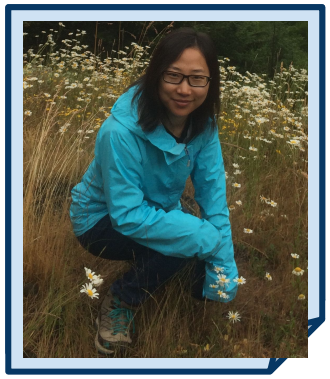

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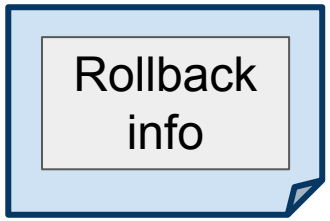

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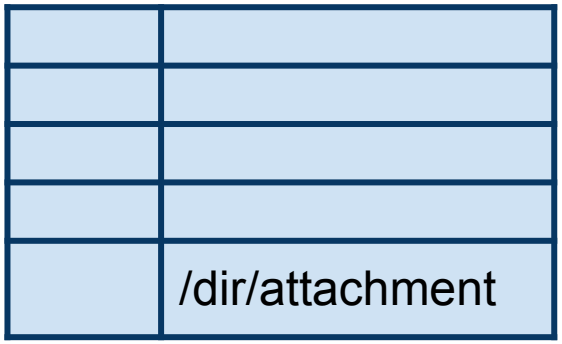

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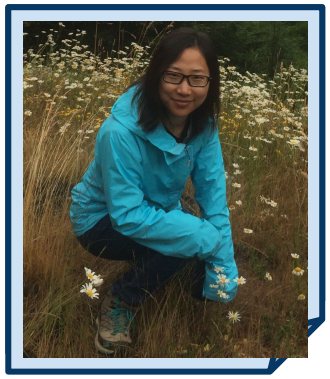

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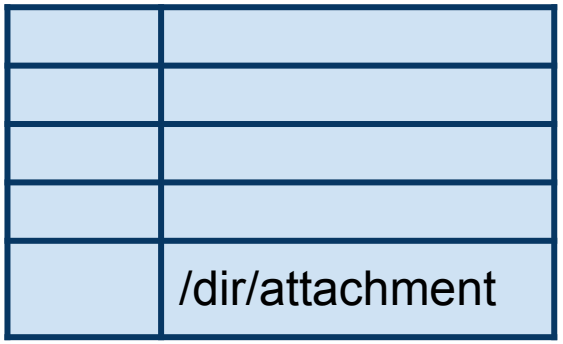

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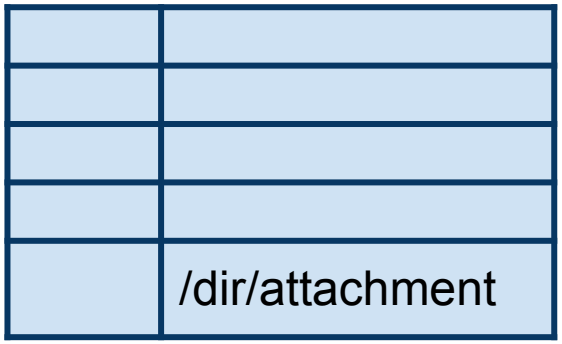

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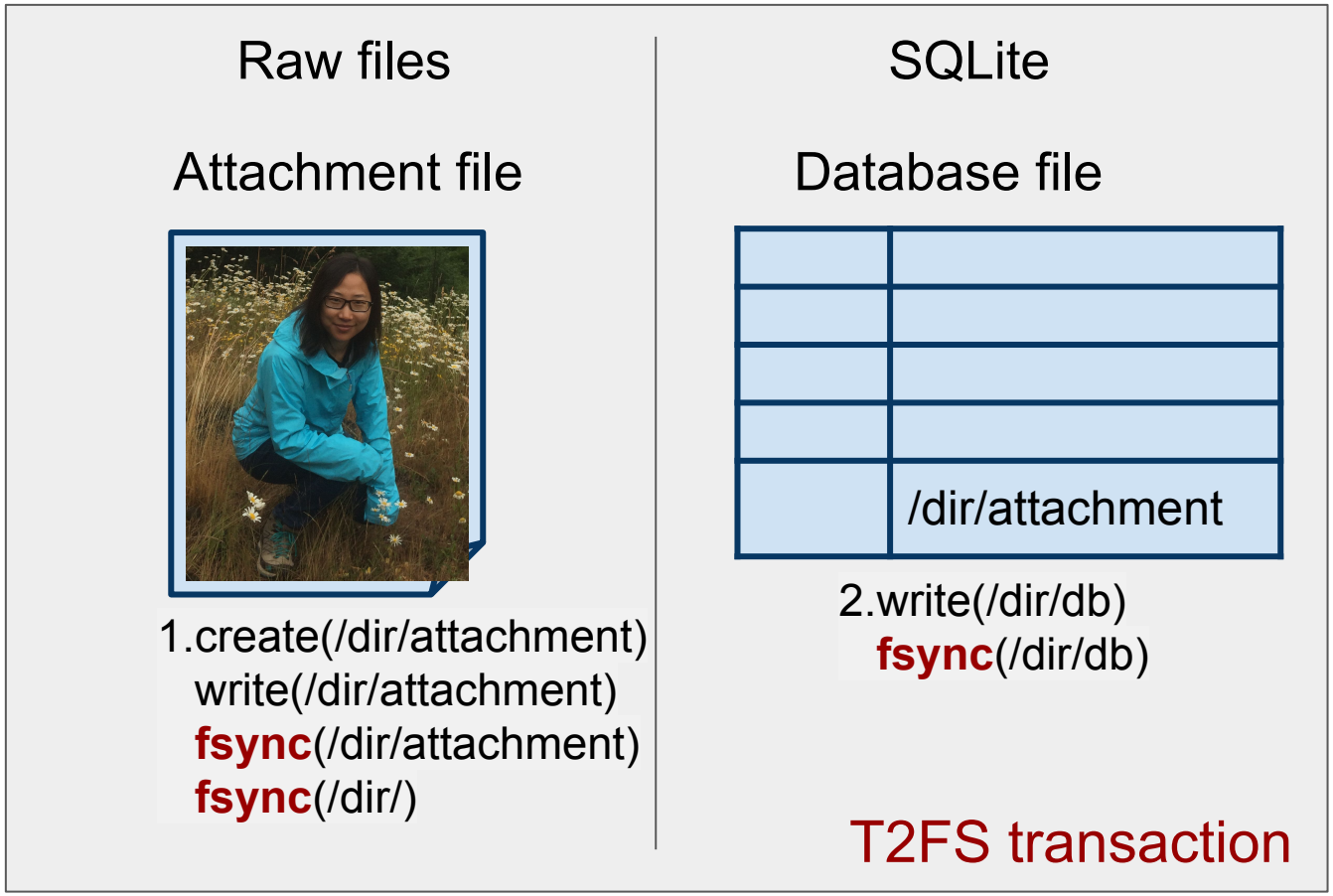

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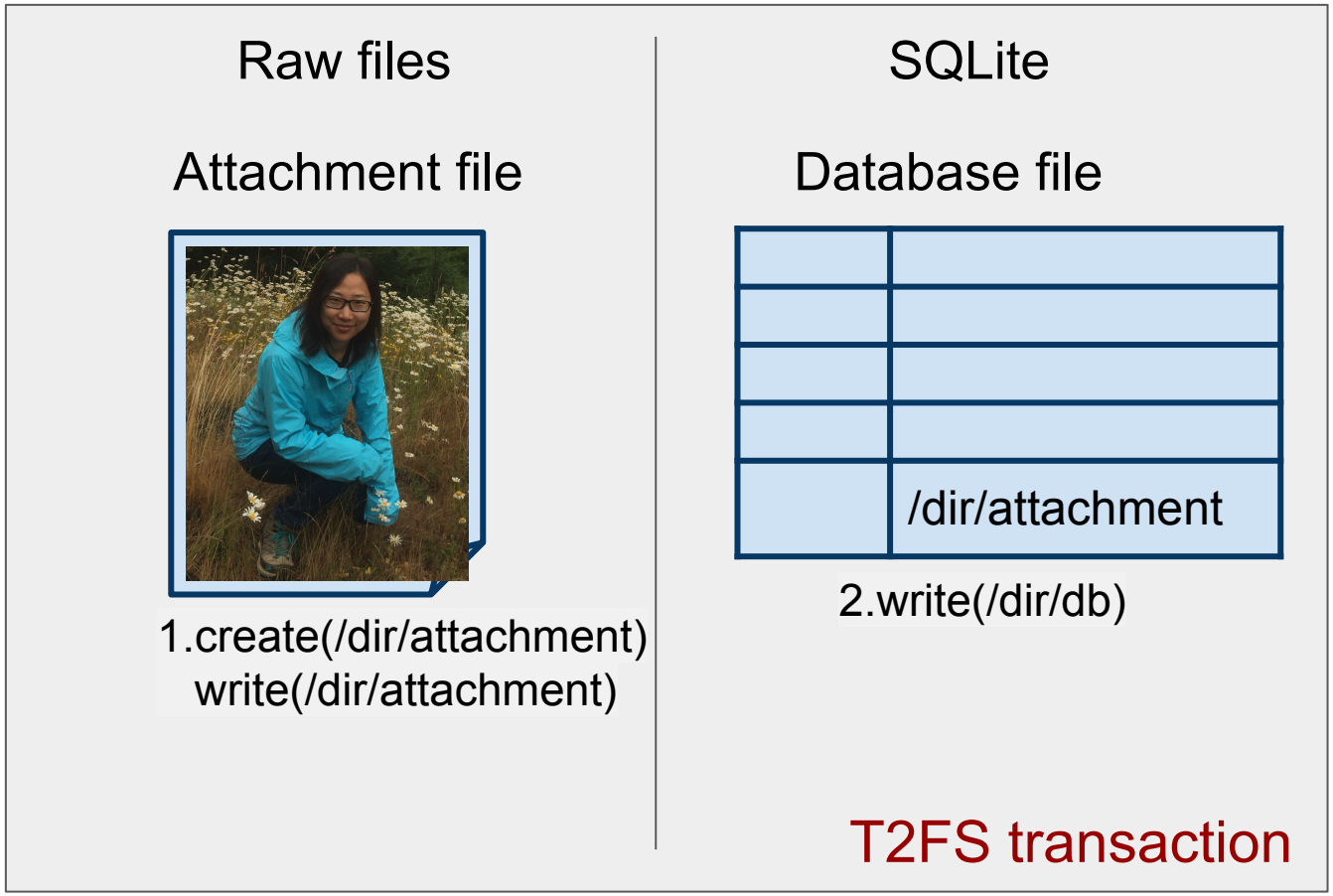

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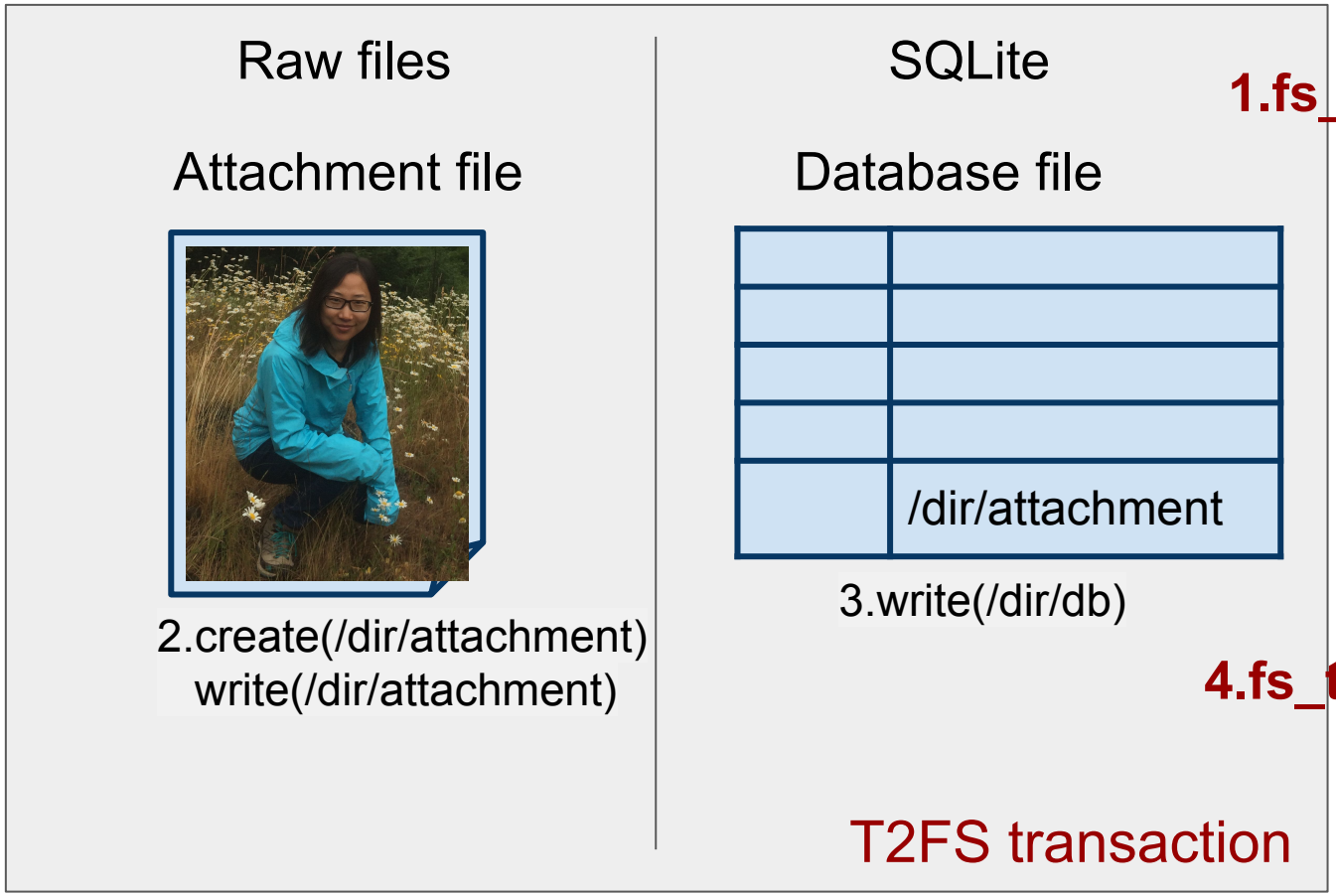

High performance

Evaluation: single-threaded SQLite

1.5M 1KB operations. 10K operations grouped in a transaction.
Database prepopulated with 15M rows.

High performance

Transactions as a foundation for other optimizations

- Enable automatic file system optimizations
  - Eliminate temporary durable files.
    - e.g. SQLite delete mode, directly wrapped by T2FS transaction
  - Consolidate IO across transactions.
    - Delay persistence during commit
- Use transactional mechanism to implement unrelated file system optimizations
  - Separate ordering from durability (osync [SOSP 13]).

Summary

Easy to use & deploy

Data safe on crash

ACID across abstractions

High performance

- Persistent data is structured; tough to make crash consistent
  - All data stored in the file system
- A transactional file system has the right API and mechanisms
- The file system journal makes implementing transactions easier
- Need transactions across storage abstractions

Thank you!