OPERATING SYSTEMS SHOULD PROVIDE TRANSACTIONS

Donald E. Porter and Emmett Witchel

The University of Texas at Austin

Example: browser plug-in upgrade

```
write new plug-in binary
start browser, old config,
     old plug-in arguments
   corrupt data files
exec post-install script
    (updates browser config)
```

- API can't ensure consistent updates to OS resources
- Concurrency and crashes cause subtle inconsistencies

System Transactions

- Express consistency requirements to OS
- Transaction wraps group of system calls
  - Results isolated until commit
  - Interfering operations automatically serialized
- Long-overdue OS feature
  - Natural abstraction
  - Solves important problems
  - Practical implementation

Transactional Software Install


```
sys_xbegin();
apt-get upgrade
sys_xend();
```

- A failed install is automatically rolled back
  - Concurrent operations are not
- System crash: reboot to entire upgrade or none
- Concurrent apps see consistent state

System Transactions

- Operating systems should provide them
- Operating systems can provide them

The POSIX API is broken

- System resources have long-standing race conditions
  - Time-of-check-to-time-of-use (TOCTTOU)
  - Temporary file creation
  - Signal handling
- Correct, concurrent apps need system-level isolation
- Multi-core chips raise importance of concurrency

System-level races

(root)

```
if(access("foo"))

   fd = open("foo");
   …
}
```

foo == secret

Complex work-arounds

- TOCTTOU: users write their own directory traversal
  - `openat(), fstatat(),` etc.
  - User re-implements filename translation
- Race between open/fcntl
  - Add `CLOSE_ON_EXEC` flags to 15 system calls
- Temporary file creation libraries
  - `mkstemp,tmpfile, etc.`

Work-arounds don't work

- Complex APIs do not yield secure programs
- Experts can't even agree
  - `mkstemp` man page:

    "Don't use this function, use **`tmpfile(3)`** instead."
  - www.securecoding.cert.org - **VOID FI039-C:**

    "It is thus recommended that…**`mkstemp()`** be used [instead of `tmpfile()`]"
- Transactions can fix the problem

TOCTTOU redux

(root)

```
sys_xbegin();
if(access("foo")) {
   fd = open("foo");
   read(fd,…);
   …
}
sys_xend();
```

Transactions solve important problems

- Applications
  - Replace databases for simple synchronization
  - Support system calls in transactional memory apps
  - Tolerate faults in untrusted software modules
  - Atomically update file contents and access control list
- Easier to write OS extensions
  - System Tx + Journal = Tx Filesystem

Hasn't this already been done?


```
donporter@wesley:~$ man transaction
No manual entry for transaction
```

Related Systems

- Similar interface, different implementation
  - QuickSilver [SOSP '91], TABS [SOSP '85]
    - Weaker guarantees
  - TxF, Valor [FAST '09]
    - Only file system transactions
- Different interface, similar implementation
  - Speculator [SOSP '05, OSDI '06]
- Terms "transaction" and "OS" appear in paper title
  - TxLinux [SOSP '07, ASPLOS '09]

Can OSes provide transactions?

- TxOS: Extends Linux 2.6.22 to support transactions
  - Runs on commodity hardware
- Rest of talk:
  - Approach
  - Validation

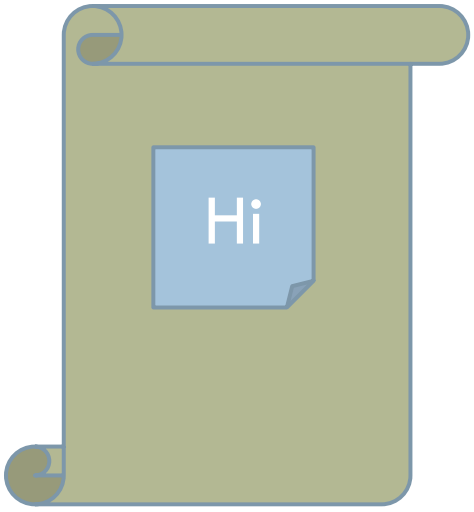
Version Management

- How to keep old and new data?
  - Need old data to roll back
- TxOS approach:
  - Transactions operate on private copies of data
  - Replace old data structures at commit
- Example: kernel data structures

TxOS Version Management


```
sys_xbegin();
if(access("foo")){
 fd = open("foo");
 write(fd, "Hi");
}
sys_xend();
```

File "foo"



Transaction

Object versioning in TxOS

- Deadlock-free
  - Transactions do not hold kernel locks across syscalls
  - Follows existing locking discipline
- Previous work used 2-phase locking, undo log
  - Prone to deadlock
- Efficient – a pointer swap per committed object
  - Copy-on-write optimizations

Serializing Tx with No-Tx

- Important property for intuitive semantics
  - Supports incremental adoption
- Serialize TOCTTOU attacker
  - Attacker will not use transactions
- Hard to support in software systems
  - Not provided by historical OSes, many STMs

Validation

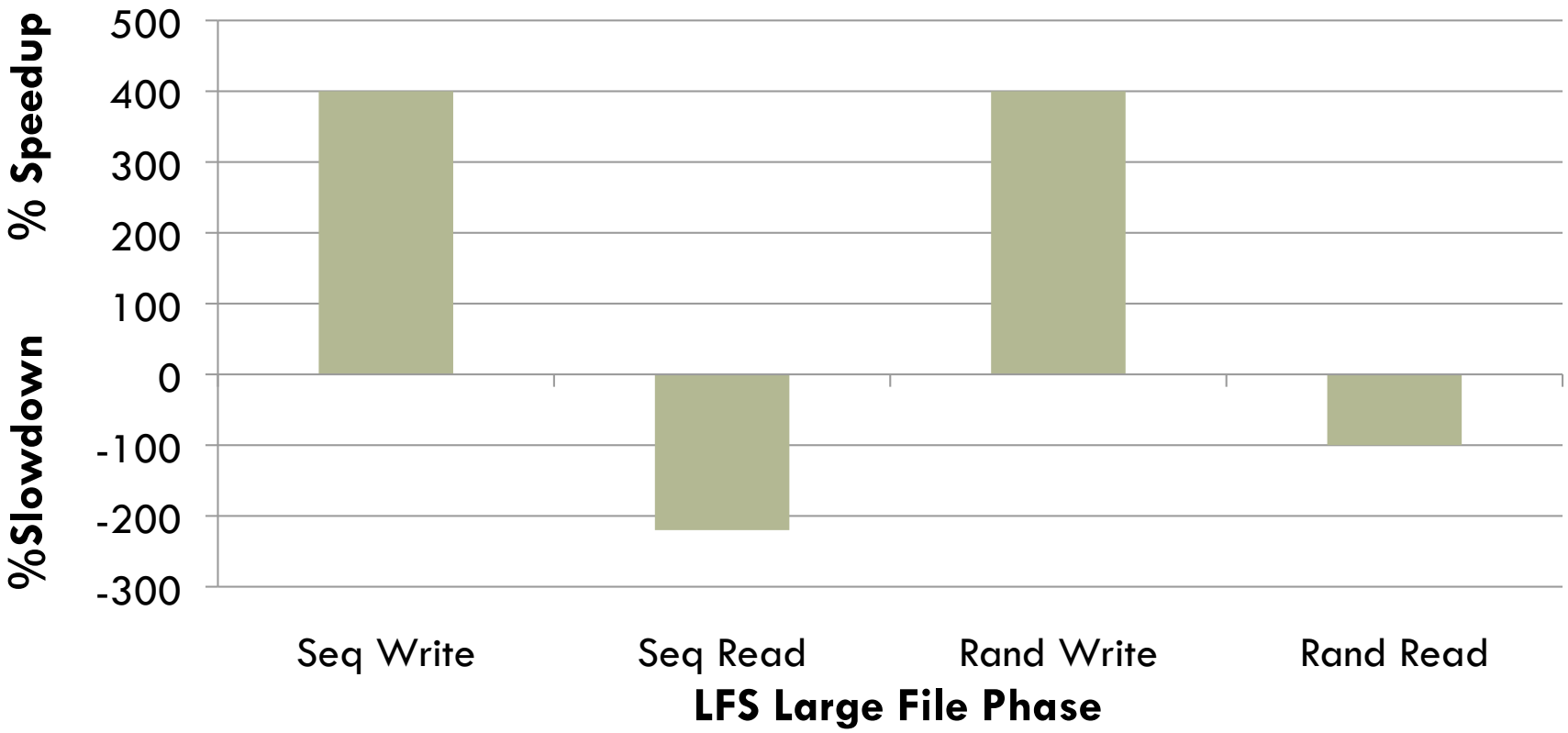
- Is implementation tractable?
- Is performance acceptable?

Tractable, challenging implementation

- Transactions:
  - Add 8,600 LOC to Linux
  - Minor modifications to 14,000 LOC
- Simple API, not a simple implementation
  - Hard to write concurrent programs
  - Developers need good abstractions
- Transactions are worth the effort

Acceptable Performance

- 40% overhead for dpkg install



- Speedup compared to unmodified Linux

OSes can support transactions

- Tractable Implementation
- Acceptable Performance

OSes should provide transactions

- Solve long-standing problems
  - Replace ad hoc solutions
- Broad range of applications
- Acceptable cost

http://www.cs.utexas.edu/~porterde/txos

porterde@cs.utexas.edu