CS 370: OPERATING SYSTEMS

[ATOMIC TRANSACTIONS]

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Topics covered in today's lecture

- Synchronization examples
- Atomic transactions

SYNCHRONIZATION EXAMPLES

Synchronization in Solaris

- Condition variables
- Semaphores
- Adaptive mutexes
- Reader-writer locks
- Turnstiles

Synchronization in Solaris: Adaptive mutex

- Starts as a standard semaphore implemented as spinlock

- On **SMP systems** if data is locked and in use?
  - If lock held by thread on another CPU
    - Spin waiting for lock to be available
  - If thread holding the lock is not in the *run* state
    - Block until awakened by release of the lock

Adaptive mutex: On a single processor system

- Only one thread can run at a time
- So thread sleeps (instead of spinning) when a lock is encountered

Adaptive mutex is used only for short code segments

- Less than a **few hundred** instructions
  - Spinlocks inefficient for code segments larger than that
- Cheaper to put a thread to sleep and awaken it
  - Busy waiting in the spinlock is expensive
- Longer code segments?
  - Condition variables and semaphores used

Reader-writer locks

- Used to protect data accessed **frequently**
  - *Usually* accessed in a read-only manner
- Multiple threads can read data **concurrently**
  - Unlike semaphores that *serialize* access to the data
- Relatively expensive to implement
  - Used only on long sections of code

Solaris: Turnstiles

- **Queue structure** containing threads blocked on a lock
- Used to order threads waiting to acquire adaptive mutex or reader-writer lock
- Each **kernel thread has its own turnstile**
  - As opposed to every synchronized object
  - Thread can be blocked only on one object at a time

Solaris: Turnstiles

- Turnstile for the first thread to block on synchronized object
  - Becomes turnstile for the object itself
  - Subsequent threads blocking on lock are added to this turnstile
- When this first thread releases its lock?
  - It *gains a new turnstile* from the list of free turnstiles maintained by kernel

Turnstiles are organized according to the priority inheritance protocol

- If the thread is holding a lock on which a higher priority thread is blocked?
  - Will *temporarily inherit* priority of higher priority thread
  - *Revert back* to original priority after releasing the lock

Linux: Prior to 2.6, Linux was a nonpreemptive kernel

- Provides spinlocks and semaphores

Single processor	Multiple processors
Disable kernel preemption	Acquire spinlock
Enable kernel preemption	Release spinlock

17 December 2003 - Linux 2.6.0 was released (5,929,913 lines of code)
4 January 2011 - Linux 2.6.37 was released (13,996,612 lines of code)
2023: tens of millions of LoC!

Kernel is not preemptible if a kernel-mode task is holding a lock

- Each task has a `thread-info` structure
  - Counter `preempt_count` indicates number of locks being held by task
  - `preempt_count` incremented when lock acquired
    - Decremented when lock released
  - If is `preempt_count > 0`; not safe to preempt
    - OK otherwise; if no `preempt_disable()` calls pending

Linux: Other mechanisms

- Atomic integers `atomic_t`
  - All math operations using atomic integers are performed without interruption
  - E.g. Set, add, subtract, increment, decrement

- Mutex locks
  - `mutex_lock()`: Prior to entering critical section
  - `mutex_unlock()`: After exiting critical section
  - If lock is unavailable, task calling `mutex_lock()` is put to sleep
    - Awakened when another task calls `mutex_unlock()`

Atomic Transactions

Atomic transactions

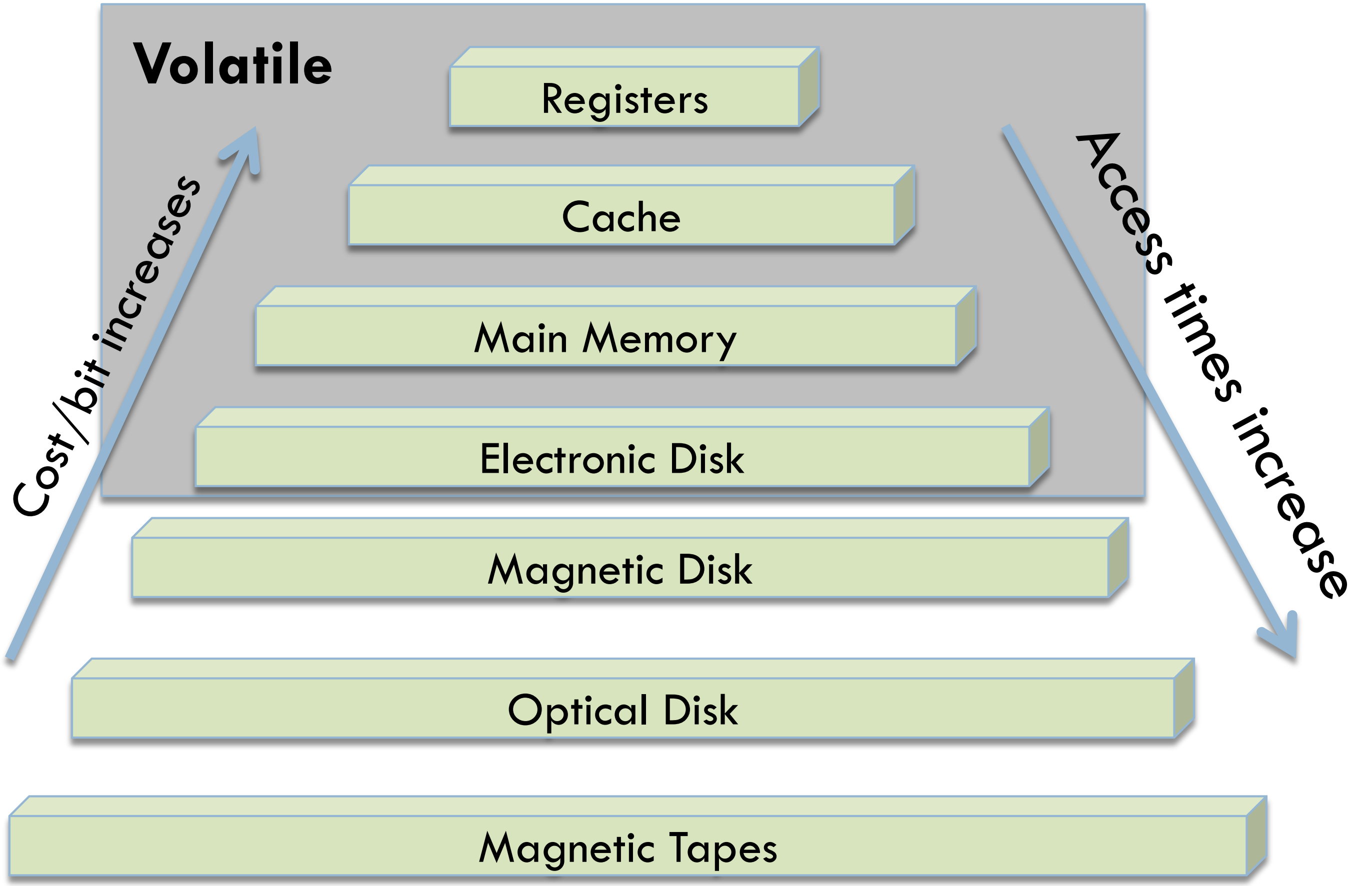
- Mutual exclusion of critical sections ensures their atomic execution
  - As one *uninterruptible unit*

- Also important to ensure, that critical section forms a **single logical unit of work**
  - Either work is performed in **its entirety or not at all**
  - E.g. transfer of funds
    - Credit one account and debit the other

Transaction

- Collection of operations performing a **single logical function**
- Preservation of **atomicity**
  - Despite the possibility of failures

Storage system hierarchy based on speed, cost, size and volatility



A disk I/O transaction that accesses/updates data items on disk

- Simply a sequence of read and write operations
  - Terminated by commit or abort

- **Commit**: Successful transaction termination
- **Abort**: Unsuccessful due to
  - Logical error or system failure

Transaction rollbacks

- An aborted transaction may have **modified** data
- State of accessed data must be **restored**
  - *To what it was* before transaction started executing

Log-based recovery to ensure atomicity: **Rely on stable storage**

- Record info describing **all** *modifications* made by transaction to various accessed data.

- Each log record describes a **single** write
  - Transaction name
  - Data item name
  - Old value
  - New value

- Other log records exist to record significant events
  - Start of transaction, commit, abort etc

Actual update cannot take place prior to the logging

- Prior to `write(`**`X`**`)` operation
  - Log records for **X** should be written to stable storage

- Two physical writes for every logical write
  - More storage needed

- Functionality worth the price:
  - Data that is extremely **important**
  - For **fast** failure recovery

Populating entries in the log

- Before transaction T_i starts execution
  - Record <T_i starts> written to the log
- Any write by T_i is **preceded** by writing to the log
- When T_i commits
  - Record <T_i commits> written to log

The system can handle any failure without loss of information: Log

- `undo(`T_i`)`
  - **Restores** value of all data updated by T_i to **old** values
- `redo(`T_i`)`
  - Sets value of all data updated by T_i to **new** values

- `undo(`T_i`)` **and** `redo(`T_i`)`
  - Are **idempotent**
  - Multiple executions have the *same result* as 1 execution

If system failure occurs restore state by consulting the log

- Determine which transactions need to be *undone*; and which need to be *redone*
- T_i is undone if log
  - Contains `<Ti starts>` but no `<Ti commits>` record
- T_i is redone if log
  - Contains both `<Ti starts>` and `<Ti commits>`

CHECKPOINTING

Rationale for checkpointing

- When failure occurs we consult the log for undoing or redoing

- But if done naively, we need to search *entire* log!
  - Time consuming
  - Recovery takes longer
    - Though no harm done by redoing (idempotency)

In addition to write-ahead logging, periodically perform checkpoints

- Output the following to stable storage
  - All log records residing in main memory
  - All modified data residing in main memory
  - A log record `<checkpoint>`
- The `<checkpoint>` allows a system to **streamline** recovery procedure

Implications of the checkpoint record

- T_i committed prior to checkpoint
  - `<T_i commits>` appears before `<checkpoint>`
  - Modifications made by T_i *must have been written* to stable storage
    - Prior to the checkpoint or
    - As part of the checkpoint

- At recovery no need to `redo` such a transaction

Refining the recovery algorithm

- Search the log **backward** for first checkpoint record.
  - Find transactions T_i *following* the last checkpoint
  - `redo` and `undo` operations applied *only* to these transactions

Looking at the log to determine which one to redo and which one to undo

<T1 starts>
<T1 … write record>
<T1 aborts>

<T2 starts>
<T2 … write record>
<T2 commits>

<checkpoint>
<T3 starts>
<T3 … write record>
….
<checkpoint>
<T4 starts>
<T4 … write record>
<T4 commits>

<T5 starts>
<T5 ..write record>

T4 will be redone

T5 will be undone

Concurrent Atomic Transactions

Concurrent atomic transactions

- Since each transaction is atomic
  - Executed serially in some arbitrary order
    - **Serializability**
  - Maintained by executing each transaction within a critical section
    - Too restrictive
- Allow transactions to **overlap** while maintaining serializability
  - **Concurrency control algorithms**

Serializability

- Serial schedule: Each transaction executes atomically

  $n!$ schedules for n transactions

T0	T1
read(A)	
write(A)	
read(B)	
write(B)	
	read(A)
	write(A)
	read(B)
	write(B)

Non-serial schedule: Allow two transactions to overlap

- Does not imply incorrect execution
  - Define the <u>notion of conflicting operations</u>

- O_i and O_j **conflict** if they access same data item
  - AND at least one of them is a `write` operation

- If O_i and O_j do not conflict; we can ***swap*** their order
  - To create a new schedule

Concurrent serializable schedule

T0	T1
read(A)	
write(A)	
read(B)	
write(B)	
	read(A)
	write(A)
	read(B)
	write(B)

Serial Schedule

T0	T1
read(A)	
write(A)	
	read(A)
	write(A)
read(B)	
write(B)	
	read(B)
	write(B)

Conflict serializability

- If schedule **S** can be **transformed** into a serial schedule **S'**
  - By a series of swaps of non-conflicting operations

The contents of this slide-set are based on the following references

- *Avi Silberschatz, Peter Galvin, Greg Gagne. Operating Systems Concepts, 9th edition. John Wiley & Sons, Inc. ISBN-13: 978-1118063330.* [Chapter 5]