File Systems: Consistency Issues

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- File systems maintain many data structures
  - Free list/bit vector
  - Directories
  - File headers and inode structures
  - Data blocks

- All data structures are cached for better performance
  - Works great for read operations
  - … but what about writes?
    - If modified data is in cache, and the system crashes → all modified data can be lost
    - If data is written in wrong order, data structure invariants might be violated (this is very bad, as data or file system might not be consistent)
  - Solutions:
    - Write-through caches: Write changes synchronously → consistency at the expense of poor performance
    - Write-back caches: Delayed writes → higher performance but the risk of losing data

What about Multiple Updates?

- Several file system operations update multiple data structures
- Examples:
  - Move a file between directories
    - Delete file from old directory
    - Add file to new directory
  - Create a new file
    - Allocate space on disk for file header and data
    - Write new header to disk
    - Add new file to a directory
- What if the system crashes in the middle?
  - Even with write-through, we have a problem!!
- The consistency problem: The state of memory+disk might not be the same as just disk. Worse, just disk (without memory) might be inconsistent.

Which is a metadata consistency problem?

- A. Null double indirect pointer
- B. File created before a crash is missing
- C. Free block bitmap contains a file data block that is pointed to by an inode
- D. Directory contains corrupt file name

Consistency: Unix Approach

- Meta-data consistency
  - Synchronous write-through for meta-data
  - Multiple updates are performed in a specific order
  - When crash occurs:
    - Run "fsck" to scan entire disk for consistency
    - Check for "in progress" operations and fix up problems
    - Example: file created but not in any directory → delete file; block allocated but not reflected in the bit map → update bit map
  - Issues:
    - Poor performance (due to synchronous writes)
    - Slow recovery from crashes

Consistency: Unix Approach (Cont'd.)

- Data consistency
  - Asynchronous write-back for user data
    - Write-back forced after fixed time intervals (e.g., 30 sec.)
    - Can lose data written within time interval
  - Maintain new version of data in temporary files; replace older version only when user commits
- What if we want multiple file operations to occur as a unit?
  - Example: Transfer money from one account to another → need to update two account files as a unit
  - Solution: Transactions

Transactions

- Group actions together such that they are
  - Atomic: either happens or does not
  - Consistent: maintain system invariants
  - Isolated (or serializable): transactions appear to happen one after another. Don't see another tx in progress.
  - Durable: once completed, effects are persistent
- Critical sections are atomic, consistent and isolated, but not durable
- Two more concepts:
  - Commit: when transaction is completed
  - Rollback: recover from an uncommitted transaction

Implementing Transactions

- Key idea:
  - Turn multiple disk updates into a single disk write!
- Example:

  Begin Transaction

  x = x + 1

  y = y – 1

  Commit

  → Create a write-ahead log for the transaction

- Sequence of steps:
  - Write an entry in the write-ahead log containing old and new values of x and y, transaction ID, and commit
  - Write x to disk
  - Write y to disk
  - Reclaim space on the log
- In the event of a crash, either "undo" or "redo" transaction

Transactions in File Systems

- Write-ahead logging → journaling file system
  - Write all file system changes (e.g., update directory, allocate blocks, etc.) in a transaction log
  - "Create file", "Delete file", "Move file" --- are transactions
- Eliminates the need to "fsck" after a crash
- In the event of a crash
  - Read log
  - If log is not committed, ignore the log
  - If log is committed, apply all changes to disk
- Advantages:
  - Reliability
  - Group commit for write-back, also written as log
- Disadvantage:
  - All data is written twice!! (often, only log meta-data)

Where on the disk would you put the journal for a journaling file system?

1. Anywhere
2. Outer rim
3. Inner rim
4. Middle
5. Wherever the inodes are

Transactions in File Systems: A more complete way

- Log-structured file systems
  - Write data only once by having the log be the only copy of data and meta-data on disk
- Challenge:
  - How do we find data and meta-data in log?
    - Data blocks → no problem due to index blocks
    - Meta-data blocks → need to maintain an index of meta-data blocks also! This should fit in memory.
- Benefits:
  - All writes are sequential; improvement in write performance is important (why?)
- Disadvantage:
  - Requires garbage collection from logs (segment cleaning)

File System: Putting it All Together

- Kernel data structures: file open table
  - Open("path") → put a pointer to the file in FD table; return index
  - Close(fd) → drop the entry from the FD table
  - Read(fd, buffer, length) and Write(fd, buffer, length) → refer to the open files using the file descriptor
- What do you need to support read/write?
  - Inode number (i.e., a pointer to the file header)
  - Per-open-file data (e.g., file position, …)

Putting It All Together (Cont’d.)

- Read with caching:

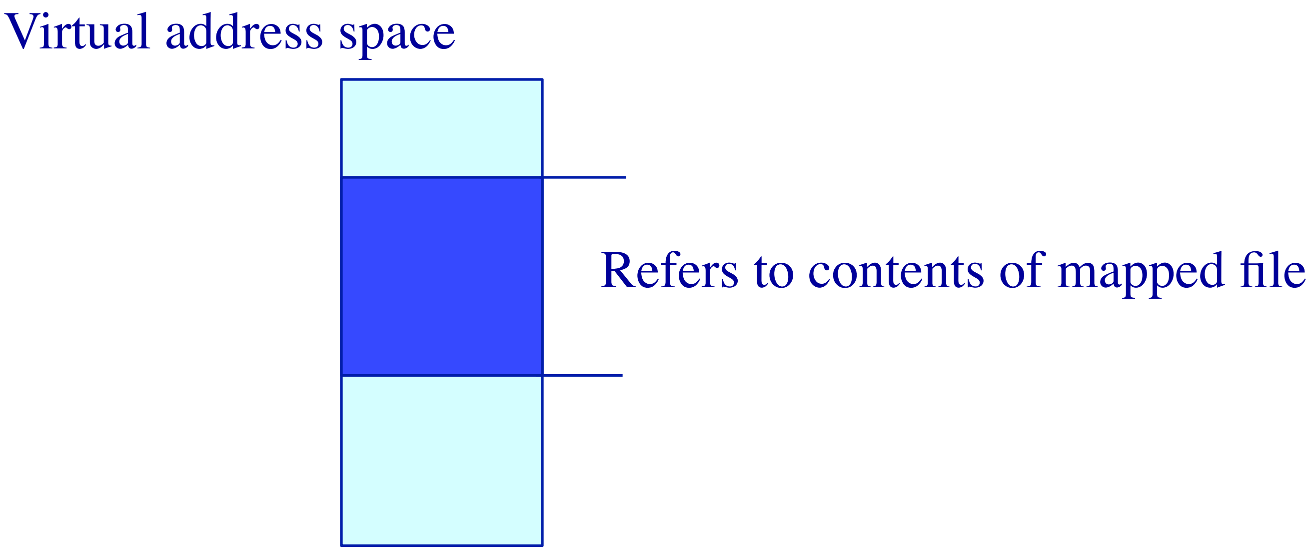
```
ReadDiskCache(blocknum, buffer) {
     ptr = cache.get(blocknum)   // see if the block is in cache
     if (ptr)
        Copy blksize bytes from the ptr to user buffer
     else {
         newOSBuf = malloc(blksize);
         ReadDisk(blocknum, newOSBuf);
         cache.insert(blockNum, newOSBuf);
         Copy blksize bytes from the newOSBuf to user buffer
     }
```

- Simple but require block copy on every read

- Eliminate copy overhead with mmap.
  - Map open file into a region of the virtual address space of a process
  - Access file content using load/store
  - If content not in memory, page fault

Putting It All Together (Cont’d.)

- Eliminate copy overhead with mmap.
  - mmap(ptr, size, protection, flags, file descriptor, offset)
  - munmap(ptr, length)



- void* ptr = mmap(0, 4096, PROT_READ|PROT_WRITE, MAP_SHARED, 3, 0);
- int foo = *(int*)ptr;
  - foo contains first 4 bytes of the file referred to by file descriptor 3.