上 海 交 通 大 学 试 卷（期中）

（ 2020 至 2021 学年　第 1 学期 ）

班级号_____ 学号_____ 姓名_____

课程名称　　计算机系统工程　　成绩_____

Problem 1: File System (24’)

Panda recently learned an inode-based file system from the CSE lessons. Panda soon implemented his own file system, named PANDAFS.

In PANDAFS, the size of each inode is 1KB, and each leaf node costs exactly one block (4KB). An inode contains 248 block pointers, where the first 247 pointers directly point to the first 247 blocks of the file, while the last one points to an indirect block (indirect block only contains direct blocks).

The detailed structure of an inode in PANDAFS is shown in the following table:

Name	Size (Bytes)	Description
Inode ID	8	Inode identifier
Size	8	File size
Type	1	File Type
Padding	3	Alignment padding
RefCount	4	Reference count of this inode
Atime	4	Last access time of this inode
Mtime	4	Last data modification time of this inode
Block Pointers	4*248	Block pointers of this inode

Table-1 inode design in PANDAFS

1) Can PANDAFS support a file as large as 5MB? (4’)

No (2’). The largest file size is 247*4K + (4K/4)*4K = 1271*4K = ~4.96M. (2’)

2) Panda wonders if he should add the file name into the inode. What is your suggestion? (4’)

To support long file names, the inode will become much larger, which can be a waste of space since most file names are usually not long (2’). Worse, a file may have multiple names (aka alias), this will preclude the use of hard links (2’).

3) In CSE2020 classes, Panda downloaded many reading materials files, one of which is a 128-byte file named ''CSE2020.txt''. Panda hopes to store it in the ''/'' directory of PANDAFS on a hard disk.

3-1) Which order is preferred to write this file to the disk? Why? (4’)

<1> update size, allocate a new block, write new data

<2> allocate a new block, write new data, update size

<3> allocate a new block, update size, write new data

Solution: <2> Reason: crash consistency

3-2) How long does it take to read this file back from the disk? Given the following hard disk features:

- Sector size = 512 bytes (basic read/write unit)
- Seek time: 0.1 ms
- Read time: 0.2 ms/sector
- Write time: 0.3 ms/sector

Assume the file has been open for the first time, and its contents are continuous on the disk. (Note: it is better to give a detailed explanation of your calculation, e.g., Time = 1 seek root inode + 1 read root inode = 0.3ms) (4’)

Time = 2 seeks inode + 2 reads inode + 8 seeks data block + 8 reads data block + 1 write Atime: 0.2+0.4+0.8+1.6+0.3 = 3.3ms (4’)

Note: if the answer lacks Atime update, the score is 0.

4) Given the formula:

$$\textbf{\textit{file utilization ratio}} = \frac{\textbf{\textit{file size}}}{\textbf{\textit{actually used disk size}}},$$

Panda found that the *file utilization ratio* of PANDAFS is low when the file size is relatively small. Panda does not want significant changes to current inode data structure, otherwise the already stored files cannot be correctly read any more. How to improve file utilization ratio while remaining backward compatible? Please briefly describe your improved design. (Note: you may reuse the Padding field, or re-design FS operations such as create, read, and write, but anyhow the file utilization ratio should be >= 96% for a 988-byte file.) (4’)

We can add a new flag to replace the Padding field. When this flag is set to *inline*, the file data is directly stored in the BlockPointers field. Storing 988-byte in the 1024-byte inode results in 988/1024 > 96% utilization ratio. (4’)

5) Panda is glad to see his PANDAFS now supports good space-efficiency for small files. However, he still observes a very poor file lookup performance in the directory full of many small files. Please explain the reason, and help Panda with an optimization solution to PANDAFS. (4’)

Reason: for each file lookup, PANDAFS performs costly disk I/O operations. (2’)

Solution: using a HTree-like structure to cache most-recently-used pathnames and the corresponding file contents in memory. (2’)

Problem 2: Transaction (25’)

We have a transaction system which operates on a key-value store. Each transaction only involves read(R)/write(W) operations on entries. Now we have four transactions (T1-T4) which access three entries(A, B, C).

1) What is final-state serializability, view serializability, and conflict serializability? Which one is the strongest among them? (4’)

Final-state serializability: A schedule is final-state serializable if its final written state is equivalent to that of some serial schedule

Conflict serializability: A schedule is conflict serializable if the order of its conflicts (the order in which the conflicting operations occur) is the same as the order of conflicts in some sequential schedule

View serializability: A schedule is view serializable if it is view equivalent to some serial schedule

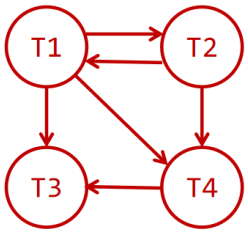
Conflict serializability is the strongest.

2) Consider the following schedule shown in the table, which type of serializability introduced in class does this schedule achieve? Please explain your reasons. (5’)

T1	T2	T3	T4
W(B)			
W(C)			
	R(B)		
			R(B)
W(A)			

		R(A)	
			W(B)
		R(B)	
	R(C)		
	W(C)		
R(C)			
			R(A)

Draw the conflict graph according to the conflicts between transactions, we get:



There is a cycle: T1->T2->T1, so this schedule is not conflict serializable.

Ignore the read operations, we can generate a serial schedule: T1->T4->T3->T2, so this schedule is final-state serializable.

3) If the schedule above cannot achieve conflict serializability, can we just remove a **SINGLE** action in the schedule to make it conflict-serializable? If true, identify this action and give a **conflict equivalent serial ordering** of this schedule. (Eg. T1->T2->T3->T4) (4')

Remove the final operation of T1(R(C)) or the final operation of T2(W(C))

Conflict equivalent serial ordering: T1->T2->T4->T3 (Only one correct answer)

4) Now we want to implement conflict serializability in this system. There are two common methods: 2-phase locking (2PL) and optimistic concurrency control (OCC). Firstly, we use the 2PL mechanism in our system, now assume that there are two threads running T1 and T2 concurrently. After transaction execution we get the following schedule:

$$W_1(B)->W_1(C)->W_1(A)->R_2(B)->R_1(C)->R_2(C)->W_2(C)$$

Is this schedule possible? If so, please list the timepoints when two transactions acquire/release lock. (4')

Yes, it's possible. $AC1(B)->W_1(B)->AC1(C)->W_1(C)->A1(A)->W_1(A)->RE1(B)->RE1(A)->AC2(B)->R_2(B)->R_1(C)->RE1(C)->R_2(C)->W_2(C)->RE2(B)->RE2(C)$

(Other reasonable answer is also acceptable)

5) Continue with the schedule produced by 2PL in question 4, if the thread running T1 crashes instantly after $R_2(B)$ which causes T1 abort, T2 must also be aborted be cause $R_2(B)$ read the value written by T1. We call this ***Cascading Abort.*** Can you mo dify the **2PL protocol** to avoid cascading abort? Please give your design.(4')

Strict 2PL protocol: release its locks only after it has ended, i.e., being eit her *committed* or *aborted.*

6) Finally, we use the OCC mechanism in our system, this time we assume there are two threads running T2 and T4 concurrently. T2 and T4 are started at the same tim e. After transaction execution we get the following schedule:

$$R_2(B)->R_4(B)->W_4(B)->R_4(A)->R_2(C)->W_2(C)$$

What will happen to the two transactions? List all possible situations.(4')

1.T1 commits before T2, T2 will be aborted (False abort).

2.T2 commits before T1, both two txns commit successfully.

Problem 3: Fault Tolerance & Crash Consistency (25')

1. Please list at least three commonly used mechanisms for fault tolerance. What a re the commonalities of these methods? (4')

including replica, log, checksum.

Information redundancy

2. RAID5 allows one disk failure. If there are five disks in a RAID5 disk array system, and the MTTF of each disk is 100,000 hours, then:

(1) if we never repair the failure disk, what is the MTTF of the system? (2')

10w/5+10w/4=2w+2.5w=4.5w hours

(2) if it takes 10 hours to repair the failure disk, what is the MTTF of the syste m? (2')

10w*10w/(5*4*10) = 0.5y hours

3. For the YFS in the lab, after it crashed, what should be checked during fsc k? (4')

Check superblock，Check free blocks，Check inode states，Check inode links，Check dup licates, Check bad blocks, Check directories (details omitted here)

4. The disk space is limited, so log size cannot grow infinitely.

(1) If we can simply stop the world when doing truncating, how to truncate the log to save storage space? (2’)

(2) For better performance, we want to continue accepting new transactions during truncating. How to truncate the log in this scene? (2’)

(1) Wait current transactions finish, log a checkpoint, flush, delete logs before checkpoint

(2) Log a truncate begin checkpoint, and when all transactions before the begin tag finished, log a truncate end checkpoint, flush, then delete logs before begin checkpoint

5. Please describe the three modes (journal, ordered, writeback) of EXT4 file systems briefly. How to choose the mode in different scenes? (4’)

journal: both metadata and data are recorded into log

ordered: data is directly written into data block and flushed before metadata is recorded into log

writeback: data is directly written into data block, metadata is recorded into log, but which becomes persistent first is not sure

journal -> ordered -> writeback: the performance is better and better, but the reliability is worse and worse. If data integrity is important, it should use journal mode. if performance is important, or it is rare to crash, writeback mode is better. Ordered mode is a balance choice.

6. Here are the steps when writing a file on EXT4 in ordered mode. Please describe the file system status if a crash happens at different times. (5’)

```
write data; flush; log metadata; (1)
flush; (2)
log commit; (3)
flush (4)
write metadata; flush; (5)
```

(1) Data must be persistent, but metadata log may or may not be persistent now.

(2) Data and metadata are both persistent, but the log is not committed. When recovery from a crash, new metadata in log should not be written to real metadata, but old data could not be recovered.

(3) If the commit is persistent in disk, it is same as (4); if the commit is only in disk cache and lost after crash, it is same as (2)

(4) Here is the commit point, the new file is committed in the journal. When recovery, the new metadata in log should be written to real metadata

(5) Here can be seen as a checkpoint, the write file transaction is finished, and old log can be truncated

Problem 4: Before-or-after Atomicity (26')

You are the cook and owner for a popular food truck - business has been booming, however, your servers have just quit! So… you decide to use your programming skills to make an automated ordering interface to automatically turn down or accept orders. You come up with the following system:

At most N orders can be accepted at a time. If there are already N orders, any extra orders are declined. The chef will work through one order at a time.

```
extern int N;
int orders = 0;
pthread_mutex_t mutex;
pthread_cond_t  cond;

void *order() {
        while(true){
                if (orders < N) {
                        orders += 1;
                        return;
                }
        }
}
void *cook(){
        while(true) {
                orders -= 1;
                cookOrder();
        }
}
```

To synchronize the two functions, you decide to use lock and conditional variables. Now, please answer following questions:

1.What is the problem of the following implementation of **order()**? (4')

```
void *order() {
        acquire(mutex);
        while(true){
                if (orders < N) {
                        orders += 1;
                        release(mutex);
                        return;
                }
        }
}
```

If you successfully acquire the lock, and 'orders >=N' at the 'if' branch, the lock will never be released, resulting in deadlock.

2. Here are two implementations of **order()**, but both have problems. Please list the problems. After that, please give your solution. (6')

```
void *order() {
        acquire(mutex);
        while(true){
                if (orders < N) {
                        orders += 1;
                        release(mutex);
                        return;
                }
                release(mutex);
                yield();
                acquire(mutex);
        }
}
```

```
void *order() {
        acquire(mutex);
        while(true){
                if (orders < N) {
                        orders += 1;
                        release(mutex);
                        notify(have_order)
                        return;
                }
                release(mutex);
                wait(not_full);
                acquire(mutex);
        }
}
```

Left：A lot of unnecessary checking as well as a lot of acquiring locks

Right: If send() notifies but there's no receiver waiting, no one will get woken up. This is potentially prone to race conditions

3. To implement new **wait()** api, your partner proposes to use a modified version of Semaphore to implement the condition variable class as follows:

```
Semaphore.set(0); //Initialize semaphore to 0
Wait(CV cv, Lock lock) {
        Semaphore.P(cv, lock); //Special semaphore that releases lock if it waits
}
Notify(CV cv) {
        Semaphore.V(cv);
}
```

Do you think this proposal will work or not? Please explain your decision. (8')

Reason 1: Semaphores are commutative, while condition variables are not. Practically speaking, if someone executes Wait() followed by Notify(), the latter will not wait. In contrast, execution of Notify() before Wait() should have no impact on Wait().

Reason 2: The above implementation of Wait() will deadlock the system if it goes to sleep on Semaphore.P() (since it will go to sleep while holding the monitor lock).

[https://inst.eecs.berkeley.edu//~cs162/fa13/sections/Worksheet-3-Answers.pdf]

Hint 1: A simple way to understand P(wait) and V(signal) operations is:

- **P()**: Decrements the value of semaphore variable by 1. If the **new** value of the semaphore variable is negative, the process executing wait is blocked. Otherwise, the process continues execution.
- **V()**: Increments the value of semaphore variable by 1. After the increment, if the **pre-increment** value was negative, it signals a blocked process to continue.

Hint 2: You can consider the different meaning of order of execution between semaphore and conditional variables.

4.Consider the following two functions implementing a producer and consumer:

```
// producer
void send(item){
        acquire(lock);
        enqueue(item);
        printf("before signal()\n");
        signal(lock);
        printf("after signal()\n");
        release(lock);
}
```

```
// consumer
item = get(){
        acquire(lock);
        while (queue.isEmpty()) {
                printf("before wait()\n");
                wait(&lock);
                printf("after wait()\n");
        }
        item = dequeue();
        release(lock);
}
```

Assume two threads T1 and T2, as follows:

T1	T2
send(item);	item = get();

What are the possible outputs?(8')

[T1, T2]
before signal
after signal
[T2, T1]
before wait
before signal
after wait
after signal

我承诺，我将严格遵守考试纪律。

承诺人：_____

题号									
得分									
批阅人(流水阅卷教师签名处)									