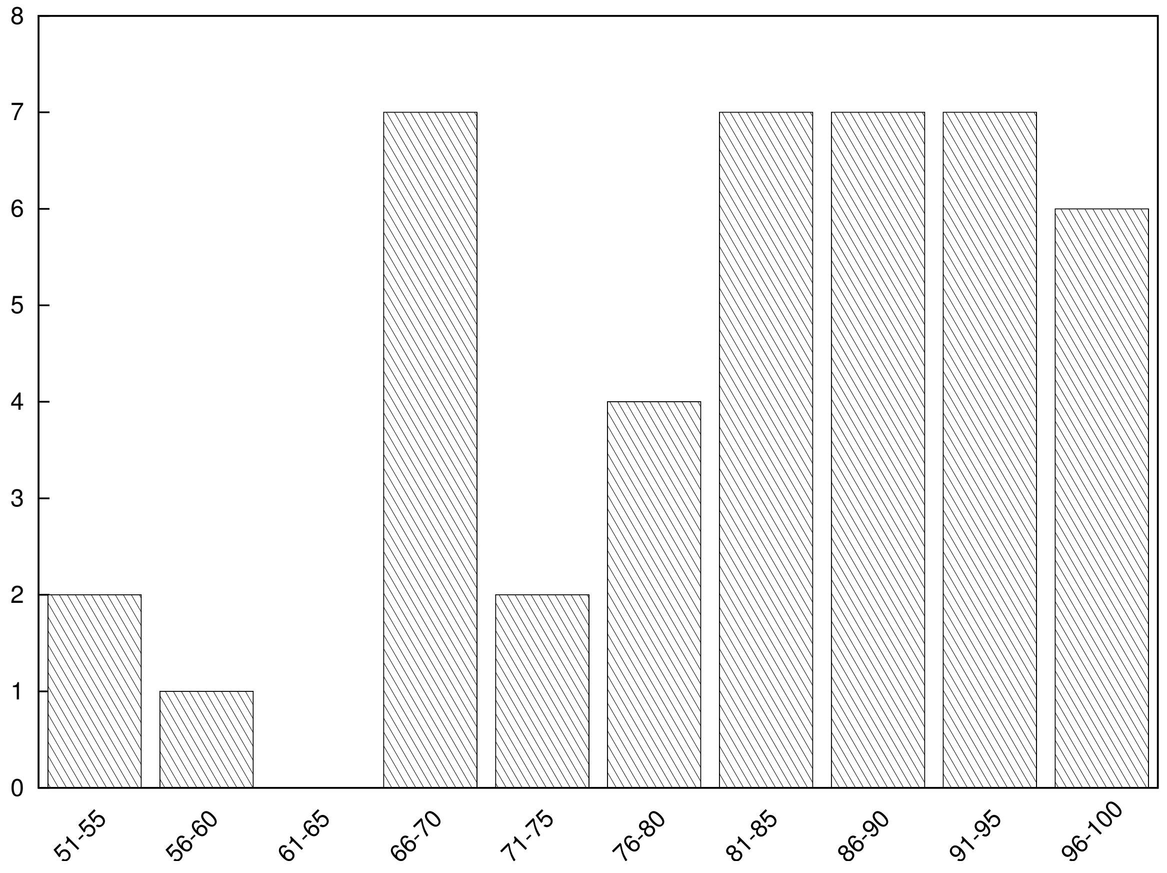
Department of Electrical Engineering and Computer Science

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

6.824 Distributed System Engineering: Spring 2011

Quiz I Solutions

Grade histogram for Quiz 1



$$\begin{aligned} \text{min} &= 52 \\ \text{max} &= 100 \\ \text{median} &= 82 \\ \text{average} &= 82 \\ \sigma &= 12 \end{aligned}$$

I Distributed Shared Memory

You are running the distributed shared memory system described in Memory Coherence in Shared Virtual Memory Systems, by Li and Hudak. You're using the version described in Section 3.1.

You're writing simple lock-like code for mutual exclusion. On computer C1 you execute this program:

```
x = 1
if(y == 0)
  print "C1 won"
```

On computer C2 you execute:

```
y = 1
if(x == 0)
  print "C2 won"
```

You start the two programs at roughly the same time. Variables x and y start out with value zero. The compiler generates machine code that references x and y exactly as shown in the above source code—the compiler does not re-order variable references, or eliminate them, or reference variables except as implied by the source code. You should assume that the manager is on a third computer, separate from C1 and C2.

Assume that the `invalidate()` function waits for acknowledgments indicating that all computers in the copy set have invalidated the page. Assume that x and y are on different pages.

1. **[9 points]:** Which of the following outputs are possible?

   A. neither computer prints anything

   B. C1 prints "C1 won", C2 prints nothing

   C. C1 prints nothing, C2 prints "C2 won"

   D. C1 prints "C1 won", C2 prints "C2 won"

Answer: A, B, and C. D is not possible: if C2 prints "C2 won," then its read of x came before C1's write of X, and thus C2's assignment to y came before C1's read of y, so C1 should have seen y==1 instead of y==0. The "came before" reasoning depends on the distributed shared memory system invalidating readable copies of pages before it allows a write.

2. [9 points]: Suppose both x and y are on the same page, and that no other data is on that page. You execute the programs, and see that afterwards C1 is the owner of the page, and that C2 is not in the page's copy_set on the manager. Give an example execution in which that would happen.

Answer: C2's program finishes before C1's program starts.

Now suppose that `invalidate()` does **not** wait for acknowledgements; it just sends a message to each computer in the copy set and returns. These messages are reliable; you can think of them as RPCs sent by a background thread.

3. [9 points]: Which of the following outputs are possible, given that `invalidate()` does not wait?

A. neither computer prints anything

B. C1 prints "C1 won", C2 prints nothing

C. C1 prints nothing, C2 prints "C2 won"

D. C1 prints "C1 won", C2 prints "C2 won"

Answer: A, B, C, and D.

II Logical Clocks

Recall the logical clocks that Bayou uses to keep track of causality: to ensure that if write X could have influenced write Y, that write Y be ordered after X. Each node maintains a logical clock. A node advances its logical clock as time passes (perhaps incrementing every nanosecond). When node N_1 sees an event from another node, marked as having occurred at logical time T, N_1 advances its logical clock so that it is greater than T.

Ben thinks that file synchronization protocols could use logical clocks instead of version vectors, for simplicity. See Section 3.1 of the Tra paper for a summary of version vectors. Ben suggests tagging each node's copy of a file with the logical time at which it was last modified. If node N_1 modifies its copy of the file, N_1 sets the file's modification time to N_1's logical clock. When N_1 synchronizes to N_2, N_2 accepts N_1's copy of the file if N_1's copy has a higher logical modification time than N_2's copy. In addition, N_2 advances its own logical clock to ensure it is greater than the logical modification time of every file N_1 sends it.

4. [9 points]: Describe a situation in which Ben's logical clock scheme would produce better behavior than using each node's real-time clock.

Answer: If the real-time clocks on different nodes are not exactly synchronized, then file synchronization can allow an earlier update to overwrite a later update, even if the later update is derived from the earlier update. Logical clocks ensure that a later update that depends on an earlier update will always win.

5. [9 points]: What crucial functionality of a file synchronizer is possible with version vectors but not possible with Ben's logical clocks?

Answer: Logical clocks do not allow conflicting updates to be detected. Version vectors can detect conflicting updates.

III Bayou

The Bayou paper says that, when two servers exchange Writes during anti-entropy, they tell each other about all the Writes they know of, so that the two servers end up with exactly the same set of Writes. See the left-hand column on page 3 of the paper.

6. [9 points]: The above property of anti-entropy usually causes the primary server (Section 6) to order committed Writes with the same order the Writes had when they were tentative—but not always. Describe a situation in which the primary would commit Writes in an order that is different from the tentative order seen on some servers.

Answer: Server A produces a write time-stamped 10. Server B produces a write time-stamped 20. B synchronizes with C, then A synchronizes with C, so C orders A's write first. Server B synchronizes with the primary. Server C synchronizes with the primary. Now C orders B's write first, since it is commited while A's write is not committed.

Suppose, instead, that anti-entropy only exchanged Writes generated by clients of the two servers performing anti-entropy. This might make each anti-entropy session complete faster. It would also make it harder for all servers to learn about a given Write, since a server could only learn about the Write by performing anti-entropy with the server that originated the Write, and not indirectly through other servers.

7. [9 points]: Describe a situation in which this change to anti-entropy would cause incorrect or surprisingly counter-intuitive behavior in the meeting room scheduler application.

Answer: Server A generates a write time-stamped 1 asking for the meeting room at 11:00, 12:00, or 13:00. Server B generates a write time-stamped 2 asking for the same times. Server C generates a write time-stamped 3 asking for the same times. A synchronizes with B. B synchronizes with C. Now, even though B and C have synchronized, they disagree about the times of meetings B and C.

Now suppose that Bayou anti-entropy behaves as described in the paper, but that a Write's timestamp is `<ID of server, local time>` rather than `<local time, ID of server>`, and that all nodes order Writes by sorting by the "ID of server" part, and breaking ties by sorting on the "local time" part. Here's an example of some writes in this new order:

```
<"server1", 27730> first write
<"server1", 27735> second write
<"server2", 20339> third write
<"server2", 30111> fourth write
```

8. [9 points]: Describe a situation in which this change to Write ordering would cause incorrect or surprisingly counter-intuitive behavior in the meeting room scheduler application.

Answer: Server B might generate a write and synchronize with all other nodes (except the primary). If server A then generates a write, all users will know that write was made later, but the system will order it before B's write.

IV Cedar FSD

At the top of the right-hand column of page 158, the paper Reimplementing the Cedar File System Using Logging and Group Commit says “Any pages logged in this new third, but not logged in a later third, are written to the file name table by the logging code.” This quote is discussing the writing of modified file name table pages from the page cache to the disk. Assume that FSD marks a cached page as “clean” when writing it to the disk, and will not write it again unless it is subsequently modified in cache.

9. [9 points]: Describe a specific scenario in which the quoted policy results in higher performance than writing to disk every dirty cached page that is logged in the new third.

Answer: Suppose a program performs a long sequence of operations that modify the same file name table page over and over. It could be that the system could recycle the whole log many times, each time observing that the page was modified in a later third, and not have to write the cached page to disk until the very end. This argument doesn’t work for just two operations, since in that case only one write is needed anyway, after which the cached page will be clean.

V Replicated Extent Server

Alyssa makes a replicated extent server, intending eventually to use it to increase performance and fault-tolerance. She has two extent servers, both of which hold a complete set of extents. Clients can send puts and gets to either extent server. Each server sends any puts it receives to the other server. Here's what some of her extent server code looks like:

```
get_handler(k){
  ScopedLock mx(&m);
  if table contains k
    return table[k]
  else
    return an error
}

put_handler(k, v){
  ScopedLock mx(&m);
  table[k] = v;
  use RPC to call the other server's put_replica(k, v)
}

put_replica_handler(k, v){
  ScopedLock mx(&m);
  table[k] = v;
}
```

Alyssa observes that most of the time her replicated extent servers works fine, but sometimes they stop replying to RPCs.

10. [9 points]: Explain the problem, and describe a specific scenario under which the problem might arise.

Answer: The problem is deadlock. If two clients each send a `put` to a different server at the same time, each server's `put_handler` will acquire that server's mutex. Then both servers will send a `put_replica` to the other server, and the `put_replica` handlers will wait forever for the mutexes.

VI 6.824

11. [4 points]: Describe the most memorable error you have made so far in one of the labs. (Provide enough detail so that we can understand your answer.)

Answer: Incorrect RPC parameter types. Mysterious STL (map/list/string) behavior. Deadlock. Missing locks. Weird FUSE behavior.

We would like to hear your opinions about 6.824, so please answer the following two questions. (Any relevant answer will receive full credit!)

12. [3 points]: What is the best aspect of 6.824?

Answer: The labs.

13. [3 points]: What is the worst aspect of 6.824?

Answer: Poor FUSE documentation. This quiz. Badly written, dry, or old papers.

End of Quiz I