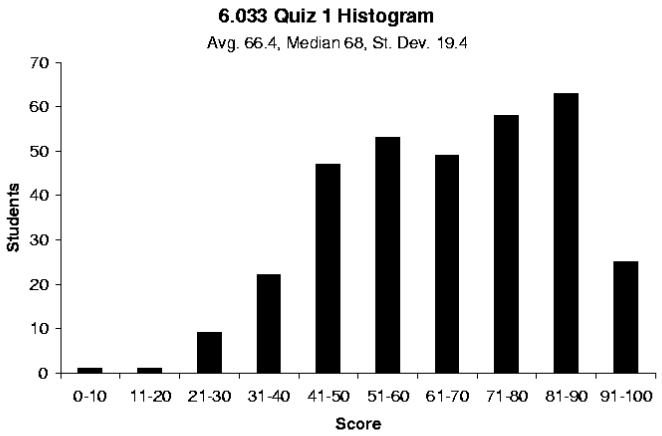
DEPARTMENT OF ELECTRICAL ENGINEERING AND COMPUTER SCIENCE

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

6.033—Computer System Engineering Handout 11—March 10, 1998

Quiz 1 Solutions



Problem	Your Score	Maximum Score
1		30
2		40
3		30
Total		100

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1. (*30 points*) ***Circle*** exactly one answer to the following questions (choose the best answer):

a. Recitations in 6.033:

1) Are not scheduled by the registrar, and require you to call Prof. Kaashoek at home to find a suitable time.
2) Are an essential part of the 6.033 educational experience, and participation in recitation discussions contributes to your final grade.
3) Are no longer held, and by not attending them you have cleverly saved a great deal of time waiting in empty rooms.
4) Have been recently increased in length from 50 minutes to 3 hours due to popular demand.

b. The errors in the Therac-25 system:

1) Were in the terminal handler, and that is why the company suggested removing the terminal up-arrow key.
2) Were dependent on timing.
3) Were caused by writing the system in assembly language which caused compatibility problems when the code was ported from the Therac-20 system.
4) Could have been fixed by correctly decoding the turntable position signals.

c. The process primitives of the UNIX system:

1) Create a new "forked" process and initialize its address space to zero.
2) Do not permit processes to wait because processes are easily terminated and new ones started.
3) Are used by the shell to create a single process for the command "ls | more" .
4) Let newly created processes inherit pipes to facilitate inter-process communication.

d. The Eraser system:

1) Detects synchronization errors by computing the "happens before" relation.
2) During compilation places checks at lock and unlock commands to log what data is being protected by locks.
3) Considers a variable “shared-modified” as soon as the first store to it executes.
4) May miss synchronization errors.

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e. In Birrell's RPC system:

1) A remote procedure call will always be executed completely, exactly once, or not at all.
2) A remote procedure call will always be executed at least once, and may be executed more than once.
3) A remote procedure call will always be executed at most once, which includes the chance that the call may not be executed at all or may be partially executed.
4) In the absence of failures it is impossible for the client to know if a remote procedure call was executed or not.

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2. *(40 points)* Ben Bitdiddle is called in to consult for Microhard. Bill Doors, the CEO, has set up an application to control the Justice department in Washington, D.C. The client running on the TNT operating system makes RPC calls from Seattle to the server running in Washington, D.C. The server also runs on TNT (surprise!). Each RPC call instructs the Justice department on how to behave; the response acknowledges the request but contains no data (the Justice department always complies with requests from Microhard). Bill Doors, however, is unhappy with the number of requests that he can send to the Justice department. He therefore wants to improve TNT's communication facilities.

   Ben Bitdiddle observes that the Microhard application runs in a single thread and uses RPC. He also notices that the link between Seattle and Washington, D.C. is reliable. He then proposes that Microhard enhance TNT with a new communication primitive, pipe calls.

   Like RPCs, pipe calls initiate remote computation on the server. Unlike RPCs, however, pipe calls return immediately to the caller and execute asynchronously on the server. TNT packs multiple pipe calls into request messages that are 1000 bytes long. TNT sends the request message to the server as soon as one of the following two conditions becomes true: 1) the message is full, or 2) the message contains at least 1 pipe call and it has been 1 second since the client last performed a pipe call. Pipe calls have no acknowledgements. Pipe calls are not synchronized with respect to RPC calls.

   Ben quickly settles down to work and measures the network traffic between Seattle and Washington. Here is what he observes:

One-way Seattle to Washington, D.C. latency:	12.5×10^{-3} seconds
One-way Washington, D.C to Seattle latency:	12.5×10^{-3} seconds
Channel bandwidth in each direction:	1.5×10^{6} bits / second
RPC or Pipe data per call:	10 bytes
Network overhead per message	40 bytes
Size of RPC request message (per call)	50 bytes = 10 bytes data + 40 bytes overhead
Size of pipe request message:	1000 bytes (96 pipe calls per message)
Size of RPC reply message (no data):	50 bytes
Client computation time between requests:	100×10^{-6} seconds
Server computation time per request:	50×10^{-6} seconds

   Note that the Microhard application is the only one sending packets on the link.

   Please show your calculations and put your final answer in the box.

   a. What is the transmission delay the client thread observes to transmit an RPC request message (the time required to transmit an entire message at the data rate of the link)?

   We accepted two answers for this question. The answer we expected was

$$\frac{\text{RPC request size in bits}}{\text{Channel bandwidth in bits/sec}} = \frac{50 \text{ bytes} \times 8 \text{ bits/byte}}{1.5 \times 10^{6} \text{ bits/sec}} = 267 \times 10^{-6} \text{sec}$$

   Many students interpreted "transmission" in the dictionary sense of moving data from sender

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to receiver, rather than in the correct technical sense of sending only, giving

transmission delay + communication latency
$= 267 \times 10^{-6}$ sec (as above) + 12.5×10^{-3} sec $= 12.767 \times 10^{-3}$ sec

b. Assuming that only RPCs are used for remote requests, what is the maximum number of RPCs per second that will be executed by this application?

In the steady state, everything running as fast as possible, the following times add up to the round trip taken by one RPC:

client computation + req. ransmission delay + req. communication latency +
server computation + reply transmission delay + reply comm. latency =
100×10^{-6} sec + 267×10^{-6} sec + 12.5×10^{-3} sec +
50×10^{-6} sec + 267×10^{-6} sec + 12.5×10^{-3} sec $= 25.684 \times 10^{-3}$ sec/RPC

Inverting this gives a sustained maximum rate of 38.9 RPC/sec.

c. Assuming that all RPC calls are changed to pipe calls, what is the maximum number of pipe calls per second that will be executed by this application?

We accepted two answers for this question. The answer we expected was based on the assertion in the problem that "pipe calls return immediately to the caller." If this is so, then the number of calls is limited only by the client computation time between calls:

$$\frac{1}{100 \times 10^{-6}\text{ sec/call}} = 10{,}000\text{ calls/sec}$$

It was also reasonable to assume, since the problem mentioned the application runs in a single thread, that the thread making the pipe calls must spend time sending the 1000 byte pipe request message after each 96 pipe calls. The total time for 96 calls is thus

$$96 \times (100 \times 10^{-6}\text{sec}) + \frac{1000\text{ bytes} \times 8\text{ bits/byte}}{1.5 \times 10^{6}\text{ bits/sec}} = 14.93 \times 10^{-3}\text{sec}$$

giving a sustained maximum rate of

$$\frac{96}{14.93 \times 10^{-3}\text{ sec}} = 6428.6\text{ calls/sec}$$

d. Assuming that every pipe call includes a serial number argument, and serial numbers increase by one with every pipe call, how could you know the last pipe call was executed? (*Circle the best answer*)

1) Ensure that serial numbers are synchronized to the time of day clock, and wait at the client until the time of the last serial number.
2) Call an RPC both before and after the pipe call, and wait for both calls to return.
3) Call an RPC passing as an argument the serial number that was sent on the last pipe call, and design the remote procedure called to not return until a pipe call with a given serial number had been processed.
4) Stop making pipe calls for twice the maximum network delay, and reset the serial number counter to zero.

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3. *(30 points)* Ben Bitdiddle has just developed a $15 single chip Network Computer - NC - and plans to scoop Intel and create a revolution in computing. In the NC network system the network interface thread calls the procedure Packet_Arrived when a packet arrives. The procedure Wait_For_Packet can be called by a thread to wait for a packet.

Part of the code in the NC is as follows:

```
VAR m: Thread.Mutex;                                  1
VAR packet_here: BOOLEAN;                             2
VAR Packet_Present: Thread.Condition;                 3
                                                      4
Packet_Arrived: PROCEDURE ();                         5
   BEGIN                                              6
      packet_here := TRUE;                            7
      Thread.Broadcast(Packet_Present);               8
   END;                                               9
                                                      10
Wait_For_Packet: PROCEDURE ();                        11
   BEGIN                                              12
      LOCK m DO                                       13
         WHILE NOT packet_here DO                     14
            Thread.Wait(m, Packet_Present);           15
         END;                                         16
      END;                                            17
   END;                                               18
```

a. It is possible that Wait_For_Packet will wait forever even if a packet arrives while it is spinning in the WHILE loop. Give an execution ordering of the above statements that would cause this problem. Your answer should be a simple list such as 1, 2, 3, 4.

*Wait-forever can occur if Thread number one is in Wait_For_Packet, and immediately after it executes line 14, Thread number two executes all of Packet_Arrived. The trouble is that **after** Thread number one has convinced itself that packet_here is FALSE (in line 14), packet_here becomes TRUE (line 8) and the condition gets signalled (line 9). Since thread one is still running, it misses the signal; it then Waits forever (line 15) for the signal that it missed.*

*The minimal sequence that leads to an endless wait is **14-7-8-15** .*

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b. Write new version(s) of Packet_Arrived and/or Wait_For_Packet to fix this problem.

To fix the problem we need to make sure that the shared variable packet_here can't be changed between the time that Wait_For_Packet tests it and Wait_For_Packet reaches its wait statement. Wait_For_Packet has done its part--it has seized lock m, and it has told Thread.Wait to release lock m atomically as part of going into the wait state. But Packet_Arrived isn't respecting the lock protocol. (Eraser would have a fit.)

The minimal repair, then is to replace line 7 with the following three lines

```
LOCK m DO                       7a
    packet_here := TRUE;        7b
END                             7c
```

In terms of the answer to part a, this change guarantees that line 7 must be executed either before line 14 or after Thread.Wait releases the lock in line 15.

Note that although it wouldn't hurt anything, it is not necessary to continue to hold the lock while calling Thread.Broadcast. The simple explanation is that surrounding line 7 with the same mutual exclusion lock that protects lines 13 through 15 is sufficient to eliminate the bad execution ordering.

An interesting exercise to explore is whether or not placing the lock only around line 8 would also be sufficient.

THE END

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