Programação em Sistemas Distribuídos

2015/16

MEI/MI/MSI

Problem Set

Distributed Systems Concepts

1. Distributed systems architectures have evolved over time. Explain what led to the emergence of architectures with "fat clients" and why were these replaced, later on, by architectures based on "HTTP thin clients".
2. Consider a distributed system based on thin-clients HTTP. It is true that thin-clients HTTP:
   - (A) Emerged to exploit the computational power of PCs, which are low cost and of generic use.
   - (B) Almost do not execute any code: they just provide an interface for accessing the service.
   - (C) Are hard to manage, because every time there is a change in the service it is necessary to upgrade the code on the clients.
   - (D) Are essentially built according to a client/server architecture based on RPC.
3. In comparison with a centralized system, a distributed system:
   - (A) Is more manageable due to the several points of access.
   - (B) Is more reliable because components can be replicated.
   - (C) Is less secure.
   - (D) Is less scalable.

Time and Clocks

4. Consider a real-time distributed system that requires a global clock with a precision π=1ms. Therefore a fault-tolerant clock synchronization protocol is used to synchronize the system clocks. The convergence of the protocol directly depends on the message transmission delay, which is T_D = 300μs. Considering that the deviation rate of physical clocks is, at worse, $\rho=10^{-5}$, determine the clock synchronization period.
5. Consider a real-time distributed system in which clocks are synchronized periodically, with period P=30s. Consider that the convergence is δ=100μs and that the deviation rate of physical clocks is, at worse, $\rho=2\text{x}10^{-5}$. Determine the precision π of the local clocks in this system.
6. In a system with externally synchronized clocks, with accuracy α:
   - (A) It may not be possible to ensure the precision π of local clocks.
   - (B) The precision π can never be more than twice the accuracy α (i.e. $\pi \leq 2\ \alpha$).
   - (C) There is a notion of *absolute time*, but not of *global time*.
   - (D) Any two events occurring in different nodes can always be correctly ordered.
7. It is true that:
   - (A) In synchronous distributed systems, local clocks always provide absolute time.
   - (B) A clock that provides global time needs to be synchronized with an external source of time.
   - (C) To have a notion of global time, clocks in the system only need to be precise.
   - (D) Internal clock synchronization only provides accuracy, not precision.

8. The precision of local clocks, synchronized with internal clock synchronization, does not depend:
   (A) On the re-synchronization period.
   (B) On the convergence.
   (C) On the maximum rate of drift of physical clocks.
   (D) On the granularity of physical clocks.
9. The **accuracy** of local clocks, synchronized by means of **internal** clock synchronization:
   (A) Can be improved if the synchronization period is reduced.
   (B) Cannot be bounded.
   (C) Is proportional to the precision of the clocks.
   (D) Is a constant.

Synchronism

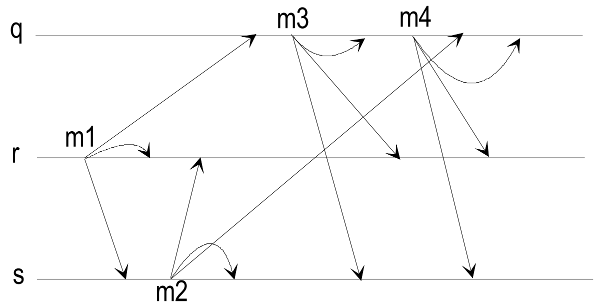
10. Is it possible to achieve steadiness and tightness in a fully asynchronous system? Explain.
11. Consider a distributed system with synchronized clocks, whose precision is π. Describe a message broadcast protocol for this system whose tightness is π.
12. In a synchronous distributed system, what is a protocol of the Δ class? How id Δ defined?

Indexing

13. When using hash tables, one well known problem is the occurrence of collisions. Explain what this problem is and how it can be addressed.
14. Distributed Hash Tables are a very commonly used construct in the context of distributed systems and protocols. Explain why and provide one use case example.

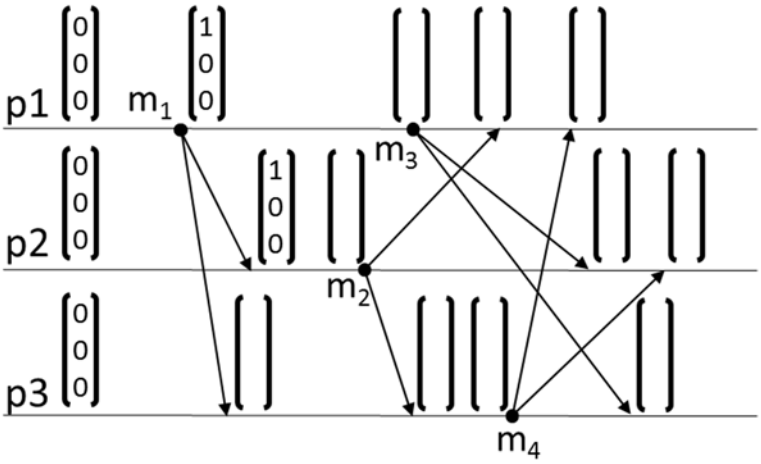
Ordering

15. Describe a protocol that secures total message ordering, indicating specific assumptions that must be made for the protocol to be correct, if any.
16. Explain the precedence (happened-before) relation between two events in a distributed system.
17. When a communication protocol is said to provide causal ordering, what does it means?
18. Does a causal ordering communication protocol also provide FIFO ordering? Explain.
19. Does a total ordering communication protocol also provide FIFO ordering? Explain.
20. Consider the following figure, which illustrates a set of message exchanged between processes q, r and s (messages are delivered as soon as they are received). It is correct to say that the communication protocol:
   (A) Only preserves FIFO order.
   (B) Preserves FIFO and Causal order, but not Total order.
   (C) Preserves FIFO and Total order, but not Causal order.
   (D) Preserves FIFO, Causal and Total order.



21. A sequencer-based protocol for total message ordering can be of the store-and-forward class or diffusion class. Compare the two approaches from the perspectives of performance and reliability.

22. The figure represents the history of an execution with causal order, based on vector clocks. However, some of the vectors are missing. Complete these vectors following the implementation rules for causal ordering with vector clocks.

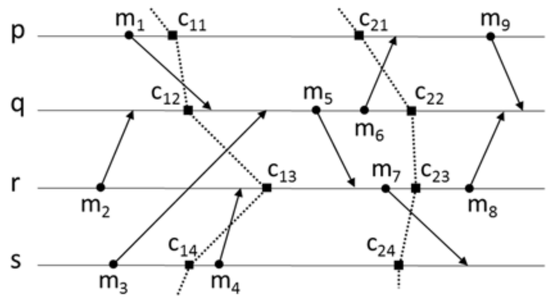


Coordination and consistency

23. What is a strongly consistent cut? And a consistent cut?

24. Consider the following figure, which illustrates a set of messages exchanged between processes p, q, r and s (messages are delivered as soon as they are received). The also illustrates two global cuts, $c1=\langle c_{11},c_{12},c_{13},c_{14}\rangle$ and $c2=\langle c_{21},c_{22},c_{23},c_{24}\rangle$. It is correct to say that:

(A) Both cuts are consistent cuts.
(B) Cut c1 is consistent and cut c2 is strongly consistent.
(C) Cut c1 is inconsistent and cut c2 is consistent.
(D) Both cuts are inconsistent cuts.



25. In distributed applications it is often necessary to coordinate processes in different sites, for instance to elect a leader process or to access a shared resource in mutual exclusion. For that, there exist several protocols based on message exchanges among processes. Describe one such protocol for leader election, assuming that the set of processes is known to all participants, that communication is reliable and that message delays are bounded.

26. Explain the "Consensus problem" in distributed computing, and why solving this problem is fundamental to also solve many other distributed computing problems.

27. The Consensus problem is defined by three properties, one of which is a liveness property. Describe this liveness property and explain why it is not possible to achieve this property in asynchronous systems. Explain also what is usually assumed to circumvent the impossibility and hence solve the Consensus problem.

28. Describe the main steps of a protocol to implement atomic broadcast based on consensus.

29. Describe in detail two advantages of passive replication in comparison to active replication, providing examples of systems or applications in which these advantages are relevant.

30. Explain how passive replication works and why it is not possible to use it to tolerate value faults.

Concurrency and Atomicity

31. Sequential consistency is one of the possible consistency criteria for replicated data objects. What is ensured by sequential consistency?

32. What are the requirements to enforce sequential consistency?

33. Consider the replicated shared variable x, such that initially x=0. Three processes, p1, p2 and p3, each access a different replica to read and write the value of x. The code executed by each of the processes is the following:

p1	p2	p3
x=1;	x=2;	x=3;
a=x;	b=x;	c=x;

Considering that the replicated variable x is implemented with sequential consistency, when the three processes complete their execution is it possible to have a=3, b=2 and c=1? What about a=1, b=2 and c=3? Justify.

34. Which of the following statements is true for the sequential consistency model:

(A) Sequential consistency is sufficient to guarantee the state convergence of replicated registers.
(B) To achieve sequential consistency it is enough that concurrent accesses to replicated registers are FIFO ordered.
(C) Sequential consistency is achieved as long as write operations are totally ordered.
(D) To achieve sequential consistency it is necessary to use the Two-Phase Commit protocol.

35. Serializability is a property usually provided by databases for dealing with concurrent transactions and preserving the correctness of data. Describe a mechanism that may be used to enforce the serializability of concurrent transactions.

36. What is the main difference between the 2 Phase Lock and the Strict 2 Phase lock mechanism to achieve isolation of concurrent transactions in a database?

37. How is it possible to achieve transaction atomicity in a distributed transaction that is performed across several nodes?

Consistency in large-scale systems

38. One approach to achieve replica consistency in a large-scale and partitionable system is to use replica quorums. What is the advantage of a weighted voting in comparison to non-weighted voting when implementing a quorum-based solution?

39. Consider a quorum-based replica management system in which there are 5 replicas, one of which is assigned 5 votes, while the remaining ones have a single vote. If the read quorum is 3, what is the write quorum in this system? Is it possible for this system to keep serving requests despite the failure of two servers? If a single server crashes, is it possible that the system will stop serving requests?

40. The CAP (Consistency, Availability and Partition Tolerance) theorem says that it is not possible to achieve all the three properties in a distributed large-scale system. However, most existing large scale services, like Google, eBay or Facebook, seem to enjoy all them. Explain the apparent paradox.

41. What is the primary partition approach and what does it mean in the context of the CAP theorem?

42. What is the meaning of “eventual consistency” in the context of the CAP theorem?

Models of Distributed Computing

43. Explain the difference between coordination, sharing and replication in a distributed system. Provide a representative example of each of these classes of distributed activities.
44. Selecting an appropriate distributed computing model may depend on the degree of desired coupling in terms of space, time and synchronization. Compare the possible options concerning space coupling.
45. Which of the following distributed computing models typically provides time decoupling: Remote operations, Group-oriented, Peer-to-Peer. Justify.

Client/Server Model

46. You've been hired by some company to develop a chat application to be used within the company's Intranet, only by employees. In the company they use a development framework that only provides RPC as a communication library. Describe how would you architect the solution, referring to the several entities needed in the system (clients/servers, role of each entity, interface provided by servers) and the relations among them (which clients interact with which servers, using which interface methods). You may use a sketch to illustrate the response.
47. What is the purpose of marshalling and unmarshalling in remote method invocations?
48. What is the task of the skeleton on the server side in RMI?
49. In the client/server model, which approaches can be used to implement multi-threaded clients?
50. In the client/server model, is there any advantage of using multi-threaded clients when the server uses a thread-per-client threading policy? Justify.
51. Concerning RPC, which of the following sentences is FALSE?
    (A) Communication is asymmetric and blocking.
    (B) A multi-threaded client is allowed to execute several concurrent RPCs.
    (C) Multi-threaded RPC servers are more reliable than single-threaded RPC servers.
    (D) Multi-threaded RPC servers require synchronization mechanisms to prevent state corruption.

Distributed Objects Model

52. When using Java RMI, is it possible to send a reference to object A when calling a method of remote object B, so that object B is able to call a method of object A? Justify.
53. Compare the distributed objects model and the client/server model concerning time, space and synchronization decoupling.
54. What is the purpose of the IDL compiler in a CORBA development environment?
55. What is the role of the ORB (Object Request Broker) in a CORBA system?

Distributed Shared Memory Model

Distributed Atomic Transactions Model

56. In a distributed transactional system the mechanism that guarantees the Atomicity property of transactions is:
    (A) Two-Phase Commit (2PC).
    (B) Two-Phase Lock (2PL).
    (C) Roll-back.
    (D) Serialization.

Message-oriented Models

57. The Message bus or Publish/Subscribe communication model is characterized by:
    - (A) Allowing time and space decoupling.
    - (B) Requiring stateless event brokers.
    - (C) Ensuring reliable delivery of events.
    - (D) Allowing events to be filtered according to FIFO or priority disciplines.

Group Communication Model

58. Explain in detail the view synchrony property and why it is useful for distributed applications. You may provide a graphical example.

59. In group communication:
    - (A) The group management service ensures that messages are delivered to all group participants.
    - (B) The group management service handles join and leave requests, as well as indications from the failure detection service.
    - (C) The view synchrony property ensures that at a given time instant all group participants have the same group membership view.
    - (D) The view synchrony property ensures that when a message is sent in view V, it is delivered to all processes in that view.

Peer-to-Peer Model

Distributed File Systems Services

60. What are the main differences between stateful and a stateless distributed file systems, referring to client/server interactions, file caching and cache consistency, performance and server recovery after failure.

61. Concerning the NFS distributed file system, it is correct to say that:
    - (A) It provides fault tolerance and availability despite server crashes.
    - (B) It is a stateful file system, because the server keeps track of files currently opened by clients.
    - (C) It is optimized for sequential access to large files.
    - (D) It provides migration transparency, although this requires the file system to be remounted.

62. Consider a distributed system based on AFS. Consider also that a client wants to open a file in the AFS space that <u>is currently present in the local cache, but has an invalid CBP</u>. Describe the main steps that are performed for the client to open the file.

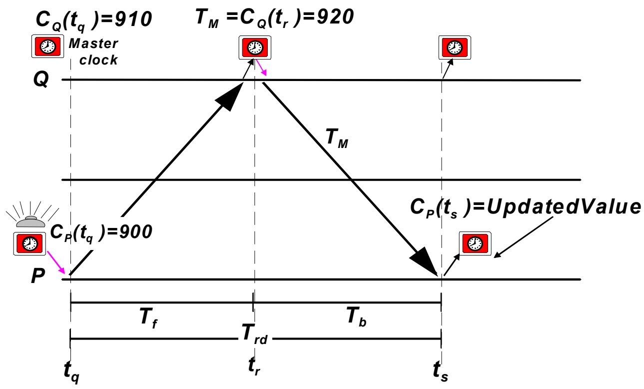
63. In the Google File System:
    - (A) There are several Master nodes serving client requests, for load balancing purposes.
    - (B) There is a single Master node, which stores file mappings on a disk log for fault tolerance.
    - (C) Files are split in chunks that are replicated in Chunk Servers using passive replication.
    - (D) When a client requests a write operation, the operation is concluded as soon as one of the replicas writes all the data to disk, to achieve higher throughput.

Time Services

64. Explain the NTP operation when the synchronization mode is based on multicast.

65. Explain the NTP operation when using symmetric message exchanges.

66. The figure below represents an execution of the NTP protocol, in which a client P in stratum 3 is synchronizing with a server Q in stratum 2.



In this execution, T_{rd}=100ms. Assume that the response time within server Q is negligible. If the minimum message delivery delay T_{min}=10ms, determine the error associated to the value of the clock at P after the synchronization, that is, the maximum possible difference between the clocks at P and Q.

67. Consider a system with synchronized clocks using NTP, where the NTP server is equipped with a GPS receiver for synchronizing its own clock. In this system, it is true that:

(A) All clocks will provide accuracy.
(B) All clocks will provide precision.
(C) All clocks will provide both accuracy and precision.
(D) The master clock will provide both accuracy and precision and the remaining clocks will only provide precision.

Directory services

68. Concerning the DNS and the X.500 directory services, it is true that:

(A) The execution of functional queries is only possible in the X.500 service.
(B) Only DNS is locally managed.
(C) The X.500 service is not hierarchical.
(D) The DNS service is not hierarchical.

Coordination services

69. Explain how you would implement node failure detection with Zookeeper.

70. Explain how you would implement leader election with Zookeeper.

71. Explain how you would implement mutual exclusion with Zookeeper.

72. Explain what is done by the sync() primitive available in the Zookeeper API. In which situation is this primitive useful?

73. Explain the purpose of the watch mechanism provided by Zookeeper. In which situation is this mechanism useful?

74. When using Zookeeper, the method that allows checking if a node has been previously created is:

(A) created.
(B) test.
(C) exists.
(D) check.