

- 1a Explain what is meant by *middleware*. 5pt
- 1b Why is it normally so hard to scale traditional client/server applications? 5pt
- 1c Under what conditions would you expect that server-initiated client-side caching in the Web would work? 5pt
- 1d Some distributed file systems give clients a lease on cached entries. Why are leases sometimes useful? 5pt
- 2a What is the difference between a hard link and a soft link in a naming system? 5pt
- 2b Having only pure names as object references (i.e., names containing no information at all) how can you efficiently locate an object in a worldwide distributed systems? 10pt
- 2c Explain what a closure mechanism is, and why such mechanisms are inherently implicit. 5pt
- 3a Give a precise description of reliable multicasting. 5pt
- 3b Why is reliable multicasting so hard to scale to large numbers of receivers? 10pt
- 3c In virtual synchrony, a process  $P[i]$  piggybacks  $N[i][j]$  on its multicast message to the others, where  $N[i][j] = N$  means that  $P[i]$  has successfully received messages #1, ..., #N from process  $P[j]$ . A process  $P[i]$  will *deliver* message #N from  $P[j]$  only if it knows that all others have received #N as well. What global message ordering does this scheme impose. Explain your answer! 10pt
- 4a Under which failure semantics do you need  $2k + 1$  members to implement a  $k$ -fault tolerant service? 5pt
- 4b Give an example in which masking an omission failure leads to a performance failure. 5pt
- 4c Explain how quorum-based replication works. 10pt
- 4d What is the relation between quorum-based replication and group failure masking? 5pt

**Grading:** The final grade is calculated by accumulating the scores per question (maximum: 90 points), and adding 10 bonus points. The maximum total is therefore 100 points.