Principles of Computer Systems

Final Exam Solutions

19-Dec-2017

This exam has 9 questions totaling 100 points. You have 105 minutes to answer them, which means you earn about 1 point per minute of work – please consider spending on each question no more minutes than the number of points attributed to it. Some questions are multiple-choice, with zero, one, or more correct choices; please mark the box(es) next to the correct answer(s) with a checkmark and leave the incorrect one(s) unchecked. The last 3 questions require answers in the form of 1-2 paragraphs of prose; exceeding this limit is unlikely to provide any benefit.

You are allowed to have any amount of printed material (books, papers, notes, etc.), but no devices with the *capability* of connecting to the Internet (laptops, tablets, cellphones, etc.) are permitted during the exam.

Best of luck!

Do not open the exam until instructed to do so.

Your name: _____ **SCIPER:** _____

Short Questions

Question S.1 *[4 points]*
Consider a phone switch whose availability *A* is 99.999% (five nines). Due to a hardware upgrade, the MTBF of the switch is doubled. Which is the new value of *A*, assuming nothing else changed?

- ☐ 99.9991%
- ☑ 99.9995% ("five and a half nines")
- ☐ 99.9999% ("six nines")
- ☐ 99.99999% ("seven nines")

Solution: A = 1 - U(navailability), so U=0.001%. Doubling MTBF halves U (since U = MTTR/MTBF), so instead of subtracting 0.001% from 1 we now subtract only 0.0005% => new A is five and a half nines.

Question S.2 *[4 points]*
Is there a difference between the "consistency" in the CAP principle and the "consistency" in the formulation of ACID? Explain in 1-2 sentences.

Solution: Yes. The C in CAP refers to whether values at different replicas match or not, whereas the C in ACID refers to whether the constraints and invariants defined on the database are upheld by committed transactions.

Question S.3 *[5 points]*
Remember that the DQ principle states that (Data/Query) x (Queries/Time) is constant. Say you have a cluster that runs a search engine, with the index split into equally sized shards across the nodes, each of which is operating at 80% utilization. If a quarter of the nodes fail, what happens to Harvest (i.e., fraction of the data reflected in responses) and what happens to Yield (i.e., probability of completing a request)?

- [ ] Neither Harvest nor Yield are affected
- [ ] Both Harvest and Yield increase
- [x] Both Harvest and Yield decrease
- [ ] Yield decreases, and Harvest stays the same
- [ ] Yield stays the same, and Harvest decreases

Solution: Since we're removing 25% of the resources in an 80%-utilized cluster, some queries will by necessity go unanswered, therefore Yield will decrease. Since the page index is sharded across the nodes, losing 25% of them loses 25% of the data, so Harvest must decrease as well.

Question S.4 *[2 points]*

Answer the same question as above, but instead of a search engine consider an object store that is fully replicated on each node in the cluster.

- [ ] Neither Harvest nor Yield are affected
- [ ] Both Harvest and Yield increase
- [ ] Both Harvest and Yield decrease
- [x] Yield decreases, and Harvest stays the same
- [ ] Yield stays the same, and Harvest decreases

Solution: Yield decreases for the same reason as above. However, the Harvest stays the same, since all data is available on every node, so the queries it answers provide the complete data.

Question S.5 *[3 points]*
Say *a* and *b* are events in a distributed system, and *C(event)* is the Lamport clock timestamp of *event*. Which of the following is/are true?

- [x] if *a* happened before *b*, then *C(a)* < *C(b)*
- [ ] if a happened before *b*, then *C(b)* < *C(a)*
- [ ] if *C(a)* < *C(b)*, then *a* happened before *b*
- [ ] if *C(a)* < *C(b)*, then *b* happened before *a*

Question S.6 *[2 points]*
Answer the same question as above, but for vector clocks instead of Lamport clocks:

- [x] if *a* happened before *b*, then *C(a)* < *C(b)*
- [ ] if a happened before *b*, then *C(b)* < *C(a)*
- [x] if *C(a)* < *C(b)*, then *a* happened before *b*
- [ ] if *C(a)* < *C(b)*, then *b* happened before *a*

Long Questions

Question L.1 *[20 points]*

Consider the system described in Lampson's "Designing a global name service" paper. State which consistency model it follows and justify your answer. Describe the failure model it assumes.

Question L.2 *[25 points]*

Make an argument against the exokernel design (i.e., identify its drawbacks and argue why they are important).

Question L.3 *[35 points]*

Suppose you are tasked with changing the Internet network layer (i.e., IP and the routing protocols) to compute and use multiple end-to-end paths between pairs of communicating end-points if available. Describe the changes (if any) to the interface between the new network layer and the transport layer. Please justify your answer.

Hints: Think about what extra functionality you want to implement at the network layer, and what extra functionality (if any) you want to implement at the transport layer. Think about the trade-offs involved. Think about the relationship between path properties and TCP behavior.