# Exam: Distributed Systems

**Means allowed:** Nothing except paper, pencil, pen and English - xx dictionary.

**Please**

1. **Check your name and student-id number on the first page, sign next to it** (next to "Unterschrift").
2. **Write your student-id number (but not your name) on each page the exam answer sheets. Sheets without ID number will not counted.**
3. **Place an identification document in front of you, it will be checked during the exam.**

**General information:** All questions should be answered in English. Write clearly and use the pages in a structured way so your answers are easy to read. All answers should be motivated, explained, detailed, precise and accurate.

**Important suggestion:** Read all questions before answering. Plan your time so that you can (at least) write a brief answer to all questions (and sub-questions). Please notice the weight that is given to each question (and sub-question).

## 1. Basics about Distributed Systems (6 points)

1 a) (2 points) Define the term "Distributed System". Be brief and precise.

1 b) (4 points) The Internet is one of the largest Distributed Systems today. Its architecture follows the so-called OSI Reference Model of 7 layers. Briefly name the seven layers and note the functions of each layer in keywords.

## 2. Naming (4 points)

In the lecture we discussed the concept Chord. Chord is a Distributed Hash Table (DHT). Answer the following questions about Chord:

- What topology do the nodes form?
- What operations does a DHT, e.g., Chord, provide?
- How is redundancy in Chord achieved?
- In Chord, how many hops does it take on average to lookup a data item? (Assume that the number of nodes in the Chord is "n").
- How does a node join a Chord DHT?
- Neighbor Table: Which nodes are stored in a neighbor table (called finger table in Chord) of a node in the DHT?
- Dynamo introduces the concept of virtual nodes, what are they used for?

## 3. Leader Election and Mutual Exclusion (4 points)

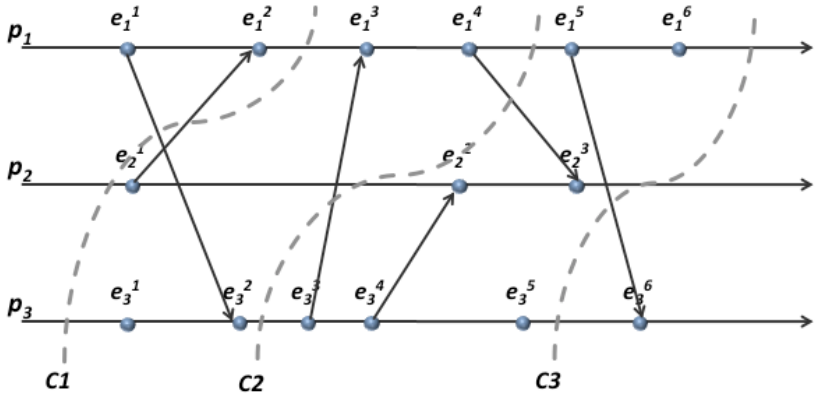
Electing a leader among multiple nodes in the network.

- What properties should a leader election algorithm in distributed systems have?
- What challenges does leader election in distributed systems face?
- Please name two algorithms we described in the course that elect a leader.
- When you compare both algorithms, what key advantages and disadvantages do your see for each?

## 4. Time and Synchronization (4 points)

We discussed the concept of consistent and inconsistent cuts.

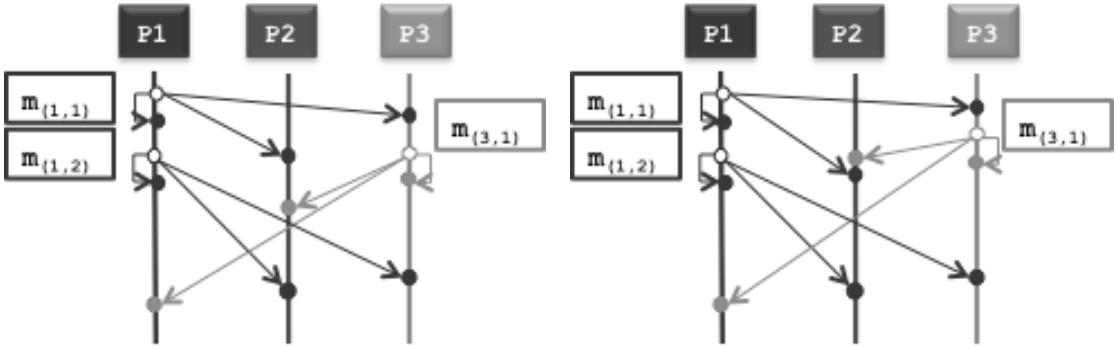
- Please explain this concept briefly and formally define the term consistent cut.
- Please note for each cut (C1, C2, C3) depicted below whether it is a consistent or an inconsistent cut. Explain your reasoning briefly.




## 5. Consistency and Replication (4 points)

We discussed the concepts of Total Ordering, Sequential Ordering, and Causal Ordering

- Briefly explain and formally define each concept.
- Below you see two figures. For each figure, please note weather it describes Total Ordering, Sequential Ordering, and Causal Ordering. Briefly describe your decisions.




## 6. Fault Tolerance (4 points)

We discussed the "Byzantine Generals Problem".

- In the "Byzantine Generals Problem" there are honest generals and dishonest generals (traitors). What is the goal of the honest generals? What is the goal of the traitors?
- In the lecture, we introduced an algorithm with multiple phases to enable consensus among the generals. Explain the algorithm and its different phases.
- Under what conditions can the generals achieve consensus. How many honest generals are required, assuming that there are *k* dishonest ones?

## 7. Applications (4 points)

We discussed TOR, which enables, for example, anonymous Internet browsing.

- Briefly explain how TOR provides anonymous Internet browsing. You can draw a figure to illustrate your argumentation.
- TOR also allows so called hidden services. Please briefly explain what a hidden service is and how TOR enables it. You can draw a figure to illustrate your argumentation.