Chair of Application and Middleware Systems
Department of Informatics
Technical University of Munich

Esolution
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- During the attendance check a sticker containing a unique code will be put on this exam.
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Distributed Systems Retake Exam

Exam: IN2259 / Retake Final
Examiner: Prof. Dr. Hans-Arno Jacobsen
Date: Monday 13th July, 2020
Time: 13:45 – 15:00

	P 1	P 2	P 3	P 4	P 5	P 6	P 7
I							

Working instructions

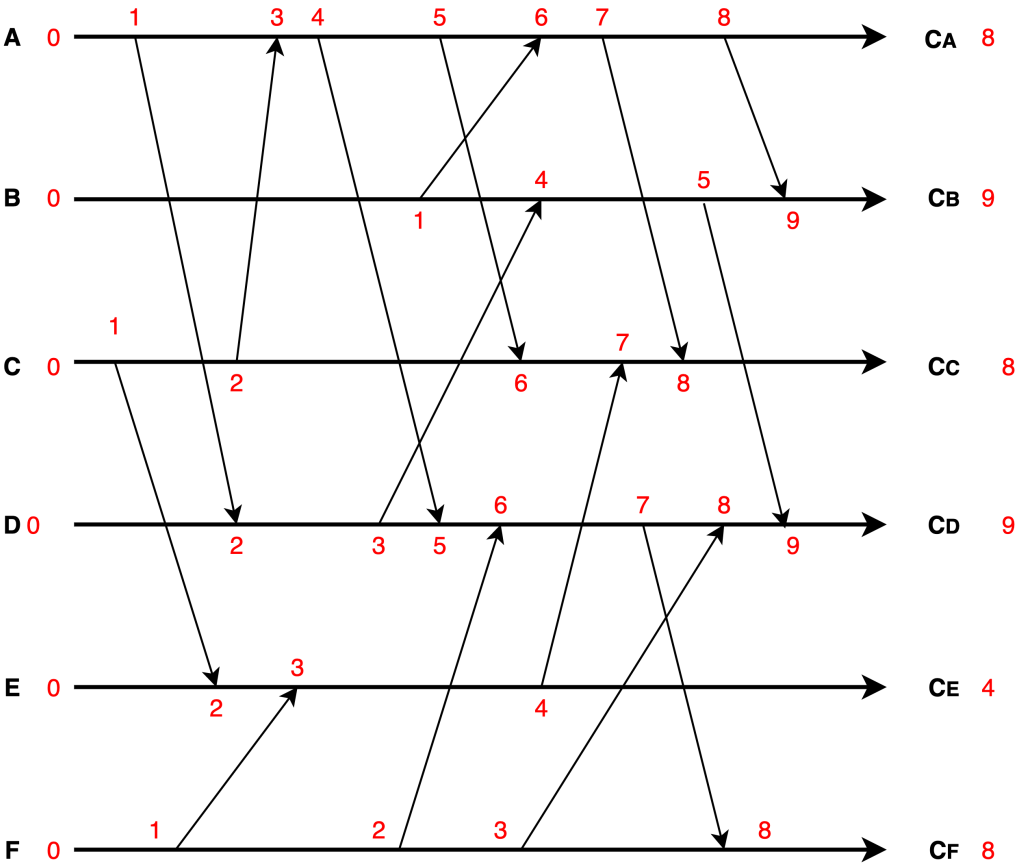
- This exam consists of **26 pages** with a total of **7 problems**.
  Please make sure now that you received a complete copy of the exam.
- The total amount of achievable credits in this exam is 100 credits.
- Detaching pages from the exam is prohibited.
- Allowed resources:
  - The exam is an open book, and course materials are allowed to be used.
  - **Any collaboration is cheating and will be reported to administrations!**
- Unless stated differently, please use the algorithms that have been introduced in the lecture or the tutorial.
  Self-defined algorithms may reduce the awarded credits.
- **Do not write with red or green colors.**

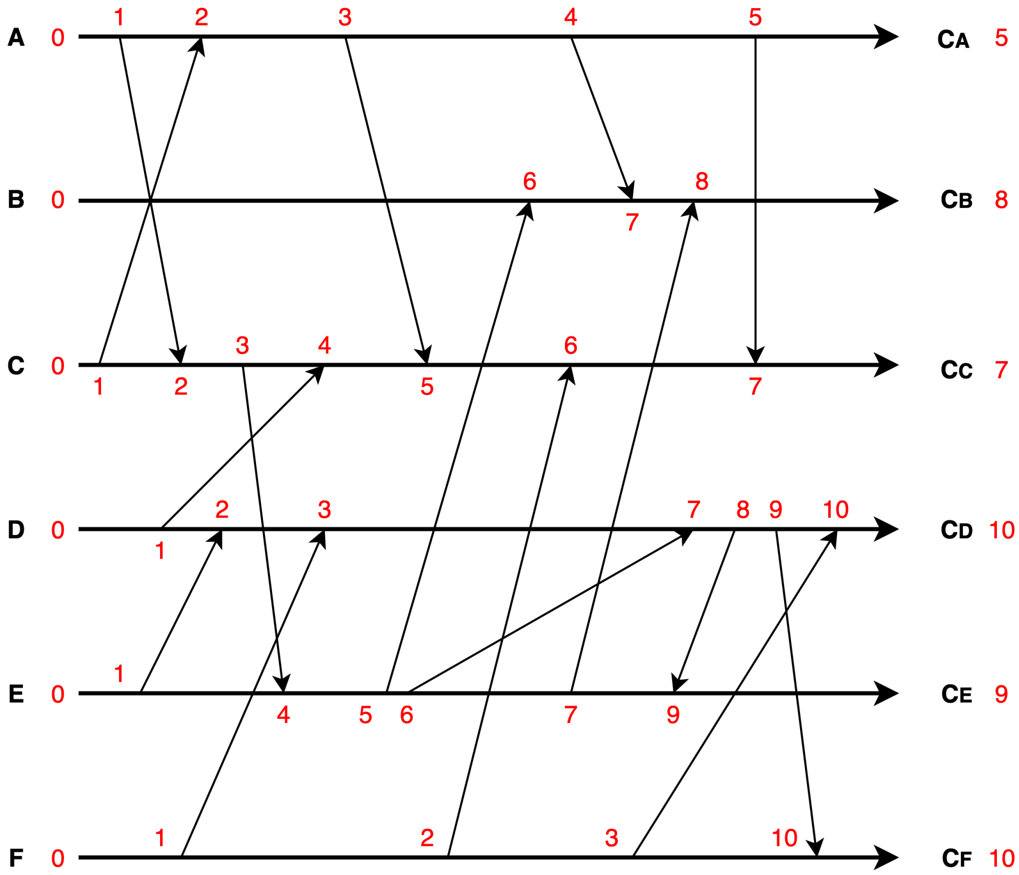
Left room from ____________ to ____________ / Early submission at ____________

Problem 1 Lamport Logical Clock (12 credits)

For each process $p_i \in \{A, B, C, D, E, F\}$ determine the logical time ($\{C_A, C_B, C_C, C_D, C_E, C_F\}$) at the **end** of the time/event diagram according to **Lamport's Logical Clock** algorithm. Write the final value of clocks in the table below.

Solution: All variations included in the exam:
Each correct clock 2 points otherwise 0.

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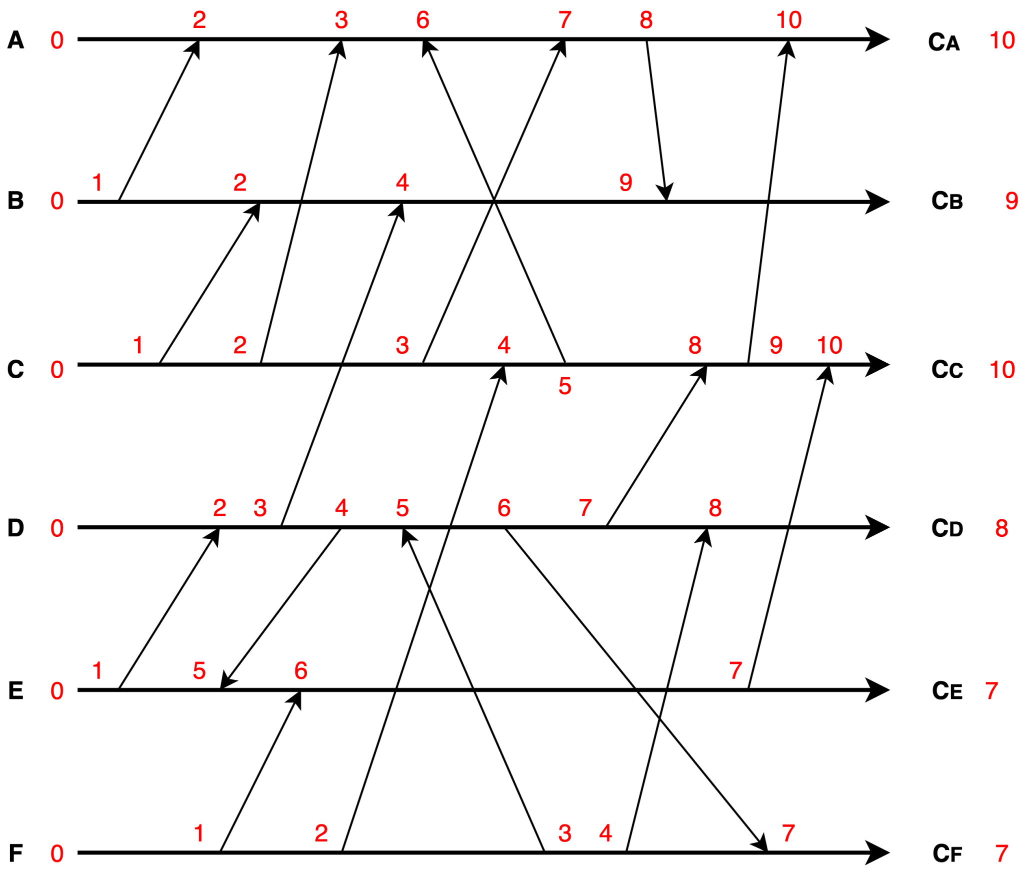
B 0 6 7 8 CB 8
C 0 1 2 3 4 5 6 7 CC 7
D 0 1 2 3 7 8 9 10 CD 10
E 0 1 4 5 6 7 9 CE 9
F 0 1 2 3 10 CF 10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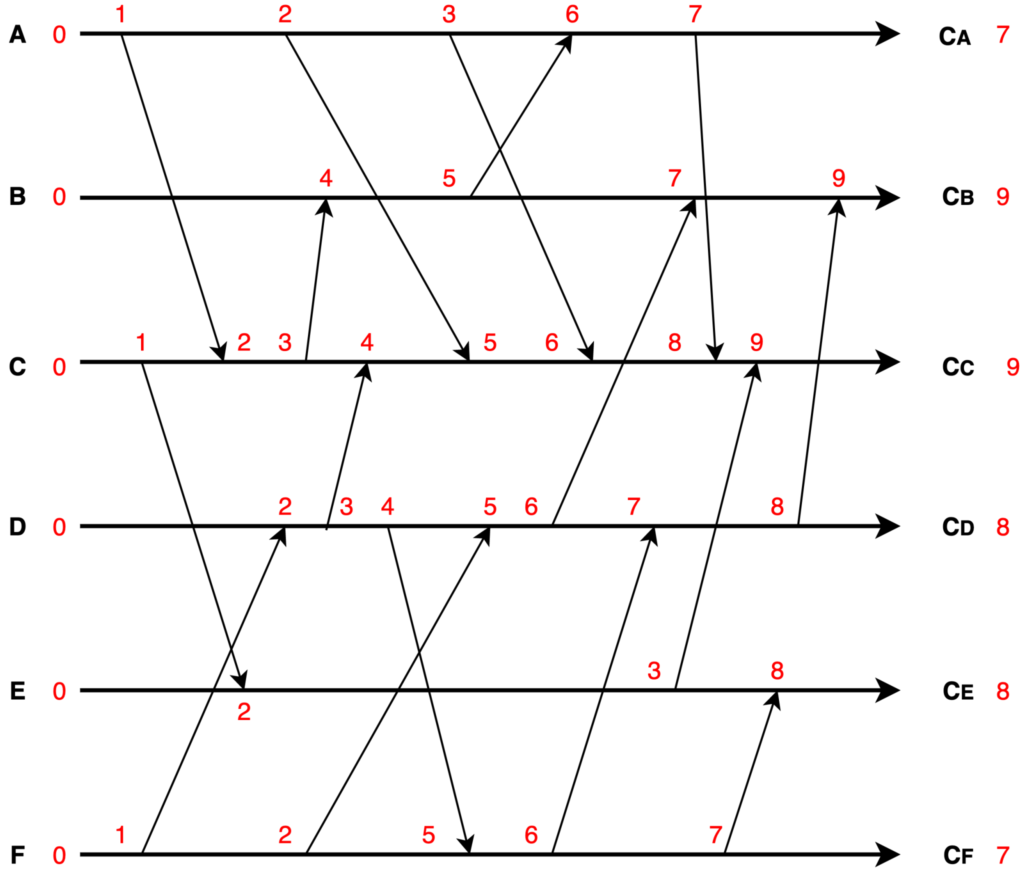
D 0 2 3 4 5 6 7 8 CD 8
E 0 1 5 6 7 CE 7
F 0 1 2 3 4 7 CF 7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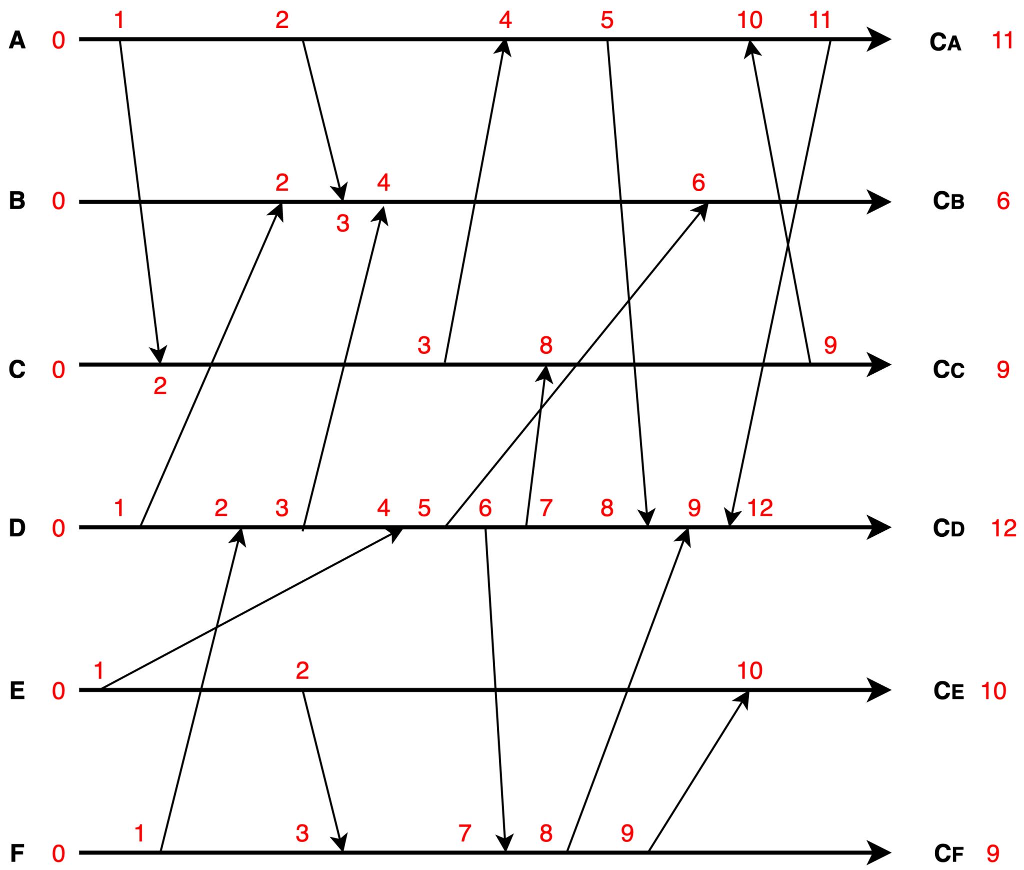
B 0 4 5 7 9 CB 9
C 0 1 2 3 4 5 6 8 9 CC 9
D 0 2 3 4 5 6 7 8 CD 8
E 0 2 3 8 CE 8
F 0 1 2 5 6 7 CF 7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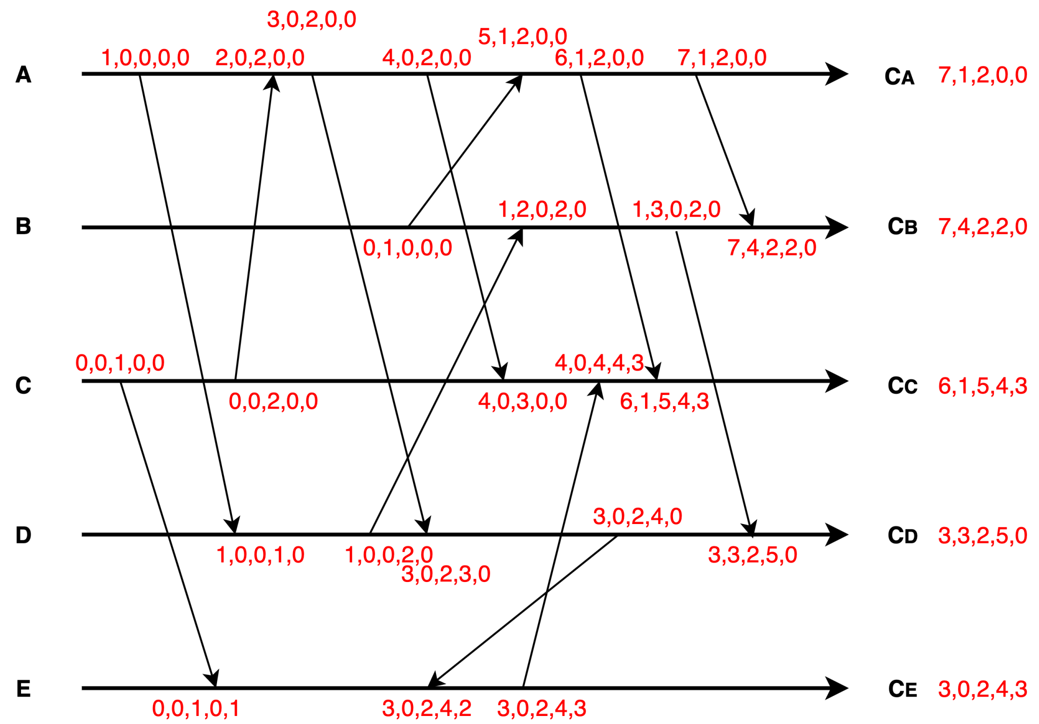
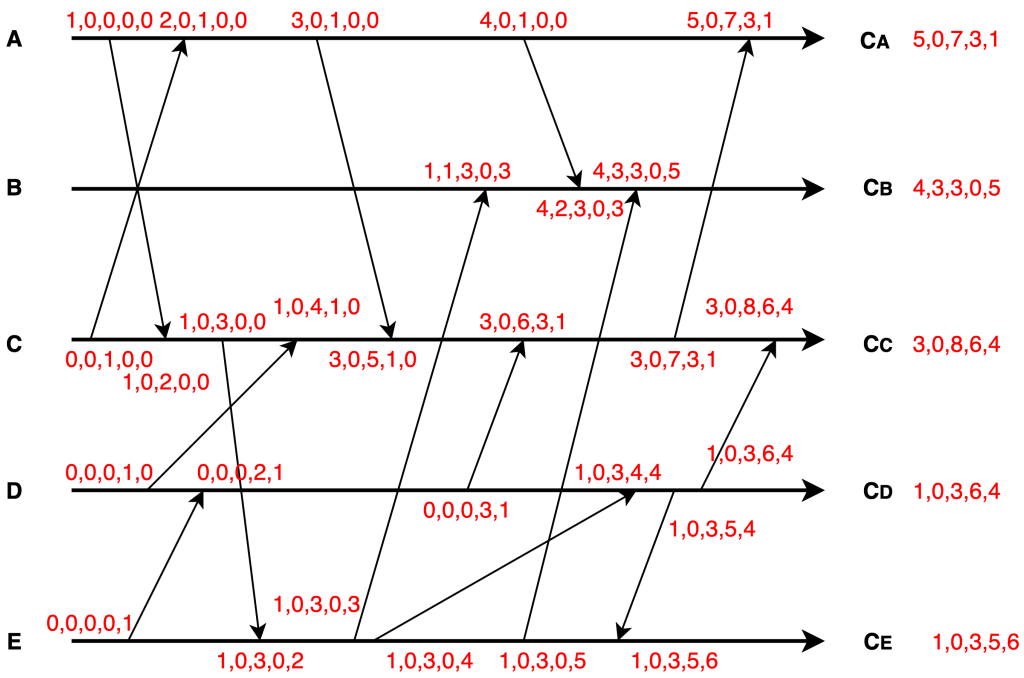
B 0 2 3 4 6 CB 6
C 0 2 3 8 9 CC 9
D 0 1 2 3 4 5 6 7 8 9 12 CD 12
E 0 1 2 10 CE 10
F 0 1 3 7 8 9 CF 9

Problem 2 Vector Clock (12.5 credits)

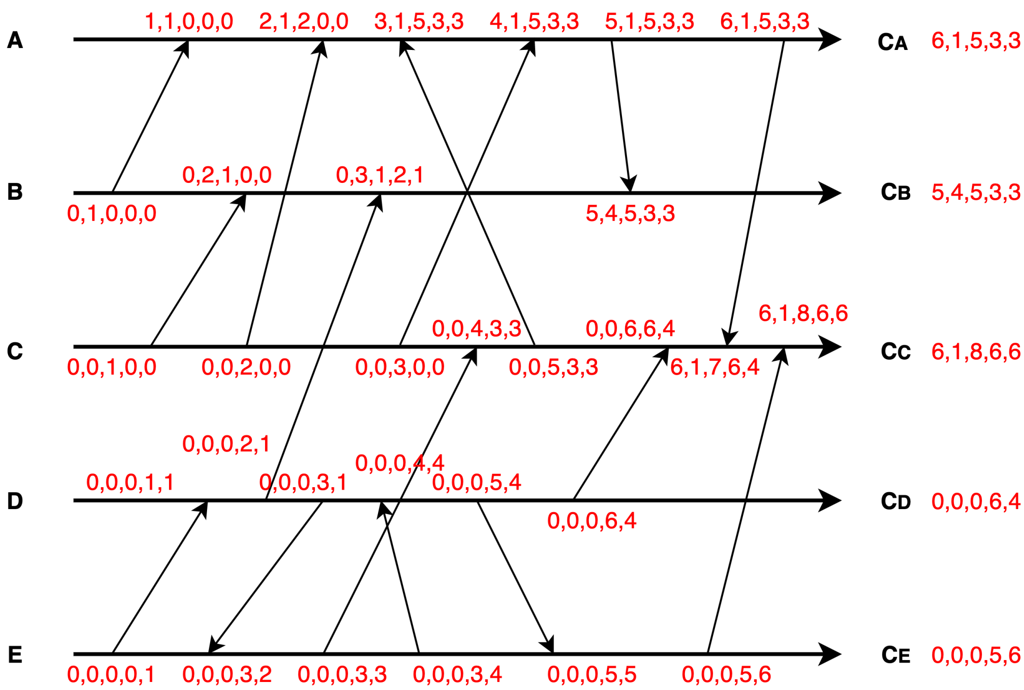
For each process $p_i \in \{A, B, C, D, E\}$ determine the logical time ($\{C_A, C_B, C_C, C_D, C_E\}$) at the **end** of the time/event diagram according to the **Vector Clock** algorithm. Write the final value of clocks in the table below.

Solution: All variations included in the exam:
Each wrong element in the vector -0.5.





A
B
C
D
E
1,0,0,0,0
2,0,1,0,0
3,0,1,0,0
4,0,1,0,0
5,0,7,3,1
1,1,3,0,3
4,3,3,0,5
4,2,3,0,3
1,0,3,0,0
1,0,4,1,0
3,0,6,3,1
3,0,8,6,4
0,0,1,0,0
1,0,2,0,0
3,0,5,1,0
3,0,7,3,1
0,0,0,1,0
0,0,0,2,1
1,0,3,4,4
1,0,3,6,4
0,0,0,3,1
1,0,3,5,4
0,0,0,0,1
1,0,3,0,3
1,0,3,0,2
1,0,3,0,4
1,0,3,0,5
1,0,3,5,6
CA 5,0,7,3,1
CB 4,3,3,0,5
CC 3,0,8,6,4
CD 1,0,3,6,4
CE 1,0,3,5,6



A
B
C
D
E
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3,1,5,3,3
4,1,5,3,3
5,1,5,3,3
6,1,5,3,3
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0,3,1,2,1
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0,0,4,3,3
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6,1,8,6,6
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0,0,2,0,0
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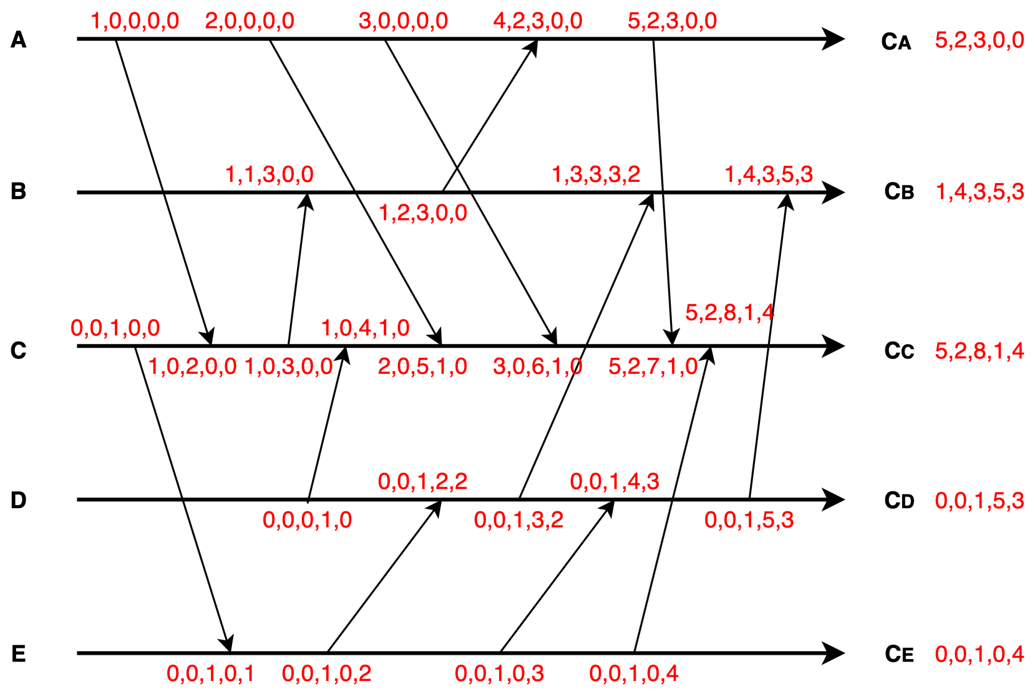
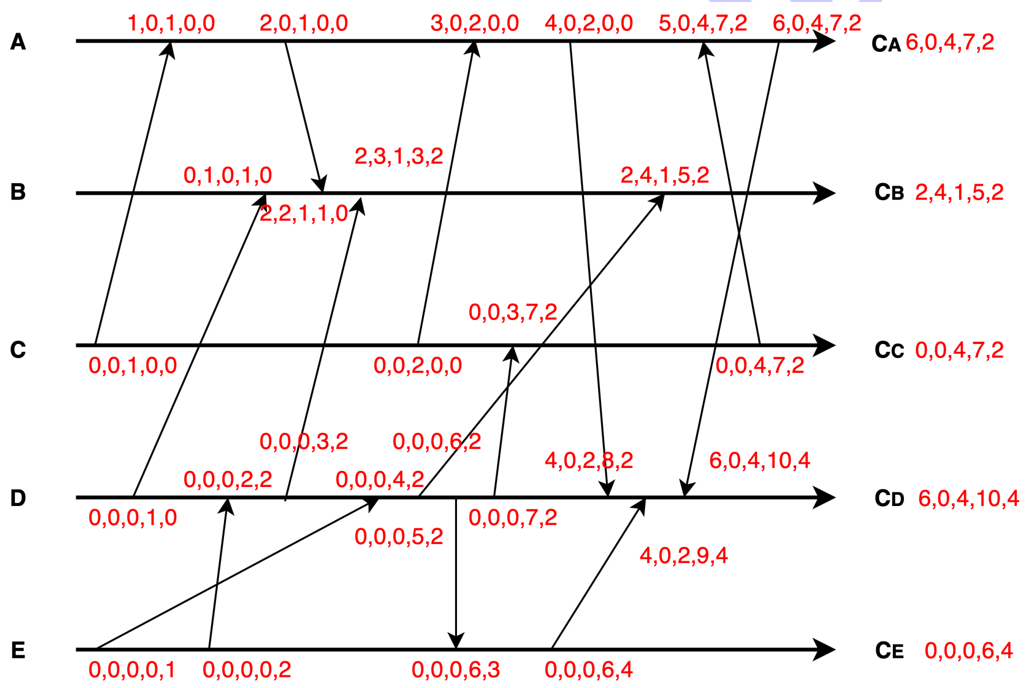
6,1,7,6,4
0,0,0,2,1
0,0,0,4,4
0,0,0,1,1
0,0,0,3,1
0,0,0,5,4
0,0,0,6,4
0,0,0,0,1
0,0,0,3,2
0,0,0,3,3
0,0,0,3,4
0,0,0,5,5
0,0,0,5,6
CA 6,1,5,3,3
CB 5,4,5,3,3
CC 6,1,8,6,6
CD 0,0,0,6,4
CE 0,0,0,5,6


A
1,0,0,0,0
2,0,0,0,0
3,0,0,0,0
4,2,3,0,0
5,2,3,0,0
CA 5,2,3,0,0
B
1,1,3,0,0
1,2,3,0,0
1,3,3,3,2
1,4,3,5,3
CB 1,4,3,5,3
C
0,0,1,0,0
1,0,2,0,0
1,0,3,0,0
1,0,4,1,0
2,0,5,1,0
3,0,6,1,0
5,2,7,1,0
5,2,8,1,4
CC 5,2,8,1,4
D
0,0,0,1,0
0,0,1,2,2
0,0,1,3,2
0,0,1,4,3
0,0,1,5,3
CD 0,0,1,5,3
E
0,0,1,0,1
0,0,1,0,2
0,0,1,0,3
0,0,1,0,4
CE 0,0,1,0,4


A
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3,0,2,0,0
4,0,2,0,0
5,0,4,7,2
6,0,4,7,2
CA 6,0,4,7,2
B
0,1,0,1,0
2,2,1,1,0
2,3,1,3,2
2,4,1,5,2
CB 2,4,1,5,2
C
0,0,1,0,0
0,0,2,0,0
0,0,3,7,2
0,0,4,7,2
CC 0,0,4,7,2
D
0,0,0,1,0
0,0,0,2,2
0,0,0,3,2
0,0,0,4,2
0,0,0,5,2
0,0,0,6,2
0,0,0,7,2
4,0,2,8,2
4,0,2,9,4
6,0,4,10,4
CD 6,0,4,10,4
E
0,0,0,0,1
0,0,0,0,2
0,0,0,6,3
0,0,0,6,4
CE 0,0,0,6,4

Problem 3 Consistency Models (17 credits)

Consider the execution depicted in the figure below and answer the following questions.

a) Is the execution **sequentially consistent** (Yes/No)? If Yes, give **complete** and valid execution sequence. If No, give an explanation.

b) Is it **causally consistent** (Yes/No)? If Yes, give **complete** and valid execution sequences for P_2, P_4, P_6. If No, give an explanation.

Solution: All variations included in the exam:
For Problem a, the correct sequence 5 points. Half correct 2.5 points. All wrong 0 points.
For Problem b, each correct sequence 4 points. Half correct 2 points. All wrong 0 points.

P_1	W_1(X)a	R1(Z)d	R1(Z)h	W_1(Y)k
P_2	W2(Y)c	W2(X)f	W2(X)j	R2(Y)k
P_3	R3(Z)d	W3(Y)g	R3(Y)g	R3(X)j
P_4	R4(X)a	W4(Z)e	W4(Z)h	R4(X)j
P_5	W5(z)d	R5(X)f	R5(X)j	R5(Y)k
P_6	R6(Y)c	R6(Z)d	R6(Y)g	W6(Z)m

Time →

Problem a, Yes sequentially consistent:
W1(X)a R4(X)a W2(Y)c R6(Y)c W5(Z)d R3(Z)d | R1(Z)d R6(Z)d W2(X)f R5(X)f W4(Z)e W3(Y)g | R3(Y)g R6(Y)g W4(Z)h R1(Z)h W2(X)j R5(X)j | R3(X)j R4(X)j W1(Y)k R2(Y)k R5(Y)k W6(Z)m

Problem b, Yes causally consistent:

P2: W1(X)a W2(Y)c W5(Z)d | W2(X)f W4(Z)e W3(Y)g | W4(Z)h W2(X)j | W1(Y)k R2(Y)k W6(Z)m

P4: W1(X)a R4(X)a W2(Y)c W5(Z)d | W2(X)f W4(Z)e W3(Y)g | W4(Z)h W2(X)j | R4(X)j W1(Y)k W6(Z)m

P6: W1(X)a W2(Y)c R6(Y)c W5(Z)d | R6(Z)d W2(X)f W4(Z)e W3(Y)g | R6(Y)g W4(Z)h W2(X)j | W1(Y)k W6(Z)m

P_1	W1(Y)c	W1(X)f	W1(X)j	R1(Y)k
P_2	R2(Z)d	W2(Y)g	R2(Y)g	R2(X)j
P_3	R3(X)a	W3(Z)e	W3(Z)h	R3(X)j
P_4	W4(z)d	R4(X)f	R4(X)j	R4(Y)k
P_5	R5(Y)c	R5(Z)d	R5(Y)g	W5(Z)n
P_6	W6(X)a	R6(Z)d	R6(Z)h	W6(Y)k

Time $\longrightarrow$

Problem a, Yes sequentially consistent:

W6(X)a R3(X)a W1(Y)c R5(Y)c W4(Z)d R2(Z)d | R6(Z)d R5(Z)d W1(X)f R4(X)f W3(Z)e W2(Y)g | R2(Y)g R5(Y)g W3(Z)h R6(Z)h W1(X)j R4(X)j | R2(X)j R3(X)j W5(Y)k R1(Y)k R4(Y)k W5(Z)n

P2: W6(X)a W1(Y)c W4(Z)d R2(Z)d | W1(X)f W3(Z)e W2(Y)g | R2(Y)g W3(Z)h W1(X)j | R2(X)j W5(Y)k W5(Z)n

P4: W6(X)a W1(Y)c W4(Z)d | W1(X)f R4(X)f W3(Z)e W2(Y)g | W3(Z)h W1(X)j R4(X)j | W5(Y)k R4(Y)k W5(Z)n

P6: W6(X)a W1(Y)c W4(Z)d | R6(Z)d W1(X)f W3(Z)e W2(Y)g | W3(Z)h R6(Z)h W1(X)j | W5(Y)k W5(Z)n

P_1	R1(Z)d	W1(Y)g	R1(Y)g	R1(X)j
P_2	R2(X)a	W2(Z)e	W2(Z)h	R2(X)j
P_3	W3(z)d	R3(X)f	R3(X)j	R3(Y)k
P_4	R4(Y)c	R4(Z)d	R4(Y)g	W4(Z)o
P_5	W5(X)a	R5(Z)d	R5(Z)h	W5(Y)k
P_6	W6(Y)c	W6(X)f	W6(X)j	R6(Y)k

Time ⟶

Problem a, Yes sequentially consistent:

W5(X)a R2(X)a W6(Y)c R4(Y)c W3(Z)d R1(Z)d | R5(Z)d R4(Z)d W6(X)f R3(X)f W2(Z)e W1(Y)g | R1(Y)g R4(Y)g W2(Z)h R5(Z)h W6(X)j R3(X)j | R1(X)j R2(X)j W4(Y)k R6(Y)k R3(Y)k W4(Z)o

P2: W5(X)a R2(X)a W6(Y)c W3(Z)d | W6(X)f W2(Z)e W1(Y)g | W2(Z)h W6(X)j | R2(X)j W4(Y)k W4(Z)o

P4: W5(X)a W6(Y)c R4(Y)c W3(Z)d | R4(Z)d W6(X)f W2(Z)e W1(Y)g | R4(Y)g W2(Z)h W6(X)j | W4(Y)k W4(Z)o

P6: W5(X)a W6(Y)c W3(Z)d | W6(X)f W2(Z)e W1(Y)g | W2(Z)h W6(X)j | W4(Y)k R6(Y)k W4(Z)o

P_1	R1(X)a	W1(Z)e	W1(Z)h	R1(X)j
P_2	W2(z)d	R2(X)f	R2(X)j	R2(Y)k
P_3	R3(Y)c	R3(Z)d	R3(Y)g	W3(Z)p
P_4	W4(X)a	R4(Z)d	R4(Z)h	W4(Y)k
P_5	W5(Y)c	W5(X)f	W5(X)j	R5(Y)k
P_6	R6(Z)d	W6(Y)g	R6(Y)g	R6(X)j

Time ⟶

Problem a, Yes sequentially consistent:

W4(X)a R1(X)a W5(Y)c R3(Y)c W2(Z)d R6(Z)d | R4(Z)d R3(Z)d W5(X)f R2(X)f W1(Z)e W6(Y)g | R6(Y)g R3(Y)g W1(Z)h R4(Z)h W5(X)j R2(X)j | R6(X)j R1(X)j W3(Y)k R5(Y)k R2(Y)k W3(Z)p

P2: W4(X)a W5(Y)c W2(Z)d | W5(X)f R2(X)f W1(Z)e W6(Y)g | W1(Z)h W5(X)j R2(X)j | W3(Y)k R2(Y)k W3(Z)p

P4: W4(X)a W5(Y)c W2(Z)d | R4(Z)d W5(X)f W1(Z)e W6(Y)g | W1(Z)h R4(Z)h W5(X)j | W3(Y)k W3(Z)p

P6: W4(X)a W5(Y)c W2(Z)d | W5(X)f W1(Z)e W6(Y)g | R6(Y)g W1(Z)h h W5(X)j | R6(X)j W3(Y)k W3(Z)p

P_1	W1(z)d	R1(X)f	R1(X)j	R1(Y)k
P_2	R2(Y)c	R2(Z)d	R2(Y)g	W2(Z)q
P_3	W3(X)a	R3(Z)d	R3(Z)h	W3(Y)k
P_4	W4(Y)c	W4(X)f	W4(X)j	R4(Y)k
P_5	R5(Z)d	W5(Y)g	R5(Y)g	R5(X)j
P_6	R6(X)a	W6(Z)e	W6(Z)h	R6(X)j

Time ⟶

Problem a, Yes sequentially consistent:

W3(X)a R6(X)a W4(Y)c R2(Y)c W1(Z)d R5(Z)d | R3(Z)d R2(Z)d W4(X)f R1(X)f W6(Z)e W5(Y)g | R5(Y)g R2(Y)g W6(Z)h R3(Z)h W4(X)j R1(X)j | R5(X)j R6(X)j W2(Y)k R4(Y)k R1(Y)k W2(Z)q

P2: W3(X)a W4(Y)c R2(Y)c W1(Z)d | R2(Z)d W4(X)f W6(Z)e W5(Y)g | R2(Y)g W6(Z)h W4(X)j | W2(Y)k W2(Z)q

P4: W3(X)a W4(Y)c W1(Z)d | W4(X)f W6(Z)e W5(Y)g | W6(Z)h W4(X)j | W2(Y)k R4(Y)k W2(Z)q

P6: W3(X)a R6(X)a W4(Y)c W1(Z)d | W4(X)f W6(Z)e W5(Y)g | W6(Z)h W4(X)j | R6(X)j W2(Y)k W2(Z)q

Problem 4 Gossip-based Replication (22.5 credits)

Figure 4.1 shows lazy replication over a Gossip protocol. In Gossip architecture, messages (gossip) between servers are periodically exchanged to store data over a set of replicas redundantly. Clients can issue (1) write requests (update) and (2) read requests (query). In order to provide consistency, the clients and replicas keep track of clocks, $clock_c$ and $clock_{rep}$, where $clock_c$ is the client clock and $clock_{rep}$ is the replica clock.

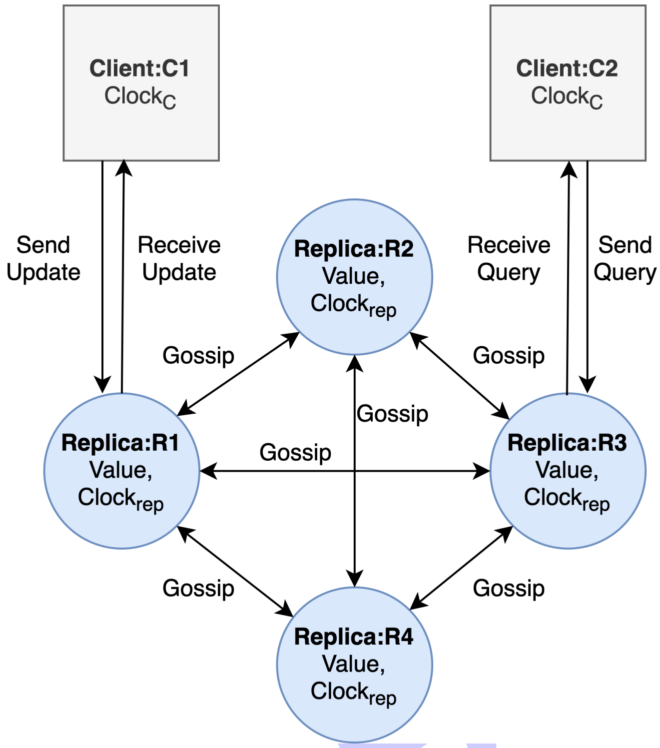

Figure 4.1: Gossip-based Replication

a) Assume you are asked to integrate replication to a system for collaboratively working on a shared document in real-time. Would you use the gossip-based replication? If yes, give a short motivation for your answer. If no, suggest an appropriate replication scheme discussed in the lecture and provide a short motivation for your answer.
Solution: Due to the lazy propagation of updates, a gossip-based system is inappropriate for updating replicas in near-real-time. A multicast-based system would be more appropriate for that scenario as update latencies are shorter (2 points for correct answer and justification). Such replication schemes are either active replication or passive replication with primary backup (1.5 points for mentioning a possible better scheme).

0 1 2 3

b) Which level of consistency does the Gossip protocol implement (name the consistency model)? Briefly describe how this level of consistency is achieved with the help of timestamps (Give a short example).
Solution: The gossip protocol is causally consistent (2 points). The data, which is retrieved by the client, is not always up-to-date. However, causal consistency guarantees that updates, which are causally related, are always applied in the right order. For example, if a client issued an update Update2, which was calculated based on a value contained in updated Update1 (and TimestampUpdate1 < TimestampUpdate2), then Update2 should never be applied before Update1 (i.e., all clients see this order). (2 points for explanation or example)

0 1 2 3 4

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

c) The following messages are exchanged between the processes. Iterate through the steps manually and fill in the table provided below.
Solution: All variations included in the exam:

Each correct column 3, half complete 1.5 points, otherwise 0.

1. C2 sends update U1(Blue) to R3
2. C1 sends update U2(Red) to R2
3. C1 sends query Q1 to R1
4. C2 sends query Q2 to R4
5. R3 sends gossip G1 to R4

		Initial	1	2	3	4	5
Client C_1	$Clock_c$	[0, 0, 0, 0]		[0,1,0,0]			
Client C_2	$Clock_c$	[0, 0, 0, 0]	[0,0,1,0]				[0,0,1,0]
Replica R_1	Value	-					
	$Clock_{rep}$	[0, 0, 0, 0]					
	Pending	$\emptyset$			Q<1, [0,1,0,0] >		
Replica R_2	Value	0		Red			
	$Clock_{rep}$	[0, 0, 0, 0]		[0,1,0,0]			
	Pending	$\emptyset$					
Replica R_3	Value	-	Blue				
	$Clock_{rep}$	[0, 0, 0, 0]	[0,0,1,0]				
	Pending	$\emptyset$					
Replica R_4	Value	-					Blue
	$Clock_{rep}$	[0, 0, 0, 0]					[0,0,1,0]
	Pending	$\emptyset$				Q<2, [0,0,1,0] >	0

1. C1 sends update U1(Yellow) to R2
2. C2 sends update U2(Red) to R4
3. C2 sends query Q1 to R3
4. C1 sends query Q2 to R1
5. R2 sends gossip G1 to R3

		Initial	1	2	3	4	5
Client C_1	$Clock_c$	[0, 0, 0, 0]	[0,1,0,0]				
Client C_2	$Clock_c$	[0, 0, 0, 0]		[0,0,0,1]			
Replica R_1	Value	-					
	$Clock_{rep}$	[0, 0, 0, 0]					
	Pending	$\emptyset$				Q<2,[0,1,0,0] >	
Replica R_2	Value	0	Yellow				
	$Clock_{rep}$	[0, 0, 0, 0]	[0,1,0,0]				
	Pending	$\emptyset$					
Replica R_3	Value	-					Yellow
	$Clock_{rep}$	[0, 0, 0, 0]					[0,1,0,0]
	Pending	$\emptyset$			Q<1,[0,0,0,1] >		Q<1,[0,0,0,1] >
Replica R_4	Value	-		Red			
	$Clock_{rep}$	[0, 0, 0, 0]		[0,0,0,1]			
	Pending	$\emptyset$					

1. C1 sends update U1(Purple) to R1
2. C2 sends update U2(Blue) to R4
3. C1 sends query Q1 to R3
4. C1 sends query Q2 to R2
5. R1 sends gossip G1 to R3

		Initial	1	2	3	4	5
Client C_1	$Clock_c$	[0, 0, 0, 0]	[1,0,0,0]				[1,0,0,0]
Client C_2	$Clock_c$	[0, 0, 0, 0]		[0,0,0,1]			
Replica R_1	Value	-	Purple				
	$Clock_{rep}$	[0, 0, 0, 0]	[1,0,0,0]				
	Pending	$\emptyset$					
Replica R_2	Value	0					
	$Clock_{rep}$	[0, 0, 0, 0]					
	Pending	$\emptyset$				Q<2,[1,0,0,0] >	
Replica R_3	Value	-					Purple
	$Clock_{rep}$	[0, 0, 0, 0]					[1,0,0,0]
	Pending	$\emptyset$			Q<1,[1,0,0,0] >		0
Replica R_4	Value	-		Blue			
	$Clock_{rep}$	[0, 0, 0, 0]		[0,0,0,1]			
	Pending	$\emptyset$					

1. C1 sends update U1(Red) to R2
2. C2 sends update U2(Yellow) to R3
3. C2 sends query Q1 to R1
4. C2 sends query Q2 to R4
5. R2 sends gossip G1 to R1

		Initial	1	2	3	4	5
Client C_1	$Clock_c$	[0, 0, 0, 0]	[0,1,0,0]				
Client C_2	$Clock_c$	[0, 0, 0, 0]		[0,0,1,0]			
Replica R_1	Value	-					Red
	$Clock_{rep}$	[0, 0, 0, 0]					[0,1,0,0]
	Pending	$\emptyset$			Q<1,[0,0,1,0] >		Q<1,[0,0,1,0] >
Replica R_2	Value	0	Red				
	$Clock_{rep}$	[0, 0, 0, 0]	[0,1,0,0]				
	Pending	$\emptyset$					
Replica R_3	Value	-		Yellow			
	$Clock_{rep}$	[0, 0, 0, 0]		[0,0,1,0]			
	Pending	$\emptyset$					
Replica R_4	Value	-					
	$Clock_{rep}$	[0, 0, 0, 0]					
	Pending	$\emptyset$				Q<2,[0,0,1,0] >	

1. C2 sends update U1(Orange) to R4
2. C1 sends update U2(Green) to R1
3. C1 sends query Q1 to R2
4. C2 sends query Q2 to R3
5. R4 sends gossip G1 to R2

		Initial	1	2	3	4	5
Client C_1	$Clock_c$	[0, 0, 0, 0]		[1,0,0,0]			
Client C_2	$Clock_c$	[0, 0, 0, 0]	[0,0,0,1]				
Replica R_1	Value	-		Green			
	$Clock_{rep}$	[0, 0, 0, 0]		[1,0,0,0]			
	Pending	$\emptyset$					
Replica R_2	Value	0					Orange
	$Clock_{rep}$	[0, 0, 0, 0]					[0,0,0,1]
	Pending	$\emptyset$			Q<1,[1,0,0,0]>		Q<1,[1,0,0,0]>
Replica R_3	Value	-					
	$Clock_{rep}$	[0, 0, 0, 0]					
	Pending	$\emptyset$				Q<2,[0,0,0,1]>	
Replica R_4	Value	-	Orange				
	$Clock_{rep}$	[0, 0, 0, 0]	[0,0,0,1]				
	Pending	$\emptyset$					

Problem 5 Erasure Coding (12 credits)

Consider a distributed data storage consisting of a cluster of several storage servers. To be able to recover corrupted data, we use *Reed-Solomon Encoding* for sharding the data. Each shared is stored on a different server. Assume that every data is divided into **4 shards**, and we can recover up to **3 shards**.

While querying the string below, we realized that some shards are corrupted (The corrupted parts are marked with underscores (_), which has an ASCII value of 95). Construct the original string with the following assumptions (the string is case sensitive):

- Matrix Calculator (or any other calculator of your choice): https://matrixcalc.org/en/
- String to ASCII Converter: https://onlinestringtools.com/convert-string-to-ascii
- ASCII Table: http://www.asciitable.com/

4 points for each correctly calculated missing char or ASCII value, otherwise 0.
6 points if answer is correct and no solution is showed.

All variations included in the exam:

Solution : El candidato art
69 108 32 99 97 110 100 105 100 97 116 111 32 97 114 116

Solution : Esperamos public
69 115 112 101 114 97 109 111 115 32 112 117 98 108 105 99

Solution : Los inestigadora
76 111 115 32 105 110 101 115 116 105 103 97 100 111 114 97

Solution : Pfizer y BioNTec
80 102 105 122 101 114 32 121 32 66 105 111 78 84 101 99

Solution : Estamos dedicado
69 115 116 97 109 111 115 32 100 101 100 105 99 97 100 111

Problem 6 Peer-To-Peer Systems (12 credits)

Consider the Pastry network, where every node ID $\in \{0, 1, 2, 3, 4, 5\}^6$ and contains the following nodes:

{ 002124, 012312, 111324, 112553, 120150, 122140, 140531, 144545, 202043, 205103, 211000, 211230, 221511, 222454, 223525, 224123, 225355, 225521, 230234, 233424, 235014, 240050, 240253, 240302, 242510, 243330, 244514, 245305, 250541, 251310, 251540, 300231, 314411, 335550, 405302, 405542, 413515, 420501, 422002, 424320, 424414, 443023, 444514, 514332, 551154 }

0 1 2 3 4 5 6 7 8 9

a) Complete the routing table of node **242510** in the table below:

Solution: All variations included in the exam:

Each wrong answer -0.5 until reach 0.

Table 6.1: Routing Table for **202043**

RT	0	1	2	3	4	5
0	002124	112553	**202043**	300231	413515	514332
1	**202043**	211230	222454	235014	240050	250541
2	-	-	**202043**	-	-	205103
3	**202043**	-	-	-	-	-
4	-	-	-	-	**202043**	-
5	-	-	-	**202043**	-	-

Table 6.2: Routing Table for **211230**

RT	0	1	2	3	4	5
0	002124	112553	**211230**	300231	413515	514332
1	202043	**211230**	223525	230234	240050	250541
2	-	**211230**	-	-	-	-
3	211000	-	**211230**	-	-	-
4	-	-	-	**211230**	-	-
5	**211230**	-	-	-	-	-

Table 6.3: Routing Table for **225355**

RT	0	1	2	3	4	5
0	002124	112553	**225355**	300231	413515	514332
1	205103	211230	**225355**	230234	240253	251310
2	-	221511	222454	223525	224123	**225355**
3	-	-	-	**225355**	-	225521
4	-	-	-	-	-	**225355**
5	-	-	-	-	-	**225355**

Table 6.4: Routing Table for **233424**

RT	0	1	2	3	4	5
0	002124	112553	**233424**	300231	413515	514332
1	205103	211230	225355	**233424**	245305	250541
2	230234	-	-	**233424**	-	235014
3	-	-	-	-	**233424**	-
4	-	-	**233424**	-	-	-
5	-	-	-	-	**233424**	-

Table 6.5: Routing Table for **242510**

RT	0	1	2	3	4	5
0	002124	112553	**242510**	300231	413515	514332
1	202043	211000	221511	230234	**242510**	250541
2	240302	-	**242510**	243330	244514	245305
3	-	-	-	-	-	**242510**
4	-	**242510**	-	-	-	-
5	**242510**	-	-	-	-	-

0
1
2
3

b) Provided that the leaf-set has a size of **6**, give the leaf set of node **242510**:
Complete list 3 points, otherwise 0..
Solution: All variations included in the exam:

LF 202043 = { 122140, 140531, 144545, 205103, 211000, 211230 }

LF 211230 = { 202043, 205103, 211000, 221511, 222454, 223525 }

LF 225355 = { 222454, 223525, 224123, 225521, 230234, 233424 }

LF 233424 = { 225355, 225521, 230234, 235014, 240050, 240253 }

LF 242510 = { 240050, 240253, 240302, 243330, 244514, 245305 }

Problem 7 Publish/Subscribe (12 credits)

Consider an overlay broker network based on a **subscription-based** routing model, containing 8 brokers, as demonstrated in the figure below. Each broker maintains a Publication Routing Table (PRT) and subscription covering **is enabled**.

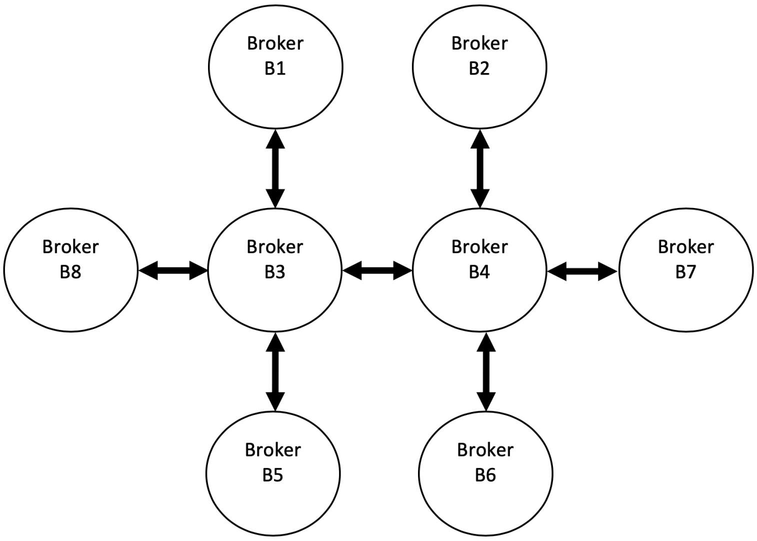

Figure 7.1: Broker overlay

Assume that we have several subscribers in the network, which can subscribe to any brokers. Subscribers issue the following subscriptions. Update the PRT table of brokers in the tables below.

1. $S2$ connects to $B4$ and subscribes to $[l, =, MUC], [temp, >, 30]$
2. $S4$ connects to $B1$ and subscribes to $[t, =, FILM], [r, <, 5]$
3. $S8$ connects to $B5$ and subscribes to $[t, =, FILM], [r, > 10]$
4. $S2$ connects to $B8$ and subscribes to $[l, =, MUC], [temp, >, 20]$
5. $S1$ connects to $B7$ and subscribes to $[t, =, FILM], [r, <, 7]$
6. $S4$ connects to $B3$ and subscribes to $[l, =, MUC], [temp, >, 10]$

Solution: All variations included in the exam:
Each correct cell 0.5 otherwise 0 points.

Table 7.1: PRT of Broker **B1**

$[l, =, MUC], [temp, >, 30]$	B3
$[t, =, FILM], [r, <, 5]$	S4
$[t, =, FILM], [r, > 10]$	B3
$[l, =, MUC], [temp, >, 20]$	B3
$[t, =, FILM], [r, <, 7]$	B3
$[l, =, MUC], [temp, >, 10]$	B3

Table 7.2: PRT of Broker **B2**

$[l, =, MUC], [temp, >, 30]$	B4
$[t, =, FILM], [r, <, 5]$	B4
$[t, =, FILM], [r, > 10]$	B4
$[l, =, MUC], [temp, >, 20]$	B4
$[t, =, FILM], [r, <, 7]$	B4
$[l, =, MUC], [temp, >, 10]$	B4

Table 7.3: PRT of Broker **B3**

$[l, =, MUC], [temp, >, 30]$	B4
$[t, =, FILM], [r, <, 5]$	B1
$[t, =, FILM], [r, > 10]$	B5
$[l, =, MUC], [temp, >, 20]$	B8
$[t, =, FILM], [r, <, 7]$	B4
$[l, =, MUC], [temp, >, 10]$	S4

Table 7.4: PRT of Broker **B4**

$[l, =, MUC], [temp, >, 30]$	S2
$[t, =, FILM], [r, <, 5]$	B3
$[t, =, FILM], [r, > 10]$	B3
$[l, =, MUC], [temp, >, 20]$	B3
$[t, =, FILM], [r, <, 7]$	B7
$[l, =, MUC], [temp, >, 10]$	B3

Table 7.5: PRT of Broker **B5**

$[l, =, MUC], [temp, >, 30]$	B3
$[t, =, FILM], [r, <, 5]$	B3
$[t, =, FILM], [r, > 10]$	S8
$[l, =, MUC], [temp, >, 20]$	B3
$[t, =, FILM], [r, <, 7]$	B3
$[l, =, MUC], [temp, >, 10]$	B3

Table 7.6: PRT of Broker **B6**

$[l, =, MUC], [temp, >, 30]$	B4
$>, 20]$ $[t, =, FILM], [r, <, 5]$	B4
$[t, =, FILM], [r, > 10]$	B4
$[l, =, MUC], [temp, >, 20]$	B4
$[t, =, FILM], [r, <, 7]$	B4
$[l, =, MUC], [temp, >, 10]$	B4

Table 7.7: PRT of Broker **B7**

$[l, =, MUC], [temp, >, 30]$	B4
$[t, =, FILM], [r, <, 5]$	B4
$[t, =, FILM], [r, > 10]$	B4
$[l, =, MUC], [temp, >, 20]$	B4
$[t, =, FILM], [r, <, 7]$	S1
$[l, =, MUC], [temp, >, 10]$	B4

Table 7.8: PRT of Broker **B8**

$[l, =, MUC], [temp, >, 30]$	B3
$[t, =, FILM], [r, <, 5]$	B3
$[t, =, FILM], [r, > 10]$	B3
$[l, =, MUC], [temp, >, 20]$	S2
$[t, =, FILM], [r, <, 7]$	B3
$[l, =, MUC], [temp, >, 10]$	B3

Additional space for solutions–clearly mark the (sub)problem your answers are related to and strike out invalid solutions.