The Paxos Register

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The University of Texas at Austin

Consensus & Paxos

- Validity
- Integrity
- Agreement
- Termination

Consensus & Paxos

Part-time Parliament [Lamport '98]

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Consensus & Paxos

Part-time Parliament [Lamport '98]

Safety

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Liveness

Consensus & Paxos

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Frangipani [Thekkath et al. '97]

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Byzantine Paxos [Castro & Liskov '99]

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Fast Paxos	[Lamport '05]
Hybrid Quorums	[Cowling et al. '06]
Chubby	[Burrows '06]
Zyzzyva	[Kotla et al. '07]

What Makes Paxos Paxos?

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- Guarantee safety
- Provide liveness during periods of synchrony
- Use leaders to coordinate quorums

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Is that it?

Understanding Paxos

Abstract Paxos	[Lampson '01]
◇Register & ◇Leader	[Boichat et al. '01]
Ranked Register	[Chockler & Malkhi '05]
Alpha of Indulgent Consensus	[Guerraoui & Raynal '07]

Understanding Paxos

Crash and Byzantine

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Register-based

No register-based description encompassing both crash and Byzantine variants

Paxos Register

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read ⟶ write

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- Describes Classic, Byzantine, and FaB Paxos
- Leads to Byzantine Paxos using secret sharing

Outline

- Motivation
- Paxos Register specification
- Crash implementation
- Byzantine implementation

Consensus & Paxos Register

world time ⟶

Consensus & Paxos Register

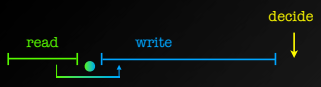
read

world time ⟶

Consensus & Paxos Register

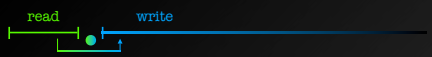
world time

Consensus & Paxos Register



world time

Consensus & Paxos Register



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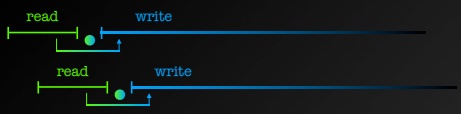

world time

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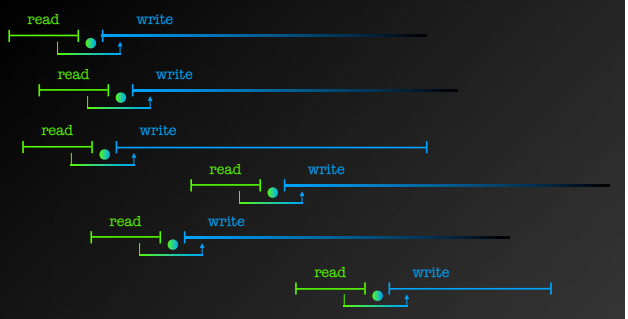

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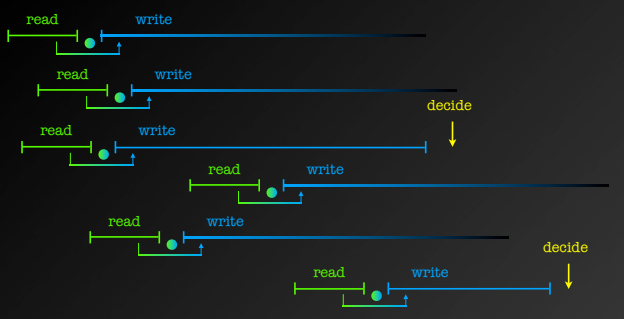

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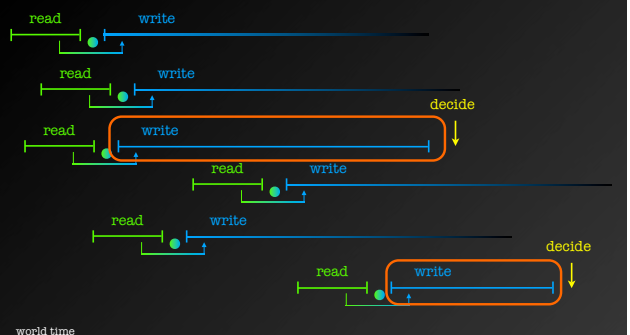

Details

world time

Details

read
token (v=⊥, ts=0)

world time

Details

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token (v=⊥, ts=0)

write
v=a, token = (⊥,0)

write starts as partial

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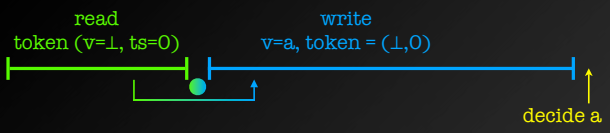

write starts as partial
partial write may become visible
visible write may become total

world time

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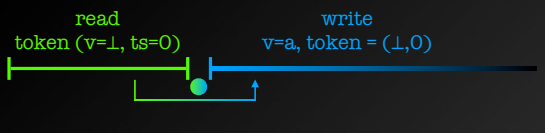

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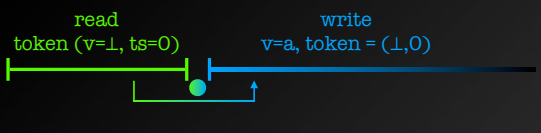

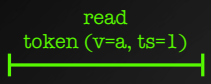

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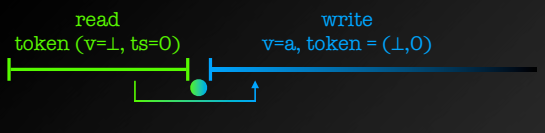

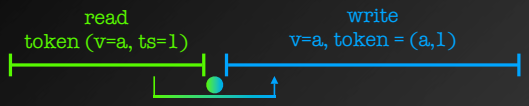

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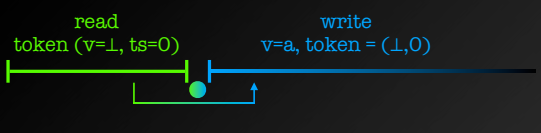

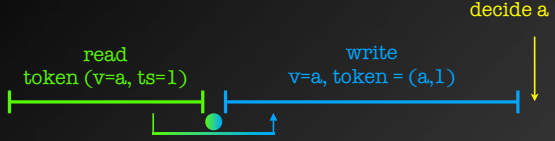

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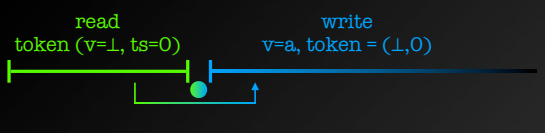

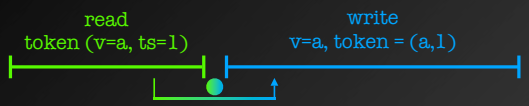

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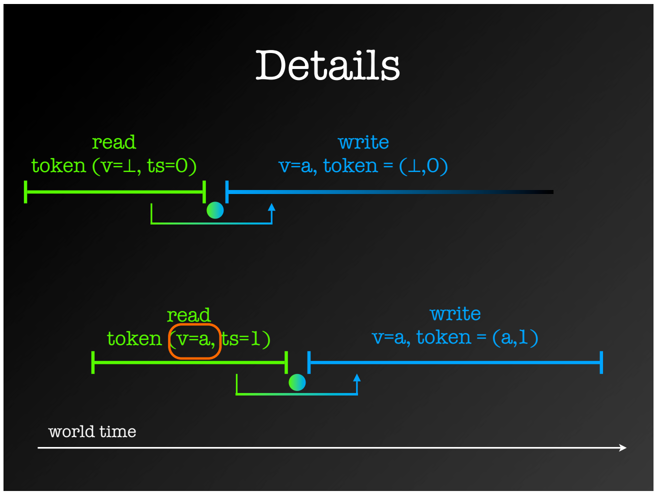

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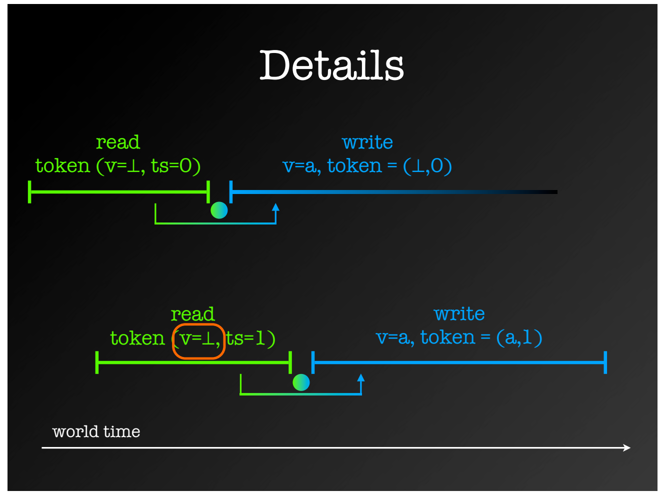

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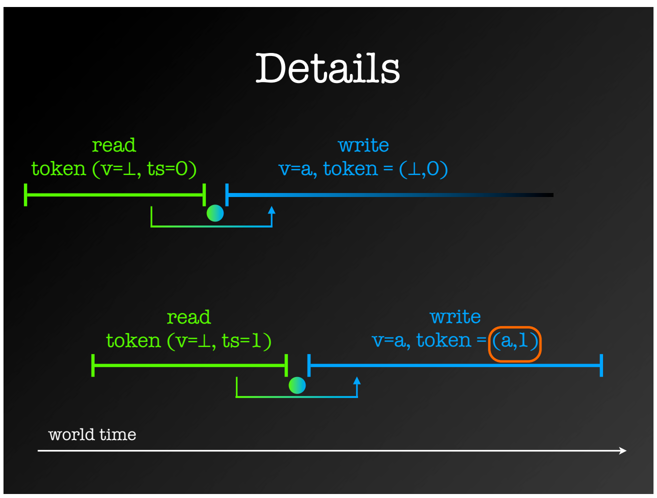

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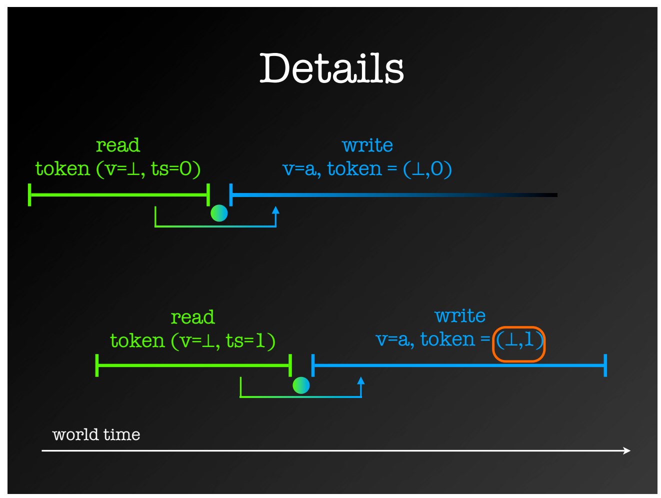

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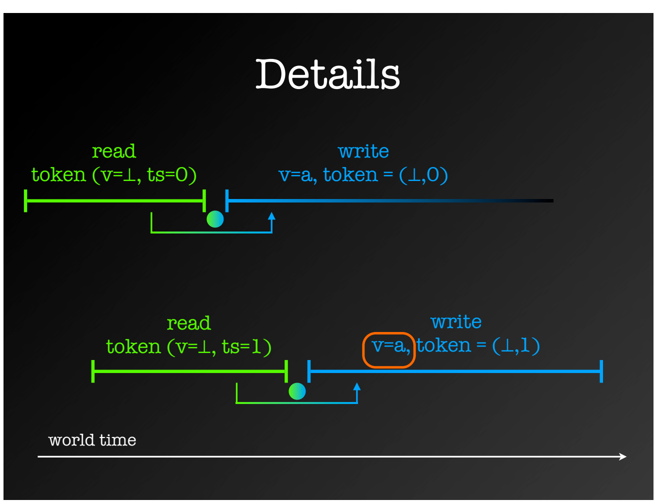

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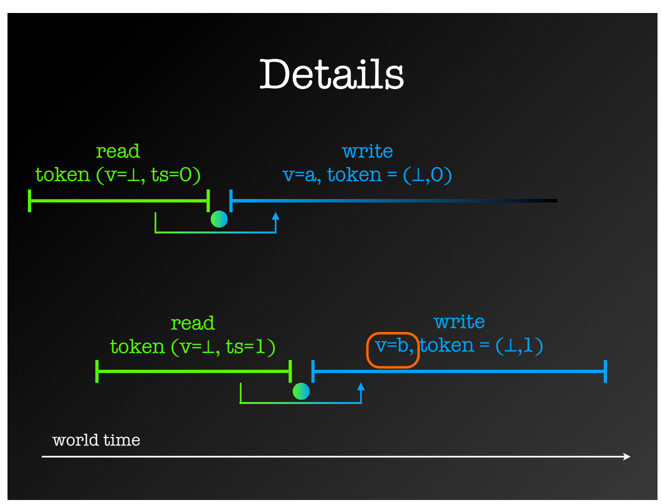

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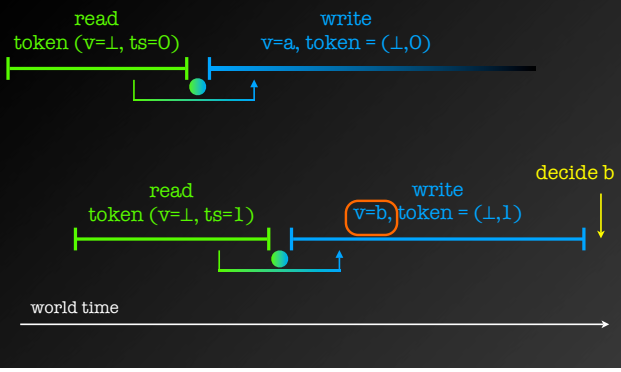

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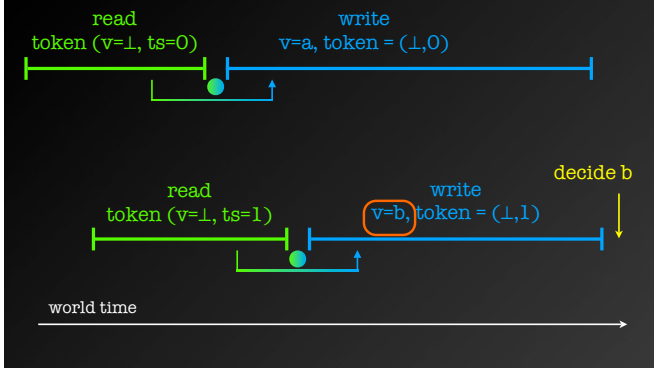

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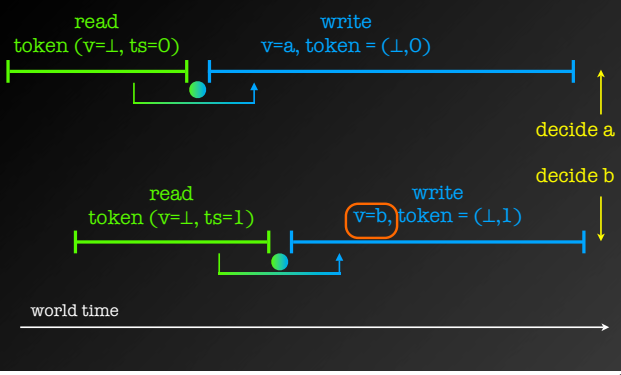

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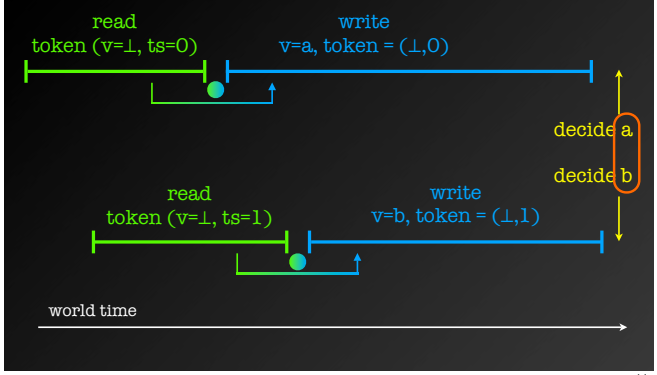
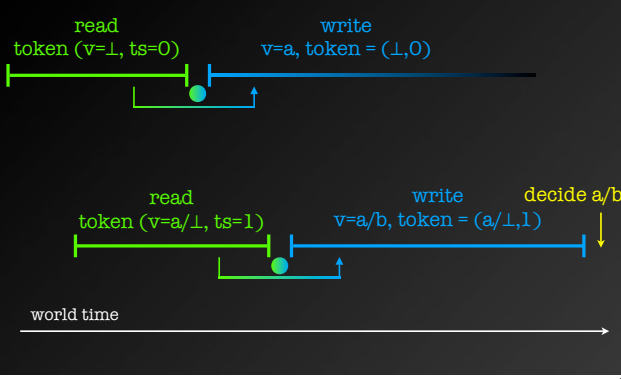


Concurrent Operations



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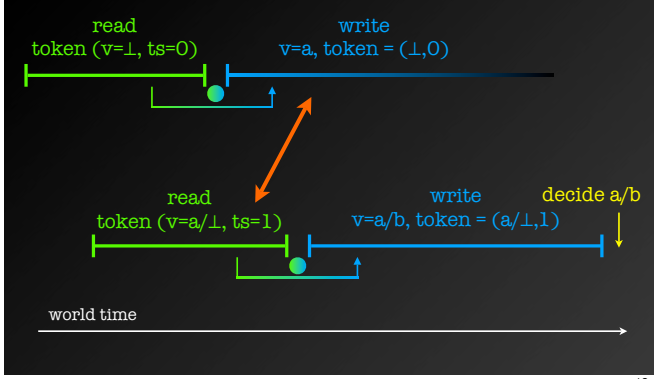
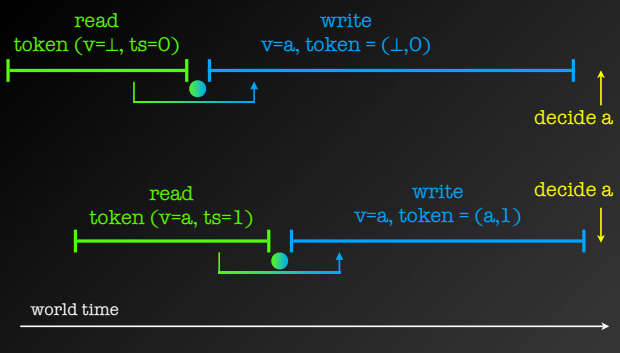


Almost Regular



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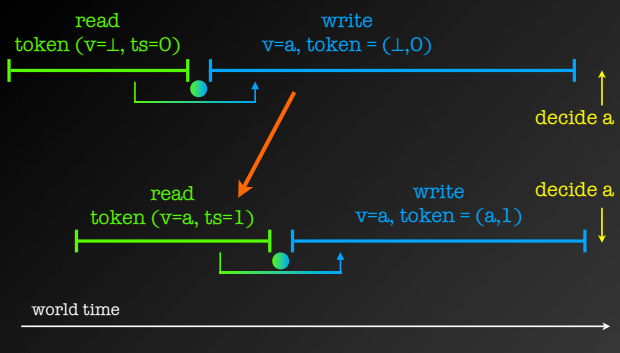

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  1. Writes ordered by increasing timestamp
  2. Total write precedes higher timestamped read
  3. Read precedes higher or same timestamped write

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Modified Partial Order

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world time

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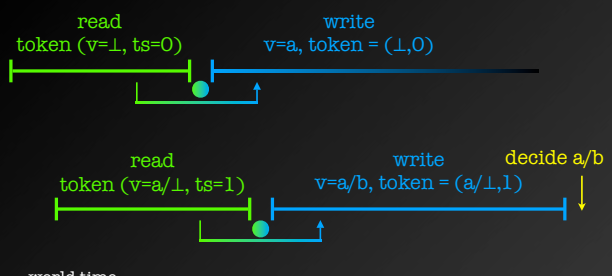
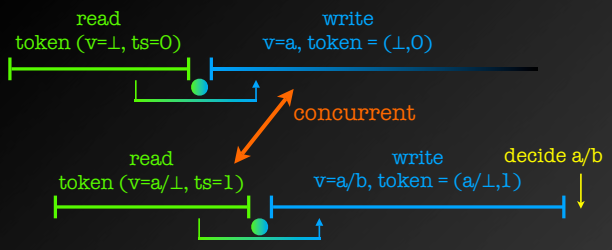


world time

Modified Partial Order

2. Total write precedes higher timestamped read



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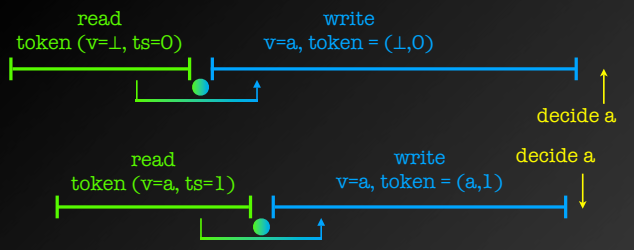

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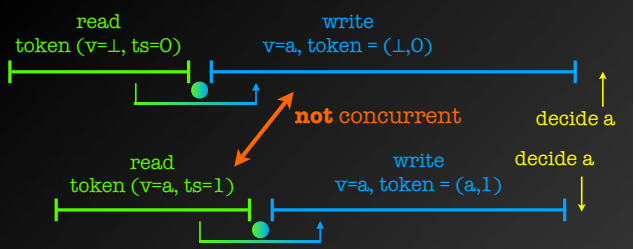

world time

Write-Once Register

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Theorem: All total writes write the same value.

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- Paxos variants share high-level protocol

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- Paxos variants share high-level protocol
- Paxos variants use common abstractions
  - Timestamps, tokens
  - Partial, total, and visible writes

Write-Once Register

Theorem: All total writes write the same value.

- Paxos variants share high-level protocol
- Paxos variants use common abstractions
  - Timestamps, tokens
  - Partial, total, and visible writes
  - Implementations differ

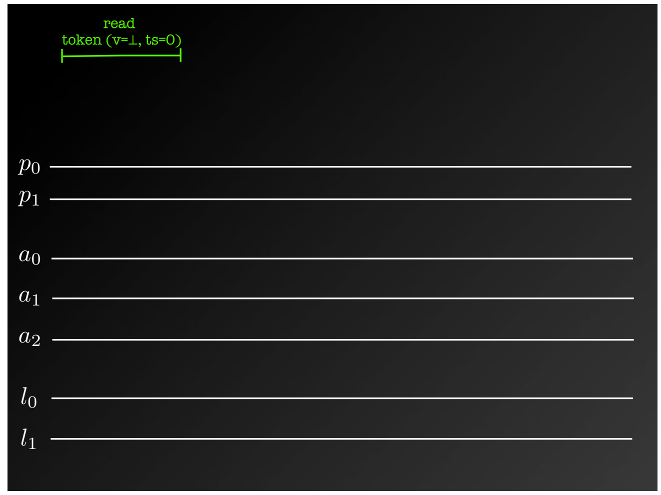
Outline

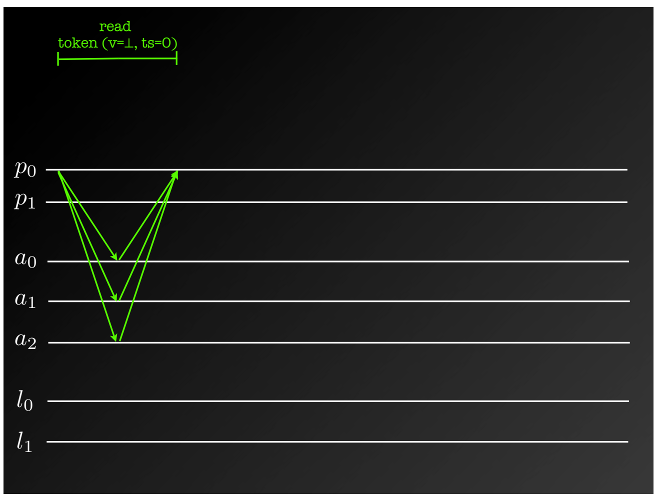
- Motivation
- Paxos Register specification
- Crash Implementation
- Byzantine Implementation

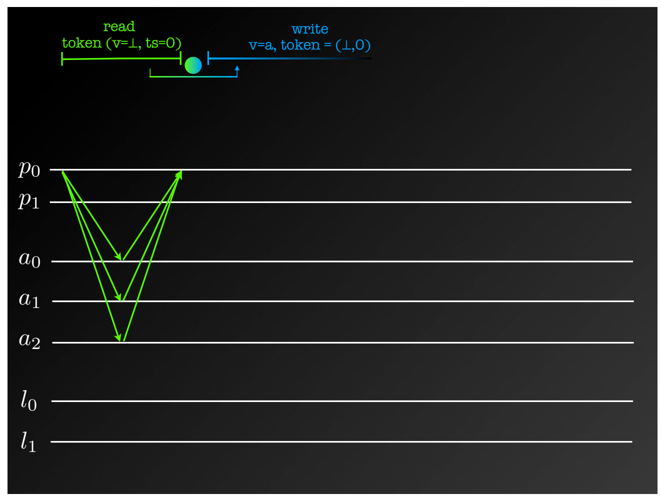
Crash Model

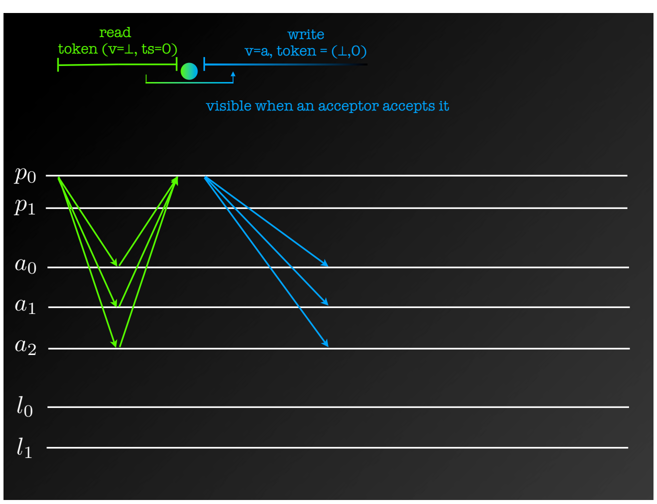
- Asynchronous system
- Proposers, acceptors, learners
- At least one proposer correct
- Majority of acceptors correct

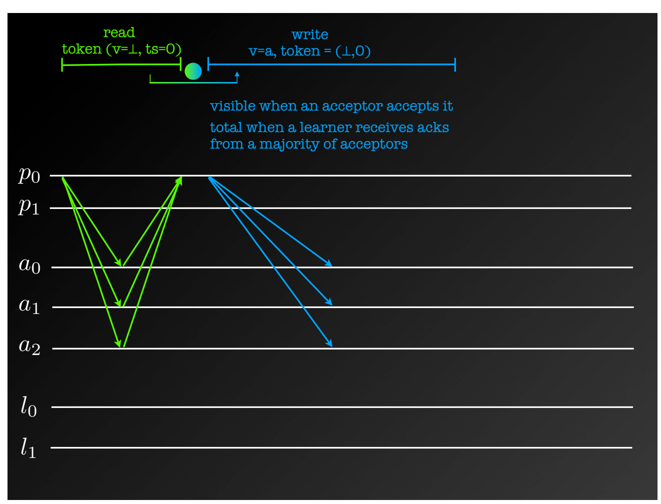

p0
p1
a0
a1
a2
l0
l1

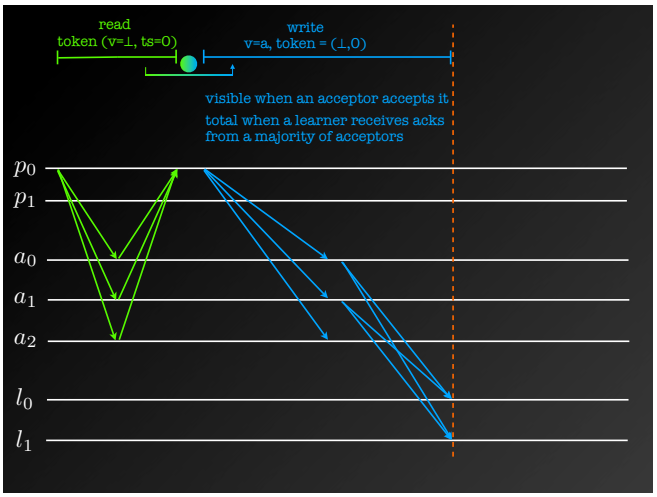

read
token (v=⊥, ts=0)
p0
p1
a0
a1
a2
l0
l1


read
token (v=⊥, ts=0)
p0
p1
a0
a1
a2
l0
l1

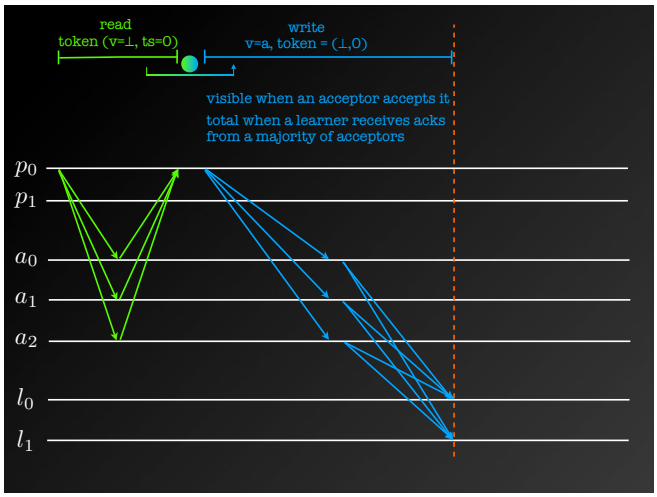

read
token (v=⊥, ts=0)
write
v=a, token = (⊥,0)
p0
p1
a0
a1
a2
l0
l1


read
token (v=⊥, ts=0)
write
v=a, token = (⊥,0)
visible when an acceptor accepts it
p0
p1
a0
a1
a2
l0
l1

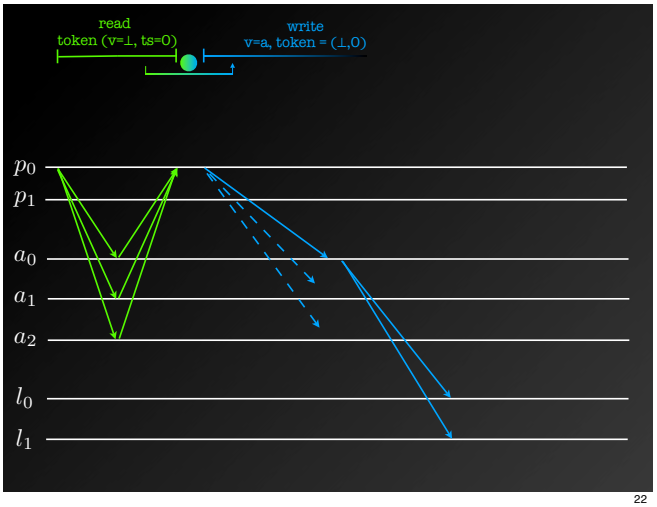

read
token (v=⊥, ts=0)
write
v=a, token = (⊥,0)
visible when an acceptor accepts it
total when a learner receives acks
from a majority of acceptors
p0
p1
a0
a1
a2
l0
l1



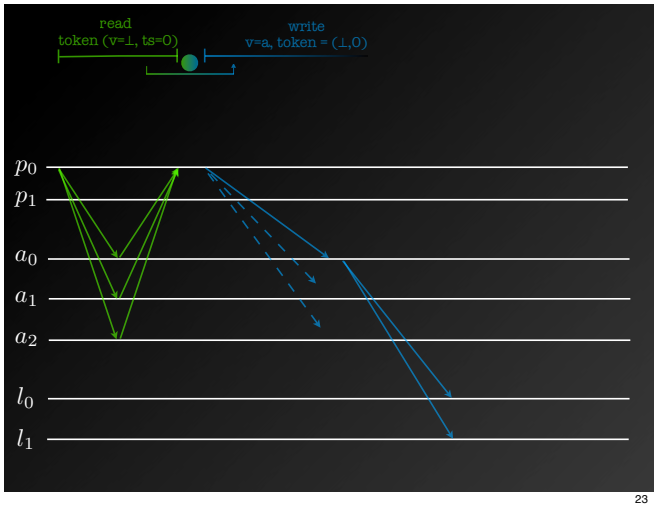
21



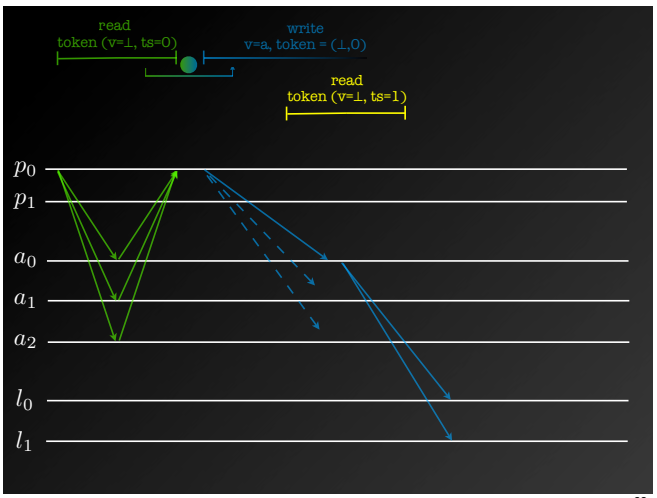
21



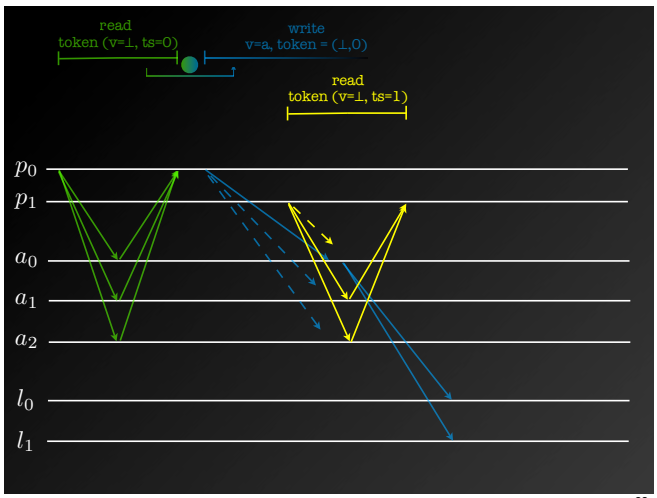
22



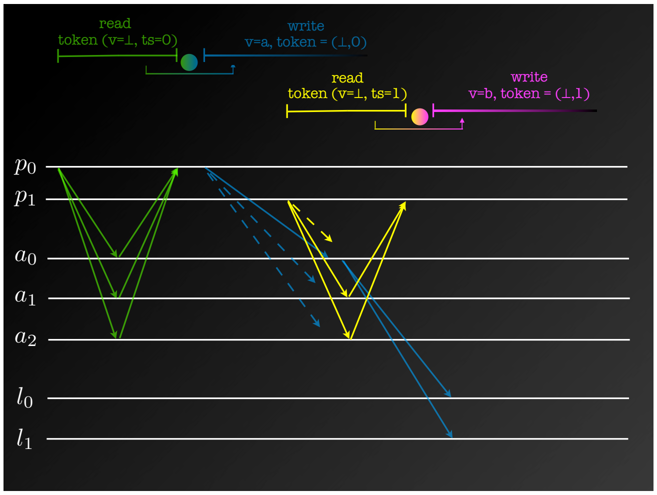
23

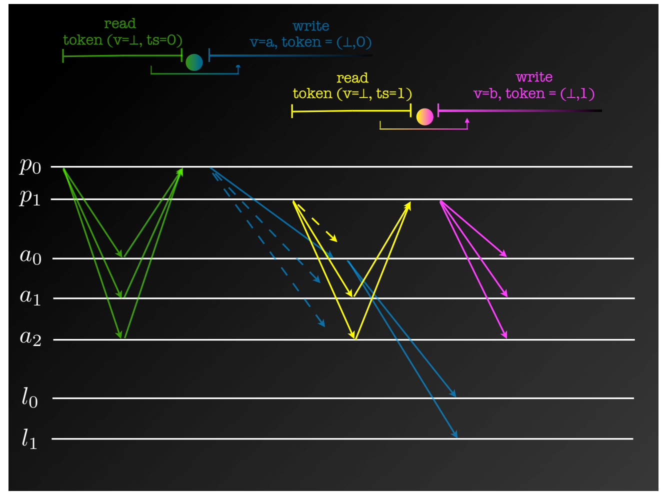


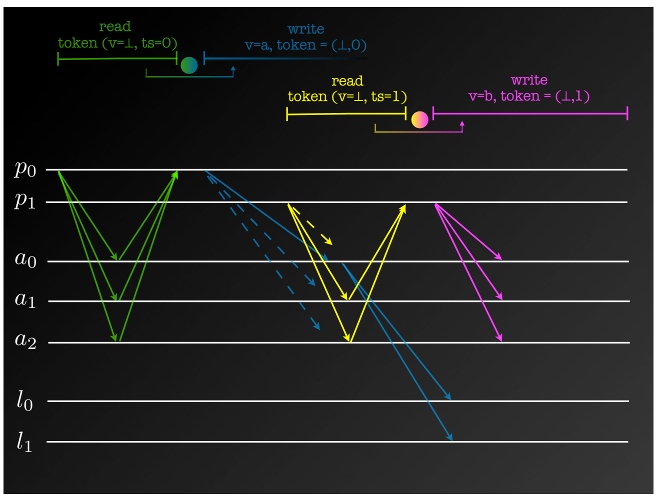
23

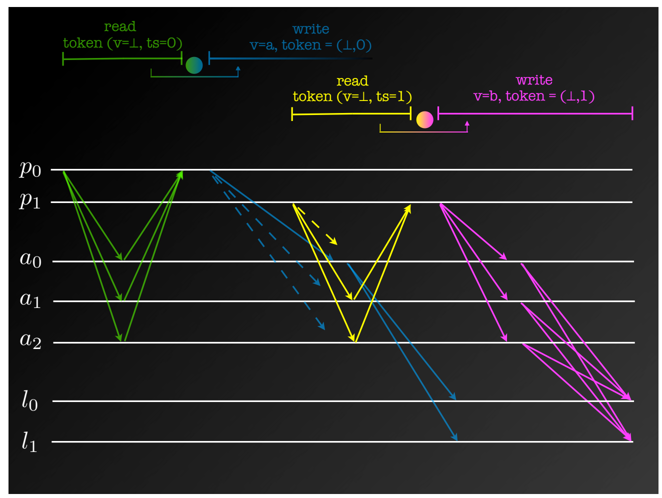


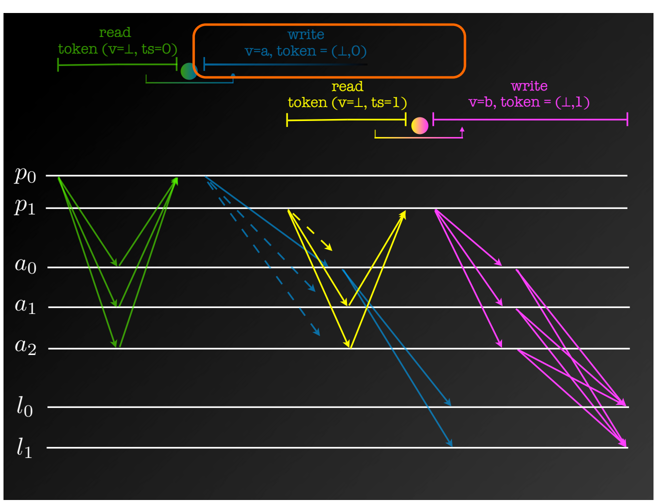
23

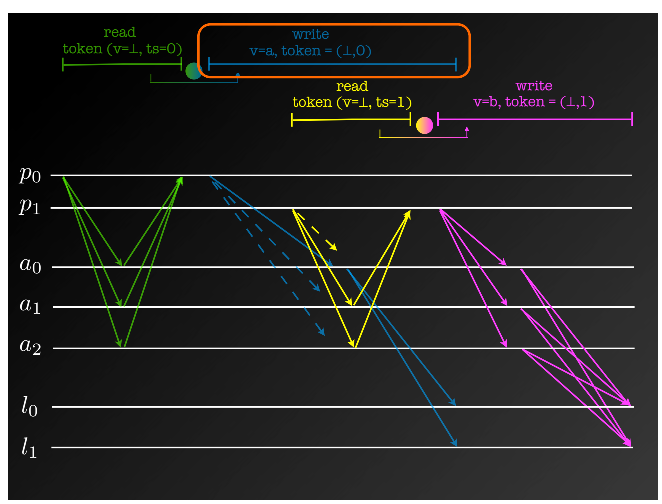

read
token (v=⊥, ts=0)
write
v=a, token = (⊥,0)
read
token (v=⊥, ts=1)
write
v=b, token = (⊥,1)
p_0
p_1
a_0
a_1
a_2
l_0
l_1

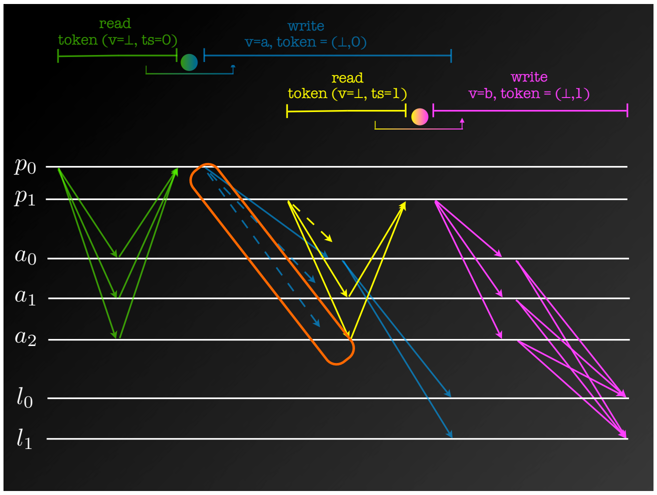

read
token (v=⊥, ts=0)
write
v=a, token = (⊥,0)
read
token (v=⊥, ts=1)
write
v=b, token = (⊥,1)
p_0
p_1
a_0
a_1
a_2
l_0
l_1


read
token (v=⊥, ts=0)
write
v=a, token = (⊥,0)
read
token (v=⊥, ts=1)
write
v=b, token = (⊥,1)
p_0
p_1
a_0
a_1
a_2
l_0
l_1


read
token (v=⊥, ts=0)
write
v=a, token = (⊥,0)
read
token (v=⊥, ts=1)
write
v=b, token = (⊥,1)
p_0
p_1
a_0
a_1
a_2
l_0
l_1


read
token (v=⊥, ts=0)
write
v=a, token = (⊥,0)
read
token (v=⊥, ts=1)
write
v=b, token = (⊥,1)
p_0
p_1
a_0
a_1
a_2
l_0
l_1


read
token (v=⊥, ts=0)
write
v=a, token = (⊥,0)
read
token (v=⊥, ts=1)
write
v=b, token = (⊥,1)
p_0
p_1
a_0
a_1
a_2
l_0
l_1



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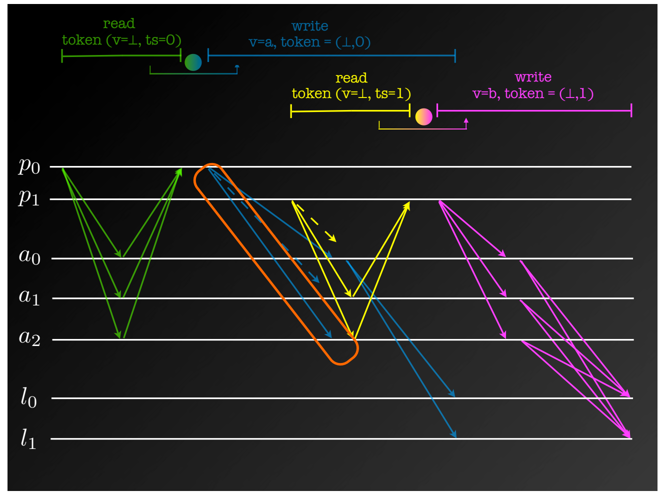

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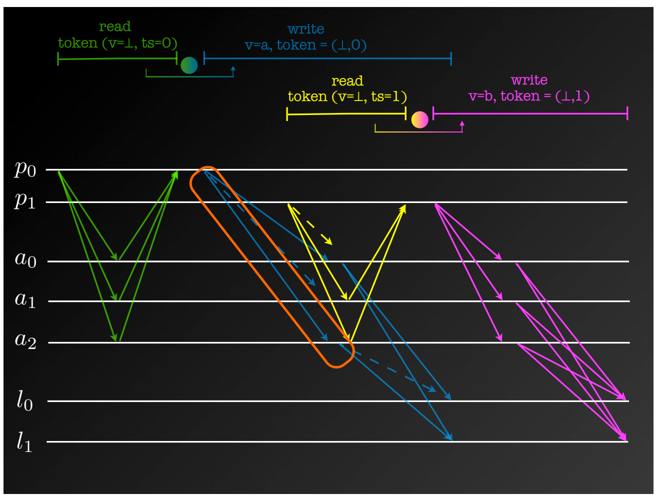

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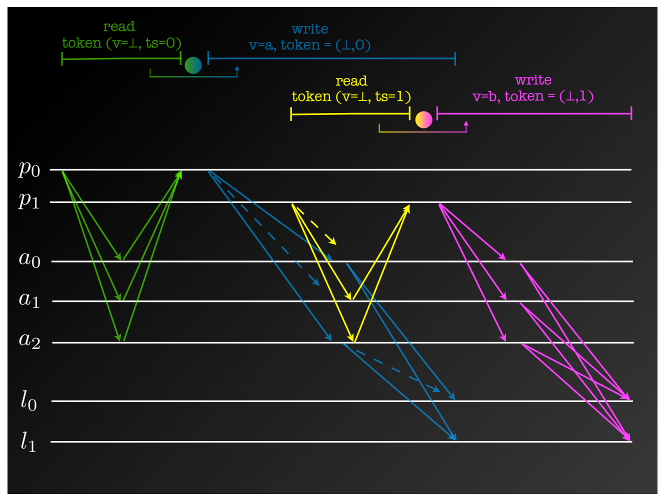
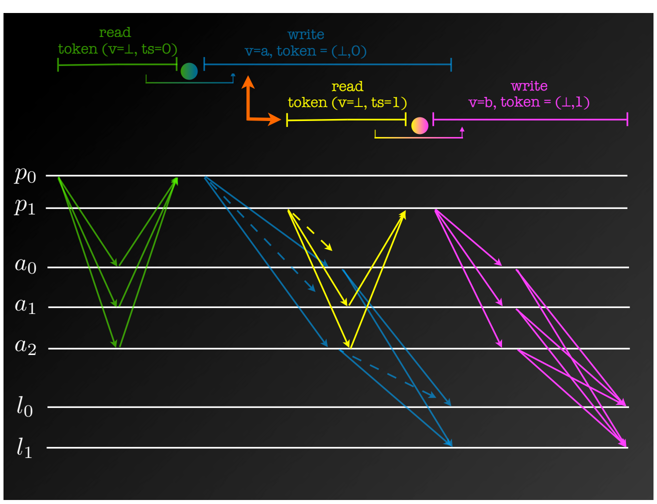


24



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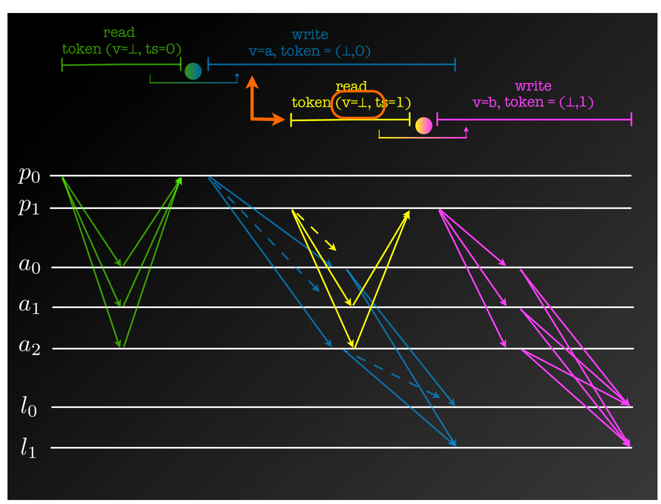
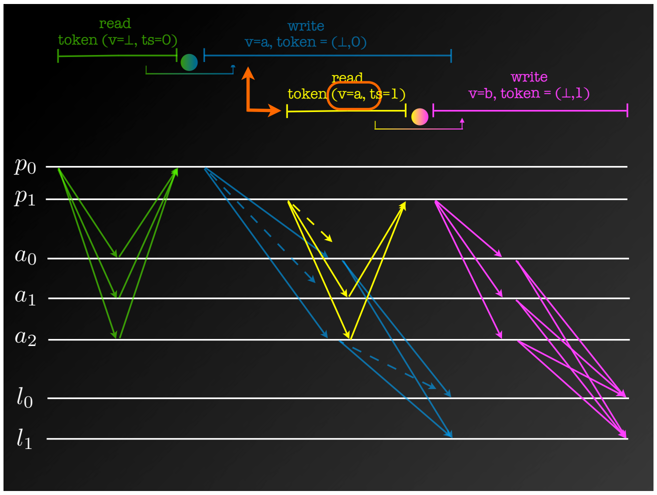


24



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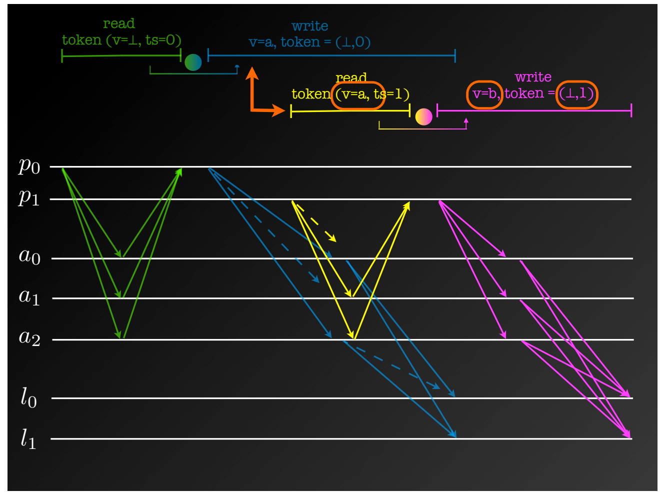

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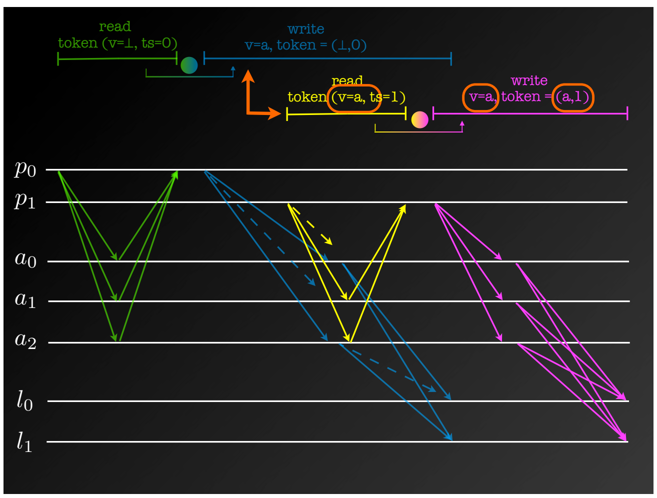

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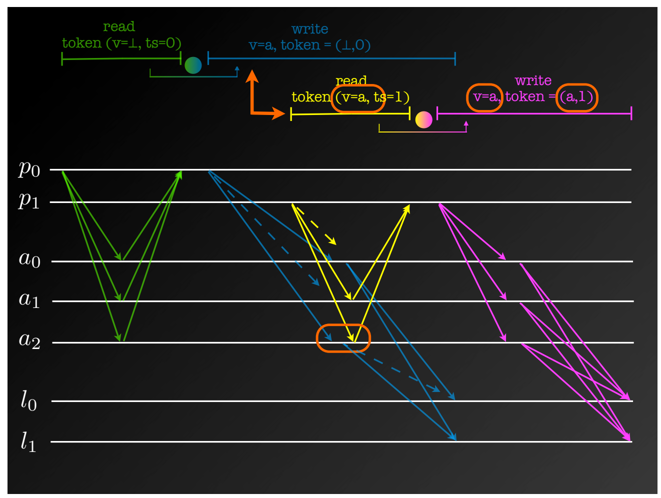

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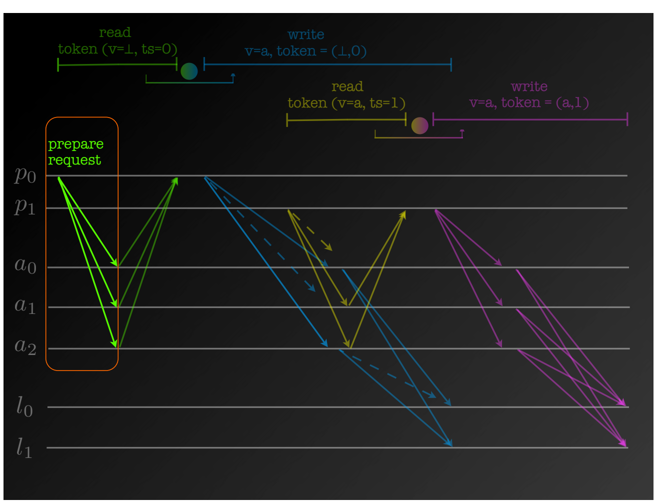
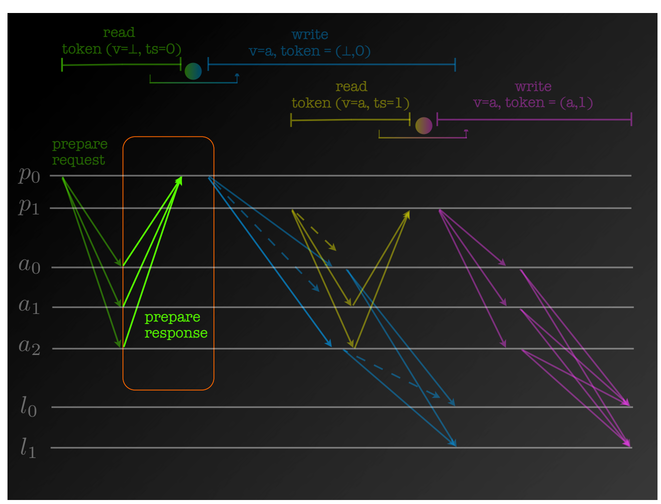
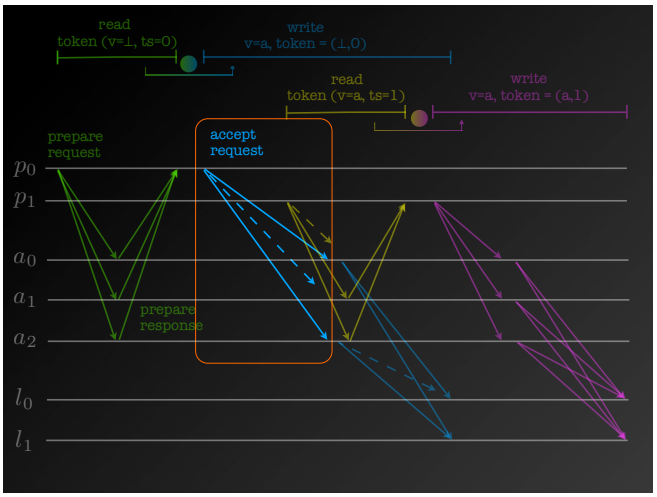
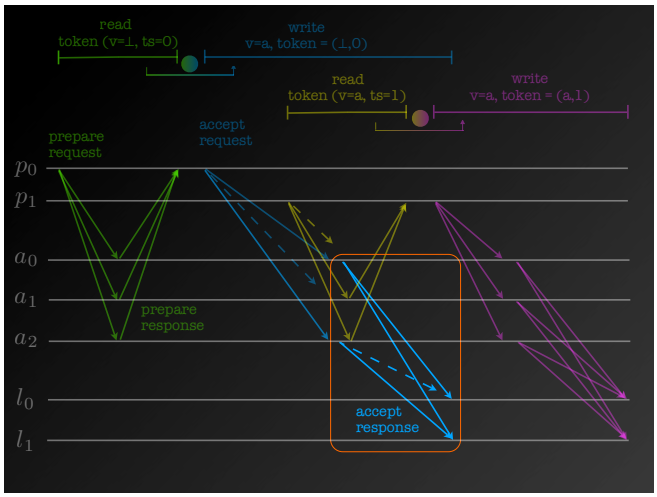


25



26



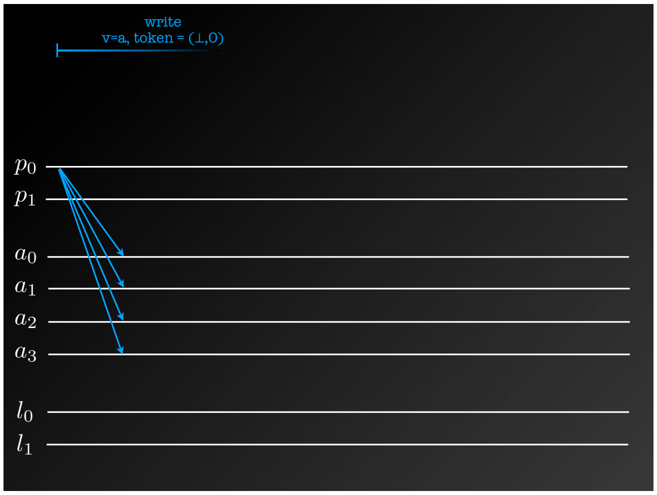


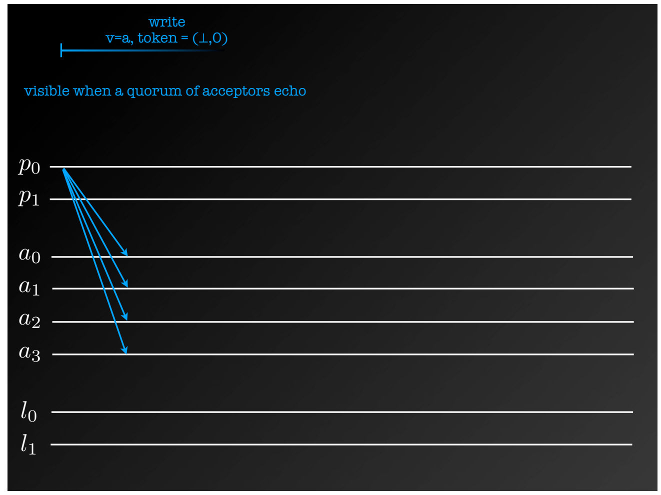
Outline

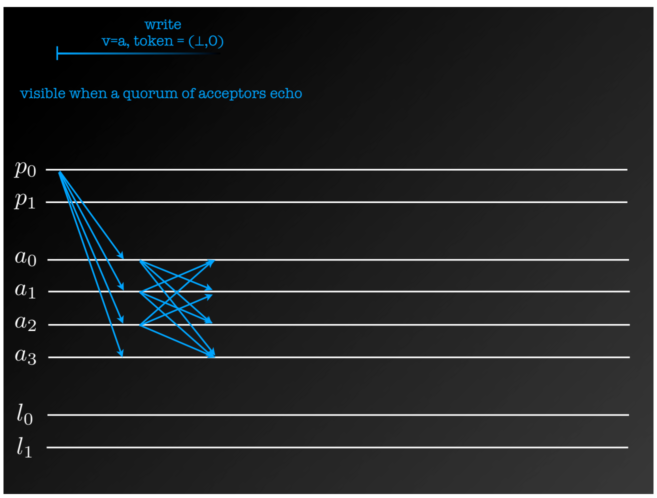
- Motivation
- Paxos Register specification
- Crash implementation
- Byzantine implementation

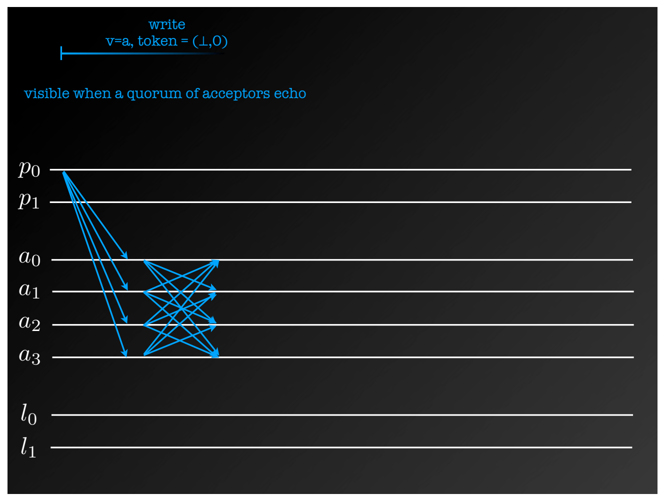
Byzantine Model

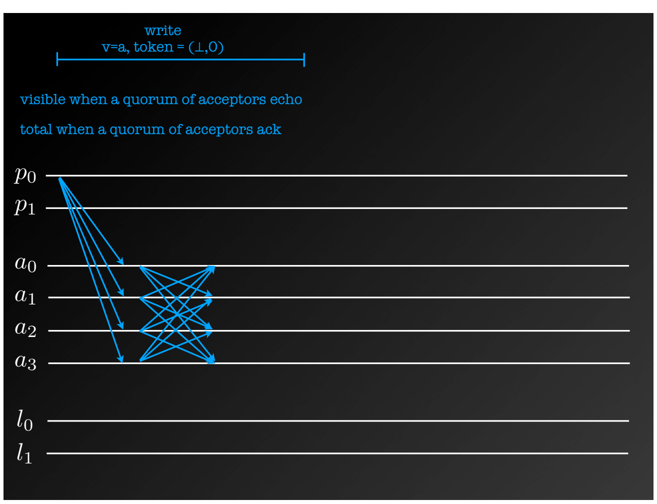
- Asynchronous system
- Digital signatures
- Proposers, acceptors, learners
- At least one proposer correct
- More than two thirds acceptors correct

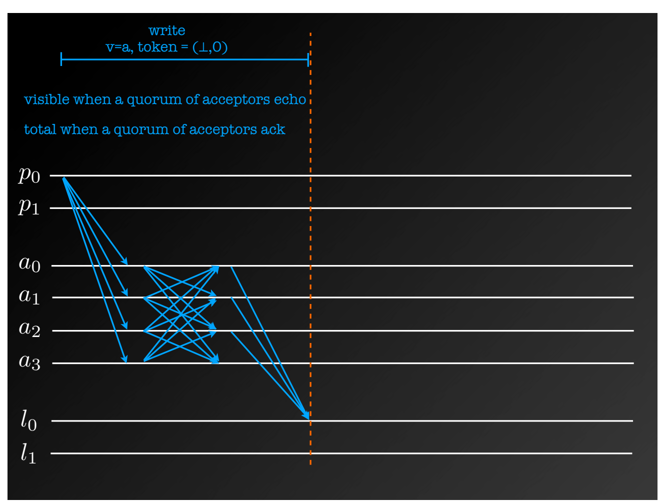

write
v=a, token = (⊥,0)
p_0
p_1
a_0
a_1
a_2
a_3
l_0
l_1

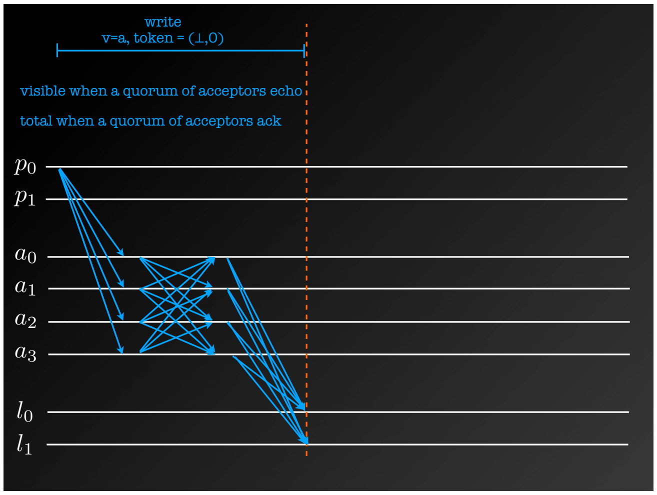

write
v=a, token = (⊥,0)
visible when a quorum of acceptors echo
p_0
p_1
a_0
a_1
a_2
a_3
l_0
l_1


write
v=a, token = (⊥,0)
visible when a quorum of acceptors echo
p_0
p_1
a_0
a_1
a_2
a_3
l_0
l_1

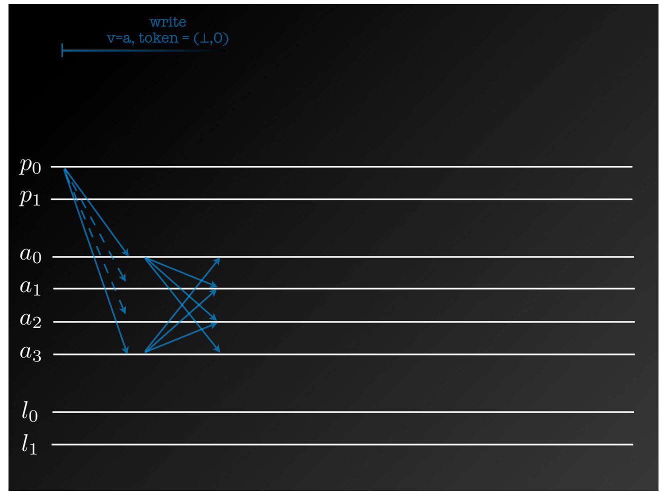

write
v=a, token = (⊥,0)
visible when a quorum of acceptors echo
p_0
p_1
a_0
a_1
a_2
a_3
l_0
l_1


write
v=a, token = (⊥,0)
visible when a quorum of acceptors echo
total when a quorum of acceptors ack
p_0
p_1
a_0
a_1
a_2
a_3
l_0
l_1


write
v=a, token = (⊥,0)
visible when a quorum of acceptors echo
total when a quorum of acceptors ack
p_0
p_1
a_0
a_1
a_2
a_3
l_0
l_1



31



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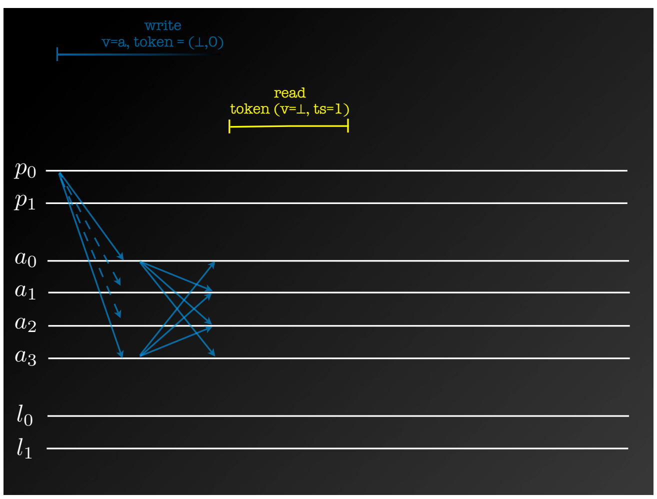

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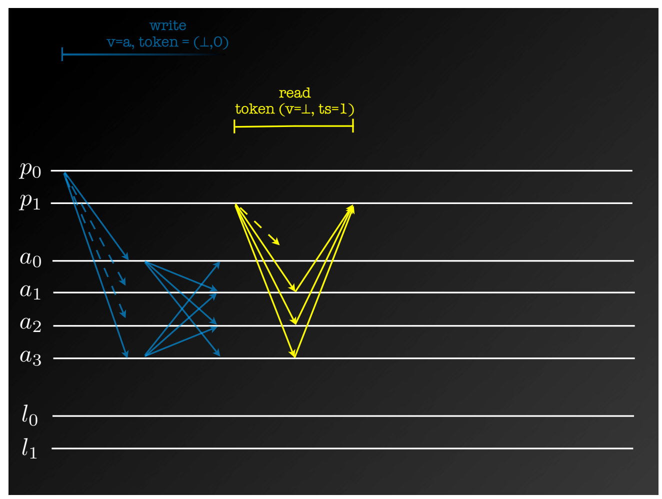

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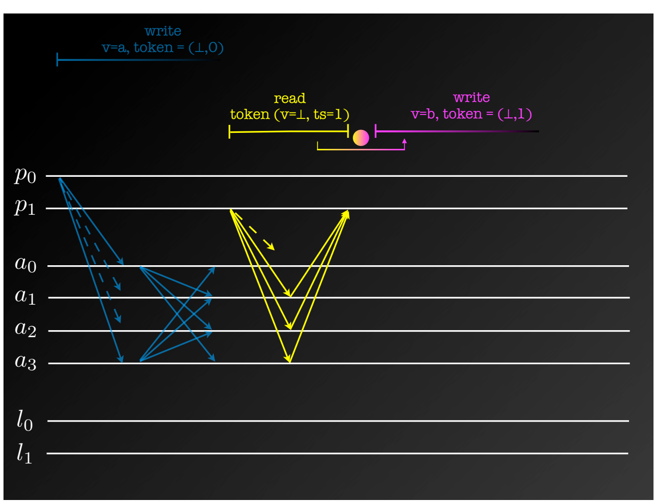

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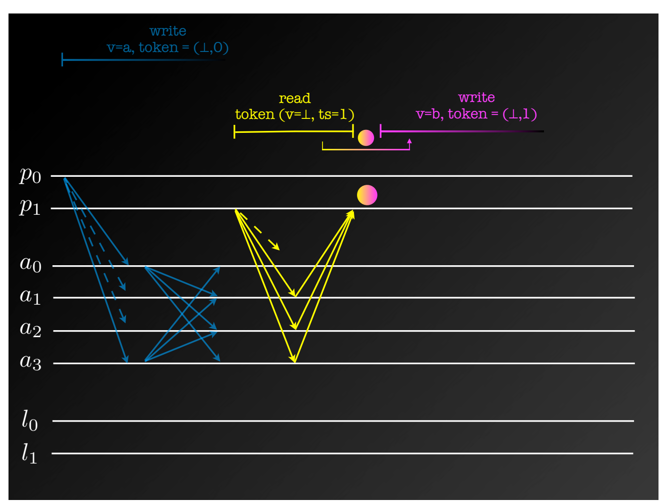
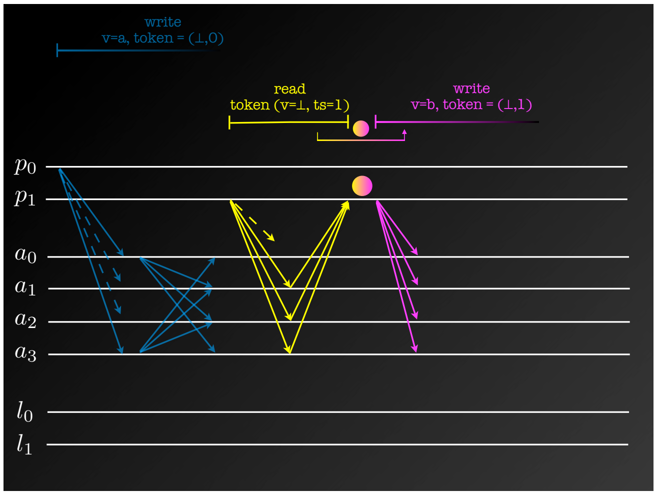
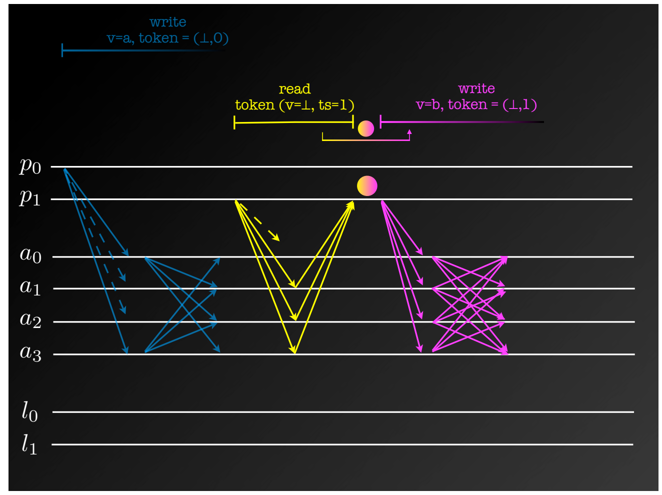
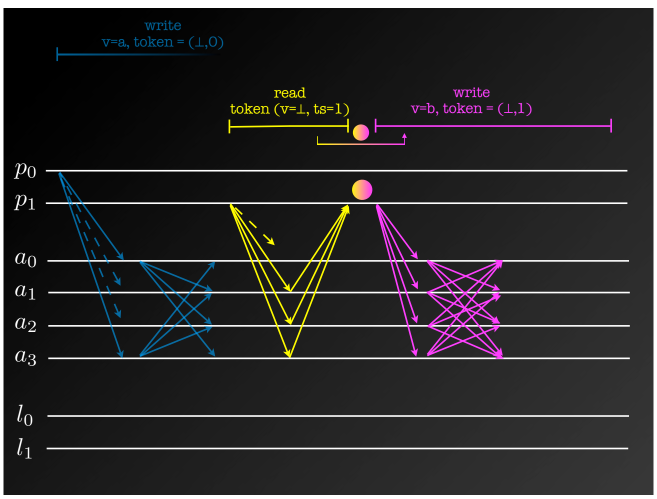
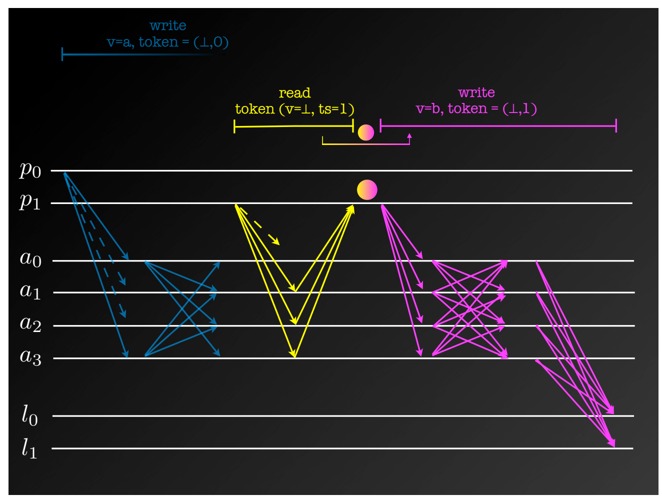


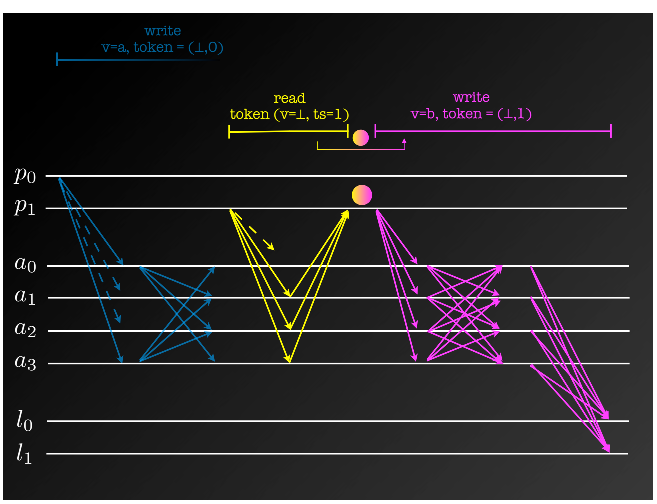
32

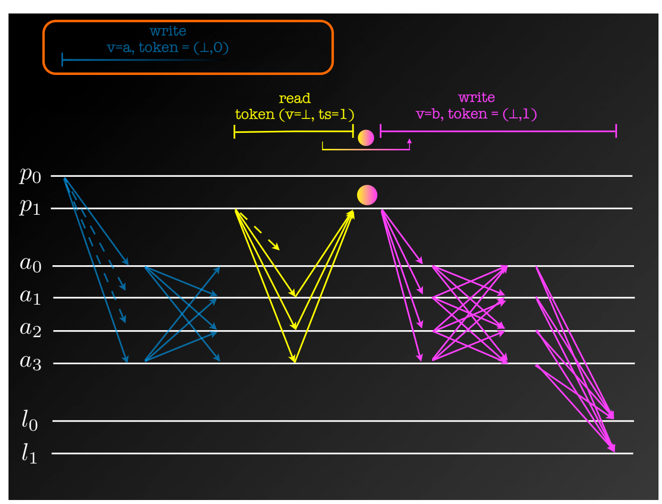

write
v=a, token = (⊥,0)
read
token (v=⊥, ts=1)
write
v=b, token = (⊥,1)
p_0
p_1
a_0
a_1
a_2
a_3
l_0
l_1

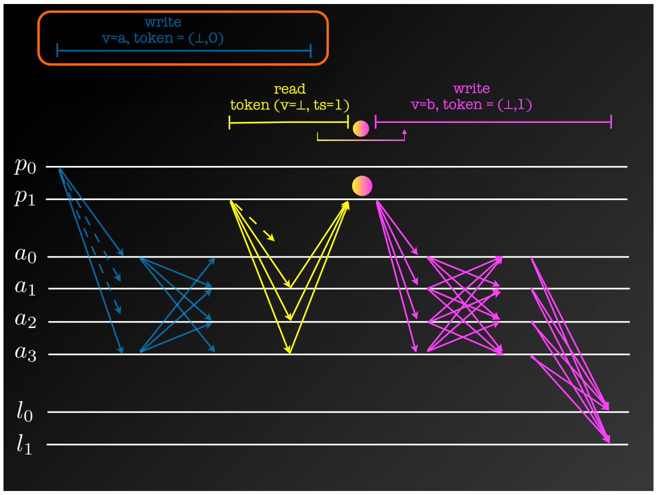

write
v=a, token = (⊥,0)
read
token (v=⊥, ts=1)
write
v=b, token = (⊥,1)
p_0
p_1
a_0
a_1
a_2
a_3
l_0
l_1


write
v=a, token = (⊥,0)
read
token (v=⊥, ts=1)
write
v=b, token = (⊥,1)
p_0
p_1
a_0
a_1
a_2
a_3
l_0
l_1

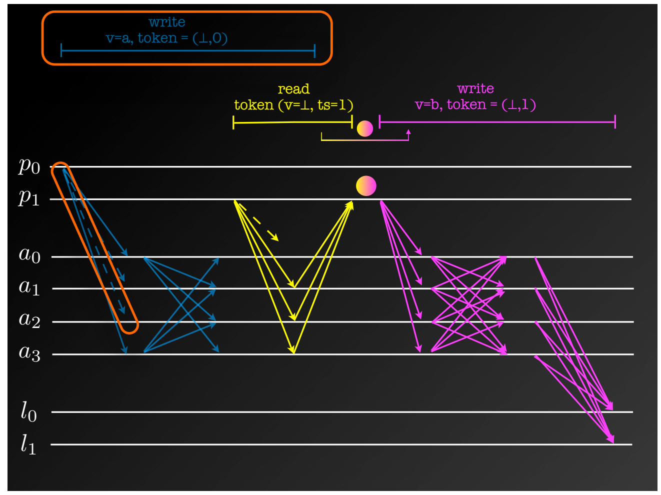

write
v=a, token = (⊥,0)
read
token (v=⊥, ts=1)
write
v=b, token = (⊥,1)
p_0
p_1
a_0
a_1
a_2
a_3
l_0
l_1


write
v=a, token = (⊥,0)
read
token (v=⊥, ts=1)
write
v=b, token = (⊥,1)
p_0
p_1
a_0
a_1
a_2
a_3
l_0
l_1

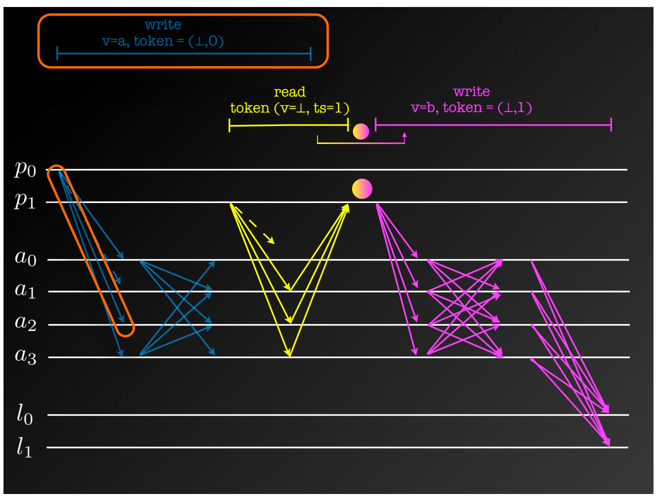

write
v=a, token = (⊥,0)
read
token (v=⊥, ts=1)
write
v=b, token = (⊥,1)
p_0
p_1
a_0
a_1
a_2
a_3
l_0
l_1



33



33



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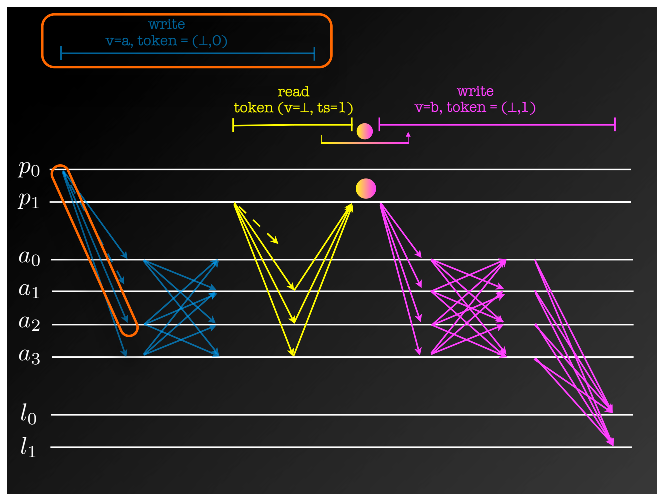

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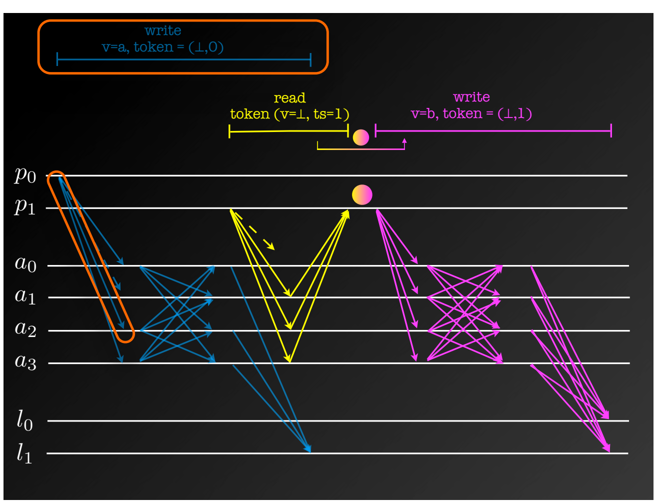

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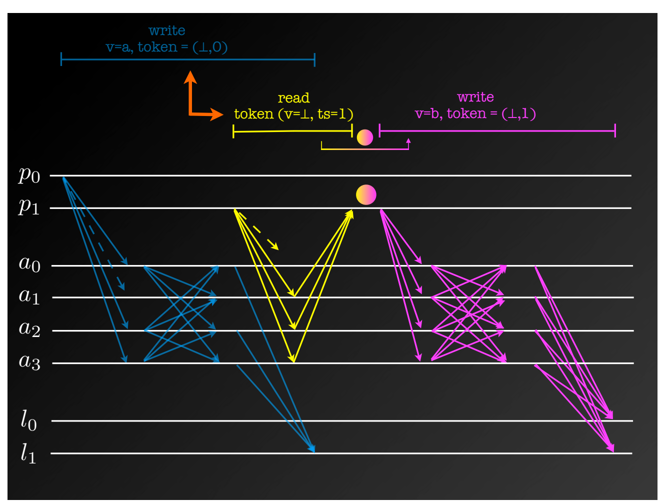

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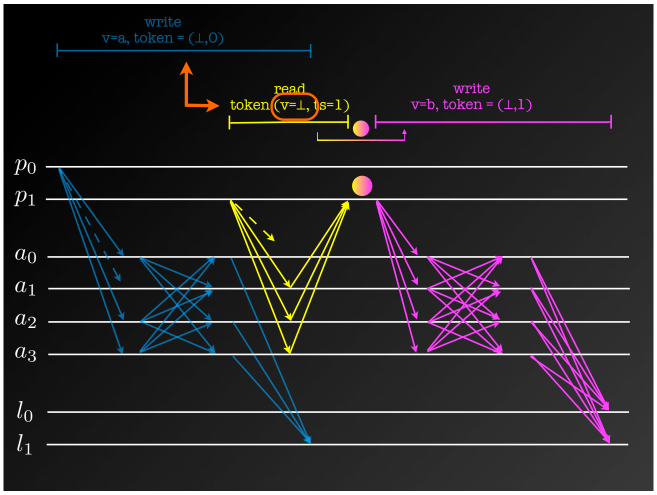

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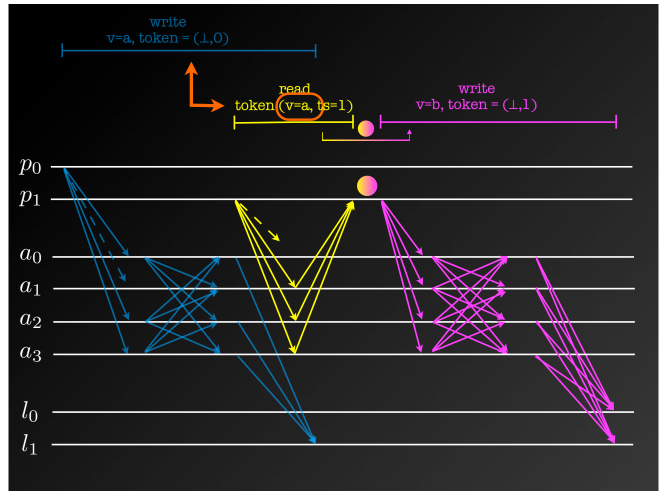

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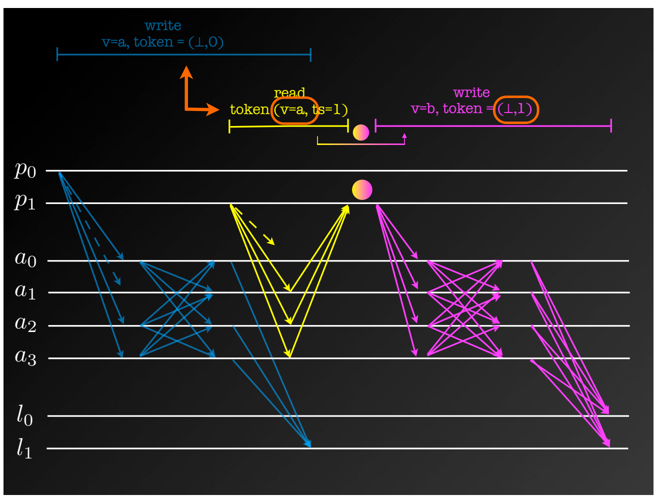

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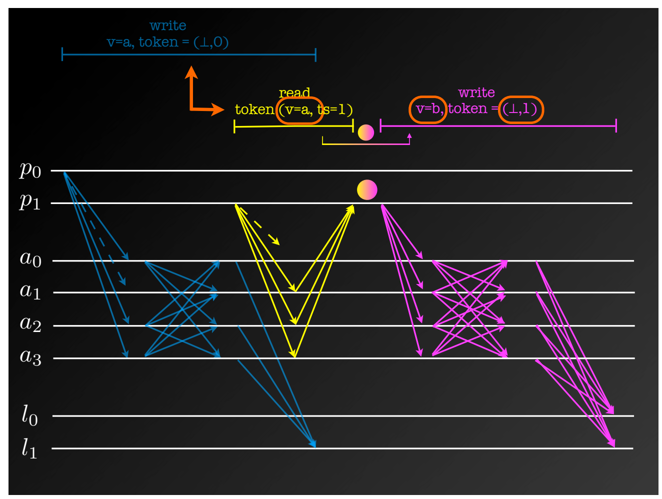

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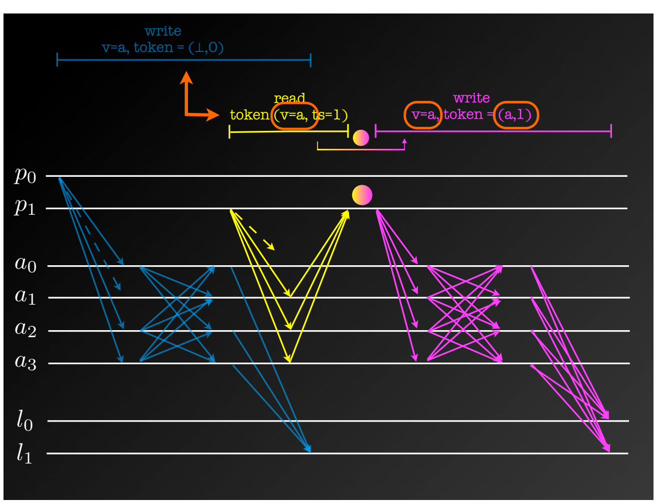

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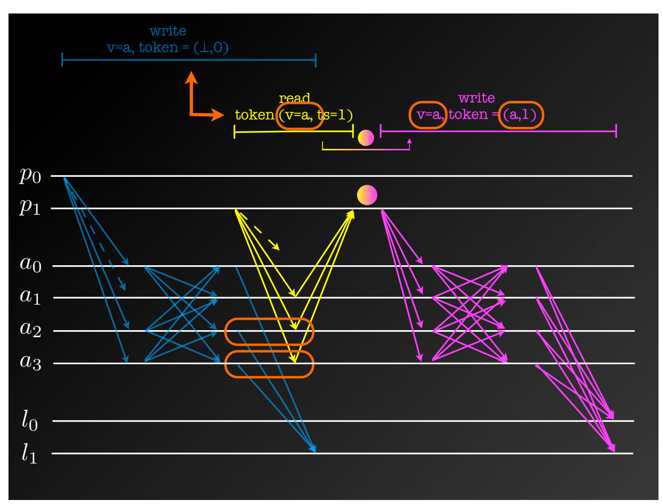

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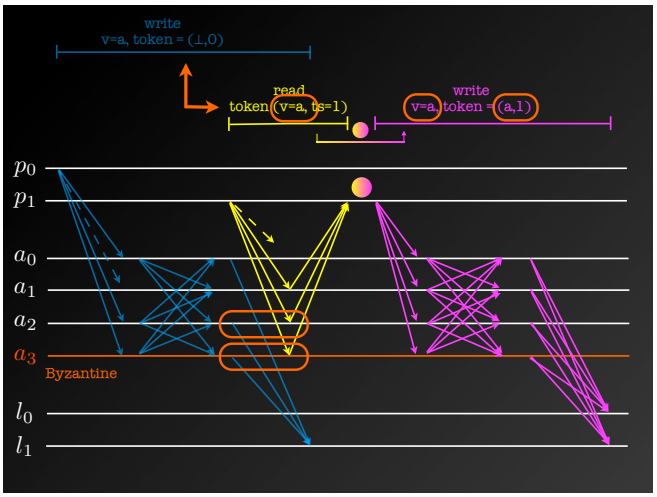

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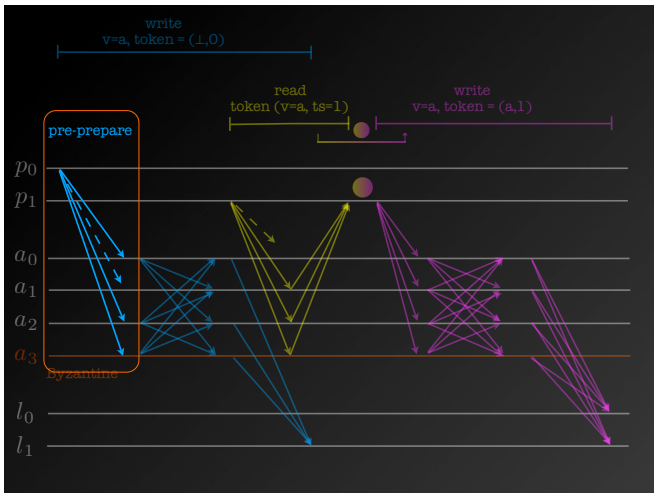

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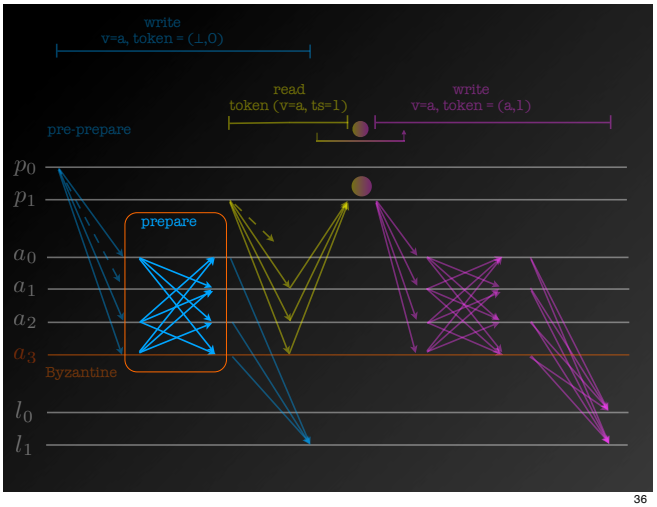

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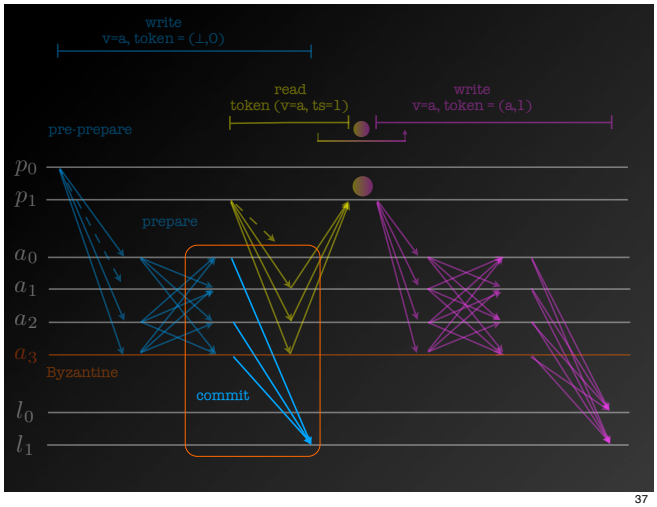

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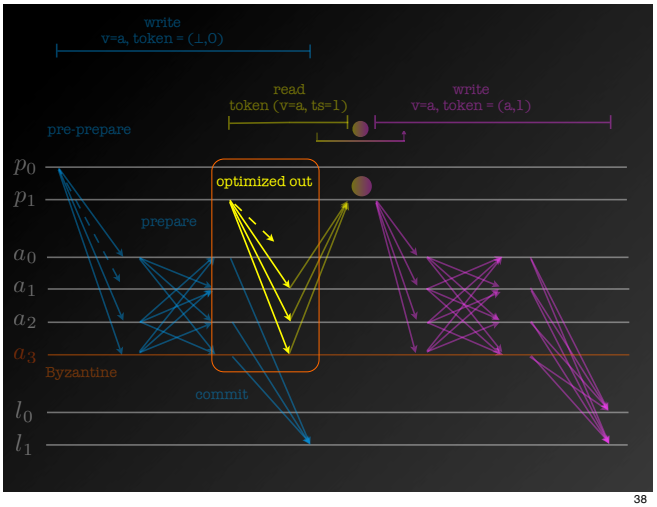

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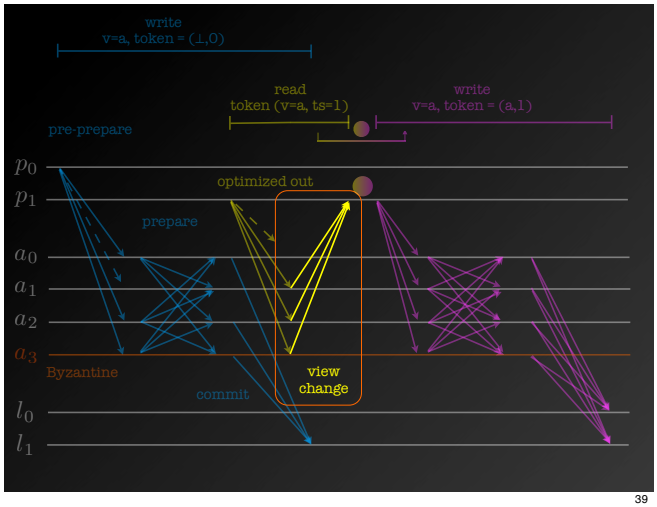

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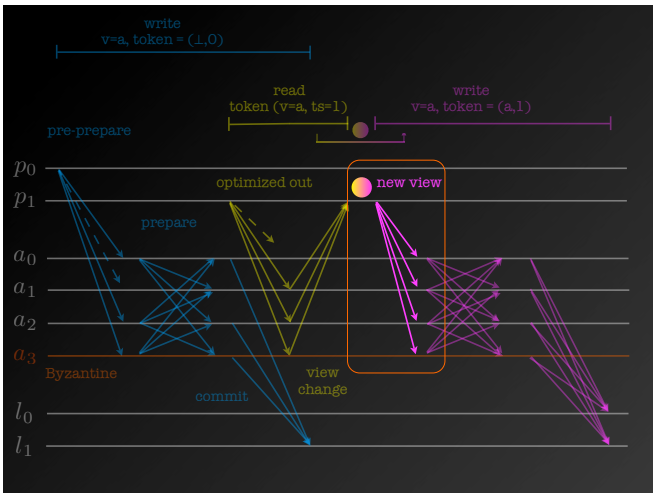

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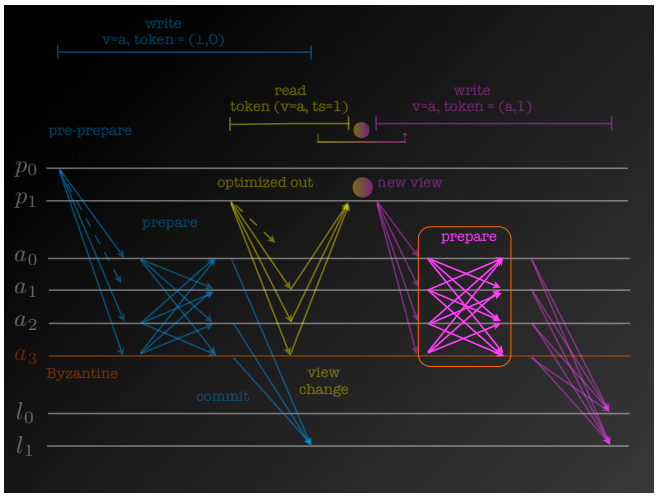

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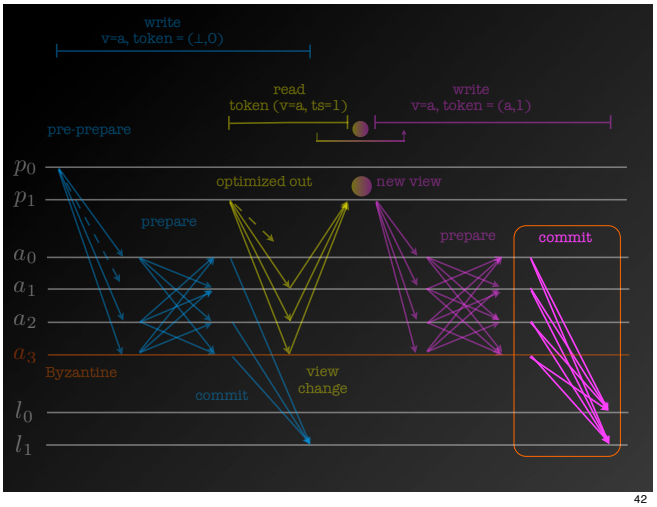

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Take Away Points

Paxos Register

- Captures similarities in Paxos protocols
- Hides implementation details
- Important abstractions:

  tokens, visible writes, total writes

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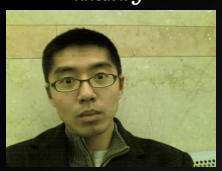
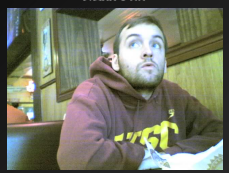
Harry



Allen



Amit

Lorenzo

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