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Logging and Recovery

COMP3211 Advanced Databases

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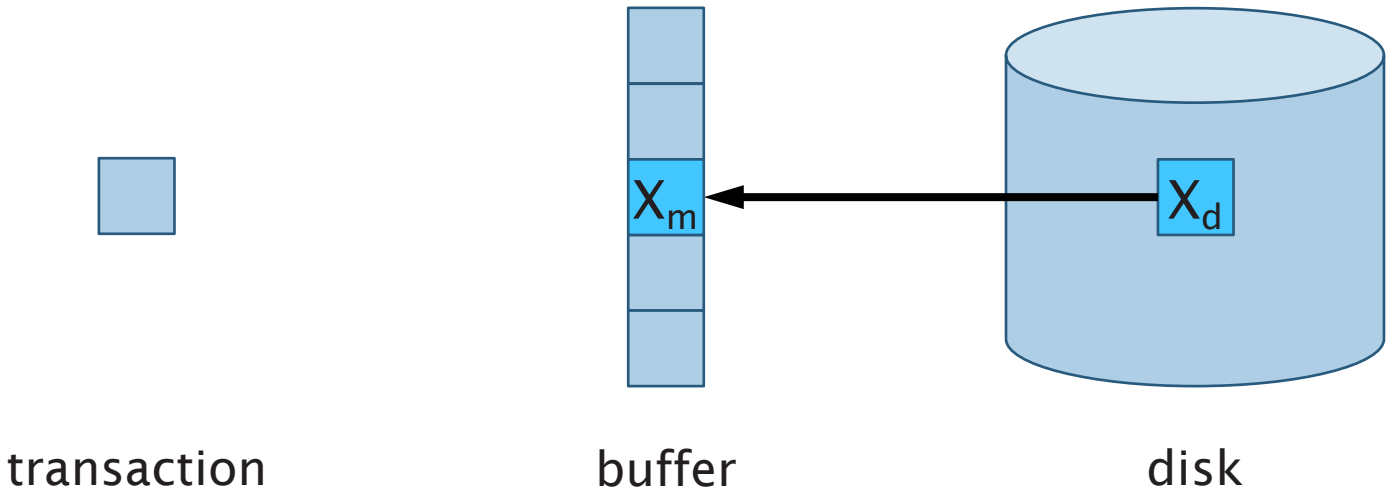
Durability

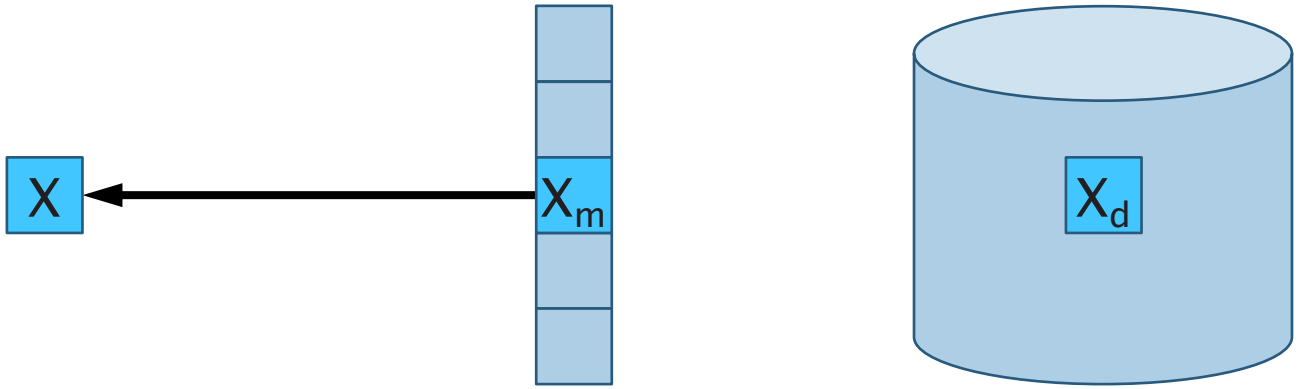
Once a database is changed and committed,
changes should not be lost because of failure

input(X)



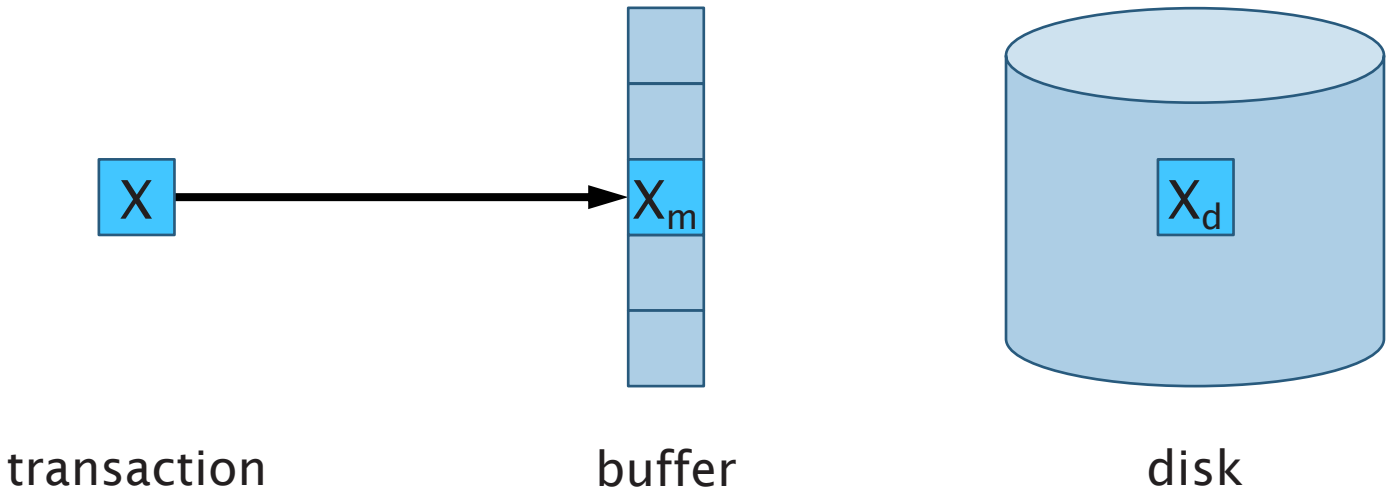
Copy the disk block containing
database item X into a buffer frame

read(X)



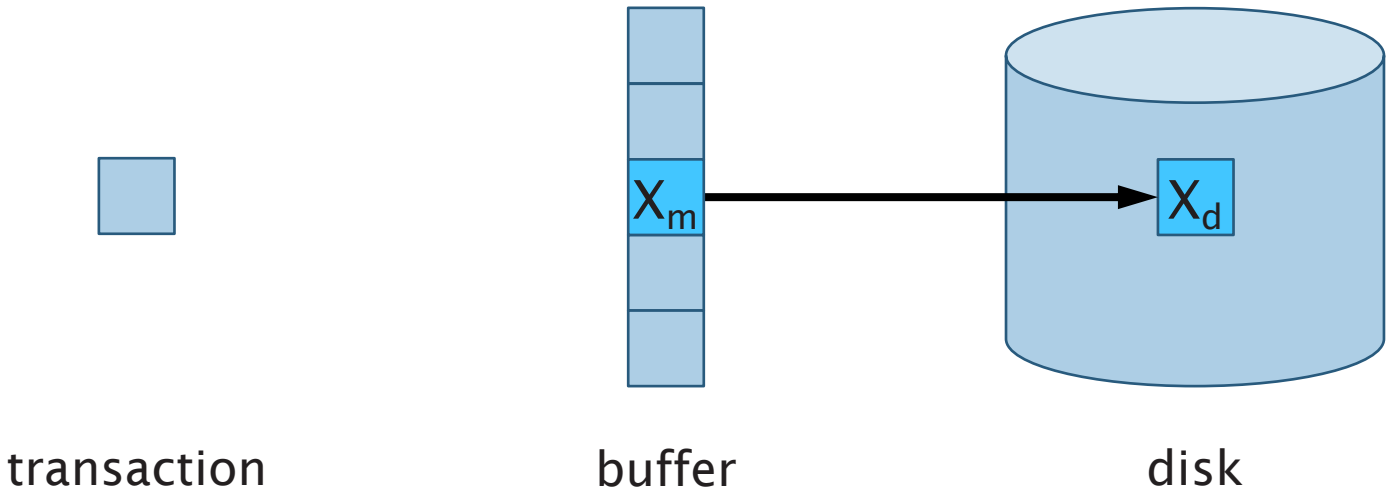
Read a database item X into a local variable. If the block containing X is not already in a buffer frame, first input(X)

write(X)



Write the value of local variable into database item X in a buffer frame

output(X)



Copy the block containing X from
buffer frame to disk

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Expanded Transaction

read(X)

X := X – 10

write(X)

read(Y)

Y := Y+10

write(Y)

output(X)

output(Y)

Action	X	Y	X_m	Y_m	X_d	Y_d	Log
					20	50	

Action	X	Y	X_m	Y_m	X_d	Y_d	Log
					20	50	
read(X)	**20**	←	**20**	←	20	50	

Action	X	Y	X_m	Y_m	X_d	Y_d	Log
					20	50	
read(X)	**20**	←	**20**	←	20	50	
X := X – 10	**10**		20		20	50	

Action	X	Y	X_m	Y_m	X_d	Y_d	Log
					20	50	
read(X)	**20**	←	**20**	←	20	50	
X := X – 10	**10**		20		20	50	
write(X)	10	→	**10**		20	50	

Action	X	Y	X_m	Y_m	X_d	Y_d	Log
					20	50	
read(X)	**20**		**20**		20	50	
X := X – 10	**10**		20		20	50	
write(X)	10		**10**		20	50	
read(Y)	10	**50**	10	**50**	20	50	

Action	X	Y	X_m	Y_m	X_d	Y_d	Log
					20	50	
read(X)	**20**		**20**		20	50	
X := X – 10	**10**		20		20	50	
write(X)	10		**10**		20	50	
read(Y)	10	**50**	10	**50**	20	50	
Y := Y+10	10	**60**	10	50	20	50	

Action	X	Y	X_m	Y_m	X_d	Y_d	Log
					20	50	
read(X)	**20**		**20**		20	50	
X := X – 10	**10**		20		20	50	
write(X)	10		**10**		20	50	
read(Y)	10	**50**	~~10~~	**50**	~~20~~	50	
Y := Y+10	10	**60**	10	50	20	50	
write(Y)	10	60	~~10~~	**60**	20	50	

Action	X	Y	X_m	Y_m	X_d	Y_d	Log
					20	50	
read(X)	**20**		**20**		20	50	
X := X – 10	**10**		20		20	50	
write(X)	10		**10**		20	50	
read(Y)	10	**50**	~~10~~	**50**	~~20~~	50	
Y := Y+10	10	**60**	10	50	20	50	
write(Y)	10	60	~~10~~	**60**	20	50	
output(X)	10	60	10	~~60~~	**10**	50	

Action	X	Y	X_m	Y_m	X_d	Y_d	Log
					20	50	
read(X)	**20**		**20**		20	50	
X := X – 10	**10**		20		20	50	
write(X)	10		**10**		20	50	
read(Y)	10	**50**	~~10~~	**50**	~~20~~	50	
Y := Y+10	10	**60**	10	50	20	50	
write(Y)	10	60	~~10~~	**60**	20	50	
output(X)	10	60	10	~~60~~	**10**	50	
output(Y)	10	60	10	60	~~10~~	**60**	

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Logging

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Logging

Main approach to recovering from a system crash relies on a persistent record of changes made during a transaction

Append-only files used by log manager to record events

Three main approaches to logging:

- Undo Logging
- Redo Logging
- Undo/Redo Logging

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Log Records

<start *T*>
Transaction T has started execution

<commit *T*>
Transaction T has completed successfully and will make no further changes to database items

<abort *T*>
Transaction T could not complete successfully. No changes made by T will be copied to disk.

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Undo Logging

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Undo Logging

Repair a database following a system crash by undoing the effects of transactions that were incomplete at the time of the crash

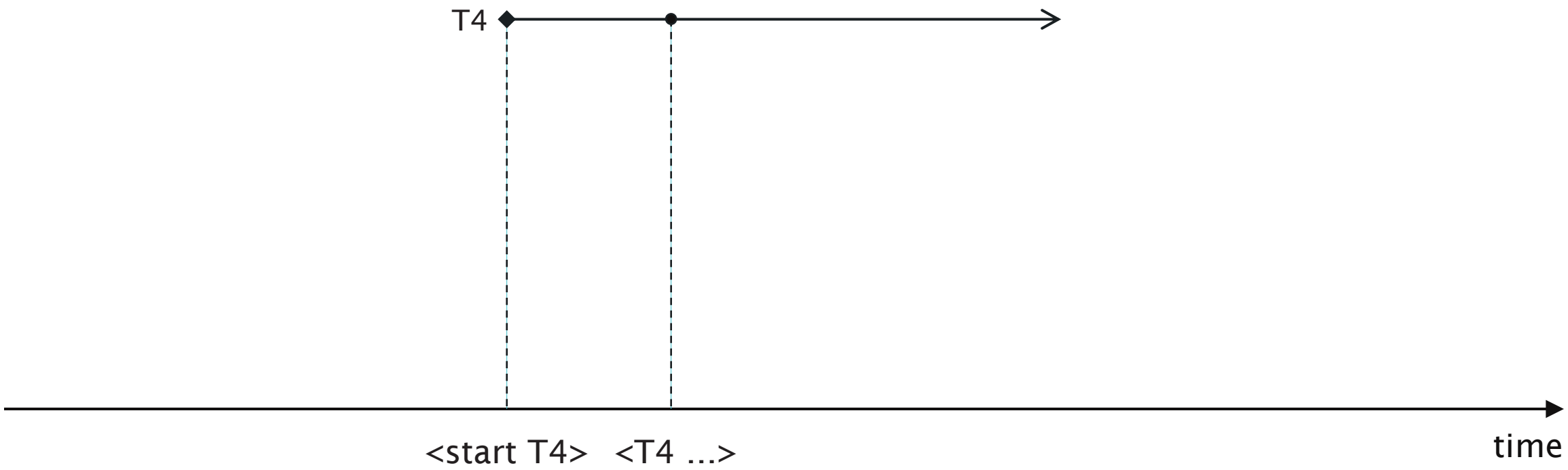
Introduces a new record type to record changes:

<T, X, old>
Transaction T has changed database item X from its old value

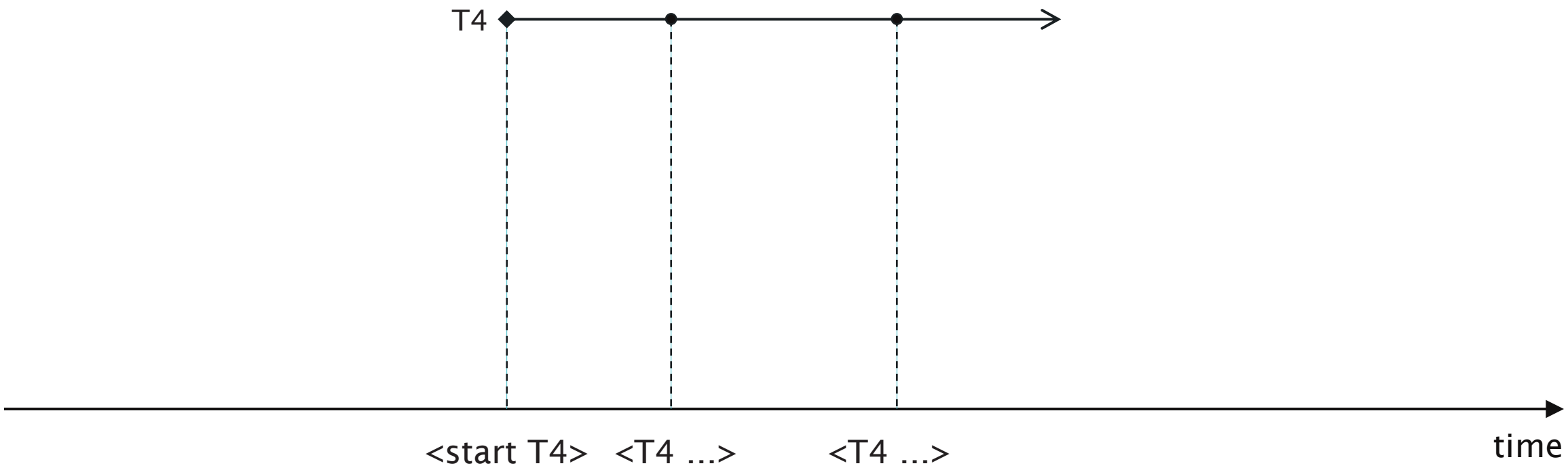
Undo Logging

Undo Logging

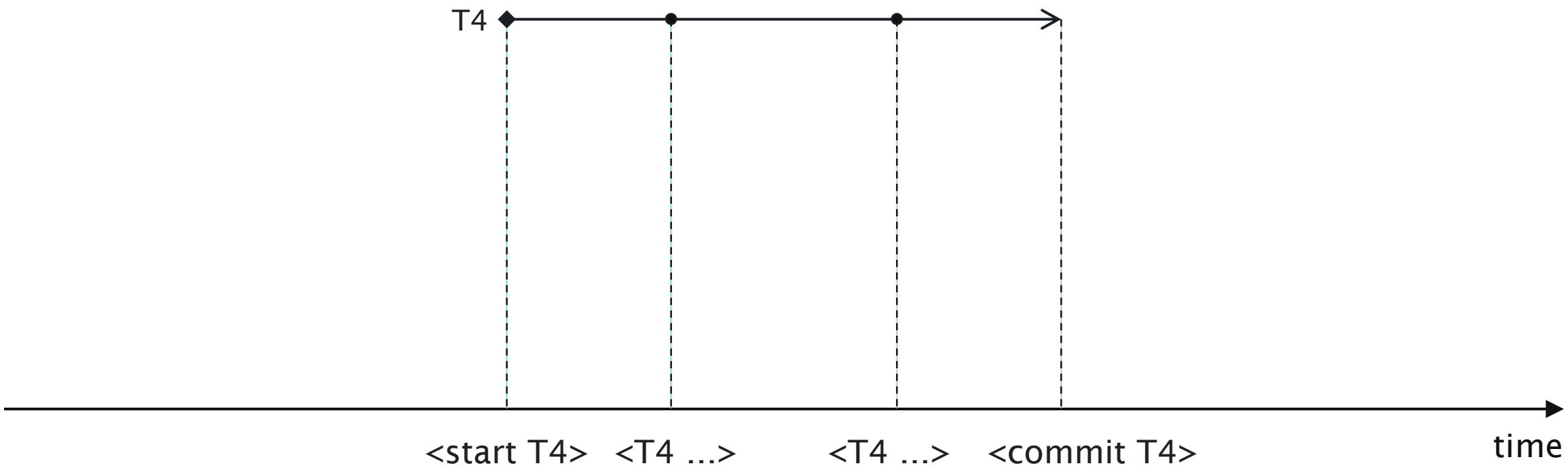
Undo Logging



Undo Logging



Undo Logging



Undo Logging Rules

U1: If transaction T modifies database item X, then a log record of the form <T, X, old> must be written to disk **before** the new value of X is output to disk

U2: If a transaction T commits, then its <commit T> log record must be written to disk only **after** all database items changed by T have been output to disk (but then as soon as possible)

Action	X	Y	X_m	Y_m	X_d	Y_d	Log
					20	50	<start T>
read(X)	**20**		**20**		20	50	
X := X – 10	**10**		20		20	50	
write(X)	10		**10**		20	50	<T, X, 20>
read(Y)	10	**50**	10	**50**	20	50	
Y := Y+10	10	**60**	10	50	20	50	
write(Y)	10	60	10	**60**	20	50	<T, Y, 50>
flush log							
output(X)	10	60	10	60	**10**	50	
output(Y)	10	60	10	60	10	**60**	
							<commit T>
flush log							

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Recovery with Undo Logging

```
foreach log entry <T, X, old>, scanning backwards {
      if <commit T> has been seen {
            do nothing
      } else {
            change the value of X in the database back to old
      }
}
foreach incomplete transaction T (that was not aborted) {
      write <abort T> to log
}
flush log
```

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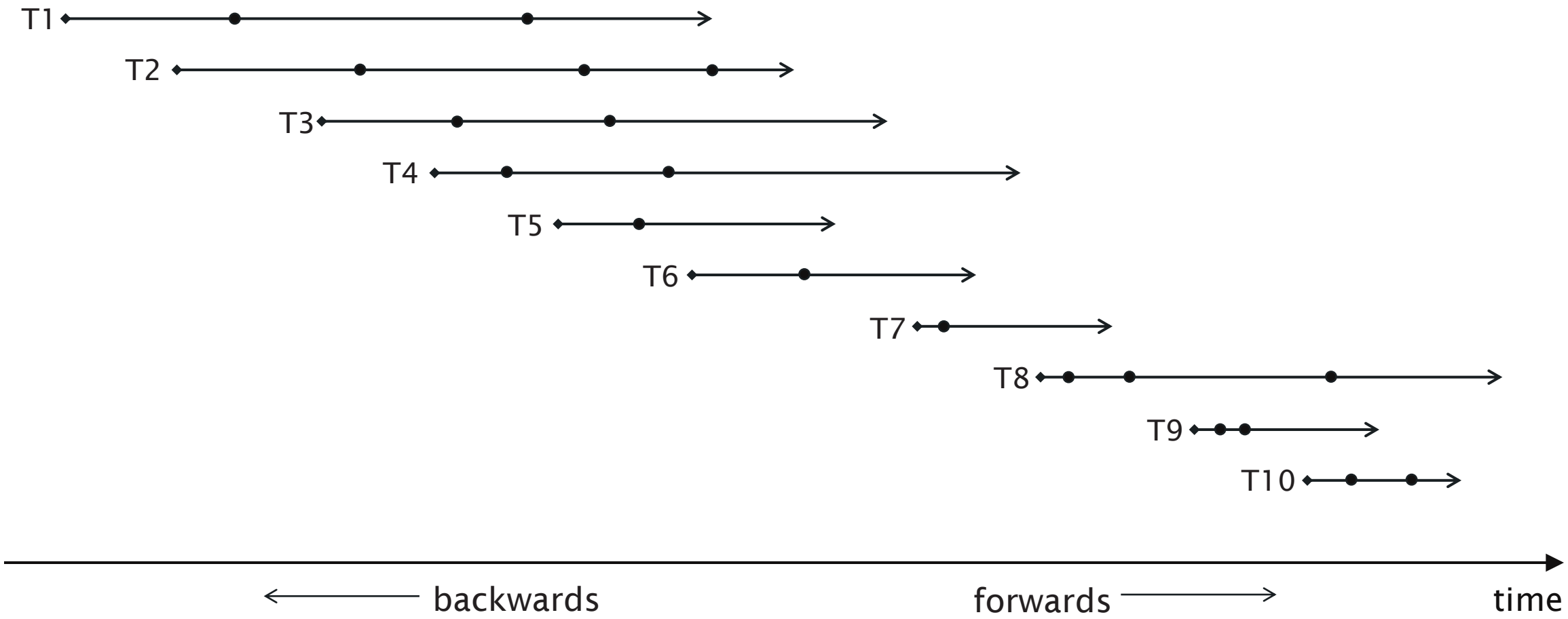
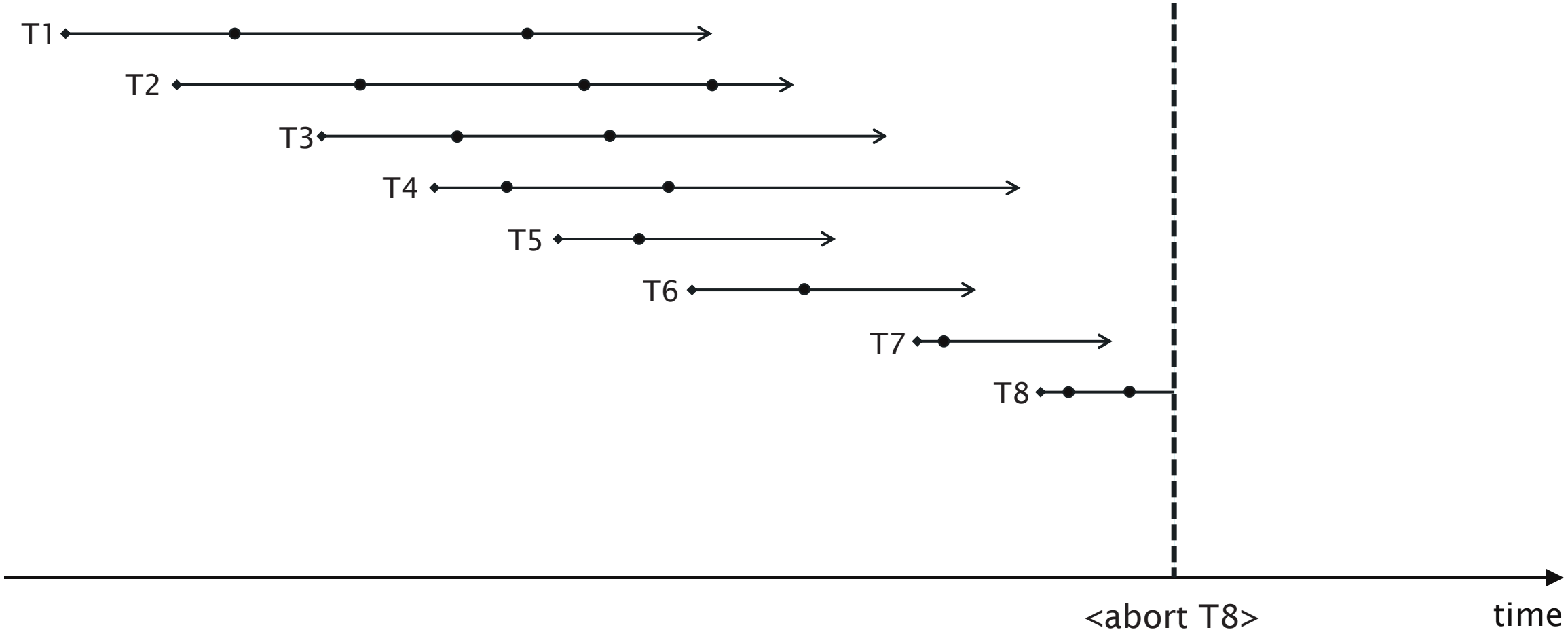
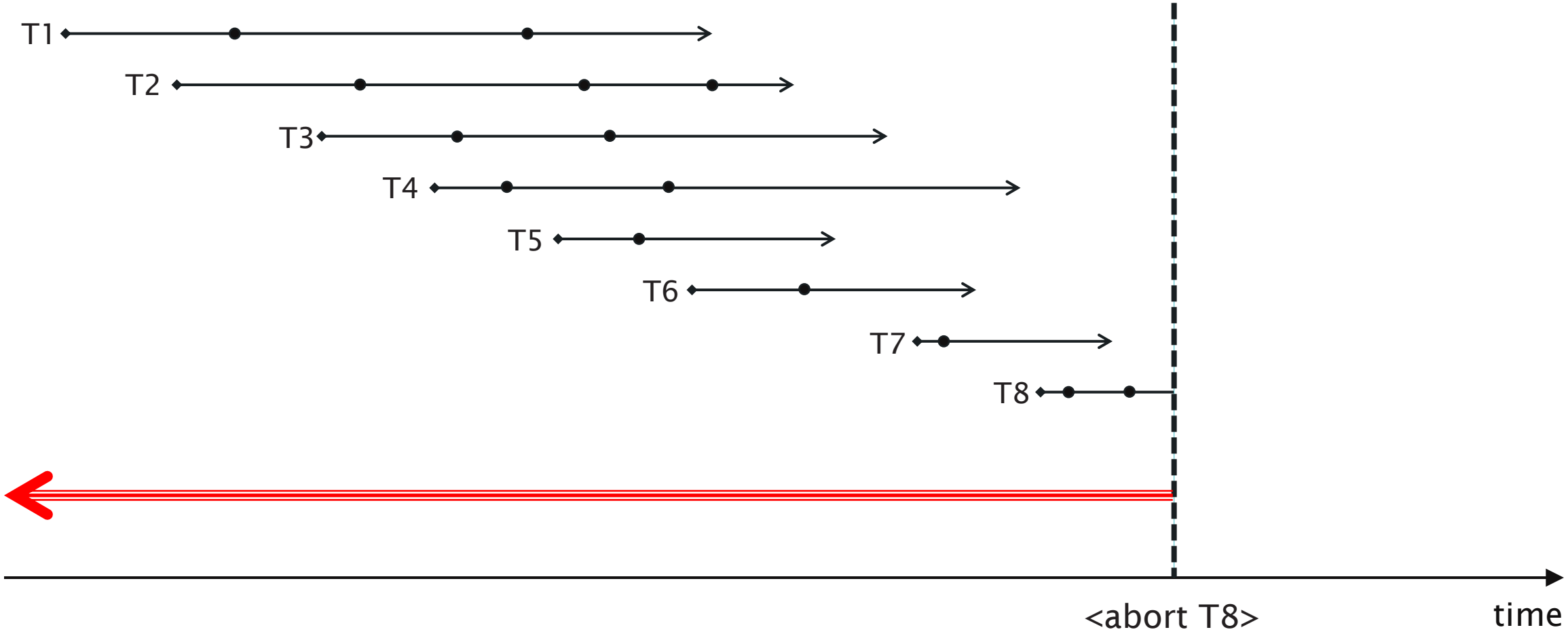
Recovery with Undo Logging



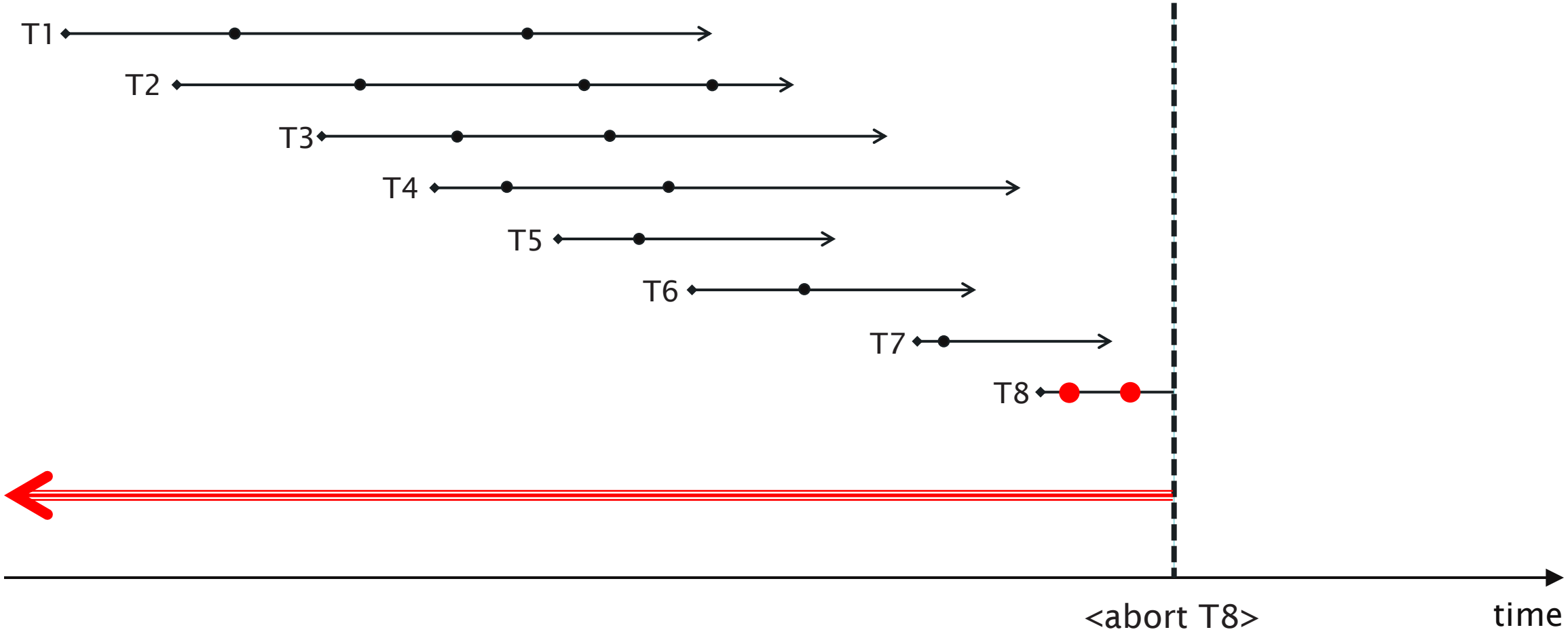
Recovery with Undo Logging



Recovery with Undo Logging



Recovery with Undo Logging



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Undo Logging with Checkpointing

Disadvantage of this approach: we must scan the entire log

Introduce a periodic checkpoint in the log

- Before checkpoint, all transactions have committed or aborted
- Only need search backwards through the log to the most recent checkpoint

New log record type:

<ckpt>
The database has been checkpointed

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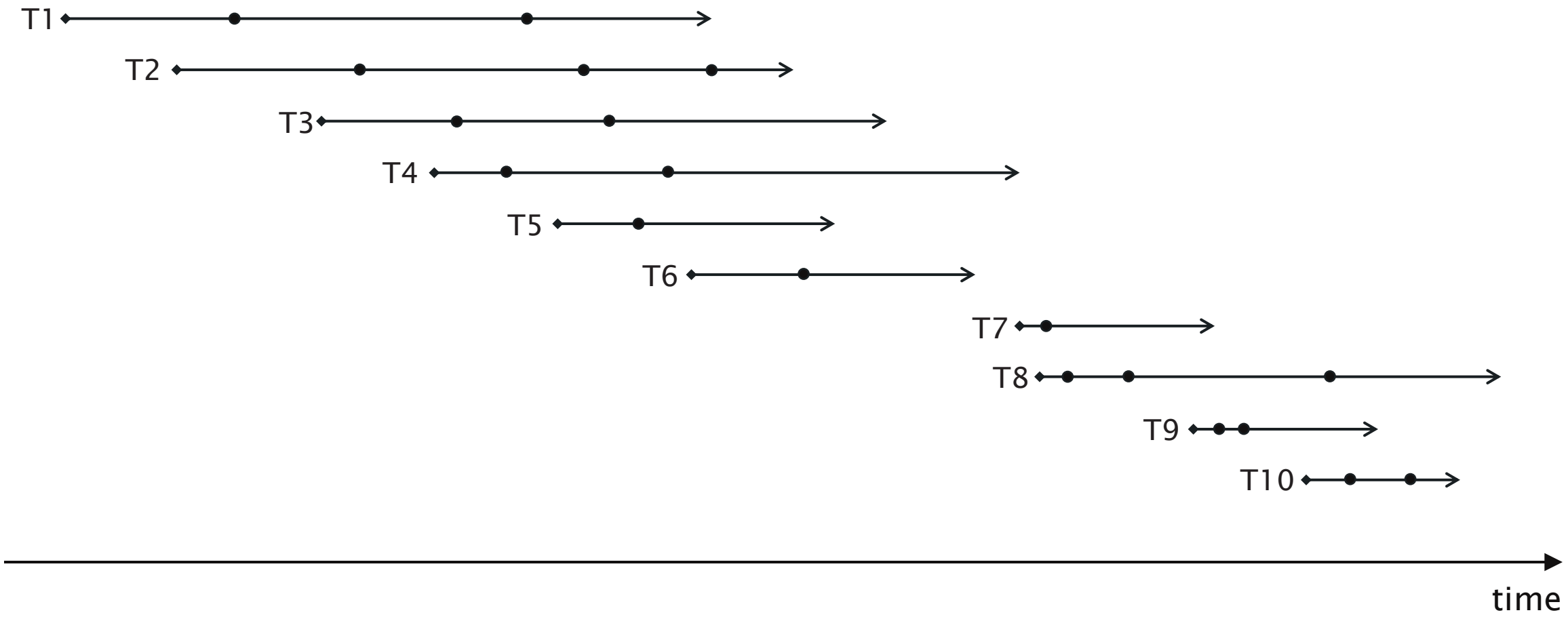
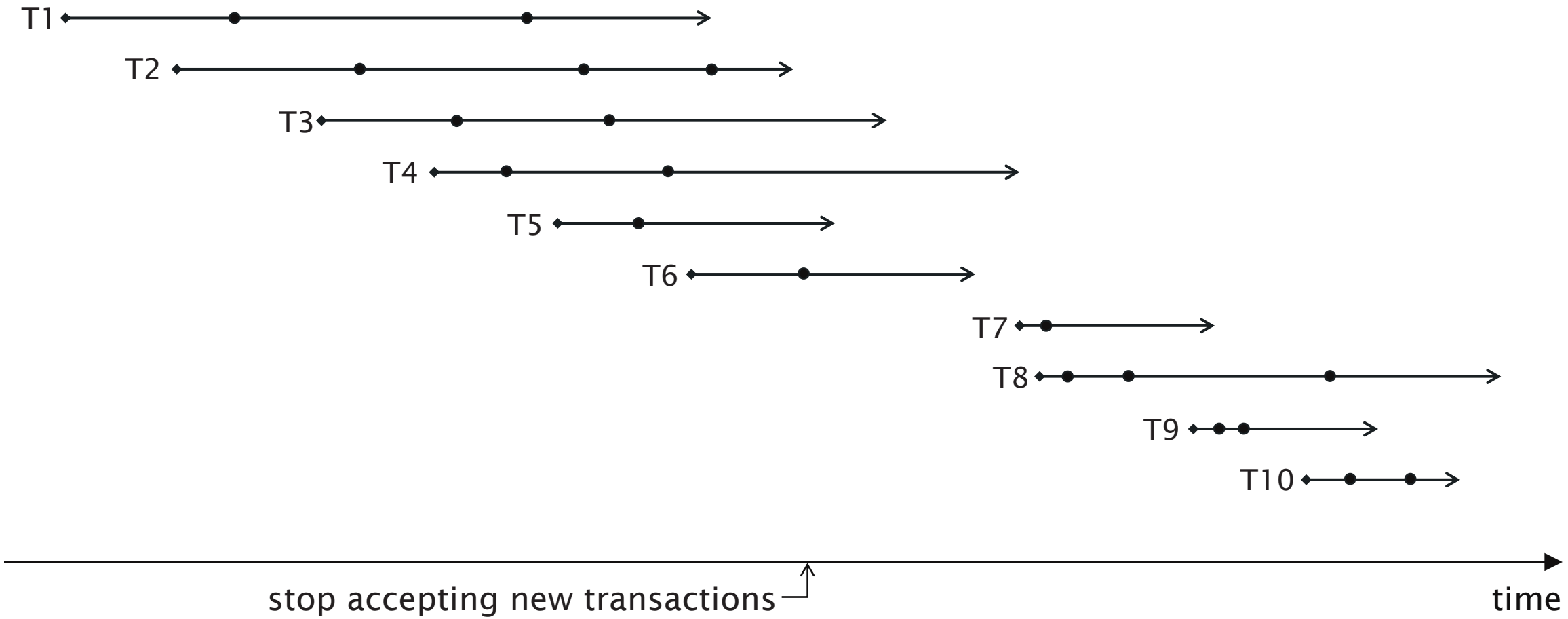
Checkpointing

1. Stop accepting new transactions
2. Wait until all active transactions commit/abort and write <commit T>/<abort T> to the log
3. flush log
4. write <ckpt> to log
5. flush log
6. Resume accepting transactions

Recovery with Checkpointed Undo Logging



Recovery with Checkpointed Undo Logging



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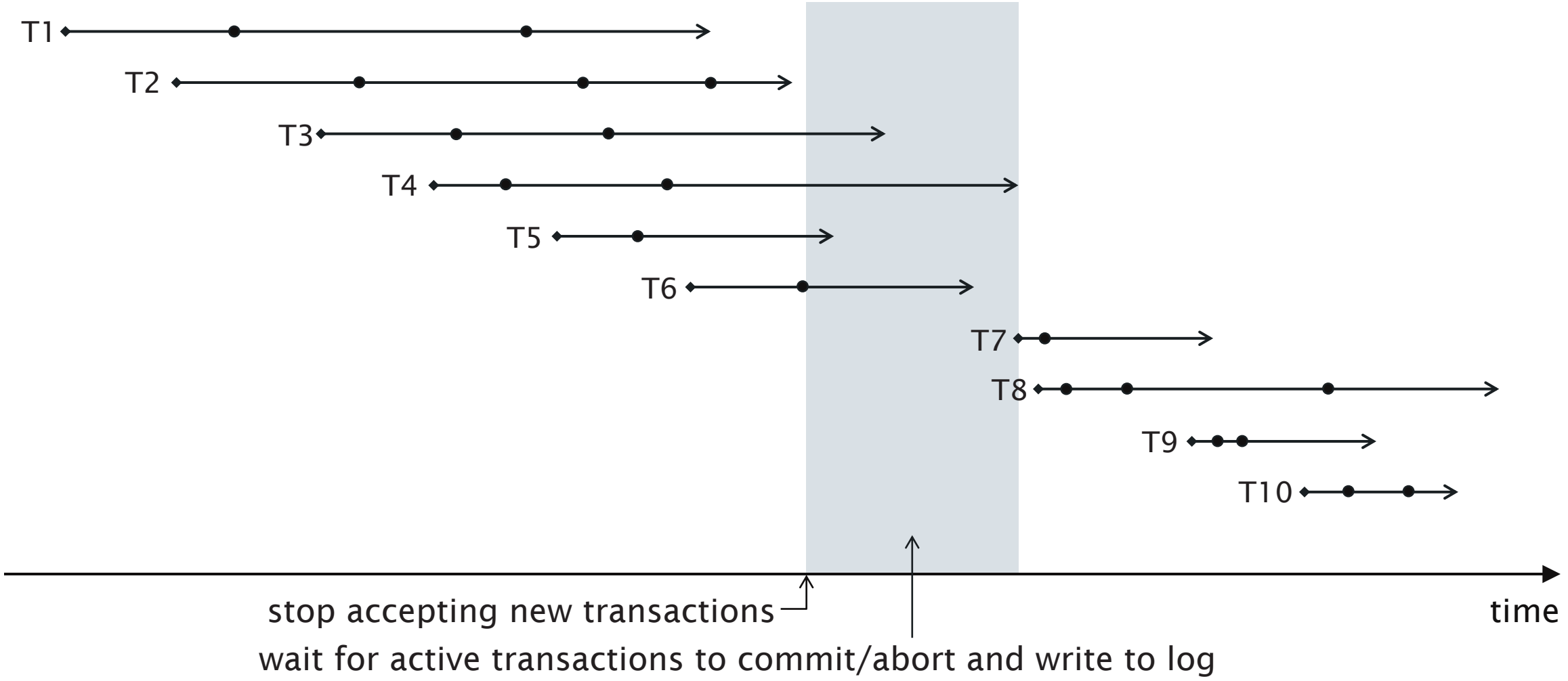
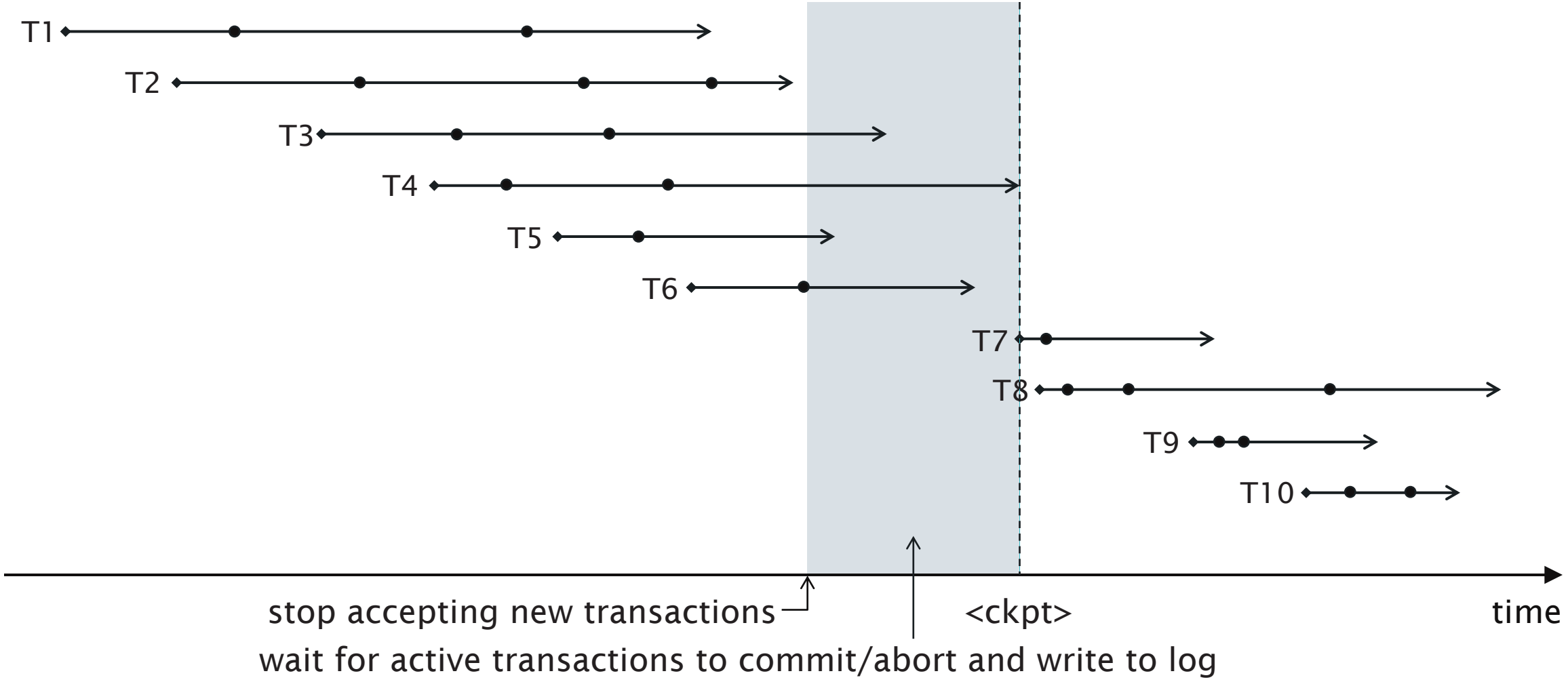
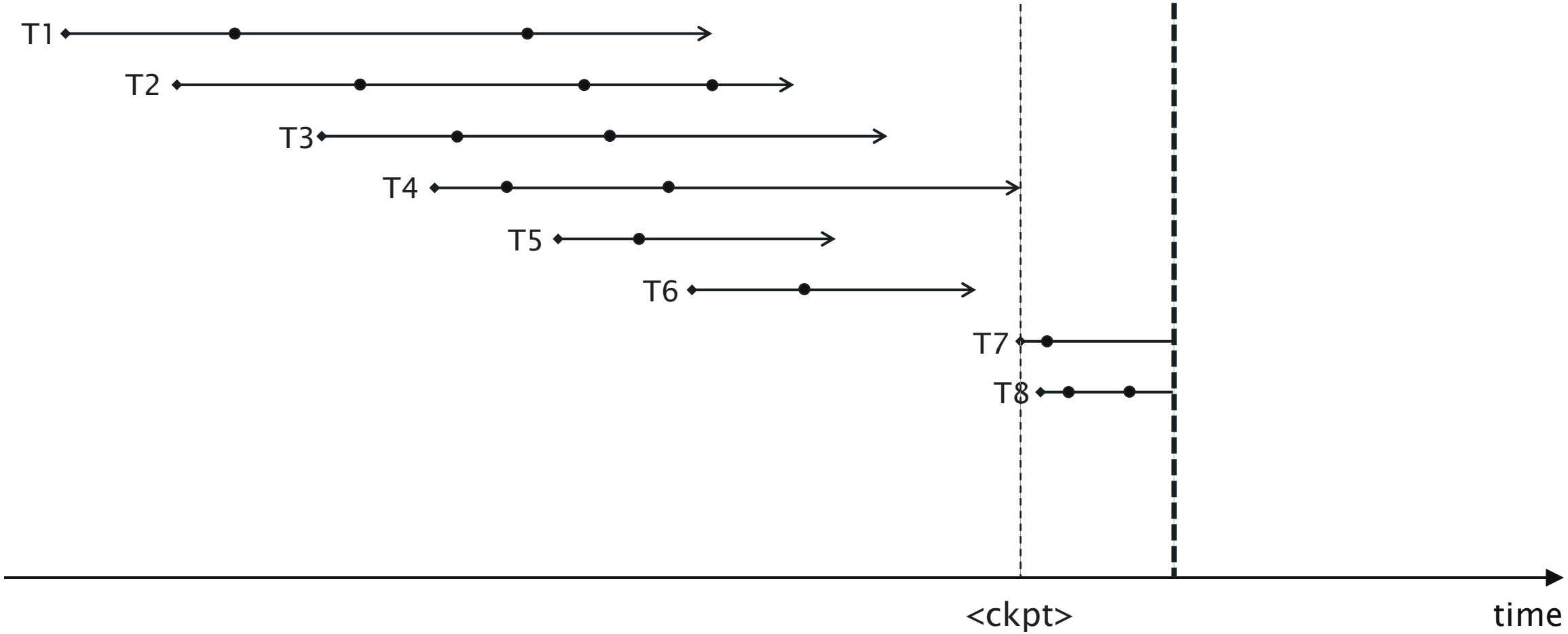
Recovery with Checkpointed Undo Logging



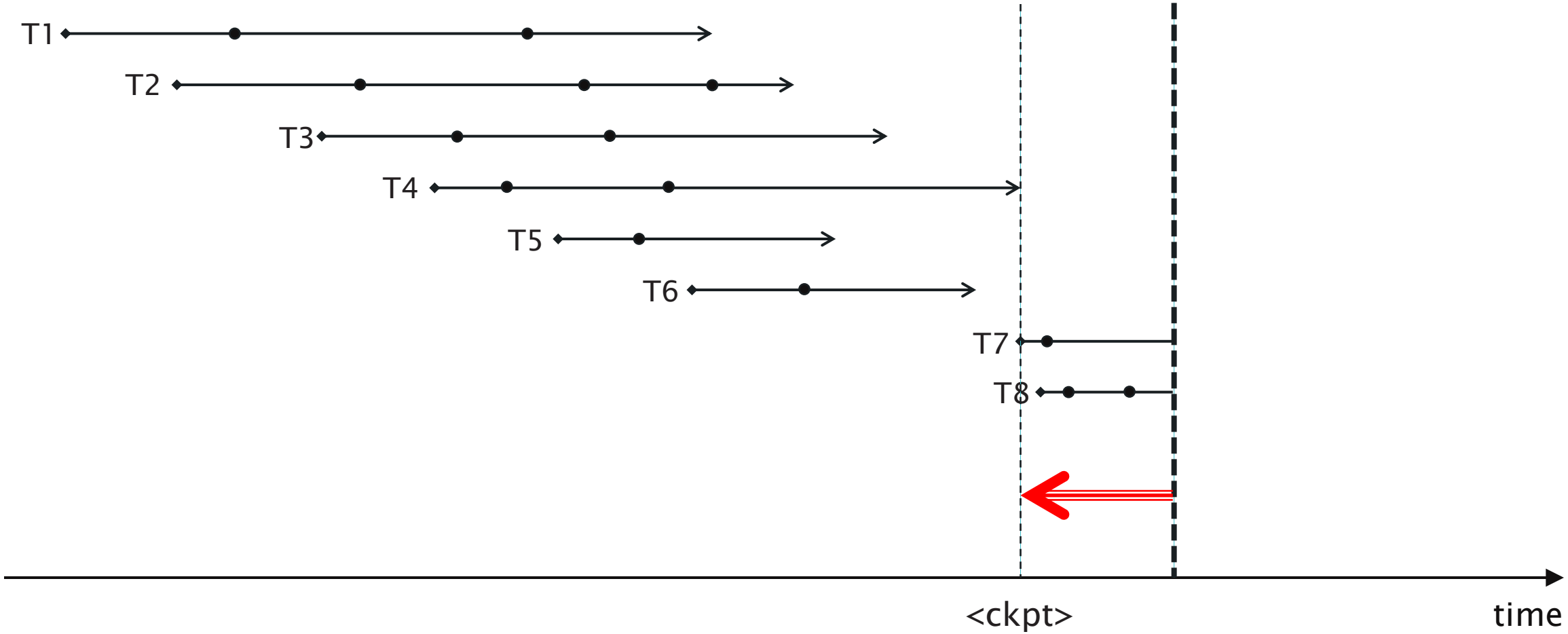
Recovery with Checkpointed Undo Logging



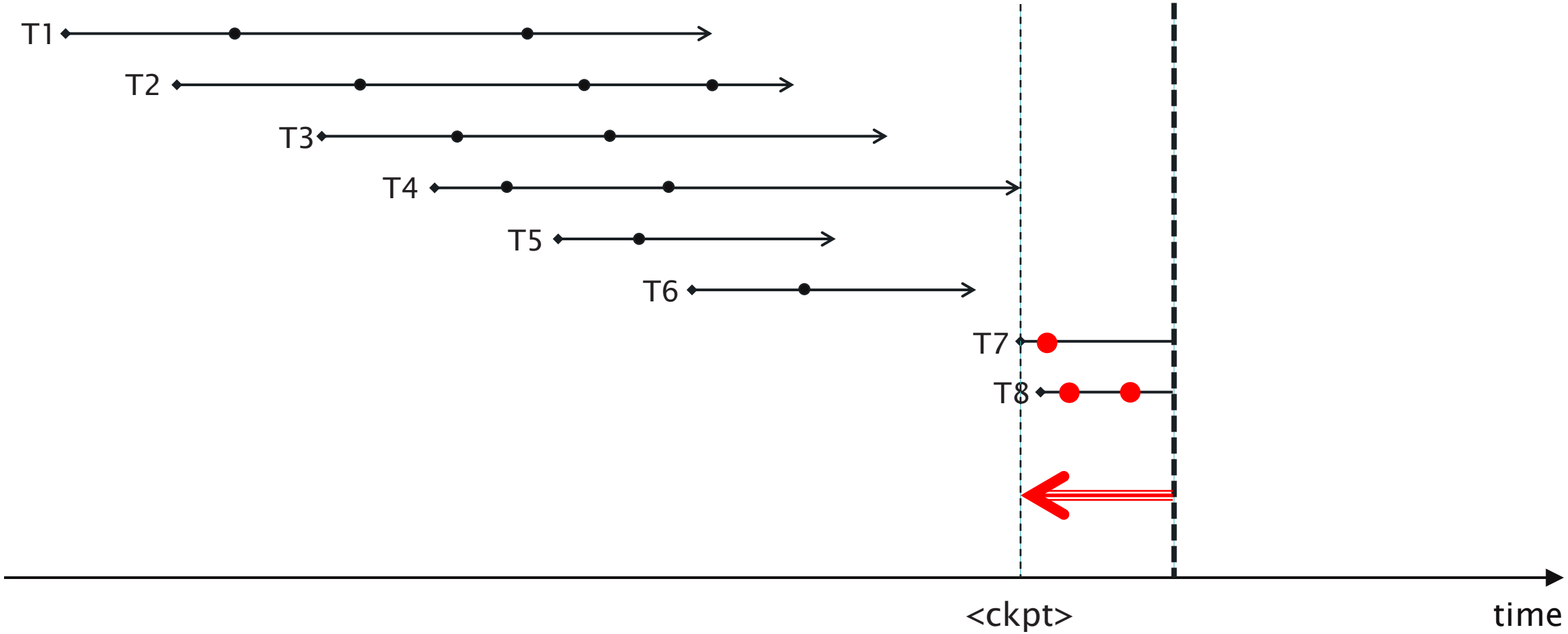
Recovery with Checkpointed Undo Logging



Recovery with Checkpointed Undo Logging



Recovery with Checkpointed Undo Logging



Nonquiescent Checkpointing

Need to stop transaction processing while checkpointing

- System may appear to stall
- Allow new transactions to enter the system during the checkpoint.

New log record types:

<start ckpt (T1…Tn)>
Checkpoint starts. T1…Tn are active transactions that have not yet committed

<end ckpt>
Checkpoint ends

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Nonquiescent Checkpointing

1. Write <start ckpt (T1…Tn)> to log and flush log
2. Wait until T1..Tn have all committed or aborted
3. Write <end ckpt> to log and flush log

Note that new transactions may be started during step 2

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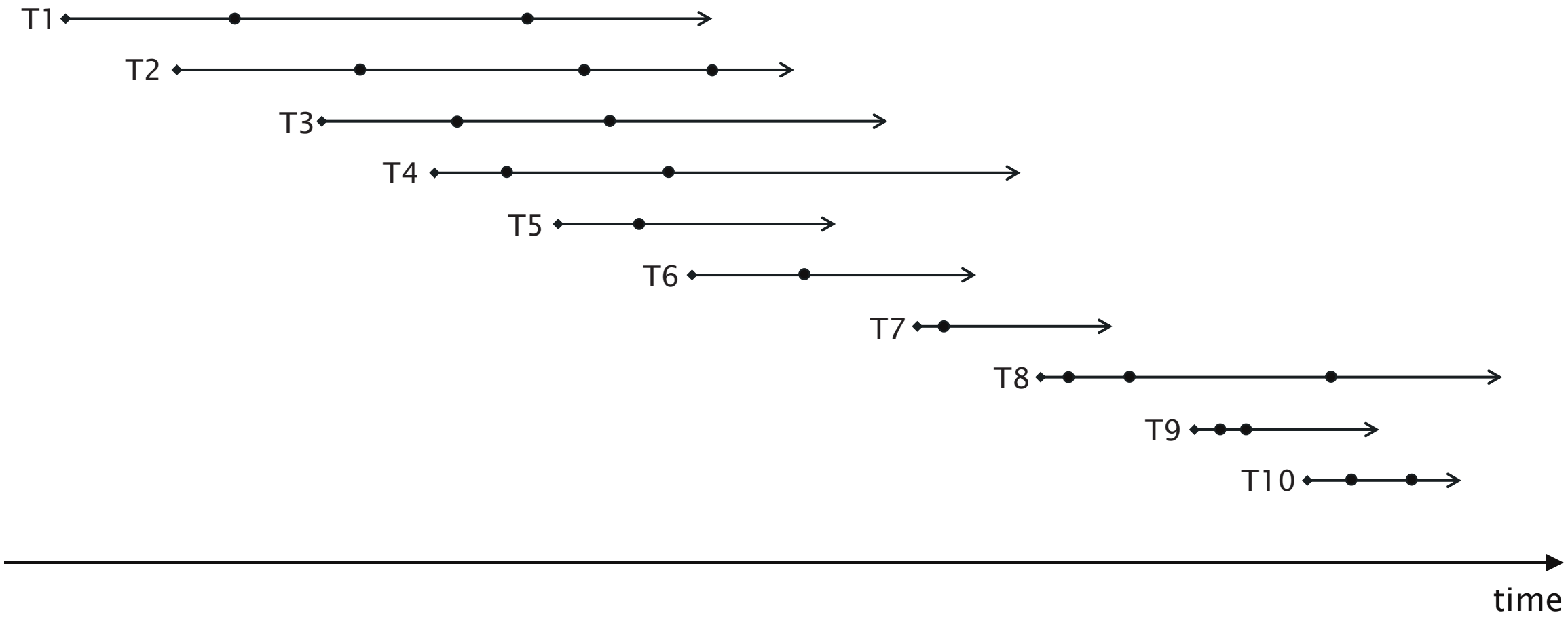
Nonquiescent Checkpointing



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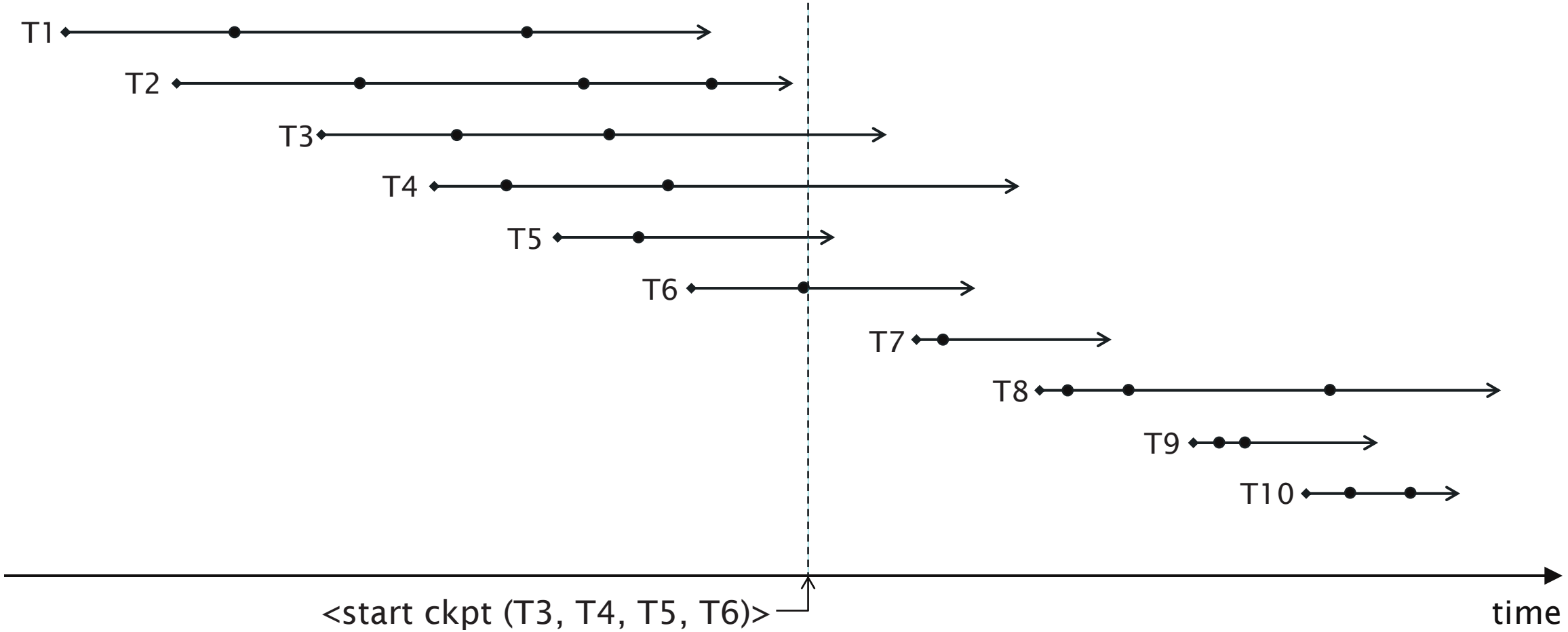
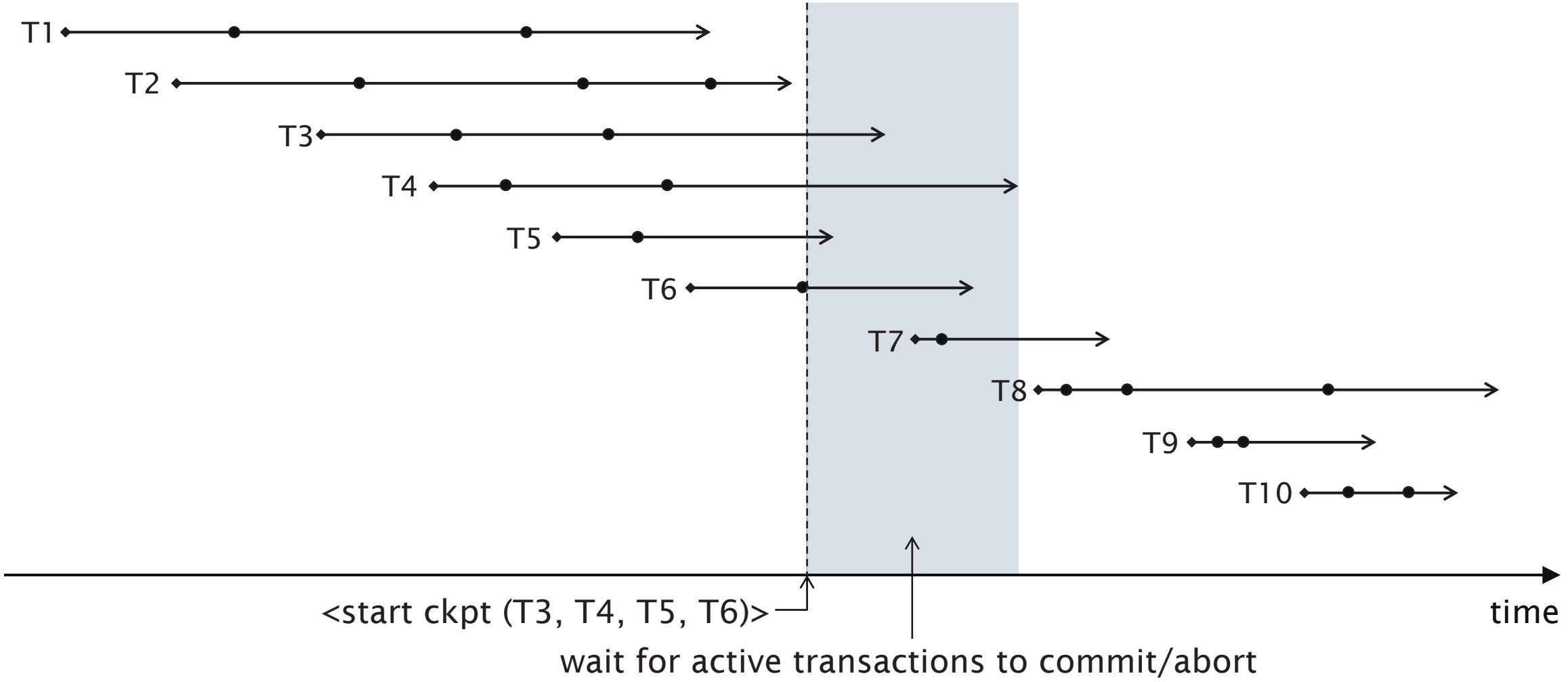
Nonquiescent Checkpointing



Nonquiescent Checkpointing



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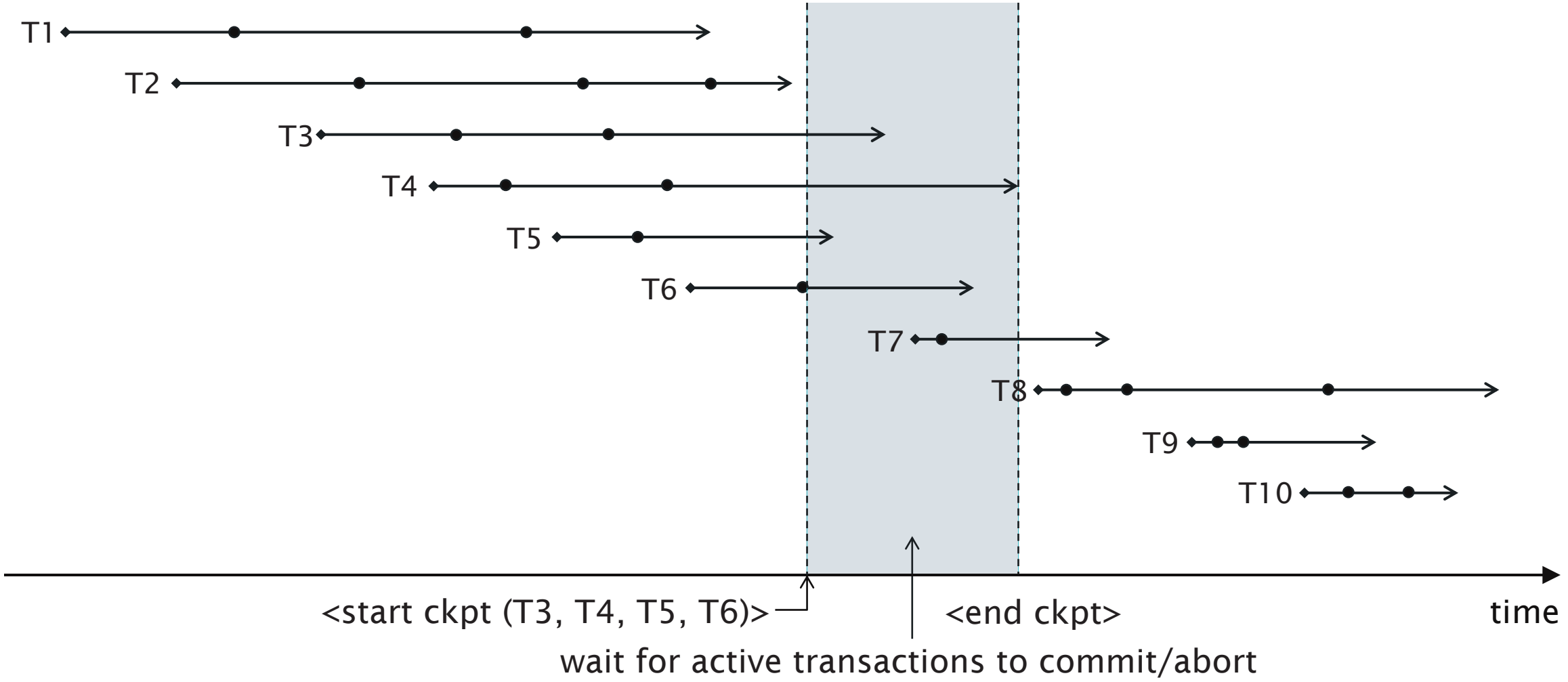
Nonquiescent Checkpointing



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Recovery with Checkpointed Undo Logging

Two cases for recovery depending on latest checkpoint log record:

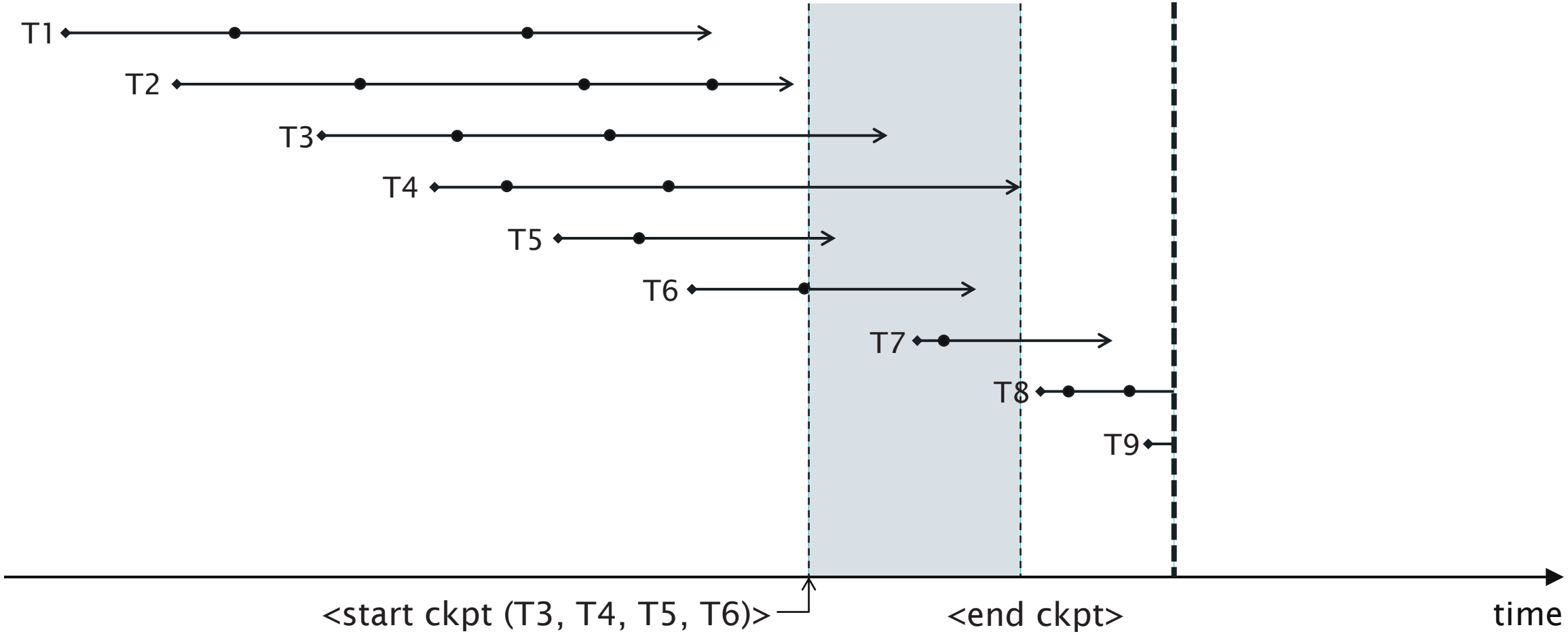
- **<end ckpt>**
- **<start ckpt (T1…Tn)>**

Recovery with Checkpointed Undo Logging

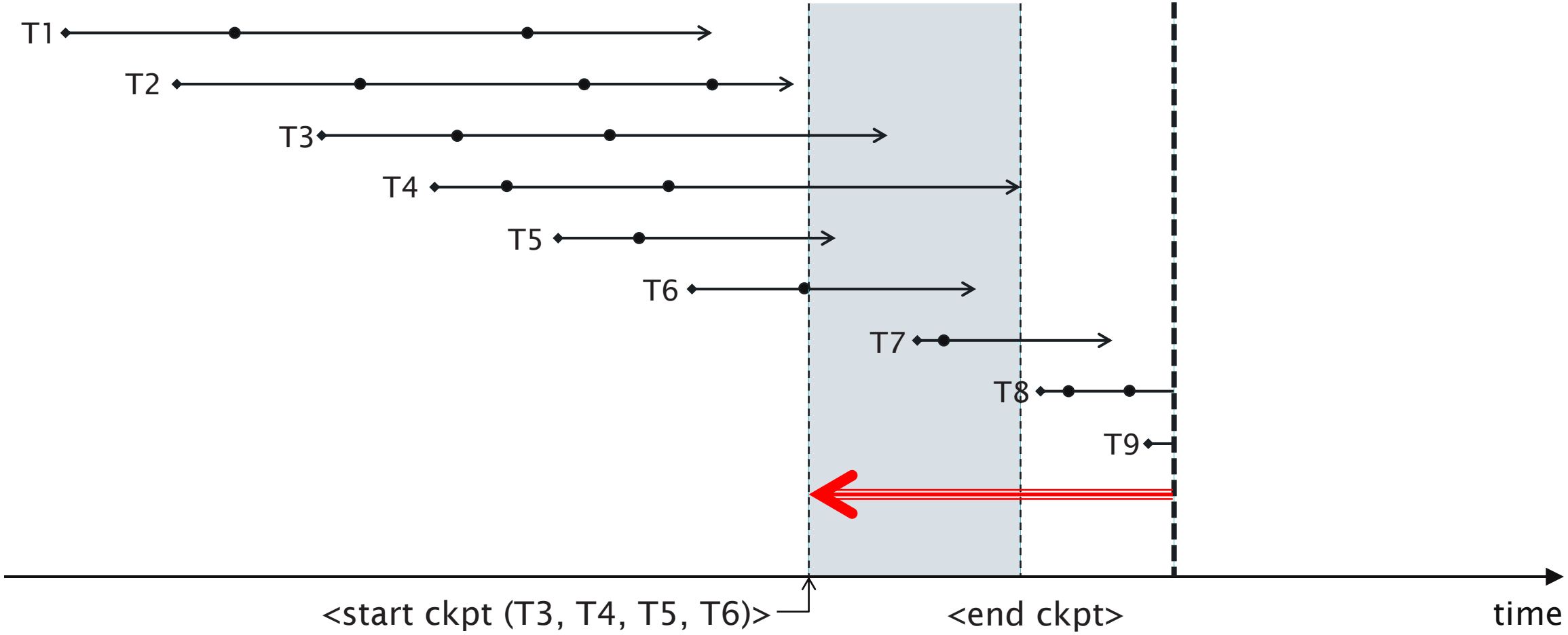
<end ckpt> appears latest

- All incomplete transactions began after the previous <start ckpt (...)>
- Disregard the log before the previous <start ckpt (...)>

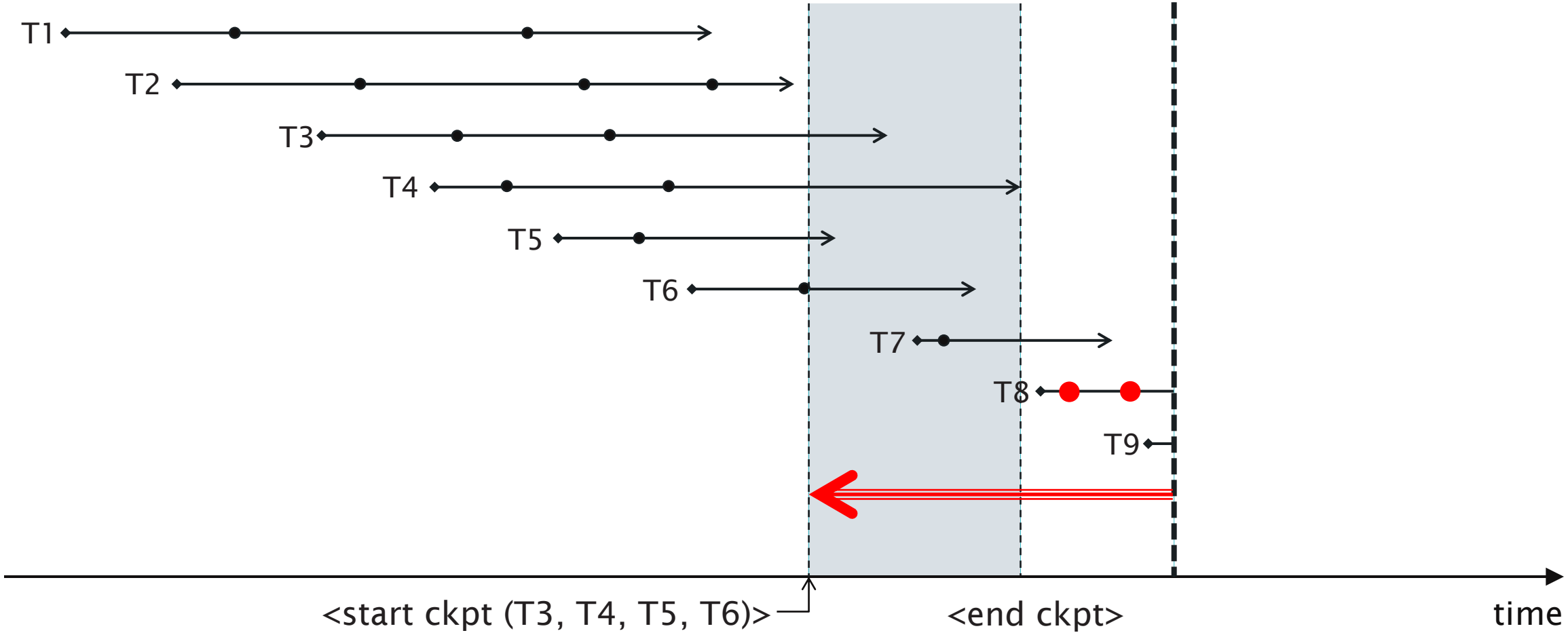
Recovery with Checkpointed Undo Logging



Recovery with Checkpointed Undo Logging



Recovery with Checkpointed Undo Logging

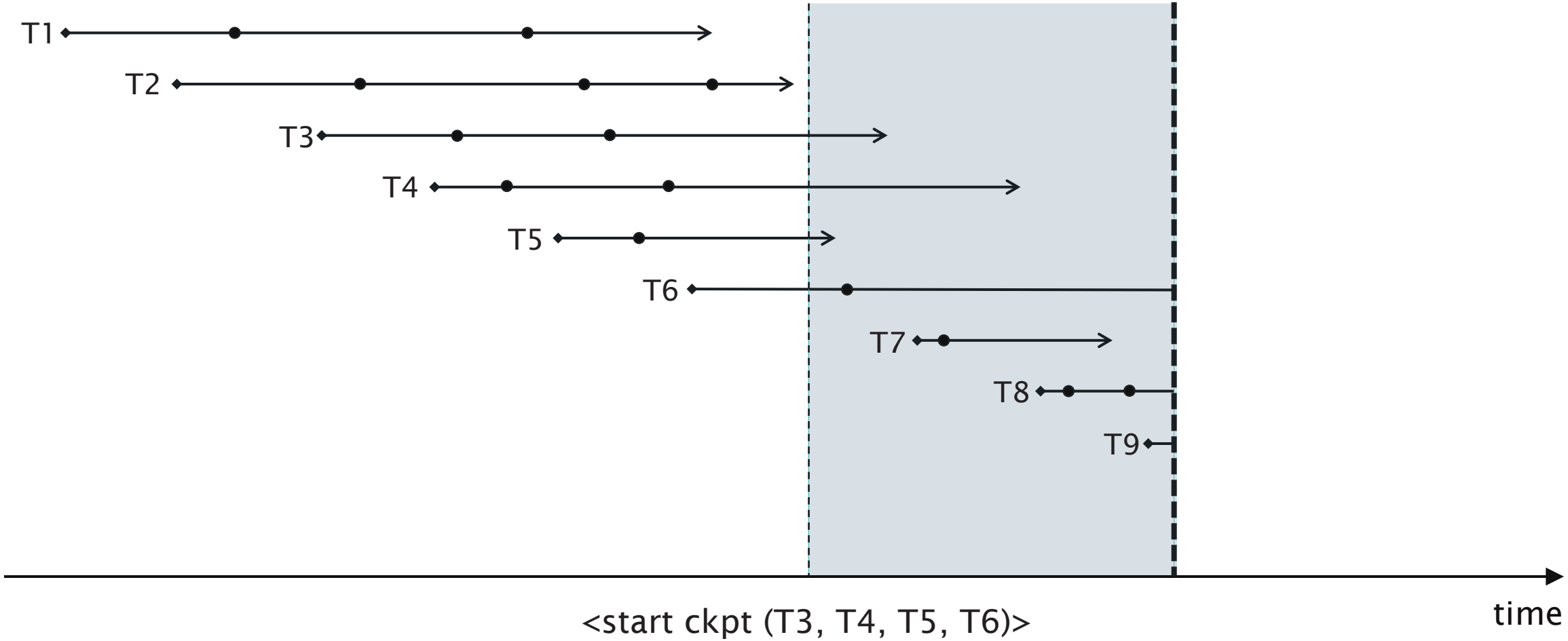


Recovery with Checkpointed Undo Logging

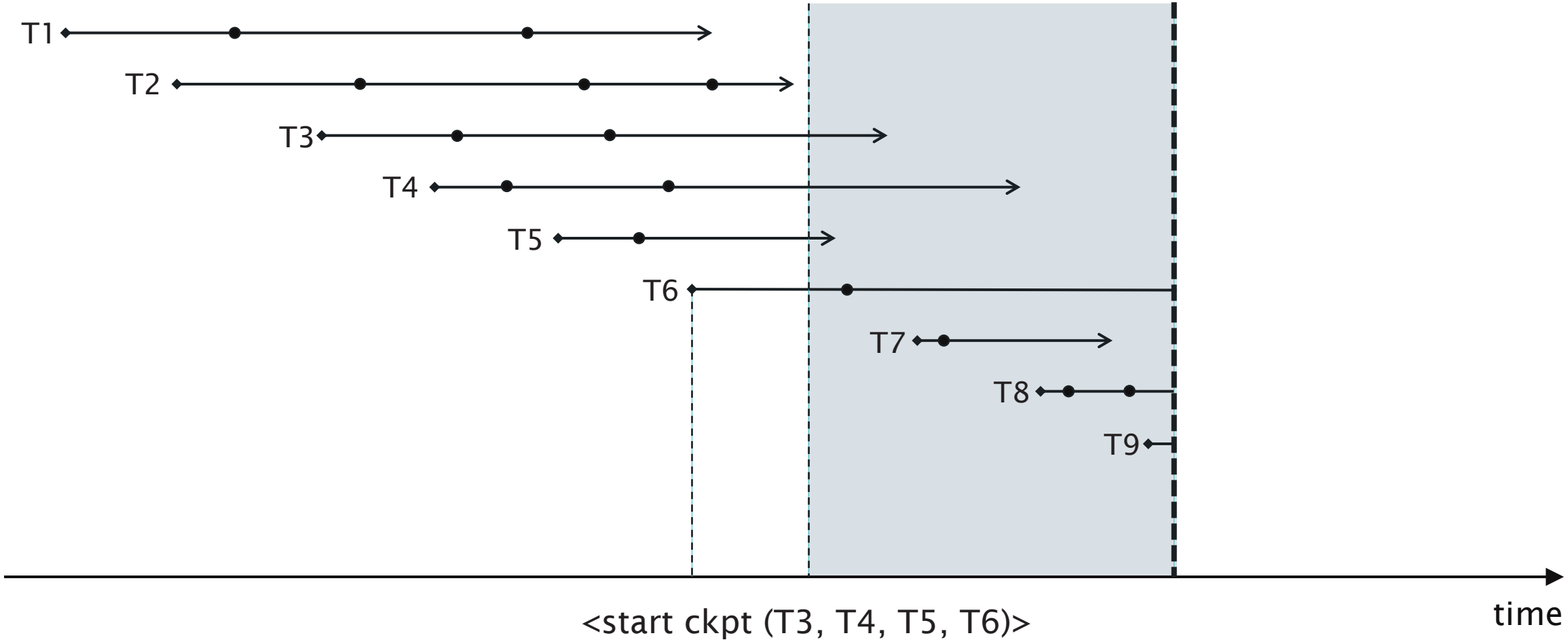
<start ckpt (T1…Tn)> appears latest

- System crash occurred during checkpoint
- Incomplete transactions are those encountered after the <start ckpt (…)> and those of T1…Tn that were not committed before the crash
- Disregard the log before the start of the earliest incomplete transaction

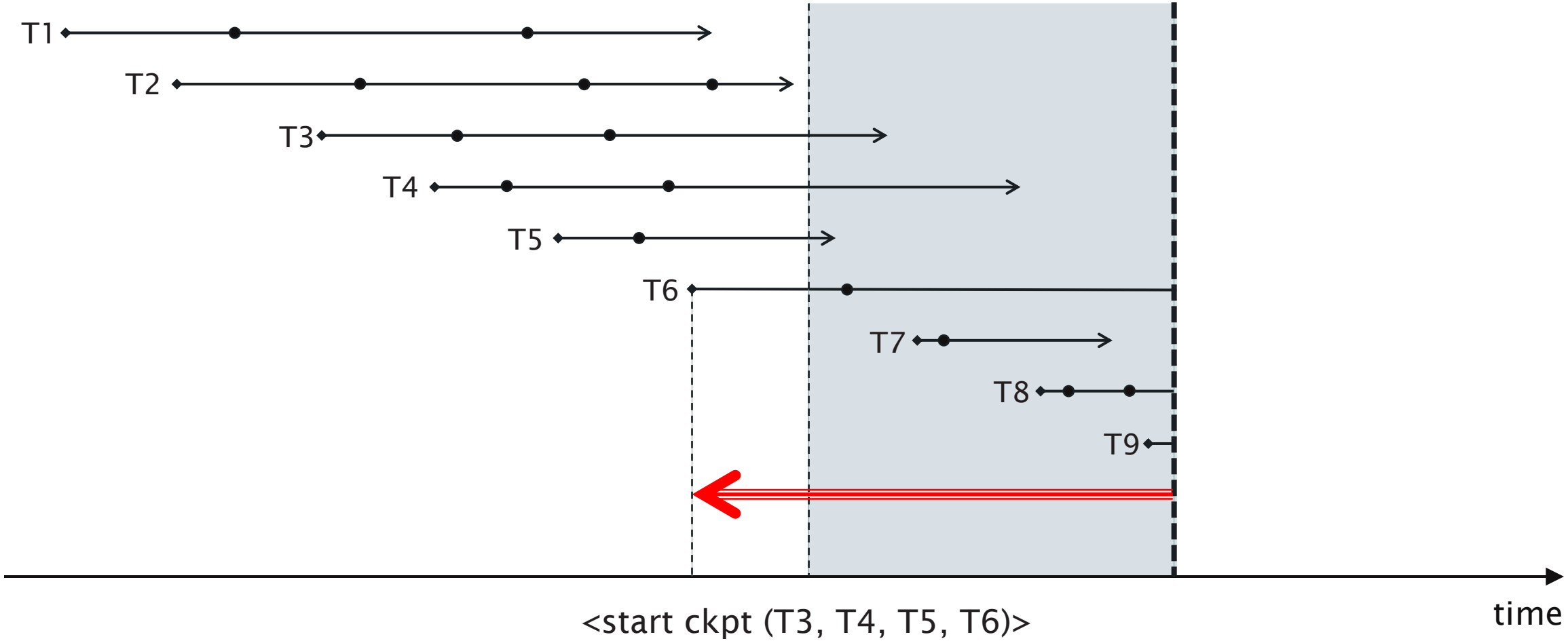
Recovery with Checkpointed Undo Logging



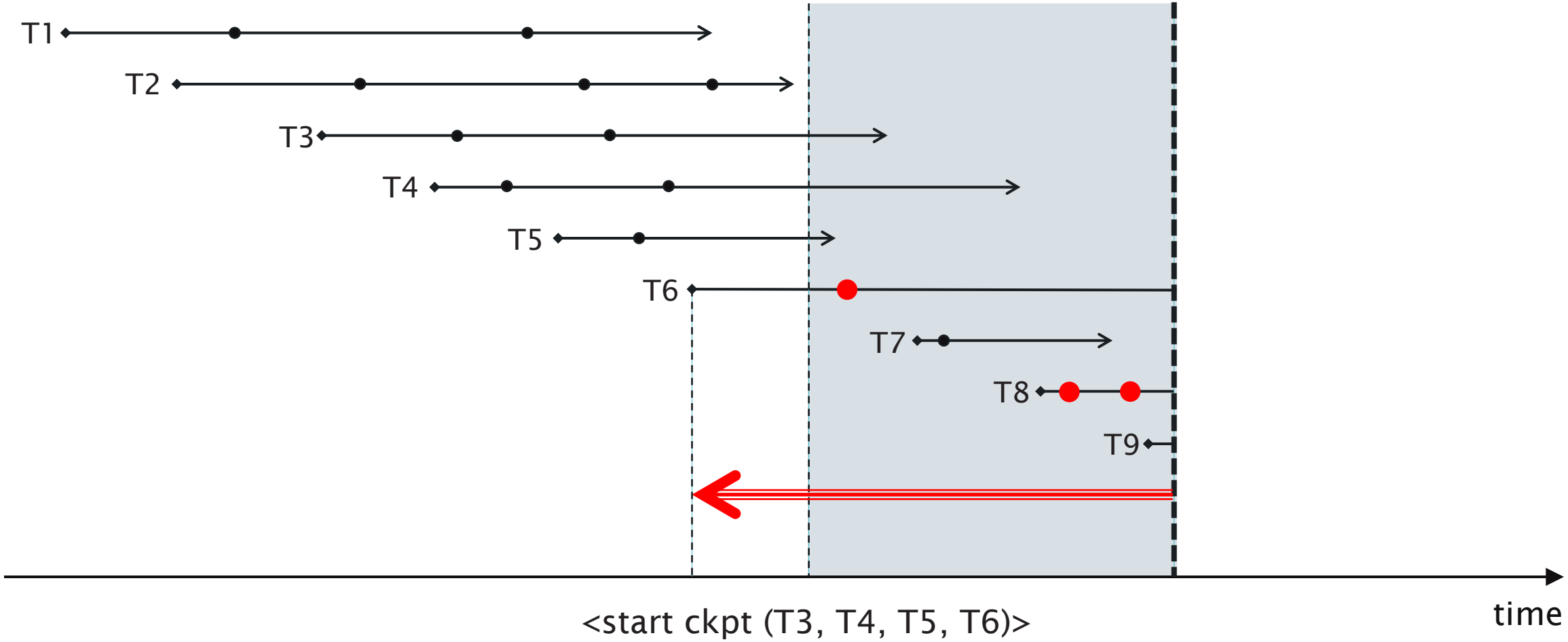
Recovery with Checkpointed Undo Logging



Recovery with Checkpointed Undo Logging



Recovery with Checkpointed Undo Logging



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Redo Logging

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Issues with Undo Logging

U2: If a transaction T commits, then its <commit T> log record must be written to disk only **after** all database items changed by T have been written to disk (but then as soon as possible)

- Potentially causes more disk i/o operations
- Can we let changes reside in buffer memory for longer?

Redo Logging

Ignore incomplete transactions, repeat changes made by committed transactions

Write <commit T> log record to disk **before** changed values are written to disk

- If no <commit T> record has been written, no changes by T have been written to disk

Introduces a different record type to record changes:

<T, X, new>
Transaction T has changed database item X to a new value

Redo Logging Rule

R1: Before modifying a database item X on disk, all log records related to the modification (<T, X, new>, <commit T>) must be written to disk

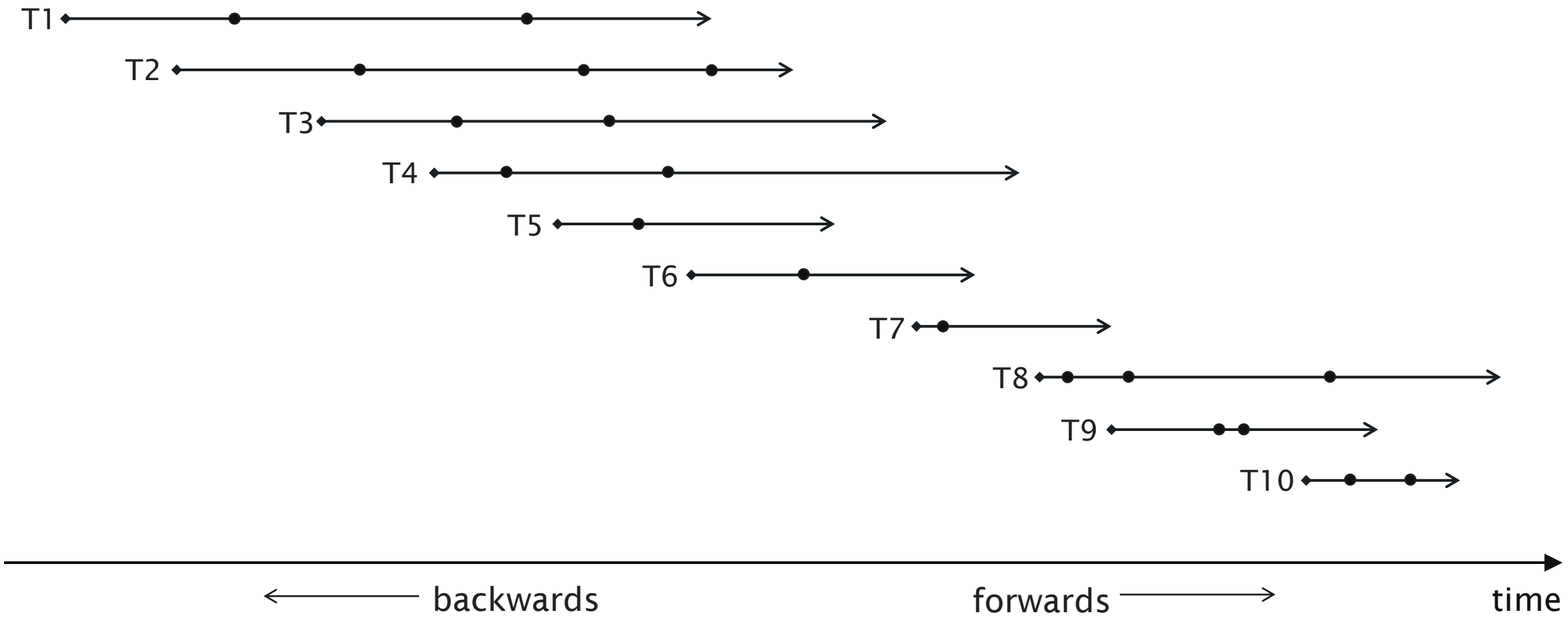
Action	X	Y	X_m	Y_m	X_d	Y_d	Log
					20	50	<start T>
read(X)	**20**		**20**		20	50	
X := X – 10	**10**		20		20	50	
write(X)	10		**10**		20	50	<T, X, 10>
read(Y)	10	**50**	10	**50**	20	50	
Y := Y+10	10	**60**	10	50	20	50	
write(Y)	10	60	10	**60**	20	50	<T, Y, 60>
							<commit T>
flush log							
output(X)	10	60	10	60	**10**	50	
output(Y)	10	60	10	60	10	**60**	

Recovery with Redo Logging

```
identify the committed transactions

foreach log entry <T, X, new>, scanning forwards {
      if  T is not committed {
            do nothing
      } else {
            write value new for X to the database
      }
}
foreach incomplete transaction T {
      write <abort T> to log
}
flush log
```

Recovery with Redo Logging



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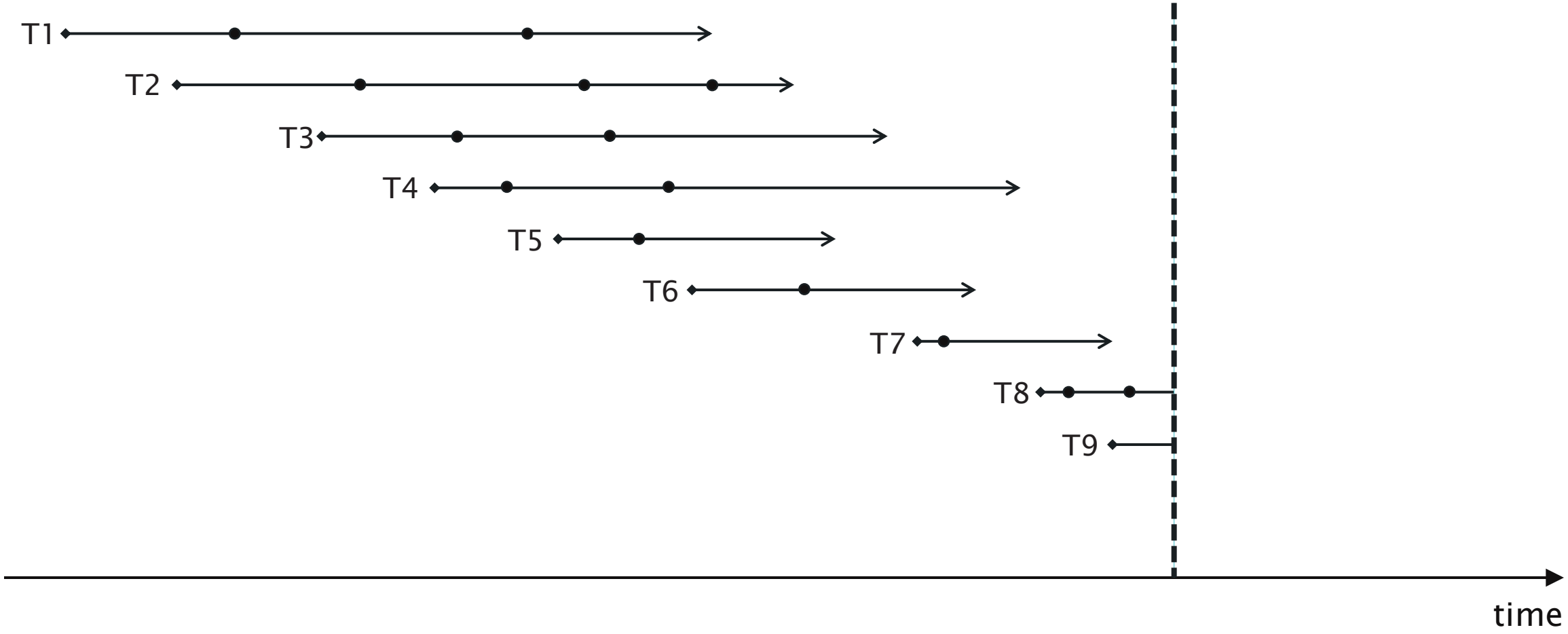
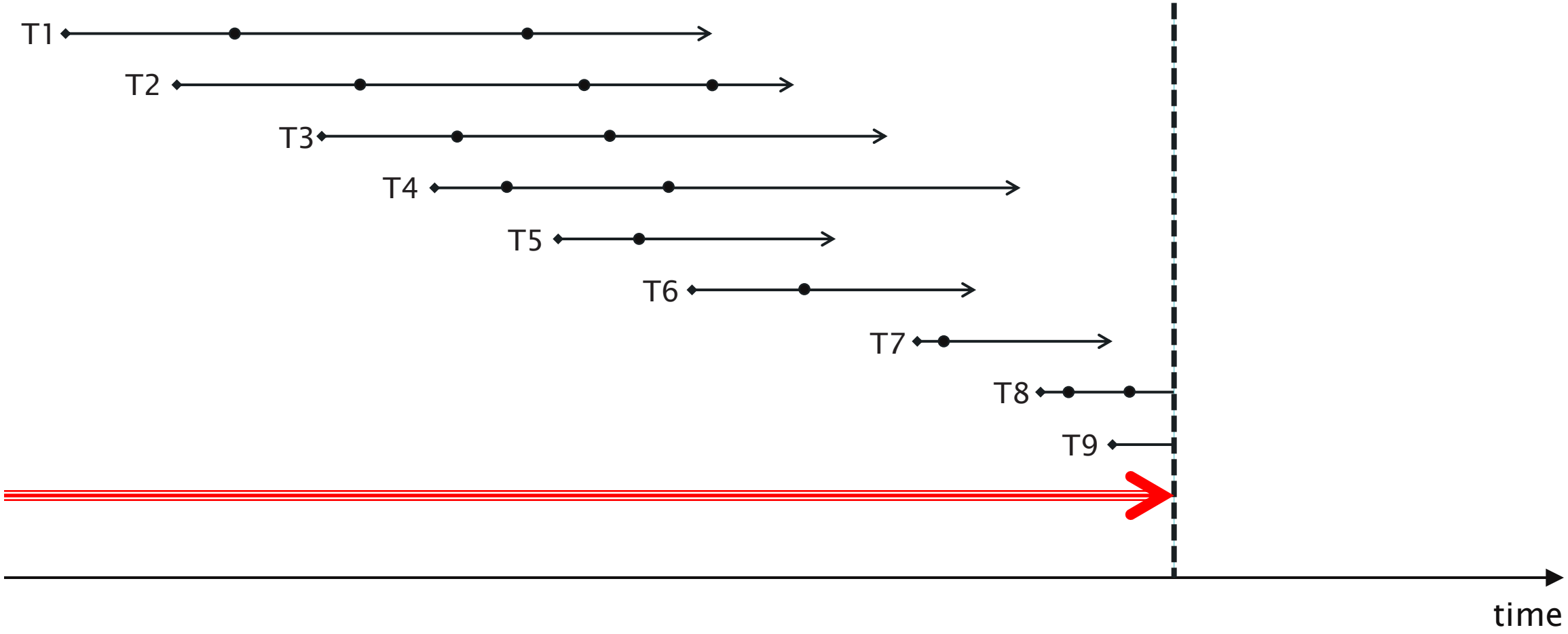
Recovery with Redo Logging



Recovery with Redo Logging



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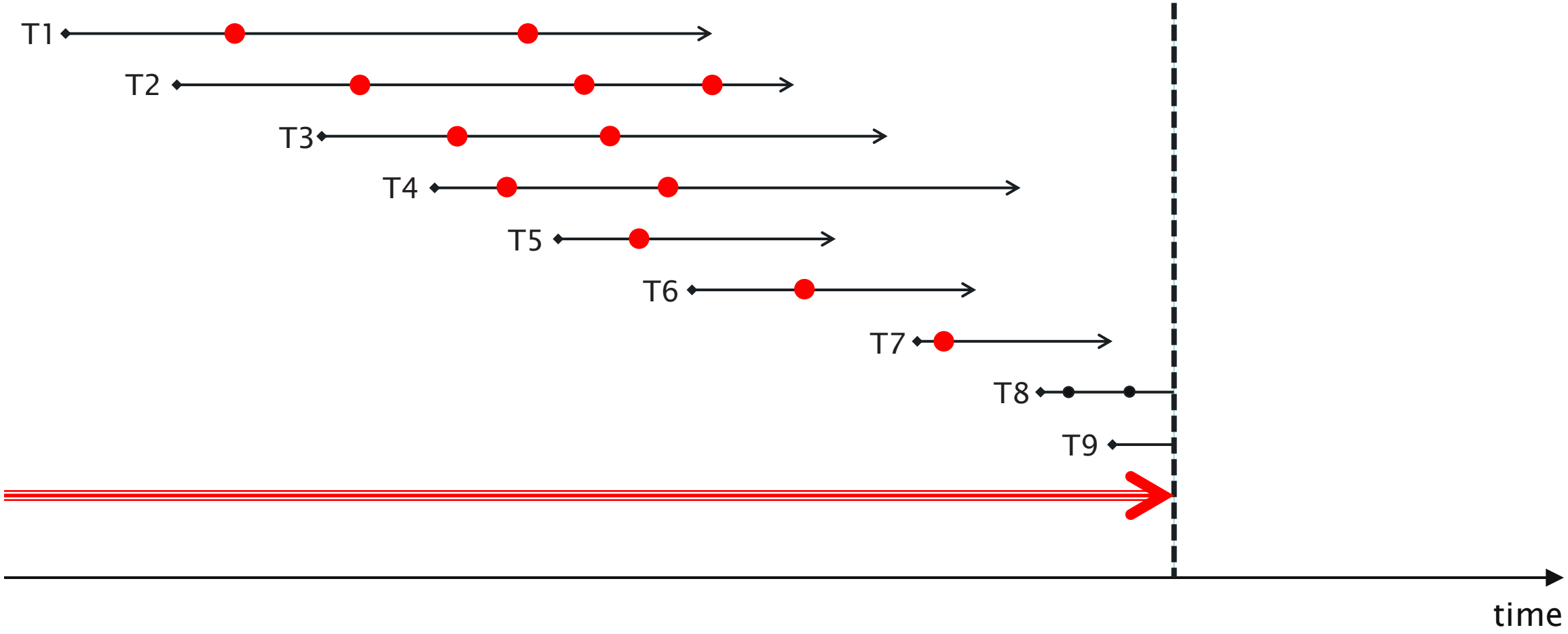
Recovery with Redo Logging



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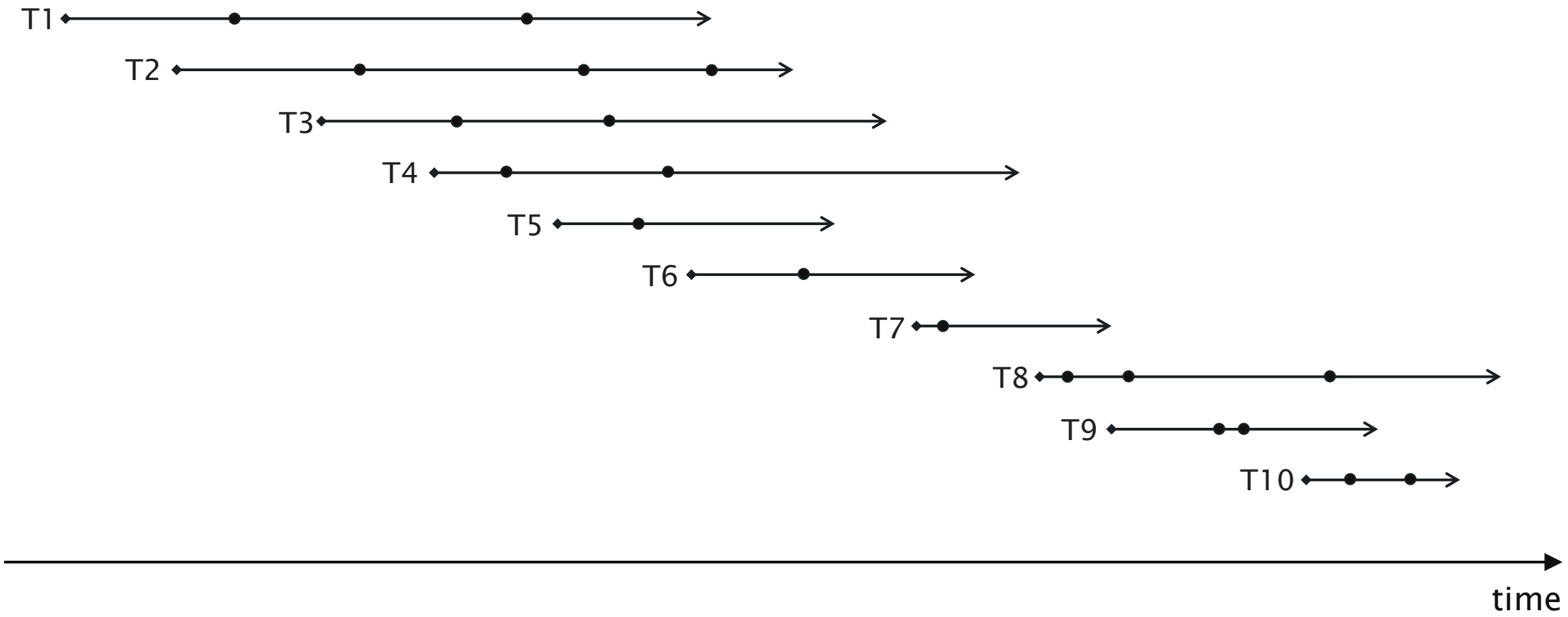
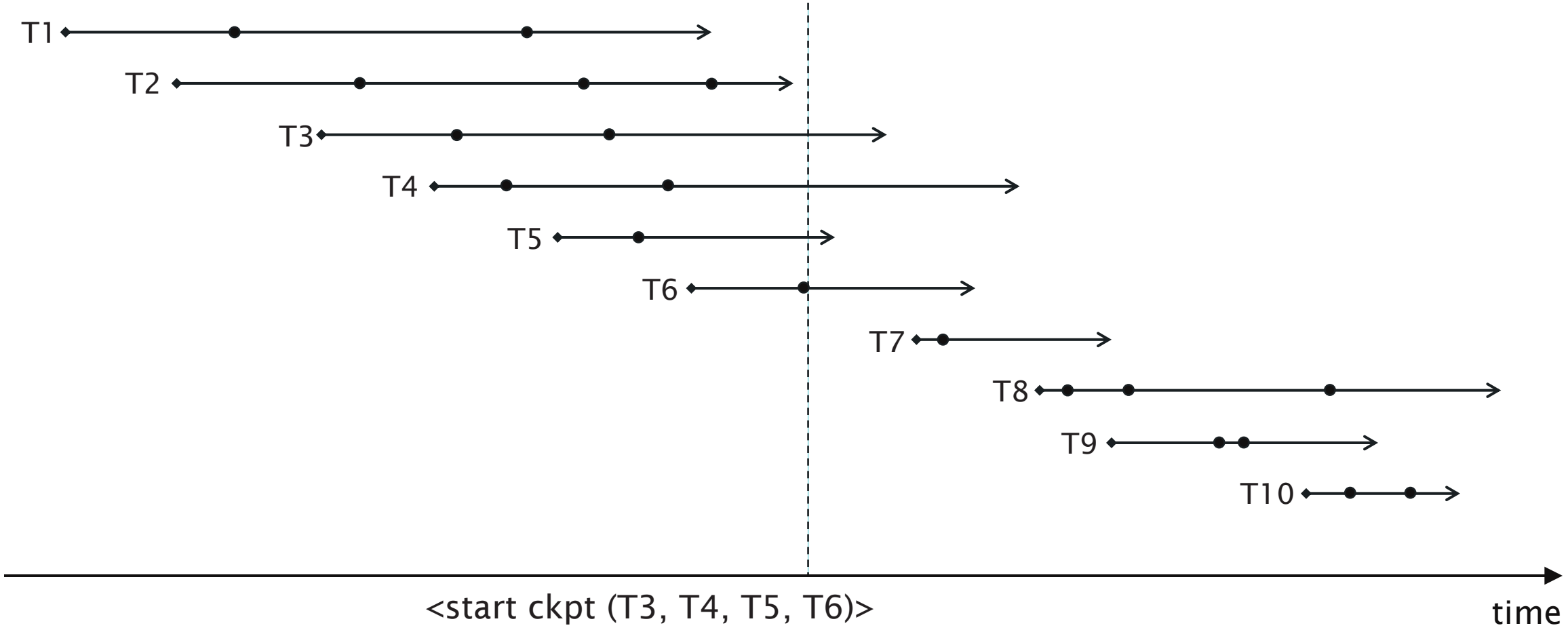
Checkpointing with Redo Logging

1. Write log record <start ckpt (T1..Tn)>, where T1...Tn are uncommitted, and flush log
2. Write to disk all database items that have been written to buffers but not yet to disk, by transactions that have already committed
3. Write log record <end ckpt> and flush log

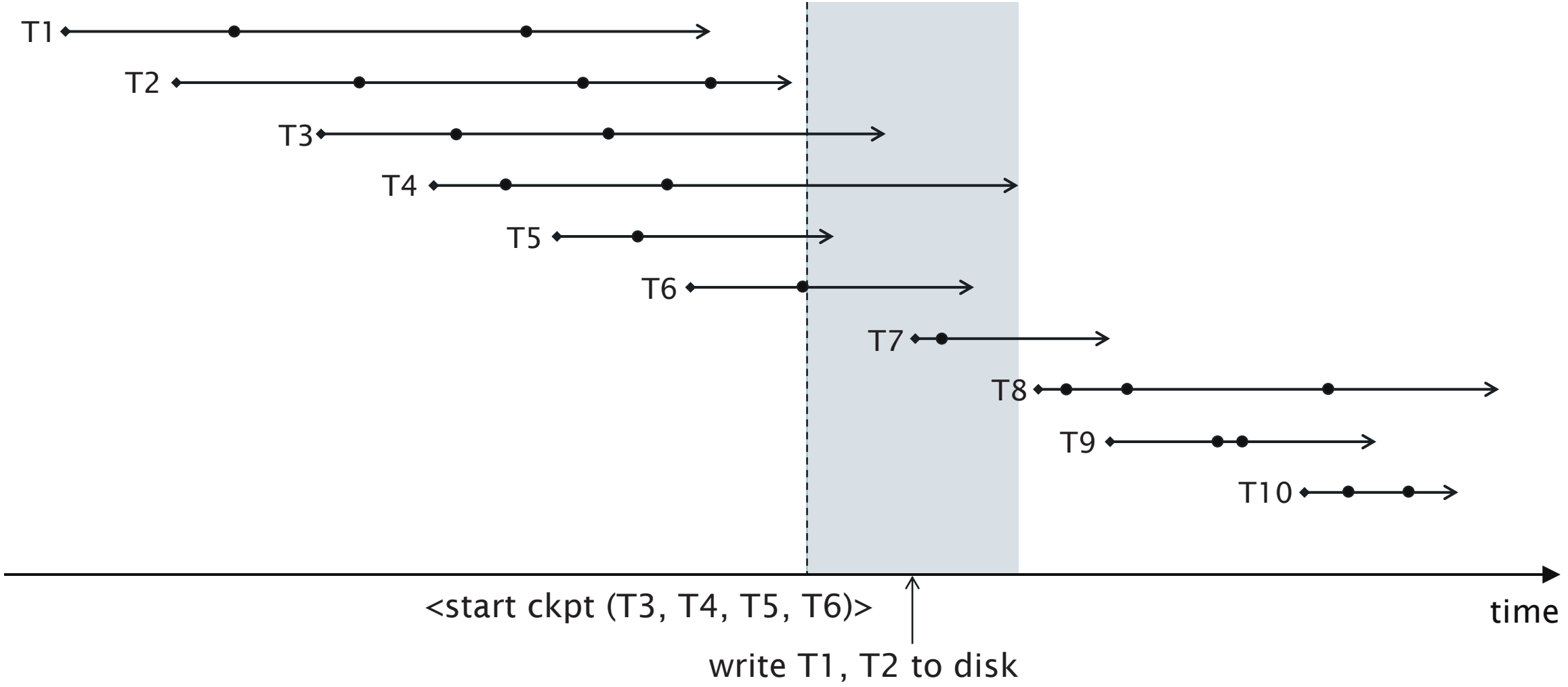
Recovery with Redo Logging



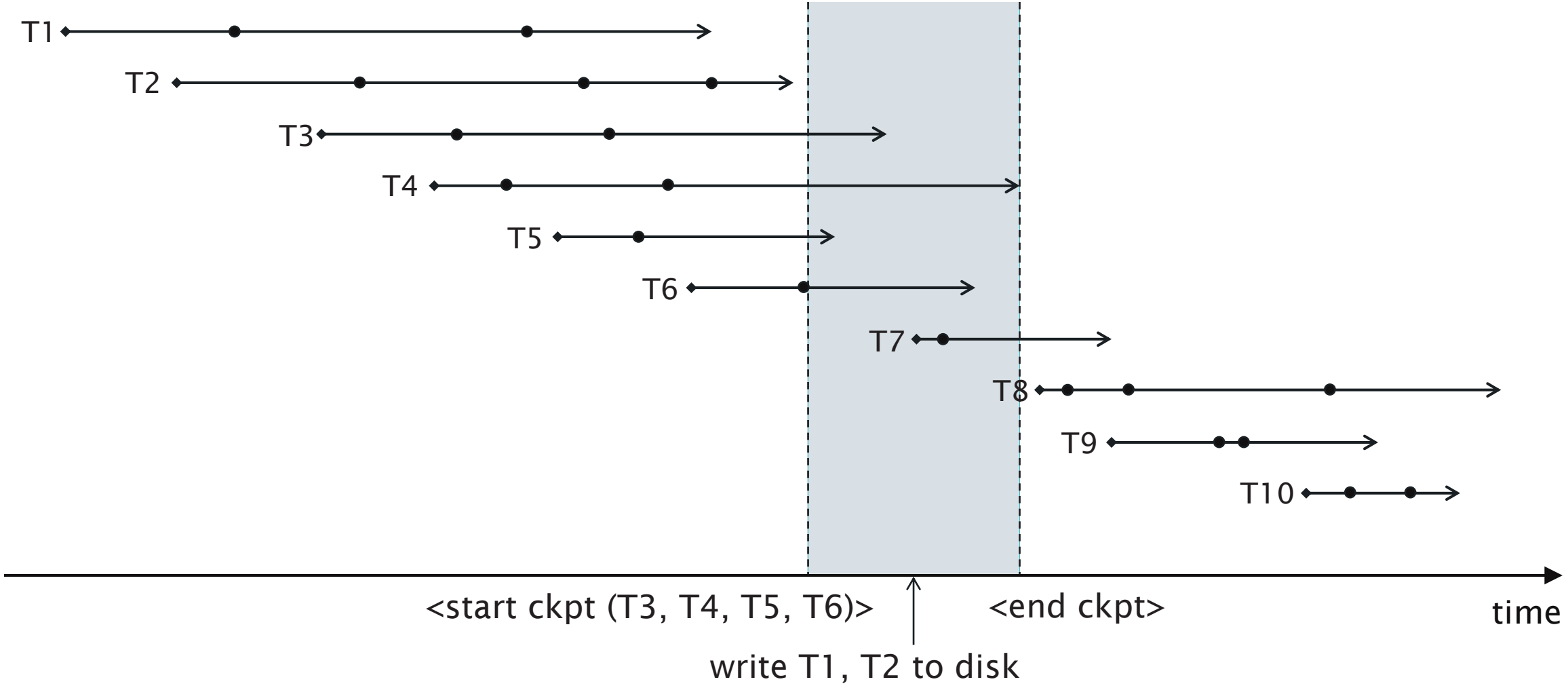
Recovery with Redo Logging



Recovery with Redo Logging



Recovery with Redo Logging



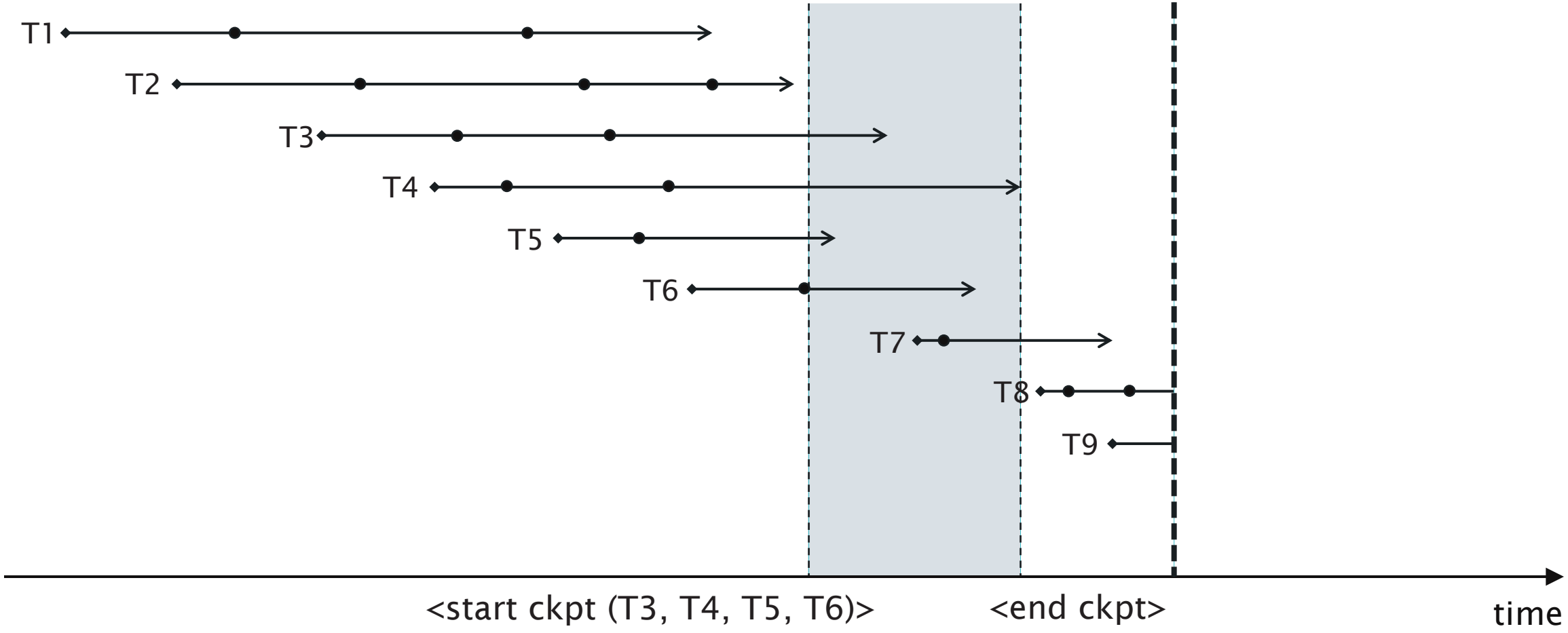
Recovery with Checkpointed Redo Logging

As with checkpointed undo logging, two cases:

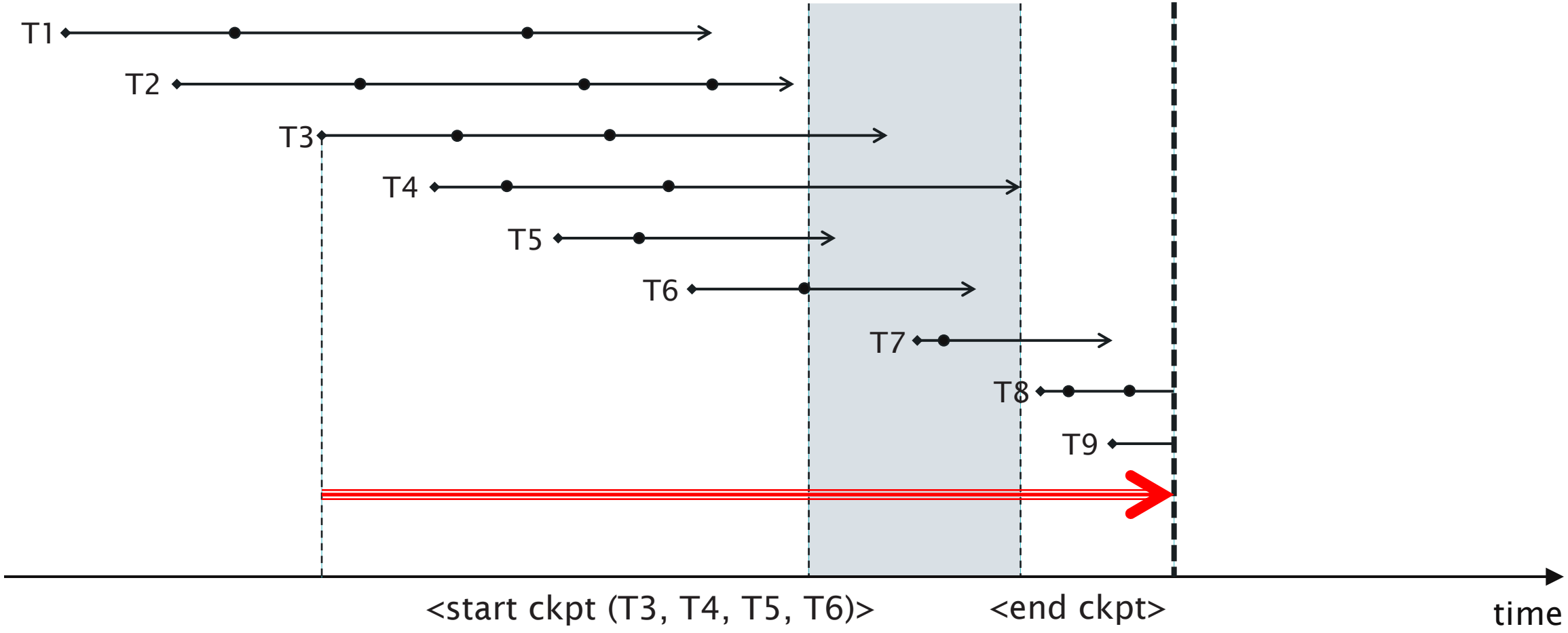
<end ckpt>

- Every value written by transactions that committed before the corresponding <start ckpt ()> has been written to disk – ignore
- Any transaction named in the checkpoint start, or which has started since, may have changes that have not been written to disk (even if the transaction has committed)

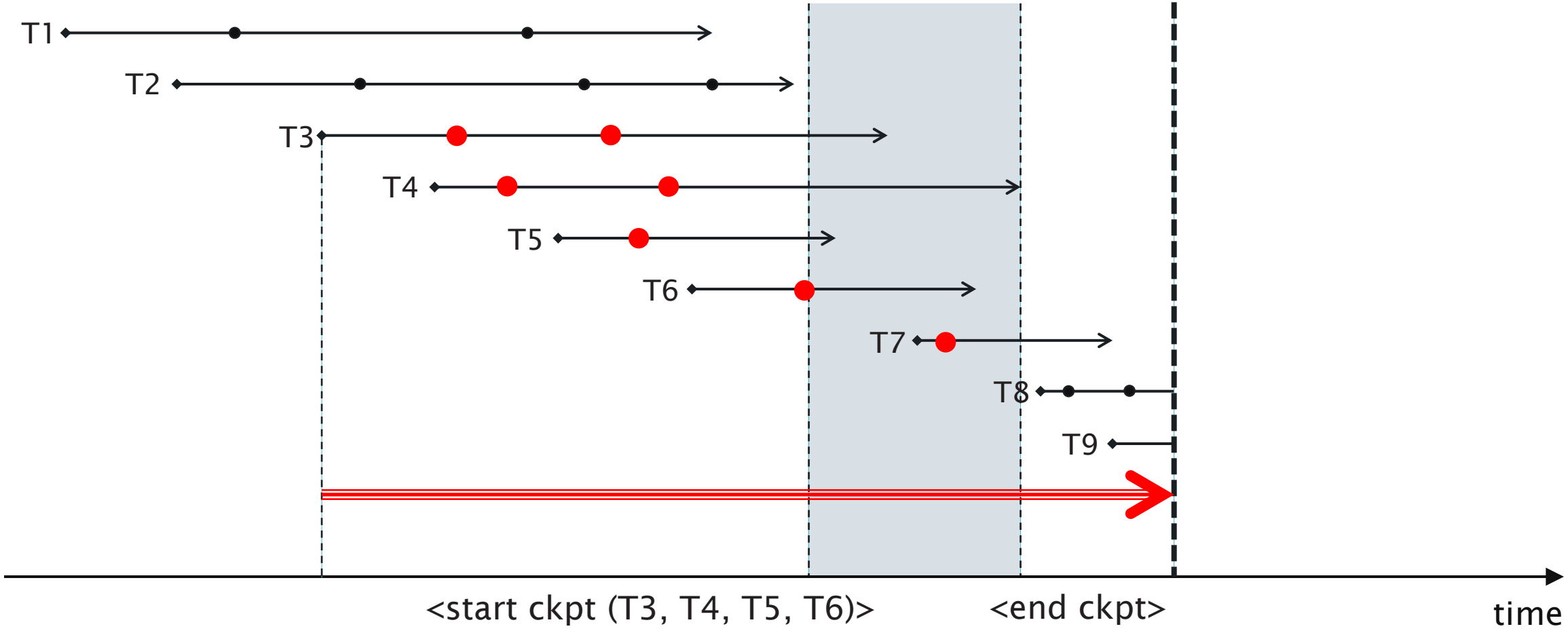
Recovery with Checkpointed Redo Logging



Recovery with Checkpointed Redo Logging



Recovery with Checkpointed Redo Logging



Recovery with Checkpointed Redo Logging

As with checkpointed undo logging, two cases:

<start ckpt (T1…Tn)>

- Can't tell whether committed transactions prior to this checkpoint had their changes written to disk
- Search back to the previous <end ckpt>, find its corresponding <start ckpt ()> and treat as before

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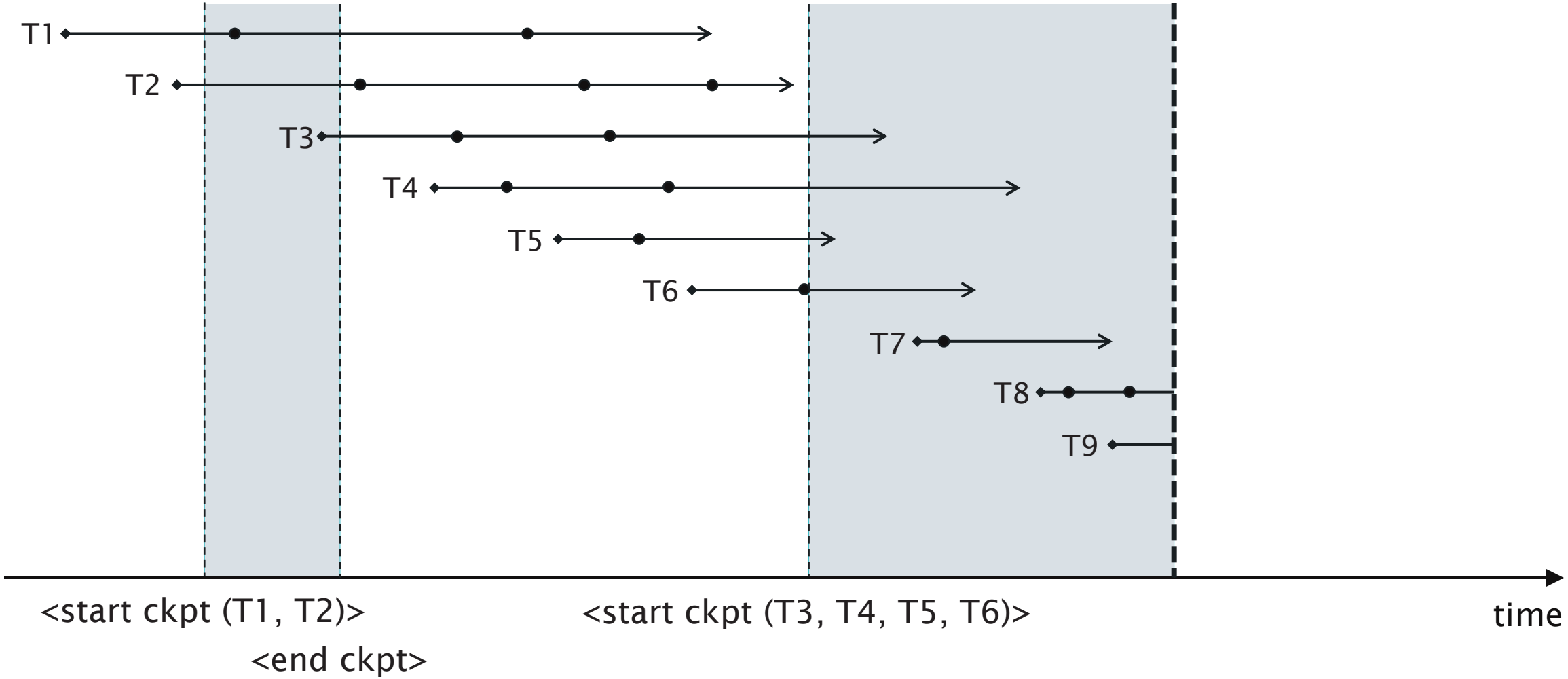
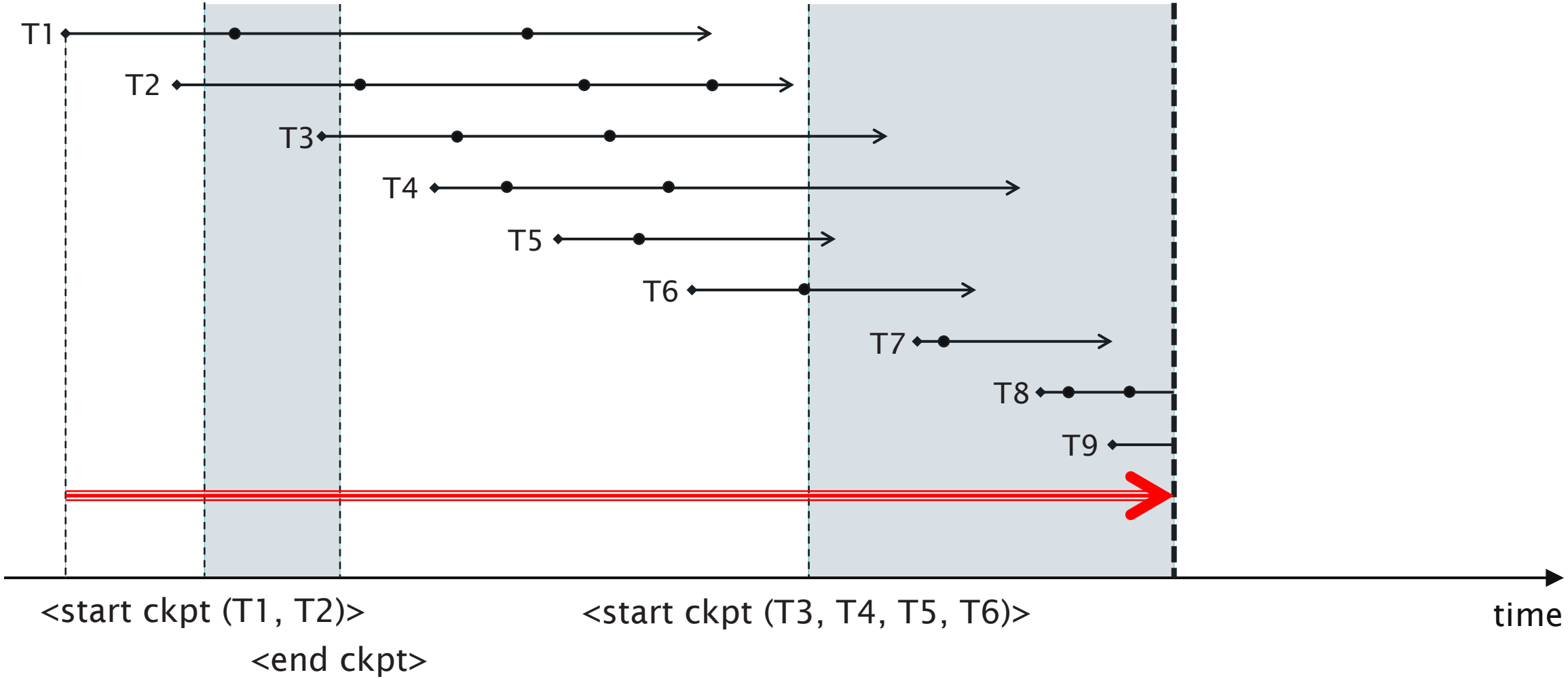
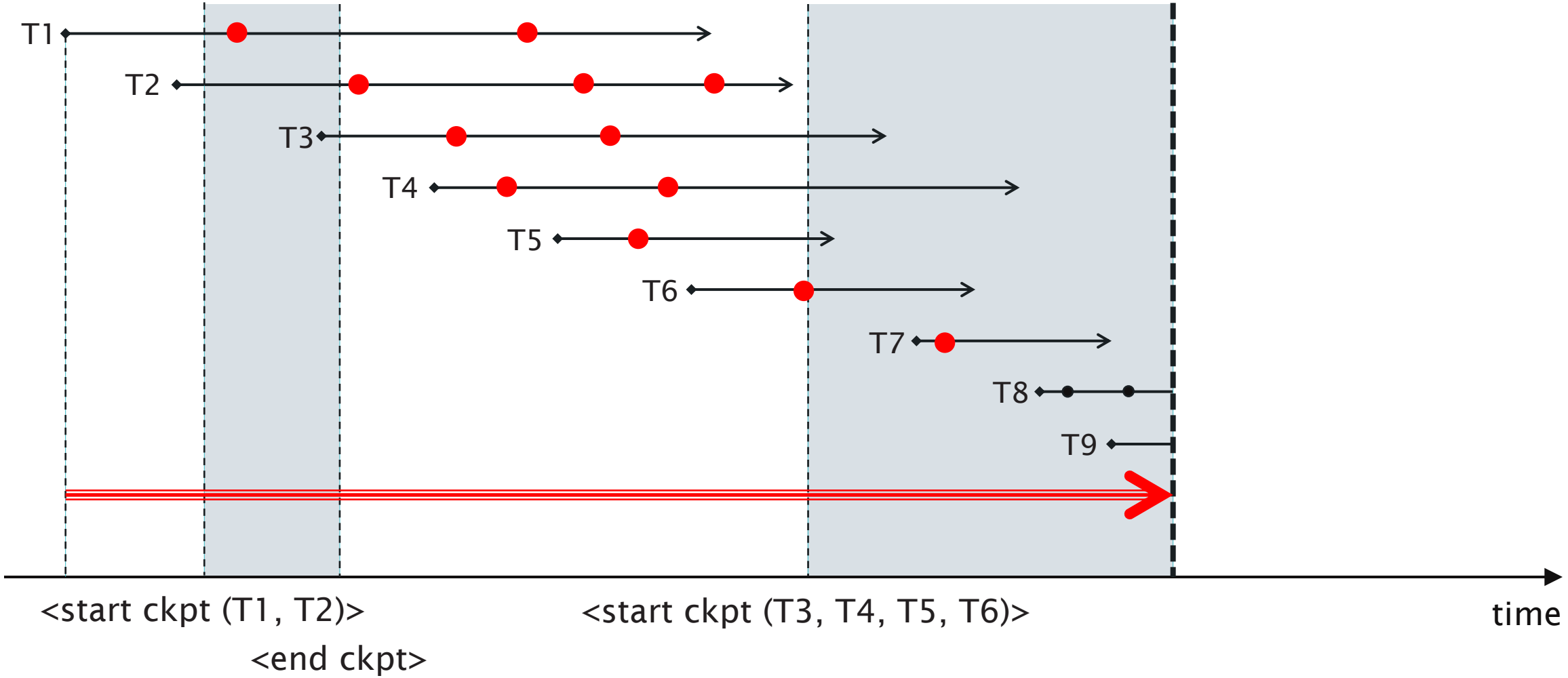
Recovery with Checkpointed Redo Logging



Recovery with Checkpointed Redo Logging



Recovery with Checkpointed Redo Logging



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Undo/Redo Logging

Undo/Redo Logging

Aims to address issues with both undo and redo logging

- Undo logging may increase number of disk i/o operations
- Redo logging requires that all modified blocks be kept in buffers until the transaction commits and the logs flushed

Introduces a different record type to record changes:

<T, X, old, new>
Transaction T has changed database item X from an old to a new value

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Undo/Redo Logging Rules

UR1: Before transaction T modifies any database item X on disk, the update record <T, X, old, new> must be written to disk

UR2: A <commit T> record must be flushed to disk as soon as it it written to the log

Note: the <commit T> log record may come before or after any of the changes on disk

Action	X	Y	X_m	Y_m	X_d	Y_d	Log
					20	50	<start T>
read(X)	**20**		**20**		20	50	
X := X – 10	**10**		20		20	50	
write(X)	10		**10**		20	50	<T, X, 20, 10>
read(Y)	10	**50**	10	**50**	20	50	
Y := Y+10	10	**60**	10	50	20	50	
write(Y)	10	60	10	**60**	20	50	<T, Y, 50, 60>
flush log							
output(X)	10	60	10	60	**10**	50	
							<commit T>
flush log							
output(Y)	10	60	10	60	10	**60**	

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Recovery with Undo/Redo Logging

1. Redo all committed transactions from oldest to newest
2. Undo all incomplete transactions from newest to oldest

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Checkpointing with Undo/Redo Logging

1. Write <start ckpt (T1…Tn)> to log and flush log
2. Write to disk all dirty buffers (i.e. those with one or more changed database items, not just those from committed transactions)
3. Write <end ckpt> to log and flush log

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Next Lecture: Parallel Databases