Dare 2023 - Summer School

NOVA SCHOOL OF
SCIENCE & TECHNOLOGY

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TLA+: 2PC and 3PC Spec

Introduction

- Two Phase Commit
- Leslie Lamport's Spec

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Specification of Atomic Commit

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Model:

Crash Recovery

Synchronous System

Specification of Atomic Commit

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Agreement: Any two processes that decide, decide the same value.

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Two Phase Commit

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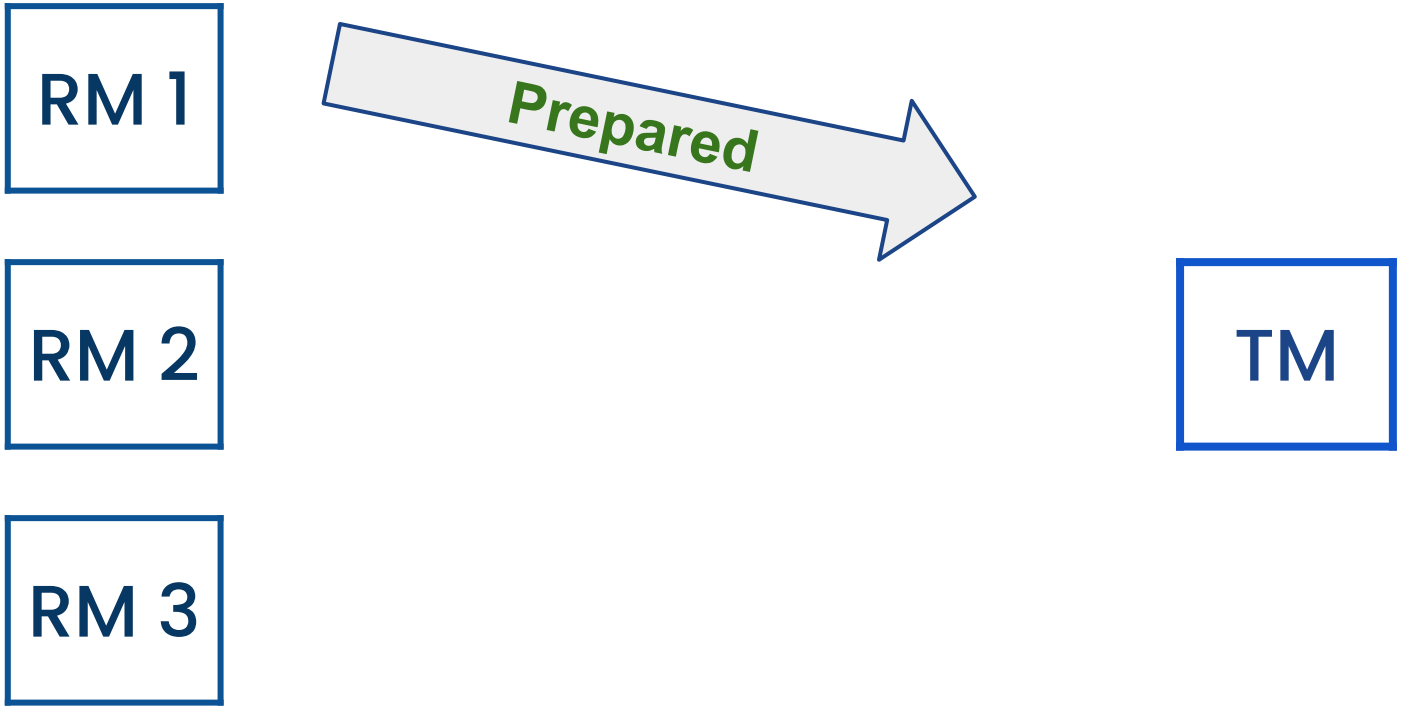

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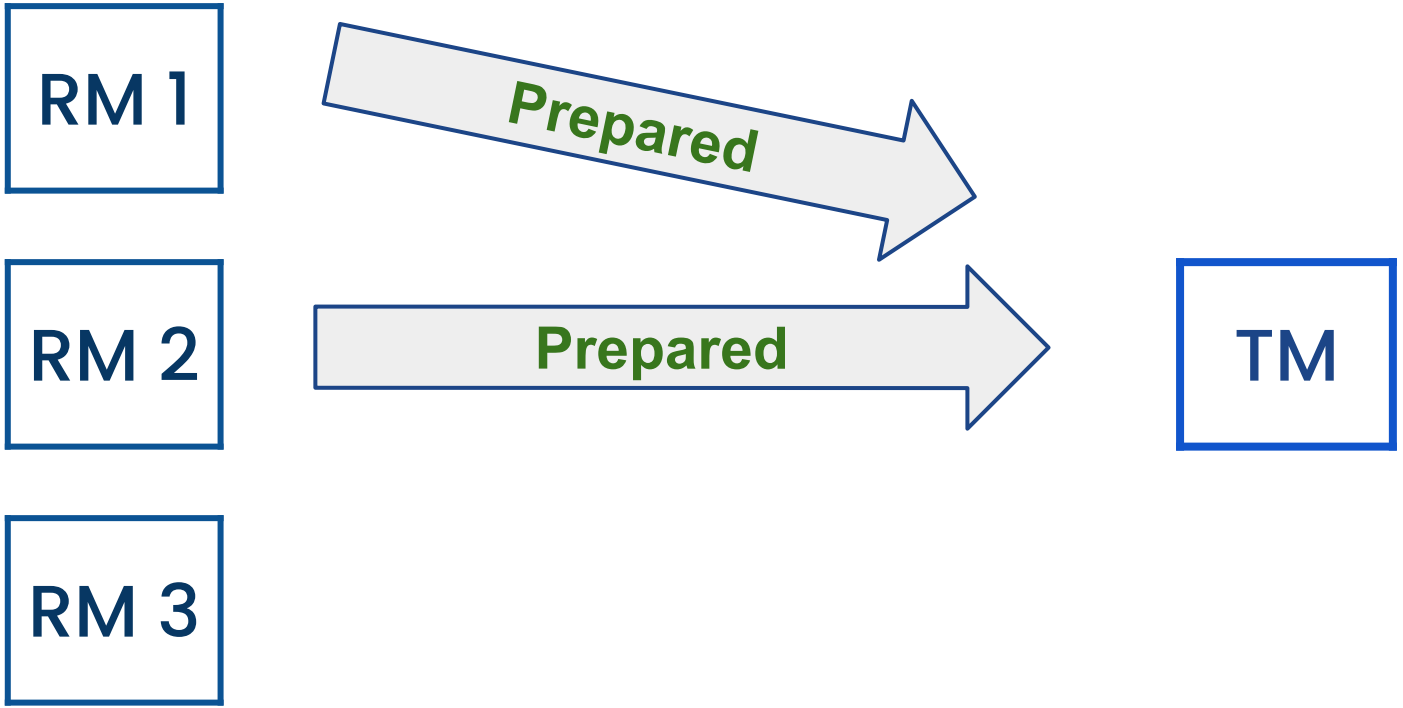

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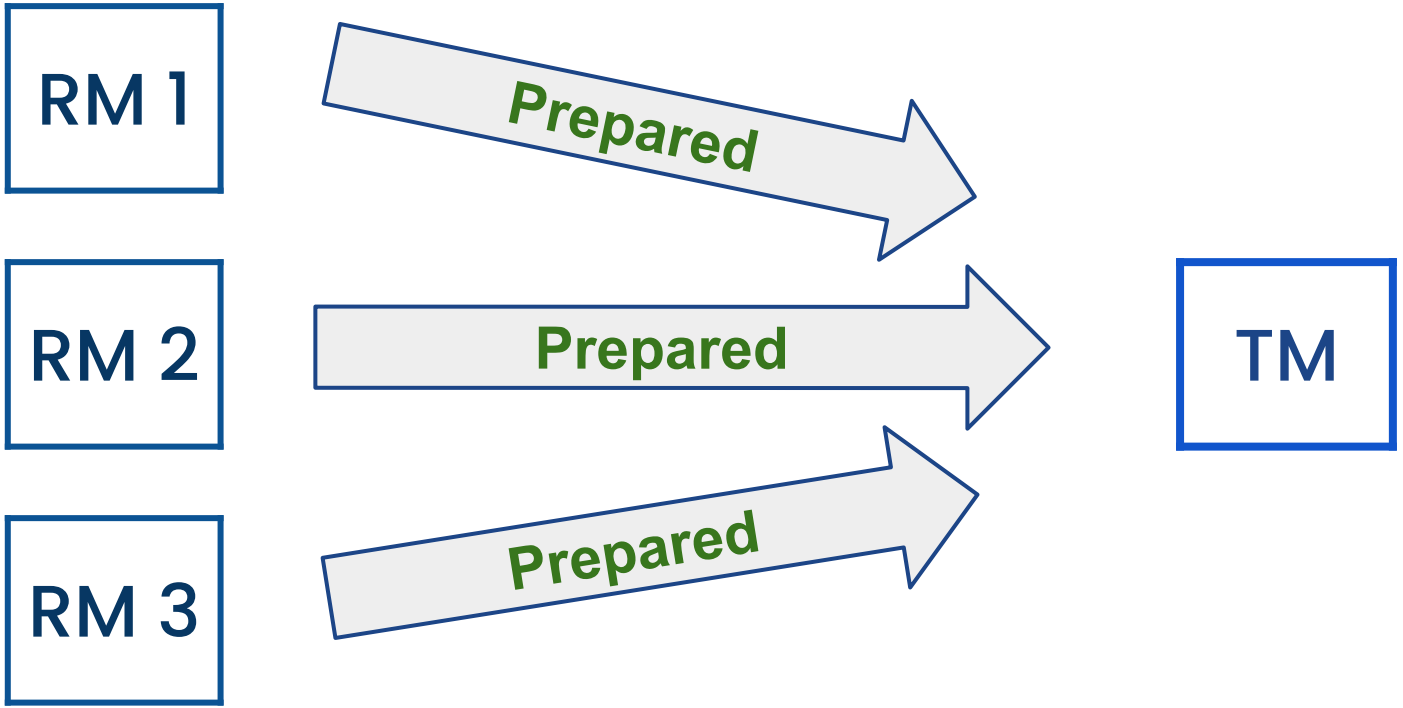

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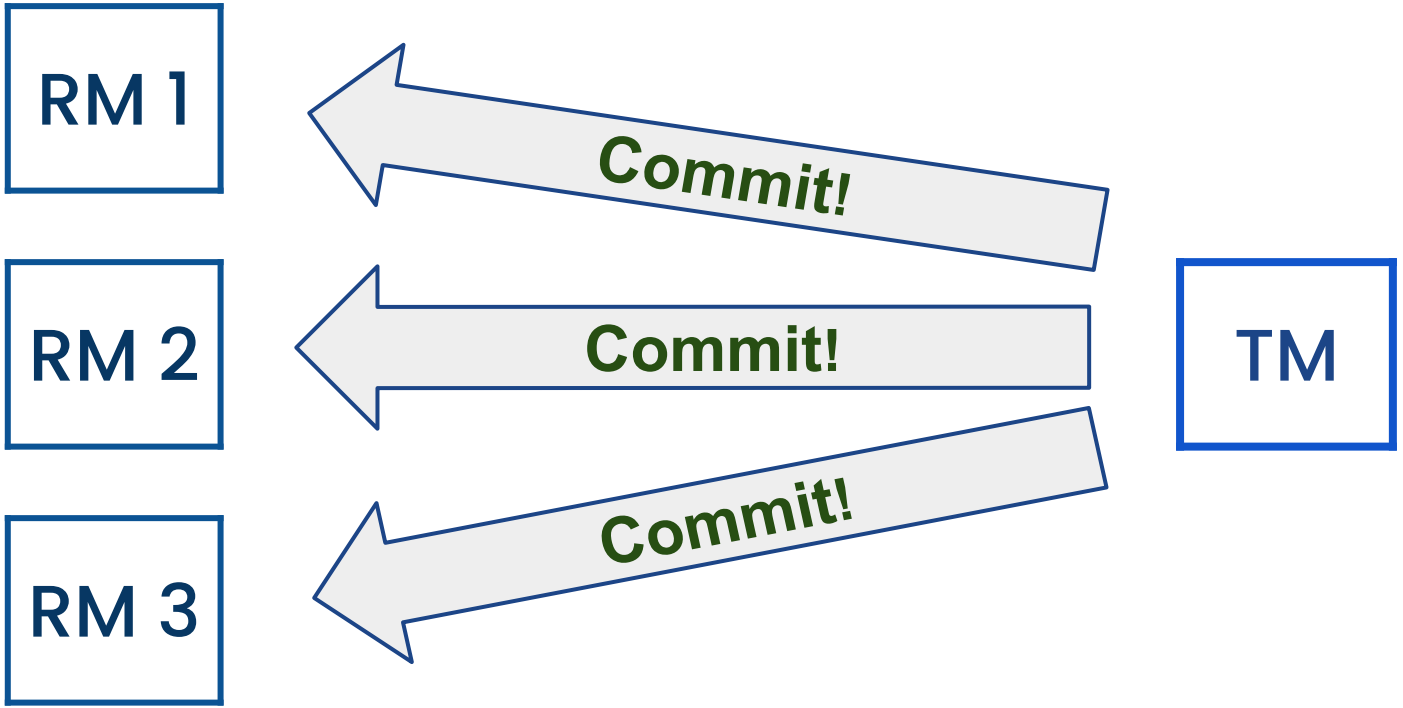

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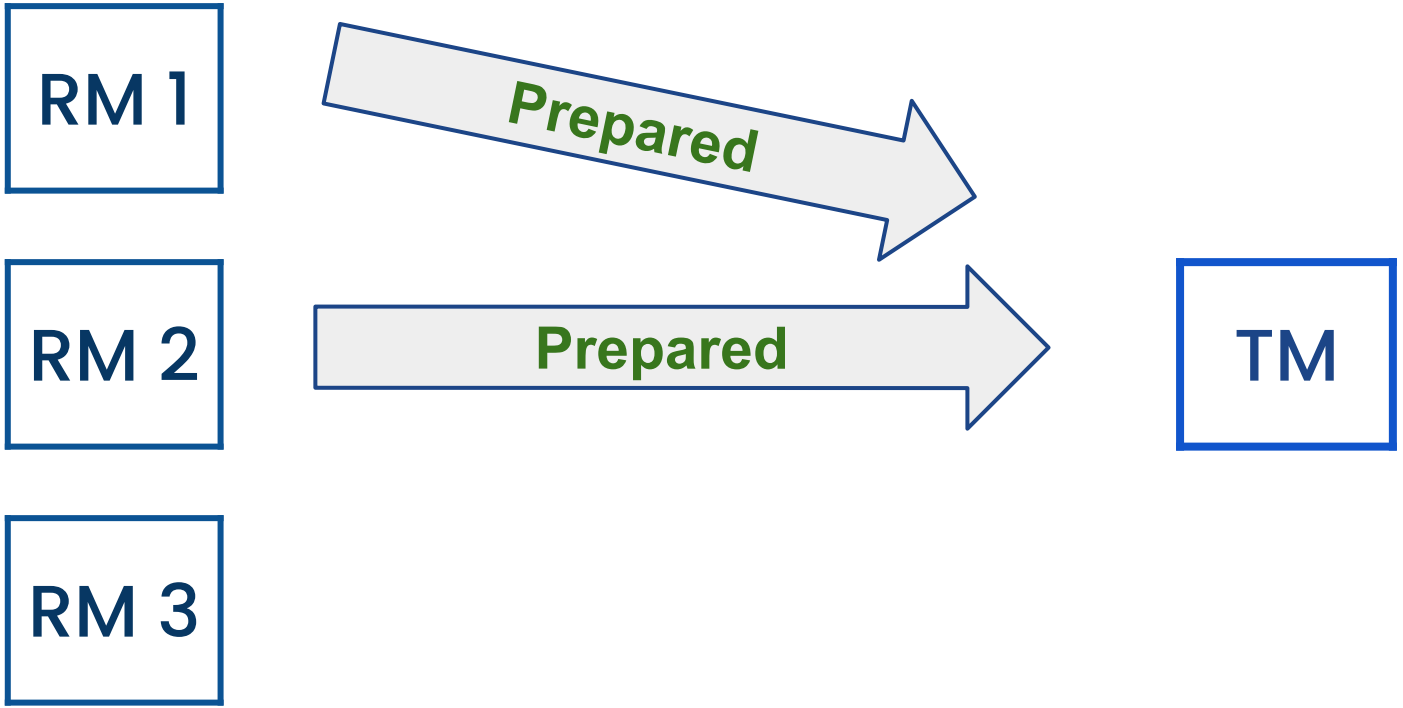

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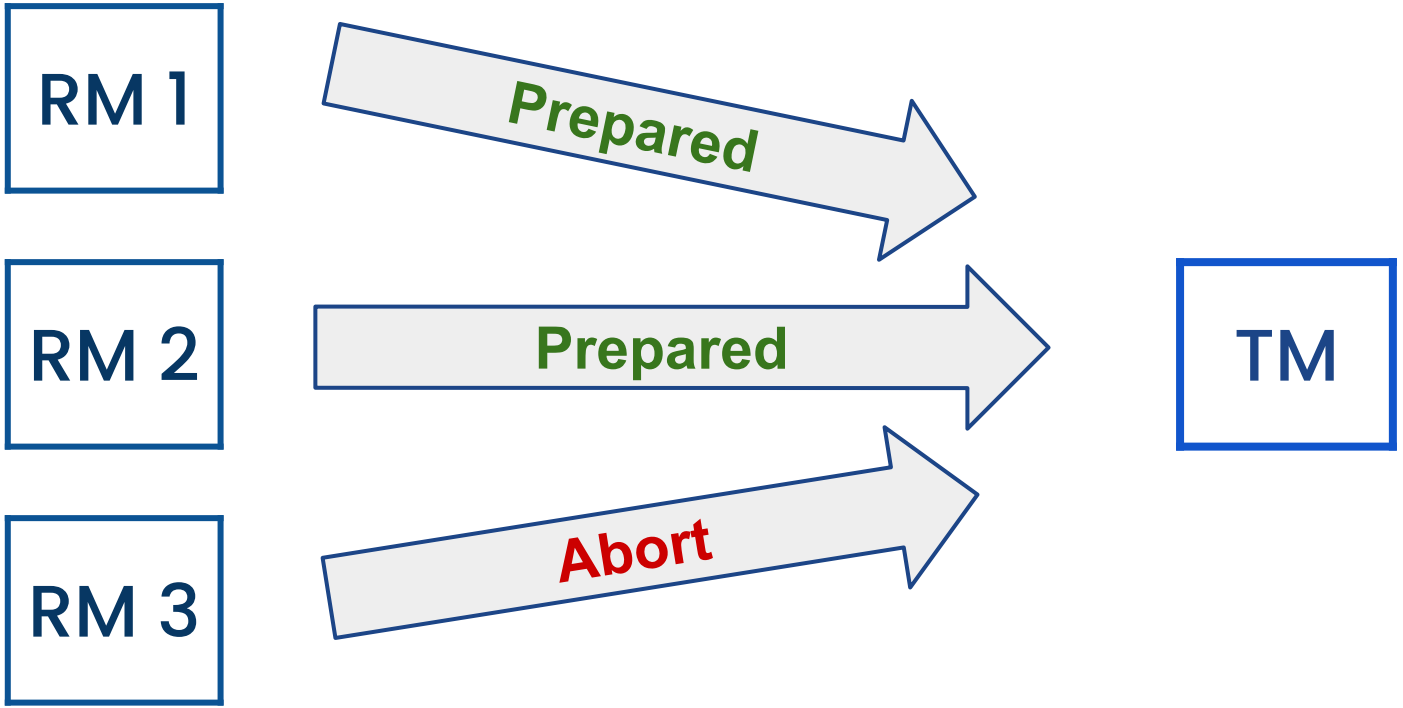

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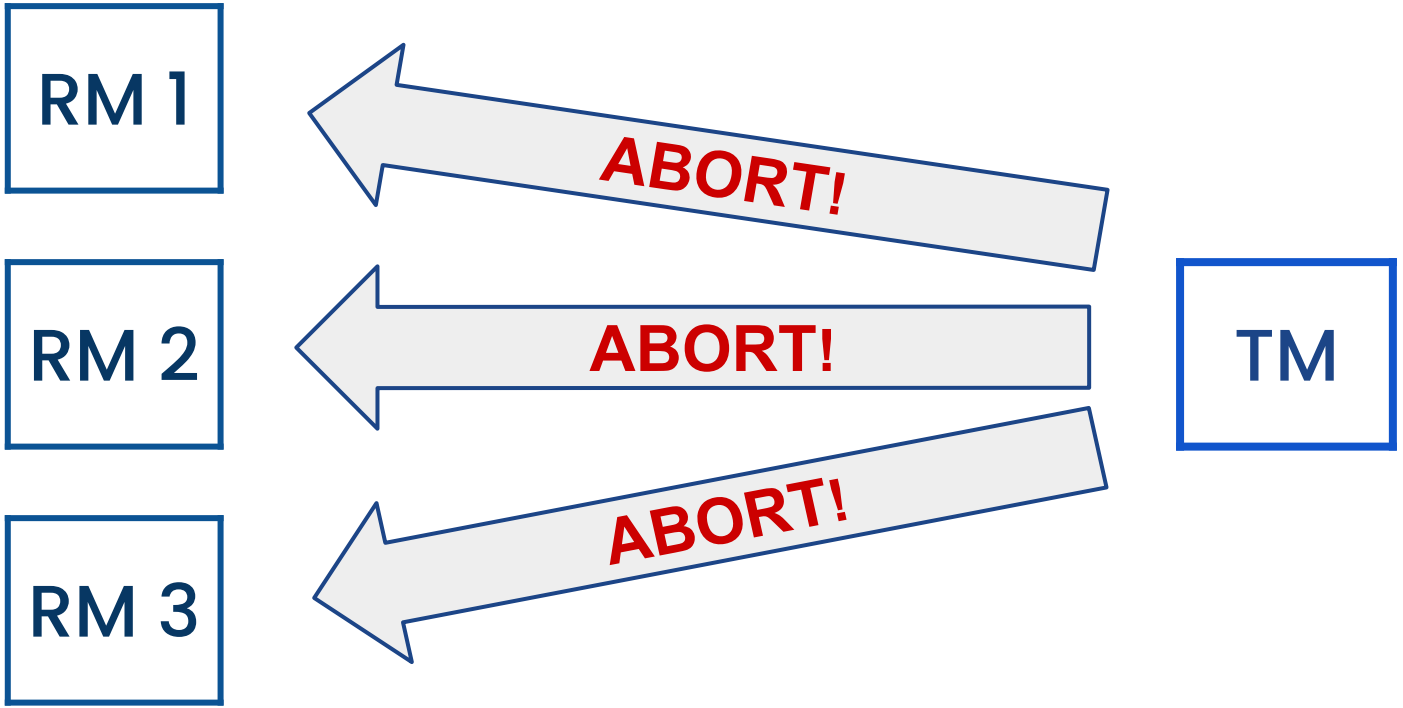

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Leslie Lamport’s Specification

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 rmState     \* State of each resource manager.
 tmState     \* The state of the transaction manager.
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 msgs        \* The set of all messages ever sent
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(Actions that lead to Commit)

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TPAgreement ==
        \A rm1, rm2 \in RM :
            ~ /\ rmState[rm1] = "aborted"
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Every Atomic Commit Property is checked:

Agreement: Any two processes that decide, decide the same value

```
TPAgreement ==
        \A rm1, rm2 \in RM :
            ~ /\ rmState[rm1] = "aborted"
              /\ rmState[rm2] = "committed"
```

Translation: No two processes can ever be in different decision states (i.e., decide different things).

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    (\E rm \in RM : rmState[rm] = "aborted") ~> (tmState = "aborted")
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Validity (1): If some process starts with the value “no” then “abort” is the only possible decision

```
TPValidity1 ==
    (\E rm \in RM : rmState[rm] = "aborted") ~> (tmState = "aborted")
```

Translation: If any process is in aborted state (decided abort), then TM will eventually decide abort.

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Validity (2): If all processes start with value “yes” and none fails, then “commit” is the only possible decision

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TPValidity2 ==
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```

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Every Atomic Commit Property is checked:

Validity (2): If all processes start with value “yes” and none fails, then “commit” is the only possible decision

```
TPValidity2 ==
~ (\E rm \in RM : rmState[rm] /= "prepared") ~> (tmState = "committed")
```

Translation: If all processes are prepared (which also means it is not crashed), then eventually TM will decide commit.

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Termination: If eventually all processes recover from all faults, then, eventually all processes decide

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TPTermination ==
(~ (\E rm \in RM : rmState[rm] = "crashed")) ~>
      (~ (\E rm \in RM : rmState[rm] /= "aborted"   /\ rmPrevState[rm] /= "aborted"))
  \/ (~ (\E rm \in RM : rmState[rm] /= "committed" /\ rmPrevState[rm] /= "committed"))
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```

Translation: If eventually no process is crashed, then eventually all will decide (the same thing). A process has decided if: it is in a decided state OR it was in a decided state (and is now crashed).

Our 2PC Specification

TLC reports no errors!

Time	Diameter	States Found	Distinct States	Queue Size
00:04:22	17	61 396	9 756	0

Our Specification

- Two Phase Commit
- Three Phase Commit

Our Specification

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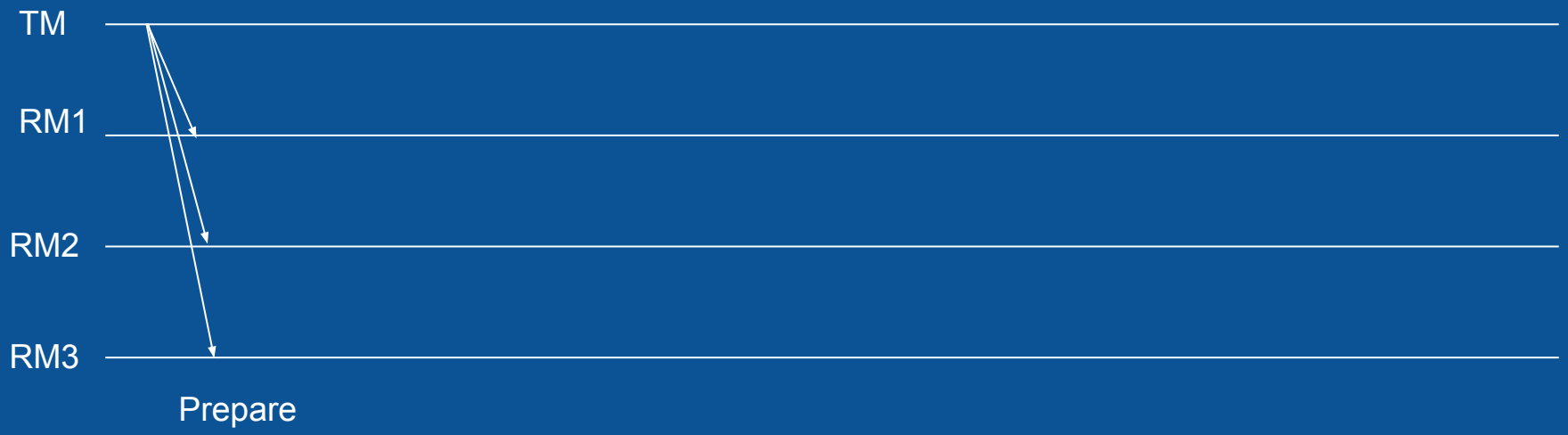
- Three Phase Commit

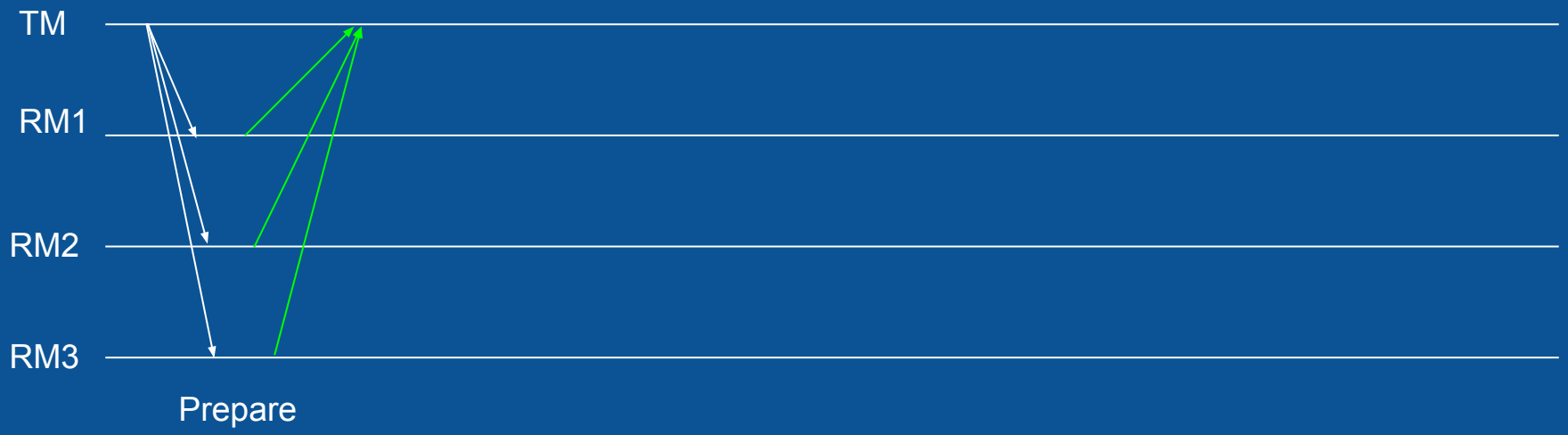
Three-Phase Commit

- Converts 2PC into a non blocking protocol
- Timeouts
- Adds Pre-commit round

Three-Phase Commit



Three-Phase Commit



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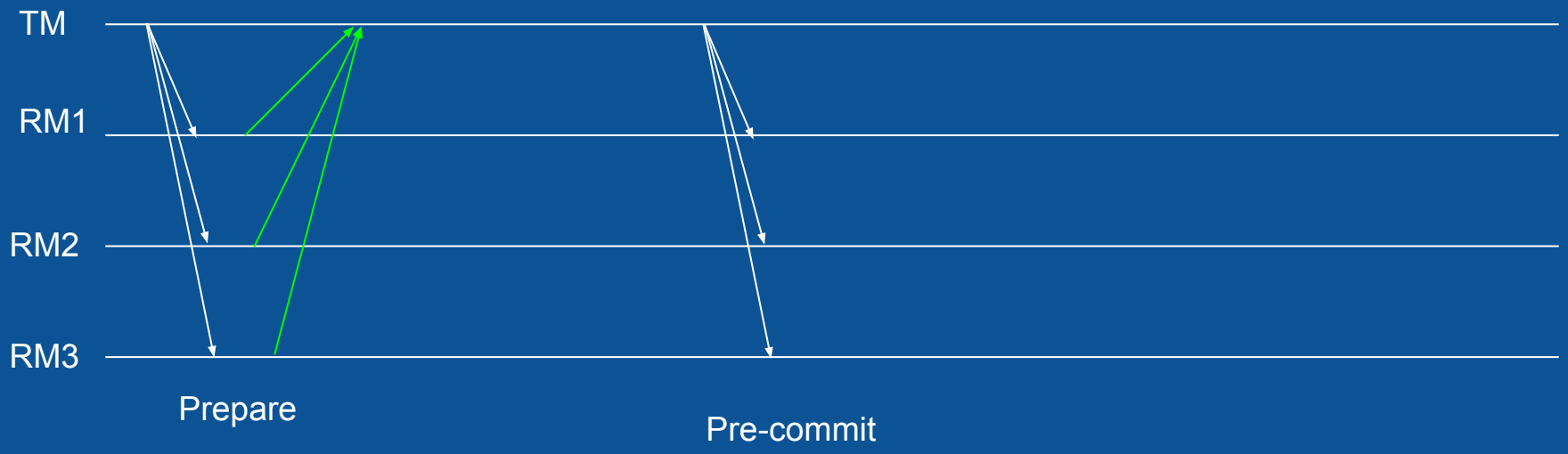
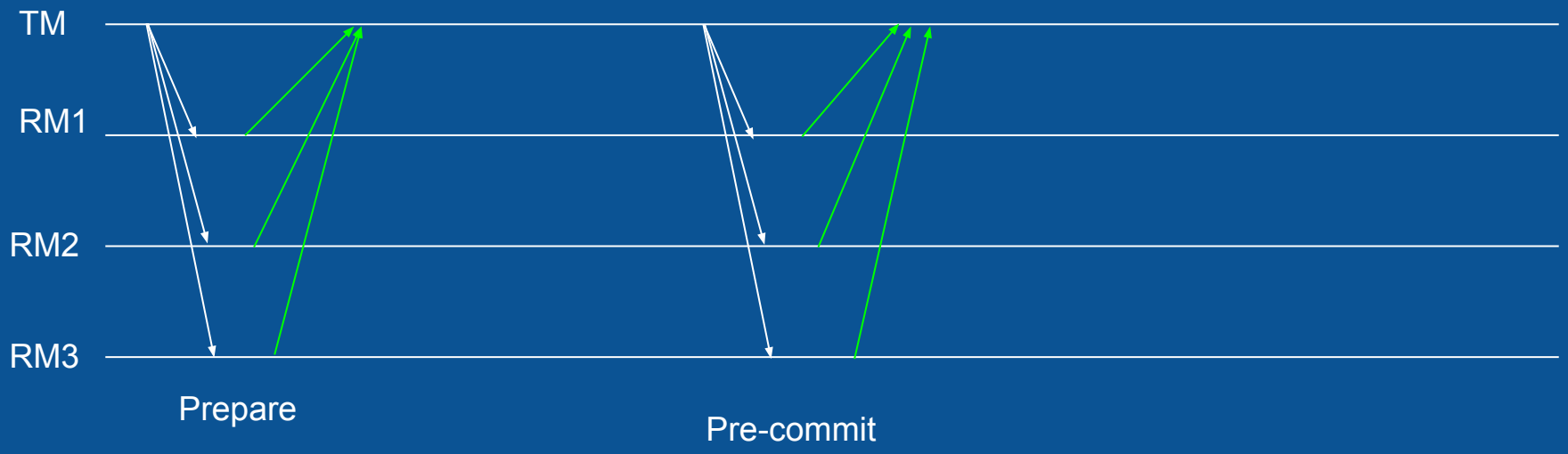


Three-Phase Commit



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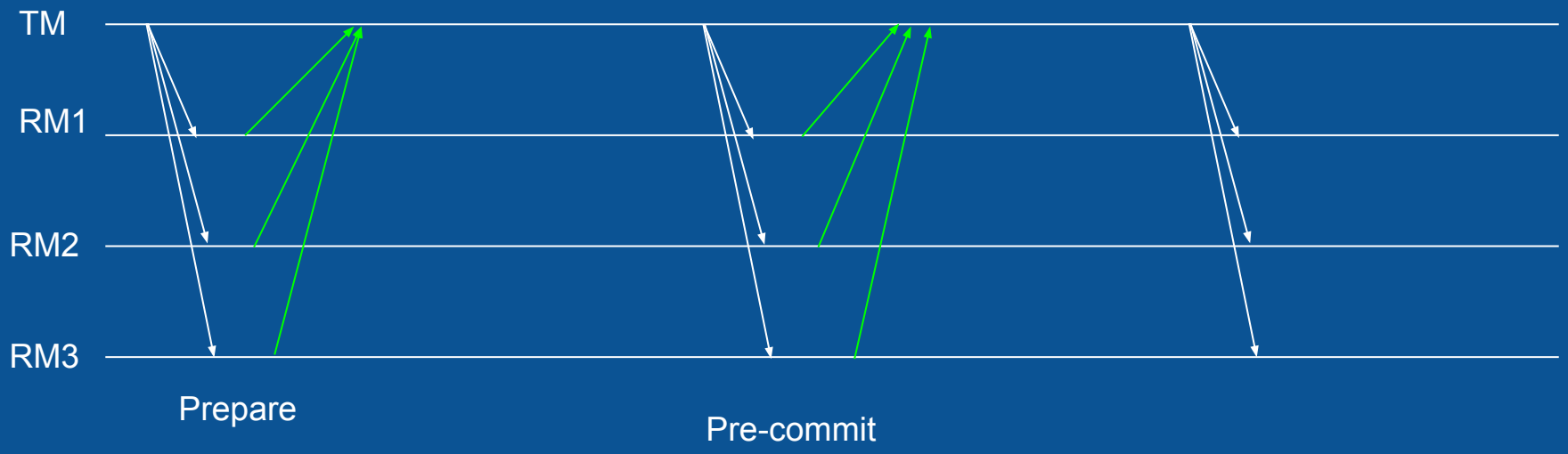
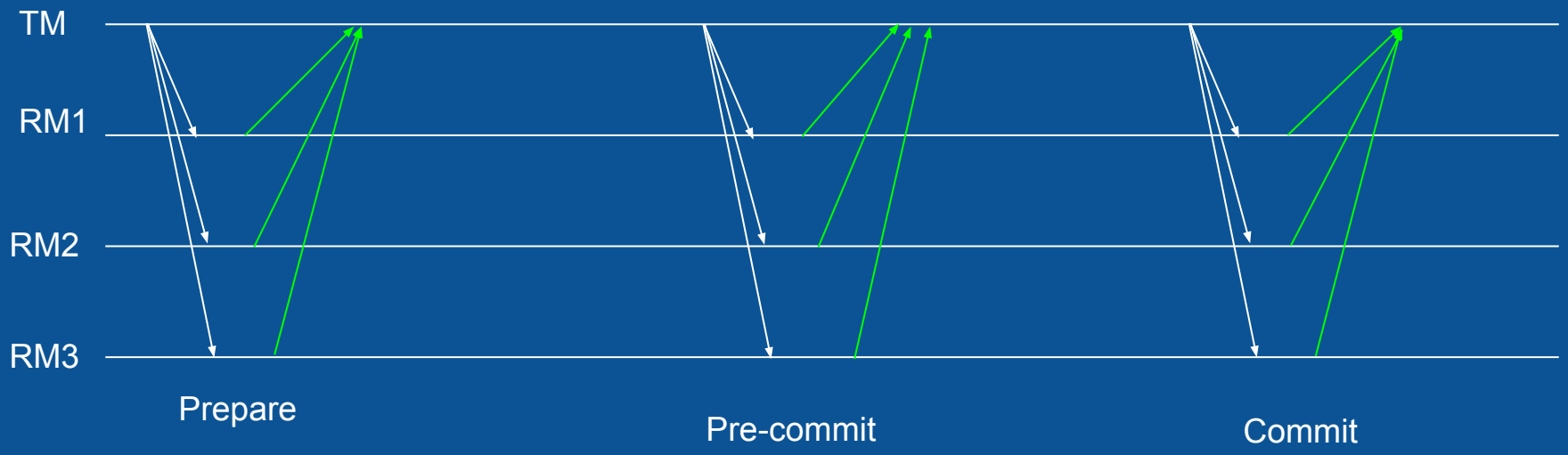
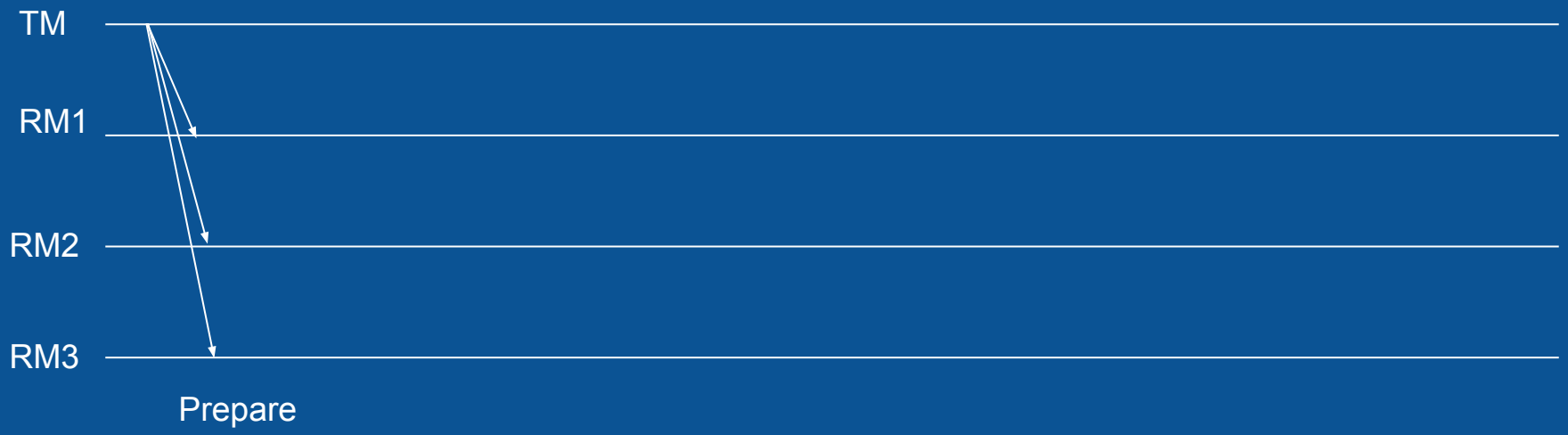


Three-Phase Commit

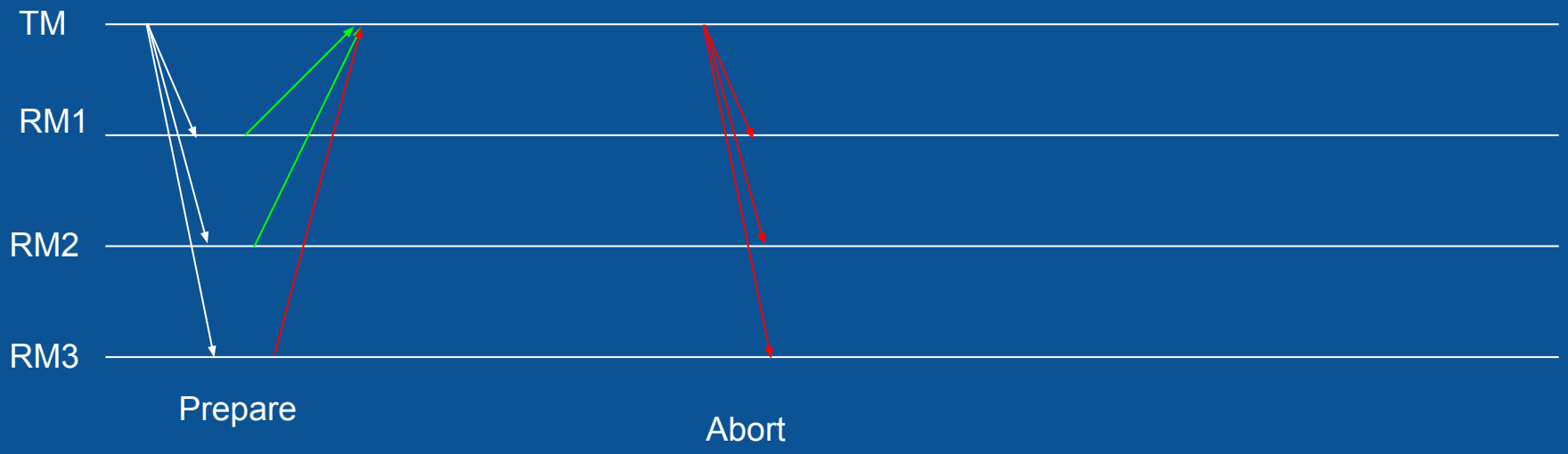


Three-Phase Commit

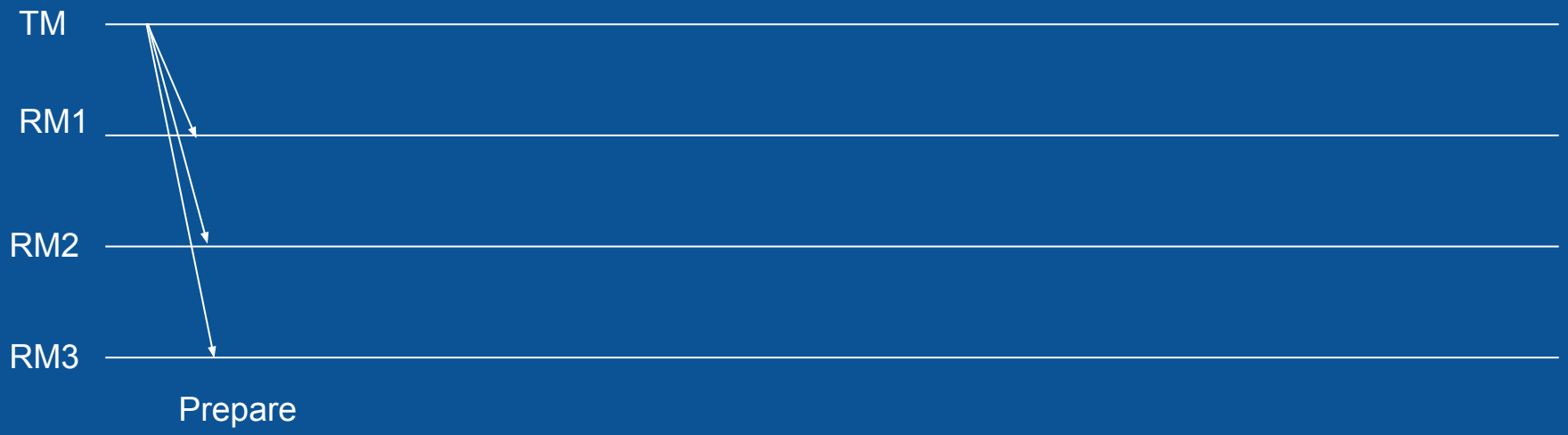


Three-Phase Commit

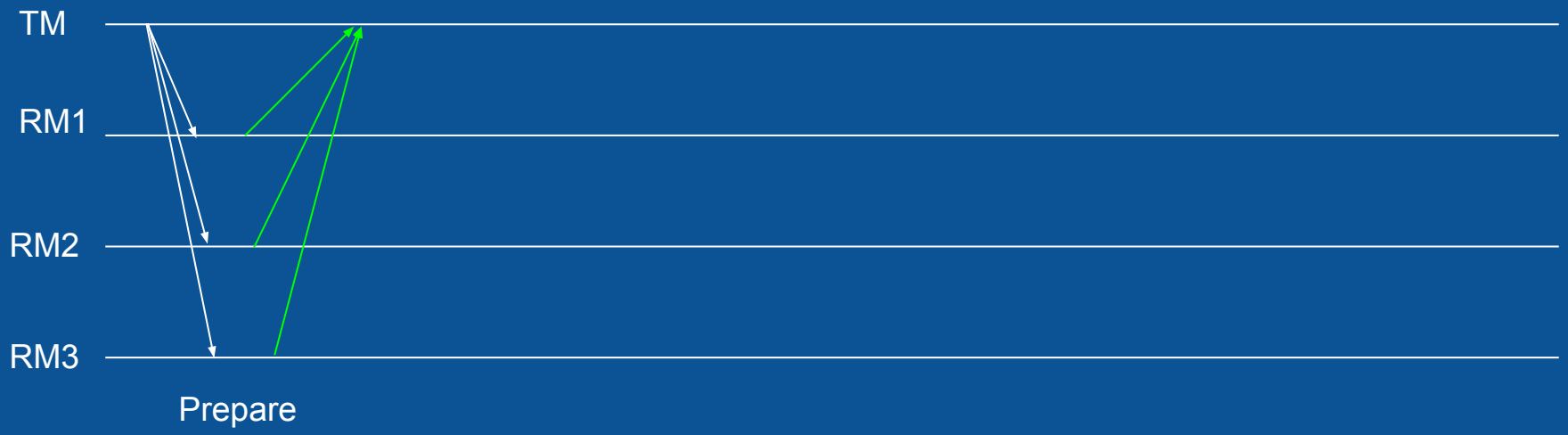
Three-Phase Commit



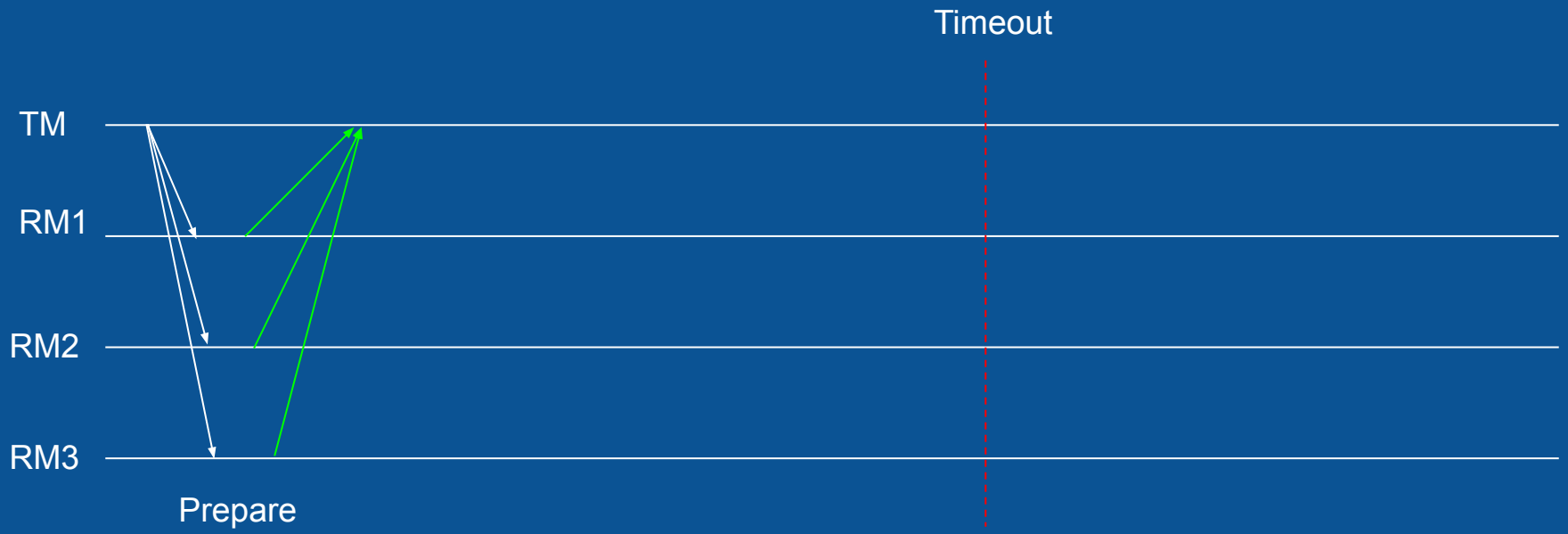
Three-Phase Commit



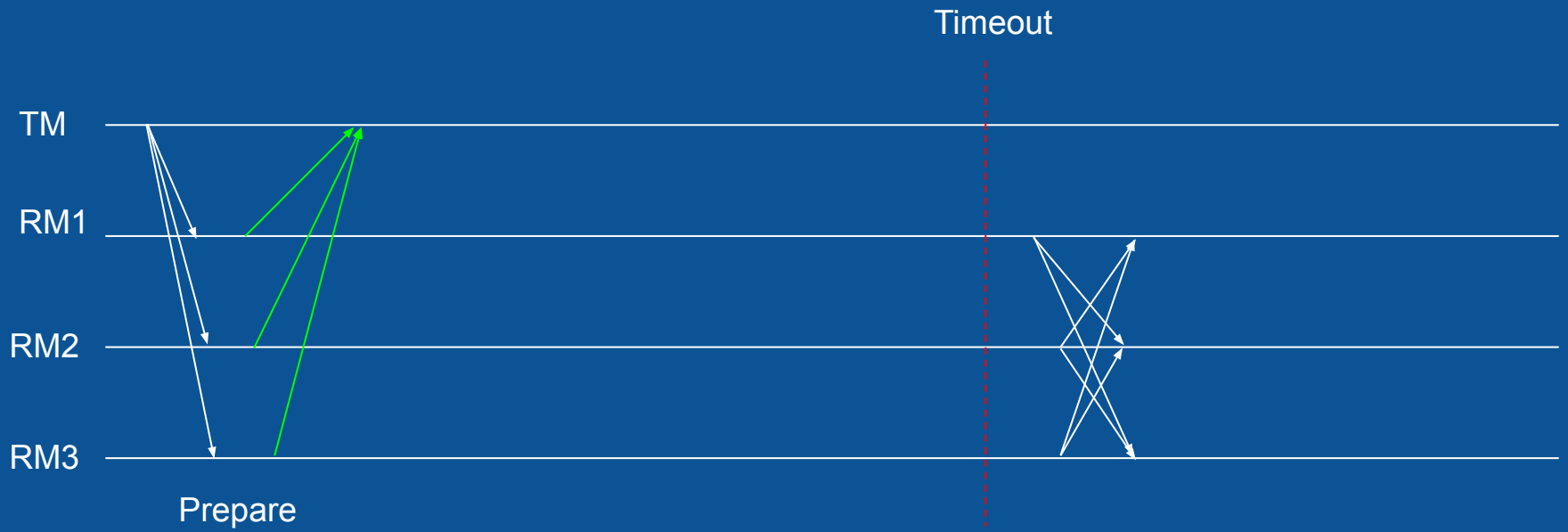
Three-Phase Commit



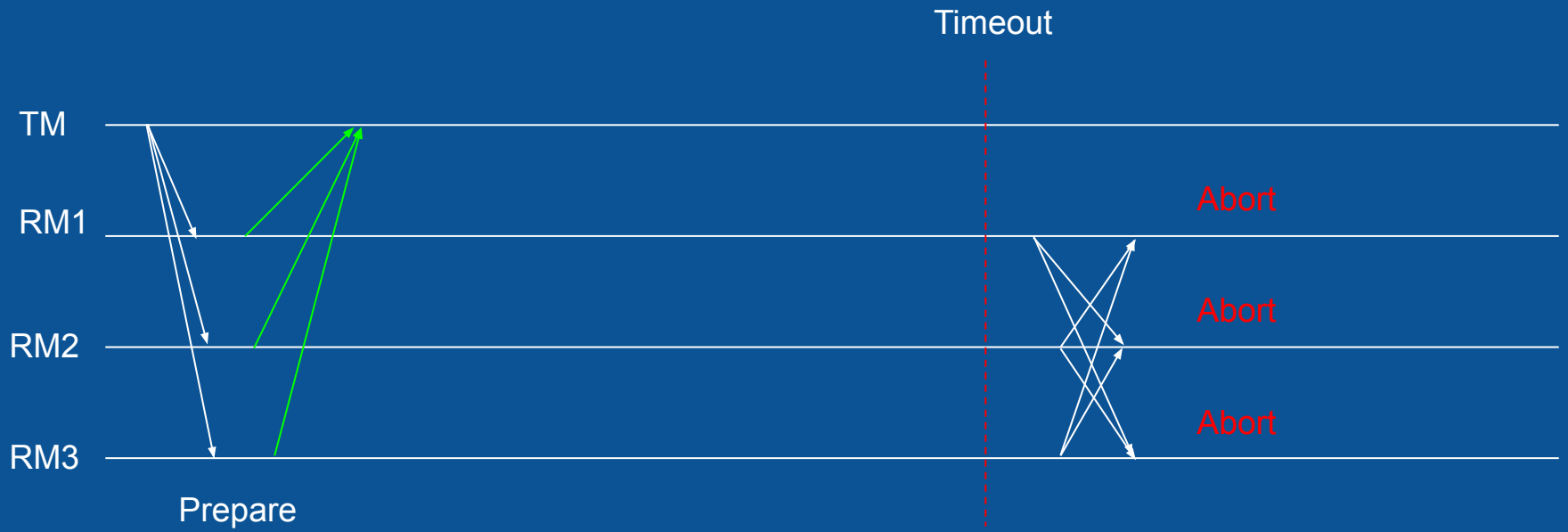
Three-Phase Commit



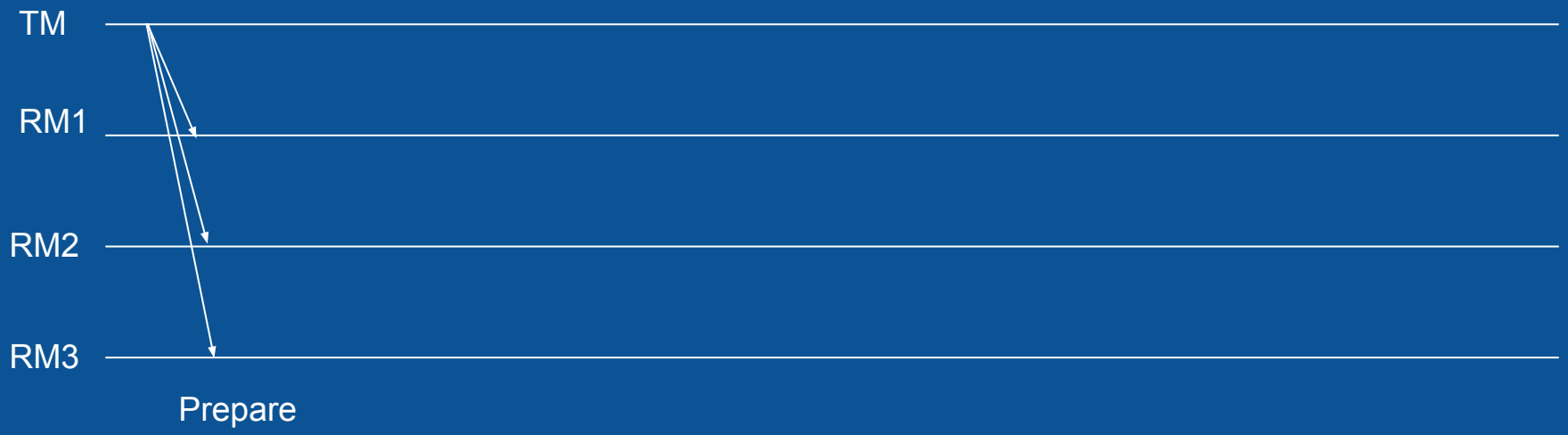
Three-Phase Commit



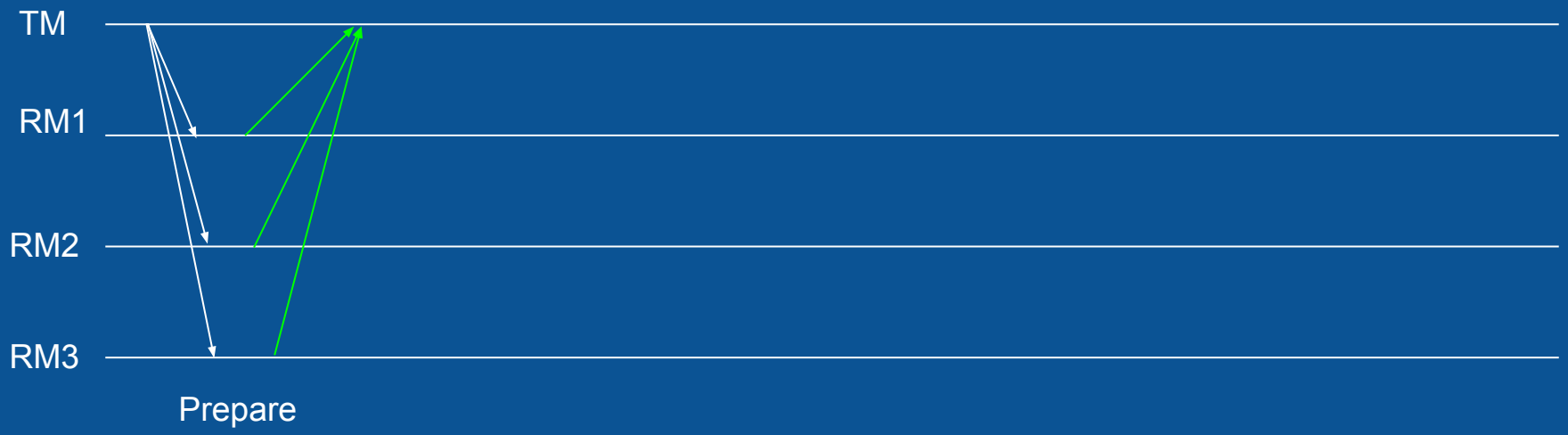
Three-Phase Commit



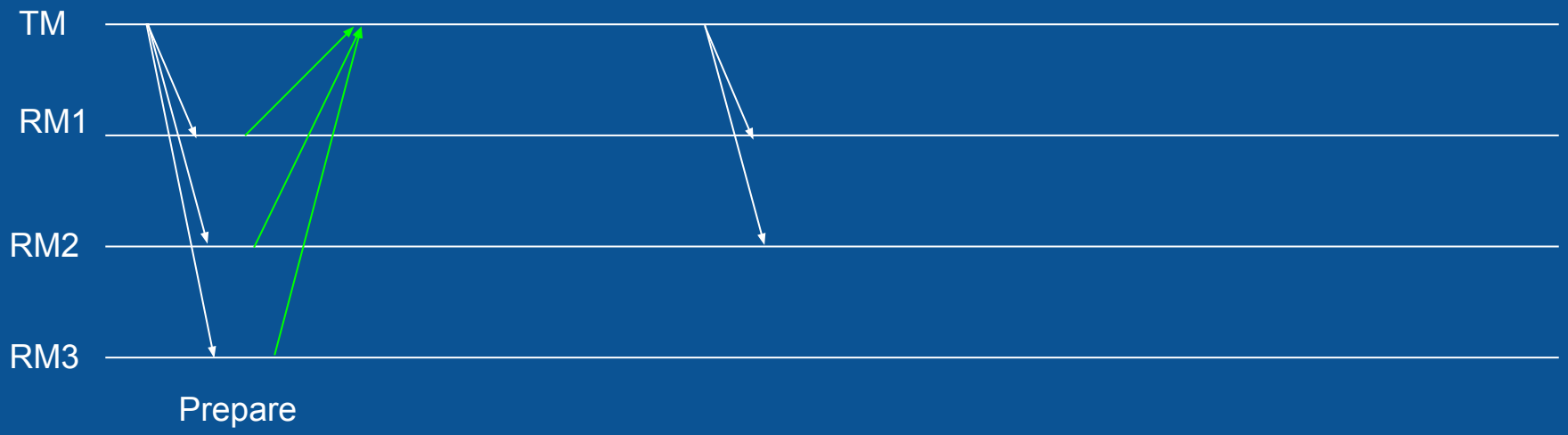
Three-Phase Commit



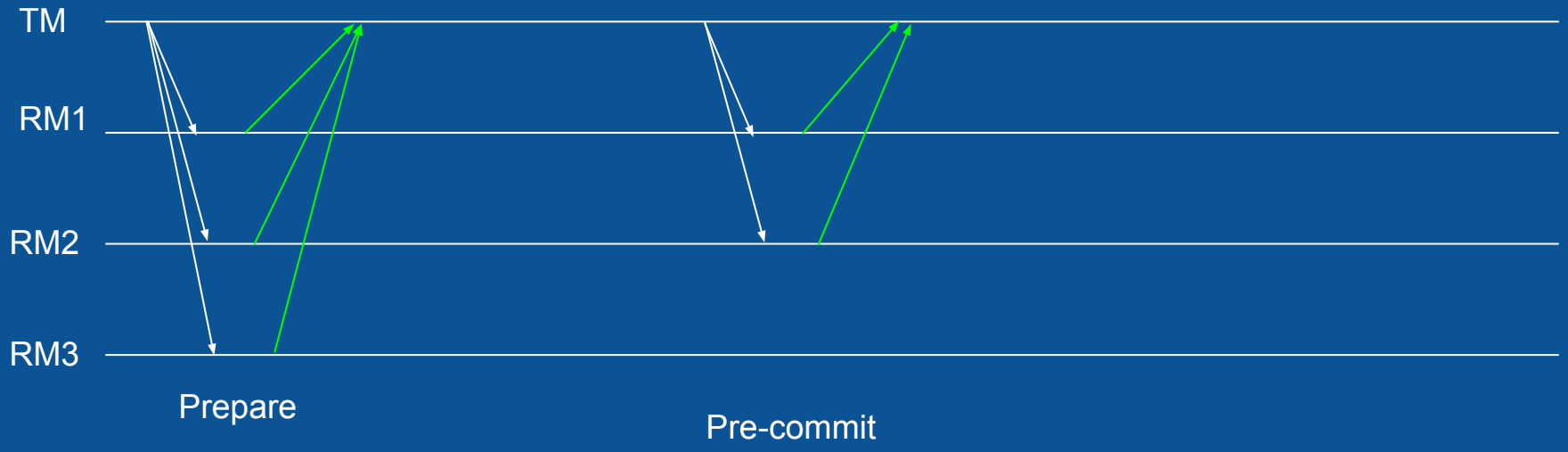
Three-Phase Commit



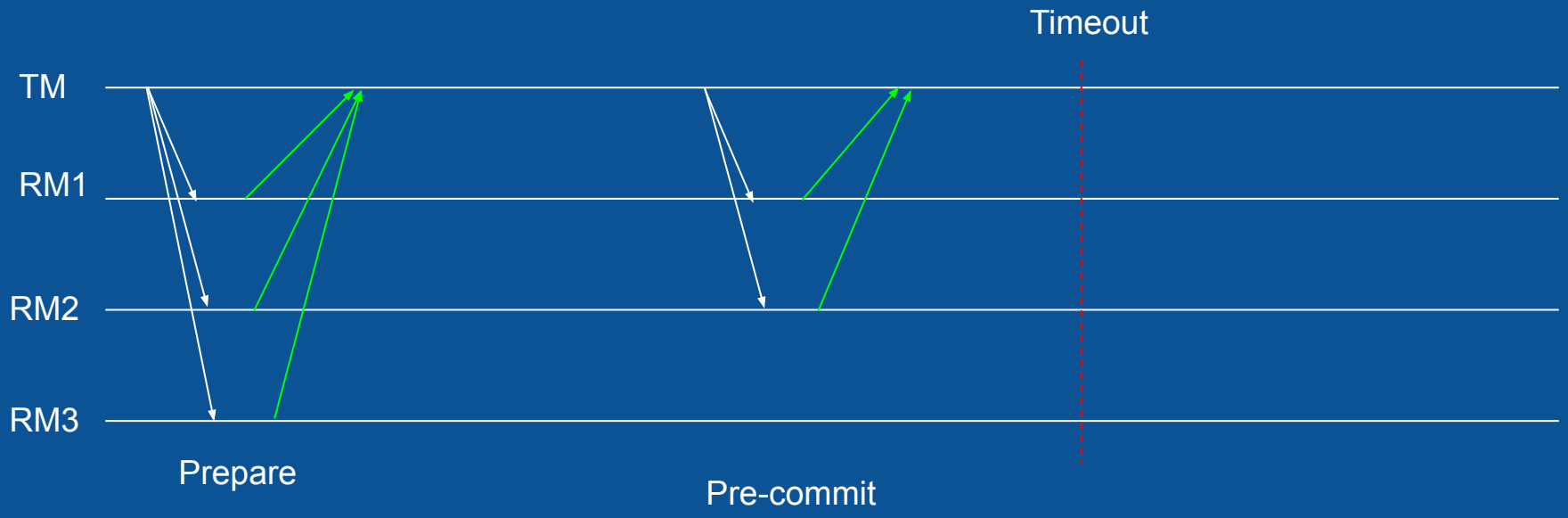
Three-Phase Commit



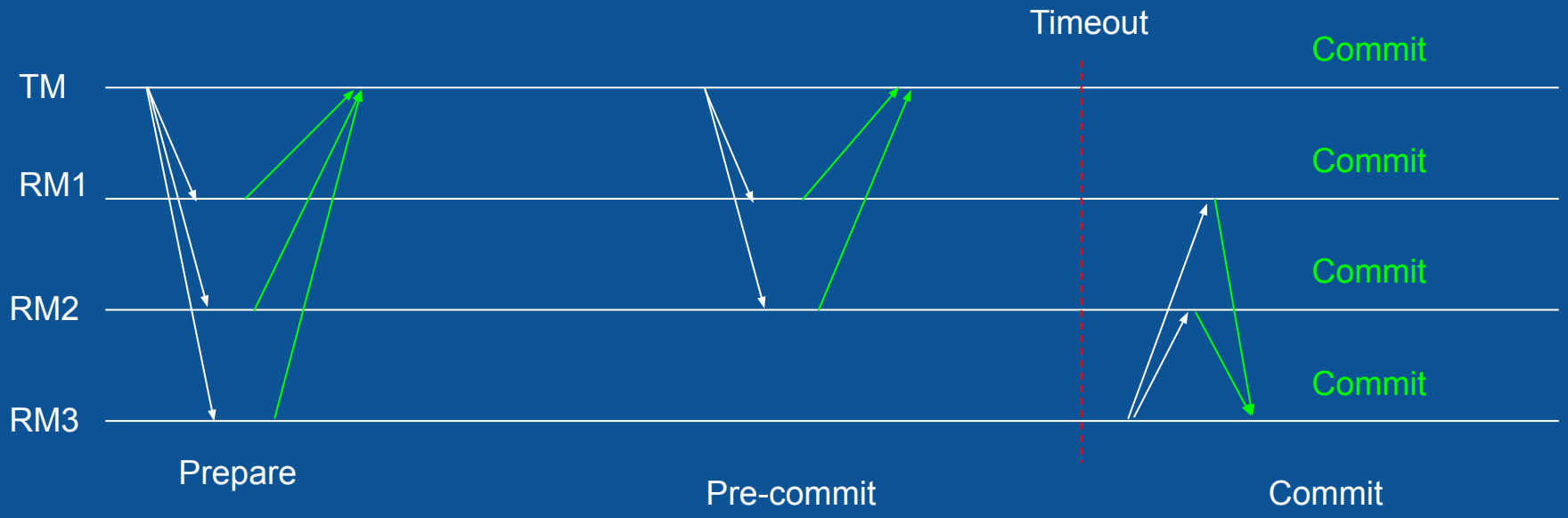
Three-Phase Commit



Three-Phase Commit



Three-Phase Commit



Three-Phase Commit

- Leslie Lamport 2 Phase Commit Specification
- Timeouts
- Pre-commit round

Three-Phase Commit

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Three-Phase Commit

- Leslie Lamport 2 Phase Commit Specification
- Timeouts
- Pre-commit round

Specification of Atomic Commit

3 Phase Commit Specification:

Three-Phase Commit

```
CONSTANT RM \* The set of resource managers

VARIABLE
        rmState,       \* State of each resource manager
        tmState,       \* State of the transaction manager
        rmPrepared,    \* The set of RMs from which the TM has received prepared
messages
        rmPrecommitted, \* The set of RMs from which the TM has received
pre-committed messages
         msgs,         \* Set of all messages
         timeout       \* Timeout flag
```

Three-Phase Commit

```
\* All possible states the RMs and TM can assume
_WORKING == "working"
_PREPARED == "prepared"
_PREPARE == "prepare"
_PRECOMMIT == "pre-commit"
_PRECOMMITTED == "pre-committed"
_COMMIT == "commit"
_COMMITTED == "committed"
_ABORT == "abort"
_ABORTED == "aborted"
_INIT == "init"
```

Three-Phase Commit

```
\* The set of all possible messages.
Message == [ type: {_PREPARE, _PRECOMMIT, _COMMIT, _ABORT}] \cup
           [ type: {_PREPARED, _PRECOMMITTED, _ABORTED}, rm: RM ]
```

Three-Phase Commit

```
\* The set of all possible messages.
Message == [ type: {_PREPARE, _PRECOMMIT, _COMMIT, _ABORT}] \cup
           [ type: {_PREPARED, _PRECOMMITTED, _ABORTED}, rm: RM ]

\* Initial State of the Spec
Init ==
    /\ rmState = [r \in RM |-> _WORKING ]
    /\ tmState = _INIT
    /\ rmPrepared = {}
    /\ rmPrecommitted = {}
    /\ msgs = {}
    /\ timeout = "off"
```

Three-Phase Commit

```
\* TM receives a prepare message from r
TMRcvPrepare(r) ==
        /\ timeout = "off"
        /\ tmState = _INIT
        /\ [ type |-> _PREPARED, rm  |-> r ] \in msgs
        /\ r \notin rmPrepared
        /\ rmPrepared' = rmPrepared \cup {r}
        /\ UNCHANGED<<tmState, rmState, rmPrecommitted, msgs, timeout>>
```

Three-Phase Commit

```
\* TM receives a prepare message from r
TMRcvPrepare(r) ==
        /\ timeout = "off"
        /\ tmState = _INIT
        /\ [ type |-> _PREPARED, rm  |-> r ] \in msgs
        /\ r \notin rmPrepared
        /\ rmPrepared' = rmPrepared \cup {r}
        /\ UNCHANGED<<tmState, rmState, rmPrecommitted, msgs, timeout>>

\* RM decides to go into prepare state
RMPrepare(r) ==
   /\ timeout = "off"
   /\ rmState[r] = _WORKING
   /\ rmState' = [rmState EXCEPT ![r] = _PREPARED]
   /\ msgs' = msgs \cup {[ type |-> _PREPARED, rm |-> r ]}
   /\ UNCHANGED<<tmState, rmPrepared, rmPrecommitted, timeout>>
```

Three-Phase Commit

```
\* TM sends pre-commit message after receiving prepared message from RMs
TMPrecommit ==
        /\ timeout = "off"
        /\ tmState = _INIT
        /\ rmPrepared = RM
        /\ rmPrecommitted = {}
        /\ [ type |-> _PRECOMMIT ] \notin msgs
        /\ msgs' = msgs \cup {[ type |-> _PRECOMMIT ]}
        /\ UNCHANGED<<tmState, rmState, rmPrepared, rmPrecommitted, timeout>>
```

Three-Phase Commit

```
\* TM receives a precommit message from r
TMRcvPrecommit(r) ==
        /\ timeout = "off"
        /\ tmState = _INIT
        /\ [ type |-> _PRECOMMITTED, rm |-> r ] \in msgs
        /\ r \notin rmPrecommitted
        /\ rmPrecommitted' = rmPrecommitted \cup {r}
        /\ UNCHANGED<<tmState, rmState, rmPrepared, msgs, timeout>>
```

Three-Phase Commit

```
\* TM receives a precommit message from r
TMRcvPrecommit(r) ==
        /\ timeout = "off"
        /\ tmState = _INIT
        /\ [ type |-> _PRECOMMITTED, rm |-> r ] \in msgs
        /\ r \notin rmPrecommitted
        /\ rmPrecommitted' = rmPrecommitted \cup {r}
        /\ UNCHANGED<<tmState, rmState, rmPrepared, msgs, timeout>>

\* RM decides to pre-commit after seeing a pre-commit message from TM
RMPrecommit(r) ==
   /\ timeout = "off"
   /\ rmState[r] = _PREPARED
   /\ [ type |-> _PRECOMMIT ] \in msgs
   /\ rmState' = [ rmState EXCEPT ![r] = _PRECOMMITTED ]
   /\ msgs' = msgs \cup {[ type |-> _PRECOMMITTED, rm |-> r ]}
   /\ UNCHANGED<<tmState, rmPrepared, rmPrecommitted, timeout>>
```

Three-Phase Commit

```
\* TM changes to the commit state and sends message to commit
TMCommit ==
   /\ timeout = "off"
   /\ tmState = _INIT
   /\ rmPrecommitted = RM
   /\ tmState' = _COMMITTED
   /\ msgs' = msgs \cup {[ type |-> _COMMIT ]}
   /\ UNCHANGED<<rmState, rmPrepared, rmPrecommitted, timeout>>
```

Three-Phase Commit

```
\* TM changes to the commit state and sends message to commit
TMCommit ==
   /\ timeout = "off"
   /\ tmState = _INIT
   /\ rmPrecommitted = RM
   /\ tmState' = _COMMITTED
   /\ msgs' = msgs \cup {[ type |-> _COMMIT ]}
   /\ UNCHANGED<<rmState, rmPrepared, rmPrecommitted, timeout>>

\* RM receives commit message and changes state to commit
RMCommit(r) ==
   /\ timeout = "off"
   /\ rmState[r] = _PRECOMMITTED
   /\ [ type |-> _COMMIT ] \in msgs
   /\ rmState' = [ rmState EXCEPT ![r] = _COMMITTED ]
   /\ UNCHANGED<<tmState, rmPrepared, rmPrecommitted, msgs, timeout>>
```

Three-Phase Commit

```
\* TM decides to abort the transaction
TMAbort ==
   /\ timeout = "off"
   /\ rmPrecommitted = {}
   /\ ~ ([ type |-> _PRECOMMIT ] \in msgs \/ [ type |-> _COMMIT ] \in msgs)
   /\ tmState = _INIT
   /\ tmState' = _ABORTED
   /\ msgs' = msgs \cup {[type |-> _ABORT]}
   /\ UNCHANGED <<rmState, rmPrepared, rmPrecommitted, timeout>>
```

Three-Phase Commit

```
\* TM decides to abort the transaction
TMAbort ==
   /\ timeout = "off"
   /\ rmPrecommitted = {}
   /\ ~ ([ type |-> _PRECOMMIT ] \in msgs \/ [ type |-> _COMMIT ] \in msgs)
   /\ tmState = _INIT
   /\ tmState' = _ABORTED
   /\ msgs' = msgs \cup {[type |-> _ABORT]}
   /\ UNCHANGED <<rmState, rmPrepared, rmPrecommitted, timeout>>

\* TM decides to abort the transaction after seeing an aborted message from an RM and sends abort message
TMRcvAbort(r) ==
   /\ timeout = "off"
   /\ tmState = _INIT
   /\ [type |-> _ABORTED, rm |-> r] \in msgs
   /\ rmPrecommitted = {}
   /\ tmState' = _ABORTED
   /\ msgs' = msgs \cup {[type |-> _ABORT]}
   /\ UNCHANGED <<rmState, rmPrepared, rmPrecommitted, timeout>>
```

Three-Phase Commit

```
\* RM Chooses to abort during the prepare phase
RMChooseToAbort(r) ==
   /\ timeout = "off"
   /\ rmState[r] = _WORKING
   /\ rmState' = [rmState EXCEPT ![r] = _ABORTED]
   /\ r \notin rmPrepared
   /\ msgs' = msgs \cup {[type |-> _ABORTED, rm |-> r ]}
   /\ UNCHANGED <<tmState, rmPrepared, rmPrecommitted, timeout>>
```

Three-Phase Commit

```
\* RM Chooses to abort during the prepare phase
RMChooseToAbort(r) ==
    /\ timeout = "off"
    /\ rmState[r] = _WORKING
    /\ rmState' = [rmState EXCEPT ![r] = _ABORTED]
    /\ r \notin rmPrepared
    /\ msgs' = msgs \cup {[type |-> _ABORTED, rm |-> r ]}
    /\ UNCHANGED <<tmState, rmPrepared, rmPrecommitted, timeout>>

\* RM decides to abort after seeing the abort message from TM
RMRcvAbortMsg(r) ==
    /\ timeout = "off"
    /\ rmState[r] = _PREPARED \/ rmState[r] = _WORKING
    /\ [type |-> _ABORT] \in msgs
    /\ rmState' = [rmState EXCEPT ![r] = _ABORTED]
    /\ UNCHANGED <<tmState, rmPrepared, rmPrecommitted, msgs, timeout>>
```

Three-Phase Commit

```
Timeout ==
   /\ ~ tmState = _COMMITTED
   /\ timeout = "off"
   /\ timeout' = "on"
   /\ UNCHANGED<<msgs, rmState, tmState, rmPrepared, rmPrecommitted>>
```

Three-Phase Commit

```
RMWhenTimeout(r) ==
   /\ timeout = "on"
   /\ rmState[r] \notin {_ABORTED, _COMMITTED}
   /\ IF rmPrecommitted # {}
         THEN
            /\ rmState' = [rmState EXCEPT ![r] = _COMMITTED]
         ELSE
            /\ rmState' = [rmState EXCEPT ![r] = _ABORTED]
   /\ UNCHANGED<<msgs,tmState, rmPrepared, rmPrecommitted, timeout>>
```

Three-Phase Commit

```
RMWhenTimeout(r) ==
   /\ timeout = "on"
   /\ rmState[r] \notin {_ABORTED, _COMMITTED}
   /\ IF rmPrecommitted # {}
            THEN
               /\ rmState' = [rmState EXCEPT ![r] = _COMMITTED]
            ELSE
               /\ rmState' = [rmState EXCEPT ![r] = _ABORTED]
   /\ UNCHANGED<<msgs,tmState, rmPrepared, rmPrecommitted, timeout>>

TMWhenTimeout ==
   /\ timeout = "on"
   /\ tmState = _INIT
   /\  IF rmPrecommitted # {} /\ ~ [ type |-> _ABORT ] \in msgs
      THEN
         /\ tmState' = _COMMITTED
      ELSE
         /\ tmState' = _ABORTED
   /\ UNCHANGED<<msgs,rmState, rmPrepared, rmPrecommitted, timeout>>
```

Three-Phase Commit

- **Remember:**

```
VARIABLE
    rmState,        \* State of each resource manager
    tmState,        \* State of the transaction manager
    rmPrepared,     \* The set of RMs from which the TM has received prepared messages
    rmPrecommitted, \* The set of RMs from which the TM has received pre-committed messages
     msgs,          \* Set of all messages
     timeout        \* Timeout flag
```

Three-Phase Commit

- **Remember:**

```
VARIABLE
        rmState,       \* State of each resource manager
        tmState,       \* State of the transaction manager
        rmPrepared,    \* The set of RMs from which the TM has received prepared messages
        rmPrecommitted, \* The set of RMs from which the TM has received pre-committed messages
         msgs,         \* Set of all messages
         timeout       \* Timeout flag

TypeOK ==
        /\ rmState \in [ RM -> { _WORKING, _PREPARED, _PRECOMMITTED, _COMMITTED, _ABORTED } ]
        /\ tmState \in { _INIT, _COMMITTED, _ABORTED }
        /\ rmPrepared \subseteq RM
        /\ rmPrecommitted \subseteq RM
        /\ msgs \subseteq Message
        /\ timeout \in {"on", "off"}
```

Three-Phase Commit

```
Agreement ==
        \A rm1, rm2 \in RM : ~ /\ rmState[rm1] = _ABORTED
                               /\ rmState[rm2] = _COMMITTED

Validity ==
        \E r \in RM: rmState[r] = _ABORTED ~> tmState = _ABORTED

Fairness ==
                /\ WF_vars(TMCommit)
                /\ WF_vars(TMAbort)
                /\ WF_vars(TMPrecommit)
                /\ \A r \in RM: WF_vars(TMRcvPrecommit(r))
                /\ \A r \in RM: WF_vars(TMRcvPrepare(r))
                /\ \A r \in RM: WF_vars(TMRcvAbort(r))
                /\ \A r \in RM: WF_vars(TMWhenTimeout)
                /\ \A r \in RM: WF_vars(RMWhenTimeout(r))
```

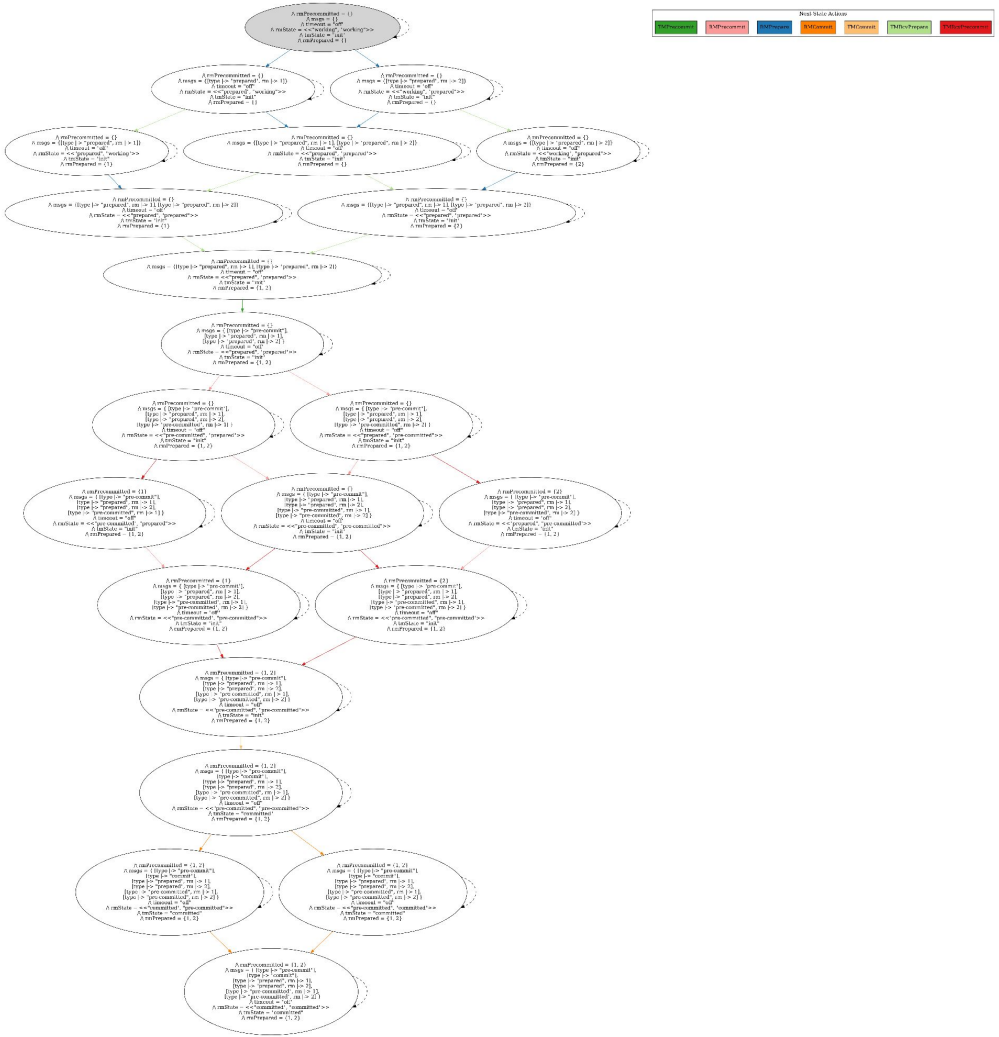
Three-Phase Commit

```
Next ==
    \/ TMPrecommit
    \/ TMCommit
    \/ TMAbort
    \/ Timeout
    \/ TMWhenTimeout
    \/ \E r \in RM:
        \/ TMRcvPrepare(r)
        \/ TMRcvPrecommit(r)
        \/ TMRcvAbort(r)
        \/ RMPrepare(r)
        \/ RMPrecommit(r)
        \/ RMCommit(r)
        \/ RMWhenTimeout(r)
        \/ RMChooseToAbort(r)
        \/ RMRcvAbortMsg(r)
```

Our 3PC Specification

TLC reports no errors!

Time	Diameter	States Found	Distinct States	Queue Size
00:00:48	29	256,756	84,111	0
00:00:05	8	42,827	16,907	8,530
00:00:01	0	1	1	1


Real State Actions
TMPrecommit
TMPrecommit
TMPrepare
TMCommit
TMCommit
TMNoPrepare
TMNoPrecommit

Evaluation Questions

Conclusion

- TLA+ is a useful tool to verify properties of an algorithm
- Complex systems are hard to specify
- Only validates the provided specification

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Future Work

Future Work

Two-Phase Commit

- Allow Transaction manager to crash
- Model message loss / Network partitions

Future Work

Two-Phase Commit

- Allow Transaction manager to crash
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Future Work

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- Allow Transaction manager to crash
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Future Work

Three-Phase Commit

- Verify Validity
- Verify Termination
- Model Network Partitions
- Model Process crashes

Future Work

Three-Phase Commit

- Verify Validity
- Verify Termination
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- Model Process crashes

Future Work

Three-Phase Commit

- Verify Validity
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Future Work

Three-Phase Commit

- Verify Validity
- Verify Termination
- Model Network Partitions
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Thank you!

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Questions?