

Atomic Commit

The objective

Preserve data consistency for distributed transactions in the presence of failures

Model

- For each distributed transaction T:
 - one coordinator
 - a set of participants
- Coordinator knows participants; participants don't necessarily know each other
- Each process has access to a Distributed Transaction Log (DT Log) on stable storage

The setup

- Each process p_i has an input value $vote_i$:
 $vote_i \in \{\text{Yes, No}\}$
- Each process p_i has output value $decision_i$:
 $decision_i \in \{\text{Commit, Abort}\}$

AC Specification

AC-1: All processes that reach a decision reach the same one.

AC-2: A process cannot reverse its decision after it has reached one.

AC-3: The Commit decision can only be reached if all processes vote Yes.

AC-4: If there are no failures and all processes vote Yes, then the decision will be Commit.

AC-5: If all failures are repaired and there are no more failures, then all processes will eventually decide.

Comments

AC-1: All processes that reach a decision reach the same one.

AC-2: A process cannot reverse its decision after it has reached one

AC-3: The Commit decision can only be reached if all processes vote Yes

AC-4: If there are no failures and all processes vote Yes, then the decision will be Commit

AC-5: If all failures are reported and there are no more failures, then all processes will eventually decide

AC1:

- We do not require all processes to reach a decision
- We do not even require all correct processes to reach a decision (impossible to accomplish if links fail)

AC4:

- Avoids triviality
- Allows Abort even if all processes have voted yes

NOTE:

- A process that does not vote Yes can unilaterally abort

Liveness & Uncertainty

- A process is uncertain if it has voted Yes but does not have sufficient information to commit
- While uncertain, a process cannot decide unilaterally
- Uncertainty + communication failures = blocking!

Liveness & Independent Recovery

- Suppose process p fails while running AC.
- If, during recovery, p can reach a decision without communicating with other processes, we say that p can **independently recover**
- Total failure (i.e. all processes fail) - independent recovery = blocking

A few character-building facts

Proposition 1

If communication failures or total failures are possible, then every AC protocol may cause processes to become blocked

Proposition 2

No AC protocol can guarantee independent recovery of failed processes

2-Phase Commit

Coordinator c

Participant p_i

I. sends VOTE-REQ to all participants

2-Phase Commit

Coordinator c

Participant p_i

I. sends VOTE-REQ to all participants

II. sends $vote_i$ to Coordinator
if $vote_i = \text{NO}$ then
 $decide_i := \text{ABORT}$
halt

2-Phase Commit

Coordinator c

Participant p_i

I. sends VOTE-REQ to all participants

II. sends $vote_i$ to Coordinator
if $vote_i = \text{NO}$ then
 $decide_i := \text{ABORT}$
halt

III. c votes
if all vote YES then
 $decide_c := \text{COMMIT}$
send COMMIT to all
else
 $decide_c := \text{ABORT}$
send ABORT to all who voted YES
halt

2-Phase Commit

Coordinator c

Participant p_i

I. sends VOTE-REQ to all participants

II. sends $vote_i$ to Coordinator
if $vote_i = \text{NO}$ then
 $decide_i := \text{ABORT}$
halt

III. c votes

if all vote YES then
 $decide_c := \text{COMMIT}$
send COMMIT to all

else

$decide_c := \text{ABORT}$
send ABORT to all who voted YES

halt

IV. if received COMMIT then
 $decide_i := \text{COMMIT}$
else
 $decide_i := \text{ABORT}$
halt

Notes on 2PC

- Satisfies AC-1 to AC-4
- But not AC-5 (at least "as is")
 - i. A process may be waiting for a message that may never arrive
 - Use Timeout Actions
 - ii. No guarantee that a recovered process will reach a decision consistent with that of other processes
 - Processes save protocol state in DT-Log

Timeout actions

Processes are waiting on steps 2, 3, and 4

Step 2 p_i is waiting for VOTE-REQ from coordinator

Step 3 Coordinator is waiting for vote from participants

Step 4 p_i (who voted YES) is waiting for COMMIT or ABORT

Timeout actions

Processes are waiting on steps 2, 3, and 4

Step 2 p_i is waiting for VOTE-REQ from coordinator

Since it has not cast its vote yet, p_i can decide ABORT and halt.

Step 3 Coordinator is waiting for vote from participants

Step 4 p_i (who voted YES) is waiting for COMMIT or ABORT

Timeout actions

Processes are waiting on steps 2, 3, and 4

Step 2 p_i is waiting for VOTE-REQ from coordinator

Since it has not cast its vote yet, p_i can decide ABORT and halt.

Step 3 Coordinator is waiting for vote from participants

Coordinator can decide ABORT, send ABORT to all participants which voted YES, and halt.

Step 4 p_i (who voted YES) is waiting for COMMIT or ABORT

Timeout actions

Processes are waiting on steps 2, 3, and 4

Step 2 p_i is waiting for VOTE-REQ from coordinator

Since it has not cast its vote yet, p_i can decide ABORT and halt.

Step 3 Coordinator is waiting for vote from participants

Coordinator can decide ABORT, send ABORT to all participants which voted YES, and halt.

Step 4 p_i (who voted YES) is waiting for COMMIT or ABORT

p_i cannot decide: it must run a **termination protocol**

Termination protocols

I. Wait for coordinator to recover

- It always works, since the coordinator is never uncertain

- may block recovering process unnecessarily

II. Ask other participants

Cooperative Termination

- c appends list of participants to VOTE-REQ
- when an uncertain process p times out, it sends a DECISION-REQ message to every other participant q
- if q has decided, then it sends its decision value to p , which decides accordingly
- if q has not yet voted, then it decides ABORT, and sends ABORT to p
- What if q is uncertain?

Logging actions

1. When c sends VOTE-REQ, it writes START-2PC to its DT Log
2. When p_i is ready to vote YES,
 - i. p_i writes YES to DT Log
 - ii. p_i sends YES to c (p_i writes also list of participants)
3. When p_i is ready to vote NO, it writes ABORT to DT Log
4. When c is ready to decide COMMIT, it writes COMMIT to DT Log before sending COMMIT to participants
5. When c is ready to decide ABORT, it writes ABORT to DT Log
6. After p_i receives decision value, it writes it to DT Log

p recovers

1. When coordinator sends VOTE-REQ, it writes START-2PC to its DT Log
2. When participant is ready to vote Yes, writes Yes to DT Log before sending yes to coordinator (writes also list of participants)
When participant is ready to vote No, it writes ABORT to DT Log
3. When coordinator is ready to decide COMMIT, it writes COMMIT to DT Log before sending COMMIT to participants
When coordinator is ready to decide ABORT, it writes ABORT to DT Log
4. After participant receives decision value, it writes it to DT Log

p recovers

1. When coordinator sends VOTE-REQ, it writes START-2PC to its DT Log
 2. When participant is ready to vote Yes, writes Yes to DT Log before sending yes to coordinator (writes also list of participants)
When participant is ready to vote No, it writes ABORT to DT Log
 3. When coordinator is ready to decide COMMIT, it writes COMMIT to DT Log before sending COMMIT to participants
When coordinator is ready to decide ABORT, it writes ABORT to DT Log
 4. After participant receives decision value, it writes it to DT Log
- if DT Log contains START-2PC, then $p = c$:
 - if DT Log contains a decision value, then decide accordingly
 - else decide ABORT

p recovers

1. When coordinator sends VOTE-REQ, it writes START-2PC to its DT Log
 2. When participant is ready to vote Yes, writes Yes to DT Log before sending yes to coordinator (writes also list of participants)
When participant is ready to vote No, it writes ABORT to DT Log
 3. When coordinator is ready to decide COMMIT, it writes COMMIT to DT Log before sending COMMIT to participants
When coordinator is ready to decide ABORT, it writes ABORT to DT Log
 4. After participant receives decision value, it writes it to DT Log
- if DT Log contains START-2PC, then $p = c$:
 - if DT Log contains a decision value, then decide accordingly
 - else decide ABORT
 - otherwise, p is a participant:
 - if DT Log contains a decision value, then decide accordingly
 - else if it does not contain a Yes vote, decide ABORT
 - else (Yes but no decision) run a termination protocol

2PC and blocking

- Blocking occurs whenever the progress of a process depends on the repairing of failures
- No AC protocol is non blocking in the presence of communication or total failures
- But 2PC can block even with non-total failures and no communication failures among operating processes!

3-Phase Commit

- Two approaches:

1. Focus only on site failures

- Non-blocking, unless all sites fails
- Timeout \equiv site at the other end failed
- Communication failures can produce inconsistencies

2. Tolerate both site and communication failures

- partial failures can still cause blocking, but less often than in 2PC

Blocking and uncertainty

Why does uncertainty lead to blocking?

Blocking and uncertainty

Why does uncertainty lead to blocking?

- An uncertain process does not know whether it can safely decide COMMIT or ABORT because some of the processes it cannot reach could have decided either

Blocking and uncertainty

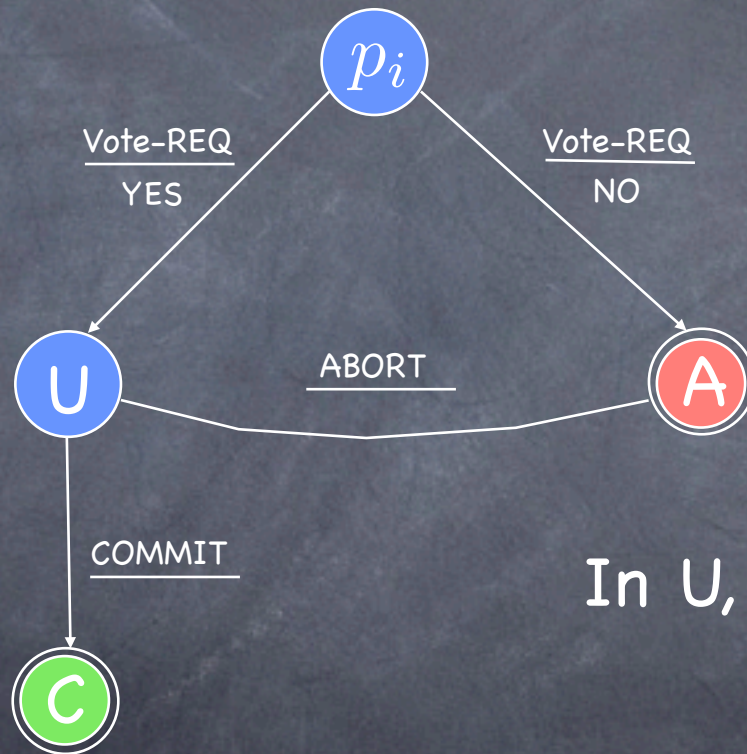
Why does uncertainty lead to blocking?

- An uncertain process does not know whether it can safely decide COMMIT or ABORT because some of the processes it cannot reach could have decided either

Non-blocking Property

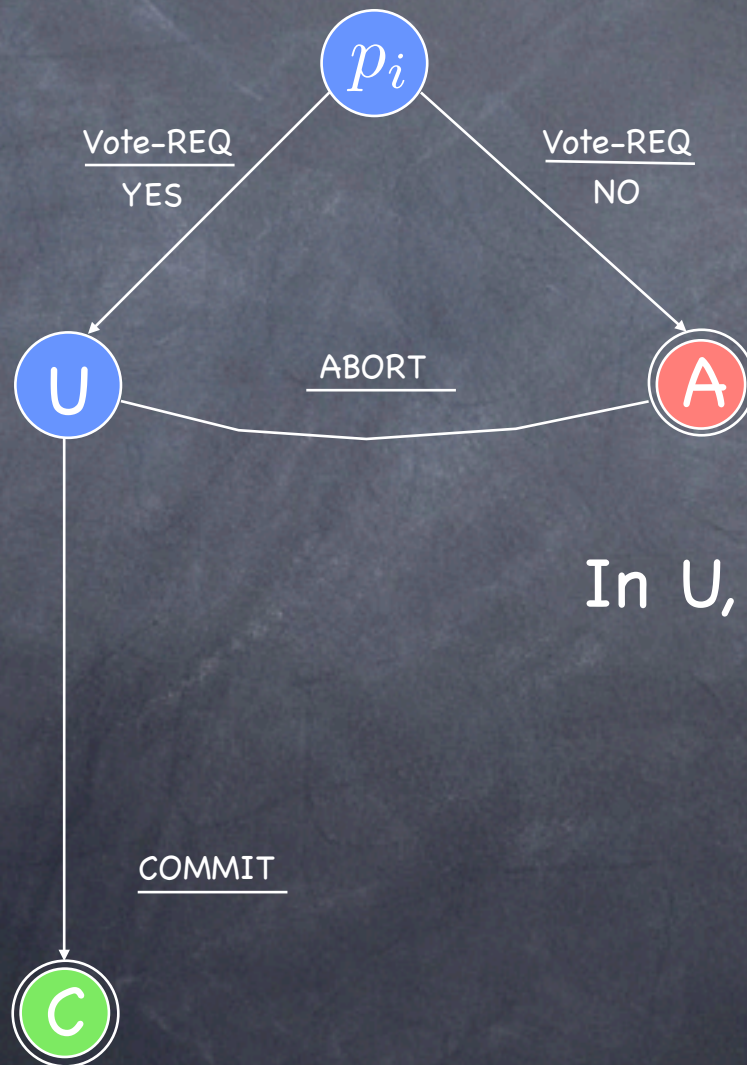
If any operational process is uncertain, then no process has decided COMMIT

2PC Revisited



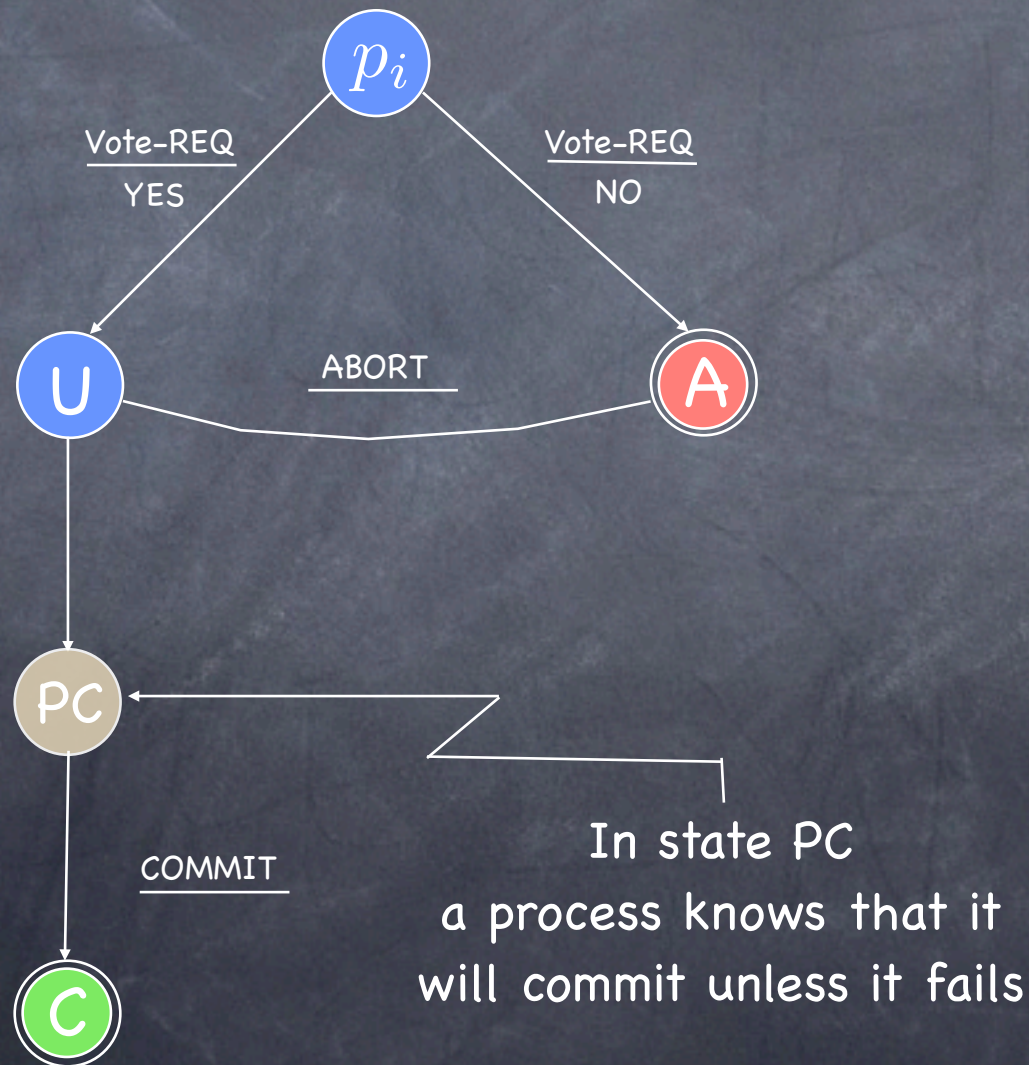
In U, both A and C are reachable!

2PC Revisited

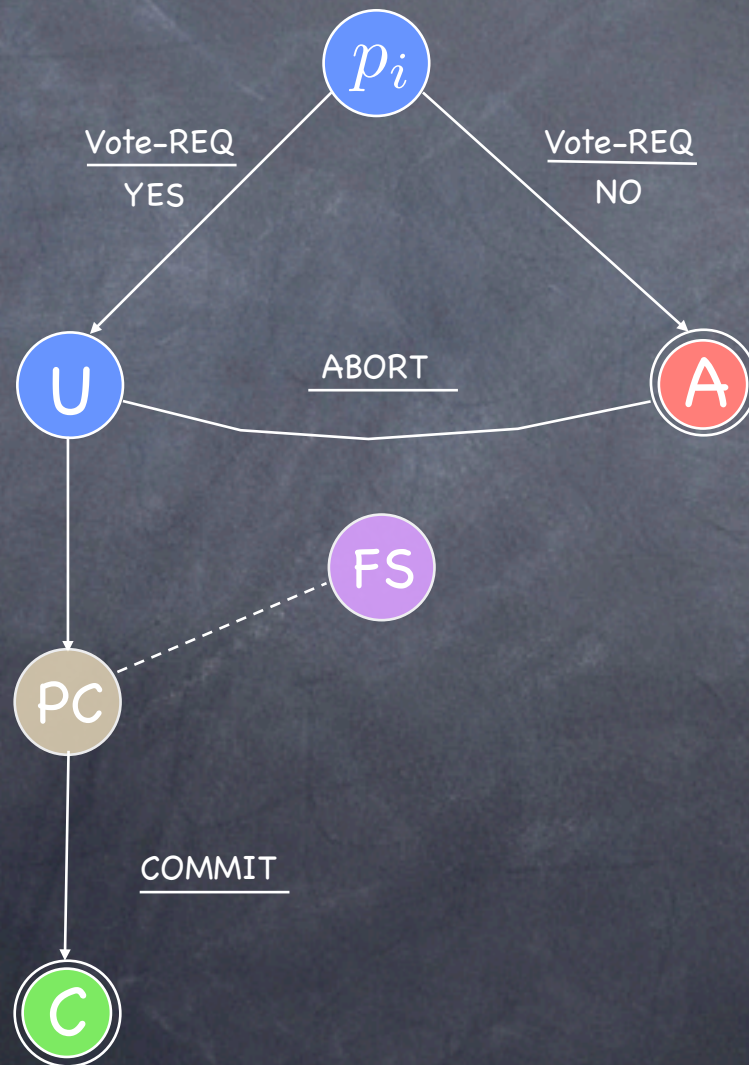


In U, both A and C are reachable!

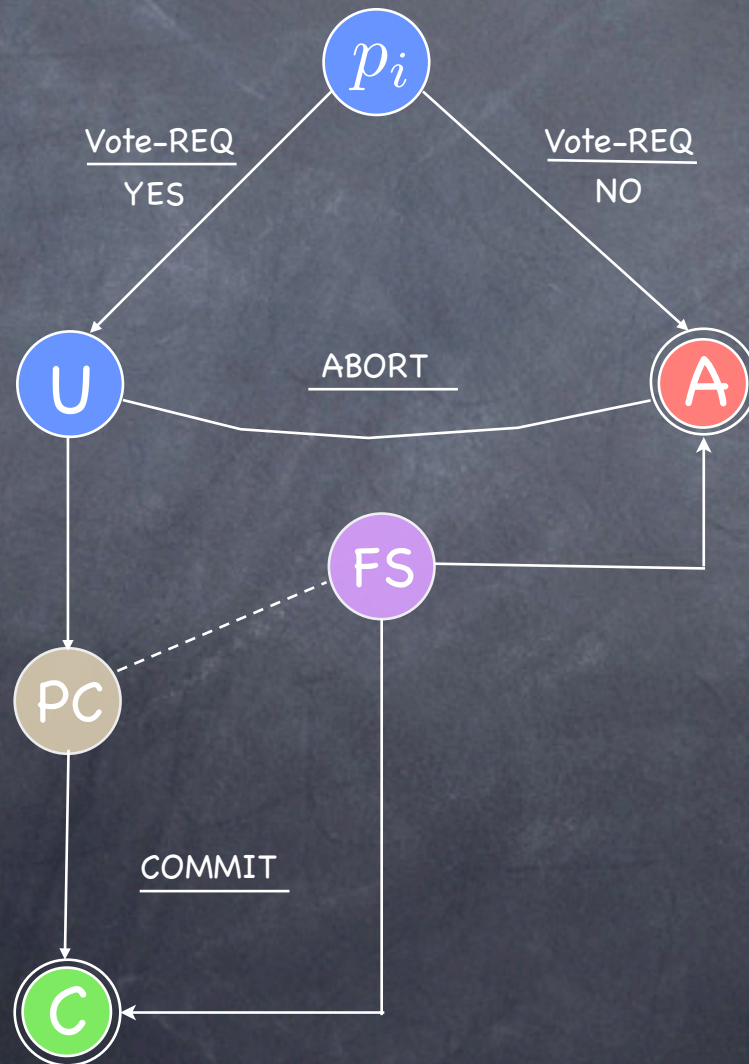
2PC Revisited



2PC Revisited



2PC Revisited



3PC: The Protocol

Dale Skeen (1982)

- I. c sends VOTE-REQ to all participants.
- II. When p_i receives a VOTE-REQ, it responds by sending a vote to c
if $vote_i = \text{No}$, then $decide_i := \text{ABORT}$ and p_i halts.
- III. c collects votes from all (including itself).
if all votes are Yes, then c sends PRECOMMIT to all
else $decide_c := \text{ABORT}$; sends ABORT to all who voted Yes halts
- IV. if p_i receives PRECOMMIT then it sends ACK to c
- V. c collects ACKs from all.
When all ACKs have been received, $decide_c := \text{COMMIT}$;
 c sends COMMIT to all.
- VI. When p_i receives COMMIT, p_i sets $decide_i := \text{COMMIT}$ and halts.

Wait a minute!

1. c sends VOTE-REQ to all participants
2. When participant p_i receives a VOTE-REQ, it responds by sending a vote to c
if $vote_i = \text{No}$, then $decide_i = \text{ABORT}$ and p_i halts
3. c collects vote from all (including itself)
if all votes are Yes, then c sends PRECOMMIT to all
else $decide_c = \text{ABORT}$; c sends ABORT to all who voted Yes
 c halts
4. if p_i receives PRECOMMIT then it sends ACK to c
5. c collects ACKs from all
when all ACKs have been received, $decide_c = \text{COMMIT}$
 c sends COMMIT to all
6. When p_i receives COMMIT, p_i sets $decide_i = \text{COMMIT}$
 p_i halts

- Messages are known to the receiver before they are sent...so, why **are** they sent?

Wait a minute!

1. c sends VOTE-REQ to all participants
2. When participant p_i receives a VOTE-REQ, it responds by sending a vote to c
if $vote_i = \text{No}$, then $decide_i = \text{ABORT}$ and p_i halts
3. c collects vote from all (including itself).
if all votes are Yes, then c sends PRECOMMIT to all
else $decide_c = \text{ABORT}$; c sends ABORT to all who voted Yes
 c halts
4. if p_i receives PRECOMMIT then it sends ACK to c
5. c collects ACKs from all
when all ACKs have been received, $decide_c = \text{COMMIT}$
 c sends COMMIT to all
6. When p_i receives COMMIT, p_i sets $decide_i = \text{COMMIT}$
 p_i halts

- Messages are known to the receiver before they are sent...so, why **are** they sent?

They inform the recipient of the protocol's progress!

- When c receives ACK from p , it knows p is not uncertain
- When p receives COMMIT, it knows no participant is uncertain, so it can commit

Timeout Actions

Processes are waiting on steps 2, 3, 4, 5, and 6

Step 2 p_i is waiting for VOTE-REQ from coordinator

Step 3 Coordinator is waiting for vote from participants

Step 4 p_i waits for PRECOMMIT

Step 5 Coordinator waits for ACKs

Step 6 p_i waits for COMMIT

Timeout Actions

Processes are waiting on steps 2, 3, 4, 5, and 6

<p>Step 2 p_i is waiting for VOTE-REQ from coordinator</p> <p>Exactly as in 2PC</p>	<p>Step 3 Coordinator is waiting for vote from participants</p>
<p>Step 4 p_i waits for PRECOMMIT</p>	<p>Step 5 Coordinator waits for ACKs</p>
<p>Step 6 p_i waits for COMMIT</p>	

Timeout Actions

Processes are waiting on steps 2, 3, 4, 5, and 6

<p>Step 2 p_i is waiting for VOTE-REQ from coordinator</p> <p>Exactly as in 2PC</p>	<p>Step 3 Coordinator is waiting for vote from participants</p> <p>Exactly as in 2PC</p>
<p>Step 4 p_i waits for PRECOMMIT</p>	<p>Step 5 Coordinator waits for ACKs</p>
<p>Step 6 p_i waits for COMMIT</p>	

Timeout Actions

Processes are waiting on steps 2, 3, 4, 5, and 6

<p>Step 2 p_i is waiting for VOTE-REQ from coordinator</p> <p>Exactly as in 2PC</p>	<p>Step 3 Coordinator is waiting for vote from participants</p> <p>Exactly as in 2PC</p>
<p>Step 4 p_i waits for PRECOMMIT</p>	<p>Step 5 Coordinator waits for ACKs</p> <p>Coordinator sends COMMIT</p>
<p>Step 6 p_i waits for COMMIT</p>	

Timeout Actions

Processes are waiting on steps 2, 3, 4, 5, and 6

<p>Step 2 p_i is waiting for VOTE-REQ from coordinator</p> <p>Exactly as in 2PC</p>	<p>Step 3 Coordinator is waiting for vote from participants</p> <p>Exactly as in 2PC</p>
<p>Step 4 p_i waits for PRECOMMIT</p> <p>Run some Termination protocol</p>	<p>Step 5 Coordinator waits for ACKs</p> <p>Coordinator sends COMMIT</p>
<p>Step 6 p_i waits for COMMIT</p>	

Timeout Actions

Processes are waiting on steps 2, 3, 4, 5, and 6

<p>Step 2 p_i is waiting for VOTE-REQ from coordinator</p> <p>Exactly as in 2PC</p>	<p>Step 3 Coordinator is waiting for vote from participants</p> <p>Exactly as in 2PC</p>
<p>Step 4 p_i waits for PRECOMMIT</p> <p>Run some Termination protocol</p>	<p>Step 5 Coordinator waits for ACKs</p> <p>Coordinator sends COMMIT</p>
<p>Step 6 p_i waits for COMMIT</p>	<p>Participant knows what is going to receive...</p>

Timeout Actions

Processes are waiting on steps 2, 3, 4, 5, and 6

<p>Step 2 p_i is waiting for VOTE-REQ from coordinator</p> <p>Exactly as in 2PC</p>	<p>Step 3 Coordinator is waiting for vote from participants</p> <p>Exactly as in 2PC</p>
<p>Step 4 p_i waits for PRECOMMIT</p> <p>Run some Termination protocol</p>	<p>Step 5 Coordinator waits for ACKs</p> <p>Coordinator sends COMMIT</p>
<p>Step 6 p_i waits for COMMIT</p> <p>Run some Termination protocol</p>	<p>Participant knows what is going to receive...</p> <p>but NB property can be violated!</p>

Termination protocol: Process states

At any time while running 3 PC, each participant can be in exactly one of these 4 states:

Aborted Not voted, voted NO, received ABORT

Uncertain Voted YES, not received PRECOMMIT

Committable Received PRECOMMIT, not COMMIT

Committed Received COMMIT

Not all states are compatible

	Aborted	Uncertain	Committable	Committed
Aborted	Y	Y	N	N
Uncertain	Y	Y	Y	N
Committable	N	Y	Y	Y
Committed	N	N	Y	Y

Termination protocol

- When p_i times out, it starts an election protocol to elect a new coordinator
- The new coordinator sends STATE-REQ to all processes that participated in the election
- The new coordinator collects the states and follows a **termination rule**

- TR1.** if some process decided ABORT, then
decide ABORT
send ABORT to all
halt
- TR2.** if some process decided COMMIT, then
decide COMMIT
send COMMIT to all
halt
- TR3.** if all processes that reported state are uncertain, then
decide ABORT
send ABORT to all
halt
- TR4.** if some process is committable, but none committed, then
send PRECOMMIT to uncertain processes
wait for ACKs
send COMMIT to all
halt

Termination protocol and failures

Processes can fail while executing the termination protocol...

- if c times out on p , it can just ignore p
- if c fails, a new coordinator is elected and the protocol is restarted (election protocol to follow)
- total failures will need special care...

Recovering p

- if p fails before sending YES, decide ABORT
- if p fails after having decided, follow decision
- if p fails after voting YES but before receiving decision value
 - p asks other processes for help
 - 3PC is non blocking: p will receive a response with the decision
- if p has received PRECOMMIT
 - still needs to ask other processes (cannot just COMMIT)

Recovering p

- if p fails before sending YES, decide ABORT
- if p fails after having decided, follow decision
- if p fails after voting YES but before receiving decision value
 - p asks other processes for help
 - 3PC is non blocking: p will receive a response with the decision
- if p has received PRECOMMIT
 - still needs to ask other processes (cannot just COMMIT)

No need to log PRECOMMIT!?!

The election protocol

- Processes agree on linear ordering (e.g. by pid)
- Each p maintains set UP_p of all processes that p believes to be operational
- When p detects failure of c , it removes c from UP_p and chooses smallest q in UP_p to be new coordinator
- If $q = p$, then p is new coordinator
- Otherwise, p sends UR-ELECTED to q

A few observations

- What if p' , which has not detected the failure of c , receives a STATE-REQ from q ?

A few observations

- What if p' , which has not detected the failure of c , receives a STATE-REQ from q ?
 - it concludes that c must be faulty
 - it removes from $UP_{p'}$ every $q' < q$

A few observations

- What if p' , which has not detected the failure of c , receives a STATE-REQ from q ?
 - it concludes that c must be faulty
 - it removes from $UP_{p'}$ every $q' < q$
- What if p' receives a STATE-REQ from c after it has changed the coordinator to q ?

A few observations

- What if p' , which has not detected the failure of c , receives a STATE-REQ from q ?
 - it concludes that c must be faulty
 - it removes from $UP_{p'}$ every $q' < q$
- What if p' receives a STATE-REQ from c after it has changed the coordinator to q ?
 - p' ignores the request

Total failure

- Suppose p is the first process to recover, and that p is uncertain
- Can p decide ABORT?

Total failure

- Suppose p is the first process to recover, and that p is uncertain
- Can p decide ABORT?

Some processes could have decided COMMIT after p crashed!

Total failure

- Suppose p is the first process to recover, and that p is uncertain
- Can p decide ABORT?

Some processes could have decided COMMIT after p crashed!

- p is blocked until some q recovers s.t. either
 - q can recover independently
 - q is the last process to fail—then q can simply invoke the termination protocol

Determining the last process to fail

- Suppose a set R of processes has recovered
- Does R contain the last process to fail?

Determining the last process to fail

- Suppose a set R of processes has recovered
- Does R contain the last process to fail?
 - the last process to fail is in the UP set of every process
 - so the last process to fail must be in

$$\bigcap_{p \in R} UP_p$$

Determining the last process to fail

- Suppose a set R of processes has recovered
- Does R contain the last process to fail?
 - the last process to fail is in the UP set of every process
 - so the last process to fail must be in

$$\bigcap_{p \in R} UP_p$$

R contains the last process to fail if

$$\bigcap_{p \in R} UP_p \subseteq R$$