

CS5412: TWO AND THREE PHASE COMMIT

Continuing our consistency saga

2

- Recall from last lecture:
 - ▣ Cloud-scale performance centers on replication
 - ▣ Consistency of replication depends on our ability to talk about notions of time.
 - Lets us use terminology like “If B accesses service S after A does, then B receives a response that is at least as current as the state on which A’s response was based.”
 - Lamport: Don’t use clocks, use logical clocks
 - We looked at two forms, logical clocks and *vector* clocks
 - ▣ We also explored notion of an “instant in time” and related it to something called a consistent cut

Next steps?

3

- We'll create a second kind of building block
 - ▣ Two-phase commit
 - ▣ It's cousin, three-phase commit
- These commit protocols (or a similar pattern) arise often in distributed systems that replicate data
- Closely tied to “consensus” or “agreement” on events, and event order, and hence replication

The Two-Phase Commit Problem

4

- The problem first was encountered in database systems
- Suppose a database system is updating some complicated data structures that include parts residing on more than one machine
- So as they execute a “transaction” is built up in which participants join as they are contacted

... so what's the “problem”?

5

- Suppose that the transaction is interrupted by a crash before it finishes
 - ▣ Perhaps, it was initiated by a leader process L
 - ▣ By now, we've done some work at P and Q, but a crash causes P to reboot and “forget” the work L had started
 - Implicitly assumes that P might be keeping the pending work in memory rather than in a safe place like on disk
 - But this is actually very common, to speed things up
 - Forced writes to a disk are very slow compared to in-memory logging of information, and “persistent” RAM memory is costly
 - ▣ How can Q learn that it needs to back out?

The basic idea

6

- We make a rule that P and Q (and other participants) treat pending work as transient
 - ▣ You can safely crash and restart and discard it
 - ▣ If such a sequence occurs, we call it a “forced abort”
- Transactional systems often treat commit and abort as a special kind of keyword

A transaction

7

- L executes:

Begin

{

Read some stuff, get some **locks**

Do some **updates** at P, Q, R...

}

Commit

- If something goes wrong, executes “Abort”

Transaction...

8

- Begins, has some kind of system-assigned id
- Acquires pending state
 - ▣ Updates it did at various places it visited
 - ▣ Read and Update or Write locks it acquired
- If something goes horribly wrong, can Abort
- Otherwise if all went well, can *request* a Commit
 - ▣ But commit can fail. This is where the 2PC and 3PC algorithms are used

The Two-Phase Commit (2PC) problem

9

- Leader L has a set of places { P, Q, ... } it visited
 - ▣ Each place may have some pending state for this xtn
 - ▣ Takes form of pending updates or locks held
- L asks “Can you still commit” and P, Q ... must reply
 - ▣ “No” if something has caused them to discard the state of this transaction (lost updates, broken locks)
 - ▣ Usually occurs if a member crashes and then restarts
 - ▣ No reply treated as “No” (handles failed members)

What about “Yes”?

10

- If a member replies “Yes” it moves to a state we call *prepared to commit*
 - ▣ Up to then it could just abort in a unilateral way, i.e. if data or locks were lost due to a crash/restart (or a timeout)
 - ▣ But once it says “I’m prepared to commit” it must not lose locks or data. So it will probably need to force data to disk at this stage
 - ▣ Many systems push data to disk in background so all they need to do is update a single bit on disk: “prepared=true” but this disk-write is still considered costly event!

- Then can reply “Yes”

Role of leader

11

- So.... L sends out “Are you prepared?”
- It waits and eventually has replies from {P, Q, ... }
 - ▣ “No” if someone replies no, or if a timeout occurs
 - ▣ “Yes” only if that participant actually replied “yes” and hence is now in the prepared to commit state
- If all participants are prepared to commit, L can send a “Commit” message. Else L must send “Abort”
 - ▣ Notice that L could mistakenly abort. This is ok.

Participant receives a commit/abort

12

- If participant is prepared to commit it waits for outcome to be known
 - ▣ Learns that leader decided to Commit: It “finalizes” the state by making updates permanent
 - ▣ Learns that leader decided to Abort: It discards any updates
 - ▣ Then can release locks

Failure cases to consider

13

- Two possible worries
 - ▣ Some participant might fail at some step of the protocol
 - ▣ The leader might fail at some step of the protocol
- Notice how a participant moves from “participating” to “prepared to commit” to “committed/aborted”
- Leader moves from “doing work” to “inquiry” to “committed/aborted”

Can think about cross-product of states

14

- This is common in distributed protocols
 - ▣ We need to look at each member, and each state it can be in
 - ▣ The system state is a vector (S_L, S_P, S_Q, \dots)
 - ▣ Since each can be in 4 states there are 4^N possible scenarios we need to think about!

- Many protocols are actually written in a state-diagram form, but we'll use English today

How the leader handles failures

15

- Suppose L stays healthy and only participants fail
- If a participant failed before voting, leader just aborts the protocol
- The participant might later recover and needs a way to find out what happened
 - ▣ If failure causes it to forget the txn, no problem
 - ▣ For cases where a participant may know about the txn and want to learn the outcome, we just keep a long log of outcomes and it can look this txn up by its ID to find out
 - ▣ Writing to this log is a role of the leader (and slows it down)

What about a failure after vote?

16

- The leader also needs to handle a participant that votes “Yes” and hence is prepared, but then fails

- In this case it won't receive the Commit/Abort message
 - ▣ Solved because the leader logs the outcome
 - ▣ On recovery that participant notices that it has a prepared txn and consults the log
 - ▣ Must find the outcome there and must wait if it can't find the outcome information

- Implication: Leader must log the outcome before sending the Commit or Abort outcome message!

Now can think about participants

17

- If a participant was involved but never was asked to vote, it can always unilaterally abort
- But once a participant votes “Yes” it must learn the outcome and can’t terminate the txn until it does
 - ▣ E.g. must hold any pending updates, and locks
 - ▣ Can’t release them without knowing outcome
- It obtains this from L , or from the outcomes log

The bad case

18

- Some participant, maybe P , votes “Yes” but then leader L seems to vanish
 - ▣ Maybe it died... maybe became disconnected from the system (partitioning failure)
 - ▣ P is “stuck”. We say that it is “blocked”

- Can P deduce the state?
 - ▣ If log reports outcome, P can make progress
 - ▣ What if the log doesn't know the outcome? As long as we follow rule that L logs outcome before telling anyone, safe to commit in this case

So 2PC makes progress with a log

19

- But this assumes we can access either the leader L, or the log.
- If neither is accessible, we're stuck
- In any real system that uses 2PC a log is employed but in many textbooks, 2PC is discussed *without* a log service. What do we do in this case?

2PC but no log (or can't reach it)

20

- If P was told the list of participants when L contacted it for the vote, P could poll them
 - ▣ E.g. P asks Q, R, S... “what state are you in?”

- Suppose someone says “pending” or even “abort”, or someone knows outcome was “commit”?
 - ▣ Now P can just abort or commit!

- But what if N-1 say “pending” and 1 is inaccessible?

P remains blocked in this case

21

- L plus one member, perhaps S, might know outcome
- P is unable to determine what L could have done
- Worse possible situation: L is both leader and also participant and hence a single failure leaves the other participants blocked!

Skeen & Stonebraker: 3PC

22

- Skeen proposed a 3PC protocol, that adds one step (and omits any log service)

- With 3PC the leader runs 2 rounds:
 - ▣ “Are you able to commit”? Participants reply “Yes/No”
 - ▣ “Abort” or “Prepare to commit”. They reply “OK”
 - ▣ “Commit”

- Notice that Abort happens in round 2 but Commit only can happen in round 3

State space gets even larger!

23

- Now we need to think of 5^N states
 - ▣ But Skeen points out that many can't occur
 - ▣ For example we can't see a mix of processes that are in the Commit and Abort state
 - We could see some in "Running" and some in "Yes"
 - We could see some in "Yes" and some in "Prepared"
 - We could see some in "Prepared" and some in "Commit"
 - ▣ But by pushing "Commit" and "Abort" into different rounds we reduce uncertainty

3PC recovery is complex

24

- Skeen shows how, on recovery, we can poll the system state
- Any (or all) processes can do this
- Can always deduce a safe outcome... provided that we have an *accurate failure detector*
- Concludes that 3PC, without any log service, and with accurate failure detection is non-blocking

Failure detection in a network

25

- Many think of Skeen's 3PC as a practical protocol

- But to really use 3PC we would need a perfect failure detection service that never makes mistakes
 - ▣ It always says "P has failed" if, in fact, P has failed
 - ▣ And it never says "P has failed" if P is actually up

- Is it possible to build such a failure service?

Notions of failure

26

- This leads us to think about failure “models”

Best: “Fail-stop” with trusted notifications

Many things can fail in a distributed system

- ▣ Network can drop packets, or the O/S can do so
- ▣ Links can break causing a network partition that isolates one or more nodes
- ▣ Processes can fail by halting suddenly
- ▣ A clock could malfunction, causing timers to fire incorrectly
- ▣ A machine could freeze up for a while, then resume
- ▣ Processes can corrupt their memory and behave badly without actually crashing
- ▣ A process could be taken over by a virus and might behave in a malicious way that deliberately disrupts our system

Worst: Byzantine

“Real” systems?

- Linux and Windows use timers for failure detection
 - ▣ These can fire even if the remote side is healthy
 - ▣ So we get “inaccurate” failure detections
 - ▣ Of course many kinds of crashes can be sensed accurately so for those, we get trusted notifications

- Some applications depend on TCP, but TCP itself uses timers and so has the same problem

Byzantine case

28

- Much debate around this
- Since programs are buggy (always), it can be appealing to just use a Byzantine model. A bug gives random corrupt behavior... like a mild attack
- But Byzantine model is hard to work with and can be costly (you often must “outvote” the bad process)

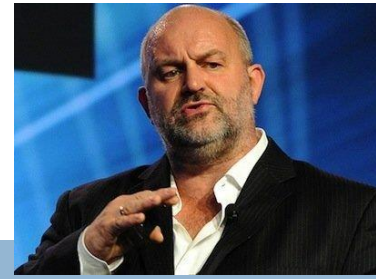
Failure detection in a network

29

- Return to our use case

- 2PC and 3PC are normally used in standard Linux or Windows systems with timers to detect failure
 - ▣ Hence we get *inaccurate* failure sensing with possible mistakes (e.g. P thinks L is faulty but L is fine)
 - ▣ 3PC is also blocking in this case, although less likely to block than 2PC
 - ▣ Can prove that any commit protocol would have blocking states with inaccurate failure detection

World-Wide Failure Sensing



30

- Vogels wrote a paper in which he argued that we really could do much better
 - ▣ In a cloud computing setting, the cloud management system often “forces” slow nodes to crash and restart
 - Used as a kind of all-around fixer-upper
 - Also helpful for elasticity and automated management
 - ▣ So in the cloud, management layer is a fairly trustworthy partner, if we were to make use of it
 - We don’t make use of it, however, today

The Postman Always Rings Twice

31

- Suppose the mailman wants to see you.
 - He rings and waits a few seconds
 - Nobody comes to the door... should he assume you've died?
- Hopefully not
- Vogels suggests that there are many reasons a machine might timeout and yet not be faulty

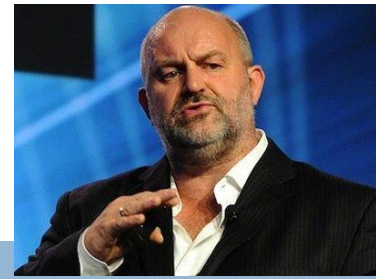


Causes of delay in the cloud

32

- Scheduling can be sluggish
- A node might get a burst of messages that overflow its input sockets and triggers message loss, or network could have some kind of malfunction in its routers/links
- A machine might become overloaded and slow because too many virtual machines were mapped on it
- An application might run wild and page heavily

Vogels suggests?



33

- He recommended that we add some kind of failure monitoring service as a standard network component
- Instead of relying on timeout, even protocols like remote procedure call (RPC) and TCP would ask the service and it would tell them
- It could do a bit of sleuthing first... e.g. ask the O/S on that machine for information... check the network...

Why clouds *don't* do this



34

- Hamilton: In the cloud our focus tends to be on keeping the “majority” of the system running
 - ▣ No matter what the excuse it might have, if some node is slow it makes more sense to move on
 - ▣ Keeping the cloud up, as a whole, is way more valuable than waiting for some slow node to catch up
 - ▣ End-user experience is what counts!

- So the cloud is casual about killing things
- ... and avoids services like “failure sensing” since they could become bottlenecks



Also, most software is buggy!

35

- A mix of “Bohrbugs” and “Heisenbugs”
 - ▣ Bohrbugs: Boring and easy to fix. Like Bohr model of the atom
 - ▣ Heisenbugs: They seem to hide when you try to pin them down (caused by concurrency and problems that corrupt a data structure that won’t be visited for a while). Hard to fix because crash seems unrelated to bug
- Studies show that pretty much all programs retain bugs over their full lifetime.
 - ▣ So if something is acting strange, it may be failing!

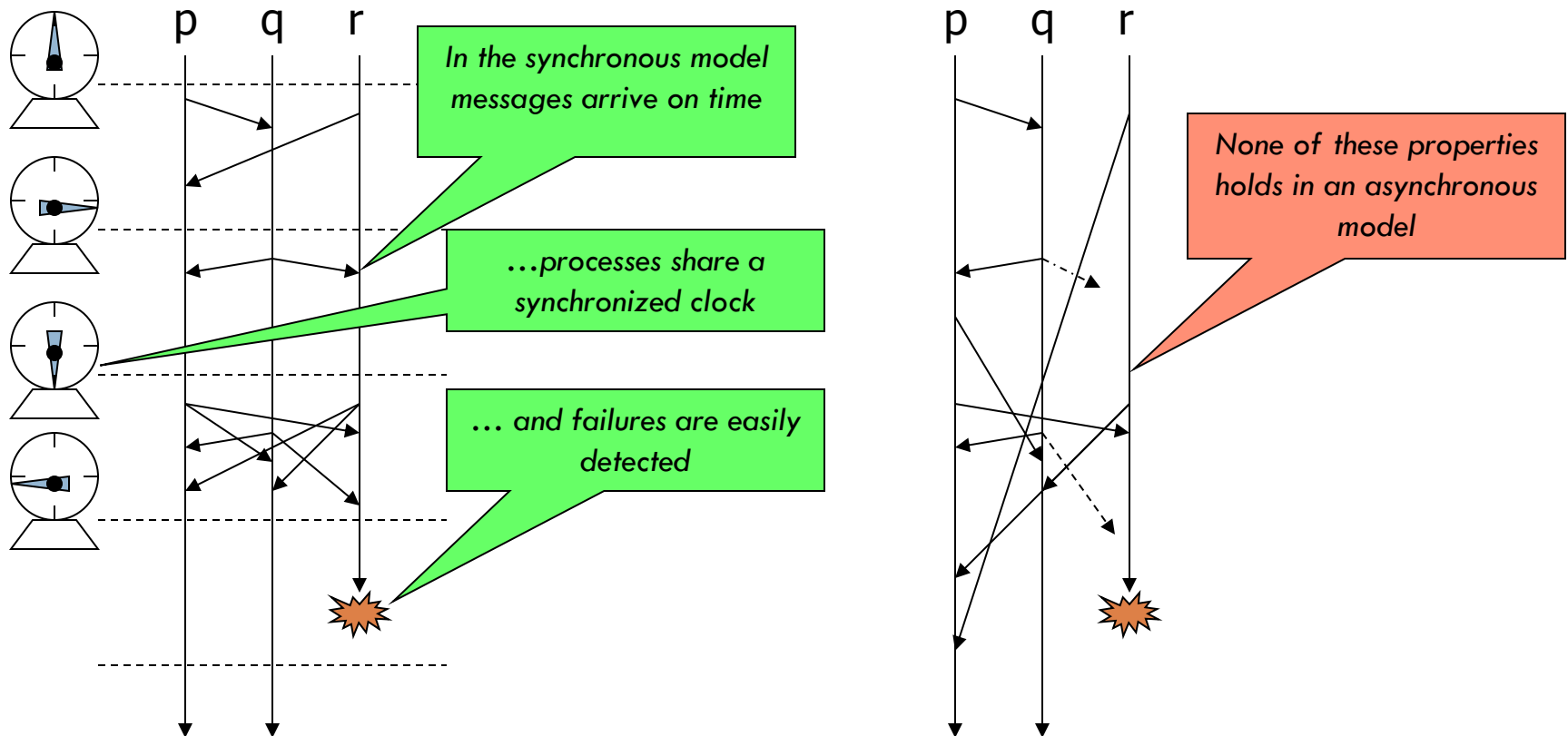
Worst of all... timing is flakey

36

- At cloud scale, with millions of nodes, we can trust timers at all
- Too many things can cause problems that manifest as timing faults or timeouts
- Again, there are some famous models... and again, none is ideal for describing real clouds

Synchronous and Asynchronous Executions

37



Reality: neither one

38

- Real distributed systems aren't synchronous
 - ▣ Although a flight control computer can come close
- Nor are they asynchronous
 - ▣ Software often treats them as asynchronous
 - ▣ In reality, clocks work well... so in practice we often use time cautiously and can even put limits on message delays
- For our purposes we usually start with an asynchronous model
 - ▣ Subsequently enrich it with sources of time when useful.
 - ▣ We sometimes assume a “public key” system. This lets us sign or encrypt data where need arises

Thought problem



39

- Ron and Hermione will meet for lunch. They'll eat in the cafeteria unless both are sure that the weather is good
 - ▣ Hermione's cubicle is in the crypt, so Ron will send email
 - ▣ Both have lots of meetings, and might not read email. So she'll acknowledge his message.
 - ▣ They'll meet inside if one or the other is away from their desk and misses the email.
- Ron sees sun. Sends email. Hermione acks's. Can they meet outside?

Ron and Hermione

40



Ron

R: Hermione, the weather is beautiful! Let's meet at the sandwich stand outside.

Hermione



H: I can hardly wait. I've been in this dungeon studying and haven't seen the sun in weeks!

They eat *inside!* Ron reasons:

41

- “Hermione sent an acknowledgement but doesn’t know if I read it
- “If I didn’t get her acknowledgement I’ll assume she didn’t get my email
- “In that case I’ll go to the cafeteria
- “She’s uncertain, so she’ll meet me there

Ron had better send an Ack

42



Ron

Hermione

R: Hermione, the weather is beautiful! Let's meet at the sandwich stand outside.

H: I can hardly wait. I've been in this dungeon studying and haven't seen the sun in weeks!

Great! See yah...



Why didn't this help?

43

- Hermione got the ack... but she realizes that Ron won't be sure she got it
- Being unsure, he's in the same state as before
- So he'll go to the cafeteria, being dull and logical. And so she meets him there.

New and improved protocol

44

- Hermione sends an ack. Ron acks the ack.
Hermione acks the ack of the ack....
- Suppose that noon arrives and Hermione has sent her 117'th ack.
 - ▣ Should she assume that lunch is outside in the sun, or inside in the cafeteria?

How Ron and Hermione's romance (should have) ended

45



Ron

Hermione

R: Hermione, the weather is beautiful! Let's meet at the sandwich stand outside.

H: I can hardly wait. I've been in this dungeon studying and haven't seen the sun in weeks!

Great! See yah...

Yup...

Got that...

...

Oops, too late for lunch

Maybe tomorrow?



H. K. Rowling

46

- “I’ve been feeling that I made a mistake... I really wonder if Hermione shouldn’t have ended up with Harry Potter”
- “I hope I’m not breaking some little girl’s heart saying this, but ever since I married her to Ron I’ve just been feeling that they aren’t right for each other...”



Moral of the story?

47

- Logicians are dull people and have miserable lives.

**Your illogical approach to chess
does have its advantages on
occasion, Captain.
--Spock in Star Trek**



Moral of the story?

48

- ~~❑ Logicians are dull people and have miserable lives.~~
- ❑ The real world demands leaps of faith: pure logic isn't enough.
- ❑ For our computing systems, this creates a puzzle, since software normally behaves logically!

How do real people meet for lunch?

49

- They send one email, then go outside
 - ▣ Mishaps happen, now and then, but we deal with those.
 - ▣ In fact we know perfectly well that we can't achieve perfect agreement, and we cope with that
 - ▣ In some sense a high probability of meeting outside for lunch is just fine and we don't insist on more

Things we just can't do

50

- We can't detect failures in a trustworthy, consistent manner
- We can't reach a state of “common knowledge” concerning something not agreed upon in the first place
- We can't guarantee agreement on things (election of a leader, update to a replicated variable) in a way certain to tolerate failures

Back to 2PC and 3PC

- Summary of the state of the world?
 - ▣ 3PC would be better than 2PC in a perfect world
 - ▣ In the real world, 3PC is more costly (extra round) but blocks just the same (inaccurate failure detection)
 - ▣ Failure detection tools could genuinely help but the cloud trend is sort of in the opposite direction
 - ▣ Cloud transactional standard requires an active, healthy logging service. If it goes down, the cloud xtn subsystem hangs until it restarts
- We'll be using both 2PC and 3PC as a building block but not necessarily to terminate transactions.