Lecture #25: 2-phase commit

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Review -- 1 min

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Motivation
Basic NW communication
3 problems
- performance
- reliability
- security

Case study: Distributed file systems

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Outline - 1 min

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- General's paradox
- 2-phase commit
- Reliable message queues

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Preview - 1 min

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If time permits: security

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Lecture - 20 min

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1. TBD Finish file systems

2. Reliability

Lamport: "A distributed system is a system where I can't get any work done if a machine I've never heard of crashes."

3. General's paradox

Want to be able to reliably coordinate activity on two different machines (e.g., both do the same thing at same time, exactly once semantics, atomically update state on two different machines, etc.)

e.g., atomically move directory from file server A to file server B
e.g., atomically move $100 from my account to Visa account

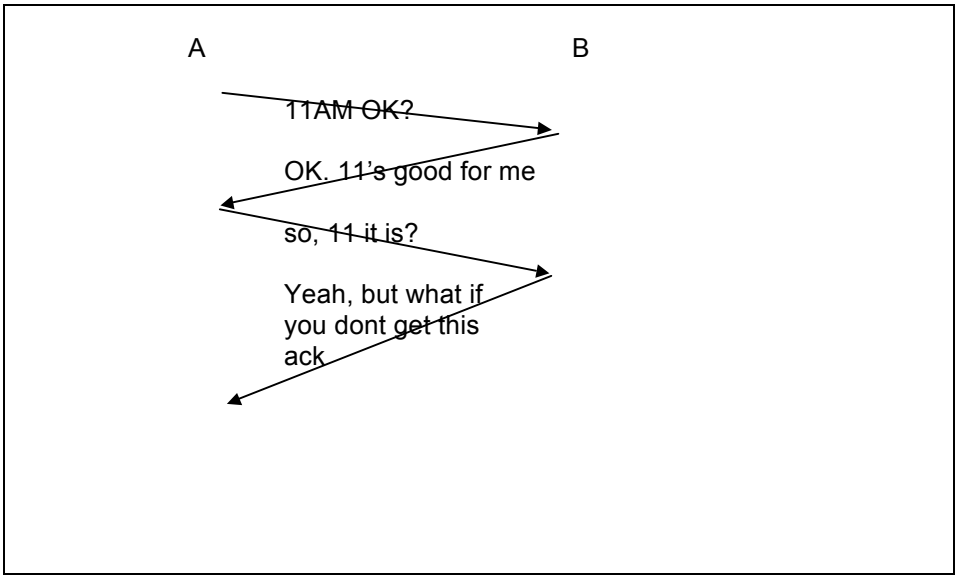
Challenge:
- messages can be lost
- machines can crash

Can I use messages and retries over an unreliable network to synchronize two machines so that they are guaranteed to do same op at same time?

Remarkably, no. Even if all messages end up getting through. Even if no machines crash.

General's paradox: two generals on separate mountains. Can only communicate via messengers; the messengers can get lost or be captured

Need to coordinate the attack; if they attack at different times, then they all die. If they attack at same time, they win.



Even if all messages are delivered, can't coordinate (B/c a chance that the last message doesn't get through). Can't simultaneously get two machines to agree to do something at same time

No solution to this – one of the few things in CS that is just impossible.
Proof: by induction

3.1 Network failures

Since I cannot solve General's Paradox, let me solve a related problem: at least once delivery

For now, assume no machine failures. Just network failures.
(1) communication interruption

- lost message
- lost reply
- cut wire
- …

Simple solution:
Request/acknowledge protocol
Common case:
1) Sender sends message (msg, msgId) and sets timer
2) Receiver receives message and sends (ack, msgId)
3) Sender receives (ack, msgId) and clears timer

If timer goes off, goto (1)

How does this work? What does it guarantee?
- What if msg 1 lost?
- What if ack lost?

Guarantees *at least once* semantics ***assuming no machines crash or otherwise discontinue protocol***
- Receiver guaranteed to recv message at least once

- Receiver may recv message multiple times. Receiver MAY use sequence number to filter repeated transmissions so that each is acted upon just once
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3.1.1 At least once delivery

safety: If call at sender returns, message was processed by receiver at least once
liveness: if sender repeatedly sends until call returns and network eventually repaired and operates correctly long enough for a send/receive to occur, then eventually message is processed by receiver (at least once)

[[until call returns => no crash, no timeout/give up]]

Example: NFS "idempotent" requests

3.1.2 Exactly once delivery

Example: TCP/IP reliable stream

safety: If call at sender returns, message was processed by receiver exactly once

liveness: if sender repeatedly sends until call returns and network eventually repaired and operates correctly long enough for a send/receive to occur, then eventually message is processed by receiver (exactly once)

[[note: implementation typically requires sender and receiver to maintain state; cannot lose state in crash...]

3.1.3 Limitation: What if a machine crashes?

Do we still get "at least once" semantics if machines can crash?
NFS/RPC: no.
NFS Solution – blocking calls – don't return until remote operation completes.

Note: after a crash, operation may have happened zero, once, or ten times.

Do we still get exactly once semantics if machine can crash?
TCP: no
TCP solution:

(1) If sender or receiver crash or network partition causes either to give up, **no guarantee of "at least once"** – local send may complete before data received by remote machine
→ if send request not return, data may be received 0 or 1 time
→ if send request does return, data may be received 0 or 1 time

(2) *at most once semantic – if crash causes sender to reuse sequence numbers, no guarantee of at most once…s* hacks to make it very unlikely – pick sequence numbers unlikely to overlap with prev attempts; don't re-use port numbers until "pretty sure" both sides know connection is closed (two generals)
→ very unlikely that after receiver crashes, a resend will be accepted as a first send (~at most once semantics…)

Don't just worry about crashes. What about "giving up." Suppose I try to send for 10 seconds and get no reply – should I report "failure" to the user? 1 minute? 10 hours?

What are at least once/at most once semantics now?

Bottom line:
If machines can crash or give up (e.g., during a network partition), then messages can be received 0, 1, or N times

➔ these things help
➔ but still have corner cases to worry about

- These corner cases sometimes OK (e.g., TCP/IP – if one side gives up, eventually tear down the connection and hand an error up to higher level – let the higher level protocol recover (or exit)
- Sometimes they require recovery protocols (e.g., AFS callback recovery)

Can we provide a more powerful abstraction?

4. Machine failures

Several variations:

- user level bug causes address space to crash
- machine failure, kernel bug causes all AS on same machine to fail
- power outage causes all machines to fail

Before, whole system would crash. Now: one machine can crash, while others stay up.
Now, one machine can crash, while others stay up. If file server goes down, what do the other machines do?

Example: simple send/ack protocol above -- Difficult to deal with machine crashes

- If sender crashes (or if sender gives up because it has tried 100 times in a row) what is the post condition?
  - Receiver may or may not have received message
- If receiver crashes, filtering repeated messages to act on them exactly once is tricky → carefully design protocol to either (a) tolerate *at least once* semantics or (b) detect/avoid replication even across sender/receiver failures

Outline:
(1) 2-phase commit – distributed atomic update
(2) persistent message queues

5. 2-phase commit

Since I cannot solve General's Paradox, let me solve a related problem

Abstraction – distributed transaction – two machines agree to do something or not do it, atomically
(but not necessarily at exactly the same time)

example: my account is at NationsBank, yours is at Wells Fargo. How to transfer $100 from you to me? (Need to guarantee that both banks agree on what happened).
Example: file system – move a file from directory A on server a to directory B on server b

Two-phase commit protocol does this. Use log on each machine to keep track of whether commit happened

Phase 1: coordinator requests
1. coordinator logs REQUEST; sends REQUEST to all participants

   e.g. C→S1 "delete foo from /", C→S2 "add foo to /"

2. participants recv request, execute transaction locally, write REQUEST, RESULT, VOTE_COMMIT or VOTE_ABORT to local log,
   and send VOTE_COMMIT or VOTE_ABORT to coordinator

Failure case	*Success case*
S1 decides OK, writes "rm /foo; VOTE_COMMIT" to log, and sends VOTE_COMMIT *S2 decides no space on device and writes and sends VOTE_ABORT*	*S1 and S2 decide OK and write updates and VOTE_COMMIT to log, send VOTE_COMMIT*

Phase 2: coordinator decides
3. case 1: coordinator recv VOTE_ABORT or timeout
   → coordinator write GLOBAL_ABORT to log, and send GLOBAL_ABORT to participants

   case 2: coordinator recvs VOTE_COMMIT from all participants
   → coordinator write GLOBAL_COMMIT to log, and send GLOBAL_COMMIT to participants

4. participant receives decision; write GLOBAL_COMMIT or GLOBAL_ABORT to log

What if

- Participant crashes at 2? Wakes up, does nothing. Coordinator will timeout, abort transaction, retry
- Coordinator crashes at 3? Wakes up,
  - Case 1: no GLOBAL_* in log → Send message to participants "abort"
  - Case 2: GLOBAL_ABORT in log → send message to participants "abort"
  - Case 3: GLOBAL_COMMIT in log → send message to participants "commit"
- Participant crashes at 4? On recovery, ask coordinator what happened and commit or abort

This is another example of the idea of a basic atomic operation. In this case – commit needs to "happen" at one place

MDD: Update this discussion for next year
Model for 2-phase and 3-phase commit is

- **Synchronous system**
- **Reliable messaging**
- **Machines can crash and then recover (need to ensure that decision you reach is compatible with state of crashed nodes because they may recover)**
- **(really should teach 3PC as well… in fact really should go further and teach the real answer – asynchronous 3pc via paxos. See jim gray and leslie lamport paper.)**
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Limitation of 2PC – what if coordinator crashes during 3 and doesn't wake up? All nodes block forever
What if participants times out waiting in step 4 for coordinator to say what happened. It can make some progress by asking other participants

1. if any participant has heard "GLOBAL_COMMIT/ABORT", we can safely commit/abort
2. if any participant has said "VOTE_ABORT" or has made no vote, we can safely abort
3. if all participants have said "VOTE_COMMIT" but none have heard "GLOBAL_*", can we commit? A: no – coordinator might have written "GLOBAL_ABORT" to its disk (e.g., local error or timeout)
   Turns out – 2PC always has risk of indefinite blocking

Solve with 3 phase commit (look it up if you ever need it…)

In practice 2PC usually good enough – but be aware of the limits

If you come to a place where you need to do something across multiple machines, don't hack

- use 2PC (or 3PC)
- if 2PC, identify circumstances under which indefinite blocking can occur (and decide if acceptable engineering risk)

QUESTION: is 2PC "at most once", "at least once", "exactly once" or "none of the above"?

6. Persistent message queues

MQSeries, etc.

Use 2-phase commit for message passing – guarantee exactly once delivery even across machine failures, long partitions

Send:

```
Add msgID++, msg to log
Send <msgID, msg> on NW (keep repeatedly sending
                         all items in log)
```

Recv <msgID, msg>

```
If <msgID> != largest stored msgID + 1
        If <msgID> <= largest stored msgID
                Send ack <msgId> to sender;
        Drop message;
        break;
Add <msgId, msg> to log
Send ack <msgId> to sender
```

Recv ack:

```
Remove <msgID, msg> from log and stop retransmission
```

Process next msg:

```
Transaction begin
```

```
        remove next msg from log
        process message
    transaction commit
```

E.g., AFS consistency state recovery – how would this now work?

QUESTION: is basic persistent message queue "at most once" "at least once" "exactly once" or "none of the above"?

How would you make it "exactly once?" (combine "at least once" with local transaction?)

7. Summary

RPC – "transparent" way to change local program into distributed program

- Generalization RMI, CORBA, SOAP – object-oriented versions of this

Case against RPC – RPC provides wrong abstraction – implies that local and remote programs can be/should be similarly structured

- focuses attention/abstraction on "common case" of everything works
- Some argue – this is wrong way to think of distributed programs. "Everything works" is the easy case –RPC encourages you to think about that case. But, the case of partial failures is the case you should focus your attention on.
- E.g., don't assume that each request will get a reply, etc.
- "Exception paths" need to be as carefully considered as the "normal case" procedure call/return paths → RPC wrong abstraction

Lower-level message passing abstraction may help program writer avoid making implicit "everything usually works" assumption and may encourage structuring programs to handle failures elegantly

Persistent message queues can greatly simplify message passing (but at a potentially significant overhead.)