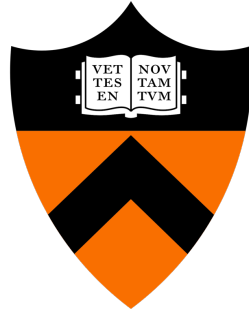


RPCs and Failure

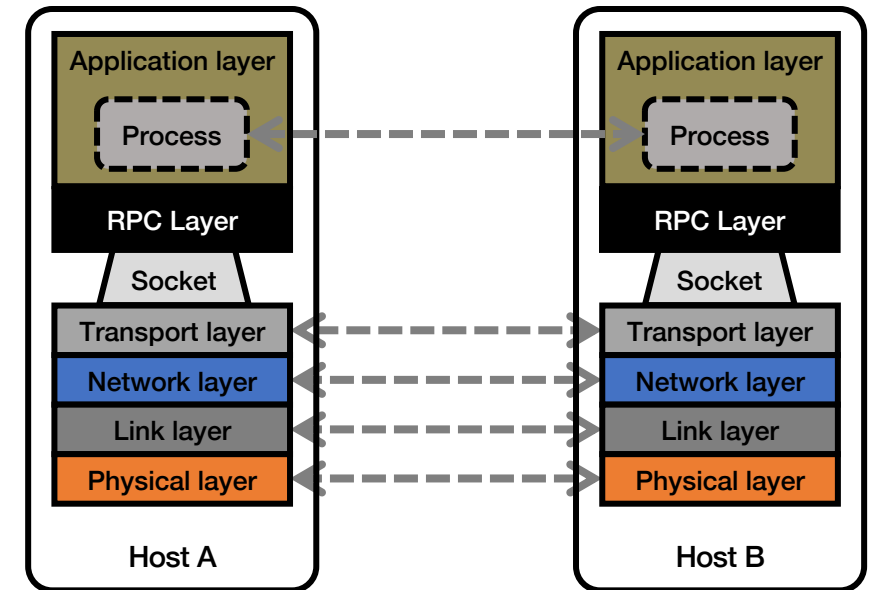


COS 418: Distributed Systems
Lecture 4

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Last Time: RPCs and Network Comm.

- Layers are our friends!
- RPCs are everywhere
- Necessary issues surrounding machine heterogeneity
- Subtle issues around failures
 - ... this time!!!

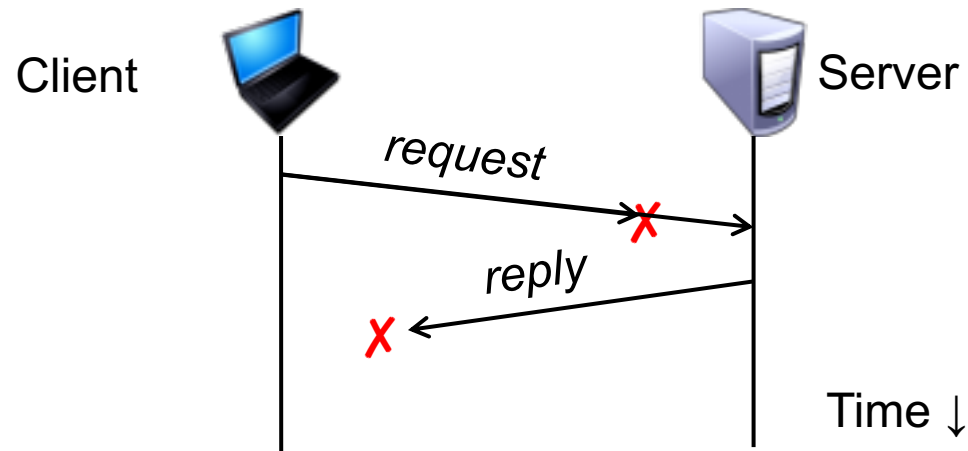


What could possibly go wrong?

1. Client may **crash and reboot**
2. Packets may be **dropped**
 - Some individual **packet loss** in the Internet
 - **Broken routing** results in many lost packets
3. Server may **crash and reboot**
4. Network or server might just be **very slow**

All of these may
look the same to
the client...

Failures, from client's perspective



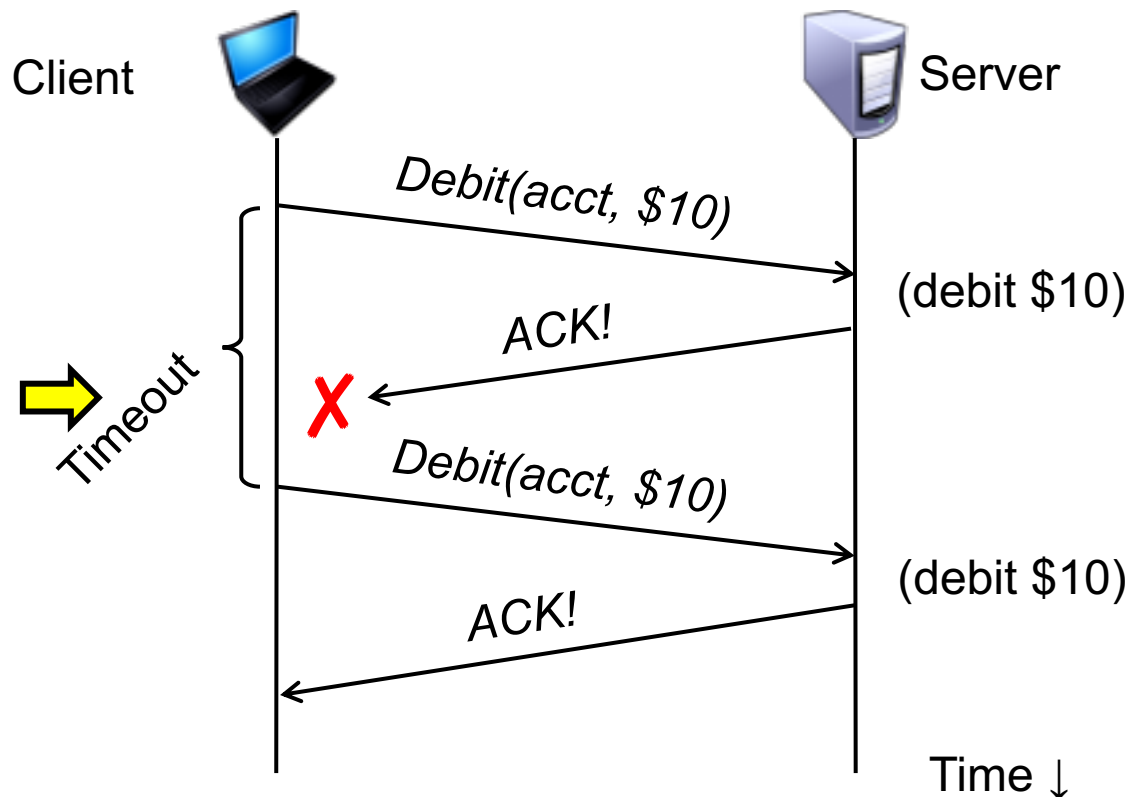
The cause of the failure is **hidden** from the **client!**

At-Least-Once scheme

- Simplest scheme for handling failures
 1. Client stub waits for a response, for a while
 - Response is an **acknowledgement** message from the server stub
 2. If no response arrives after a fixed **timeout** time period, then client stub re-sends the request
- Repeat the above a few times
 - Still no response? Return an error to the application

At-Least-Once and side effects

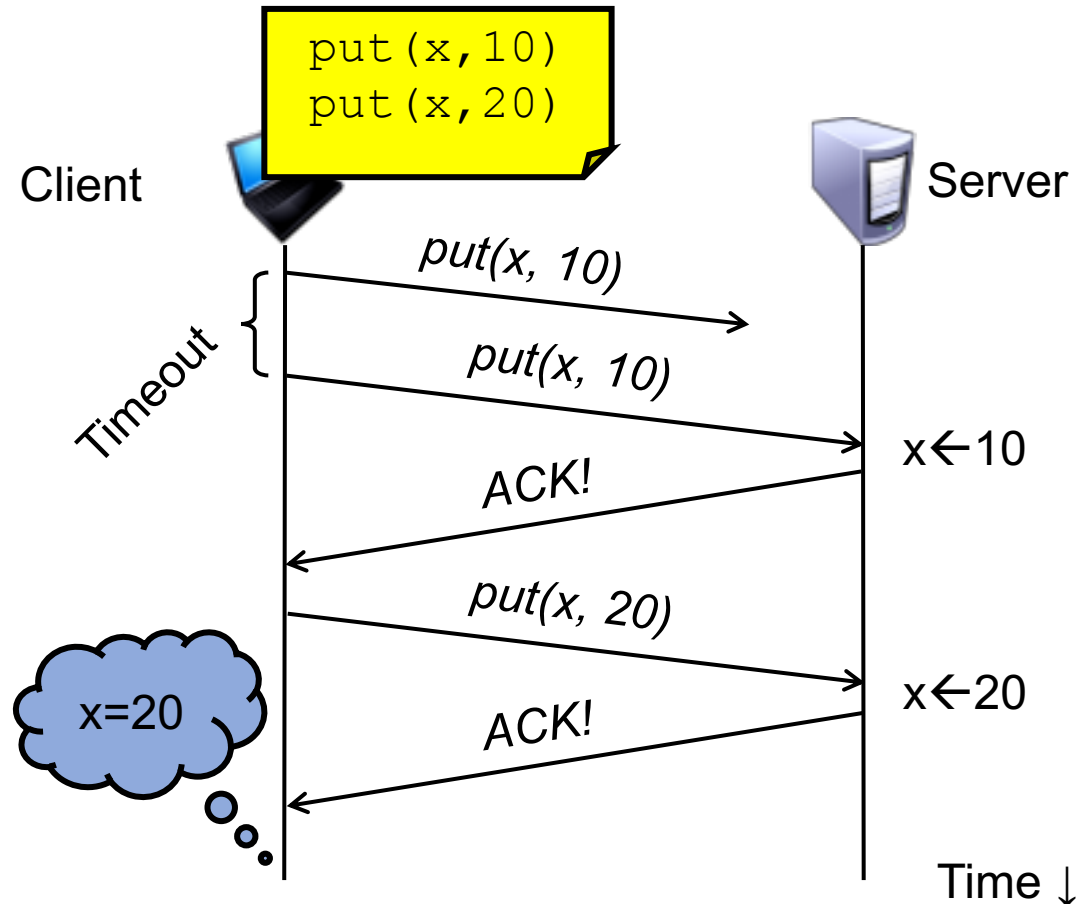
- Client sends a “debit \$10 from bank account” RPC



Debit is not
idempotent

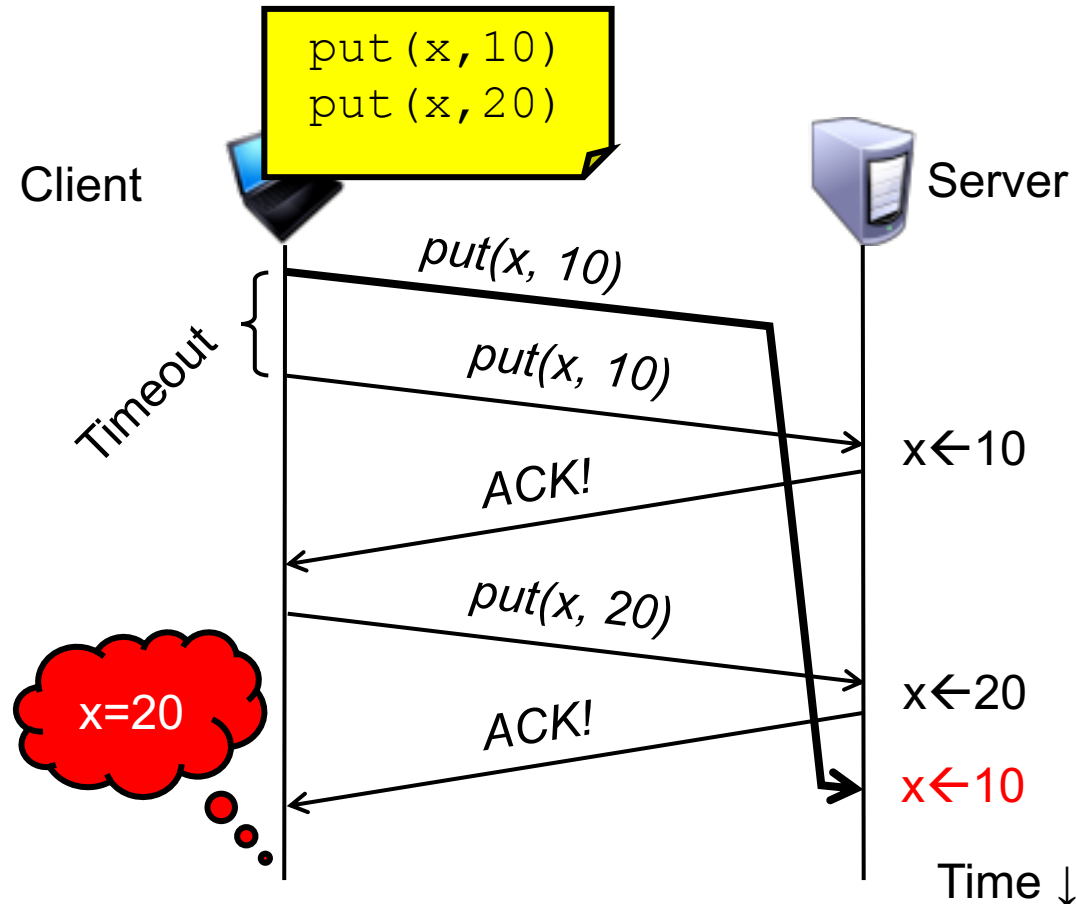
At-Least-Once and writes

- Consider a client storing key-value pairs in a database
 - `put(x, value)`, then `get(x)`: expect answer to be value



At-Least-Once and writes

- Consider a client storing key-value pairs in a database
 - `put(x, value)`, then `get(x)`: expect answer to be value



So is At-Least-Once ever okay?

- Yes: If they are read-only operations with no side effects
 - e.g., read a key's value in a database
- Yes: If the application has its own functionality to cope with duplication and reordering
 - You will need this in Assignments 3 onwards

At-Most-Once scheme

- Idea: server RPC stub detects duplicate requests
 - Returns previous reply instead of re-running handler
- How to detect a duplicate request?
 - Test: Server stub sees same function, same arguments twice
 - **No!** Sometimes applications legitimately submit the same function with same arguments, twice in a row

At-Most-Once scheme

- How to detect a duplicate request?
 - Client stub includes unique **transaction ID (xid)** with each RPC request
 - Client stub uses same xid for retransmitted requests

```
At-Most-Once Server Stub  
if seen[xid]:  
    retval = old[xid]  
else:  
    retval = handler()  
    old[xid] = retval  
    seen[xid] = true  
return retval
```

At-Most-Once: Providing unique XIDs

1. Combine a unique client ID (e.g., IP address) with the current time of day
2. Combine unique client ID with a sequence number
3. Big random number (probabilistic, not certain guarantee)

At-Most-Once: Discarding server state

- **Problem:** seen and old arrays will **grow without bound**
- **Observation:** By construction, when the client gets a response to a particular xid, it will never re-send it
- Client could tell server “I’m done with xid x – delete it”
 - Have to tell the server about **each and every** retired xid
 - Could piggyback on subsequent requests

At-Most-Once: Discarding server state

- **Problem:** seen and old arrays will **grow without bound**
- Suppose $xid = \langle \text{unique client id, sequence no.} \rangle$
 - e.g., $\langle 42, 1000 \rangle$, $\langle 42, 1001 \rangle$, $\langle 42, 1002 \rangle$
- Client includes “seen all replies $\leq X$ ” with every RPC
 - Much like TCP sequence numbers, acks
- Each one of these is cumulative: later seen messages subsume earlier ones

At-Most-Once: Concurrent requests

- **Problem:** How to handle a duplicate request while the original is still executing?
 - Server doesn't know reply yet. And we don't want to run procedure twice
- **Idea:** Add a `pending` flag per executing RPC
 - Server waits for the procedure to finish, or ignores

At-Most-Once: Server crash and restart

- **Problem:** Server may crash and restart
- Does server need to write its arrays to disk?
- Yes! On server crash and restart:
 - If `old[]`, `seen[]` arrays are only in memory:
 - Server will forget, **accept duplicate requests**

Exactly-once?

- Need retransmission of at least once scheme
- Plus the duplicate filtering of at most once scheme
 - To survive client crashes, client needs to record pending RPCs on disk
 - So it can replay them with the same unique identifier
- Plus story for making server reliable
 - Even if server fails, it needs to continue with full state
 - To survive server crashes, server should log to disk results of completed RPCs (to suppress duplicates)

Exactly-once for external actions?

- Imagine that remote operation triggers an external physical thing
 - e.g., dispense \$100 from an ATM
- ATM could crash immediately before or after dispensing
 - Don't know which one happened
 - Operation is not atomic (logging and dispensing are separate actions)
- **Can't achieve exactly-once in general**, in presence of external actions

Summary: RPCs and Network Comm.

- Layers are our friends!
- RPCs are everywhere
- Help support machine heterogeneity
- Subtle issues around failures
 - At-least-once w/ retransmission
 - At-most-once w/ duplicate filtering
 - Discard server state w/ cumulative acks
 - Exactly-once with:
 - at-least-once + at-most-once + fault tolerance + no external actions

