Remote Procedure Call

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Why Are Distributed Systems Hard?

- Asynchrony
  - Different nodes run at different speeds
  - Messages can be unpredictably, arbitrarily delayed
- Failures (partial and ambiguous)
  - Parts of the system can crash
  - Can’t tell crash from slowness
- Concurrency and consistency
  - Replicated state, cached on multiple nodes
  - How to keep many copies of data consistent?

Why Are Distributed Systems Hard?

- Performance
  - Have to efficiently coordinate many machines
  - Performance is variable and unpredictable
  - Tail latency: only as fast as slowest machine
- Testing and verification
  - Almost impossible to test all failure cases
  - Proofs (emerging field) are really hard
- Security
  - Need to assume adversarial nodes

Three-tier Web Architecture

- Scalable number of front-end web servers
  - Stateless ("RESTful"): if crash can reconnect the user to another server
- Scalable number of cache servers
  - Lower latency (better for front end)
  - Reduce load (better for database)
  - Q: how do we keep the cache layer consistent?
- Scalable number of back-end database servers
  - Run carefully designed distributed systems code

And Beyond

- Worldwide distribution of users
  - Cross continent Internet delay ~ half a second
  - Amazon: reduction in sales if latency > 100ms
- Many data centers
  - One near every user
  - Smaller data centers just have web and cache layer
  - Larger data centers include storage layer as well
  - Q: how do we coordinate updates across DCs?

MapReduce Computational Model

For each key k with value v, compute a new set of key-value pairs:

map (k,v) → list(k',v')

For each key k' and list of values v', compute a new (hopefully smaller) list of values:

reduce (k',list(v')) → list(v'')

User writes map and reduce functions.

Framework takes care of parallelism, distribution, and fault tolerance.

MapReduce Example: grep find lines that match text pattern

1. Master splits file into M almost equal chunks at line boundaries
2. Master hands each partition to mapper
3. map phase: for each partition, call map on each line of text
   - search line for word
   - output line number, line of text if word shows up, nil if not
4. Partition results among R reducers
   - map writes each output record into a file, hashed on key

Example: grep

5. Reduce phase: each reduce job collects 1/R output from each Map job

- all map jobs have completed!
- Reduce function is identity: v1 in, v1 out

6. merge phase: master merges R outputs

MapReduce (or ML or …) Architecture

- Scheduler accepts MapReduce jobs
  - finds a MapReduce master and set of avail workers
- For each job, MapReduce master <array>
  - farms tasks to workers; restarts failed jobs; syncs task completion
- Worker <array>
  - executes Map and Reduce tasks
- Storage <array>
  - stores initial data set, intermediate files, end results

Remote Procedure Call (RPC)

A request from the client to execute a function on the server.

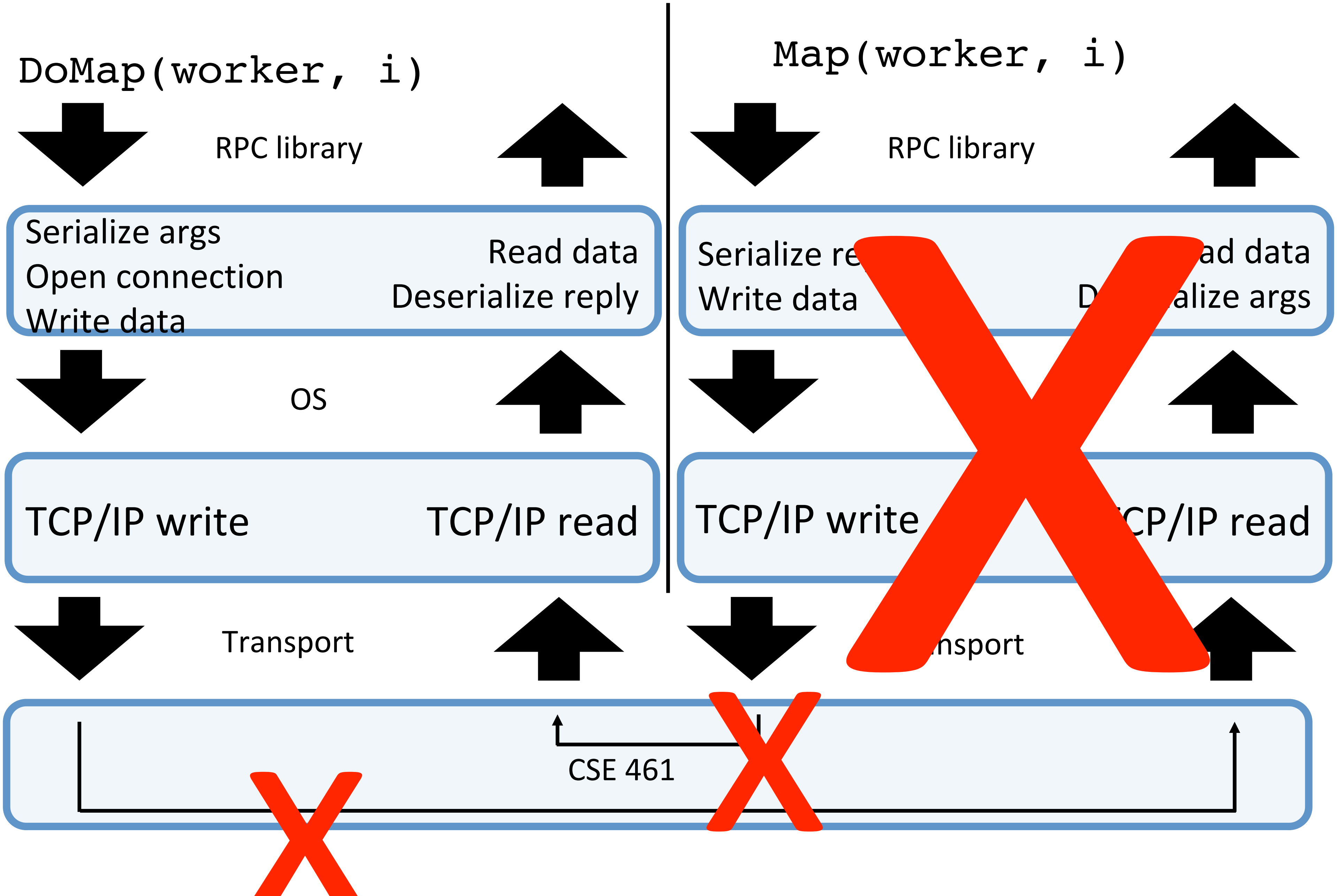
- To the client, looks like a procedure call
- To the server, looks like an implementation of a procedure call

Remote Procedure Call (RPC)

A request from the client to execute a function on the server.

- On client
  - Ex: result = DoMap(worker, i)
  - Parameters marshalled into a message (can be arbitrary types)
  - Message sent to server (can be multiple pkts)
  - Wait for reply
- On server
  - message is parsed
  - operation DoMap(i) invoked
  - Result marshalled into a message (can be multiple pkts)
  - Message sent to client

RPC implementation



RPC vs. Procedure Call

- What is equivalent of:
  - The name of the procedure?
  - The calling convention?
  - The return value?
  - The return address?

RPC vs. Procedure Call

Binding

- Client needs a connection to server
- Server must implement the required function
- What if the server is running a different version of the code?

Performance

- procedure call: maybe 10 cycles = ~3 ns
- RPC in data center: 10 microseconds => ~1K slower
- RPC in the wide area: millions of times slower

RPC vs. Procedure Call

Failures

- What happens if messages get dropped?
- What if client crashes?
- What if server crashes?
- What if server crashes after performing op but before replying?
- What if server appears to crash but is slow?
- What if network partitions?

Semantics

- Semantics = meaning

- reply == ok => ???
- reply != ok => ???

Semantics

- At least once (NFS, DNS, lab 1b)
  - true: executed at least once
  - false: maybe executed, maybe multiple times
- At most once (lab 1c)
  - true: executed once
  - false: maybe executed, but never more than once
- Exactly once
  - true: executed once
  - false: never returns false

At Least Once

RPC library waits for response for a while

If none arrives, re-send the request

Do this a few times

Still no response -- return an error to the application

Non-replicated key/value server

Client sends Put k v

Server gets request, but network drops reply

Client sends Put k v again

- should server respond "yes"?
- or "no"?

What if op is “append”?

Does TCP Fix This?

- TCP: reliable bi-directional byte stream between two endpoints
  - Retransmission of lost packets
  - Duplicate detection
- But what if TCP times out and client reconnects?
  - Browser connects to Amazon
  - RPC to purchase book
  - Wifi times out during RPC
  - Browser reconnects

When does at-least-once work?

- If no side effects
  - read-only operations (or idempotent ops)
- Example: MapReduce
- Example: NFS
  - readFileBlock
  - writeFileBlock

At Most Once

Client includes unique ID (UID) with each request

- use same UID for re-send

Server RPC code detects duplicate requests

- return previous reply instead of re-running handler

```
if seen[uid] {
    r = old[uid]
} else {
    r = handler()
    old[uid] = r
    seen[uid] = true
}
```

Some At-Most-Once Issues

How do we ensure UID is unique?

- Big random number?
- Combine unique client ID (IP address?) with seq #?
- What if client crashes and restarts? Can it reuse the same UID?
- In labs, nodes never restart
- Equivalent to: every node gets new ID on start

When Can Server to Discard Old RPCs?

Option 1:

  Never?

Option 2:

  unique client IDs

  per-client RPC sequence numbers

  client includes "seen all replies <= X" with every RPC

Option 3: only allow client one outstanding RPC at a time

  arrival of seq+1 allows server to discard all <= seq

Labs use Option 3

What if Server Crashes?

If at-most-once list of recent RPC results is stored in memory, server will forget and accept duplicate requests when it reboots

- Does server need to write the recent RPC results to disk?
- If replicated, does replica also need to store recent RPC results?

In Labs, server gets new address on restart

- Client messages aren't delivered to restarted server