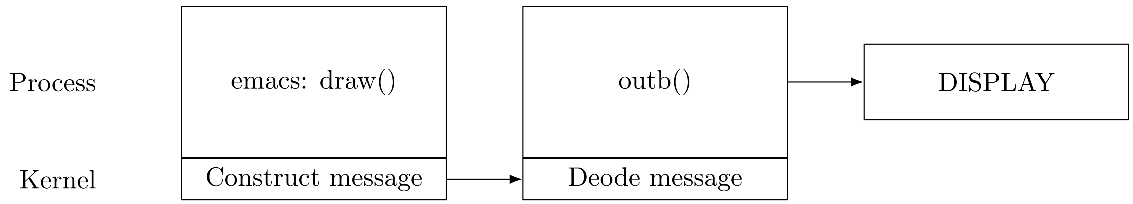
We start by observing a virtual usage of the client/server approach

X PROTOCOL



The X server handles the keyboard, mouse, and display of the system

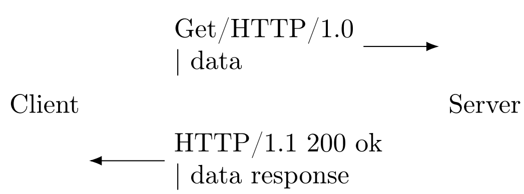
This is an example of a *distributed system* in which the server effectively acts as the system kernel. and uses *remote procedure calls*. Our goal in these systems is modularity rather than virtualization.

This has a few distinction from standard procedure calls

1. the caller and callee do not need to share an address space
2. passing by reference and pointers are not allowed
3. the client and server need not be on the same architecture (i.e. x86 vs x86-64 or x86-64 vs SPARC64)

But the last of these distinctions introduces long size and endian-ness problems. We address these by *marshaling* commands. This adds a layer of abstraction on the commands.

Messages can be passed in multiple bit pattern forms such as XML (slow), JSON, and IEE 754. One such usage is HTTP:



What could go wrong?

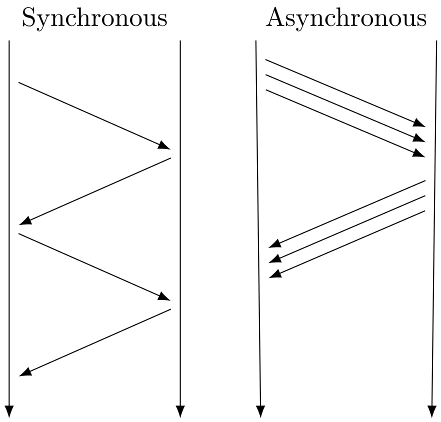
- messages can get lost/duplicated/corrupted
- the network/server can go down (or be slow)

& these appear identical to the client!

We deal with these issues as two categories:

1. Corruption
   (a) better checksums in messages
   (b) end-to-end (rather than link) encryption
      - *link encryption* := devices decrypt and re-encrypt
      - *end-to-end encryption* := data stays encrypted for the entire journey
   (c) resend messages on detection
2. Network Issues
   (a) At-Least-Once RPC (keep trying) — good for idempotent information
   (b) At-Most-Once RPC (log on error) — good for transactions
   (c) Exactly-Once RPC (don't make mistakes) — very (some would say too) difficult to implement

Another downside is INEFFICIENCY. We have 3 major approaches to combatting this:



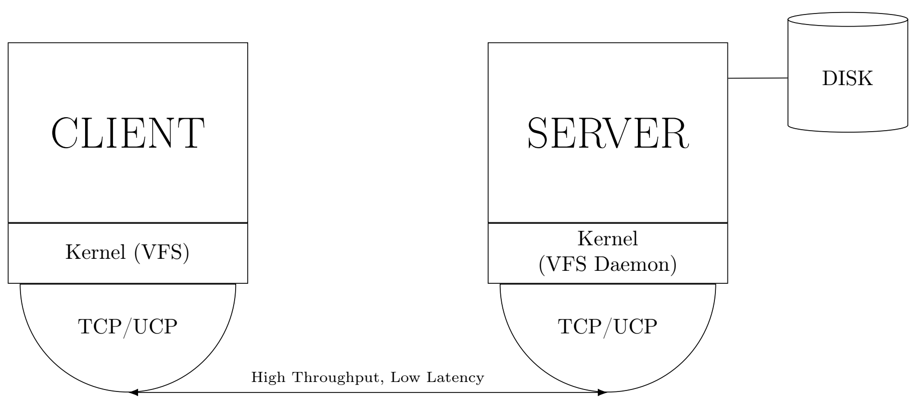
1. Asynchronous System Calls (Pipelining)
    - allows for more useful work time
    - complicated partial failure
    - out-of-order responses
    - requests must be independent
2. Cache-on-the-Client
    - cache responses to likely requests
    - common with web browsers
3. Pre-Fetching
    - guess a response prior to receiving methods
    - hogs resources

We can use these ideas to implement

0.1 Networked File Systems

We analyze *NFS models* := a Linux-type system which sends requests (like open, read, lseek...) to a network. Two commonly used versions are

v3: useful in machine rooms, since it uses *UDP* := establishes a connection before sending packets
v4: useful for the internet, since it uses *TCP* := sends packets without establishing a connection



The kernel uses a VFS (such as btts, ext4, etc) to

- transparently marshal procedure calls
- send and receive unencrypted packets (encryption started with VFSv4)

Basically, we emulate a local file system with a network! This is great for modularity (we don't even need the same underlying architecture, remember?) but now we are relying on a network; what if it goes down?

For example, note that read is short enough to avoid failure by interrupt; but what if the network goes down?

- Option A: read() hangs — this exposes us to infinite hangs!
- Option B: send a ^C to interrupt — apps which assume a return from read get complicated!

The system administrator has to choose, but we're wrong either way.

So what do we do?

- In short, don't let the network go down, but we design our protocol carefully just in case

Even without a crash, close() is costly, as the client waits for all outstanding requests

NFS Primitives:

```
# all elements are fixed-size
# fh and attr are concatenated and cast to integers
MKDIR(dirfh, name, attr) -> fh & sttr
REMOVE(dirfh, name)-> status
READ(fh, offset, size) -> data
LOOKUP(dirfh, name) -> fh & attr
# example message:
LOOKUP("/usr/local", "/bin") -> 4728 + {output of ls}
```

An nfs *file handle* uniquely identifies a file on a server

- it survives renames and reboots
- on Unux, it is a concatenation of device number, inode number, and serial number

They cause the server to be stateless, as they do not rely on the state of the client So will a concurrent WRITE and RENAME cause problems?

- NO; the file handle does not change

Will a concurrent REMOVE and WRITE?

- YES, which violates the Linux standard! (would wait to delete, but NFSv3 is stateless)

There are two cases:

1. REMOVE & WRITE are from the same client
    - save a dummy request to a temp file names ".NFS#"
    - the client is responsible for the cleanup
2. REMOVE & WRITE from different clients
    - set errno = ESTALE

A related error occurs with concurrent REMOVE & WRITE or WRITE & WRITE. With the system as we currently understand it, the NFS would not recognize the stale request and would write to the wrong file. Therefore we need a serial number to represent what version of this file handle a file is.