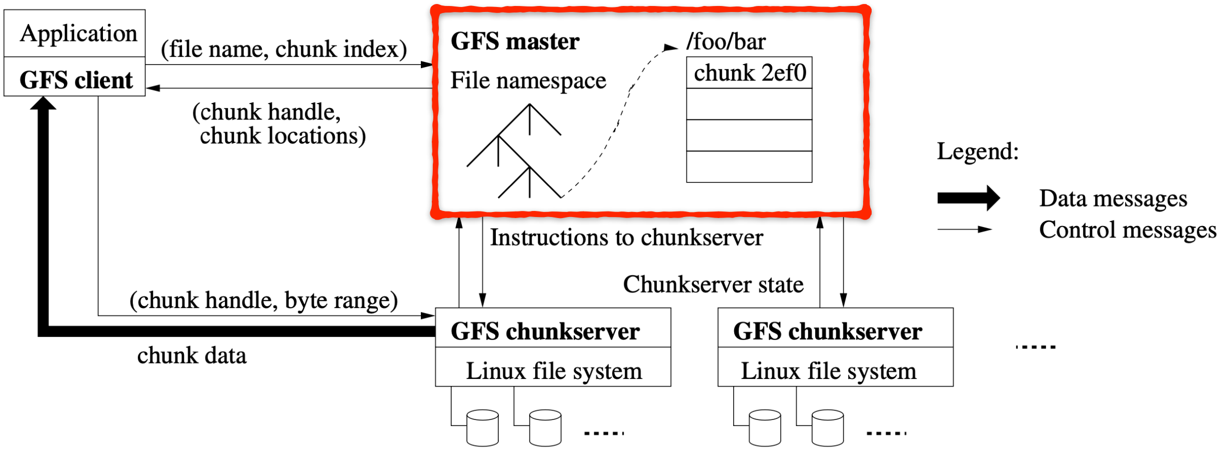
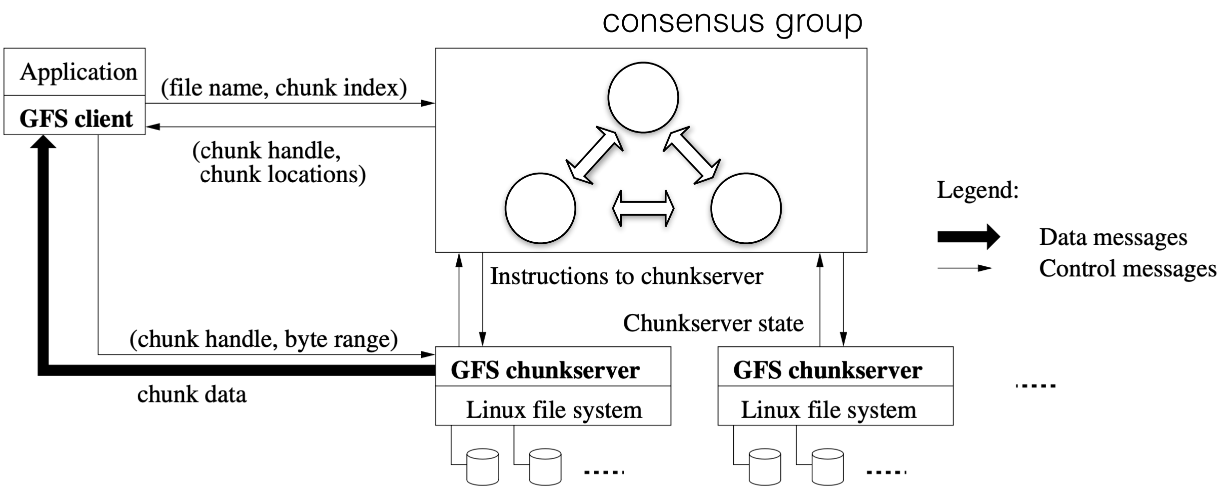
Distributed Systems

- *48 - Communication Basics*
- *49 - NFS*
- *50 - AFS*
- *GFS*
- Fault Tolerance

Distributed GFS *GFS master*



Distributed GFS *GFS master*



consensus group is fault-tolerant; any one of the three can fail without halting the entire system

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Fault Tolerance *dependability*

- A component provides services to clients.
  - To provide services, the component may require the services from other components ⇒ a component may *depend* on some other component.
- Specifically:
  - A component C depends on C_* if the correctness of C's behavior *depends* on the correctness of C_*'s behavior. (Components are processes or channels.)

Requirement	Description
Availability	Readiness for usage
Reliability	Continuity of service delivery
Safety	Very low probability of catastrophes
Maintainability	How easy can a failed system be repaired

Fault Tolerance *basics*

- Reliability *R(t)* of component *C*
  - Conditional probability that *C* has been functioning correctly during [0, t) given *C* was functioning correctly at time $T = 0$.
- Traditional metrics:
  - Mean Time To Failure (MTTF):
    - average time until a component fails.
  - Mean Time To Repair (MTTR):
    - average time needed to repair a component.
  - Mean Time Between Failures (MTBF)
    - Simply MTTF + MTTR.

Reliability vs Availability

Availability *A(t)* of component *C*:

- Average fraction of time that *C* has been up-and-running in interval *[0, t)*.
  - Long-term availability *A*: $A(\infty)$
  - Note: $A = \frac{\text{MTTF}}{\text{MTBF}} = \frac{\text{MTTF}}{\text{MTTF+MTTR}}$

- Reliability and availability make sense only if we have an accurate notion of what a failure actually is….

Terminology

Term	Description	Example
Failure	A component is not living up to its specifications	Crashed program
Error	Part of a component that can lead to a failure	Programming bug
Fault	Cause of an error	Sloppy programmer

Handling Faults

Term	Description	Example
Fault prevention	Prevent the occurrence of a fault	Don't hire sloppy programmers
Fault tolerance	Build a component such that it can mask the occurrence of a fault	Build each component by two independent programmers
Fault removal	Reduce the presence, number, or seriousness of a fault	Get rid of sloppy programmers
Fault forecasting	Estimate current presence, future incidence, and consequences of faults	Estimate how a recruiter is doing when it comes to hiring sloppy programmers

Failure Models

Type	**Description of server's behavior**
Crash failure	Halts, but is working correctly until it halts (*fail stop*)
Omission failure *receive omission* *send omission*	Fails to respond to incoming requests Fails to receive incoming messages Fails to send messages
Timing failure	Response lies outside a specified time interval
Response failure *Value failure* *State-transition failure*	Response is incorrect The value of the response is wrong Deviates from the correct flow of control
Arbitrary failure	May produce arbitrary responses at arbitrary times

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Dependability vs Security

Omission versus commission

Arbitrary failures are sometimes called *malicious*. It is better to make the following distinction:

- *Omission failures*: a component fails to take an action that it should have taken
- *Commission failures*: a component takes an action that it should not have taken

Observation

Deliberate failures, be they omission or commission failures, are typically security problems. Distinguishing between deliberate failures and unintentional ones is, in general, *impossible*.

Halting Failures

Scenario

C no longer perceives any activity from *C*∗ — a halting failure? Distinguishing between a crash or omission/timing failure is difficult to impossible.

Asynchronous versus synchronous systems

- *Asynchronous system*: no assumptions about process execution speeds or message delivery times → *cannot* reliably detect crash failures.
- *Synchronous system*: process execution speeds and message delivery times are bounded → we *can* reliably detect omission and timing failures.
- In practice we have *partially synchronous systems*: most of the time, we can assume the system to be synchronous, yet there is no bound on the time that a system is asynchronous → can normally reliably detect crash failures.

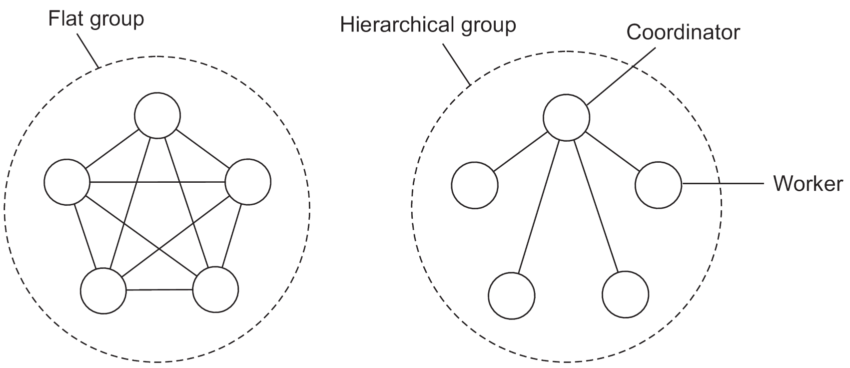
Halting Failures

Halting type	**Description**
Fail-stop	Crash failures, but reliably detectable
Fail-noisy	Crash failures, eventually reliably detectable
Fail-silent	Omission or crash failures: clients cannot tell what went wrong
Fail-safe	Arbitrary, yet benign failures (i.e., they cannot do any harm)
Fail-arbitrary	Arbitrary, with malicious failures

Process Resilience

Basic idea

Protect against malfunctioning processes through *process replication*, organizing multiple processes into a *process group*. Distinguish between *flat groups* and *hierarchical groups*.



Groups and Failure Masking

k-fault tolerant group

When a group can mask any k concurrent member failures (k is called degree of fault tolerance).

How large does a k-fault tolerant group need to be?

- With halting failures (crash/omission/timing failures): we need a total of $k + 1$ members as no member will produce an incorrect result, so the result of one member is good enough. If k fail silently, the answer of the other can be used.
- With arbitrary failures: we need $2k + 1$ members so that the correct result can be obtained through a majority vote. Up to k could be malicious (lie, prevaricate), so we need $k+1$ who agree to reach consensus. If at most fail, there should be $n+1$ correct servers left.

Important assumptions:

- All members are identical
- All members process commands in the same order

Result: We can now be sure that all *non-malicious* processes do exactly the same thing.

Consensus

Prerequisite

In a fault-tolerant process group, each nonfaulty process commits the same commands, and in the same order, as every other nonfaulty process.

Reformulation

Nonfaulty group members need to reach *consensus* on which command to commit next.

Motivating Paxos *by looking at consensus*

Assumptions (rather weak ones, and realistic)

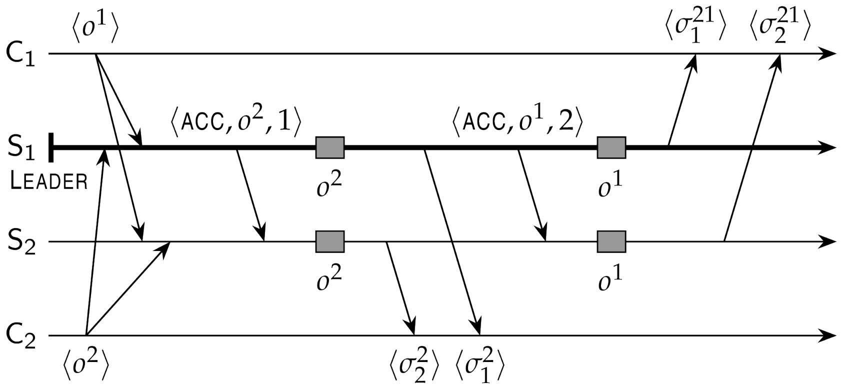
- System is *partially synchronous* (may even be *asynchronous*).
- *Communication* between processes may be *unreliable*:
  - messages may be lost, duplicated, or reordered.
- *Corrupted messages can be detected*
  - and thus subsequently ignored
- All *values are deterministic*:
  - once an execution is started, it is known exactly what it will do.
- Processes may exhibit *crash failures*, but *not arbitrary failures*.
- Processes *do not collude*.

Understanding Paxos

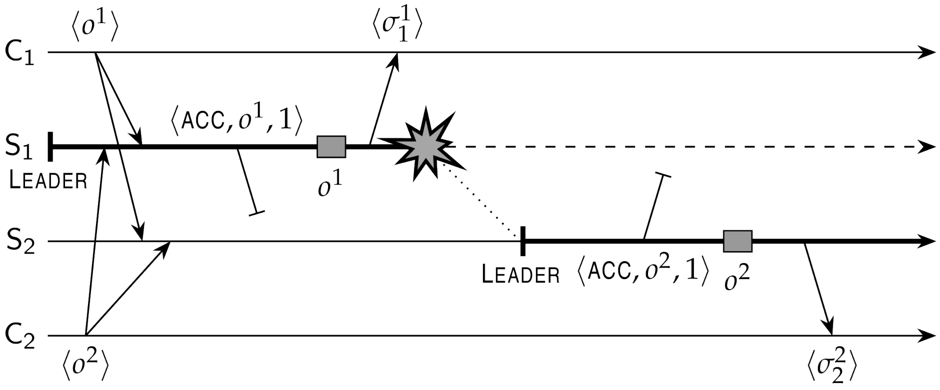
- We will build up to Paxos by looking at problems that occur.

Two Servers *leader + backup*

- The leader sends an *accept* message `ACCEPT(o,t)` to backups when assigning a timestamp *t* to command *o*.



Two Servers *and a crash!*



Problem

Servers have diverged because primary crashes *after executing* an value, but the backup *never received* the accept message.