# Large-Scale Byzantine Fault Tolerance: Safe but Not Always Live

Petr Kouznetsov, Max Planck Institute for Software Systems

Join work (in progress!) with:

Bobby Bhattacharjee, Univ. Maryland
Rodrigo Rodrigues, INESC-ID and Tech. Univ. Lisbon

FuDiCo III, June 2007

## Big picture

Choosing an adequate model to implement a system is crucial

- ***Optimistic***: the system is very efficient but likely to fail
- ***Conservative***: the system is very robust but inefficient (or impossible to implement)

How to find a good balance?

2

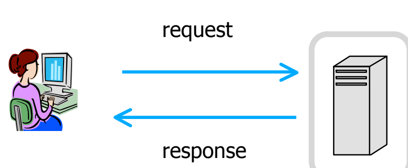
## Prepare for the worst and hope for the best

- How good is the best and how bad is the worst?
  - ✓Best case – failures are few
  - ✓Worst case – almost everything can be faulty
- What do we mean by "prepare" and "hope"?
  - ✓The system is very efficient in the best case
  - ✓The system never produces inconsistent output (even in the worst case), but …
  - ✓May become unavailable in the (rare) "intermediate" case

3

## The context: clients and services

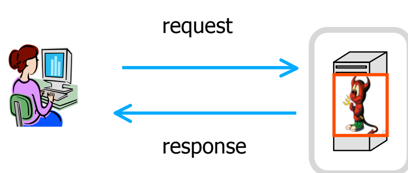
- A client issues a request to a service
- The service executes the request and returns a response to the client




4

# The *fault-tolerant* computing challenge

- Even if some system components (clients or service units) fail, the correct clients still get something useful from the service
- Failures can be Byzantine: a component can arbitrarily deviate from its expected behavior

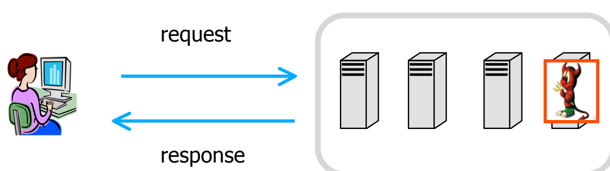



5

# The replication approach

[Lamport, 1990; Schneider, 1990]

- Replicate the service
- Correct clients treat the distributed service as one correct server:
  - ✓Requests are totally ordered, respecting the precedence relation (safety)
  - ✓Every request issued by a correct client is served (liveness)
- Byzantine fault-tolerance (BFT) [Castro and Liskov,1999]




6

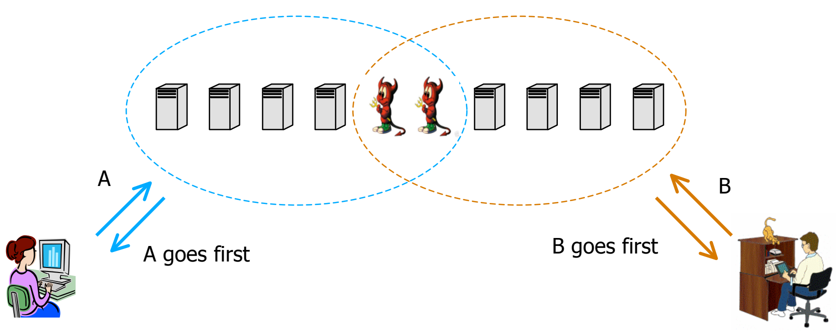
## BFT: costs and optimistic assumptions

- A request (a batch of requests) involves a three-phase agreement protocol to be executed
- A large fraction (more than 2/3) of the service replicas (servers) must be correct
  - ✓Ok if faults are independent (hardware failures)
  - ✓Questionable for software bugs or security attacks
  - ✓An obstacle for scalability (unlikely to hold for large number of *replica groups*)

7

## Why 2/3?

- Safety: every two requests should involve at least one common correct server




8

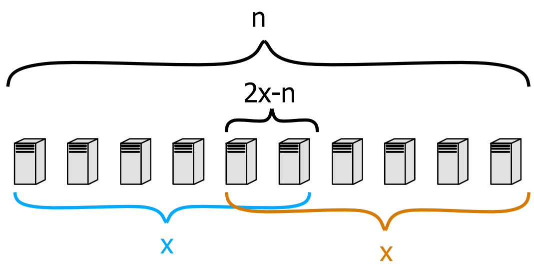
## Why 2/3?

n – number of servers
x – quorum size (number of servers involved in processing a request)
f – upper bound on the number of faulty servers

2x-n ≥ f+1 **or** x ≥ (n+f+1)/2 **(safety)**

**=>** n ≥ 3f+1

n-f ≥ x **(liveness)**




9

## Trading off liveness for safety

- Every request involves at least (n+f+1)/2 servers => safety is ensured as long as f or less servers fail
- Liveness will be provided if not more than n-(n+f+1)/2= (n-f-1)/2 servers fail

- n=10, f=7: liveness tolerates at most one failure

10

## Trading off liveness for safety

- f<n/3
  - ✓Both safety and liveness are ensured with quorums of size 2/3n+1
- f=n-1
  - ✓Safety: n-1 or less faulty servers
  - ✓Liveness: no fault-tolerance at all

11

## Unexpected benefits!

- Large quorums may make things faster!

- Very fast in the good case
- Very slow (unavailable) in the (rare) intermediate case
- But always correct

- Holds only for the special case f=n-1?

12

## Using the trade-off

- A "bimodal" failure model?
  - ✓Few failures is the common case
  - ✓Many failures is a possible (but rare) case ($f >> n/3$)
    - Software bugs and security attacks?
- Modified BFT looks like a perfect fit!



## Challenge: scalable BFT

- Farsite, Rosebud, OceanStore,…
  - ✓All of them use multiple *BFT groups*
  - ✓A group is responsible for a part of the system state (an object)
  - ✓Each group is supposed to be safe and live (the 2/3 assumption is not violated)
- The more groups we have - the more likely one of them fails: the system safety is in danger
- Going beyond 2/3 per group?

## Using the trade-off: scalable BFT

- The (large) bound on the number of faulty servers *per group* is never exceeded
- Each group runs the modified BFT: can be seen as a *crash-fault* processor

15

## Addressing liveness

- Primary-backup: from p to $p^2$
  - ✓Every object is associated with a pair of groups
- Speculative executions [Nightingale et al.,2005]
  - ✓Primary group produces tentative results
  - ✓Backup group assist in committing them

16

## Normal case

Client

- Run operations on the primary group tentatively
- Check whether the tentative results turned into definitive (the state was successfully transferred to the backup group)

Backup-primary

- Periodically transfer the system state from primary to backup

17

## Liveness checks and recovery

Takeover protocol: when the primary fails the backup takes over the speculative execution

- Primary fails: backup takes over in speculative executions
- Backup fails: select a new backup
- Configuration changes: elect new primary and backup (at least one of the old ones must remain live until the state is transferred)

18

## Properties

- Safety: always
- Liveness: as long as at least one group is available

19

## Related work

- BFT, Castro and Liskov, 1999
- “Scalable” BFT: OceanStore, 2000; Farsite, 2002; Rosebud, 2003,…
- Safety-liveness trade-offs, Lamport, 2003
- Fork consistency, Li and Mazieres, 2007
- Singh et al., 2007
- Speculative executions, Nightingale et al., 2005
- Fault isolation, Douceur et al., 2007

20

# Conclusions and Future

- Safety at the expense of liveness [HotDep07]
  - ✓ Security and tolerance to software errors
  - ✓ Scalability
- Safety + conditional liveness
  - ✓ Crash fault computing: safe algorithms + failure detectors
  - ✓ Software transactional memory: optimistic STMs + contention managers
- Does this stuff work?
  - ✓ Fault model analysis
  - ✓ Multiple backups: from $p^2$ to $p^k$
  - ✓ Paxos?
  - ✓ Implementation

21