Tackling Latency via Replication in Distributed Systems

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Failure types

Request failure:

- Request in service is lost
- Server is not affected
- Communication failures
- Timeouts of resources with limited availability
- Outputs failing to meet time constraints

Impact:

- Poor service quality
- Economic losses, environmental damage

State-of-the-Art Strategies

Fault-tolerance mechanisms

- ***Retry***: typically after a timeout handled by a central scheduler

-> Introduces unacceptable delay!

- ***Attack of the clones:***

- Launch multiple ***clones*** of a request
- Use the ***first*** successful result returned
- ***Cancel*** all outstanding replicas.

Motivation: Low Utilization

- ***Low utilization:*** heavy concurrent replication is appealing in the light of the low utilization common in data centers.
- ***Example:*** Facebook traces reveal median CPU and memory utilization under 20%.

Motivation: Cost-efficiency

- Much of the energy consumption is wasted at low utilization
- An idle server consumes 65% of its peak power consumption

Cost-effective to use these idling resources for running extra replicas of requests.

Motivation: It Works!

- Efficient to improve the system ***reliability***.
- Has the ***potential*** to reduce response times
- ***Overall latency:*** minimum of the delays of all the replicas.

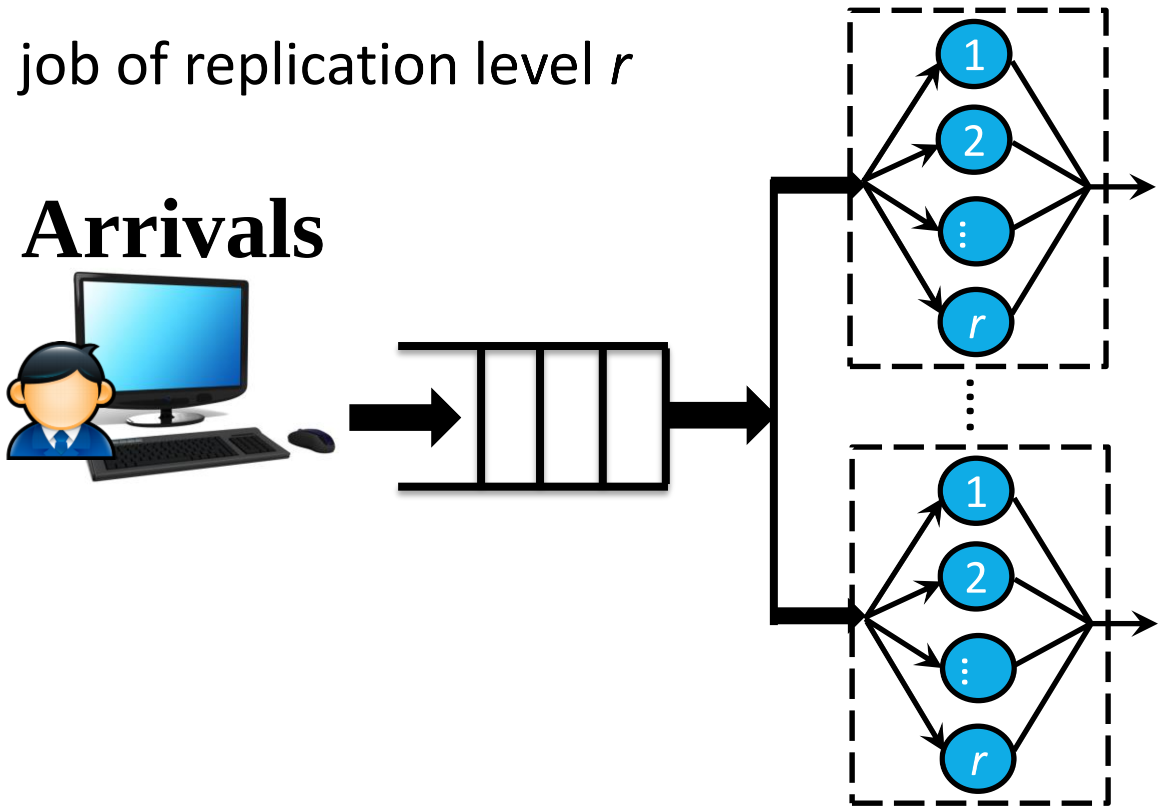
Open Questions

- ***When*** is the reduction in latency realized?
- Under what ***conditions***?
- How ***large*** is the potential reduction?
- How many clones to have?
- ***Centralized*** set-up or ***distributed***?

System Set-up

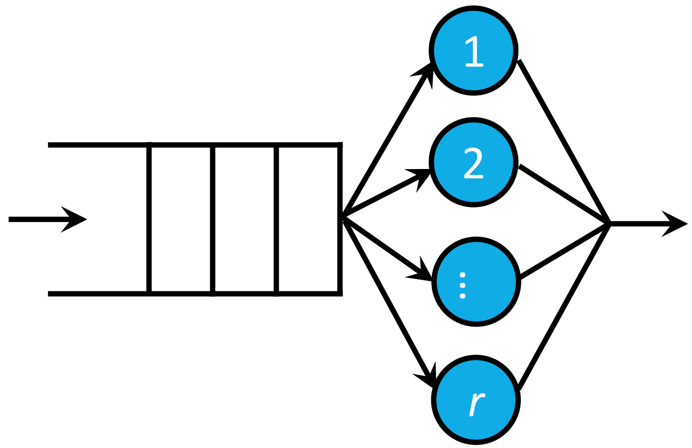
Each node

- Composed of *r* servers
- Serving a job of replication level *r*

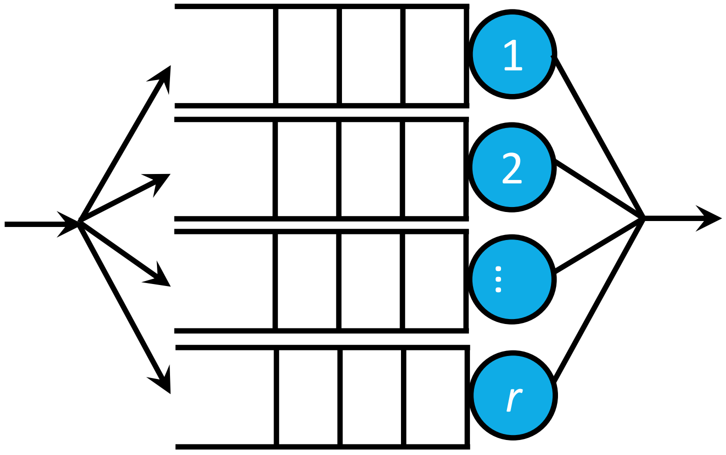


System Set-up

- ***Centralized*** set-up



- ***Distributed*** set-up



- Request arrivals: Markovian Arrival Process (MAP)
- ***Replica*** time-to-failure: exponentially distributed
- ***Replica*** processing times: exponentially distributed
- Phase type ***request*** response time

Challenges

- ~~Mean~~ response time? Response time ***distribution***
- System with replication: ***no standard model***
- Central queue: *Enhancing Reliability and Response Times via Replication in Computing Clusters, IEEE INFOCOM 2015.*
- Analyzing distributed set-up is more challenging
  - Synchronized arrivals correlates all the queues
  - Individual replicas fail asynchronously

Steps

Target:

The job response time distribution

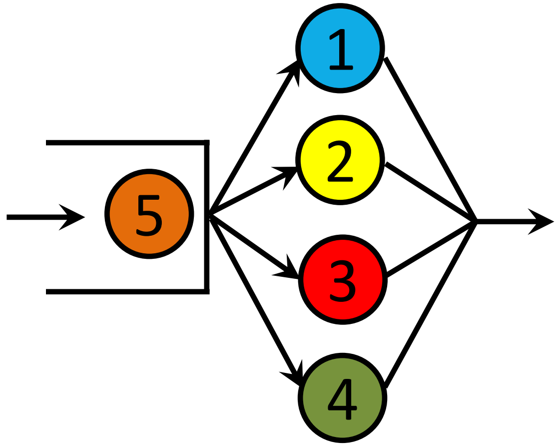
Steps：

1. The waiting-time distribution

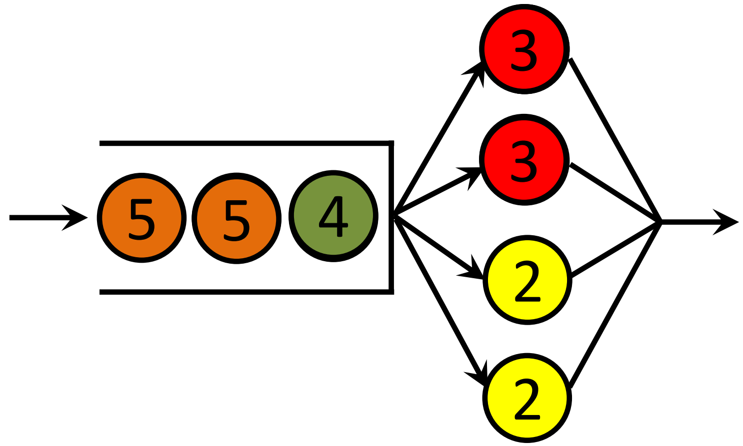
2. The service-time distribution

The Centralized Set-up

- ***Without*** replication

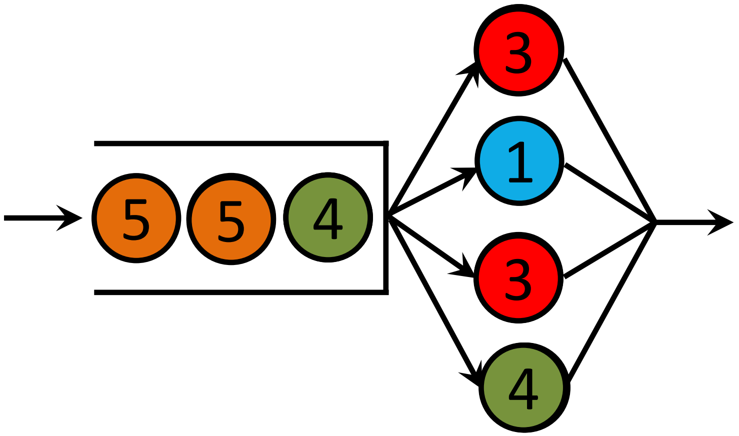


- ***With*** one extra replica



The Centralized Set-up

- ***With*** one extra replica



Y(t) = (1,1)

L1(t) = 1

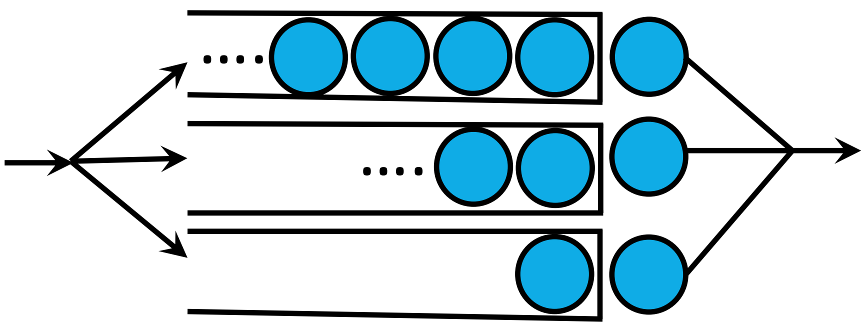
L2(t) = 1

Service state:

- *Li(t)*: number of tasks with *i* replicas in service at time *t*
- *Y(t) = (i,j)*: state of the youngest job in service
  - *i* replicas of the youngest job are in service
  - *j* replicas are waiting in the queue
  - *r-i-j* replicas already failed

The Distributed Set-up

Challenge: the queue-length



Solution:

1. Sort the queues by their lengths
2. Focus on the queue length difference.
3. Limit C : maximum queue-length difference

The Distributed Set-up

Challenge:

Dependence between waiting and service processes

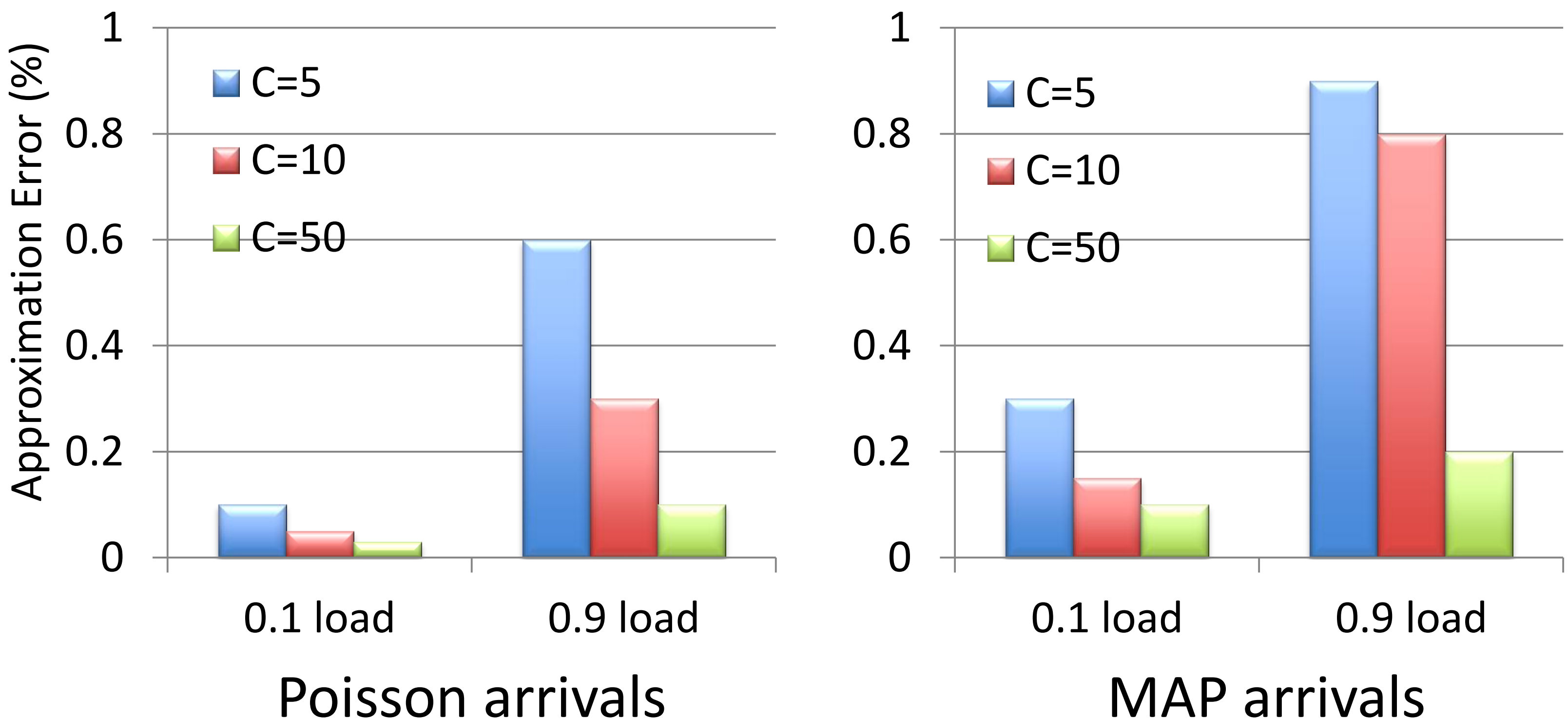
Solution:

- ***Look backwards in time!***
- Consider jobs that start service with and without waiting separately.

Approximation errors

Approximation errors compared with simulation results

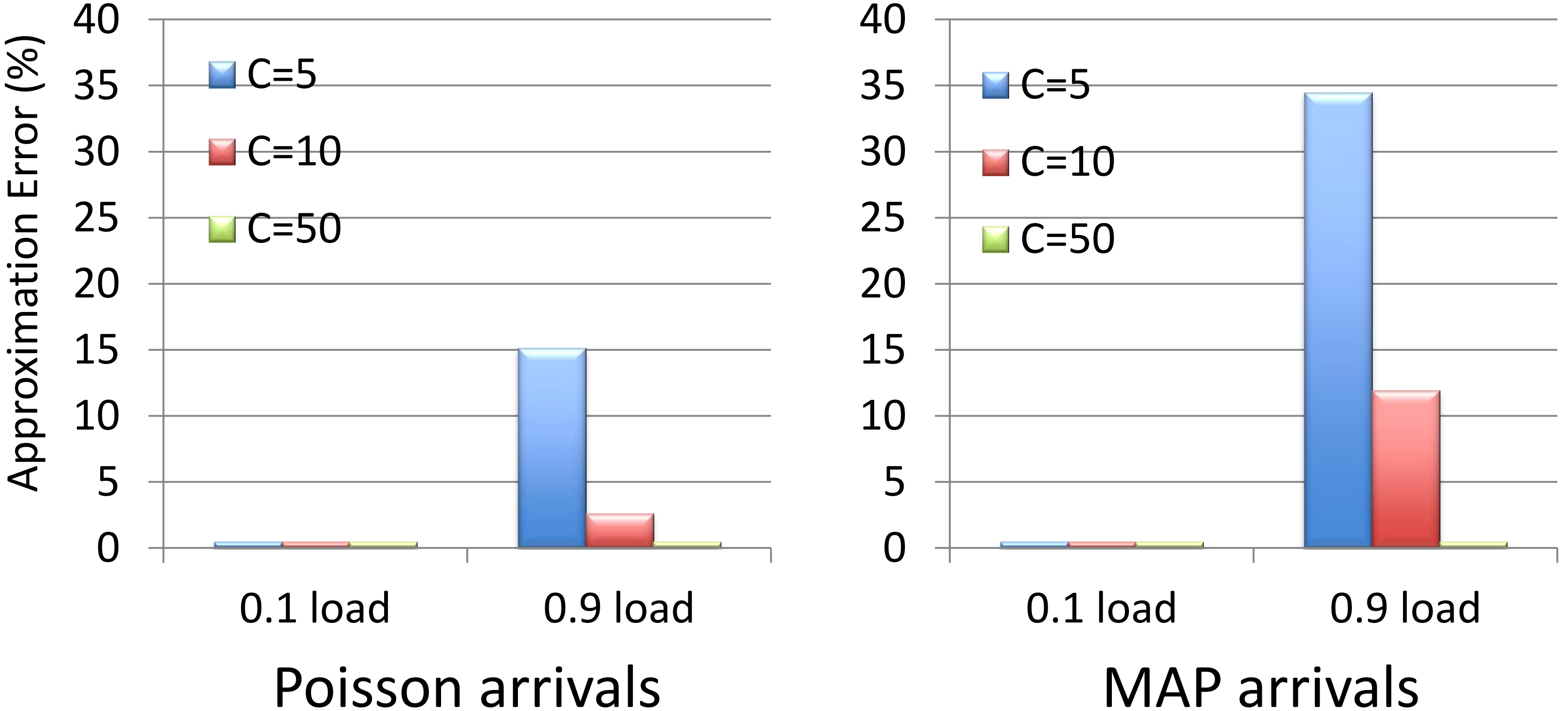
- Example: r = 3, 90% reliability, 95th percentile



Approximation errors

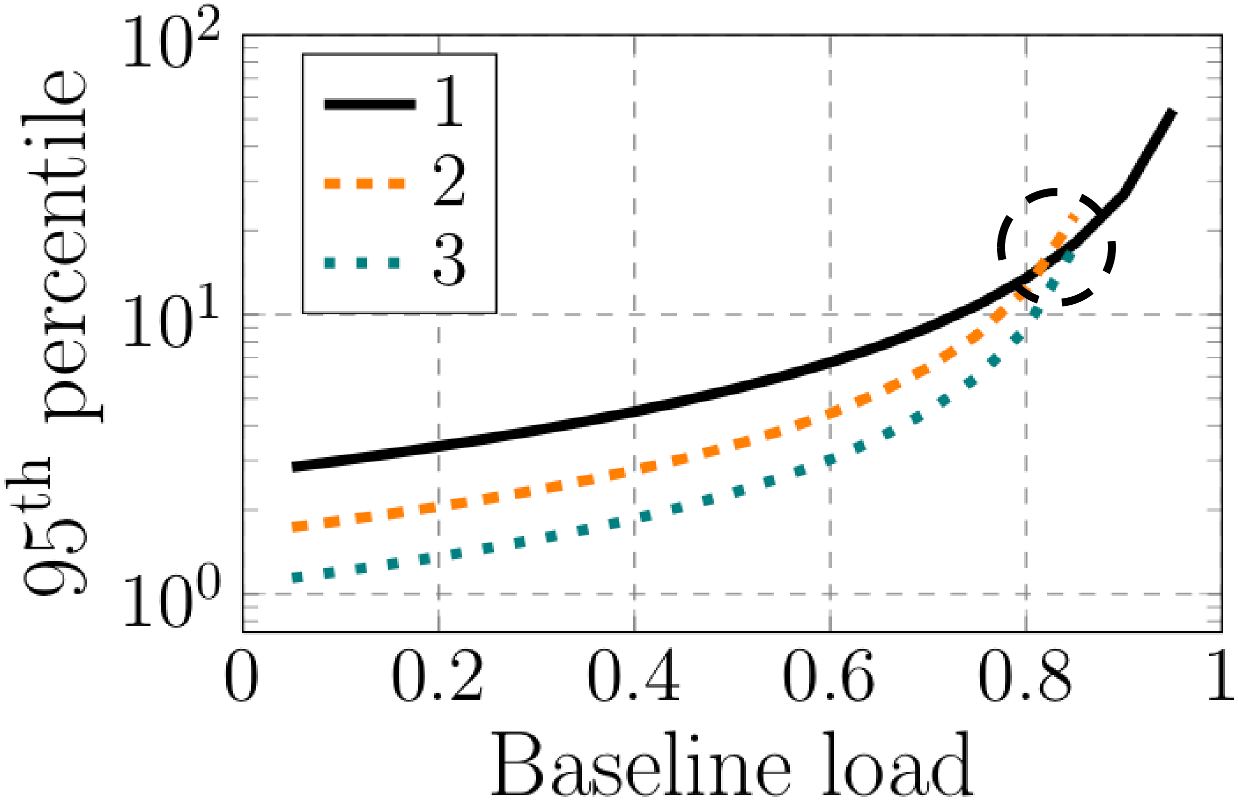
Approximation errors compared with simulation results

- Example: r = 3, 10% reliability, 95th percentile



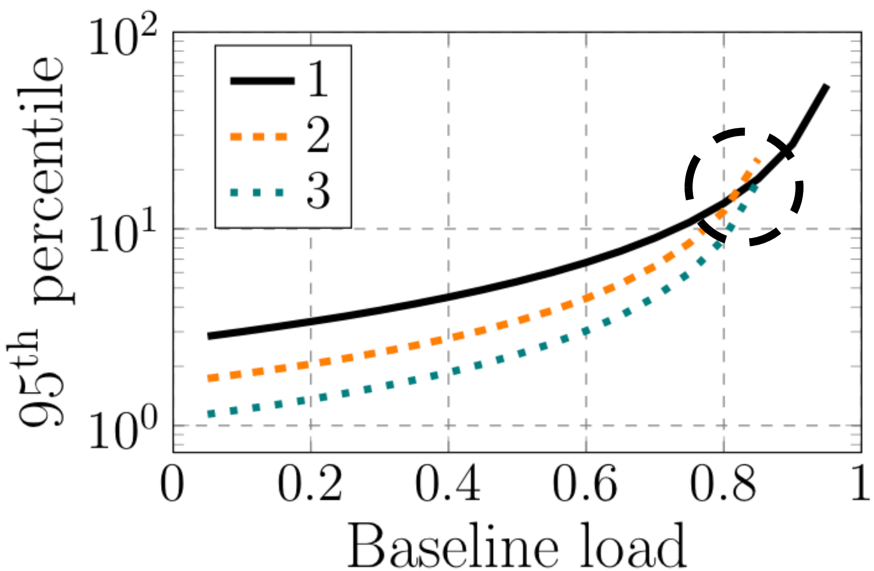
The Effect of Replication

Example: Poisson arrivals, 90% reliability

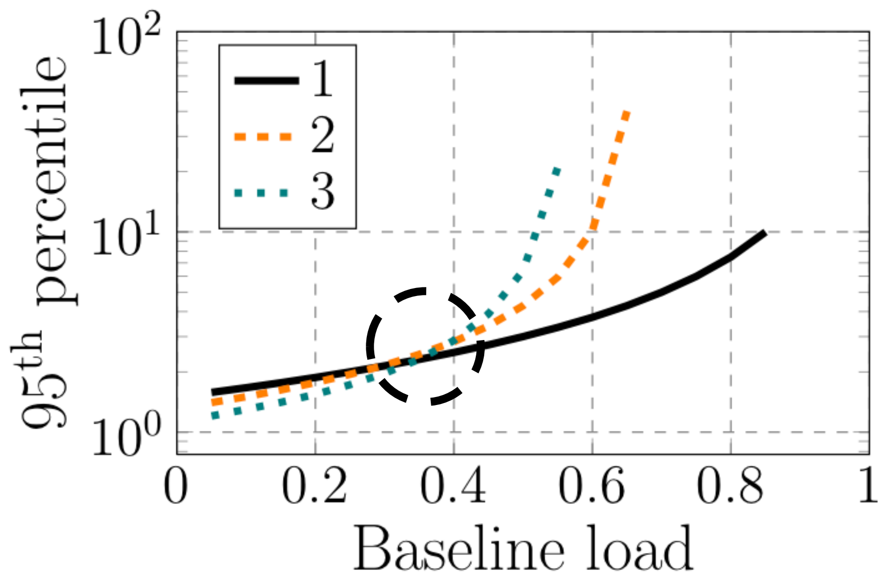


The Effect of the Reliability

Example: Poisson arrivals



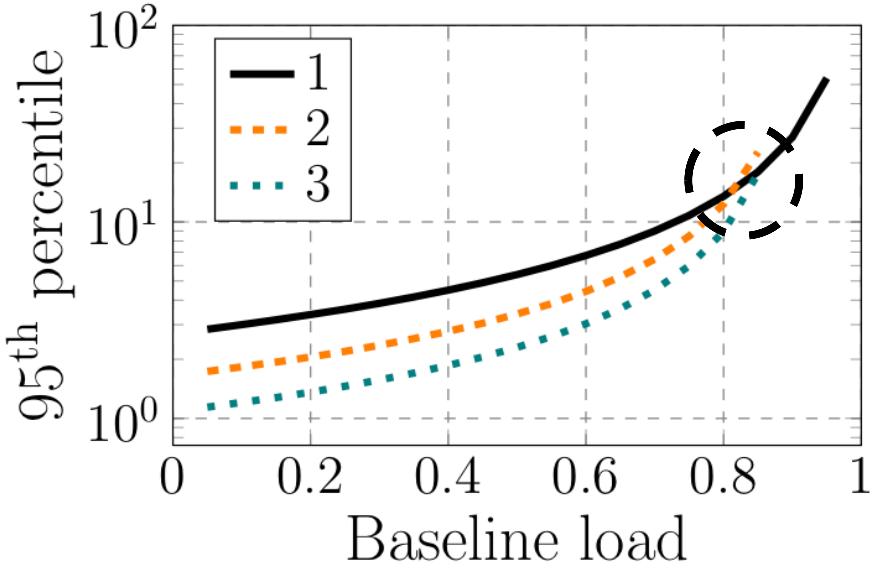
90 % reliability



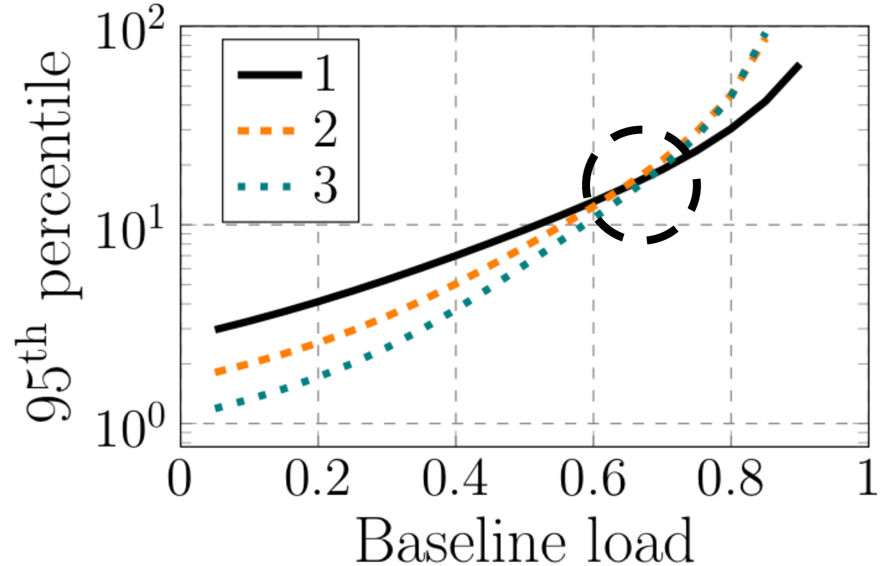
50 % reliability

The Effect of the Arrival Process

Example: 90% reliability



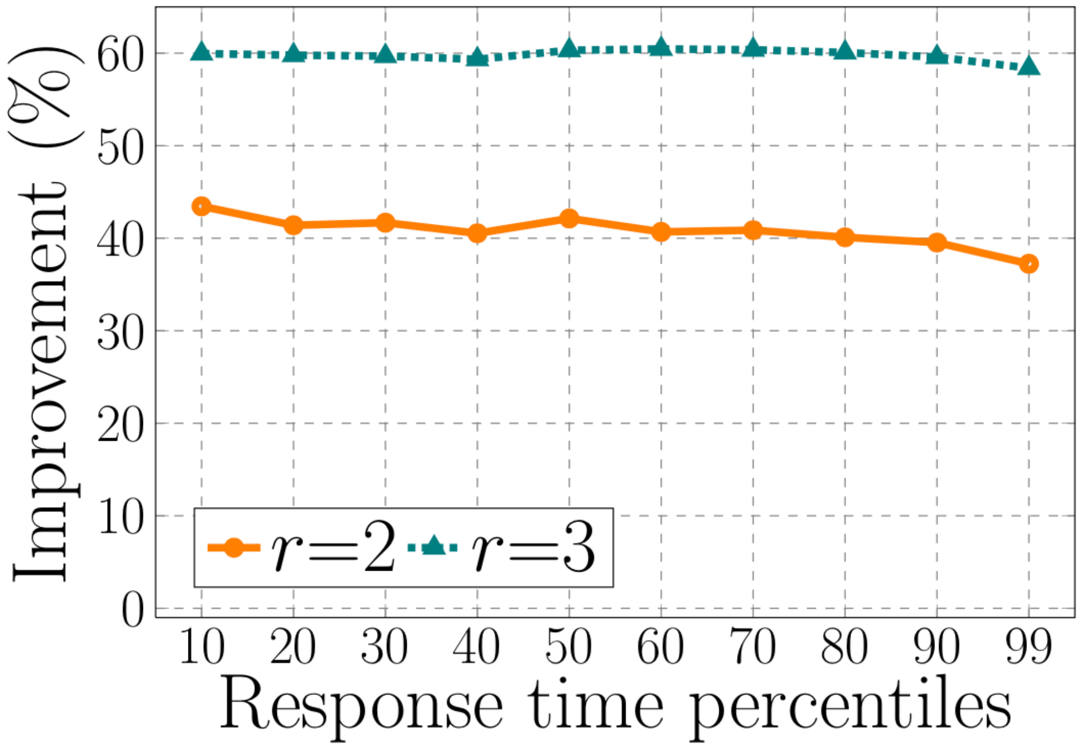
Poisson arrivals



MAP arrivals

The Effect across the Distribution

Example: Poisson arrivals, 90% NR-reliability, 0.3 load



Distributed vs Centralized

1. Advantage of the distributed set-up:

➔ More flexibility.

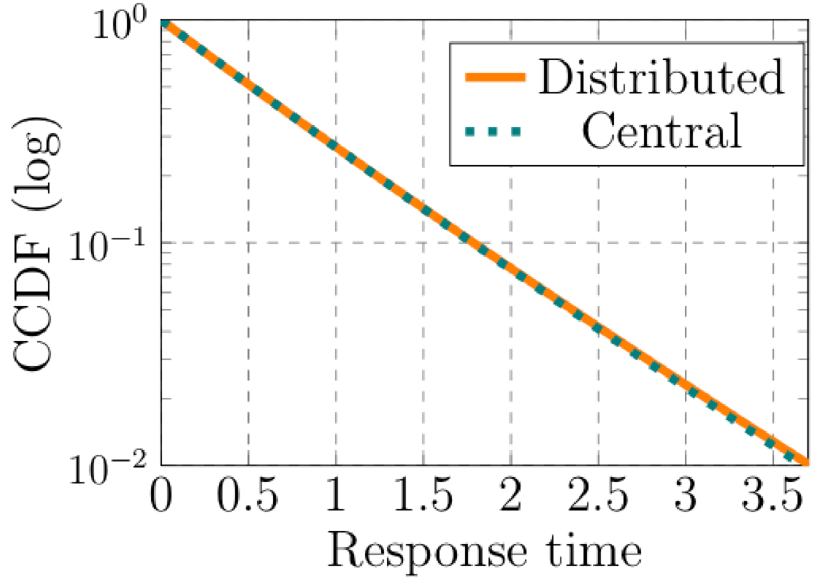
➔ Always spreads tasks across different servers.

2. Response times: centralized set-up achieves lower ones

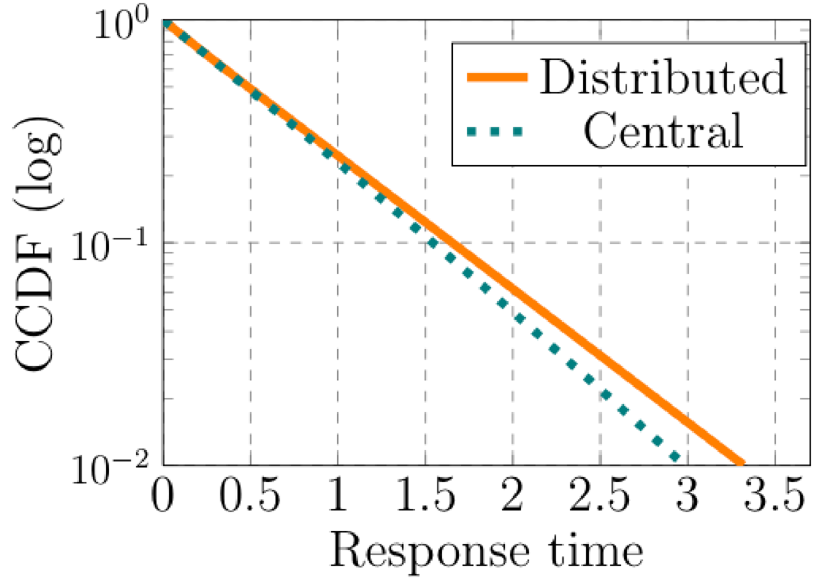
➔ How much?

Distributed vs Centralized

- Example:Poisson arrival, r = 2, 0.3 load



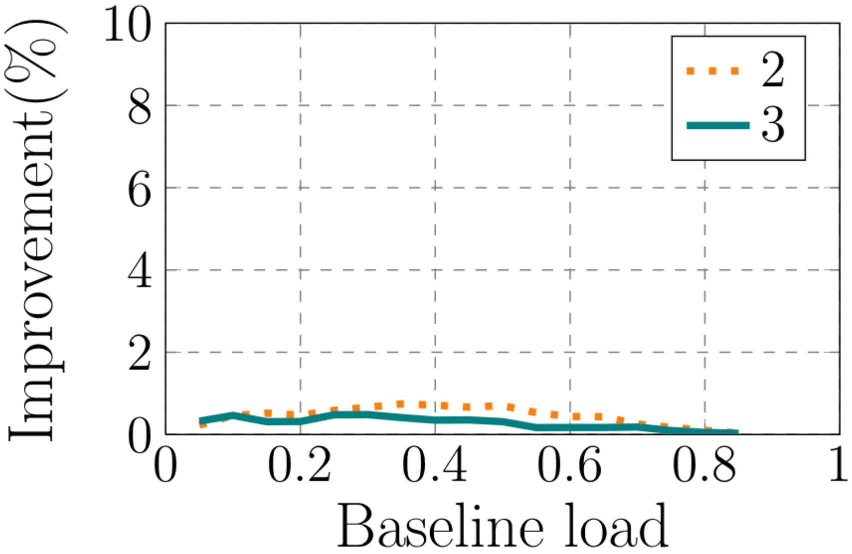
90% reliability



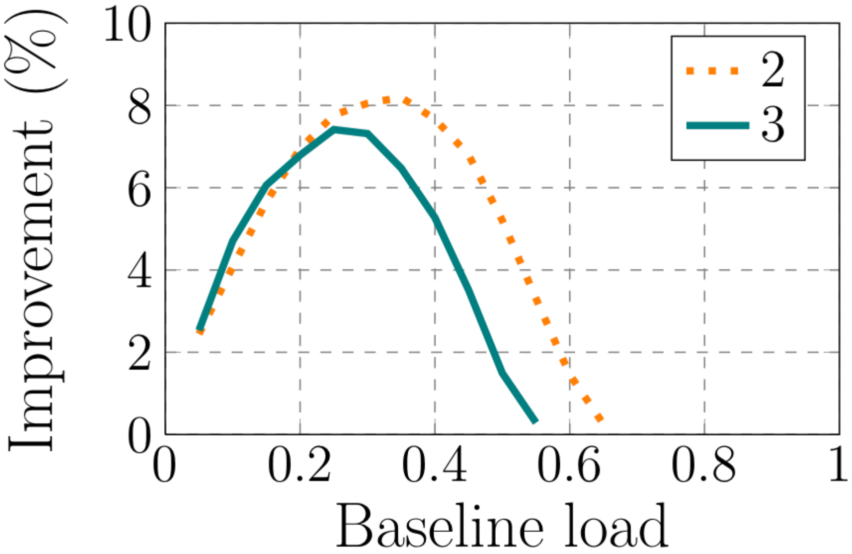
50% reliability

Distributed vs Centralized

- Example:Poisson arrival, r = 2/3



90% reliability



50% reliability

Wrap-up

1. ***Strategy***: concurrent replication with canceling

2. ***Model***: determine the response-time distribution

★Insights into conditions affecting latency reduction

★Allows to compare different set-ups

3. Other Models

★Fork-join queue (Performance 2015)

★Choice of $n \geq r$ servers (INFOCOM 2016)

★K out of N tasks to finish (Erasure Coding)

THANK YOU