Advanced Algorithms/Techniques for Complex and Hybrid cloud systems

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What is this lecture about?

- Discuss key issues when we need multiple resources for computing, data storage and messaging in edge, fog, and cloud computing
- Focus on high availability, high performance and high throughput aspects
- Examine distributed coordination, running example with Zookeeper
- Select and discuss a topic with real systems and concepts behind these systems

Motivating example: a software system for IoT scenarios

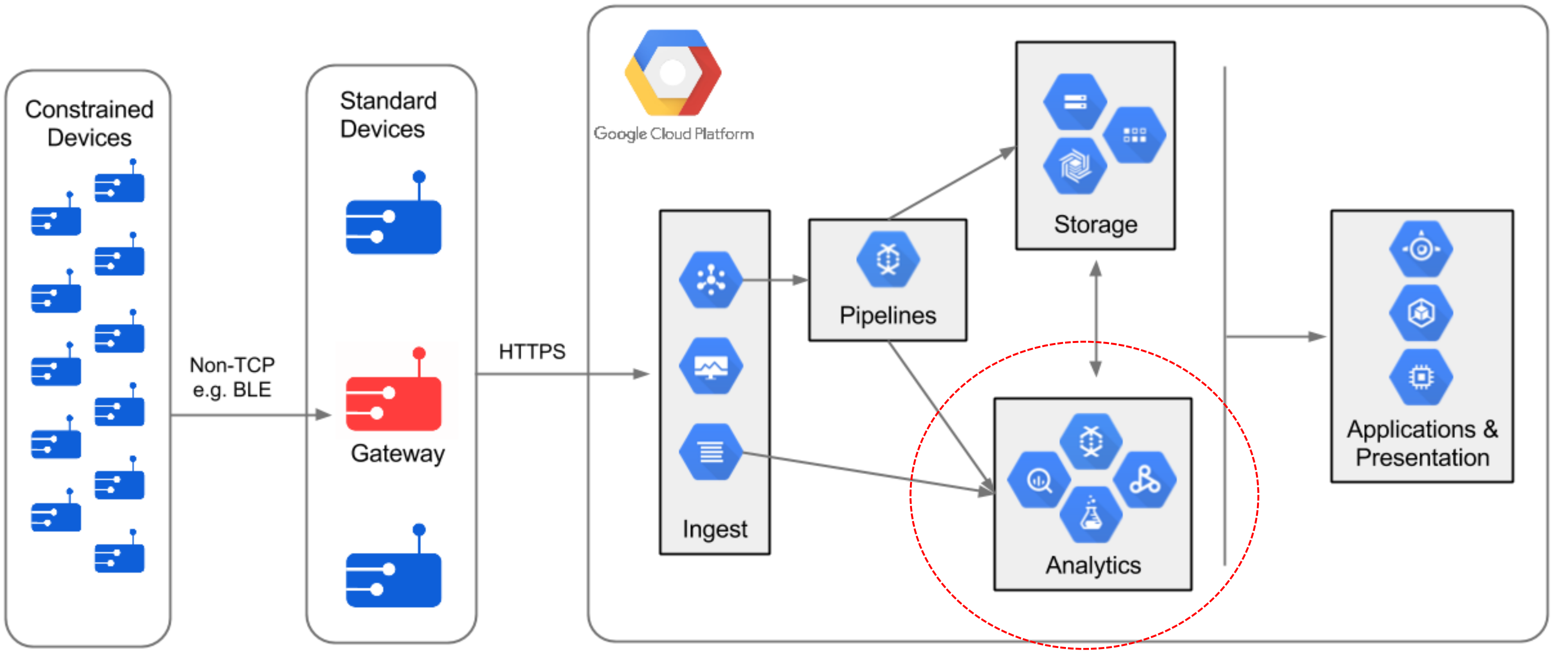
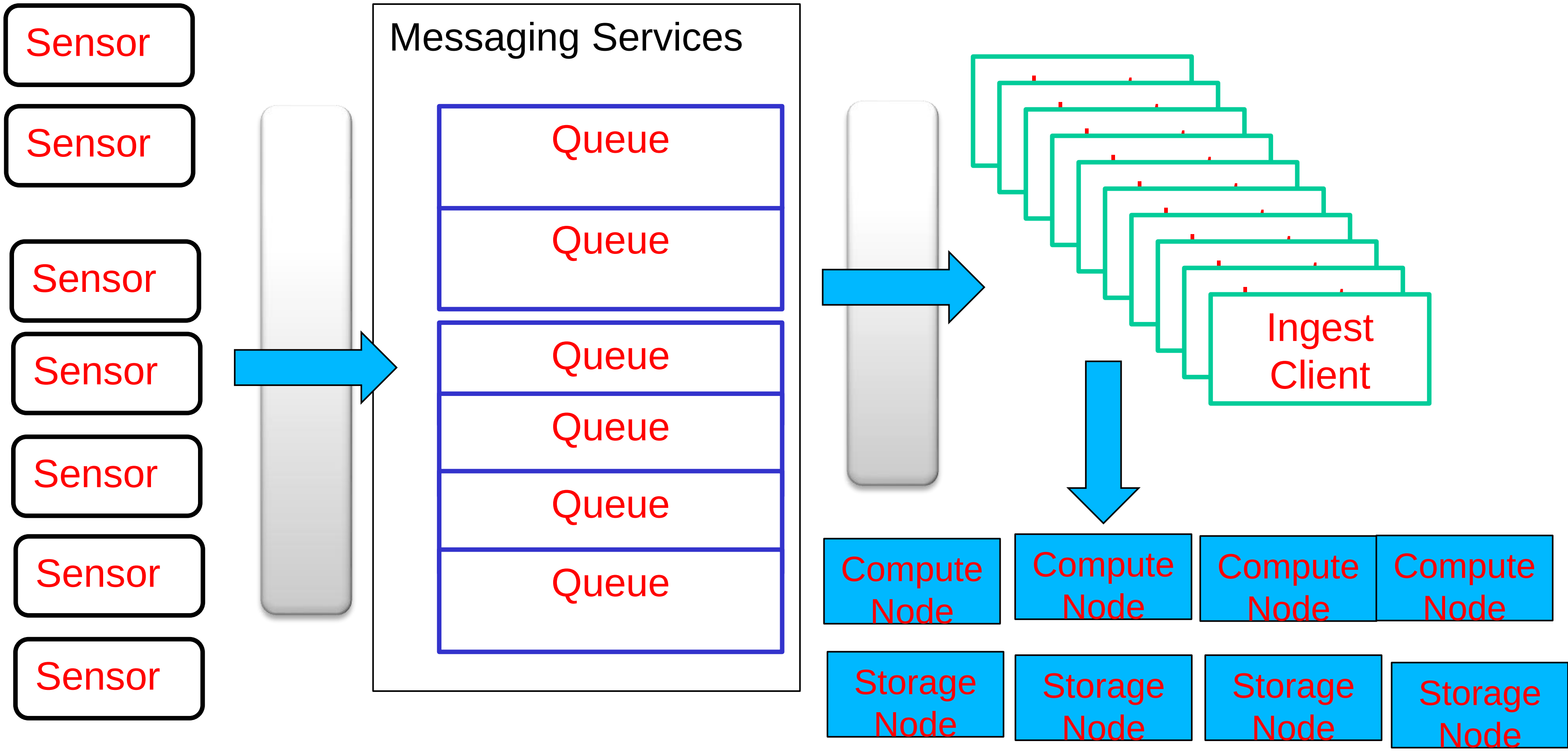


Figure source: https://cloud.google.com/solutions/architecture/streamprocessing

Real example: 5M sensor/monitoring points with ~1.4B events/day~ 72GB/day

Data, Services and Systems Management



High availability, high throughput, high performance

Motivating example: a software system for IoT scenarios

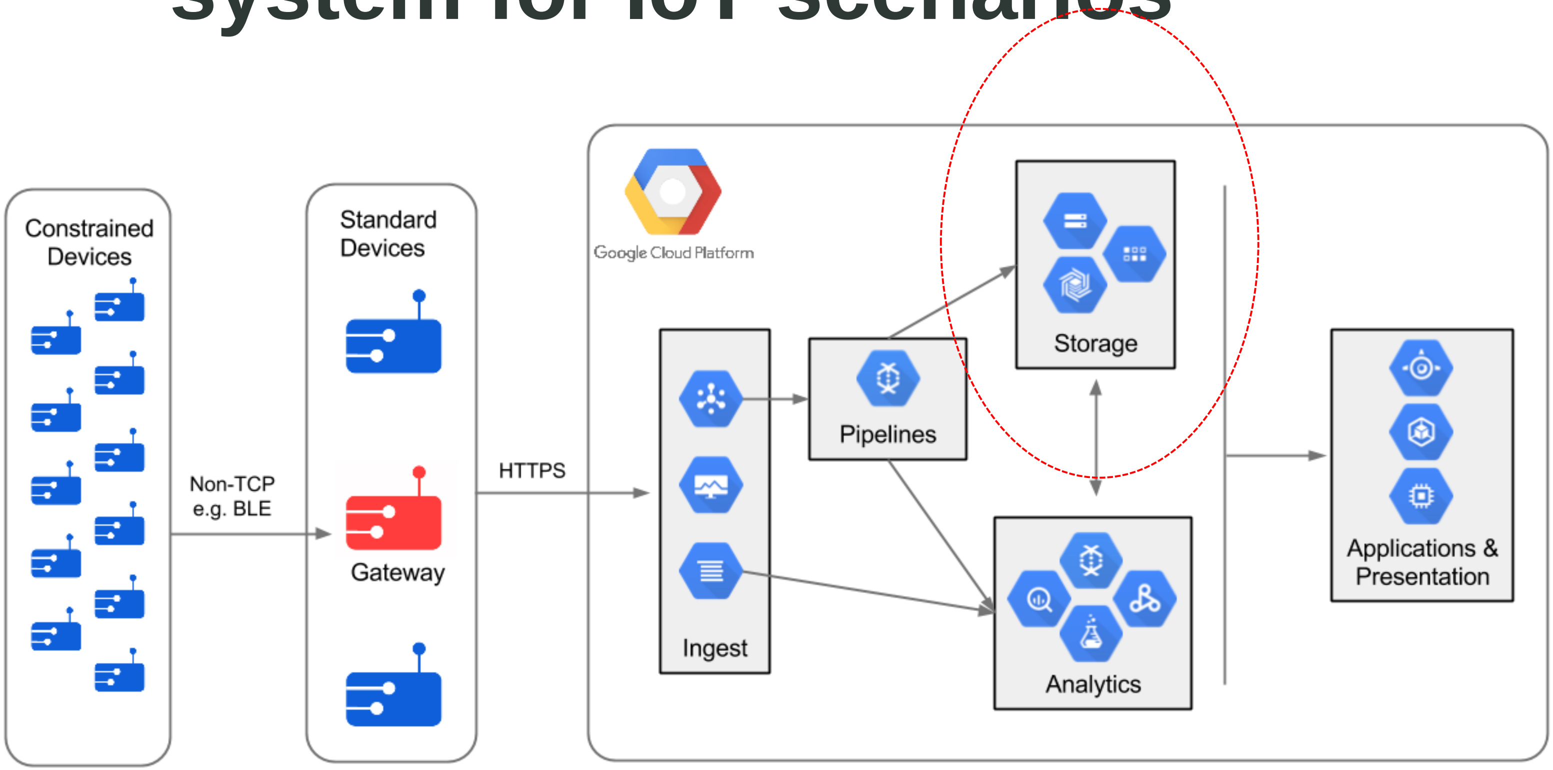
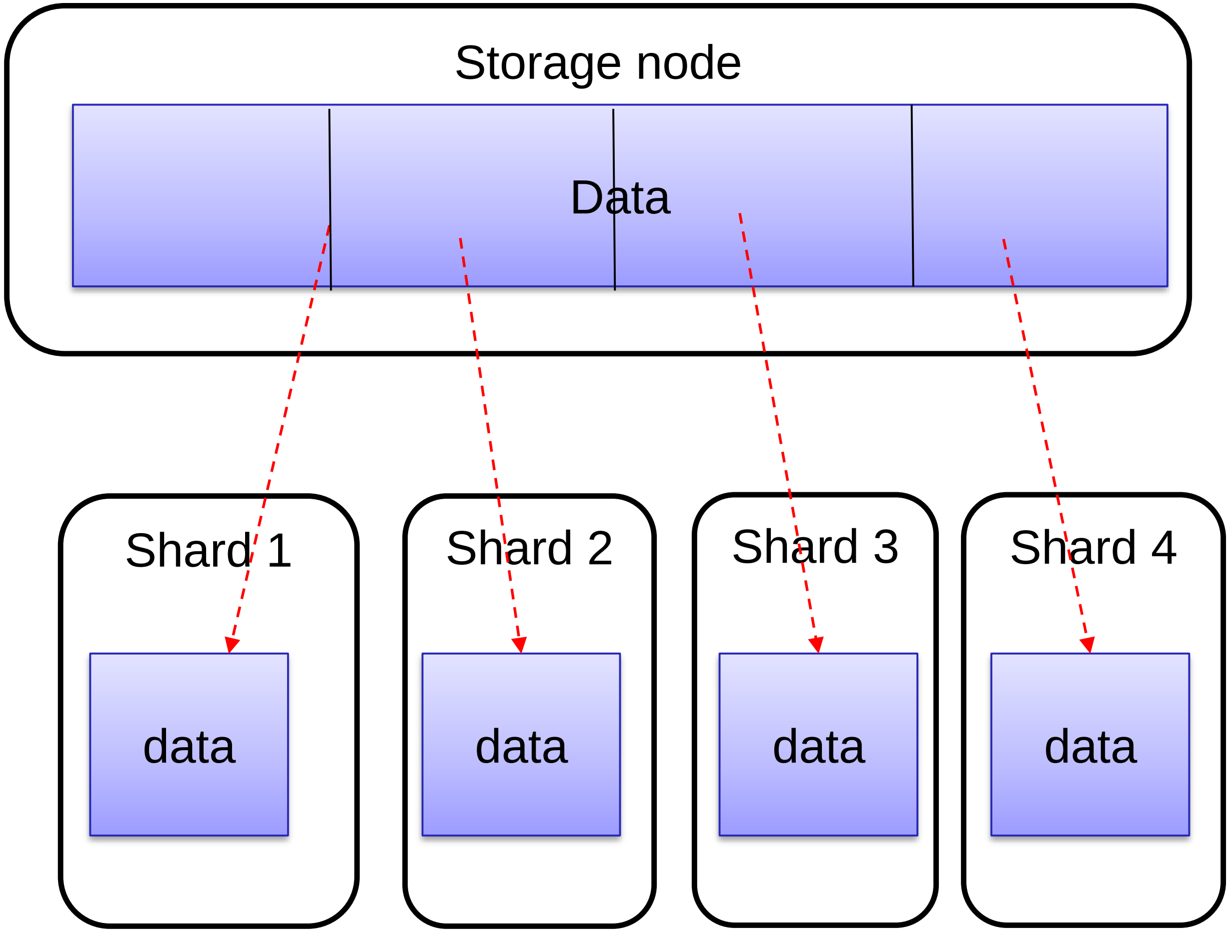


Figure source: https://cloud.google.com/solutions/architecture/streamprocessing

Data resource management

Store a big data collection in a single place?

High availability?



Geographic data distribution

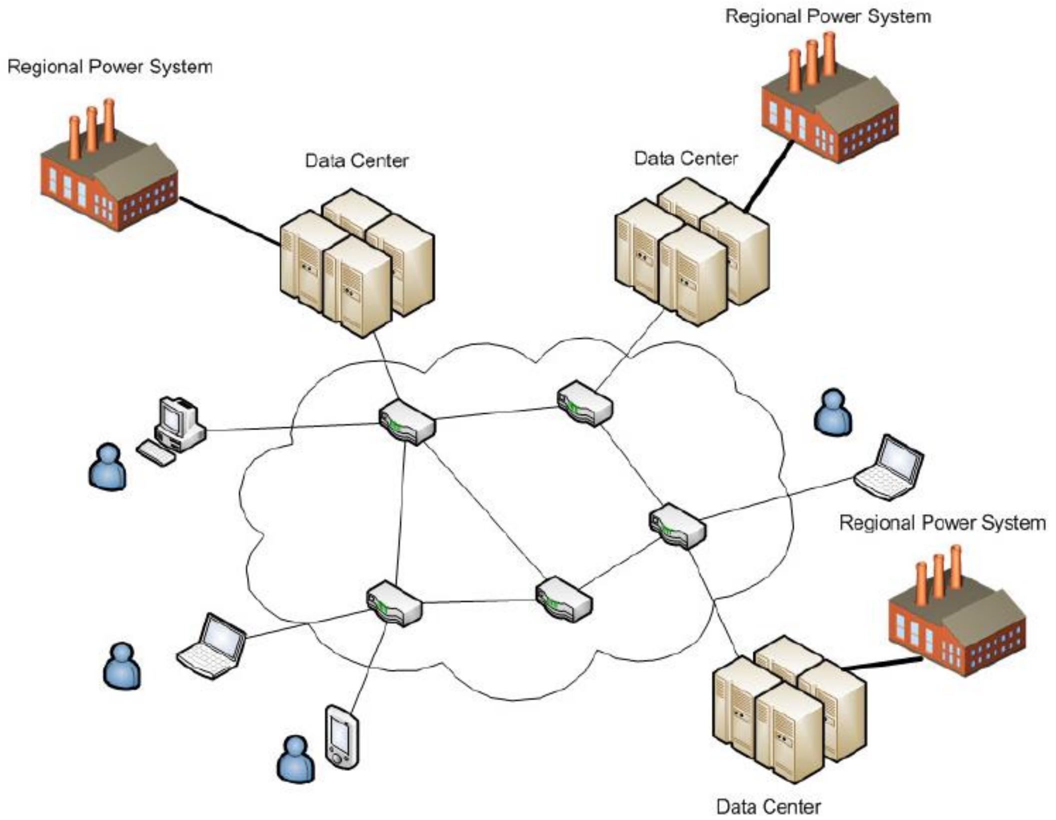


Figure 1. Model of service placement in geographically distributed data

Source: Qi Zhang, Quanyan Zhu, Mohamed Faten Zhani, and Raouf Boutaba. 2012. Dynamic Service Placement in Geographically Distributed Clouds. In Proceedings of the 2012 IEEE 32nd International Conference on Distributed Computing Systems (ICDCS '12). IEEE Computer Society, Washington, DC, USA, 526-535.

Motivating example: a software system for IoT scenarios

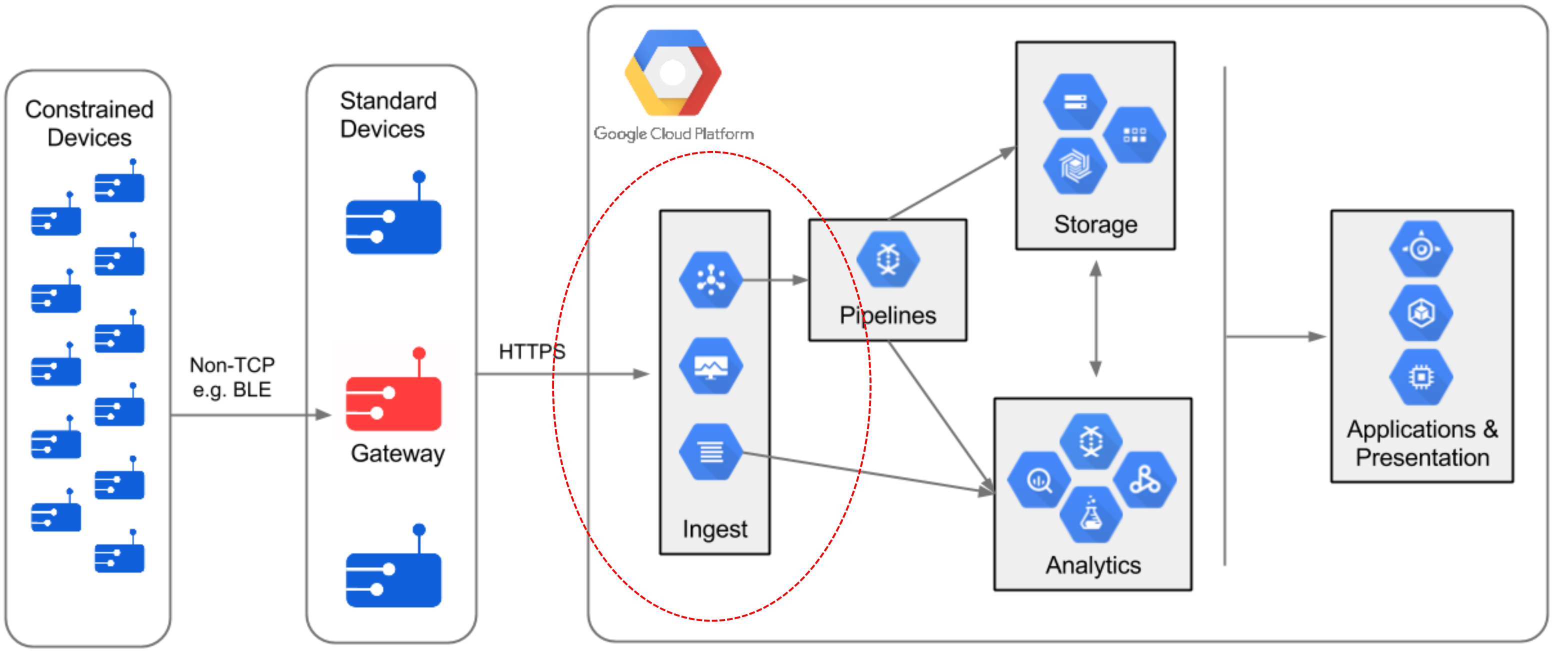
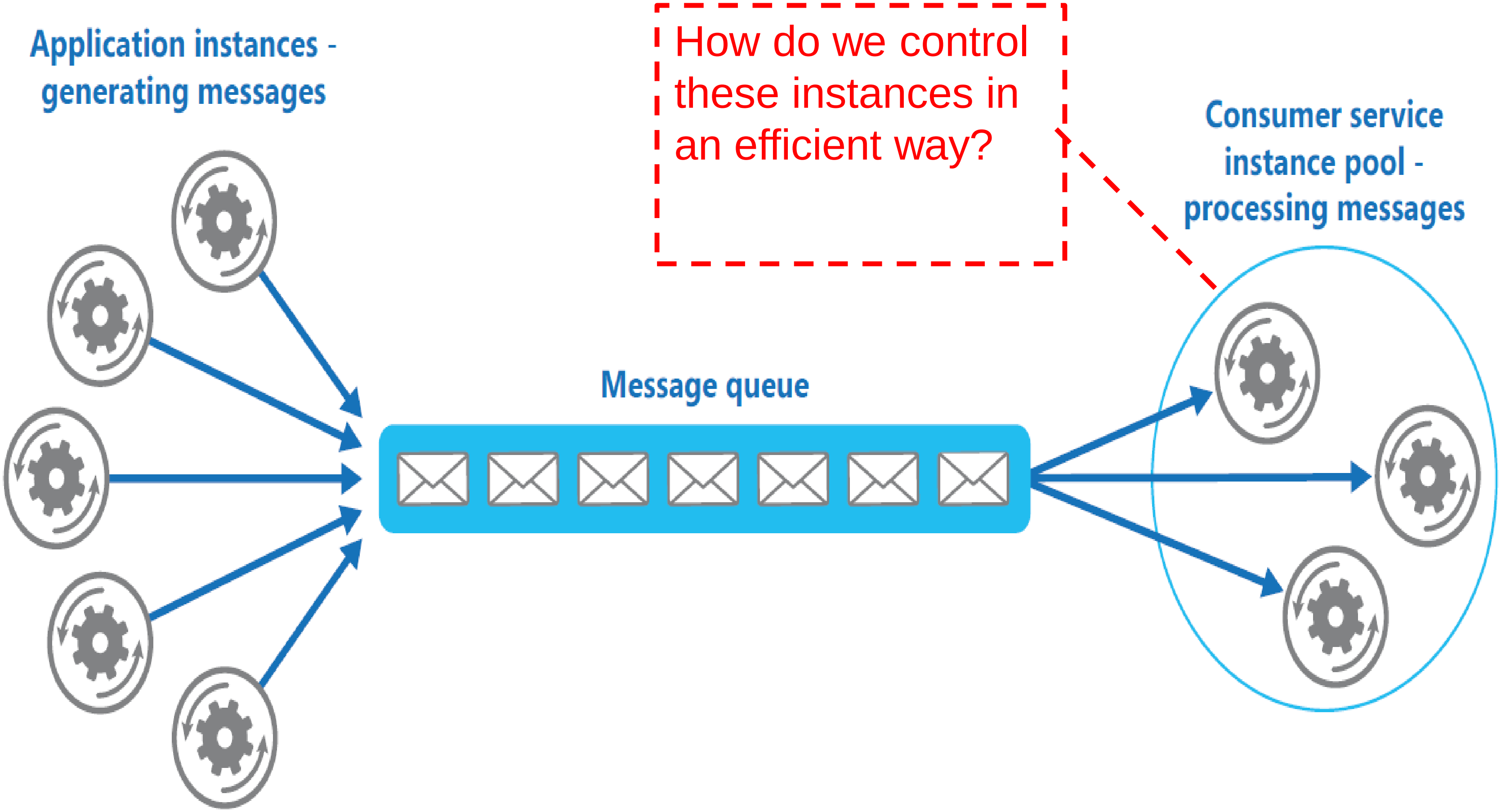


Figure source: https://cloud.google.com/solutions/architecture/streamprocessing

Queuing service management



Source: https://msdn.microsoft.com/en-us/library/dn568101.aspx

Key problems

- How to deal with failures in complex edge, fog and cloud systems?
  - Master/producer, worker/consumer, communication, etc
- How to establish and maintain high availability and high performance?
  - Reduce latency and increase concurrent access/processing

→ Algorithms and techniques for on-demand data centers, redundancy, replication and recovery

Techniques

- Resource provisioning and management
  - Also related to elasticity (lecture 3)
- Routing based on load and metadata
- Recovery from failures
  - Distributed process coordination for cloud systems
- Data sharding & replication
  - Within individual data centers
  - Among geo-distributed data centers

COMPUTING RESOURCES AND MANAGEMENT

Virtual data centers

- On-demand virtual data centers
  - Compute nodes, storage, communication, etc.
  - We focus on establishing virtual data centers working like a single distributed system (e.g., a cluster)

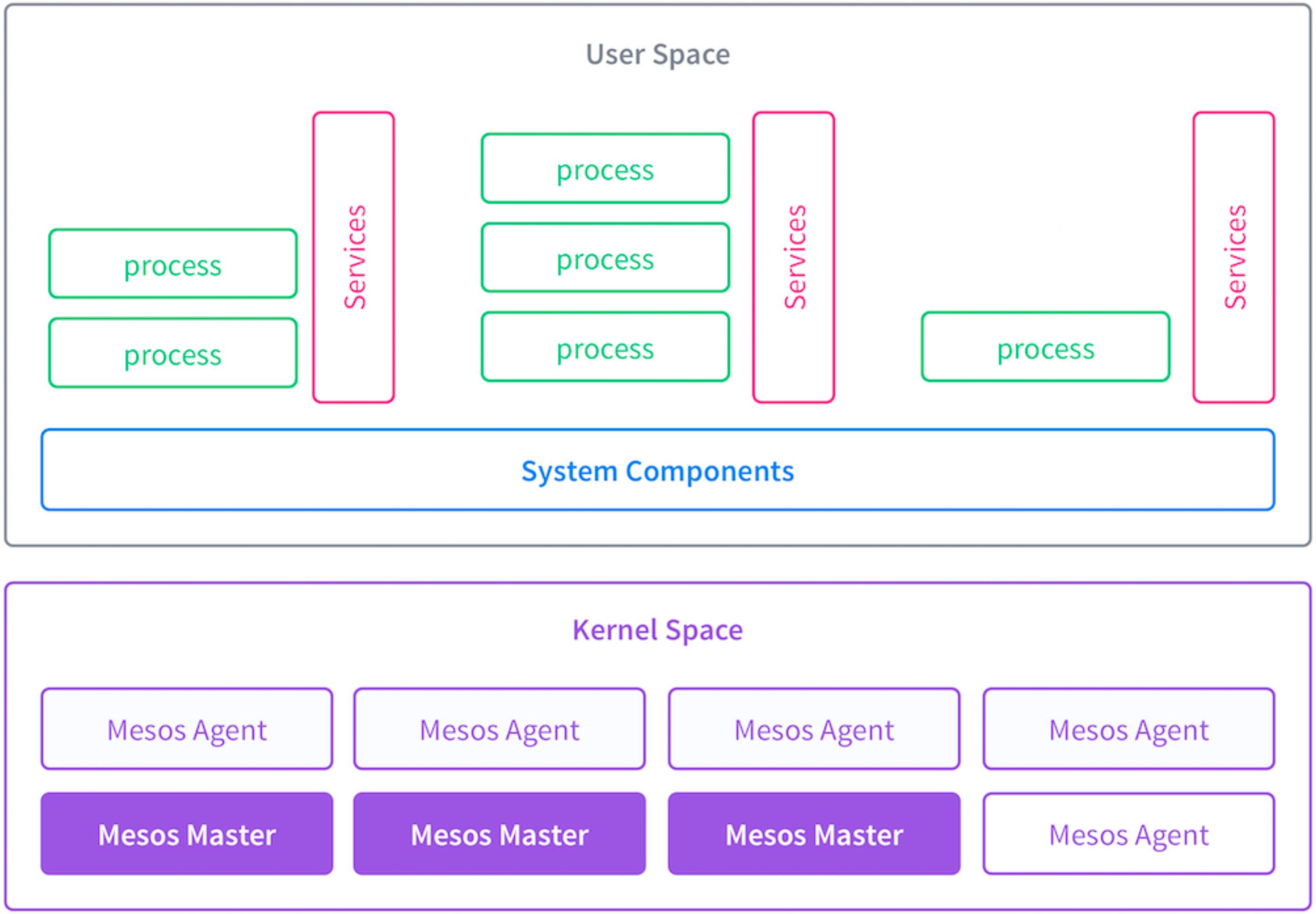
Virtual data centers

- Challenges
  - Provision resources/nodes (using VMs or containers)
  - Configure networks within virtual data centers
  - Configure networks between virtual data centers and the outside systems
  - Deploy software into the virtual data centers
  - Maintain the virtual data centers

Generic on-demand data center

- Set of VMs/containers + storage/filesystems that can be used for different purposes
  - Think about a cluster of VMs or containers, instead of a traditional cluster of physical machines
- Steps
  - Create VMs/containers and orchestration management system (e.g. using Mesos/ Kubernetes)
  - Configure VMs/containers to create a virtual network
    - Create/configure virtual networks
    - VMs/containers discovery
    - Examples: Weave (https://www.weave.works/install-weave-net/)

Example -- DC/OS



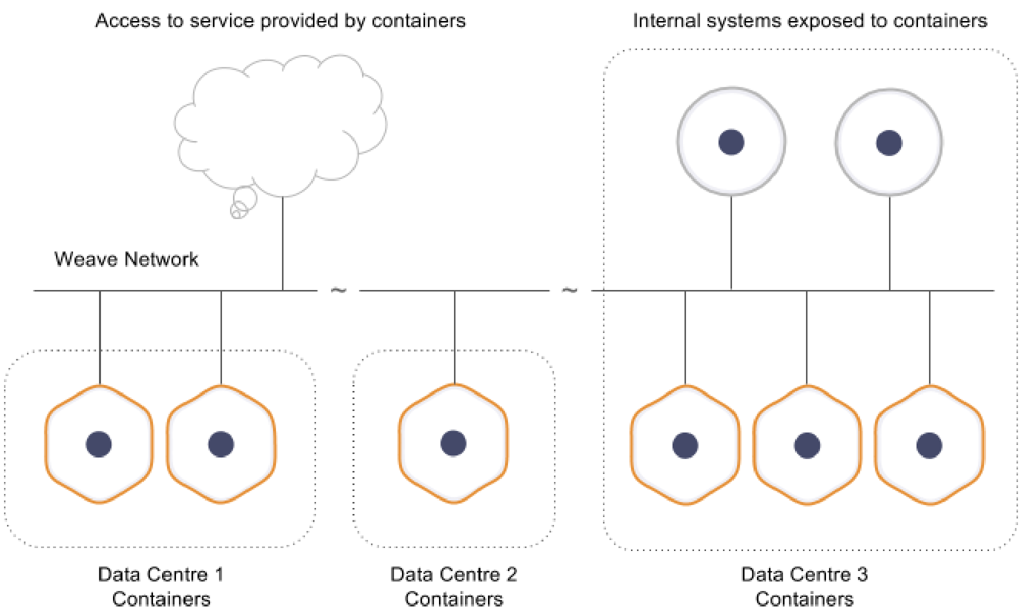
Source: https://docs.mesosphere.com/1.8/overview/architecture/

Azure Cloud and Containers

https://docs.microsoft.com/en-us/dotnet/standard/microservices-architecture/architect-microservice-container-applications/scalable-available-multi-container-microservice-applications

Example - Weave Net and docker

- Work with Kubernetes & Mesos as well
- Key idea: using network plug-in for containers + P2P overlay of routers in the host



Source: https://www.weave.works/docs/net/latest/introducing-weave/

Application-specific virtual data centers

- Specific virtual data centers for specific purposes
  - E.g., Data-center of nodes for Hadoop or Spark
- First, create generic data centers but customized for specific software stack
- Second, deploy specific software frameworks

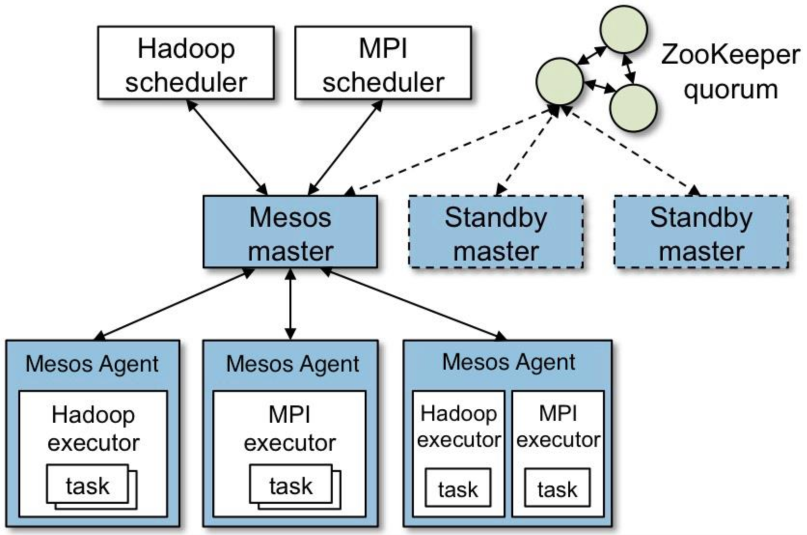


Figure source: http://mesos.apache.org/documentation/latest/architecture/

Edge/Fog and Cloud continuum

- Several issues in real world:
  - Single software stack (e.g., OpenStack) versus multiple software stacks
  - Containers versus VMs
  - Coordination across edge, fog and cloud infrastructures

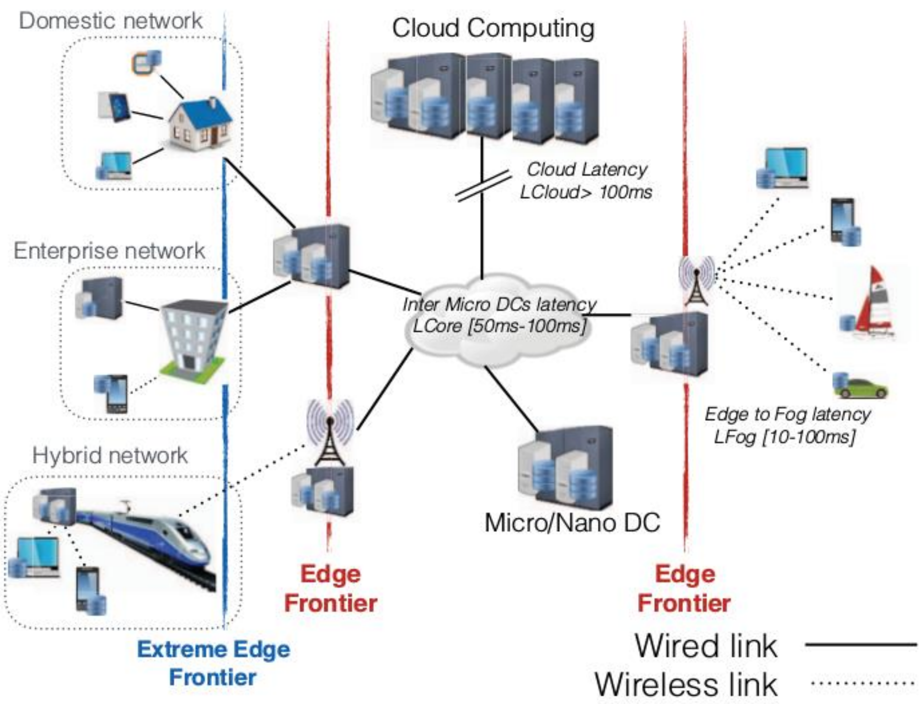


Fig. 1. Fog/Edge Computing Architecture Model

Figure source: A. Lebre, J. Pastor, A. Simonet and F. Desprez, "Revising OpenStack to Operate Fog/Edge Computing Infrastructures," 2017 IEEE International Conference on Cloud Engineering (IC2E), Vancouver, BC, 2017, pp. 138-148. doi: 10.1109/IC2E.2017.35

Key focuses on high availability and high performance

- Layers:
  - VM/container layer
  - Network layer
  - Resource management layer
- Important techniques
  - Redundancy
  - Monitoring
  - Elasticity
  - Distributed coordination for resources

DATA MANAGEMENT

Data sharding

- Limited storage space, computing capabilities and network
- High latency due to geographical communication
- Sharding
  - Distributed large-amount of data (of the same app-structure) onto distributed nodes
- Replication can be also applied

Sharding strategies

- Different strategies
  - Lookup: query to find a shard
  - Range: a range of keys is used to determine a shard
  - Hash: determined shard based on the hash of a key

Sharding patterns/strategies: https://msdn.microsoft.com/en-us/library/dn589797.aspx

Example

FIGURE 5

Two Ways to Distribute 10 Years of Sensor Data for 1,000 Sites over 10 Machines

Node 1

timestamp	sensor	reading
19990101000000	1	
19990101000015	1	
19990101000030	1	
20081231235930	1	
20081231235945	1	
19990101000000	2	
19990101000015	2	
19990101000030	2	
20081231235930	2	
20081231235945	2	
19990101000000	3	
20081231235945	100	

Node 2

timestamp	sensor	reading
19990101000000	101	
19990101000015	101	
19990101000030	101	
20081231235930	101	
20081231235945	101	
19990101000000	102	
19990101000015	102	
19990101000030	102	
20081231235930	102	
20081231235945	102	
19990101000000	103	
20081231235945	200	

Node 10

timestamp	sensor	reading
19990101000000	901	
19990101000015	901	
19990101000030	901	
20081231235930	901	
20081231235945	901	
19990101000000	902	
19990101000015	902	
19990101000030	902	
20081231235930	902	
20081231235945	902	
19990101000000	103	
20081231235945	1000	

Node 1

timestamp	sensor	reading
19990101000000	1	
19990101000000	2	
19990101000000	3	
19990101000000	1000	
19990101000015	1	
19990101000015	2	
19990101000015	3	
19990101000015	4	
19990101000015	1000	
19990101000030	1	
19990101000030	2	
19991231235945	1000	

Node 2

timestamp	sensor	reading
20000101000000	1	
20000101000000	2	
20000101000000	3	
20000101000000	1000	
20000101000015	1	
20000101000015	2	
20000101000015	3	
20000101000015	4	
20000101000015	1000	
20000101000030	1	
20000101000030	2	
20001231235945	1000	

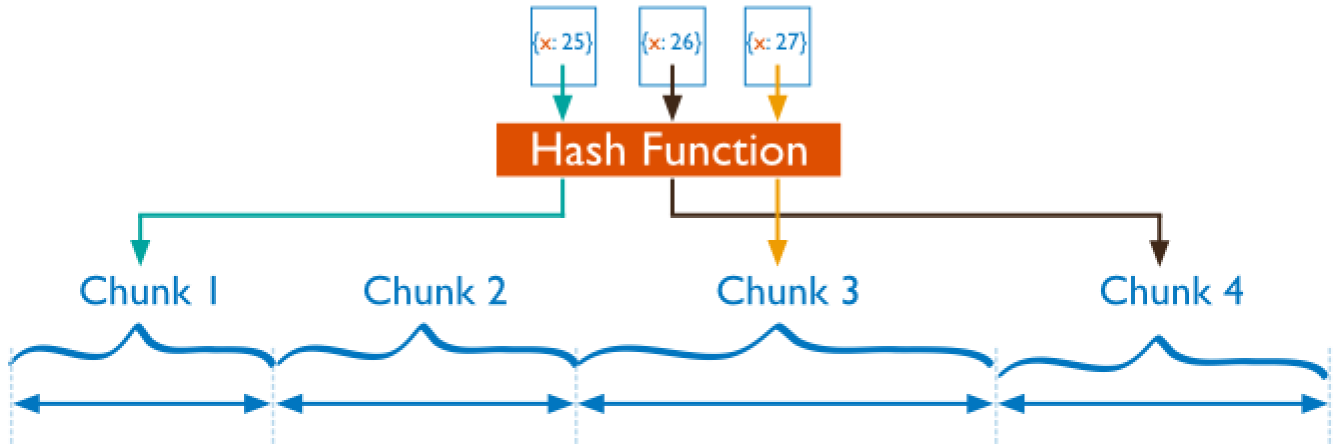
Node 10

timestamp	sensor	reading
20080101000000	1	
20080101000000	2	
20080101000000	3	
20080101000000	1000	
20080101000015	1	
20080101000015	2	
20080101000015	3	
20080101000015	4	
20080101000015	1000	
20080101000030	1	
20080101000030	2	
20081231235945	1000	

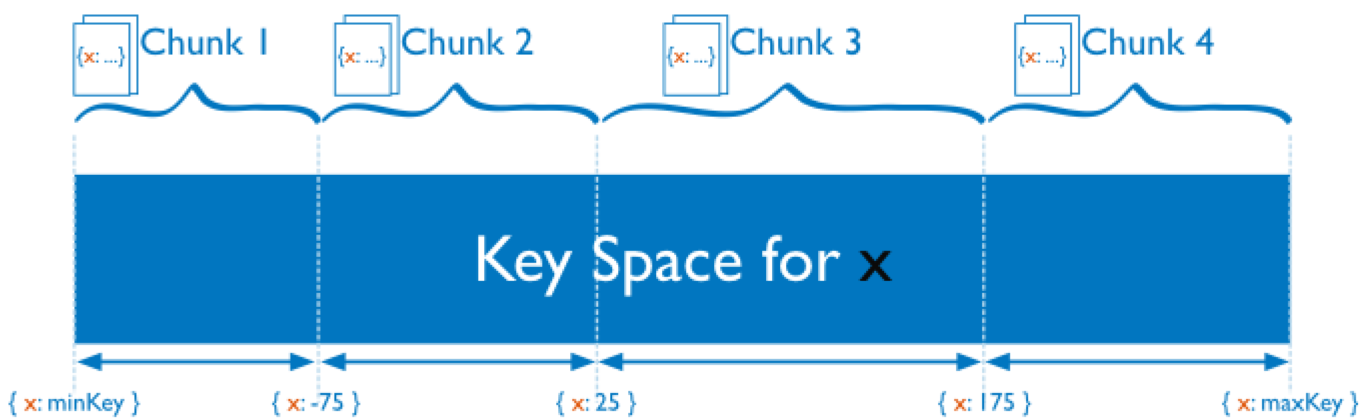
Source: http://queue.acm.org/detail.cfm?id=1563874

Example strategies in MongoDB

Hash

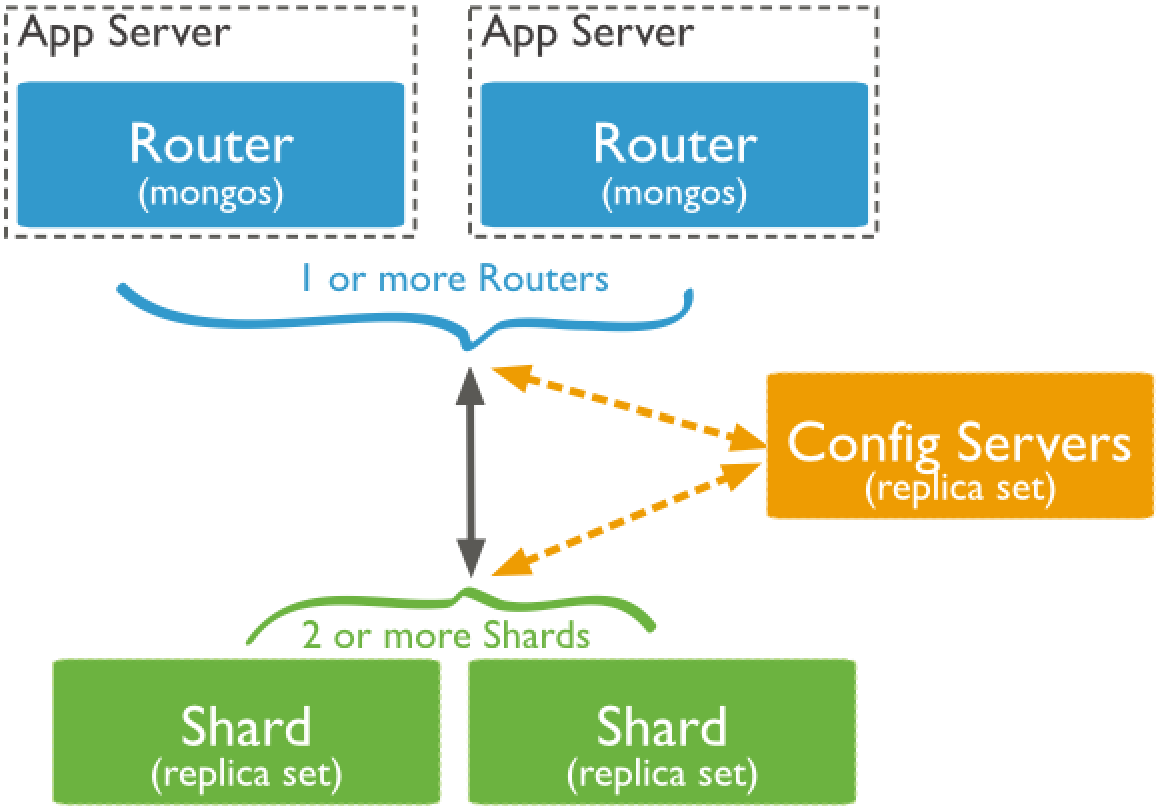


Range



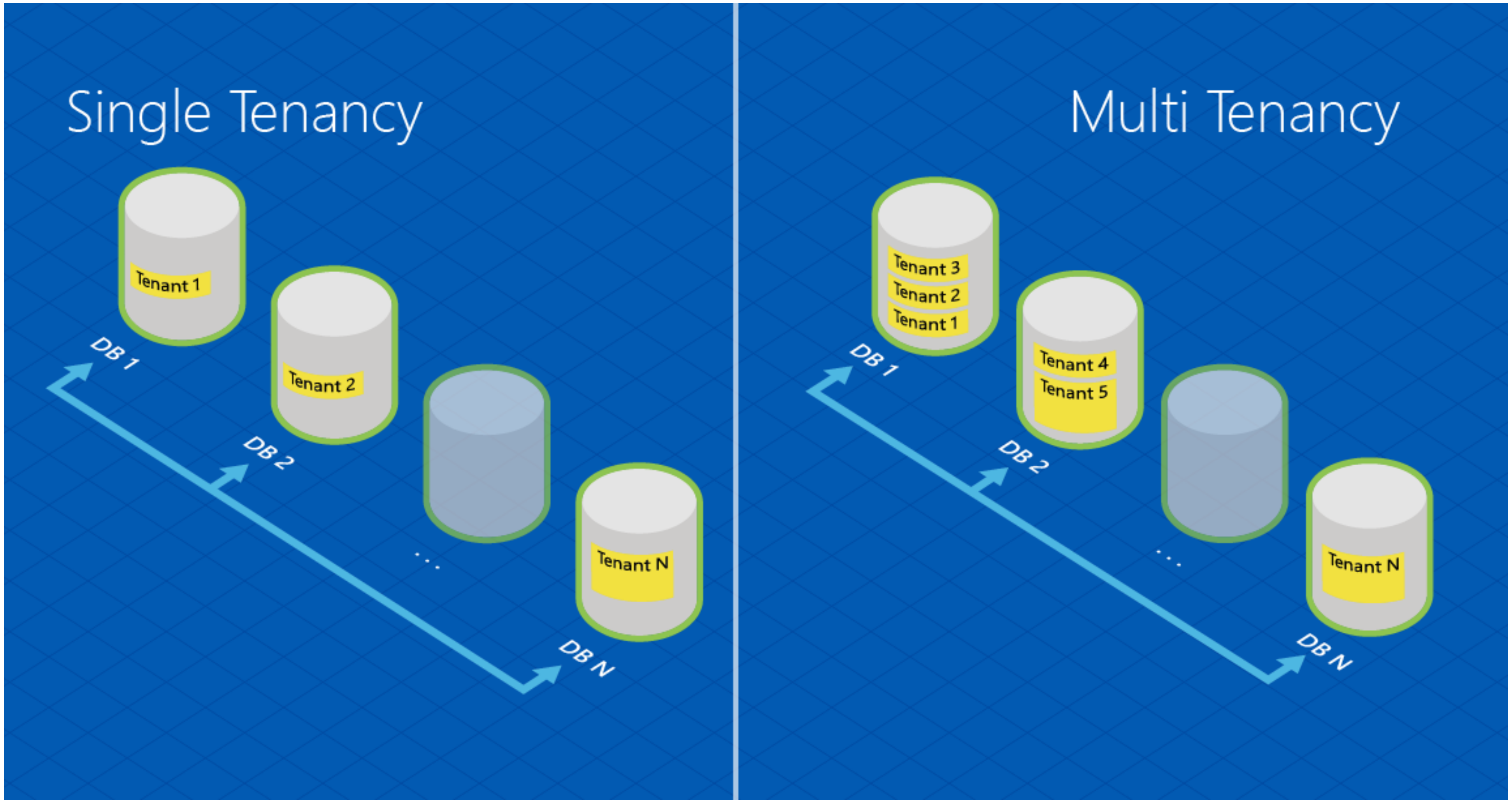
Source: https://docs.mongodb.com/v3.2/sharding/

Shard and routing



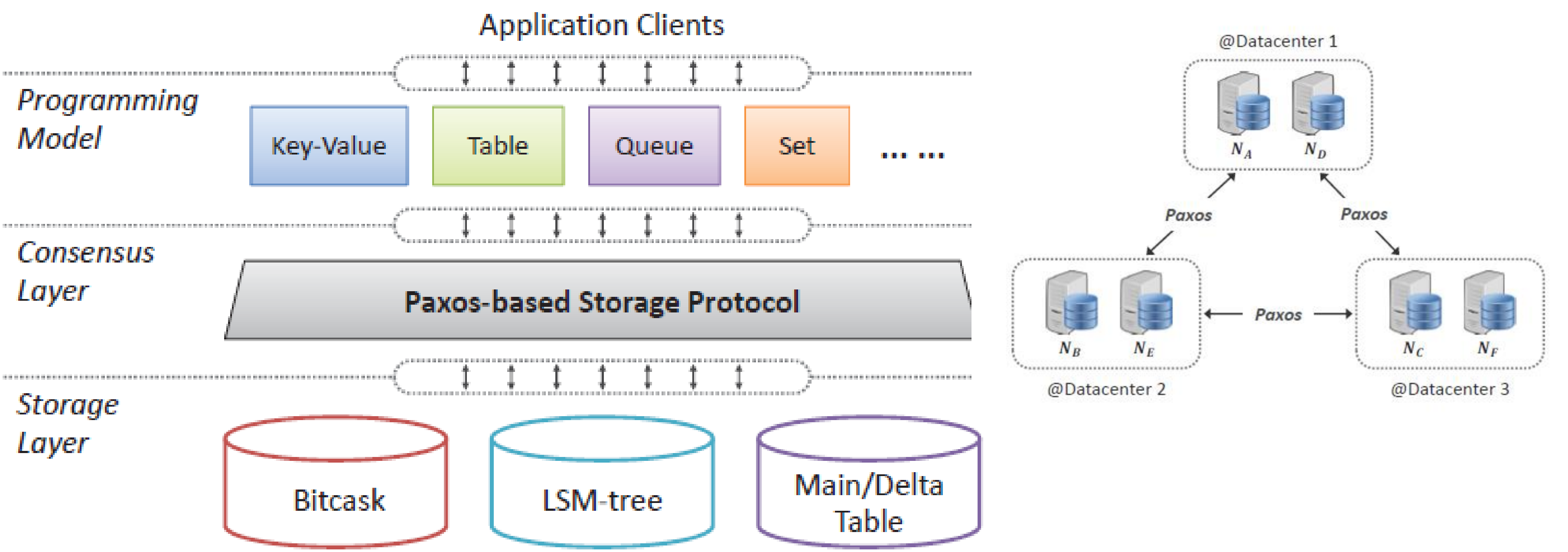
Source: https://docs.mongodb.com/v3.2/sharding/

Single or multi-tenant sharding



Source: https://azure.microsoft.com/en-us/documentation/articles/sql-database-elastic-scale-introduction/

Resources and consensus



Source: Jianjun Zheng, Qian Lin, Jiatao Xu, Cheng Wei, Chuwei Zeng, Pingan Yang, and Yunfan Zhang. 2017. PaxosStore: high-availability storage made practical in WeChat. Proc. VLDB Endow. 10, 12 (August 2017), 1730-1741. DOI: https://doi.org/10.14778/3137765.3137778

High Availability and High Performance for Cloud data

- Resources and resource management
  - High availability of data storage
  - Load balancing
- Data management
  - Data distribution
  - Replication
  - Encoding/Integrity

MESSAGING SERVICES MANAGEMENT

High Availability and High Performance in queuing systems

- Moving messages fast!
- Brokering service: load balancing and high availability
  - Clustering of several broker nodes
  - Resource management
- Client/consumer: load balancing and high availability
  - Using queues, sharing topics, and consumer groups
  - Resource management for consumers
    - This is at the consumer side, not in the queuing system, but techniques are quite similar, as discussed in resources and resource management

Clustering Brokers

Source: Philippe Dobbelaere and Kyumars Sheykh Esmaili. 2017. Kafka versus RabbitMQ: A comparative study of two industry reference publish/subscribe implementations: Industry Paper. In Proceedings of the 11th ACM International Conference on Distributed and Event-based Systems (DEBS '17). ACM, New York, NY, USA, 227-238. DOI: https://doi.org/10.1145/3093742.3093908

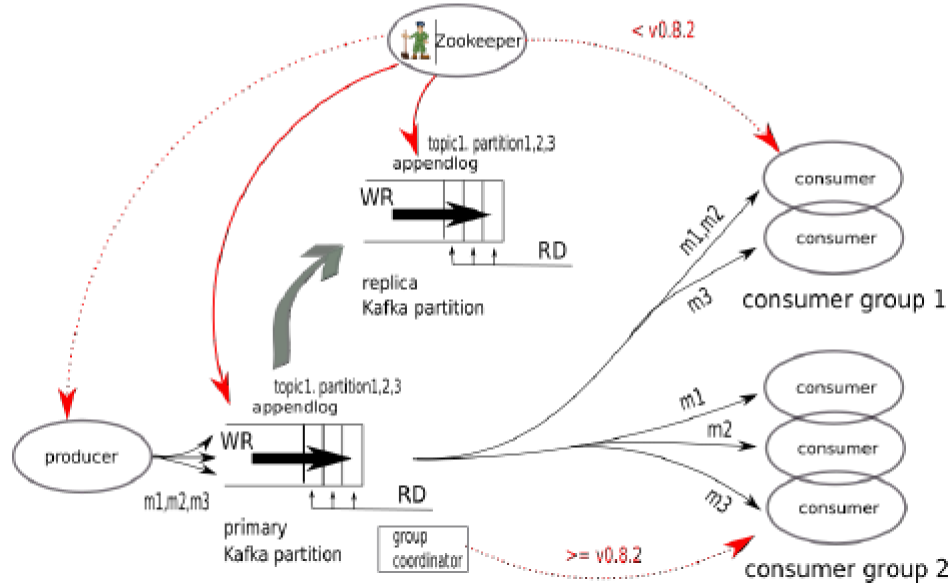


Figure 1: Kafka Architecture

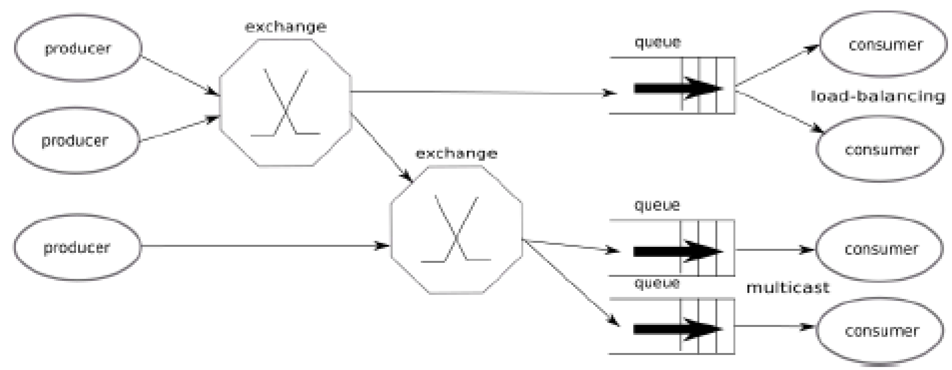
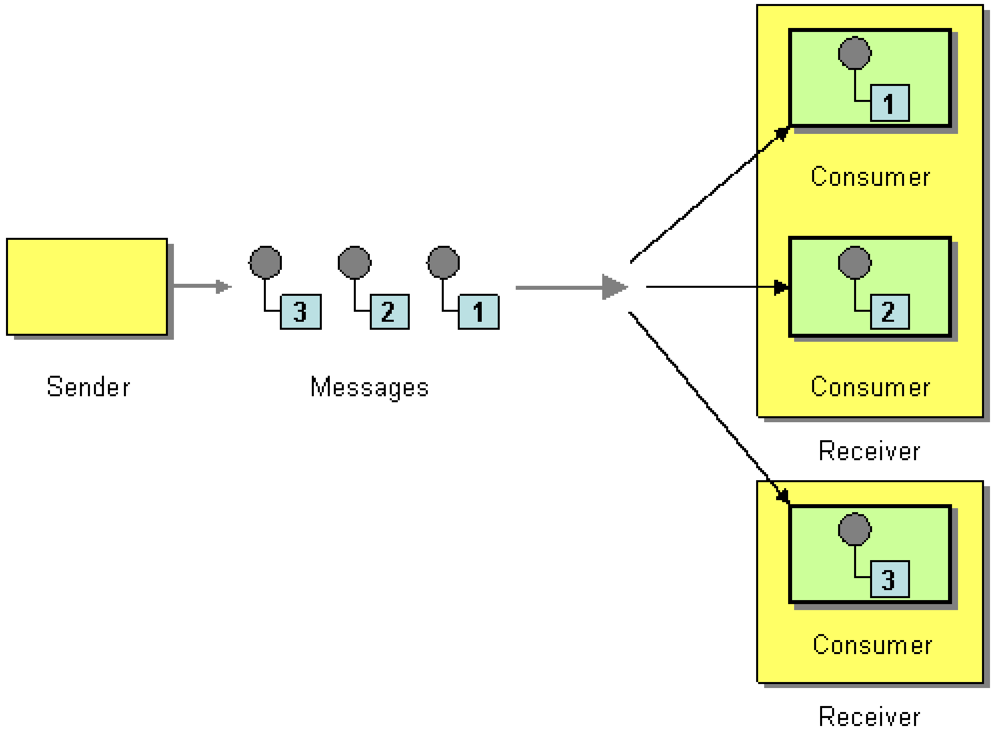


Figure 2: RabbitMQ (AMQP) Architecture

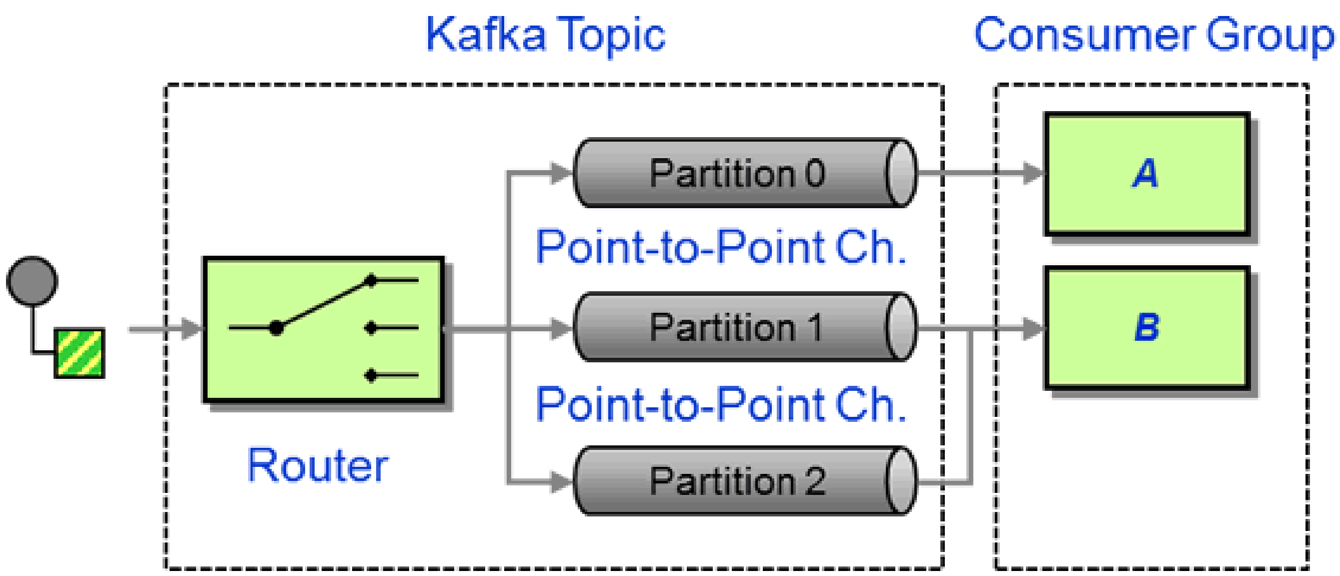
Consumer Load balancing



What do you have to do here?

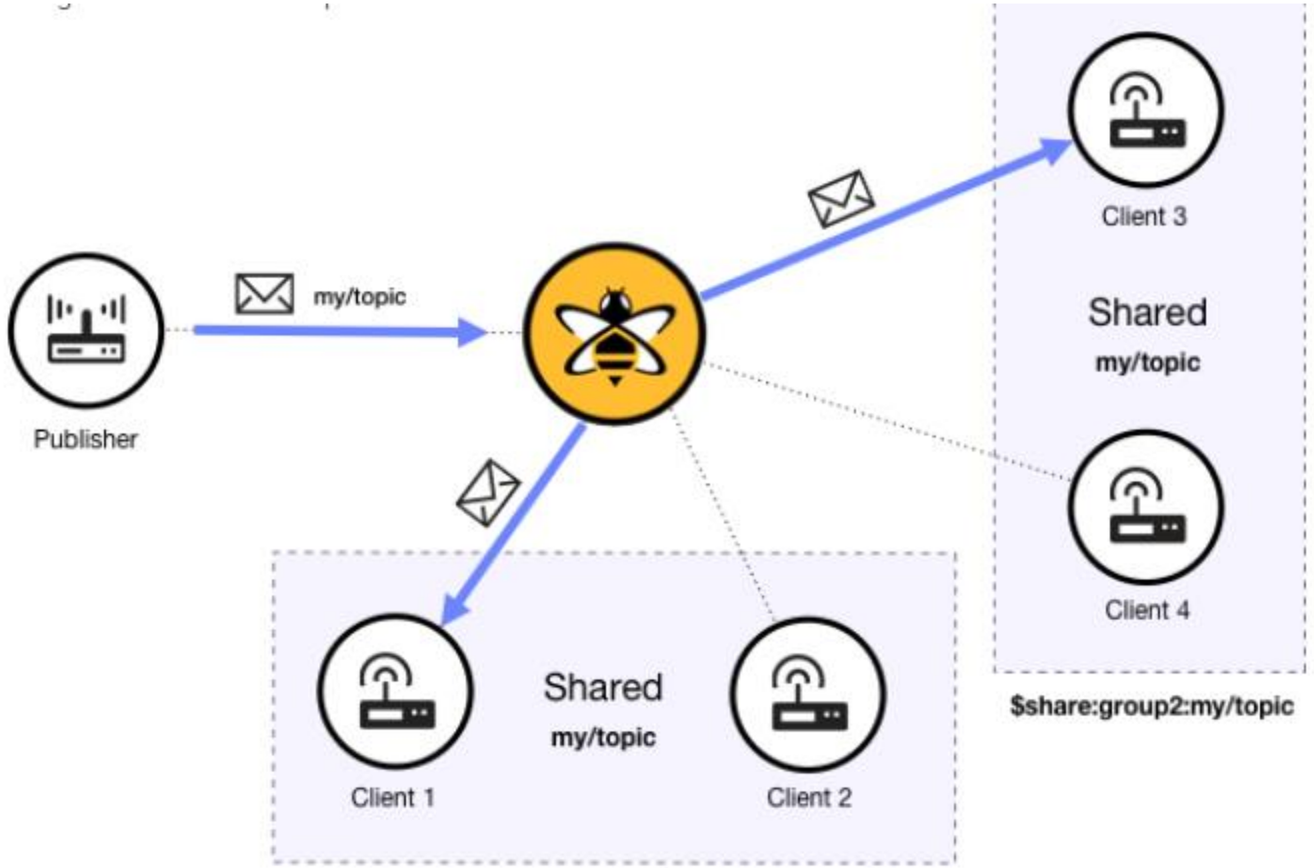
Source: http://www.enterpriseintegrationpatterns.com/patterns/messaging/CompetingConsumers.html/

Client Load in Apache Kafka



Source: http://www.enterpriseintegrationpatterns.com/patterns/messaging/CompetingConsumers.html/

Shared Topics with MQTT by HiveMQ

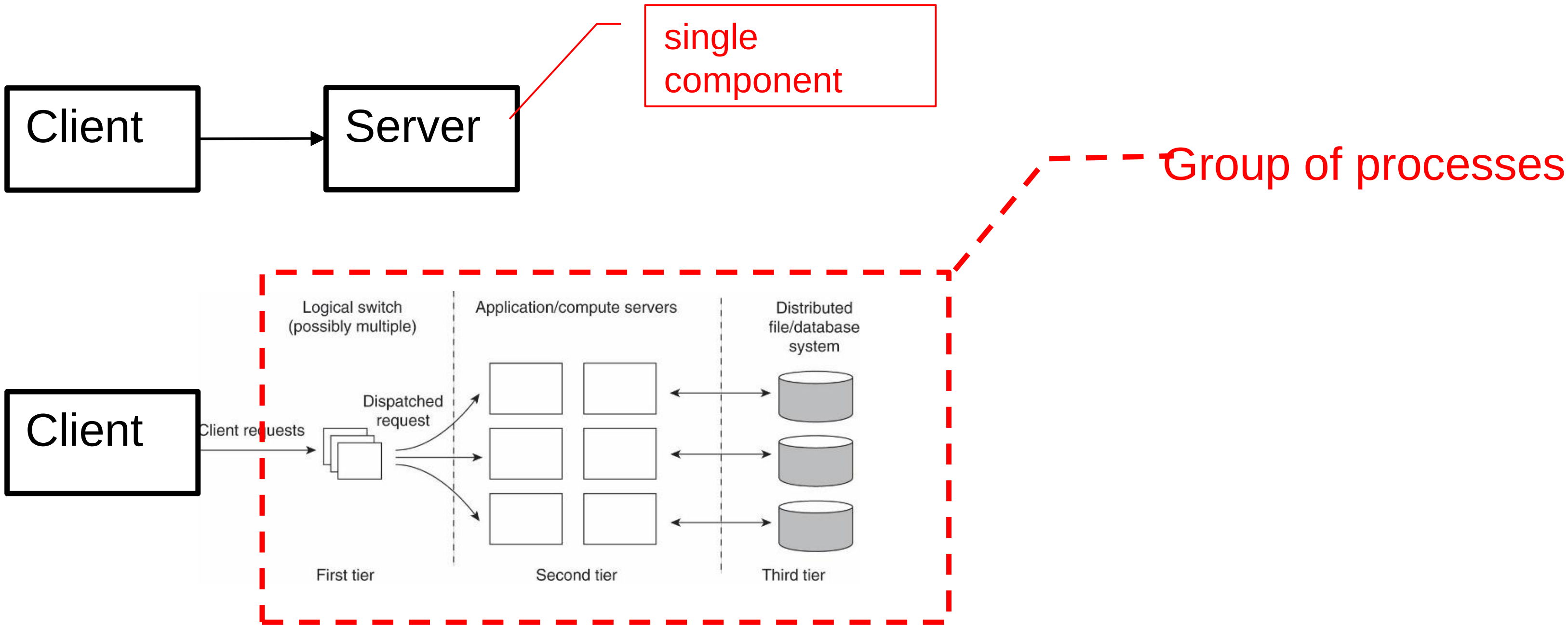


Source: https://www.hivemq.com/blog/mqtt-client-load-balancing-with-shared-subscriptions/

DISTRIBUTED COORDINATION

Group redundancy architecture

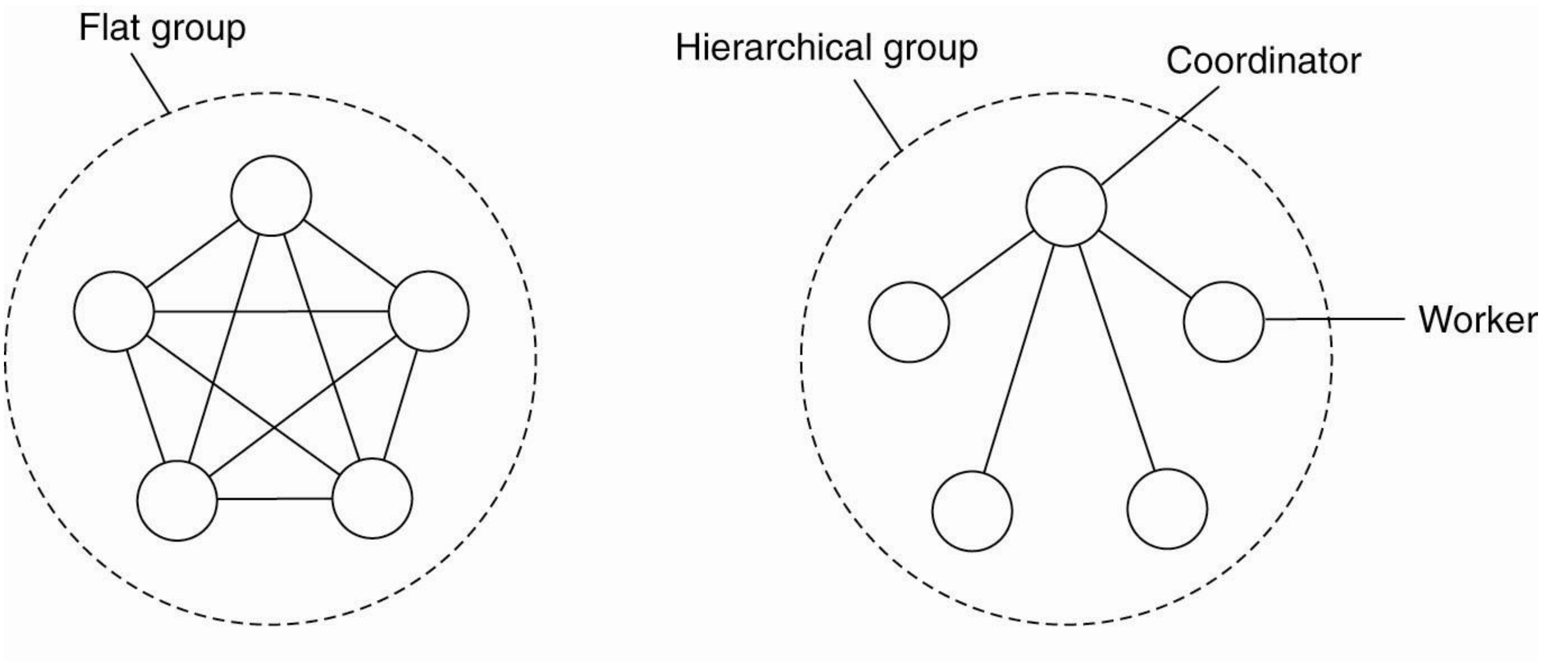
- Use group architecture for redundancy in order to support failure masking



Source: Andrew S. Tanenbaum and Maarten van Steen, Distributed Systems – Principles and Paradigms, 2nd Edition, 2007, Prentice-Hall

Design flat groups versus hierarchical groups

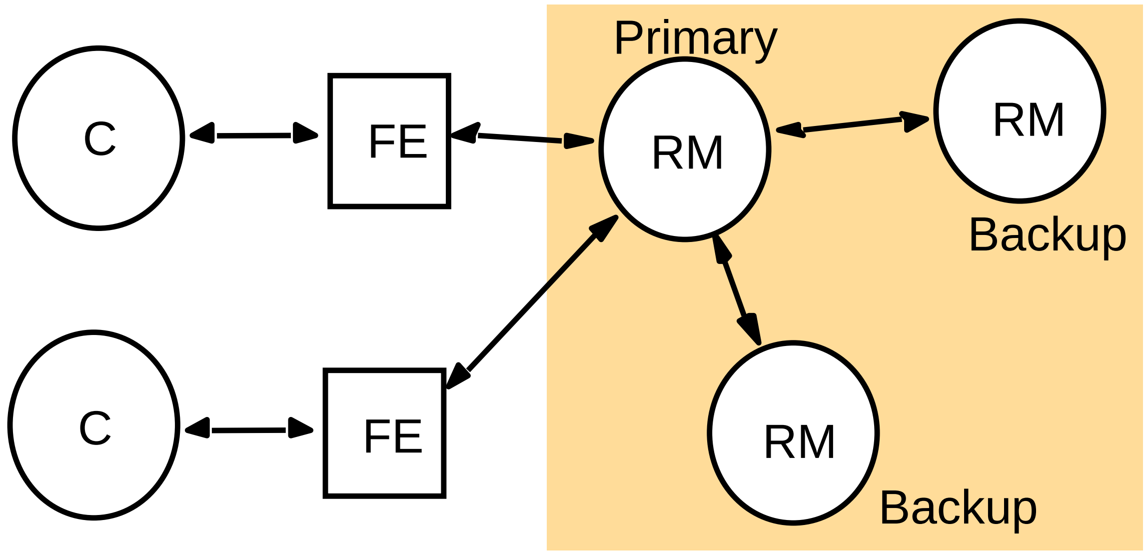
Structure a system (communication, servers, services, etc.) using a group so we can deal failures using collective capabilities



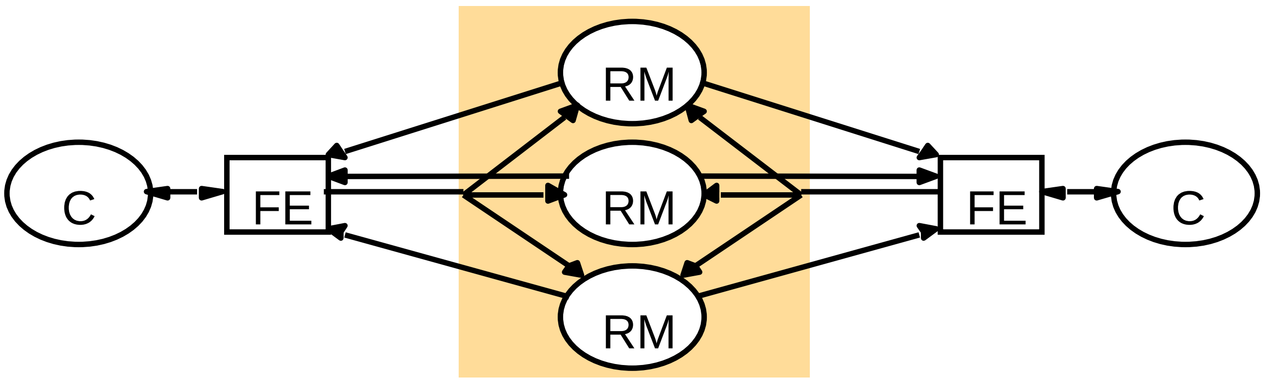
Source: Andrew S. Tanenbaum and Maarten van Steen, Distributed Systems – Principles and Paradigms, 2nd Edition, 2007, Prentice-Hall

Replication architecture

Passive (Primary backup) model



Active Replication



Source: Coulouris, Dollimore, Kindberg and Blair, Distributed Systems: Concepts and Design Edn. 5

Distributed coordination

- A lot of algorithms, etc.
  - Paxos family
- Well-known in the cloud
  - Zookeeper

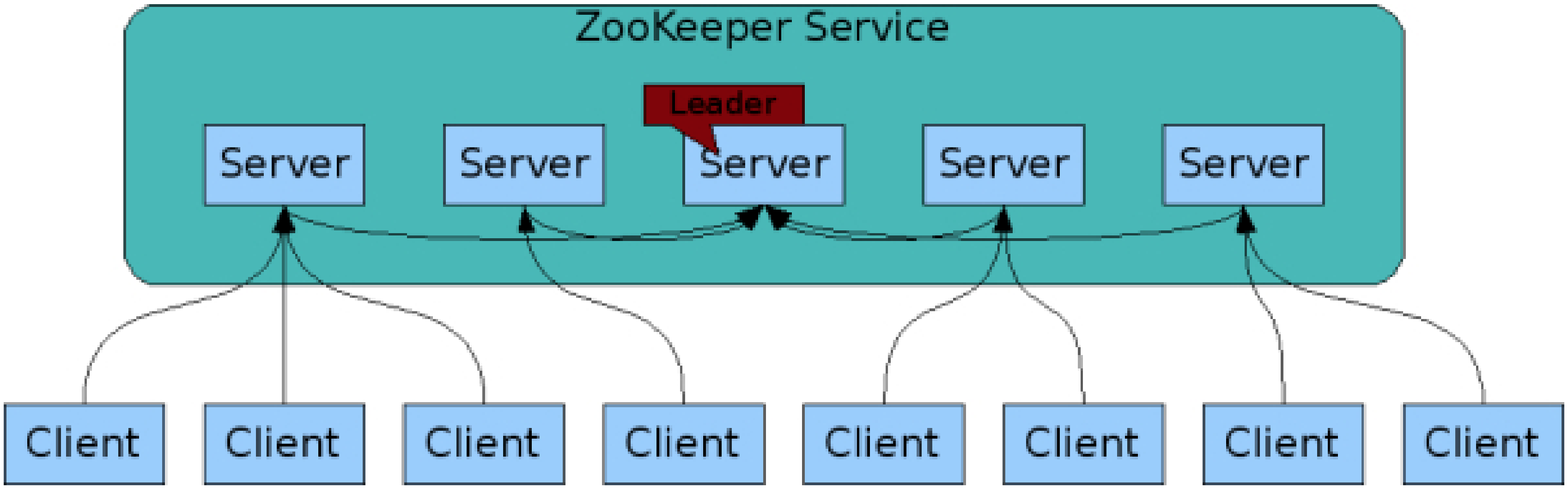
Notes from the paper: “server replication (SR), log replication (LR), synchronization service (SS), barrier orchestration (BO), service discovery (SD), group membership (GM), leader election (LE), metadata management (MM) and distributed queues (Q)”

TABLE 4. PATTERNS OF PAXOS USE IN PROJECTS

		Usage Patterns								
Project	**Consensus System**	**SR**	**LR**	**SS**	**BO**	**SD**	**GM**	**LE**	**MM**	**Q**
GFS	Chubby			✓				✓	✓	
Borg	Chubby/Paxos	✓				✓		✓		
Kubernetes	etcd						✓		✓	
Megastore	Paxos		✓							
Spanner	Paxos	✓								
Bigtable	Chubby						✓	✓	✓	
Hadoop/HDFS	ZooKeeper	✓						✓		
HBase	ZooKeeper	✓		✓			✓		✓	
Hive	ZooKeeper			✓					✓	
Configerator	Zeus								✓	
Cassandra	ZooKeeper					✓		✓	✓	
Accumulo	ZooKeeper		✓	✓					✓	
BookKeeper	ZooKeeper						✓		✓	
Hedwig	ZooKeeper						✓		✓	
Kafka	ZooKeeper						✓	✓	✓	
Solr	ZooKeeper							✓	✓	✓
Giraph	ZooKeeper		✓		✓				✓	
Hama	ZooKeeper				✓					
Mesos	ZooKeeper							✓		
CoreOS	etcd					✓				
OpenStack	ZooKeeper					✓				
Neo4j	ZooKeeper			✓				✓		

Source: Ailidani Ailijiang, Aleksey Charapkoy and Murat Demirbasz , Consensus in the Cloud: Paxos Systems Demystified, http://www.cse.buffalo.edu/tech-reports/2016-02.pdf

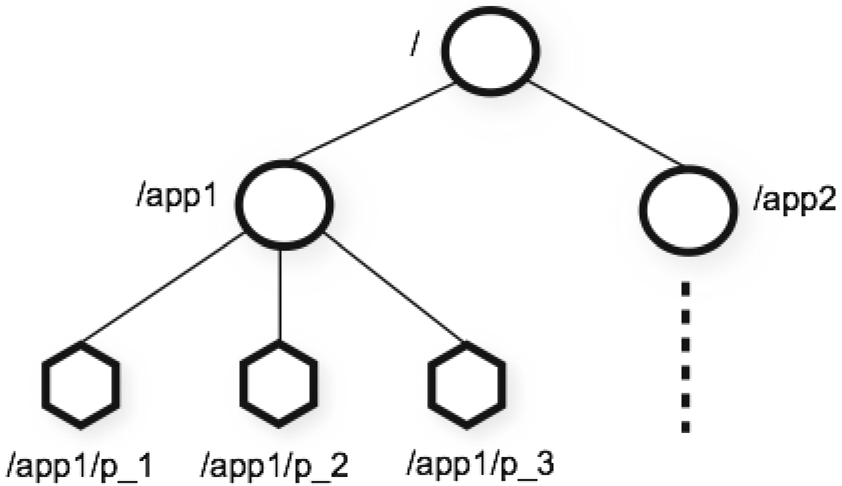
ZooKeeper Service



Source: https://zookeeper.apache.org/doc/r3.4.10/zookeeperOver.html

ZooKeeper data -- znodes

- Data nodes called znodes
- Missing data in a znode → Problems with the entity that the znode represents
- No partial read or write for a znode
- Persistent znode
  - /path deleted only through a delete call
- Ephemeral znode
  - The client created it crash
  - Session expired



Source: https://zookeeper.apache.org/doc/r3.4.10/zookeeperOver.html

ZooKeeper API

- Simple APIs
- Client call server
    - Create, delete, exists, getData, setData, getChildren
- Watch/notification
    - Clients setting a watch in order to receive notifications about znodes

Guarantees

- Sequential Consistency
- Atomicity - either succeed or fail
- Single System Image
- Reliability
- Timeliness

How can we coordinate resources in edge/fog/cloud continuum

- Which protocols/techniques can we use?
- Do the known protocols like Zookeeper, etcd, consul, etc., fit, if yes where?

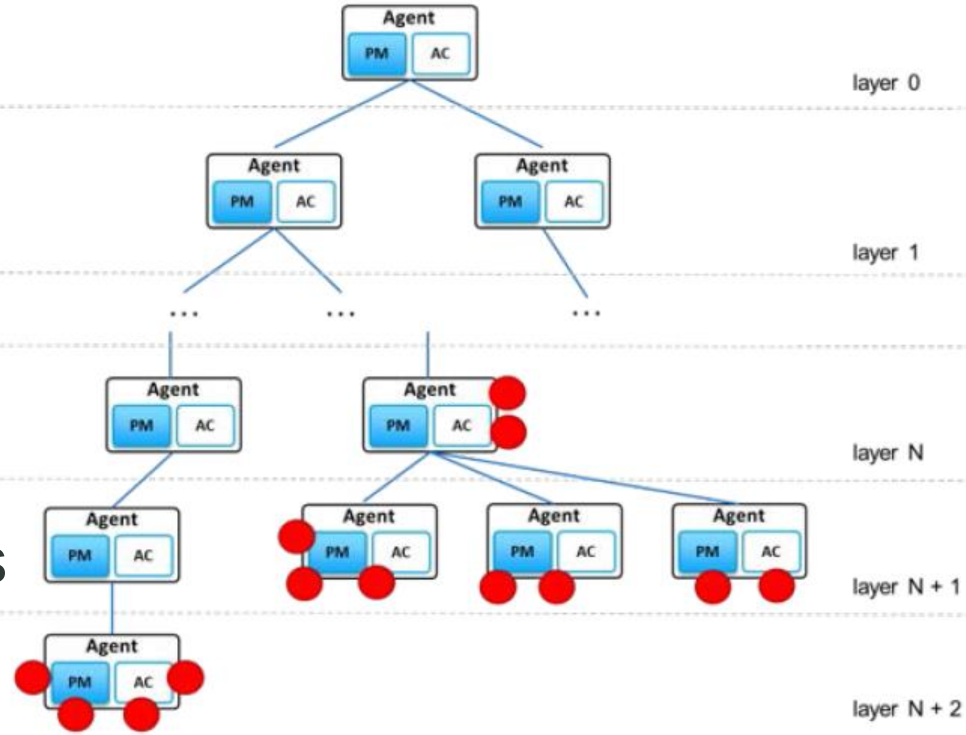


Figure 1: The mF2C Architecture.

Figure source: Xavi Masip-Bruin, Eva Marín-Tordera, Ana Juan-Ferrer, Anna Queralt, Admela Jukan, Jordi Garcia, Daniele Lezzi, Jens Jensen, Cristovao Cordeiro, Alexander Leckey, Antonio Salis, Denis Guilhot, and Matic Cankar. 2018. mF2C: towards a coordinated management of the IoT-fog-cloud continuum. In Proceedings of the 4th ACM MobiHoc Workshop on Experiences with the Design and Implementation of Smart Objects (SMARTOBJECTS '18). ACM, New York, NY, USA, Article 8, 8 pages. DOI: https://doi.org/10.1145/3213299.3213307

TOPICS FOR YOU

High availability in Hadoop

- Concepts
  - https://journalofcloudcomputing.springeropen.com/articles/10.1186/s13677-016-0066-8
  - Mina Nabi, Maria Toeroe, and Ferhat Khendek. 2016. Availability in the cloud. J. Netw. Comput. Appl. 60, C (January 2016), 54-67. DOI: http://dx.doi.org/10.1016/j.jnca.2015.11.014
  - Feng Wang, Jie Qiu, Jie Yang, Bo Dong, Xinhui Li, and Ying Li. 2009. Hadoop high availability through metadata replication. In Proceedings of the first international workshop on Cloud data management (CloudDB '09). ACM, New York, NY, USA, 37-44. DOI=http://dx.doi.org/10.1145/1651263.1651271
  - Cuong Manh Pham, Victor Dogaru, Rohit Wagle, Chitra Venkatramani, Zbigniew Kalbarczyk, and Ravishankar Iyer. 2014. An evaluation of zookeeper for high availability in system S. In Proceedings of the 5th ACM/SPEC international conference on Performance engineering (ICPE '14). ACM, New York, NY, USA, 209-217. DOI: https://doi.org/10.1145/2568088.2576801
- Practical work with Hadoop and Zookeeper
  - https://hadoop.apache.org/docs/stable/hadoop-project-dist/hadoop-hdfs/HDFSHighAvailabilityWithNFS.html
  - https://zookeeper.apache.org/

High availability with cluster of containers

- Concepts
  - https://researcher.watson.ibm.com/researcher/files/us-sseelam/Woc2016-KubeHA-Final.pdf
  - W. Li, A. Kanso and A. Gherbi, "Leveraging Linux Containers to Achieve High Availability for Cloud Services," 2015 IEEE International Conference on Cloud Engineering, Tempe, AZ, 2015, pp. 76-83. doi: 10.1109/IC2E.2015.17
  - https://arxiv.org/pdf/1708.08399.pdf
  - Large-scale cluster management at Google with Borg: https://ai.google/research/pubs/pub43438
- Practical work:
  - Kubernes: https://kubernetes.io/docs/admin/high-availability/
  - Docker: https://docs.docker.com/datacenter/ucp/1.1/high-availability/set-up-high-availability/
  - https://docs.mesosphere.com/
  - https://www.consul.io/docs/internals/consensus.html#deployment-table

High availability for resource management systems

- Concepts – Mesos, YARN, Zookeeper
  - https://www.safaribooksonline.com/library/view/apache-mesos-essentials/9781783288762/
  - Benjamin Hindman, Andy Konwinski, Matei Zaharia, Ali Ghodsi, Anthony D. Joseph, Randy Katz, Scott Shenker, and Ion Stoica. 2011. Mesos: a platform for fine-grained resource sharing in the data center. In Proceedings of the 8th USENIX conference on Networked systems design and implementation (NSDI'11).
  - Ronan-Alexandre Cherrueau, Adrien Lebre, Dimitri Pertin, Fetahi Wuhib, João Monteiro Soares: Edge Computing Resource Management System: a Critical Building Block! Initiating the debate via OpenStack. HotEdge 2018
  - Consensus in the Cloud: Paxos Systems Demystified: https://ieeexplore.ieee.org/document/7568499
  - Designing Cluster Schedulers for Internet-Scale Services: https://queue.acm.org/detail.cfm?id=3199609
  - Other papers in coordination in fog/edge systems
- Practical work:
  - http://mesos.apache.org/documentation/latest/high-availability/
  - https://dcos.io/docs/1.7/overview/high-availability/
  - https://hadoop.apache.org/docs/stable/hadoop-yarn/hadoop-yarn-site/ResourceManagerHA.html

High availability for MongoDB

- Concepts
  - https://raft.github.io/
  - In Search of an Understandable Consensus Algorithm, (Extended Version), Diego Ongaro and John Ousterhout, Stanford University
  - Wenbin Jiang, Lei Zhang, Xiaofei Liao, Hai Jin, and Yaqiong Peng. 2014. A novel clustered MongoDB-based storage system for unstructured data with high availability. Computing 96, 6 (June 2014), 455-478. DOI=http://dx.doi.org/10.1007/s00607-013-0355-8
  - Stefan Brenner, Benjamin Garbers, and Rüdiger Kapitza. 2014. Adaptive and Scalable High Availability for Infrastructure Clouds. In Proceedings of the 14th IFIP WG 6.1 International Conference on Distributed Applications and Interoperable Systems - Volume 8460, Kostas Magoutis and Peter Pietzuch (Eds.), Vol. 8460. Springer-Verlag New York, Inc., New York, NY, USA, 16-30. DOI=http://dx.doi.org/10.1007/978-3-662-43352-2_2
- Practical work:
  - https://docs.mongodb.com/manual/replication/
  - https://docs.mongodb.com/manual/core/replica-set-architecture-geographically-distributed/
  - https://www.mongodb.com/presentations/replication-election-and-consensus-algorithm-refinements-for-mongodb-3-2

High availability for RabbitMQ or Kafka or other messaging protocols

- Concepts
  - Philippe Dobbelaere and Kyumars Sheykh Esmaili. 2017. Kafka versus RabbitMQ: A comparative study of two industry reference publish/subscribe implementations: Industry Paper. In Proceedings of the 11th ACM International Conference on Distributed and Event-based Systems (DEBS '17). ACM, New York, NY, USA, 227-238. DOI: https://doi.org/10.1145/3093742.3093908
  - Stefan Brenner, Benjamin Garbers, and Rüdiger Kapitza. 2014. Adaptive and Scalable High Availability for Infrastructure Clouds. In Proceedings of the 14th IFIP WG 6.1 International Conference on Distributed Applications and Interoperable Systems - Volume 8460, Kostas Magoutis and Peter Pietzuch (Eds.), Vol. 8460. Springer-Verlag New York, Inc., New York, NY, USA, 16-30. DOI=http://dx.doi.org/10.1007/978-3-662-43352-2_2
- Practical work:
  - https://www.rabbitmq.com/pacemaker.html
  - https://www.rabbitmq.com/ha.html
  - http://clusterlabs.org/
  - https://pubs.vmware.com/vfabric53/index.jsp?topic=/com.vmware.vfabric.rabbitmq.3.2/rabbit-web-docs/ha.html

Summary

- It is important to learn some key techniques to enable big, dynamic could systems
  - On-demand data centers:
    - Allow us to obtain compute resources and storage resources for dealing with dynamic workload
    - Resources “as a data center” (rather than isolated)
  - Data sharding + resource management
    - Fundamental requirement for big data
  - Distributed coordination
    - Allow us to manage failures and support high availability
- They are highly interdependent topics that should be studied together
- We also need to look for application-specific algorithms and learn them

Some further readings

- Hussam Abu-Libdeh, Robbert van Renesse, and Ymir Vigfusson. 2013. Leveraging sharding in the design of scalable replication protocols. In Proceedings of the 4th annual Symposium on Cloud Computing (SOCC '13). ACM, New York, NY, USA, , Article 12 , 16 pages. DOI: http://dx.doi.org/10.1145/2523616.2523623
- http://rboutaba.cs.uwaterloo.ca/Papers/Conferences/2012/ZhangICDCS12.pdf
- Flavio Junqueira & Benjamin Reed, ZooKeeper, Distributed Process Coordination, O'reilly, 2013
- Werner Vogels. 2009. Eventually consistent. Commun. ACM 52, 1 (January 2009), 40-44. DOI=http://dx.doi.org/10.1145/1435417.1435432
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Thanks for your attention

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