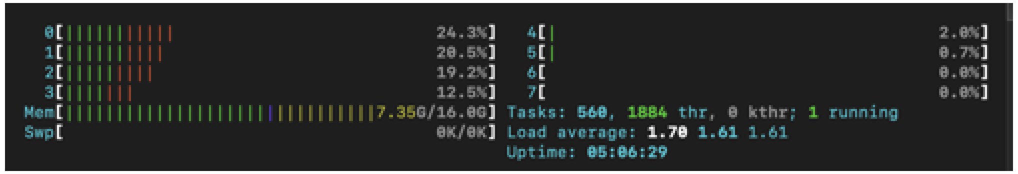
Einführung

«Parallele Systeme»

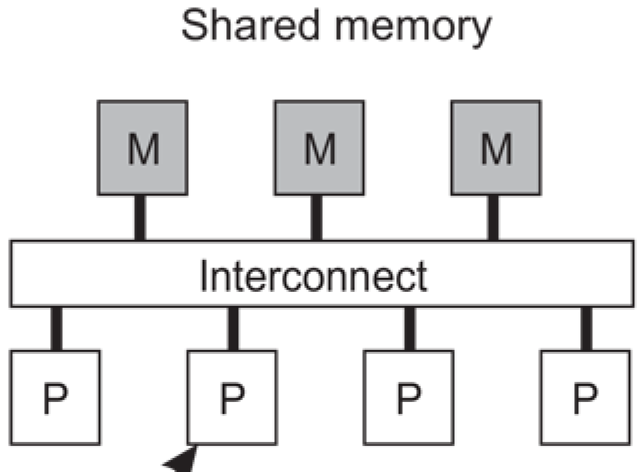
- Eine single core CPU kann nur einen Prozess gleichzeitig ausführen
- Multi-core CPUs entsprechend mehrere gleichzeitig
- Ausser in sehr einfachen Embedded Systemen müssen jedoch immer sehr viele Prozesse «gleichzeitig» ausgeführt werden

  können z.B. auf einem Server oder auf einem Desktop Computer

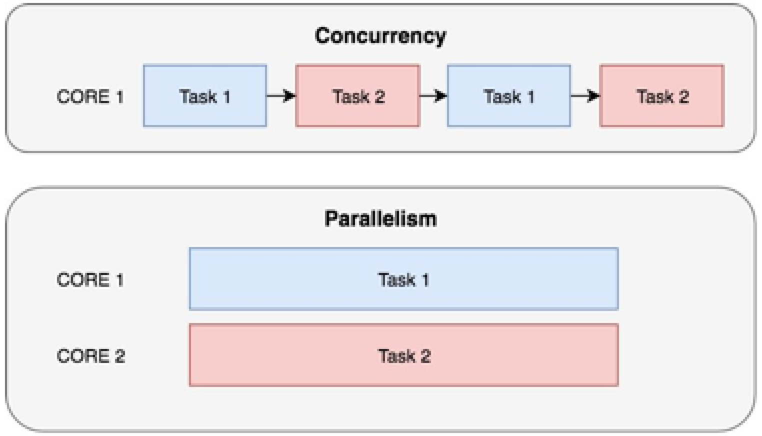


«Parallele Systeme»

- Viele verschiedene Prozesse (tausende) werden von einem oder mehreren (bis zu dutzenden) Prozessoren ausgeführt
- Ein einzelner Prozessor kann demnach nacheinander mehrere Prozesse bearbeiten
- Die Prozessoren befinden sich auf demselben Chip oder auf dem selben Mainboard
- Sie haben geteilten sowie gemeinsamen Speicher
- Die Verbindung zwischen ihnen (Interconnect) hat geringe Latenz, hohe Bandbreite und ist zuverlässig.



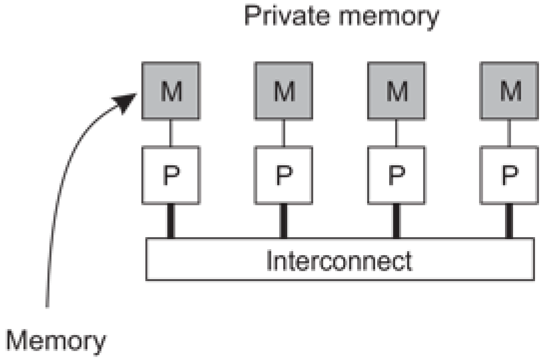
- Parallele Ausführung (parallelism): Mehr als eine Aufgabe wird gleichzeitig ausgeführt
- Nebenläufig (concurrency): Mehr als eine Aufgabe wird abgearbeitet (durch schnelles context switching)



- Eine zentrale Aufgabe von Betriebsystemen ist es, die Prozesse auf die CPUs zu verteilen.
- Dies wird «Scheduling» genannt.

Verteilte Systeme

> «A distributed system is a collection of independent computers that appears to its users as a single coherent system.»



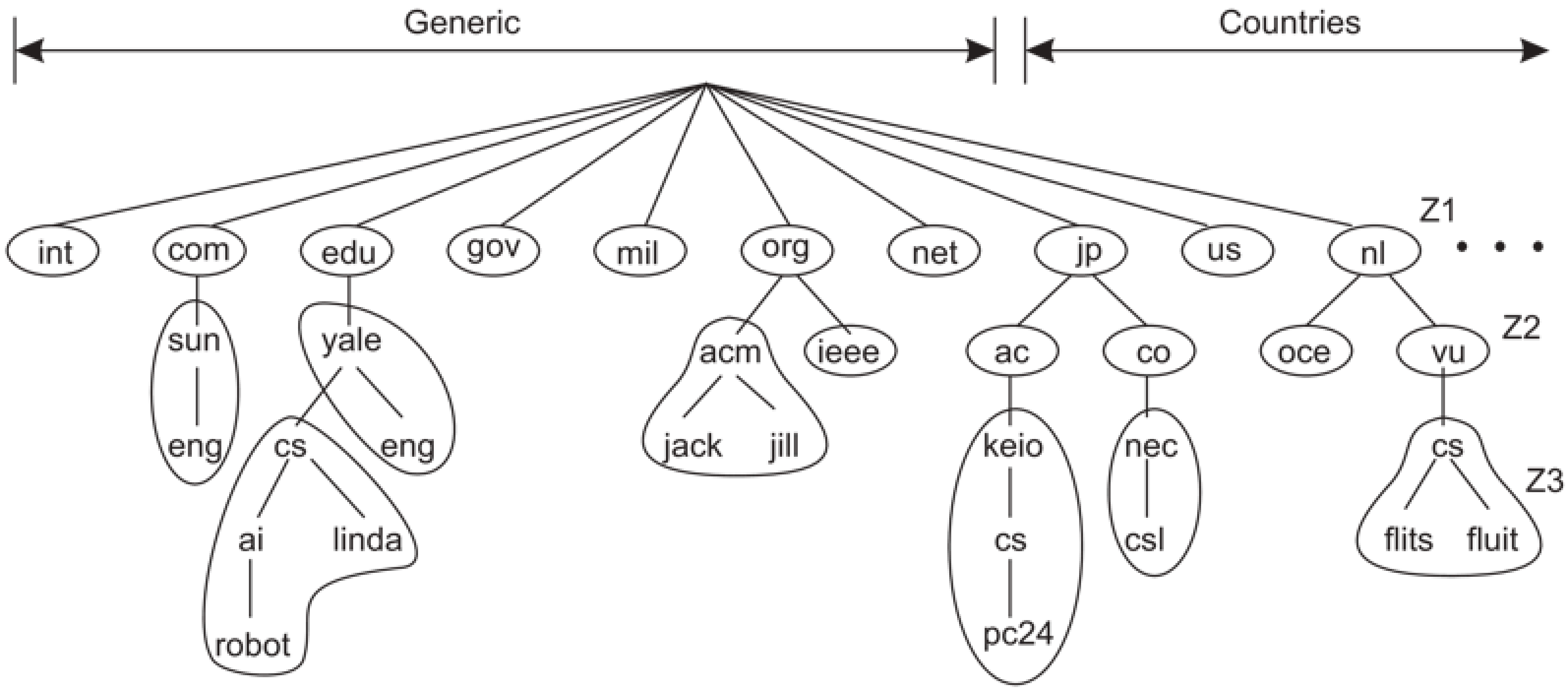
VanSteen, 2017, S. 26

P: Prozessor, Interconnect: Netzwerkverbindung, meistens HTTP, UDP/TCP, IP, Ethernet basiert

Resource Sharing

- Ressourcen verfügbar machen: Drucker, Computing, Storage, Daten, Netzwerk
- Teure Ressourcen können besser ausgelastet werden und müssen nicht mehrfach angeschafft werden
- Zusammenarbeit

Domain Name System



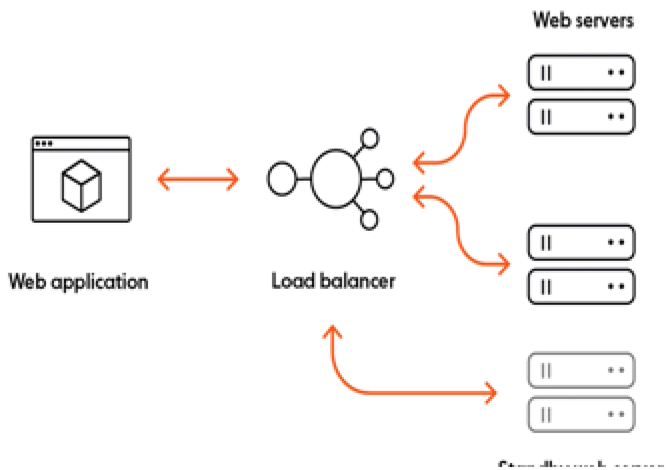

When the cloud leaves the datacenter
Meme-Generator.com

Anforderungen an moderne Software

- Hohe Verfügbarkeit
- Skalierbarkeit
- Im Katastrophenfall sollen die Systeme schnell wiederhergestellt werden können
- Soll funktionieren, auch wenn Teile des Systems Offline sind (Resilienz)
- Kostengünstig
- Einfach
- Updates müssen einfach eingespielt werden können

Lösungsansätze

- Replication: Masking Failures
- Tradeoff: Teuer und Komplex



Populäre verteilte Systeme

- Matrix
- Mastodon
- Nextcloud
- CockroachDB
- Neon
- Ably
- ...

Koordination

- Tasks können gleichzeitig ausgeführt werden
- Gleichzeitiger Zugriff auf gemeinsame Daten kann in inkonsistenten Daten resultieren

Mutex

- MUTual EXclusion: wechselseitiger Ausschluss
- Einfachste Möglichkeit, Ressourcen für alle anderen zu blockieren
- Critical Section wird mit acquire() und release() umschlossen
- acquire() und release() müssen atomare Operationen sein (Hardwareunterstützung)

Mutex

```
acquire() {
  while (!available)
    /* busy wait */
  available = false;;
}

release() {
  available = true;
}
```

```
do {
    acquire lock
       critical section
    release lock
      remainder section
 } while (true);
```

Semaphore

- Mehr Möglichkeiten als Mutex
- Schützt gemeinsame Ressourcen
- Counting semaphore: Mehrere Ressourcen
- Binary semaphore: Nur eine Ressource
- Ein Zugriff auf eine gemeinsame Ressource wird mit dem Nehmen und Geben umschlossen

Beispiel

```php
$semaphore = $this->createSemaphore($id);

sem_acquire($semaphore);
try {
    $entityPublishTime = $this->getEntityPublishTime($model, $id);

    if ($entityPublishTime < $messagePublishTime) {
        $returnCode = $this->saveStateToModel($model, $state, $data->timestamp);
    } else {
        $returnCode = 3;
    }
} finally {     // make sure to always release semaphore
    sem_release($semaphore);
}
```

Replication

The following slides adapted of Martin Kleppmann's Course at University of Cambridge: https://www.cl.cam.ac.uk/teaching/2425/ConcDisSys/materials.html

- Keeping a copy of the same data on multiple nodes: Databases, filesystems, caches, ...
- A node that has a copy of the data is called a replica
- If some replicas are faulty, others are still accessible
- Spread load across many replicas
- Easy if the data doesn’t change: just copy it
- We will focus on data changes

Idempotence

A function f is idempotent if $f(x) = f(f(x))$.

Choice of retry behaviour:

- **At-most-once semantics:** send request, don’t retry, update may not happen
- **At-least-once semantics:** retry request until acknowledged, may repeat update
- **Exactly-once semantics:** retry + idempotence or deduplication

"Consistency"

A word that means many different things in different contexts!

- **ACID**: a transaction transforms the database from one “consistent” state to another
  - Here, “consistent” = satisfying application-specific invariants e.g. “every course with students enrolled must have at least one lecturer”
- **Read-after-write consistency**
- **Replication**: replica should be “consistent” with other replicas
  - “consistent” = in the same state? (when exactly?)
  - “consistent” = read operations return same result?
- Consistency model: many to choose from

Recall atomicity in the context of ACID transactions:

- A transaction either commits or aborts
- If it commits, its updates are durable
- If it aborts, it has no visible side-effects
- ACID consistency (preserving invariants) relies on atomicity

Strong Consistency: Linearizability

- Informally: every operation takes effect atomically sometime after it started and before it finished
- All operations behave as if executed on a single copy of the data (even if there are in fact multiple replicas)
- Consequence: every operation returns an “up-to-date” value, a.k.a. “strong consistency”

Linearizability advantages:

- Makes a distributed system behave as if it were non-distributed
- Simple for applications to use

Downsides:

- Performance cost: lots of messages and waiting for responses

Eventual Consistency

- Eventual consistency: a weaker model than linearizability. Different trade-off choices.
- Replicas process operations based only on their local state.
- If there are no more updates, eventually all replicas will be in the same state.
- No guarantees how long it might take

Local-first software

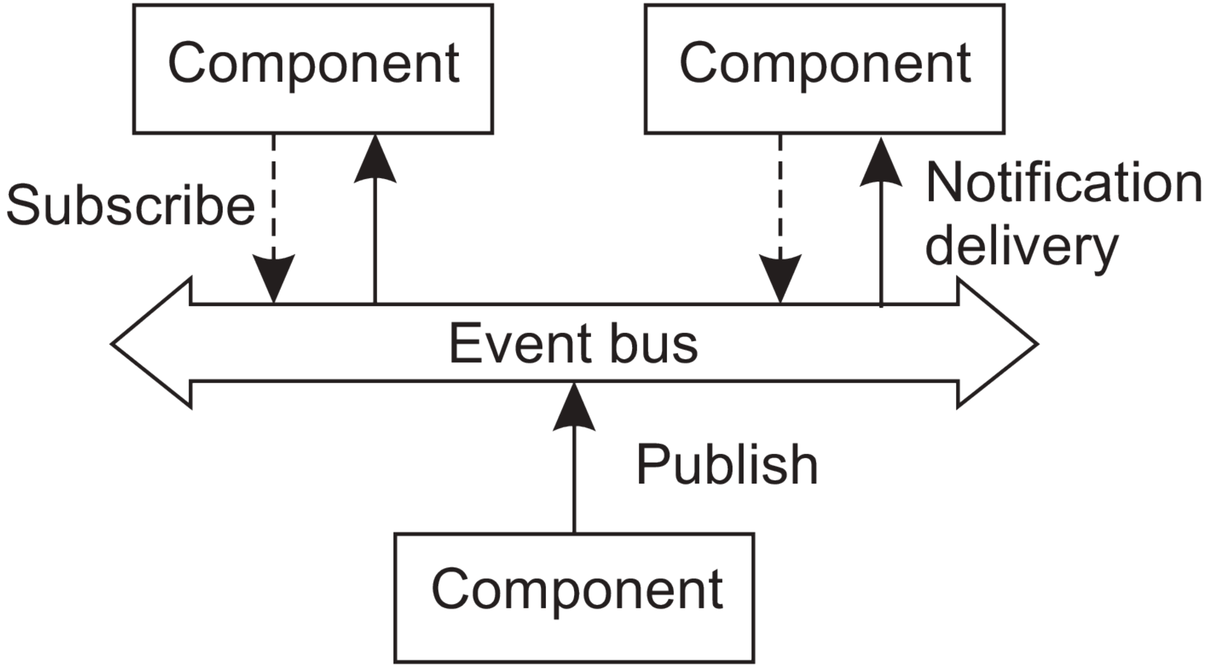
End-user device is a full replica; servers are just for backup. “Local-first”: a term introduced by me (Martin
Kleppmann) and my colleagues https://www.inkandswitch.com/local-first/

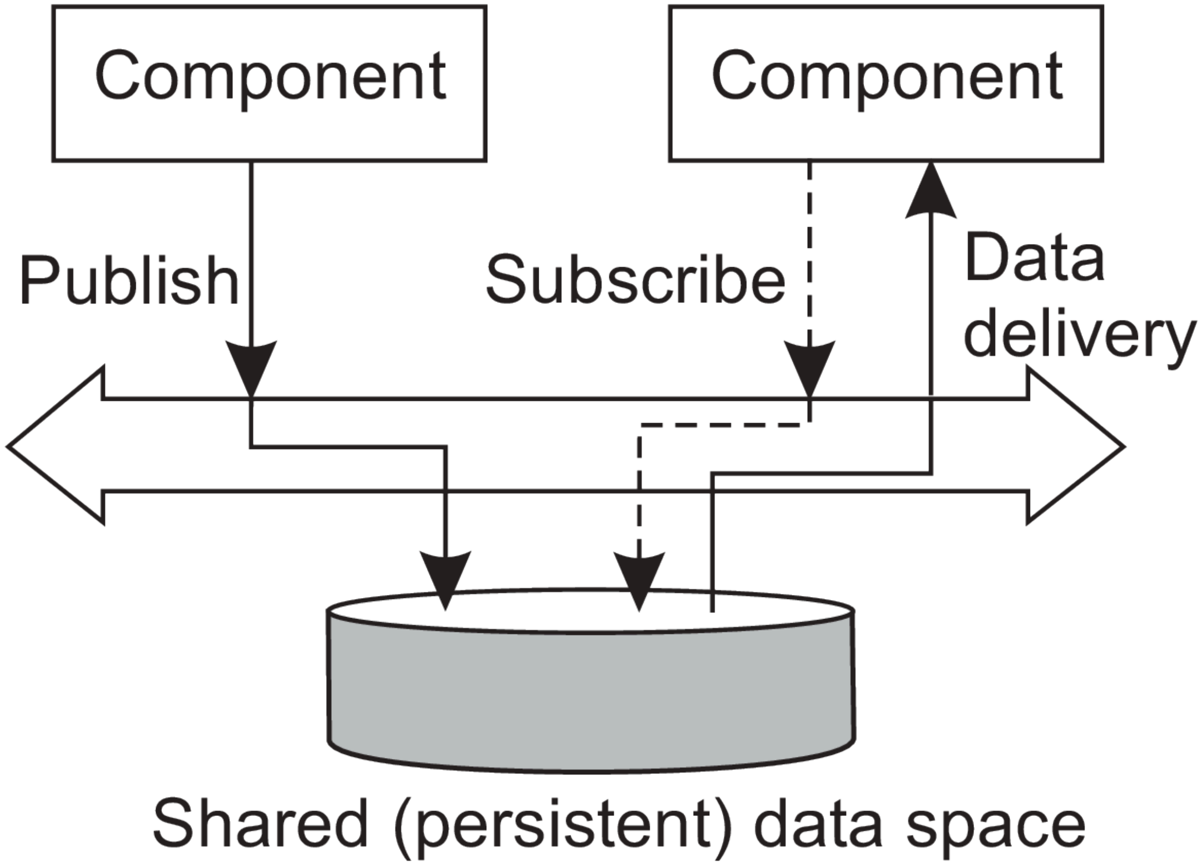
Calendar app with cross-device sync as an example:

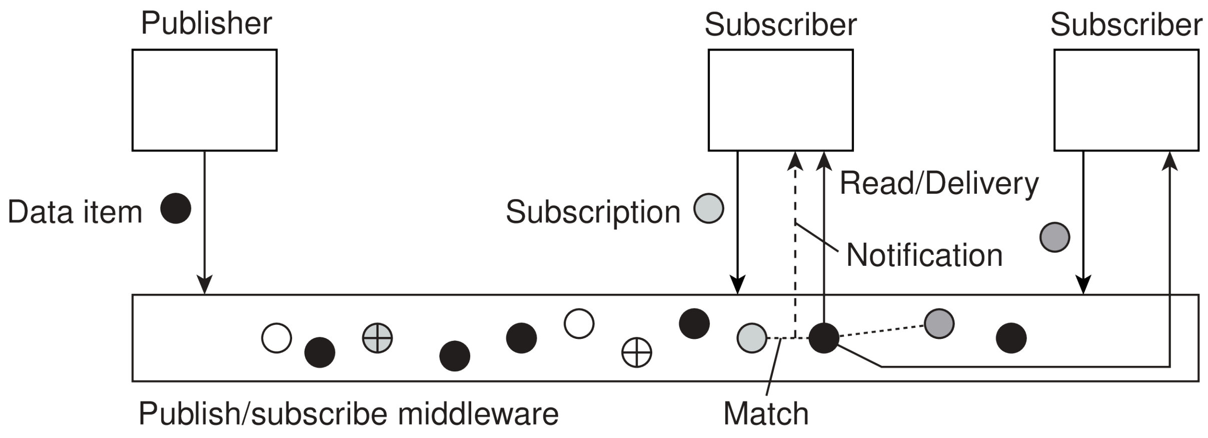
- App works offline (can both read and modify data)
- Fast: no need to wait for network round-trip
- Sync with other devices when online
- Real-time collaboration with other users
- Longevity: even if cloud service shuts down, you have a copy of your files on your own computer
- Supports end-to-end encryption for better security

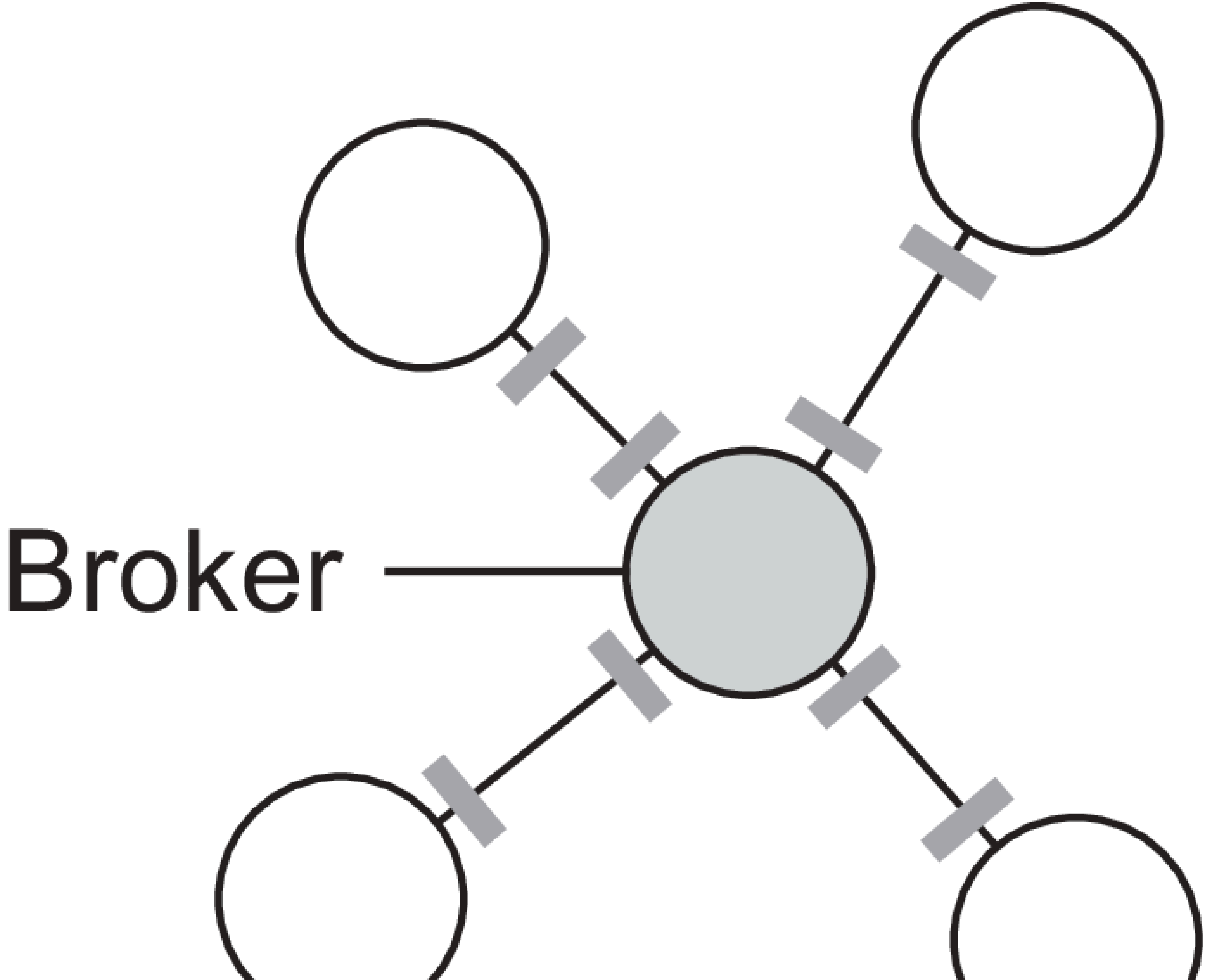
Publish-subscribe Architekturen

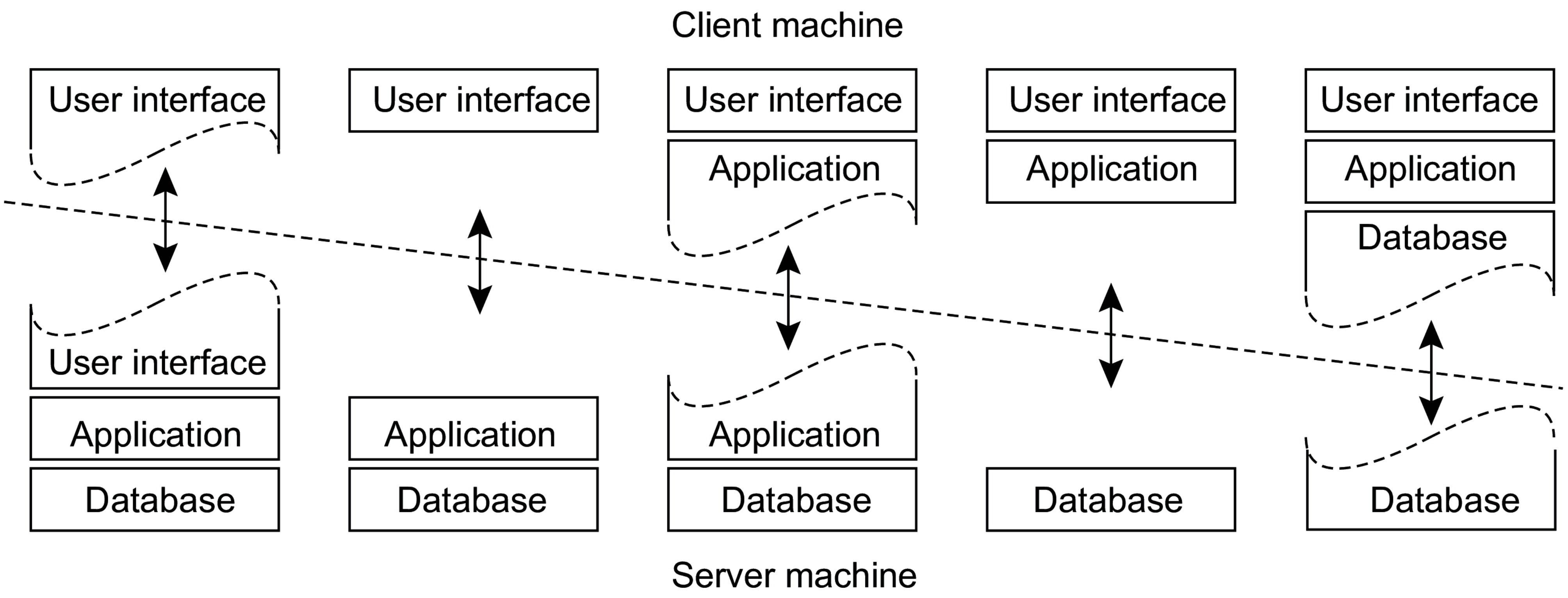
	Temporally coupled	**Temporally decoupled**
Referentially coupled	Direct	Mailbox
Referentially decoupled	Event-based	Shared data space


Component
Component
Subscribe
Notification
delivery
Event bus
Publish
Component


Component
Component
Publish
Subscribe
Data
delivery
Shared (persistent) data space


Publisher
Subscriber
Subscriber
Data item
Subscription
Read/Delivery
Notification
Publish/subscribe middleware
Match


Broker


Client machine
User interface
User interface
User interface
Application
User interface
Application
User interface
Application
Database
User interface
Application
Database
Application
Database
Application
Database
Database
Database
Server machine

Cloud und Edge Computing

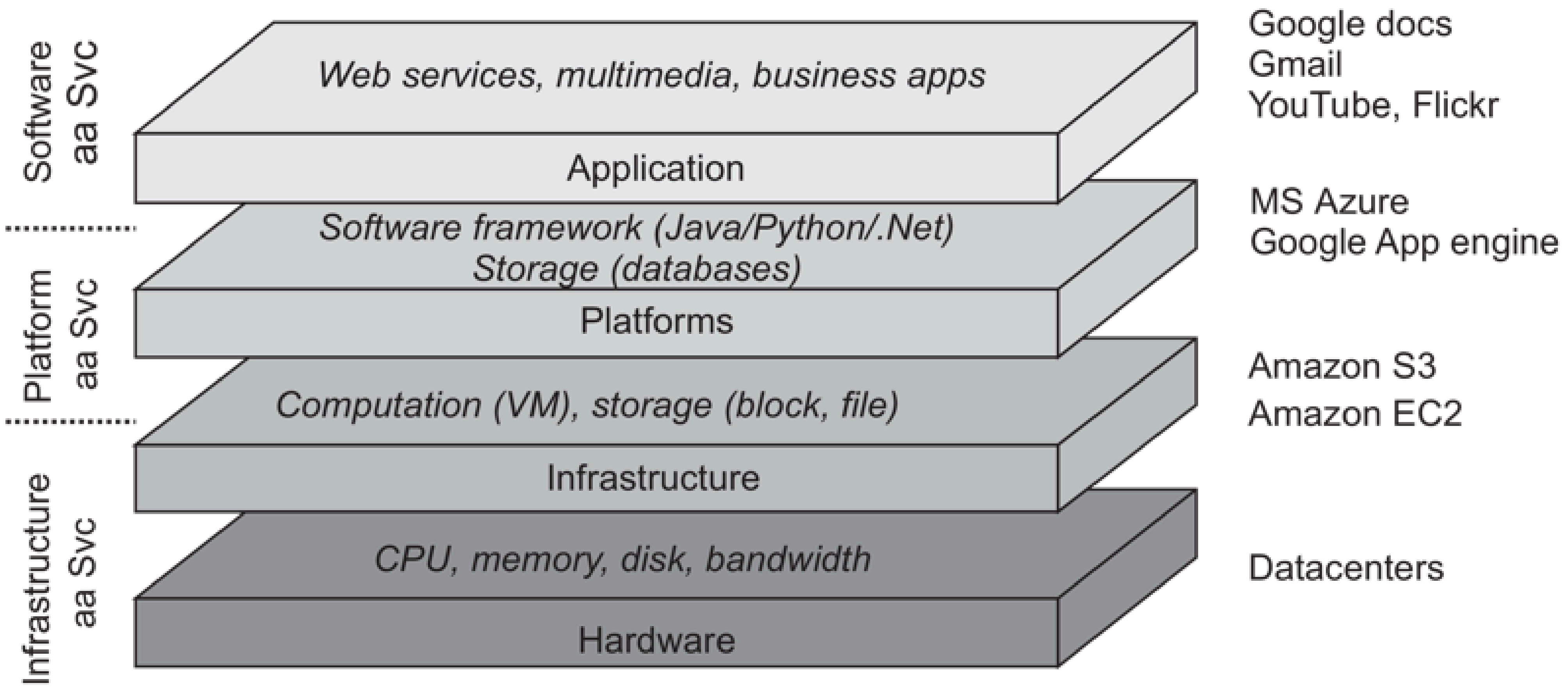
> The entire history of software engineering is that of the rise in levels of abstraction.

-- Grady Booch

New Pizza as a Service

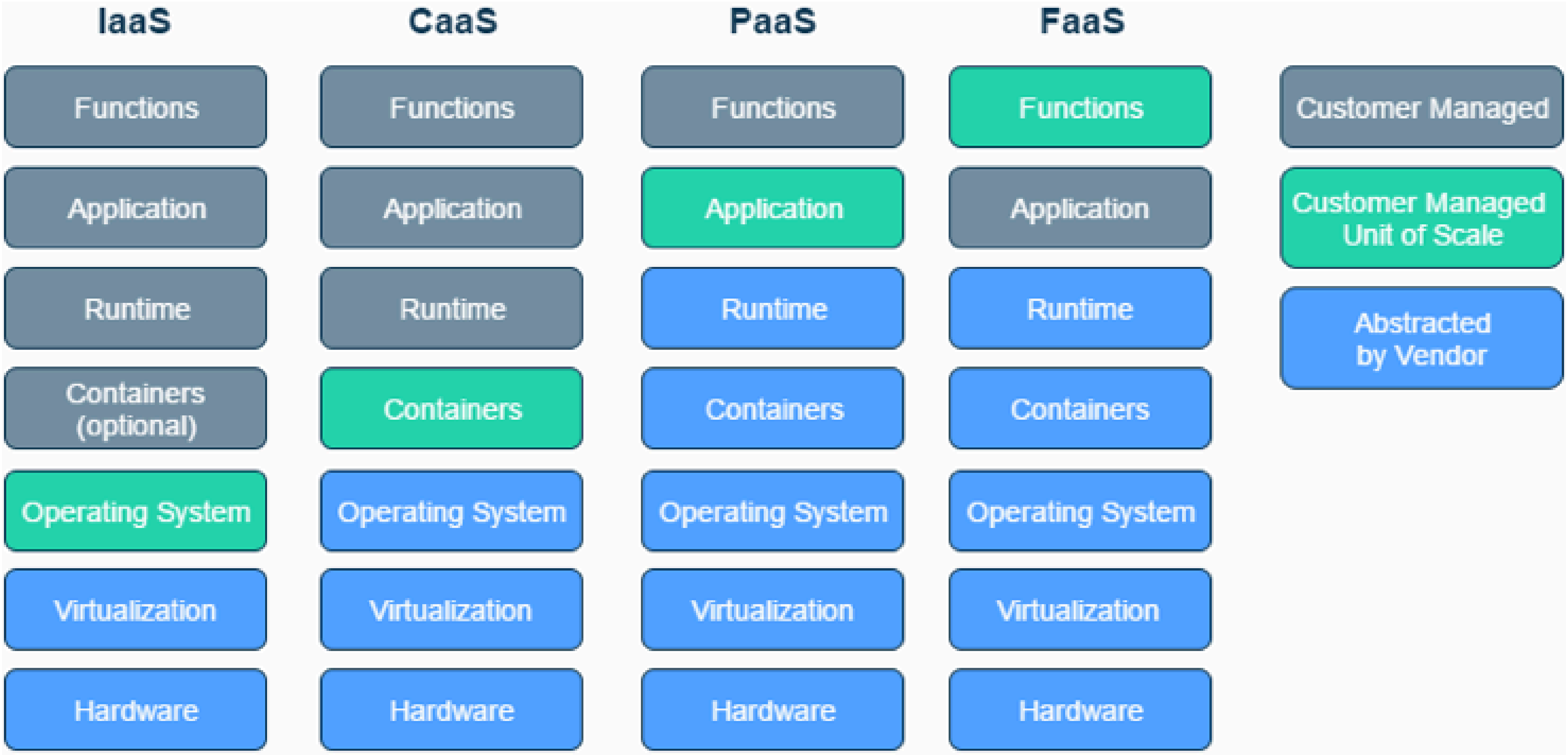
Traditional On-Premises Deployment	Infrastructure as a Service (IaaS)	Platform as a Service (PaaS)	Software as a Service (SaaS)
Kitchen	Kitchen	Kitchen	Kitchen
Gas	Gas	Gas	Gas
Oven	Oven	Oven	Oven
Pizza Dough	Pizza Dough	Pizza Dough	Pizza Dough
Toppings	Toppings	Toppings	Toppings
Cook the Pizza	Cook the Pizza	Cook the Pizza	Cook the Pizza
Made In-House	Kitchen-as-a-Service	Walk-In-and-Bake	Pizza-as-a-Service

Abstractions

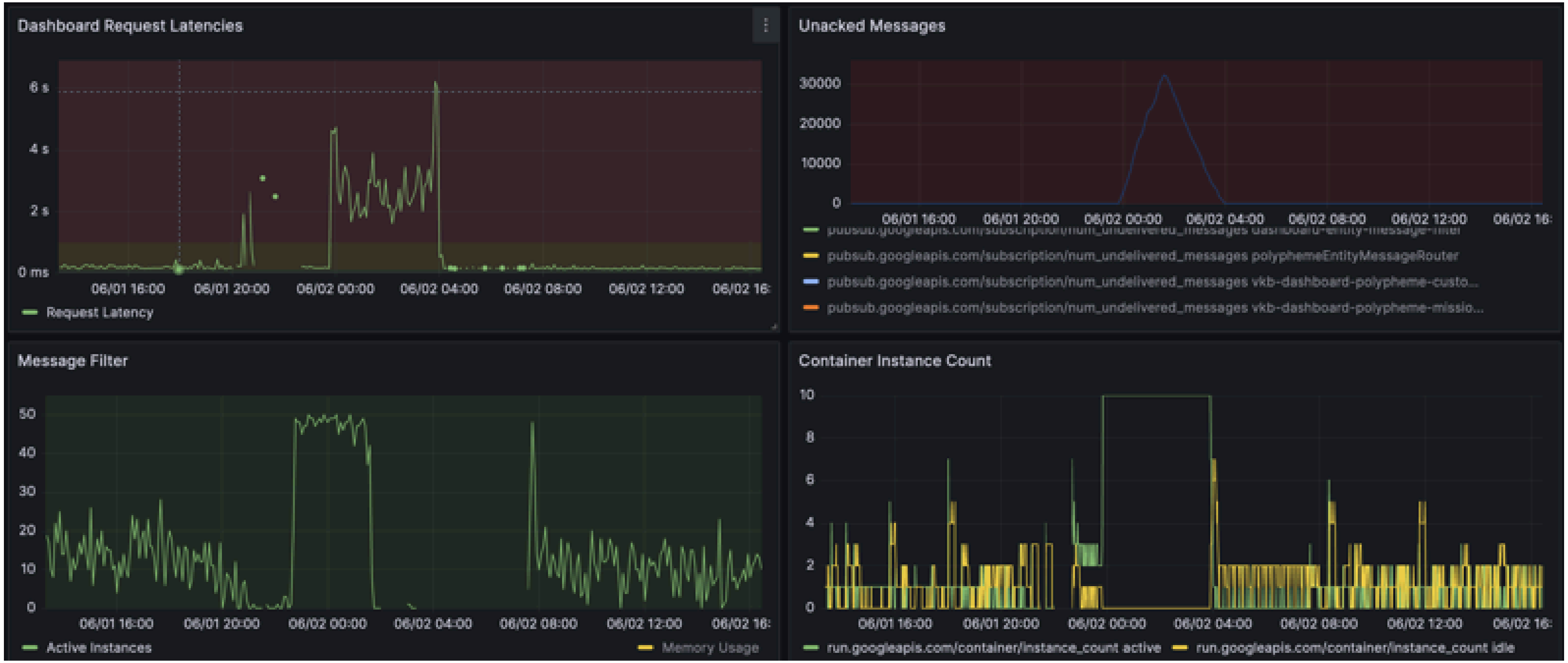


(VanSteen, 2017, S. 30)

XaaS


IaaS
CaaS
PaaS
FaaS
Functions
Functions
Functions
Functions
Customer Managed
Application
Application
Application
Application
Customer Managed Unit of Scale
Runtime
Runtime
Runtime
Runtime
Abstracted by Vendor
Containers (optional)
Containers
Containers
Containers
Operating System
Operating System
Operating System
Operating System
Virtualization
Virtualization
Virtualization
Virtualization
Hardware
Hardware
Hardware
Hardware

Fallstudie


Dashboard Request Latencies
6 s
4 s
2 s
0 ms
06/01 16:00
06/01 20:00
06/02 00:00
06/02 04:00
06/02 08:00
06/02 12:00
06/02 16:
Request Latency
Unacked Messages
30000
20000
10000
0
pubsub.googleapis.com/subscription/num_undelivered_messages polyphemeEntityMessageRouter
pubsub.googleapis.com/subscription/num_undelivered_messages vkb-dashboard-polypheme-custo...
pubsub.googleapis.com/subscription/num_undelivered_messages vkb-dashboard-polypheme-missio...
Message Filter
50
40
30
20
10
0
Active Instances
Memory Usage
Container Instance Count
10
8
6
4
2
0
run.googleapis.com/container/instance_count active
run.googleapis.com/container/instance_count idle

Edge Computing