

Data Integration and Analysis

08 Cloud Computing Fundamentals

Matthias Boehm

Graz University of Technology, Austria
Computer Science and Biomedical Engineering
Institute of Interactive Systems and Data Science
BMK endowed chair for Data Management



Announcements/Org

■ #1 Video Recording

- Link in **TUbe** & **TeachCenter** (lectures will be public)
- Optional attendance (independent of COVID)
- **Virtual lectures** (recorded) until end of the year
<https://tugraz.webex.com/meet/m.boehm>



■ #2 Open Positions → mboehm@tugraz.at

- **ReWaste F** project (Recycling and Recovery of **Waste** for **Future**)
- Bachelor thesis / undergraduate research assistants

■ #3 Programming Projects/Exercises

- Progress?, Questions & Answers

73/116



Course Outline Part B:

Large-Scale Data Management and Analysis

12 Distributed Stream Processing

13 Distributed Machine Learning Systems

11 Distributed Data-Parallel Computation

10 Distributed Data Storage

09 Cloud Resource Management and Scheduling

08 Cloud Computing Fundamentals

Compute/
Storage

Infra

Agenda

- **Motivation and Terminology**
- **Cloud Computing Service Models**
- **Cloud, Fog, and Edge Computing**

Motivation and Terminology

Motivation Cloud Computing

■ Definition Cloud Computing

- **On-demand, remote storage and compute resources, or services**
- **User:** computing as a utility (similar to energy, water, internet services)
- **Cloud provider:** computation in data centers / multi-tenancy

■ Service Models

- **IaaS: Infrastructure as a service** (e.g., storage/compute nodes)
- **PaaS: Platform as a service** (e.g., distributed systems/frameworks)
- **SaaS: Software as a Service** (e.g., email, databases, office, github)

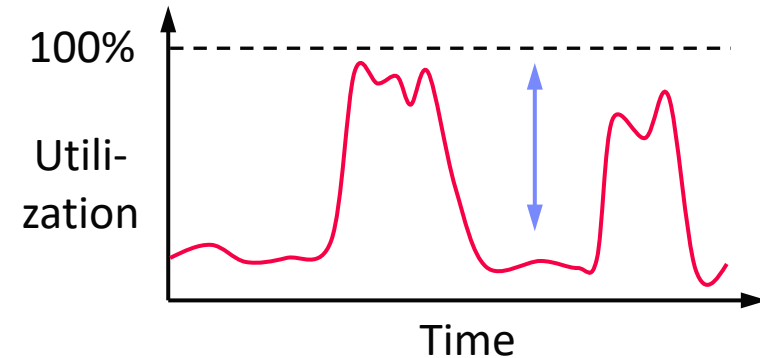
➔ Transforming IT Industry/Landscape

- Since ~2010 increasing move from on-prem to cloud resources
- System software licenses become increasingly irrelevant
- Few cloud providers dominate IaaS/PaaS/SaaS markets (w/ 2018 revenue):
Microsoft Azure Cloud (\$ 32.2B), **Amazon AWS** (\$ 25.7B), **Google Cloud** (N/A),
IBM Cloud (\$ 19.2B), **Oracle Cloud** (\$ 5.3B), **Alibaba Cloud** (\$ 2.1B)

Motivation Cloud Computing, cont.

Argument #1: Pay as you go

- No upfront cost for infrastructure
- Variable utilization → over-provisioning
- Pay per use or acquired resources



Argument #2: Economies of Scale

- Purchasing and managing IT infrastructure at scale → lower cost (applies to both HW resources and IT infrastructure/system experts)
- Focus on scale-out on commodity HW over scale-up → lower cost

Argument #3: Elasticity

- Assuming perfect scalability, work done in constant time * resources
- Given virtually unlimited resources allows to reduce time as necessary

100 days @ 1 node

≈

1 day @ 100 nodes

(but beware Amdahl's law:
max speedup $sp = 1/s$)

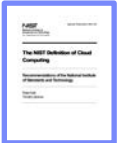


Characteristics and Deployment Models

■ Extended Definition

- ANSI recommended definitions for service types, characteristics, deployment models

[Peter Mell and Timothy Grance: The NIST Definition of Cloud Computing, **NIST 2011**]



■ Characteristics

- **On-demand self service:** unilateral resource provision
- **Broad network access:** network accessibility
- **Resource pooling:** resource virtualization / multi-tenancy
- **Rapid elasticity:** scale out/in on demand
- **Measured service:** utilization monitoring/reporting

■ Deployment Models

- **Public cloud:** general public, on premise of cloud provider
- **Hybrid cloud:** combination of two or more of the above
- **Community cloud:** single community (one or more orgs)
- **Private cloud:** single org, on/off premises

MS Azure
Private Cloud

IBM Cloud Private



Cloud Computing Service Models

(computing as a utility)

Anatomy of a Data Center



Commodity CPU:

Xeon E5-2440: 6/12 cores

Xeon Gold 6148: 20/40 cores



Server:

Multiple sockets,
RAM, disks



Rack:

16-64 servers +
top-of-rack switch



Cluster:

Multiple racks + cluster switch



Data Center:

>100,000 servers



[Google
Data Center,
Eemshaven,
Netherlands]

Fault Tolerance

[Christos Kozyrakis and Matei Zaharia: CS349D: Cloud Computing Technology, lecture, **Stanford 2018**]



■ Yearly Data Center Failures

- ~0.5 overheating (power down most machines in <5 mins, ~1-2 days)
- ~1 PDU failure (~500-1000 machines suddenly disappear, ~6 hrs)
- ~1 rack-move (plenty of warning, ~500-1000 machines powered down, ~6 hrs)
- ~1 network rewiring (rolling ~5% of machines down over 2-day span)
- ~20 rack failures (40-80 machines instantly disappear, 1-6 hrs)
- ~5 racks go wonky (40-80 machines see 50% packet loss)
- ~8 network maintenances (~30-minute random connectivity losses)
- ~12 router reloads (takes out DNS and external VIPs for a couple minutes)
- ~3 router failures (immediately pull traffic for an hour)
- ~dozens of minor 30-second blips for dns
- ~1000 individual machine failures (2-4% failure rate, at least twice)
- ~thousands of hard drive failures (1-5% of all disks will die)

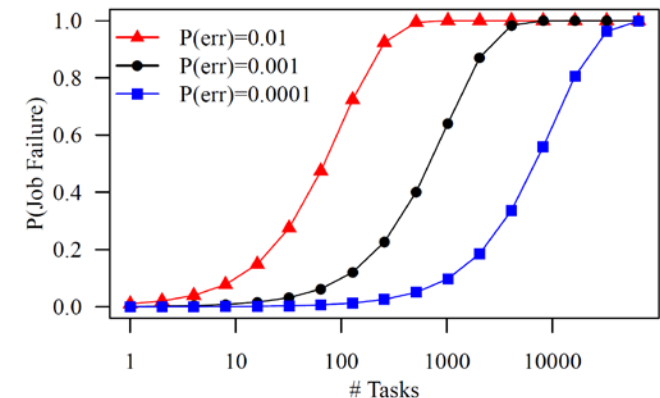
Fault Tolerance, cont.

Other Common Issues

- **Configuration issues**, partial SW updates, SW bugs
- **Transient errors**: no space left on device, memory corruption, stragglers

Recap: Error Rates at Scale

- Cost-effective commodity hardware
- Error rate increases with increasing scale
- Fault Tolerance for distributed/cloud storage and data analysis



→ Cost-effective Fault Tolerance

- **BASE** (basically **available**, soft state, **eventual consistency**)
- Effective techniques
 - ECC (error correction codes), CRC (cyclic redundancy check) for detection
 - **Resilient storage**: replication/erasure coding, checkpointing, and lineage
 - **Resilient compute**: task re-execution / speculative execution

Virtualization

■ #1 Native Virtualization

- Simulates most of the HW interface
- Unmodified guest OS to run in isolation
- **Examples:** VMWare, Parallels, AMI (HVM)

■ #2 Para Virtualization

- No HW interface simulation, but special API (hypercalls)
- Requires modified guest OS to use hyper calls, trapped by hypervisor
- **Examples:** Xen, KVM, Hyper-V, AMI (PV)

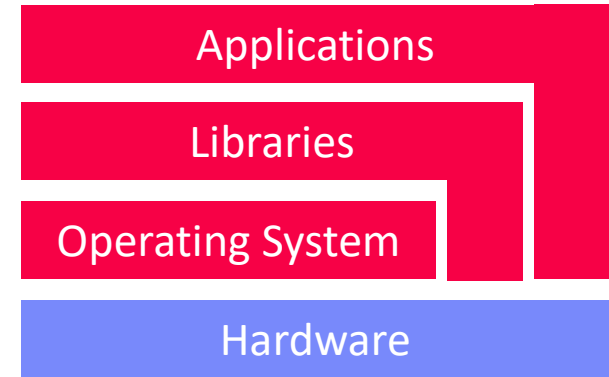
■ #3 OS-level Virtualization

- OS allows multiple secure virtual servers
- Guest OS appears isolated but same as host OS
- **Examples:** Solaris/Linux containers, Docker

[Prashant Shenoy: Distributed and Operating Systems - Module 1: Virtualization, **UMass Amherst, 2019**]

■ #4 Application-level Virtualization

- **Examples:** Java VM (JVM), Ethereum VM (EVM), Python virtualenv



Containerization

■ Docker Containers

■ Shipping container analogy

- Arbitrary, self-contained goods, standardized units
- Containers reduced loading times → efficient international trade
- #1 **Self-contained package** of necessary SW and data (read-only image)
- #2 **Lightweight virtualization** w/ shared OS and resource isolation via **cgroups**



■ Cluster Schedulers (see **Lecture 09**)

- Container orchestration: scheduling, deployment, and management
- Resource negotiation with clients
- Typical resource bundles (CPU, memory, device)
- Examples: **Kubernetes**, **Mesos**, (**YARN**), **Amazon ECS**, **Microsoft ACS**, **Docker Swarm**

[Brendan Burns, Brian Grant, David Oppenheimer, Eric Brewer, John Wilkes: Borg, Omega, and Kubernetes. **CACM 2016**]



→ **from machine- to application-oriented scheduling**



Excursus: AWS Snowmobile (since 2016)

- **Snowmobile Service:** Data transfer on-premise → cloud via **100PB trucks**



Real-World
“Containerization”



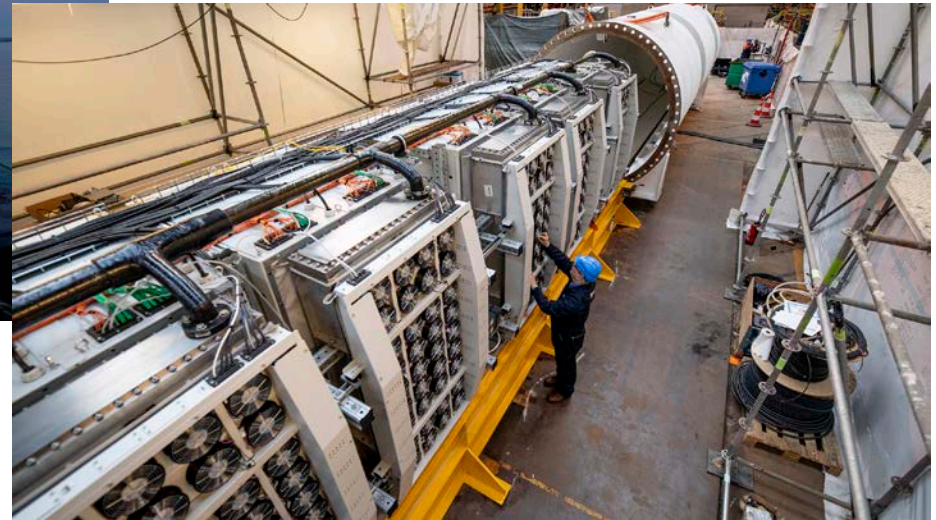
100PB
~26 years
(1Gb Link)
→ **weeks**

[https://aws.amazon.com/snowmobile/?nc1=h_ls]

Excursus: Microsoft Underwater Datacenter



Study for feasibility, and if logistically, environmentally, economically practical



[<https://news.microsoft.com/features/under-the-sea-microsoft-tests-a-datacenter-thats-quick-to-deploy-could-provide-internet-connectivity-for-years/>, 06/2018]

[<https://news.microsoft.com/innovation-stories/project-natick-underwater-datacenter/>, 09/2020]

Infrastructure as a Service (IaaS)

■ Overview

- Resources for **compute**, **storage**, **networking** as a service
→ Virtualization as key enabler (simplicity and auto-scaling)
- **Target user:** sys admin / developer

■ Storage

- Amazon AWS Simple Storage Service (S3)
- OpenStack Object Storage (Swift)
- IBM Cloud Object Storage
- Microsoft Azure Blob Storage



■ Compute

- Amazon AWS Elastic Compute Cloud (EC2)
- Microsoft Azure Virtual Machines (VM)
- IBM Cloud Compute



Infrastructure as a Service (IaaS), cont.

■ Example AWS Setup

- Create user and security credentials

> **aws2** configure

```
AWS Access Key ID [None]: XXX
AWS Secret Access Key [None]: XXX
Default region name [None]: eu-central-1
Default output format [None]:
```

■ Example AWS S3 File Upload

- Setup and configure S3 bucket
- WebUI or cmd for interactions

> **aws2 s3** cp data s3://mboehm7datab/air \
--recursive

> **aws2 s3** ls s3://mboehm7datab/air \
--recursive

```
2019-12-05 15:26:45      20097 air/Airlines.csv
2019-12-05 15:26:45     260784 air/Airports.csv
2019-12-05 15:26:45      6355 air/Planes.csv
2019-12-05 15:26:45    1001153 air/Routes.csv
```

■ Example AWS EC2 Instance Lifecycle

> **aws2 ec2** allocate-hosts \
--instance-type m4.large \
--availability-zone eu-central-1a \
--quantity 2

Platform as a Service (PaaS)

Overview

- Provide **environment setup** (libraries, configuration), platforms, and services to specific applications → additional charges
- Target user:** developer

Example AWS Elastic MapReduce (EMR)

- Environment for Apache Hadoop, MapReduce, and **Spark** over S3 data, incl entire eco system of tools and libraries

```
> clusterId=$(aws emr create-cluster --applications Name=Spark \
--ec2-attributes ... --instance-type m4.large --instance-count 100 \
--steps '[{"Args":["spark-submit","--master","yarn","${sparkParams}"--class", \
"org.tugraz.sysds.api.DMLScript","./SystemDS.jar",-f,"./test.dml"], ...}]' \
--scale-down-behavior TERMINATE_AT_INSTANCE_HOUR --region eu-central-1)
```

```
> aws emr wait cluster-running --cluster-id $clusterId
```

```
> aws emr wait cluster-terminated --cluster-id $clusterId
```

Software as a Service (SaaS)

Overview

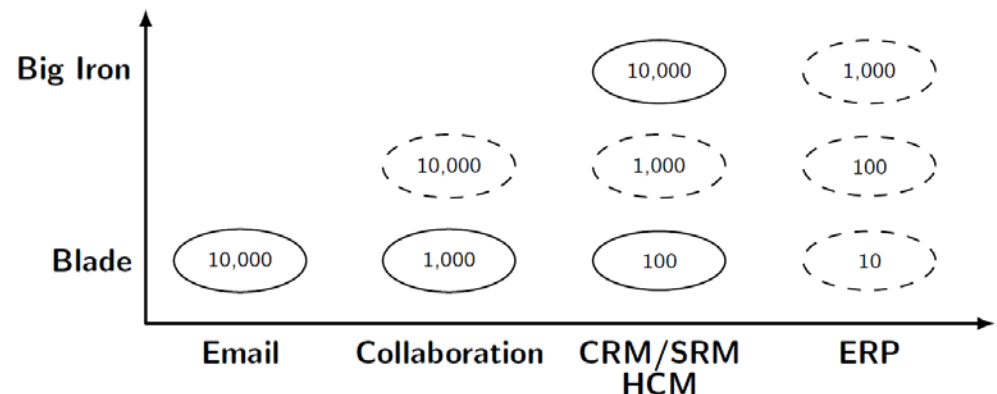
- Provide application as a service, often via simple web interfaces
- Challenges/opportunities: **multi-tenant systems** (privacy, scalability, learning)
- Target user:** end users

Examples

- Email/chat services: Google Mail (Gmail), Slack
- Writing and authoring services: Microsoft Office 365, Overleaf
- Enterprise: Salesforces, ERP as a service (SAP HANA Cloud)
- Database as a Service (DaaS)



[Stefan Aulbach, Torsten Grust, Dean Jacobs, Alfons Kemper, Jan Rittinger: Multi-tenant databases for software as a service: schema-mapping techniques. **SIGMOD 2008**]

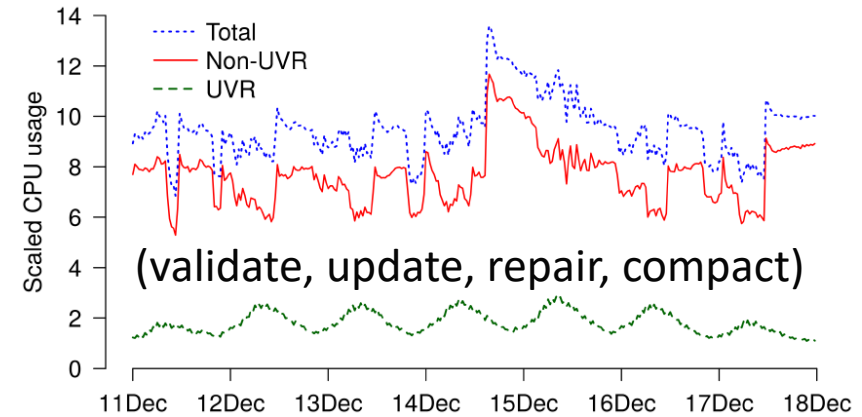
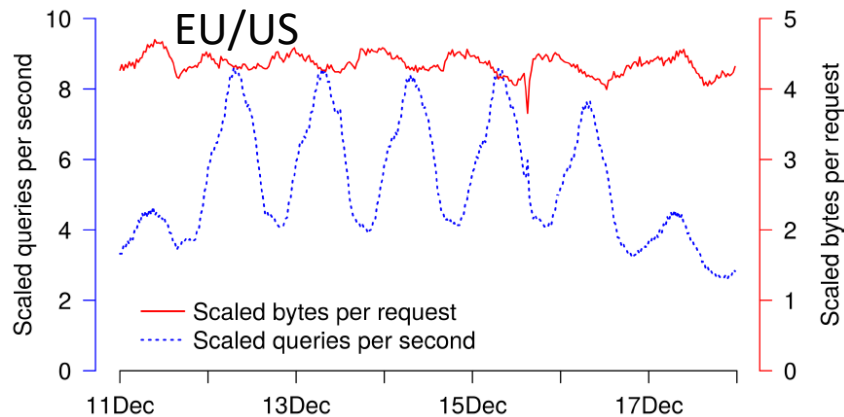


Software as a Service (SaaS)

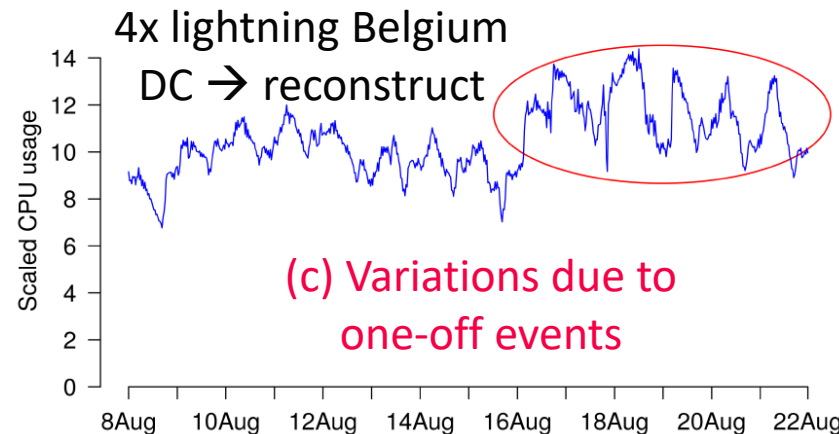
Performance Analysis on Gmail Data

- Coordinated bursty tracing via time
- Vertical context injection into kernel logs

[Dan Ardelean, Amer Diwan, Chandra Erdman: Performance Analysis of Cloud Applications. **NSDI 2018**]



(a) Variations in rate and mix of user visible requests (UVR)



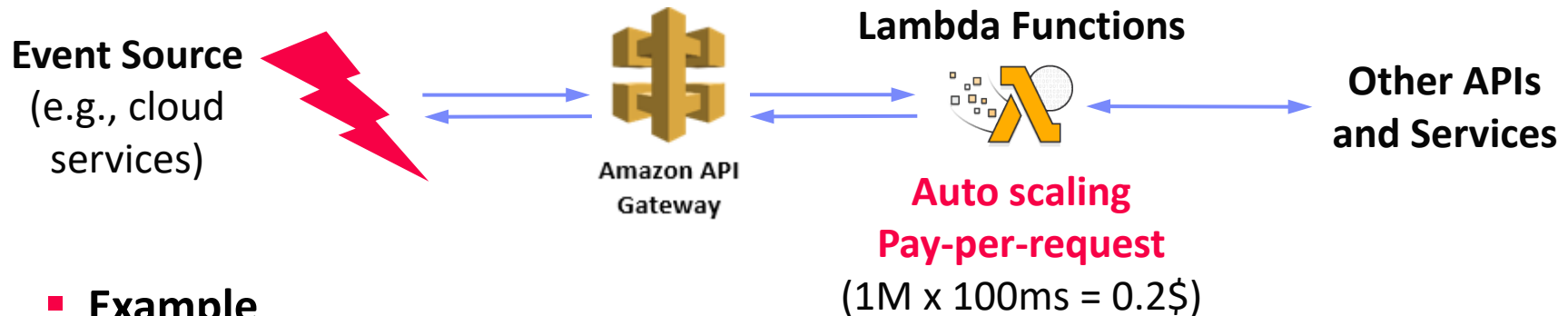
(c) Variations due to one-off events

(b) Variations in rate and mix of essential non-UVR work

Serverless Computing (FaaS)

Definition Serverless

- **FaaS:** functions-as-a-service (event-driven, stateless input-output mapping)
- Infrastructure for deployment and auto-scaling of APIs/functions
- Examples: [Amazon Lambda](#), [Microsoft Azure Functions](#), etc



Example

```
import com.amazonaws.services.lambda.runtime.Context;
import com.amazonaws.services.lambda.runtime.RequestHandler;

public class MyHandler implements RequestHandler<Tuple, MyResponse> {
    @Override
    public MyResponse handleRequest(Tuple input, Context context) {
        return expensiveStatelessComputation(input);
    }
}
```

Serverless Computing (FaaS), cont.

Advantages (One Step Forward)

[Joseph M. Hellerstein et al: Serverless Computing: **One Step Forward, Two Steps Back**. CIDR 2019]



- **Auto-scaling** (the workload drives the allocation and deallocation of resources)
- **Use cases: embarrassingly parallel functions, orchestration functions** (of proprietary auto scaling services), **function composition** (workflows)

Disadvantages (Two Steps Backward)

- **Lacks efficient data processing** (limited lifetime of state/caches, I/O bottlenecks due to lack of co-location)
- **Hinders distributed systems development** (communication through slow storage, no specialized hardware)

Func. Invoc. (1KB)	Lambda I/O (S3)	Lambda I/O (DynamoDB)	EC2 I/O (S3)	EC2 I/O (DynamoDB)	EC2 NW (0MQ)
303ms	108ms	11ms	106ms	11ms	290μs
1,045×	372×	37.9×	365×	37.9×	1×

➔ “Taken together, these challenges seem both interesting and surmountable. [...] Whether we call the new results ‘serverless computing’ or something else, the future is fluid.”

Example AWS Pricing (current gen)

as of 12/2019

■ Amazon EC2 (Elastic Compute Cloud)

- IaaS offering of different node types and generations
- **On-demand**, **reserved**, and **spot** instances

	vCores		Mem		
m4.large	2	6.5	8 GiB	EBS Only	\$0.117 per Hour
m4.xlarge	4	13	16 GiB	EBS Only	\$0.234 per Hour
m4.2xlarge	8	26	32 GiB	EBS Only	\$0.468 per Hour
m4.4xlarge	16	53.5	64 GiB	EBS Only	\$0.936 per Hour
m4.10xlarge	40	124.5	160 GiB	EBS Only	\$2.34 per Hour
m4.16xlarge	64	188	256 GiB	EBS Only	\$3.744 per Hour

■ Amazon ECS (Elastic Container Service)

- PaaS offering for Docker containers
- Automatic setup of Docker environment

Pricing according to EC2
(in EC2 launch mode)

■ Amazon EMR (Elastic Map Reduce)

- PaaS offering for Hadoop workloads
- Automatic setup of YARN, HDFS, and specialized frameworks like Spark
- **Prices in addition to EC2 prices**

m4.large	\$0.117 per Hour	\$0.03 per Hour
m4.xlarge	\$0.234 per Hour	\$0.06 per Hour
m4.2xlarge	\$0.468 per Hour	\$0.12 per Hour
m4.4xlarge	\$0.936 per Hour	\$0.24 per Hour
m4.10xlarge	\$2.34 per Hour	\$0.27 per Hour
m4.16xlarge	\$3.744 per Hour	\$0.27 per Hour

Example AWS Pricing (current gen), cont.

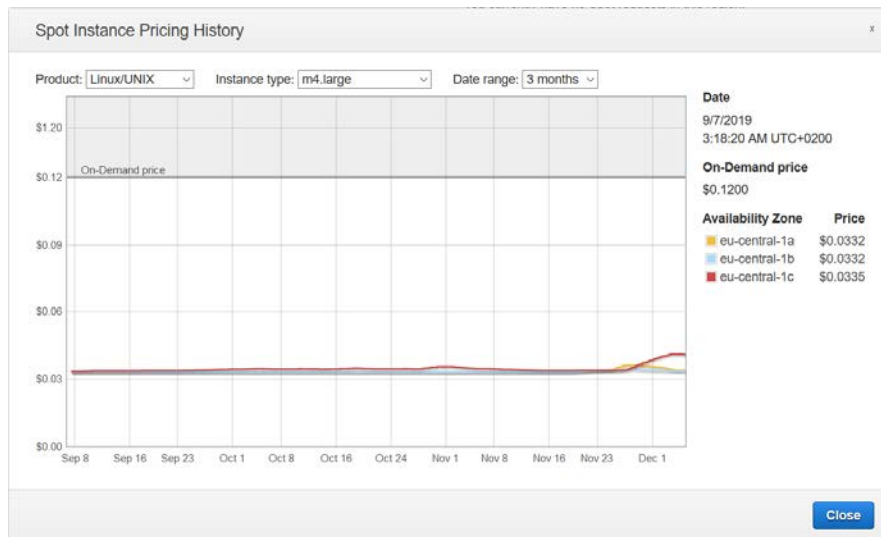
Spot Instances

- Unused cloud resources for much lower prices → bidding market
- Interruption behavior: hibernate, stop, terminate

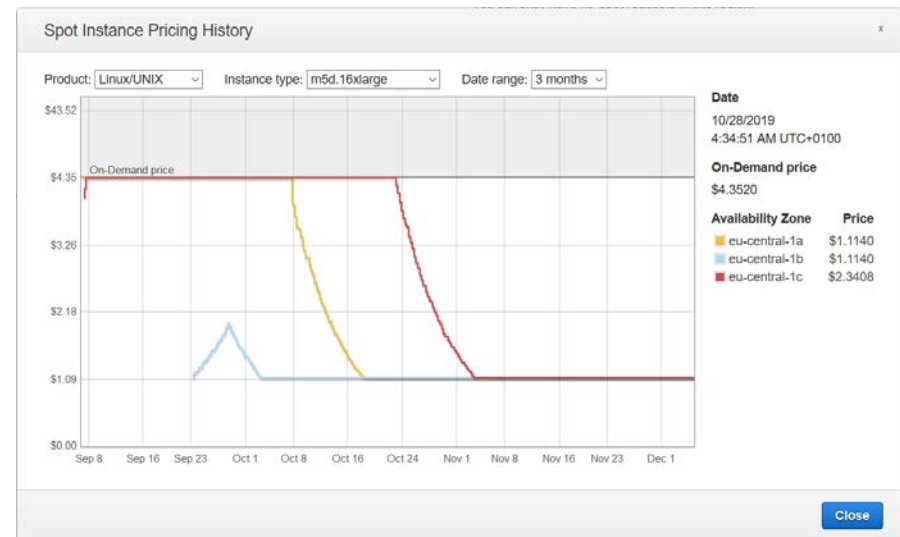
Self-regulating
effect

Example Instance Types

(m4.large, 2 vCPU, 8GB)



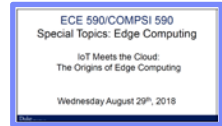
(m5d.24xlarge, 96 vCPU, 384GB)



[AWS EC2 Management Console, Spot Requests, Dec 05 2019]

Cloud, Fog, and Edge Computing

Cloud vs Fog vs Edge Overview



■ Overview Edge Computing

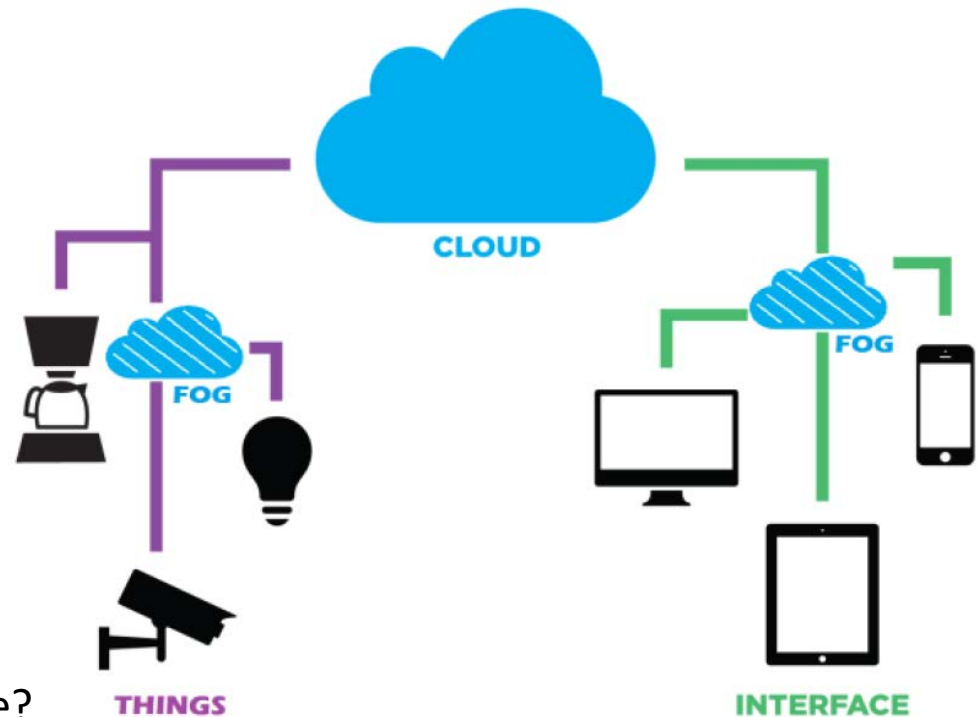
- Huge number of mobile / IoT devices
- Edge computing for **latency**, **bandwidth**, **privacy**

[Maria Gorlatova: Special Topics: Edge Computing; IoT Meets the Cloud – The Origins of Edge Computing, **Duke University 2018**]

■ Fog & Edge Computing

- Different degrees of application decentralization
- Reasons: **energy**, **performance**, **data**
- Natural hierarchy, heterogeneity
- Cloud as enabler for vibrant web ecosystem

→ **fog/edge for IoT** the same?



Example: AWS Greengrass

[Credit: https://aws.amazon.com/greengrass/?nc1=h_ls]



■ Overview AWS Greengrass

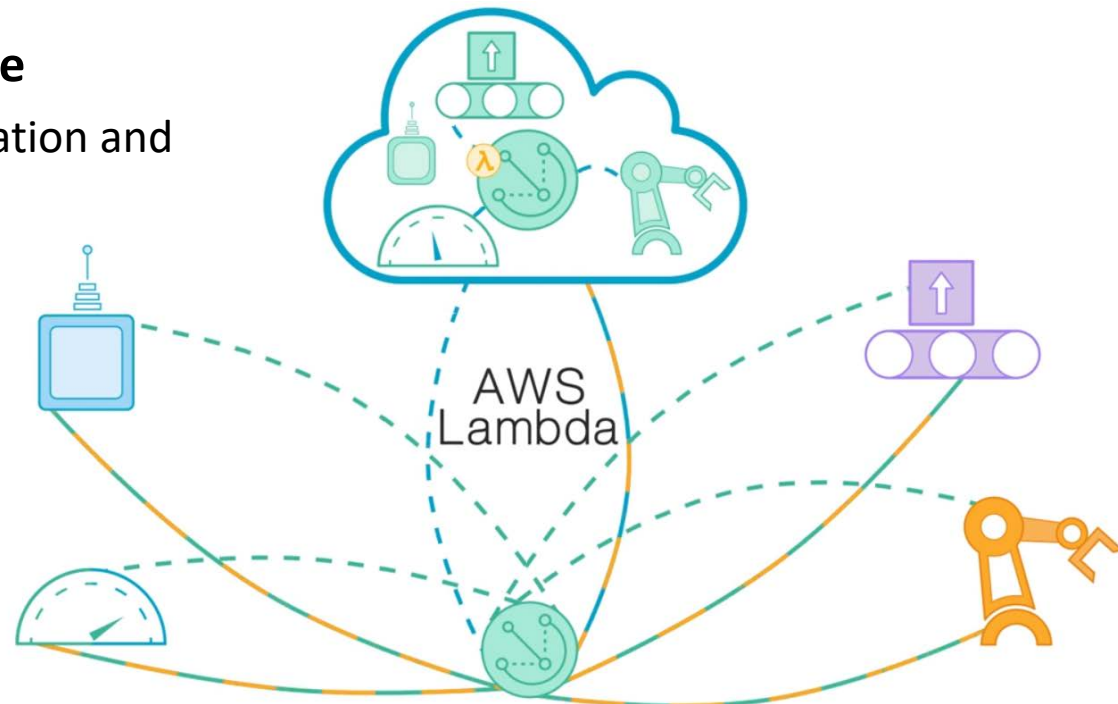
- Combine **cloud computing and groups of IoT devices**
- Cloud configuration, group cores, connected devices to groups
- Run lambda functions (FaaS) in cloud, fog, and edge – partial autonomy

■ System Architecture

- Central configuration and deployment
- Decentralized operation

Customer Use cases:

“My data doesn’t reach the cloud”



Excursus: Decentralized Infrastructure

Public/Private Infrastructure Projects

- Hierarchy of endpoints/data centers
- Analogy: **"City-Planning"**



Dan Ports
@danrkports

This is a fascinating data center disguised as a McMansion, and it can be yours for only \$989k!
[zillow.com/homedetails/13...](https://www.zillow.com/homedetails/13...)



10:37 PM · Jul 28, 2021 · Twitter Web App

[Credit:
University
of Maribor]



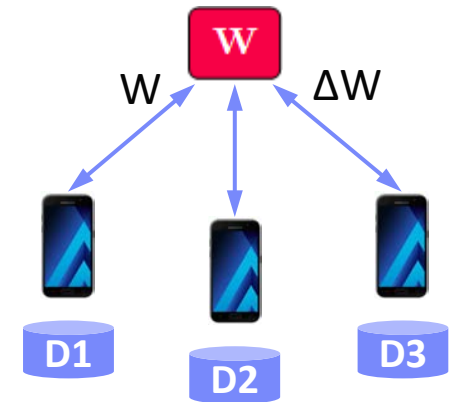
Federated ML

[Keith Bonawitz et al.: Towards Federated Learning at Scale: System Design. **SysML 2019**]



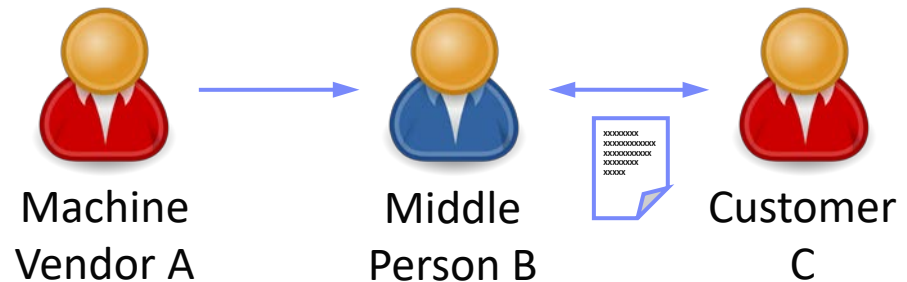
Overview Federated ML

- Learn model **w/o central data consolidation**
- Privacy** vs **personalization and sharing**
(example application: voice recognition)
- Adaptation of parameter server architecture, w/ random client sampling and **distributed agg.**
- Training when phone idle, charging, **and on WiFi**



Example Data Ownership

- Thought experiment:**
B uses machine from A to test C's equipment.
- Who owns the data?



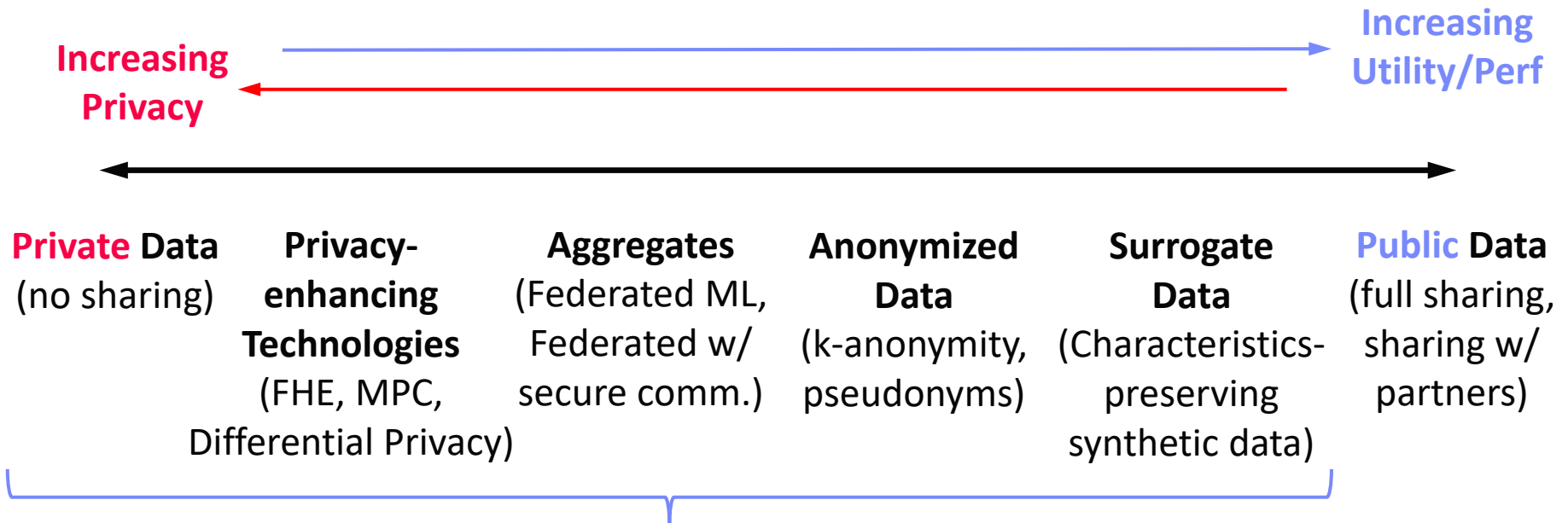
Negotiated in bilateral contracts

- Spectrum of Data Ownership:** Federated learning might create **new markets**

Spectrum of Data Sharing

■ Fine-grained Spectrum

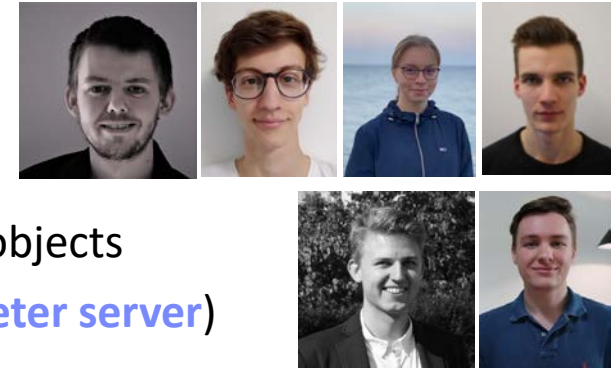
- Spectrum of technologies with **performance/privacy/utility** tradeoffs
- Different applications with different requirements
- **Potential:** New markets for data-driven services in this spectrum



Key Property: no reconstruction of private raw data

Federated Learning

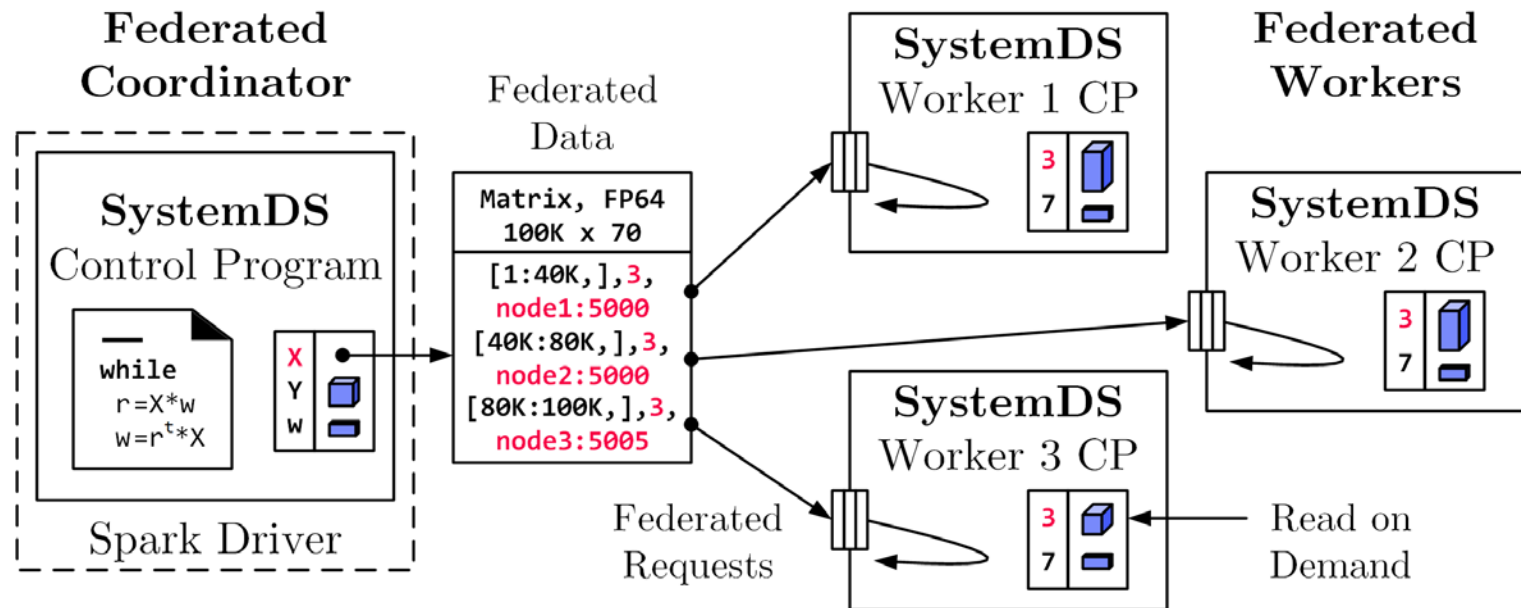
[SIGMOD 2021b]



Federated Backend

- **Federated data** (matrices/frames) as meta data objects
- **Federated linear algebra**, (and **federated parameter server**)

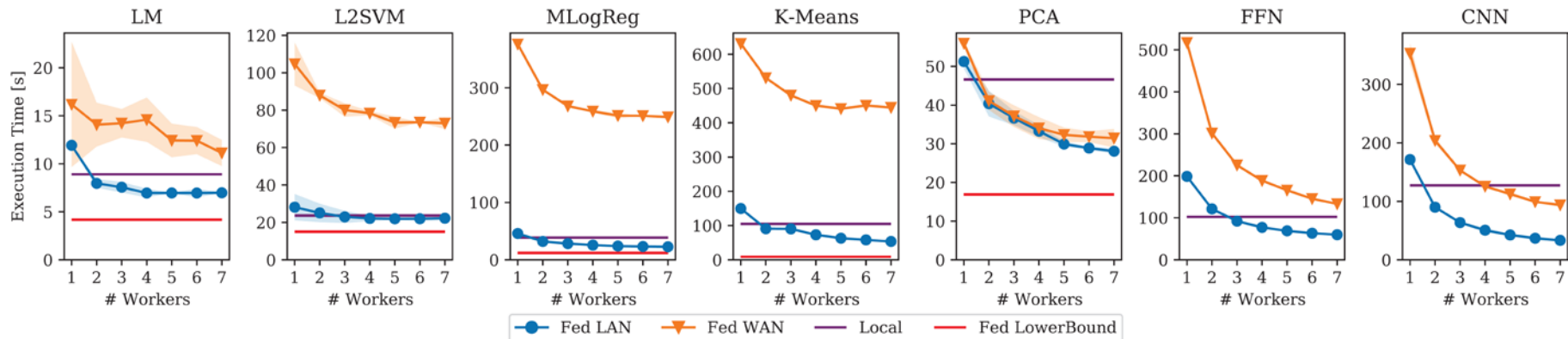
```
X = federated(addresses=list(node1, node2, node3),
              ranges=list(list(0,0), list(40K,70), ..., list(80K,0), list(100K,70)));
```



- **Federated Requests:** READ, PUT, GET, EXEC_INST, EXEC_UDF, CLEAR

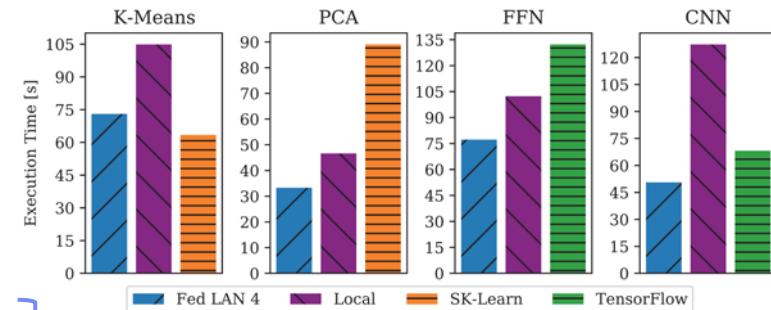
Federated Learning – Experiments

Copenhagen → Graz



Workloads and Baselines

- LM: linear regression, ImCG
- L2SVM: l2-regularized SVM
- MLogReg: multinomial logreg
- K-Means: Lloyd's alg. w/ K-Means++ init
- PCA: principal component analysis
- FFN: fully-connected feed-forward NN
- CNN: convolutional NN



Comparisons with
Scikit-learn and TensorFlow

Summary and Q&A

- **Cloud Computing Motivation and Terminology**
- **Cloud Computing Service Models**
- **Cloud, Fog, and Edge Computing**

- **Next Lectures**
 - **09 Cloud Resource Management and Scheduling** [Dec 03]
 - **10 Distributed Data Storage** [Dec 10]
 - **Holidays** (and programming projects/exercises)
 - **11 Distributed, Data-Parallel Computation** [Jan 07]
 - **12 Distributed Stream Processing** [Jan 14]
 - **13 Distributed Machine Learning Systems** [Jan 21]