

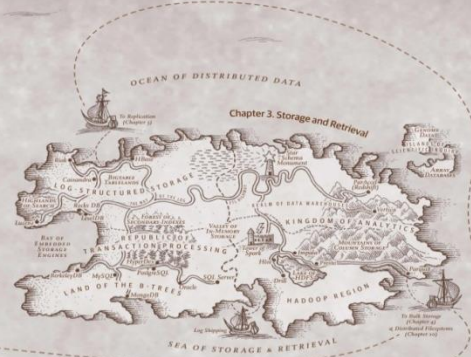
DESIGNING Data-Intensive Applications
 The big ideas behind reliable, scalable & maintainable systems

- RELIABILITY**
Tolerating hardware & software faults
Human error
- SCALABILITY**
Measuring load & performance
Latency decreases throughput
- MAINTAINABILITY**
Operability, simplicity & evolvability

Chapter 1. Reliable, Scalable, and Maintainable Applications



Chapter 2. Data Models and Query Languages



Chapter 3. Storage and Retrieval



Chapter 7. Transactions



Chapter 4. Encoding and Evolution



Chapter 9. Consistency and Consensus



Chapter 8. The Trouble with Distributed Systems



Chapter 8. The Trouble with Distributed Systems

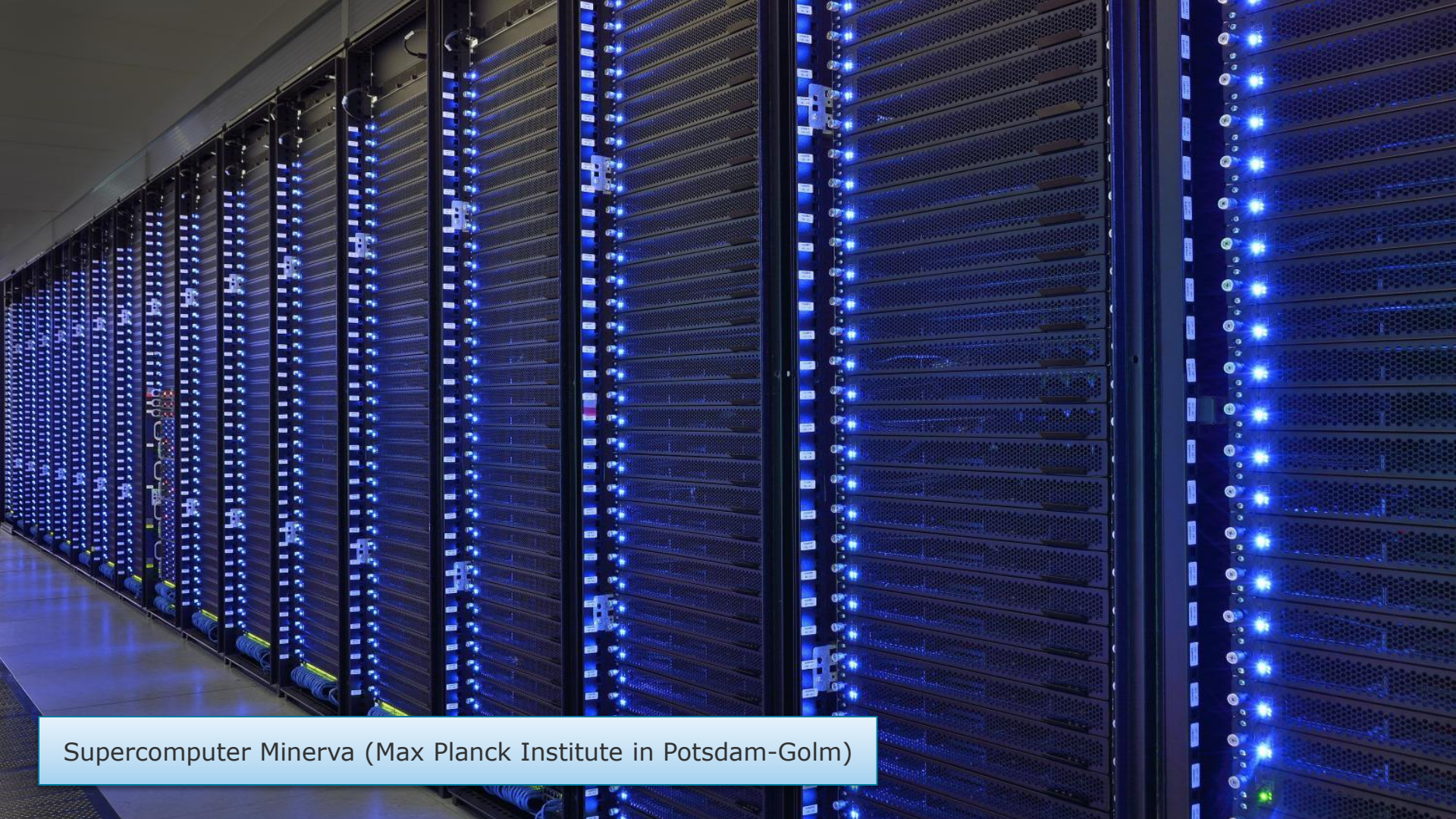


Distributed Data Management Introduction

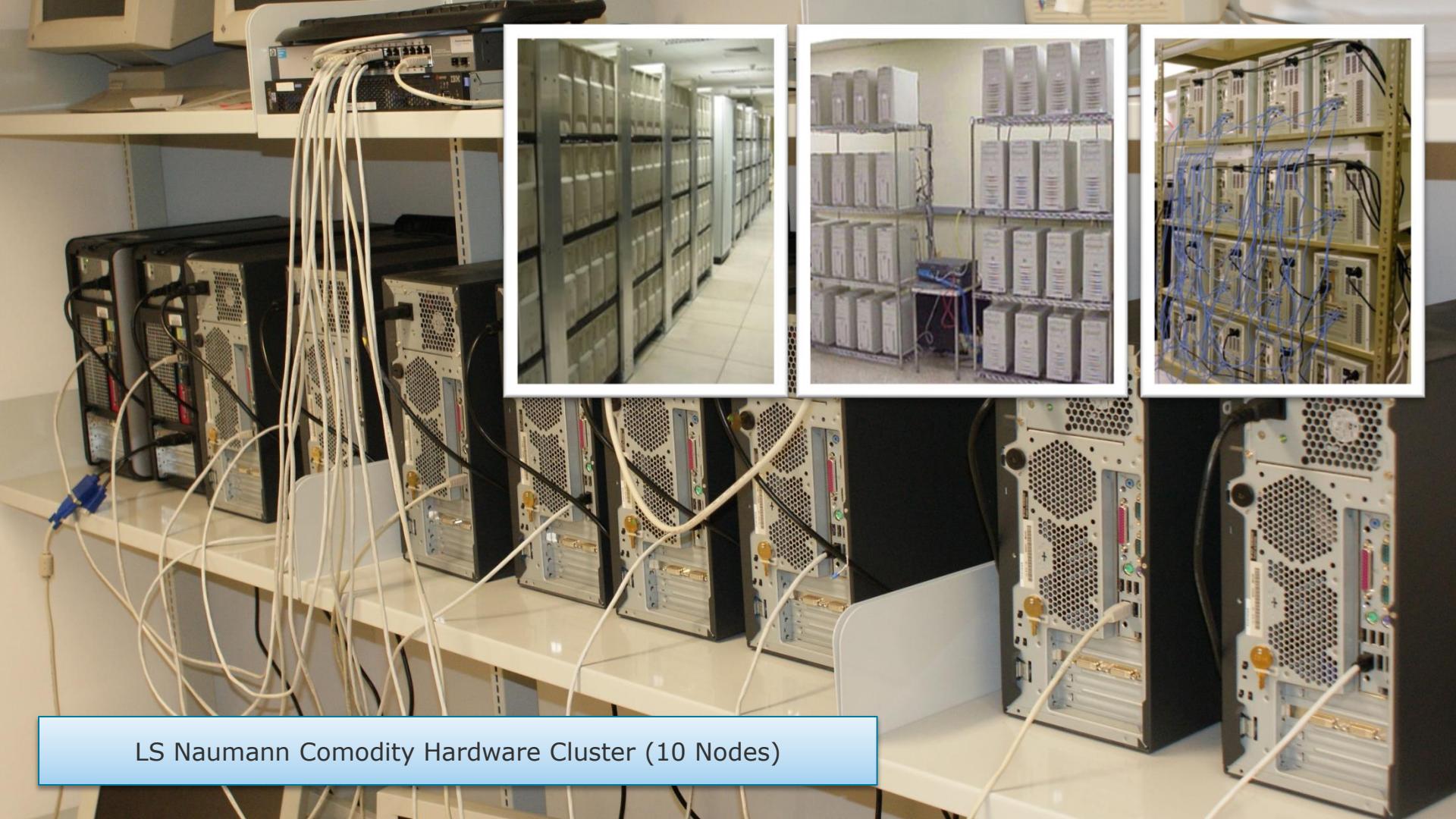
Thorsten Papenbrock

F-2.04, Campus II

Hasso Plattner Institut



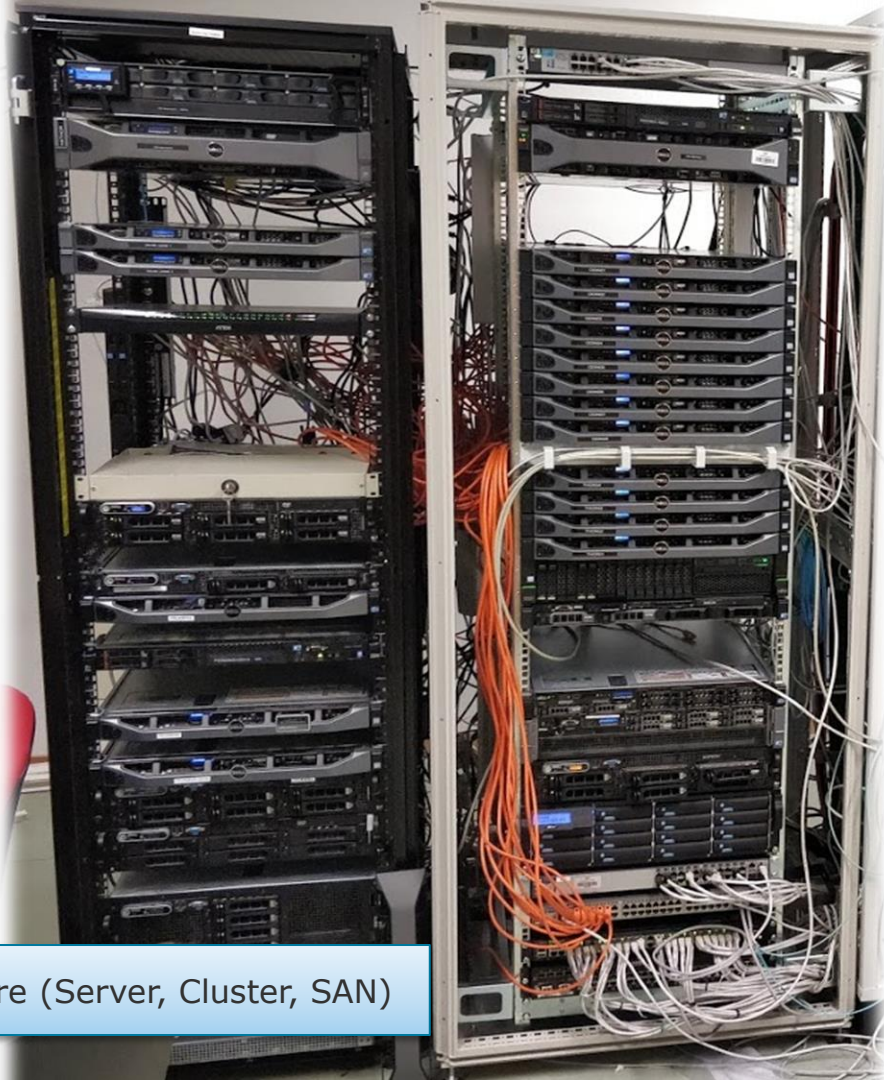
Supercomputer Minerva (Max Planck Institute in Potsdam-Golm)



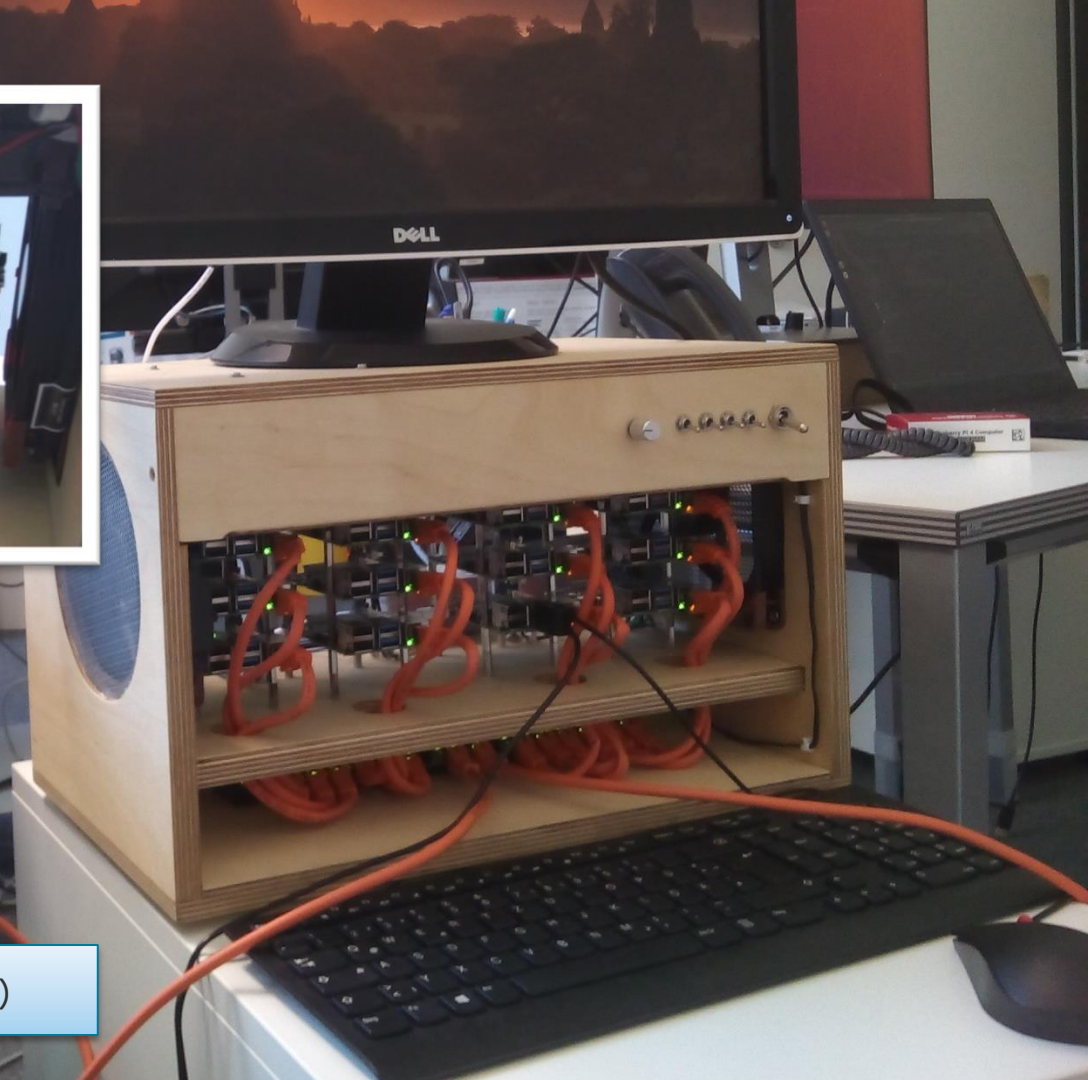
LS Naumann Comodity Hardware Cluster (10 Nodes)



Desktop Computer (multiple CPUs and GPUs)



LS Naumann Infrastructure (Server, Cluster, SAN)



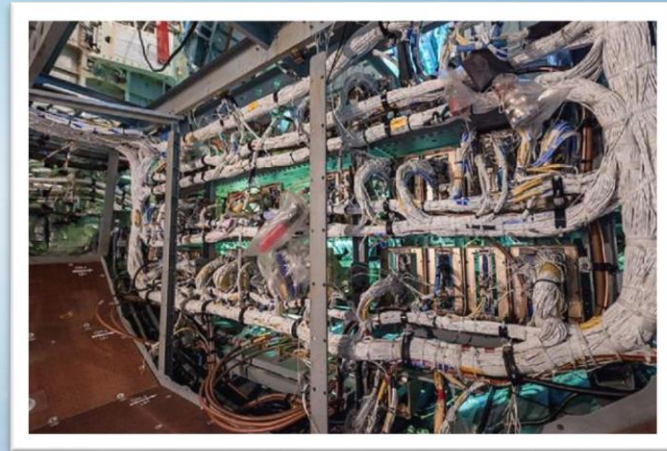
LS Naumann PI Cluster (12 Raspberry PI 4)

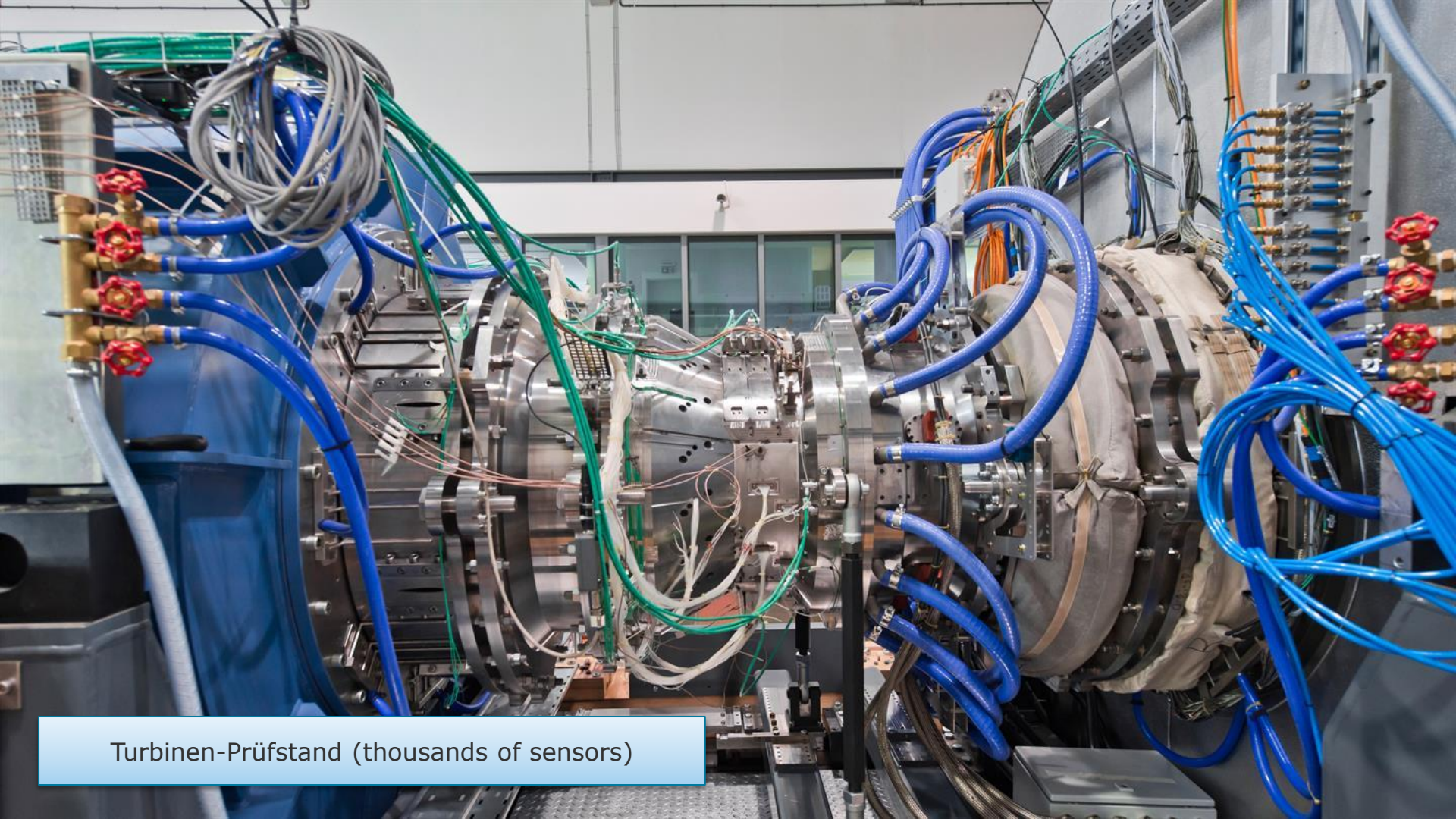


DreamHack (12,000-computer LAN party)



Boeing 747 (thousands of computers)





Turbinen-Prüfstand (thousands of sensors)

Startpage.com



The world's **most private** search engine

Startpage (search engine backed by other search engines)

Outdated Data

Concurrency

Consensus

Lost & Invalid Messages

Termination

Introduction

- Examples Distributed Systems
- **Lecture Organization**
- Motivation “Distributed”
- Motivation “Data”
- Motivation “Management”





Dr. Thorsten Papenbrock



Diana Stephan

Service-Oriented Systems



Prof. Felix Naumann

project DuDe
Data Fusion



Dr. Ralf Krestel

Data Scrubbing



Tim Repke

Entity Search



Julian Risch



Phillip Wenig

Distributed Computing

project Metanome

Agile Systems

Information Integration

Duplicate Detection

Data Profiling

Dependency Detection

Entity Recognition

project DataChEx

Linked Open Data

Data Change

Change Exploration

Data as a Service

Data Cleansing

Web Data

Opinion Mining

Web Science

Text Mining

RDF Data Mining

ETL Management

Data Preparation



Nitisha Jain



Hazar Harmouch



John Koumarelas



Tobias Bleifuß



Leon Bornemann



Lan Jiang



Michael Loster



Which semester?

ITSE, DE, DH?

English?

Database knowledge?

HPI or Guest?

Distributed experience?

Other related lectures?

- > **Datenbanksysteme II** (VL, Bachelor)
- > **Information Integration** (VL, Master)
- > **Distributed Data Management** (VL, Master)
- > **Data Engineering in Practice** (VL, Bachelor/Master)
- > **Paint it Black: Ethik in der Datenanalyse** (S, Bachelor)
- > **Paint it Black: Ethical Data Analytics** (S, Master)
- > **Machine Learning for Data Streams** (S, Master)
- > **Genealogy of Natural Language** (Masterproject)
- > **Data Analytics** - Museumserlebnisse mit Datenanalyse optimieren (Bachelorprojekt)
 - > In Kooperation mit dem **Museum Barberini**

<https://hpi.de/naumann/teaching/current-courses.html>

Distributed Data Management

Introduction

ThorstenPapenbrock
Slide **15**

Distributed Data Management

This Lecture

Lecture

- For master students
(IT-Systems Engineering,
Digital Health, Data Engineering)
- 6 credit points, 4 SWS
- Mondays 13:30 – 15:00
Tuesdays 15:15 – 16:45

Exercises

- Interleaved with lectures

Slides

- On website

Website

- <https://hpi.de/naumann/teaching/teaching/ws-1920/distributed-data-management-vl-master.html>

Prerequisites

- To participate:
A little background and interest in
databases (e.g. DBS I lecture);
object oriented programming skills
- For exam:
Attending lectures, participation in
exercises, and completion of
exercise homework tasks

Exam

- Written exam
- Probably first week after lectures

**Distributed Data
Management**

Introduction

ThorstenPapenbrock
Slide **16**

Question any time please!

- During lectures
- Visit us: Campus II, Room F-2.04
- Email:
 - thorsten.papenbrock@hpi.de

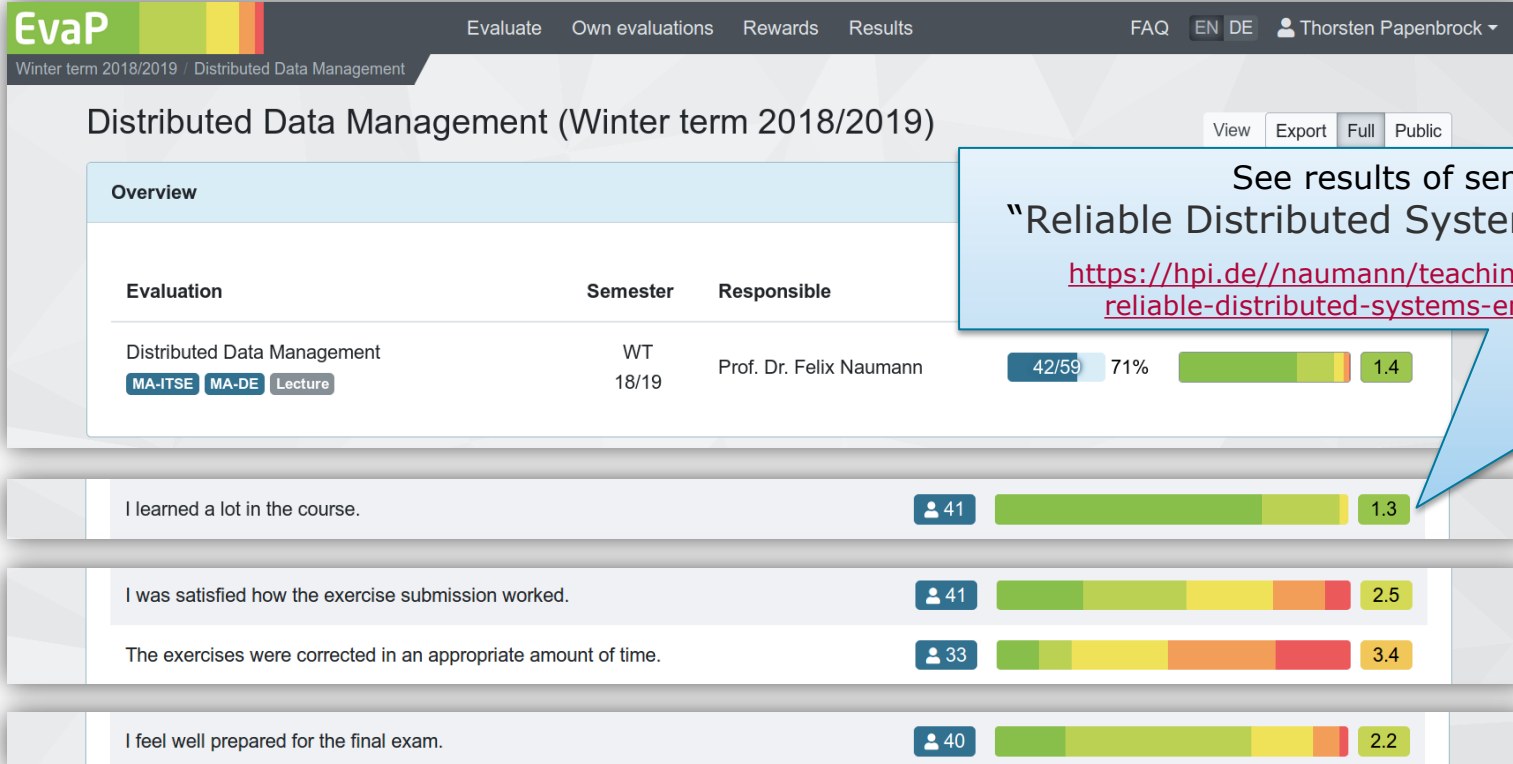
Also: Give feedback about ...

- improving lectures
- informational material
- organization

Official evaluation

- At the end of this semester
- ... too late for important feedback!

Distributed Data Management Feedback



**Distributed Data
Management**

Introduction

Thorsten Papenbrock
Slide 18

How could the course be further improved?

- Teilweise sollte der Stoff entschlackt werden. Es wurde **wirklich sehr viel** behandelt. Teilweise merkte man Thorsten zu Ende einer Vorlesung an, dass er schneller und schneller wurde, um bloß noch den Stoff dieser Vorlesung durchzubringen. Ebenso ist die Klausurvorbereitung somit extrem zeitintensiv.

Leider lief das Check-Yourself-Teil sehr schlecht. Tobias stand zu Fragen via Mail nicht zur Verfügung. Lösungen kamen ab ca. der Mitte des Semesters nur noch sehr sporadisch und zuletzt überhaupt nicht mehr. Schade!

- Time spend on Flink. Structure in which concepts are explained. Make connections to other already known concepts and describe the differences. Or give a quick overview at first and then dive into the -important- details.
- - Lösungen der Check yourselves rechtzeitig zusenden
 - Übung frühzeitig kontrollieren
 - wenn man eine Übung vorstellen soll, bescheid geben, damit man auch anwesend sein kann
- Teilweise wenig technisch. Außerdem sind die Folien verbesserungswürdig. Sie haben zu viele Überschriften, zu viele Bilder die mit dem Thema nur im übertragenen Sinne zu tun haben. Zu viele Schriftfarben. Zu wenig leicht ersichtliche Gliederung. Sie sind oft nach dem Schema: Lösung1, Lösung2, Lösung3, LösungX, ... aufgebaut. Ideal wäre aber eine manchmal deutlichere Motivation des Problems, ein kurzes heads up, dass es drei Lösungen gibt und dann eine deutlich abgegrenzte Besprechung der drei Lösungen. Diese gehen teilweise etwas ineinander über.
- - Especially with the DDM+ slides at the end, it might be worth thinking about adding that content and then splitting it into two lectures? The current lecture already has **a ton of content**, so it might make sense to go deeper on slightly fewer topics
- Es ist sooo viel. Ich würde mir vielleicht eine kleinere Klausur wünschen, mündlich zum Beispiel (in einer Gruppe?). Dann müsste man nicht nochmal coden und irgendwelche query languages auswendig lernen. :)
- Keine Klausur
- - Zwischenklausur halten, weil es **wirklich sehr viel Inhalt** war.
 - Übungsevaluierung ist etwas unklar, gibt es nur bestanden oder nicht, wo ist die Grenze?
- The **content of the course are very broad**, missed possibilities to dive deeper into a topic, since the workload was already quite high.
- Die Vorlesung war für meinen Geschmack **zu umfangreich**.
- Die Lösungen der Check Yourself Aufgaben haben zum Teil sehr lange auf sich warten lassen, sodass einem die Thematik der zu bearbeitenden Aufgaben nicht mehr genau im Kopf war, wenn es die Lösung gab.
- Point out the motivation more. Like, tell us in the beginning of each set of slides why we are talking about this topic in respect to the scope of the lecture. That would help a lot to know where we are and why we should learn und understand this topic.
- - fragen für die teletask aufzeichnung wiederholen

Distributed Data Management

Lecture Outline (2018 !)

1. Introduction
2. Foundations
3. OLAP and OLTP
4. Encoding and Evolution
5. Hands-On: Akka
6. Data Models and Query Languages
7. Storage and Retrieval
8. Replication
9. Partitioning
10. Batch Processing
11. Hands-On: Spark



12. Distributed Systems
13. Consistency and Consensus
14. Transactions
15. Stream Processing
16. Hands on: Flink
17. Mining Data Streams
18. Distributed Algorithms
19. Services and Containerization
20. Cloud-based Data Systems
21. Lecture Summary and Exam Preparation



Apache Flink

Distributed Data Management

Introduction

ThorstenPapenbrock
Slide **20**

Distributed Data Management Lecture Outline (2018 !) – Homework

1. Introduction
2. Foundations
3. OLAP and OLTP
4. Encoding and Evolution
5. Hands-On: Akka
6. Data Models and Query Languages
7. Storage and Retrieval
8. Replication
9. Partitioning
10. Batch Processing
11. Hands-On: Spark



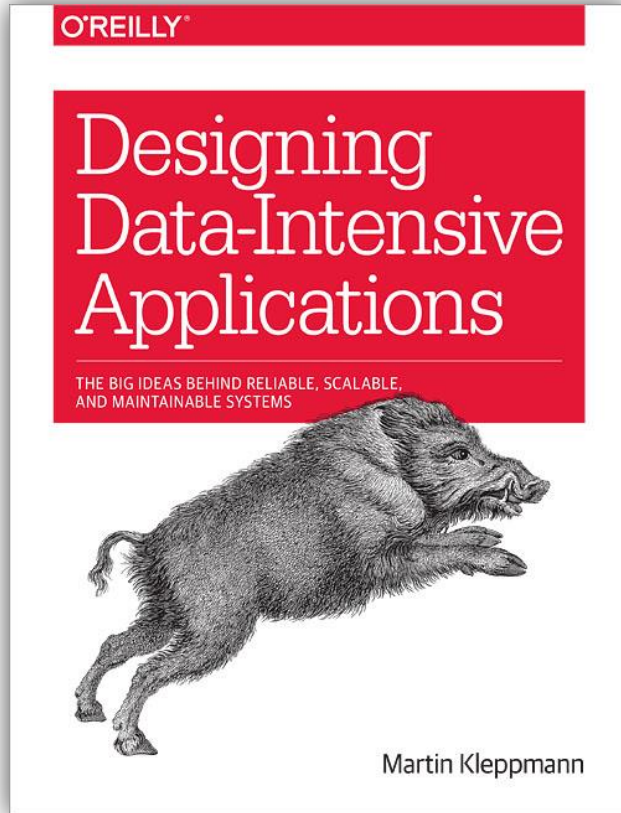
12. Distributed Systems
13. Consistency and Consensus
14. Transactions
15. Stream Processing
16. Hands on: Flink
17. Mining Data Streams
18. Distributed Algorithms
19. Services and Containerization
20. Cloud-based Data Systems
21. Lecture Summary and Exam Preparation



**Distributed Data
Management**

Introduction

ThorstenPapenbrock
Slide **21**



Designing Data-Intensive Applications

- Author: Martin Kleppmann
- Date: March 2017
- Publisher: O'Reilly Media, Inc
- ISBN: 978-1-449-37332-0
- References:
<https://github.com/ept/ddia-references>

Scope for this lecture

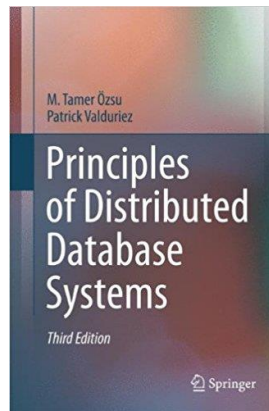
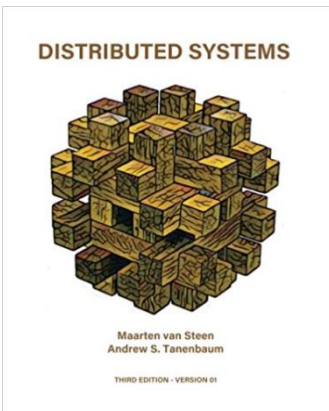
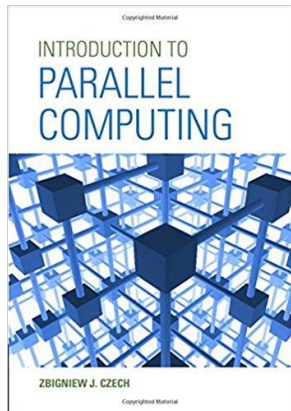
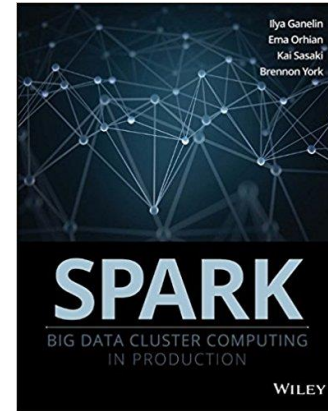
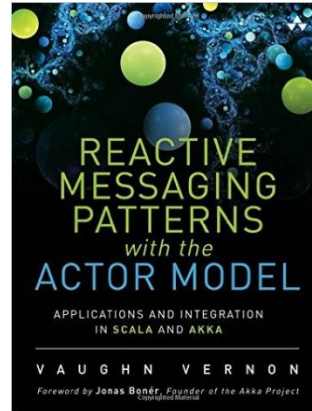
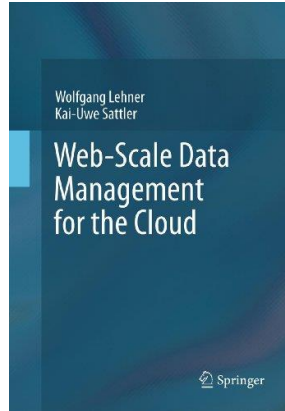
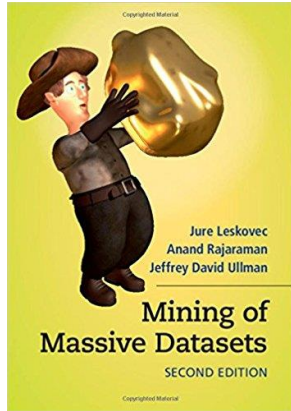
- Distributed and parallel systems
- Big data storage
- Batch and stream processing

Distributed Data Management

Introduction

Thorsten Papenbrock
Slide **22**

Distributed Data Management Literature: Further Reading



And Web-links that are given on the slides during the lecture.

Distributed Data Management

Introduction

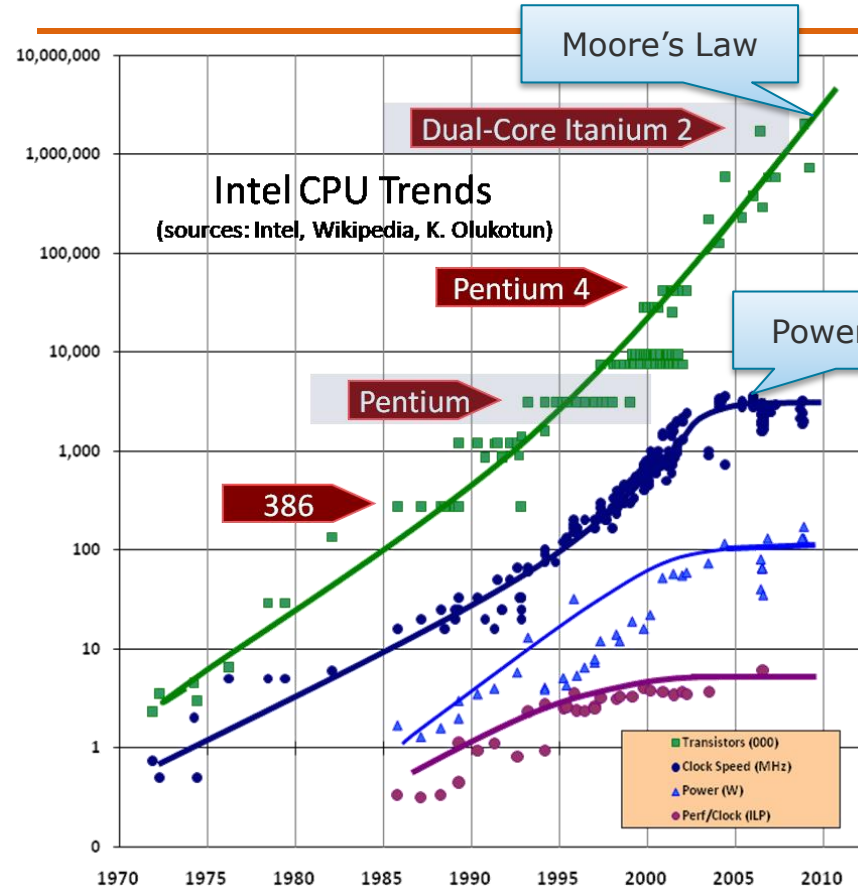
ThorstenPapenbrock
Slide 23

Introduction

- Examples Distributed Systems
- Lecture Organization
- **Motivation “Distributed”**
- Motivation “Data”
- Motivation “Management”



Motivation: "Distributed" Paradigm Shift in Software-Writing



The free lunch is over!

- Clock speeds stall
- Transistor numbers still increase
 - Cores in CPUs/GPUs
 - CPUs/GPUs in compute nodes, compute nodes in clusters
- Paradigm Shift:
 - Earlier: optimize code for a single thread
 - Now: solve tasks in parallel

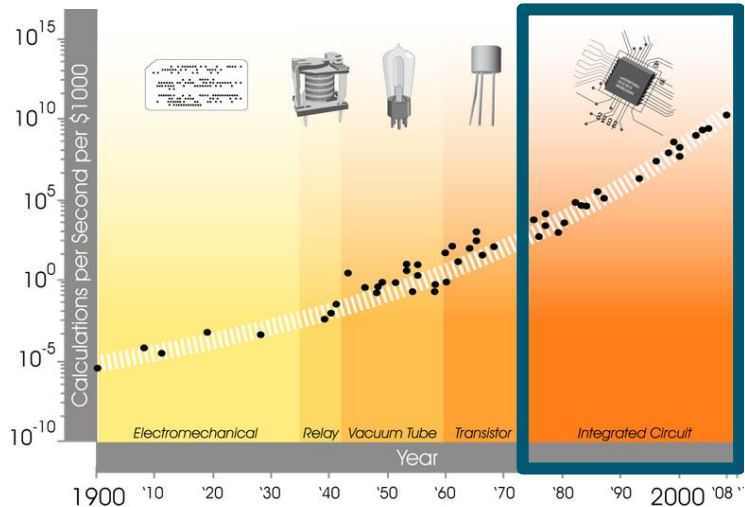
Distributed computing

"Distribution of work on (potentially) physically isolated compute nodes"

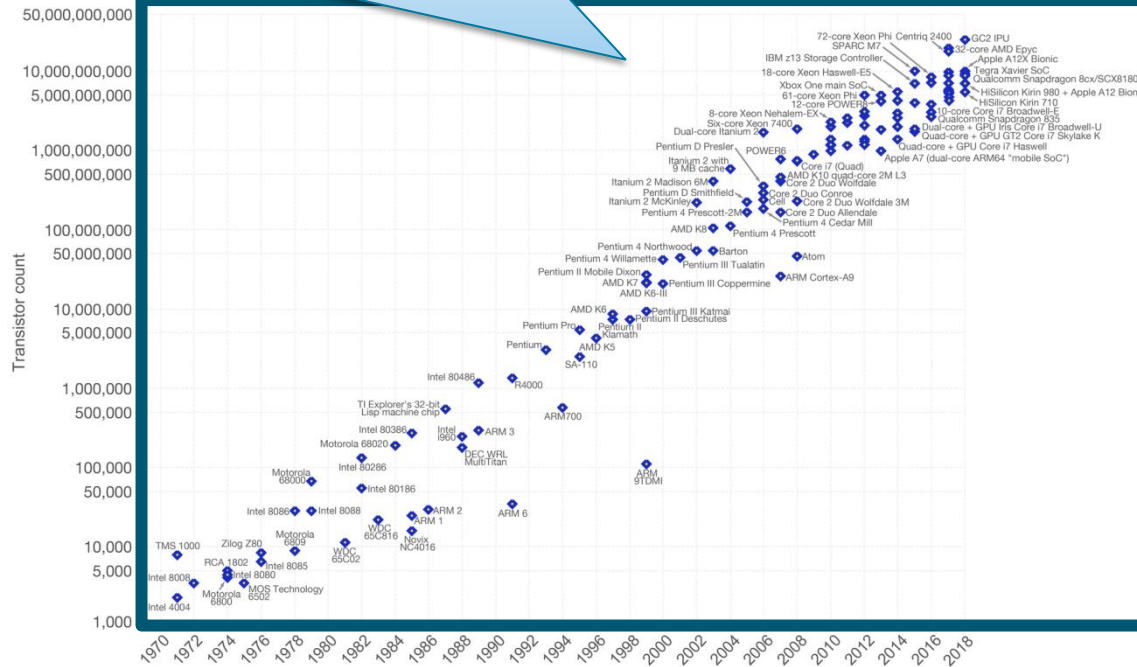
Motivation: "Distributed" Surpassing Moore's Law

Moore's Law (Observation)

"The number of transistors on integrated circuit chips doubles approximately every two years"



Hyperscale: With clusters of **distributed machines**, we can already build systems with any number of transistors!
(don't even need to wait for a new processors)



Data source: Wikipedia (https://en.wikipedia.org/wiki/Transistor_count)
The data visualization is available at OurWorldinData.org. There you find more visualizations and research on this topic.

High Performance and Hyperscale Computing

- High Performance Computing (HPC)

- Super computers
 - Specialized hardware (NUMA systems)
 - Heterogeneous hardware (FPGAs, GPUs, etc.)
- Precision matters
 - Floating points per second (FLOPS)
- Scientific and analytical use cases
 - OLAP, simulations, forecasts, machine learning, data mining, ...

Both use distributed computing!

- Hyperscale Computing

- Standard computers
 - Fast commodity servers
- Response time, availability and throughput matters
 - X-percentile response time, queries-per-second, ...
- Scalable systems (and analytical) use cases
 - OLTP, web services, application hosting, cloud, data transformation, ...

Distributed Data Management

Introduction

ThorstenPapenbrock
Slide **27**

Motivation: "Distributed" A Rule to Acknowledge

Amdahl's Law

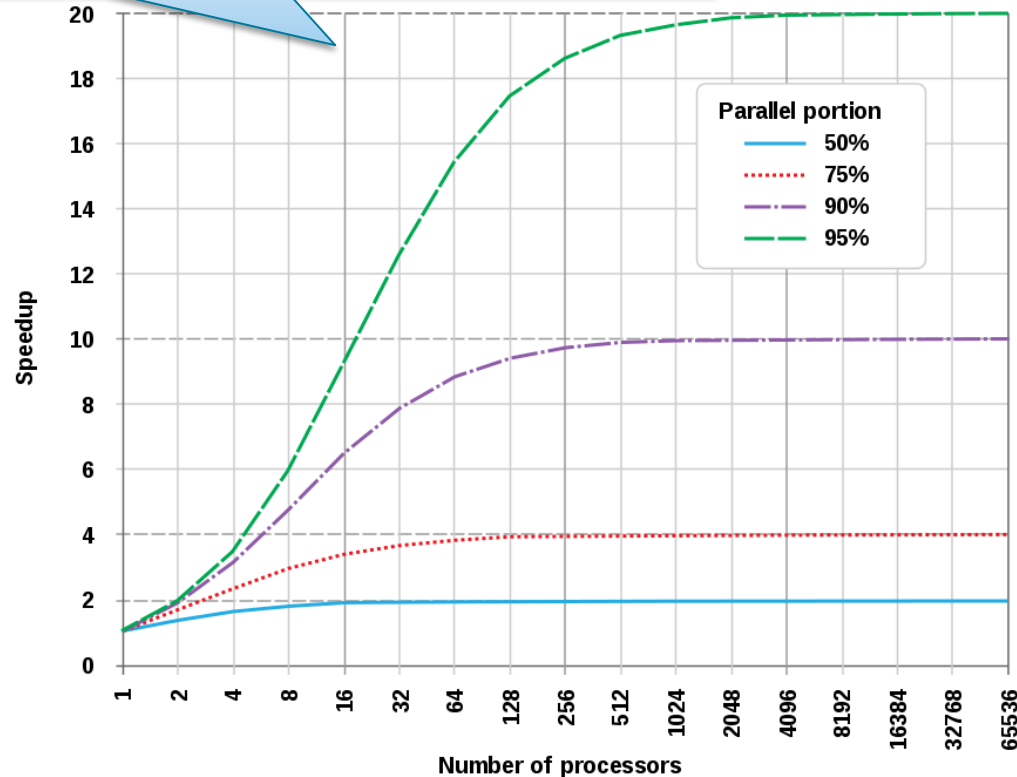
"The speedup of a program using multiple processors for parallel computing is limited by the sequential fraction of the program"

$$Speedup(s) = \frac{1}{(1 - p) + \frac{p}{s}}$$

s: degree of parallelization (e.g. #cores)

p: percentage of the algorithm that profits from parallelization

Even **distributed parallelization** cannot work around this law!

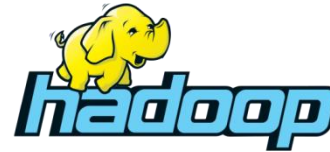


Motivation: "Distributed" New Technologies

Distributed Computing



Distributed Storage



**Distributed Data
Management**

Introduction

ThorstenPapenbrock
Slide 29

BIG DATA & AI LANDSCAPE 2018



INFRASTRUCTURE

HADOOP ON-PREMISE
 cloudera Hortonworks
 MAAP Pivotal
 IBM InfoSphere
 bluedata jethro

HADOOP IN THE CLOUD
 aws Microsoft Azure
 Google Cloud IBM InfoSphere
 CAZENA CenturyLink

STREAMING / IN-MEMORY
 aws databricks stream
 confluent gtdain
 dataartisans
 CHACALA hazelcast TERRACOTTA

NoSQL DATABASES
 Google Cloud aws
 ORACLE Microsoft Azure
 mongoDB MarkLogic
 KODIGO DATASTAR
 ASAPDB Couchbase
 redislabs SCYLLA

NewSQL DATABASES
 SAP Clustrix Pivotal
 Cockroach Labs
 MEMSQL InfluxData
 Amazon Redshift
 Amazon Neptune
 Amazon RDS
 Amazon ElastiCache

GRAPH DBs
 neo4j
 Amazon Neptune
 ORACLE
 GraphSense

MPP DBs
 TERADATA
 IBM Data Warehouse
 Microsoft Azure
 Oracle
 Amazon Redshift
 SAP
 Pivotal
 Exasol
 Greenplum

CLOUD EDW
 aws
 Google Cloud
 Pivotal
 Snowflake
 Infoworks

ANALYTICS

DATA ANALYST PLATFORMS
 Microsoft pentaho alteryx
 Qlikview QUAVUS AYASDI
 ATTIVO Datameer Quid Incofa
 interana ClearStory Origami
 ENDOR MORE Bonfirebase

DATA SCIENCE PLATFORMS
 IBM KNIME dataiku
 DOMINO rapidminer
 CONTINUUM ANALYTICS ALGORITHMIA
 DATAWATCH ZANDREX

BI PLATFORMS
 Microsoft aws
 SAP
 Google Cloud
 Looker AT SCALE
 GoodData birst

VISUALIZATION
 tableau SAP
 Google Cloud
 Qlik
 ZEPH
 CHARTIO

MACHINE LEARNING
 aws
 Google Cloud H2O
 DataRobot gamaloni
 ELEMENT VISENZE
 bonal

COMPUTER VISION
 Microsoft Azure
 Amazon Rekognition
 clarifai
 EVER AI deepomatic
 twentyfour

HORIZONTAL AI
 IBM Watson Cortana
 IBM Watson
 i Affected PROGRESSIVE
 auctus FETUM
 nardiqes ORION AI OSAR

SPEECH & NLP
 Google Cloud twitter
 Amazon Alexa
 semantich
 Soundbound Inc.
 Blindsight
 Myooq
 snippets

APPLICATIONS – ENTERPRISE

SALES
 Oracle CHORUS
 INSIDESALES.COM
 conversica
 clari aviso tact.ai
 fuselab machines TRADERS

MARKETING - B2B
 RADIUS App Annie
 EVERSTRING Lattice
 HINTIGO sense
 tubular Dataiku
 JENGA IO Reflexion

MARKETING - B2C
 bloomreach SendGrid
 BlueYonder [PARSAO] Digipulse
 ACTIONIQ SALUTRU BLUECORE
 QUANTIPIC importico Amperio
 amperity

CUSTOMER SERVICE
 MEDALLIA zendesk
 CLARABRIDGE
 Gainsight NGC DATA
 DigitalGenius ahfrnti
 AUTOMATN Frame AI
 Cyma INTERCOM

HUMAN CAPITAL
 entelo
 hiQ
 letrix
 Workday
 mya incommerce

LEGAL
 RAVEL
 Lexipol
 JUDICIALIA
 LEGALWATERS
 R. S S
 CASETEXT

FINANCE
 Anaplan
 ZUORA
 TRADESHIFT

ENTERPRISE PRODUCTIVITY
 slack
 ZUORA
 oracle
 JIRA
 claars
 butter ai Kasisto

BACK OFFICE AUTOMATION
 UiPath
 RPA
 Kofax
 AppZen
 WorkFusion

SECURITY
 TANUKI illumio COBE42 CyberCloud
 StackPath ANOMAL ProxyMesh AEMETRA
 IBM Security
 DATAVISION
 SANSIYF SentinelOne SouthSecure secure
 BlueTalon **FEEDZOO** cisco
 ACCEL
 CyberScope

DATA TRANSFORMATION
 talend pentaho
 alteryx TRIPACTA
 tamar
 StreamSets UNIFI

DATA INTEGRATION
 Informatica Microsoft
 snaplogic
 segment
 xiperty

DATA GOVERNANCE
 IBM
 Alation
 Waterline

MGMT / MONITORING
 AWS AWS New Relic
 rubrik
 HUMANIX
 spunk Signalix
 Monitix
 paperkitly Humanyly

SEARCH
 ORACLE
 ELASTICSEARCH
 SOLR
 COVEO
 SWIFTLY
 alphasphere
 omnius SINEQUA

LOG ANALYTICS
 splunk
 SUMOLOGIC
 LOGGY
 HIBANA
 libanao
 logs.io

SOCIAL ANALYTICS
 Hootsuite sprinklr
 NETBASE
 Synthesio
 simplereach
 bitly predata
 SimilarWeb

WEB / MOBILE / COMMERCE ANALYTICS
 Google Analytics
 mixpanel AMPUTAGE
 sumall
 RESCI
 SIGSPOT
 granify custora

APPLICATIONS – INDUSTRY

ADVERTISING
 AppNexus
 critical Ad
 Oracle
 theTradeDesk
 distillery
 ATLAS
 Optimor

EDUCATION
 Canvas LMS
 Clever
 Edmentum
 Blackboard
 FutureLearn
 FutureLearn
 FutureLearn

GOVERNMENT
 OPENGOV
 mark43
 FISCAL Note
 OpenText

FINANCE - LENDING
 ondeck Affirm
 KREDITCHECK AVANT
 FORTIS JIANPUAI
 FORTIS JIANPUAI
 FORTIS JIANPUAI
 FORTIS JIANPUAI
 FORTIS JIANPUAI

REAL ESTATE
 REDFIN
 Opendoor
 CREDICOM
 reonomy
 COMPTONX
 CAPE

INSURANCE
 Insuramo
 CYNCE
 SHIP Technology
 TRAVELER

STORAGE
 aws Microsoft Azure
 Pure Storage
 Alluxio
 Ceph
 COHERITY

CLUSTER SVCS
 AWS
 Docker
 Keen IO
 MESOSPHERE
 CORE3

APP DEV
 AWS
 KINOFLOW
 rainforest
 CSRS

CROWD-SOURCING
 Amazon Mechanical Turk
 Upwork
 fourm
 scode
 HIVE

HARDWARE
 Google TPU ARM
 Intel
 MYTHIC
 NVIDIA
 Movidius
 PLAINBOARD
 WAVE

GPU DBs
 kineticio
 INTEL
 MYPATH
 PLAINBOARD
 BYLLIT PLRSM

CROSS-INFRASTRUCTURE/ANALYTICS

aws Google Cloud Microsoft IBM SAP Hewlett Packard Enterprise SAS 1010DATA Vmware TIBCO TERADATA ORACLE NetApp syncsort

APPLICATIONS – INDUSTRY

HEALTHCARE
 Facion Clever
 METABOLIA Gingko Glow babylon
 3DME zebra Pharma Oviga
 TEMED patientstream AICure
 PROSSION prognos eadac

LIFE SCIENCES
 bioRxiv
 Benevolent AI verily
 WUOLNEX CODE ZEPHYR
 Clear Labs
 FORTIS JIANPUAI
 CITRINE
 Aetion

TRANSPORTATION
 CLEARPATH
 drive AI
 nauto
 PLOTIA
 PTFMUS
 moove
 nextor
 comma.ai
 nurodyne

AGRICULTURE
 FARMERS
 instacart
 Granular
 BLUEBERRY
 farmersedge
 FarmLogs
 mavrx
 iFarmers
 prospera

COMMERCE
 instacart
 STITCH FIX
 TACHYUS
 TACHYUS
 TACHYUS
 TACHYUS

INDUSTRIAL
 GIGAT PREDIX
 UPTAKE
 TACHYUS
 TACHYUS
 TACHYUS

OPEN SOURCE

FRAMEWORK
 Spark YARN HADOOP
 Flink MESOS CDAP

QUERY / DATA FLOW
 Spark SQL presto
 SLAMDATA
 Google cloud DataFlow

DATA ACCESS
 nifi mongoDB
 cassandra
 COUCHDB
 COUCHDB
 HBASE
 SECURITO

COORDINATION
 talend
 Apache Zookeeper
 Apache Ambari

STREAMING
 Spark
 Flink beam
 kafka druid
 STORM

START TOOLS
 Databricks
 Scalalab
 SciPy

AI / MACHINE LEARNING / DEEP LEARNING
 TensorFlow theano
 Caffe Microsoft Cognitive Toolkit
 Apache MEXCA FeatureFusion
 neon MLlib
 DL4J MAHOT Aerosolve

SEARCH
 elasticsearch
 Solr
 elasticsearch
 kibana
 logstash
 Prometheus

LOGGING & MONITORING
 elasticsearch
 kibana
 logstash
 Prometheus

VISUALIZATION
 Tableau
 Rodeo

COLLABORATION
 Jupyter
 Anaconda

SECURITY
 Apache Ranger
 Knox
 Sentry

DATA SOURCES & APIs

HEALTH
 Apple VALIDIC
 practice fusion
 UPTAKE
 GE Digital
 thingwork
 fitbit GARMIN
 HELIXIN kinsco

FINANCIAL & ECONOMIC DATA
 Bloomberg THOMSON REUTERS
 DOW JONES
 SAS CAPITAL IQ CBRIGHT xignite
 Quandl
 ENQUEST Vantage PREMIERE
 ESTIMATE
 English Alpha StockVitals
 PLAID Thinknum

AIR / SPACE / SEA
 Orbital Insight
 AIRBOTICS
 Airware
 INDEPENDENT WINDWARD
 telluLab
 DroneDeploy

PEOPLE / ENTITIES
 acxiom Experian
 EPSON
 insideView
 Crimson Hexagon
 BASIS SAFEGEAPH

LOCATION INTELLIGENCE
 FOURSQUARE
 sense360 PlaceIQ
 factual CARTR
 Mapillary
 cuebiq

OTHER
 qualtrics DATA GOV
 enigma
 mobiSella

DATA RESOURCES

DATA SERVICES
 Palantir OPERA
 DATAWORKS
 fractal kaggle
 Exel DataKind

INCUBATORS & SCHOOLS
 PLURALLIGHT
 galvanize
 DataCamp DataCite
 INSIGHT
 THE DATA INCUBATOR
 METIS

RESEARCH
 facebook research
 OpenAI
 MIRI
 VECTOR INSTITUTE
 A.I. RESEARCH LAB
 A.I. RESEARCH LAB

Distributed Data Management Introduction

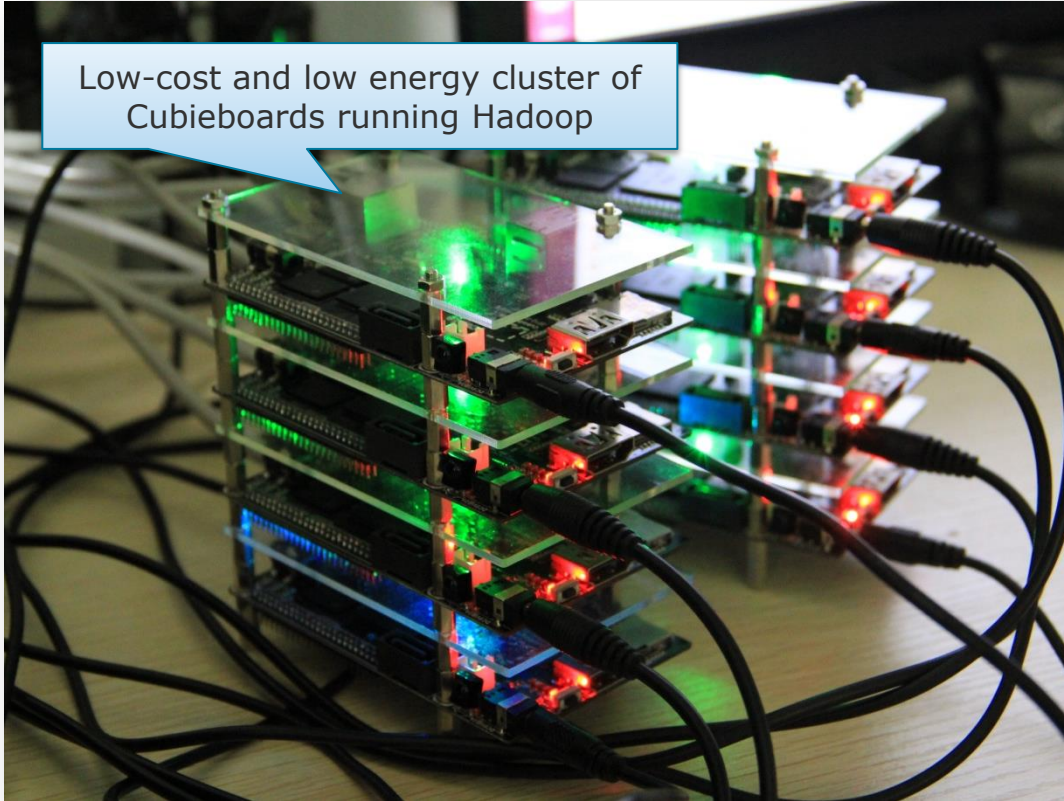


Motivation: “Distributed” Driving Forces

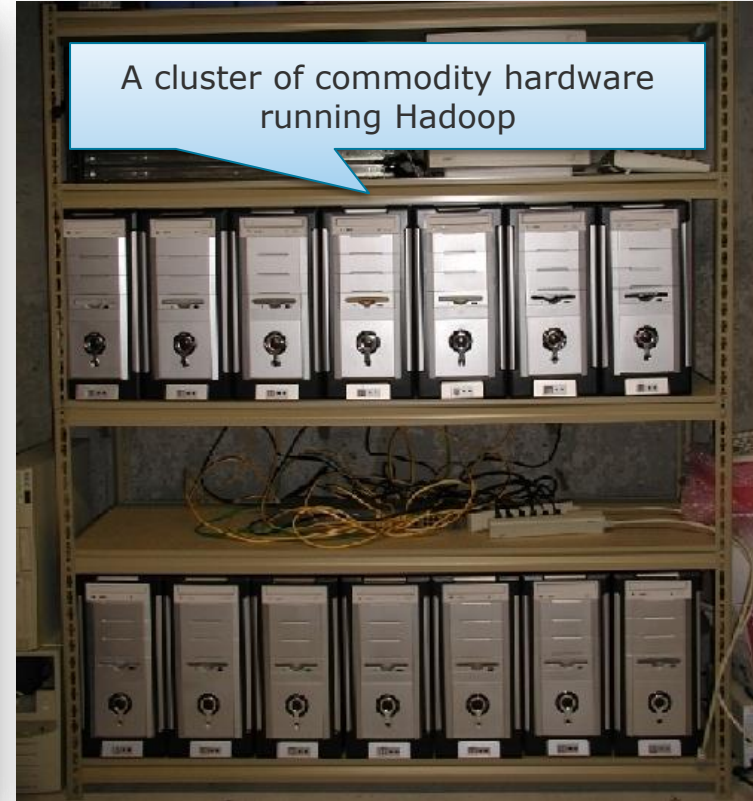
- **Data volumes increase:**
business data, sensor data, social media data, ...
- **Data analytics gains importance:**
downtime-less, real-time, predictive
- **Parallelization paradigm shifts:**
multi-core and network speeds increase while CPU clock speeds stall
- **Computation resources become more available:**
IaaS, PaaS, SaaS
- **Free and open source software gains popularity:**
setting standards, utilizing external development resources, improving software quality, avoiding vendor locks ...

Motivation: "Distributed" Small and Medium Scale

Low-cost and low energy cluster of
Cubieboards running Hadoop



A cluster of commodity hardware
running Hadoop



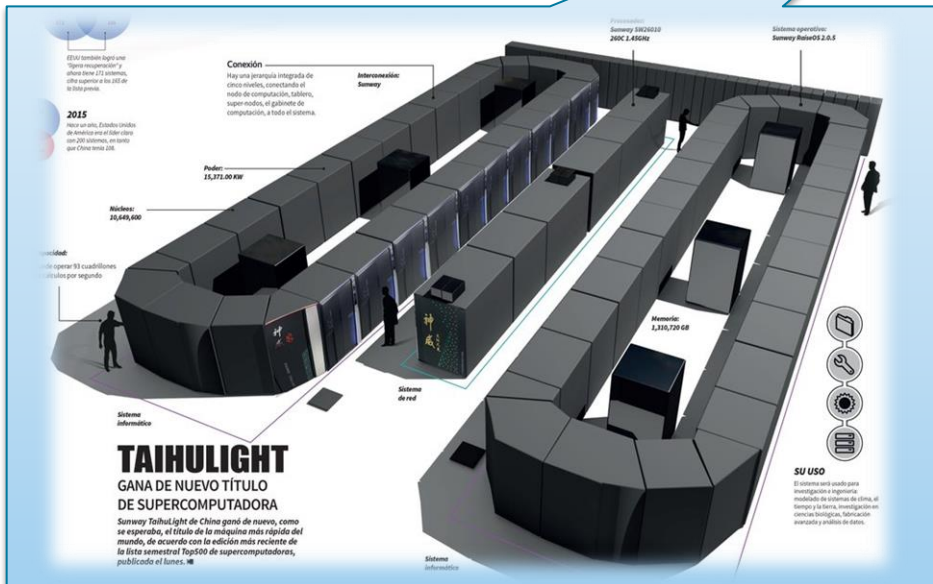
Motivation: "Distributed" Large Scale

A cluster of machines running
Hadoop at Yahoo!



Motivation: "Distributed" Super Large Scale

Top 10 Super Computers 2017



All distributed systems!

Rank	System	Cores	Rmax (TFlop/s)	Rpeak (TFlop/s)	Power (kW)
1	Sunway TaihuLight - Sunway MPP, Sunway SW26010 260C 1.45GHz, Sunway , NRCPC National Supercomputing Center in Wuxi China	10,649,600	93,014.6	125,435.9	15,371
2	Tianhe-2 (MilkyWay-2) - TH-IVB-FEP Cluster, Intel Xeon E5-2692 12C 2.200GHz, TH Express-2, Intel Xeon Phi 31S1P , NUDT National Super Computer Center in Guangzhou China	3,120,000	33,862.7	54,902.4	17,808
3	Piz Daint - Cray XC50, Xeon E5-2690v3 12C 2.6GHz, Aries interconnect , NVIDIA Tesla P100 , Cray Inc. Swiss National Supercomputing Centre (SCS) Switzerland	361,760	19,590.0	25,326.3	2,272
4	Titan - Cray XK7, Opteron 6274 16C 2.200GHz, Cray Gemini interconnect, NVIDIA K20x , Cray Inc. DOE/SC/Oak Ridge National Laboratory United States	560,640	17,590.0	27,112.5	8,209
5	Sequoia - BlueGene/Q, Power BQC 16C 1.60 GHz, Custom , IBM DOE/NNSA/LLNL United States	1,572,864	17,173.2	20,132.7	7,890
6	Cori - Cray XC40, Intel Xeon Phi 7250 68C 1.4GHz, Aries interconnect , Cray Inc. DOE/SC/LBNL/NERSC United States	622,336	14,014.7	27,880.7	3,939
7	Oakforest-PACS - PRIMERGY CX1640 M1, Intel Xeon Phi 7250 68C 1.4GHz, Intel Omni-Path , Fujitsu Joint Center for Advanced High Performance Computing Japan	556,104	13,554.6	24,913.5	2,719
8	K computer, SPARC64 VIIIffx 2.0GHz, Tofu interconnect , Fujitsu RIKEN Advanced Institute for Computational Science (AICS) Japan	705,024	10,510.0	11,280.4	12,660
9	Mira - BlueGene/Q, Power BQC 16C 1.60GHz, Custom , IBM DOE/SC/Argonne National Laboratory United States	786,432	8,586.6	10,066.3	3,945
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Motivation: "Distributed" Super Large Scale

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Motivation: "Distributed" Super Large Scale

Top 10 Super Computers 2017



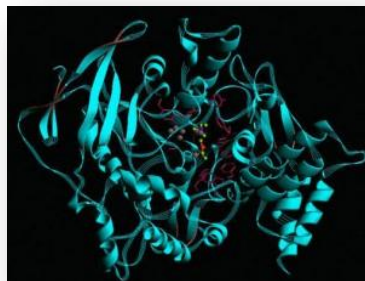
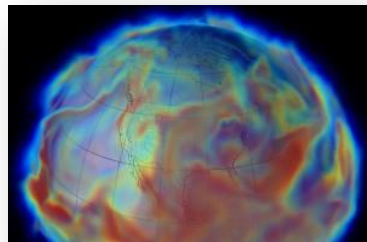
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Motivation: "Distributed" Super Large Scale

Use cases

- Weather forecasting
- Market analysis
- Crash simulation
- Disaster simulation
- Brute force decryption
- Molecular dynamics modeling
- ...



**Data-intensive analytics
tasks!**

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Introduction

- Examples Distributed Systems
- Lecture Organization
- Motivation “Distributed”
- **Motivation “Data”**
- Motivation “Management”

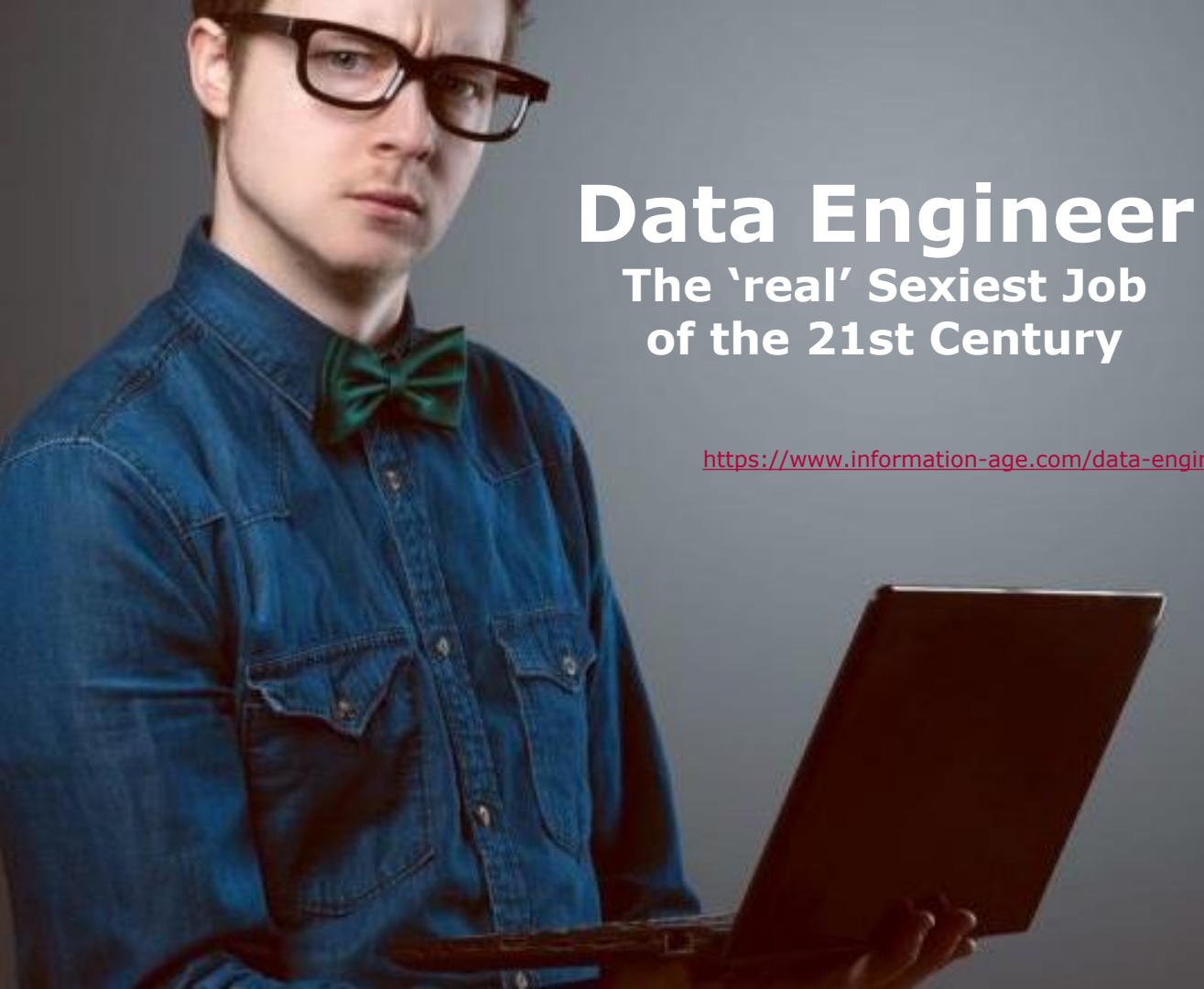




Data Scientist

The Sexiest Job
of the 21st Century

<https://hbr.org/2012/10/data-scientist-the-sexiest-job-of-the-21st-century>



Data Engineer

The 'real' Sexiest Job
of the 21st Century

<https://www.information-age.com/data-engineer-sexiest-job-21st-century-123480578/>

BIG Data & Analytics Software Vendors

Top 10 LinkedIn followers per employee:

1. Dundas
2. Predixion Software
3. iDashboards
4. Chartio
5. CXO-Cockpit
6. Kognitio
7. TARGIT
8. Prophix
9. Alpine Analytics
10. Jedox

A market worth \$122 billion in 2016 with a growth of 11.3% per year!

Excellent job opportunities in many companies!

For a world that created an entire zettabyte (which is exactly 10^{12} GB) of data in the 2010 alone!

Business users (Log-scale)

Customers (Log-scale)

Shape: Deployment types

On Prem

Cloud (Mobile)

On Prem

Color = Client focus
(Blue = Enterprise ; Orange = SMB ; Green: Mix)

Size = Completeness of vision
(BIG Data, Analytics, CPM, Data Warehousing)

Top 10 Business Analytics Vendors:

1. Microsoft
2. MicroStrategy
3. IBM
4. SAP
5. Tableau
6. Qlik
7. Alteryx
8. SAS Institute
9. TIBCO
10. GoodData

Top 5 Self Service BI Vendors:

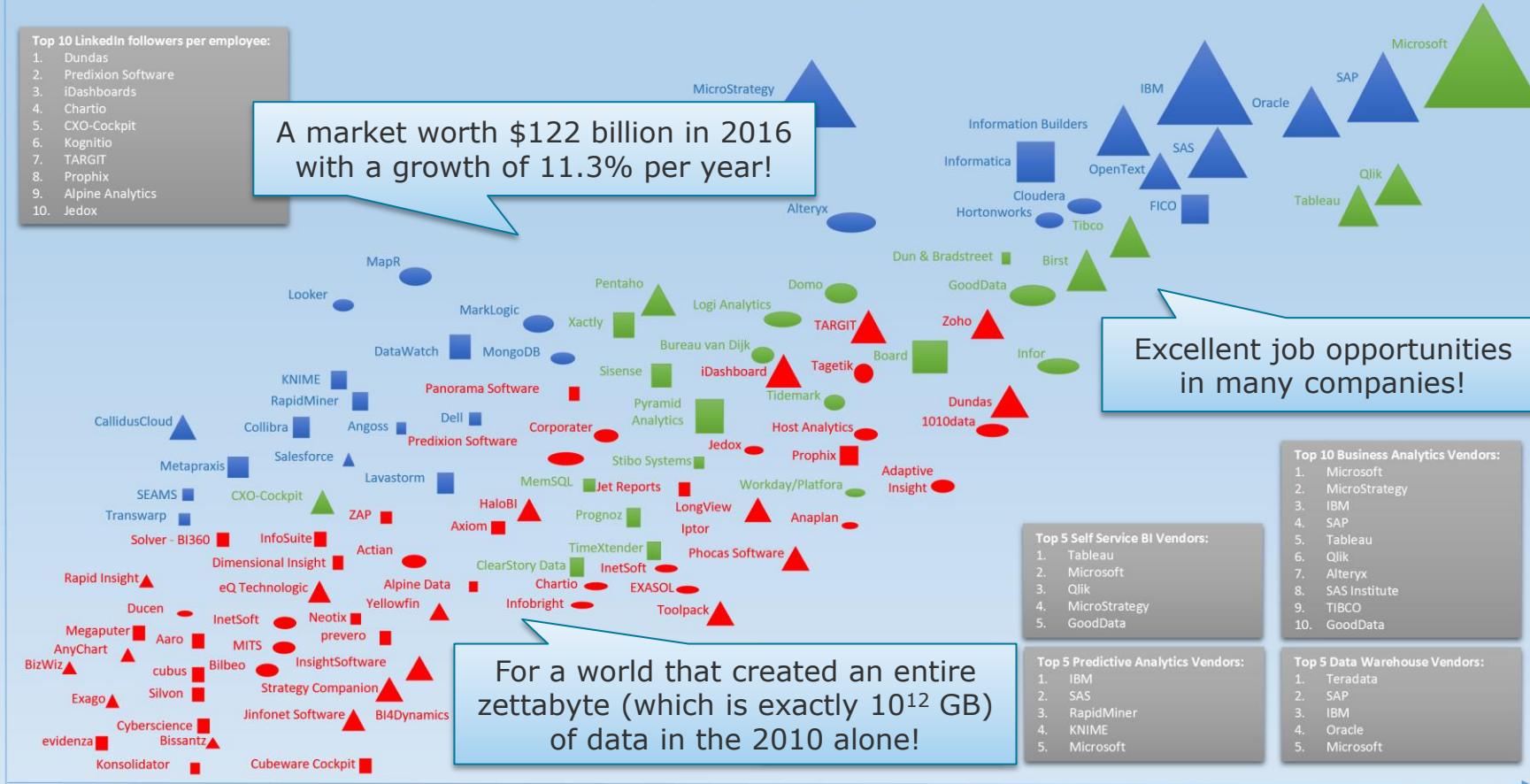
1. Tableau
2. Microsoft
3. Qlik
4. MicroStrategy
5. GoodData

Top 5 Predictive Analytics Vendors:

1. IBM
2. SAS
3. RapidMiner
4. KNIME
5. Microsoft

Top 5 Data Warehouse Vendors:

1. Teradata
2. SAP
3. IBM
4. Oracle
5. Microsoft



VLDB 2017 Program

International conference
"Very Large Data Bases"

All data processing and analytics tasks that are more and more based on distributed computing.

29 Aug (Tue)			Welcome Messages + Wolfgang Lehner keynote						
8:30-10:00									
10:00-10:30	break								
10:30-12:00			Panel	DB Engines 1	Data Cleaning	Spatial Data Management 1	Graphs and Networks 1	Tutorial: Caching at the Web Scale	
12:00-13:30	lunch								
13:30-15:00			Query Processing and Optimization	Stream Processing 1	Data Formats	Privacy and Security	Event Processing	Tutorial: Summarizing Static and Dynamic Big Graphs	
15:00-15:30	break								
15:30-17:00			Transactions	Spatial Data management 2	Graphs and Networks 2	Information Integration	Applications	Tutorial: Blockchains and Databases	
17:00-18:00				poster reception					
(Wed)									
8:30-10:00			Endowment Update + VLDB Awards + Michael Franklin keynote						
10:00-10:30	break								
10:30-12:00			High Performance Query Processing	Recommendations and Skylines	Approximation Structures	Stream Processing 2		Tutorial: New Trends on Exploratory Methods for Data Analytics	
12:00-13:30	lunch								
13:30-15:00			Scalable Storage	Crowdsourcing	Stream Processing 3	Graphs and Networks 3	Social Network Analysis	Tutorial: Geometric Approaches for Top-k Queries	
15:00-15:30	break								
15:30-17:00			Concurrency Control	Query Optimization	Specialized Data Management	Graphs and Networks 4	Data Mining and Analytics	Tutorial: Spatial Crowdsourcing: Challenges, Techniques, and Applications	
17:00-18:00				poster reception					
			"VLDB Octoberfest" banquet at the Hofbräuhaus						
(Thu)									
10:30-10:55	break		Endowment Awards + Demo Award + Jens Dittrich plenary						
10:55-12:00			Transactions and Persistence	Data Access	Data Statistics	Potpourri			
12:00-13:30	lunch								
13:30-15:00			Data Partitioning	Graphs and Networks 5	Visualization	Distributed Systems and Cloud 1	Estimation and Approximation	Tutorial: The Era of Big Spatial Data	
15:00-15:30	break								
15:30-17:00			DB Engines 2	Query Processing	Text and Semi-Structured	Spatial Data Management 3	Distributed Systems and Cloud 2	Tutorial: Complex Event Recognition in the Big Data Era	
17:00-18:00				poster reception					

Motivation: "Data"

Successful IT Startups

Example: Mobile Motion GmbH



Dubsplash

- An HPI-Startup of 2013
- Founders:
 - Jonas Drüppel, Roland Grenke, Daniel Taschik

November 19, 2014:

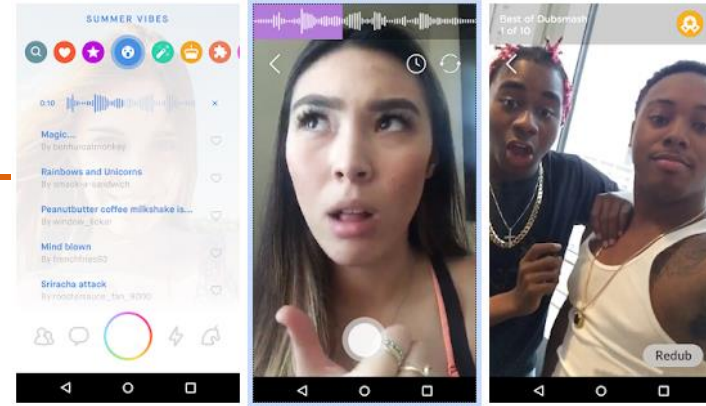
- **Launch** of the Dubsplash app

November 26, 2014:

- Dubsplash reached the **number one** downloaded app in Germany

June 1, 2015:

- Dubsplash had been downloaded over **50 million times in 192 countries**

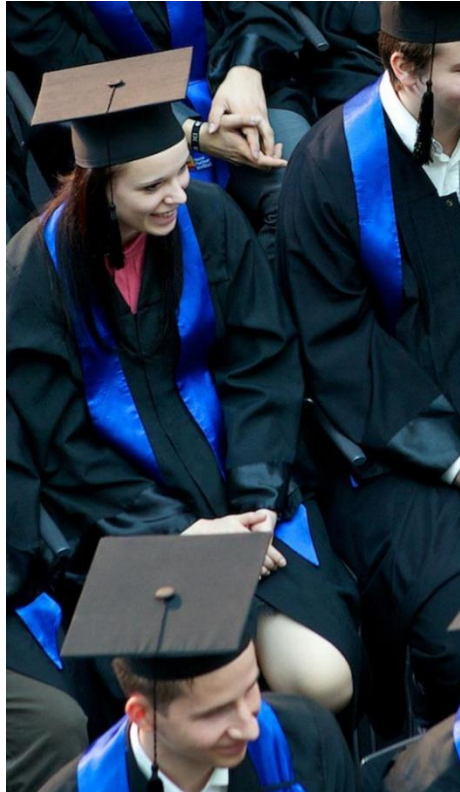


Distributed Data Management

Introduction

ThorstenPapenbrock
Slide **43**

Motivation: "Data" Successful IT Startups



Many further HPI Startups!

Distributed Data Management

Introduction

ThorstenPapenbrock
Slide 44

Motivation: "Data"

Successful IT Startups

Successful IT-Startups in recent years are masters of data:

1. **AirBnB**
2. **Instagram**
3. **Pinterest**
4. **Angry Birds**
5. **Linkedin**
6. **Uber**
7. **Snapchat**
8. **WhatsApp**
9. **Twitter**
10. **Facebook**
11.

Peta- to Exabytes of ...

- profile data (names, addresses, friends, ...)
- content data (images, videos, messages, ...)
- event data (logins, interactions, games, ...)
- ...

Challenged with ...

- streaming
- persistence
- analytics
- load-balancing
- ...

**Distributed Data
Management**

Introduction

ThorstenPapenbrock
Slide **45**

Introduction

- Examples Distributed Systems
- Lecture Organization
- Motivation “Distributed”
- Motivation “Data”
- **Motivation “Management”**

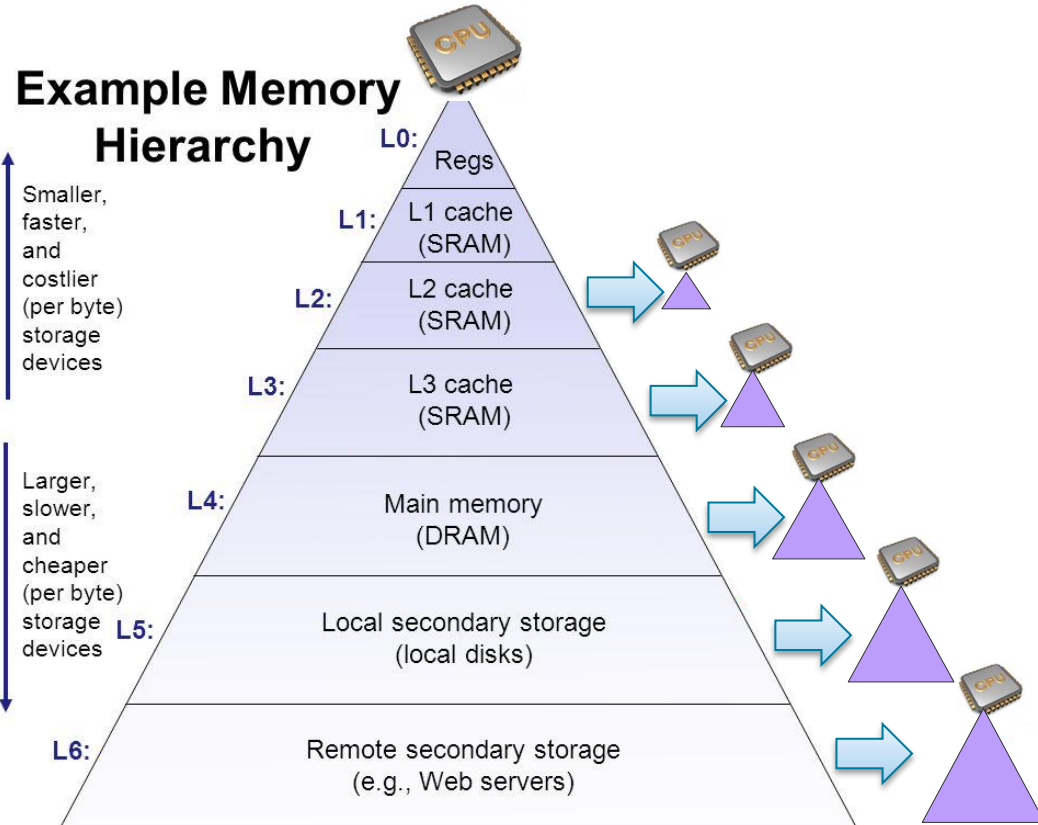


Motivation: "Management"

Rethinking Data Management

Data is distributed and replicated!

- Data needs to reach a processor to be computed.
- Processor memory is very small but data is usually large.
- Data is stored distributed and replicated in memory hierarchies.
- Data needs to be fetched, i.e., copied to a processor before it can be computed.
- Data needs to be flushed, i.e., copied to higher memory levels to become visible to other processors.



Motivation: "Management"

Rethinking Data Management

Moving data costs magnitudes more time and energy than computing data!

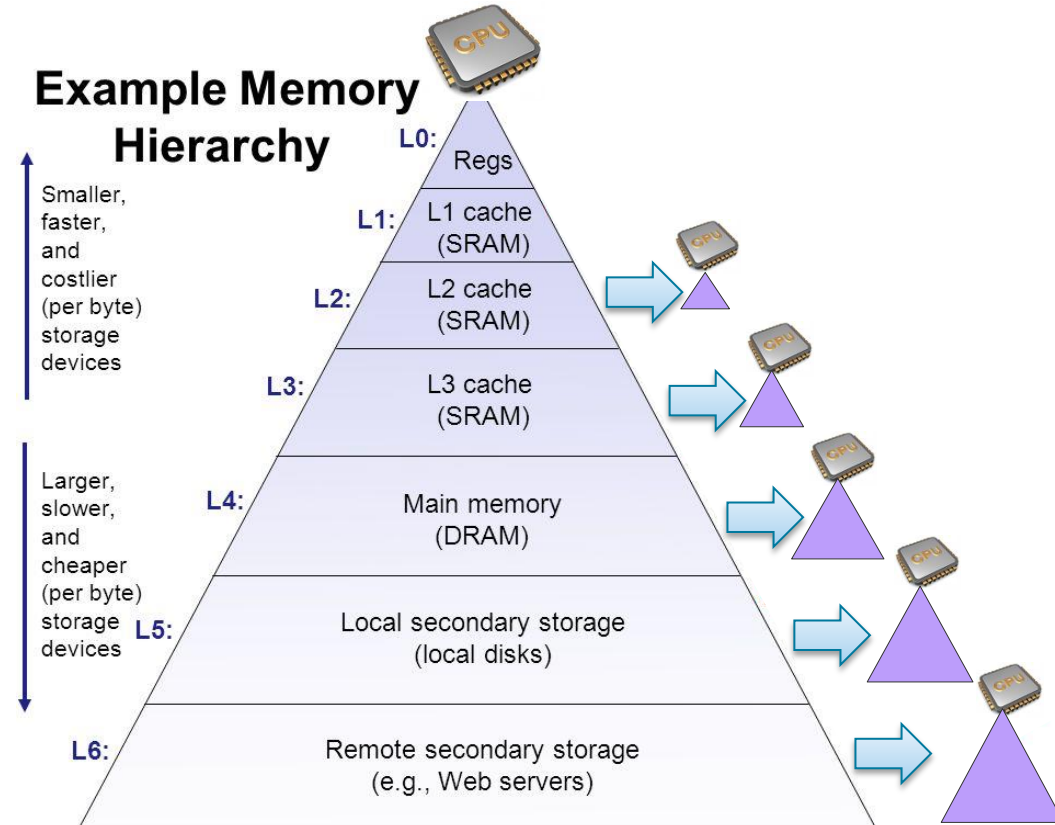
- Copying data costs time and energy.
- Stalled processors during data copying consume energy.

Operation	Operation Energy Cost (nJ)	Equivalent ADD
ADD	0.64	-
L1->REG	1.11	1.8x
L2->REG	2.21	3.5x
L3->REG	9.80	15.4x
MEM->REG	63.64	99.7x
Stall	1.43	-
Prefetching	65.08	-

<https://hpc.pnl.gov/modsim/2014/Presentations/Kestor.pdf>

- Push computation to the data not data to the computation.

Example Memory Hierarchy



Motivation: "Management"

Rethinking Data Management

Moving data costs magnitudes more time and energy than computing data!

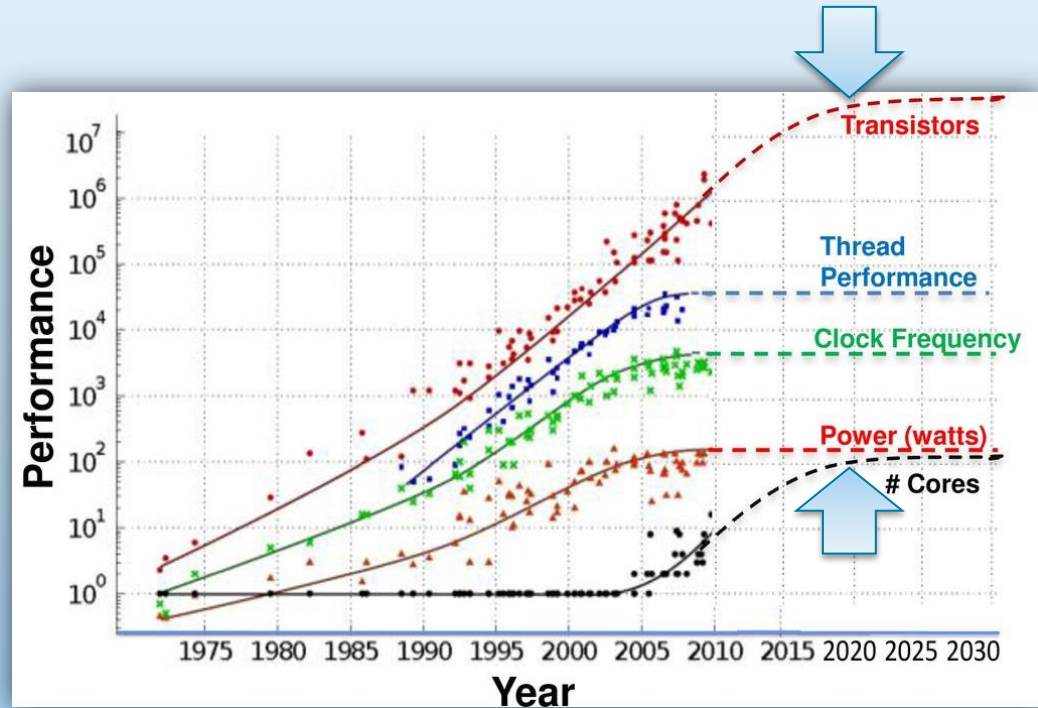
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- Push computation to the data not data to the computation.

Why energy is a concern:



Motivation: "Management"

Rethinking Data Management

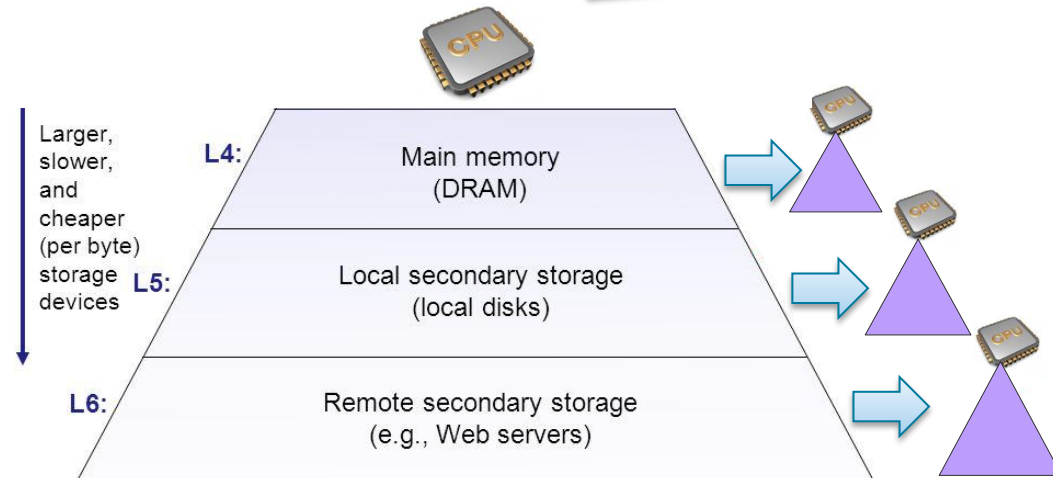
➤ Data engineers and data scientists need to be good data manager!

- Data encoding
- Data transmission
- Data replication
- Data partitioning
- Data consistency management
- Load scheduling
- Load balancing

We do not consider L0-L3 in this lecture, but this is super relevant for High Performance Computing!

I recommend:

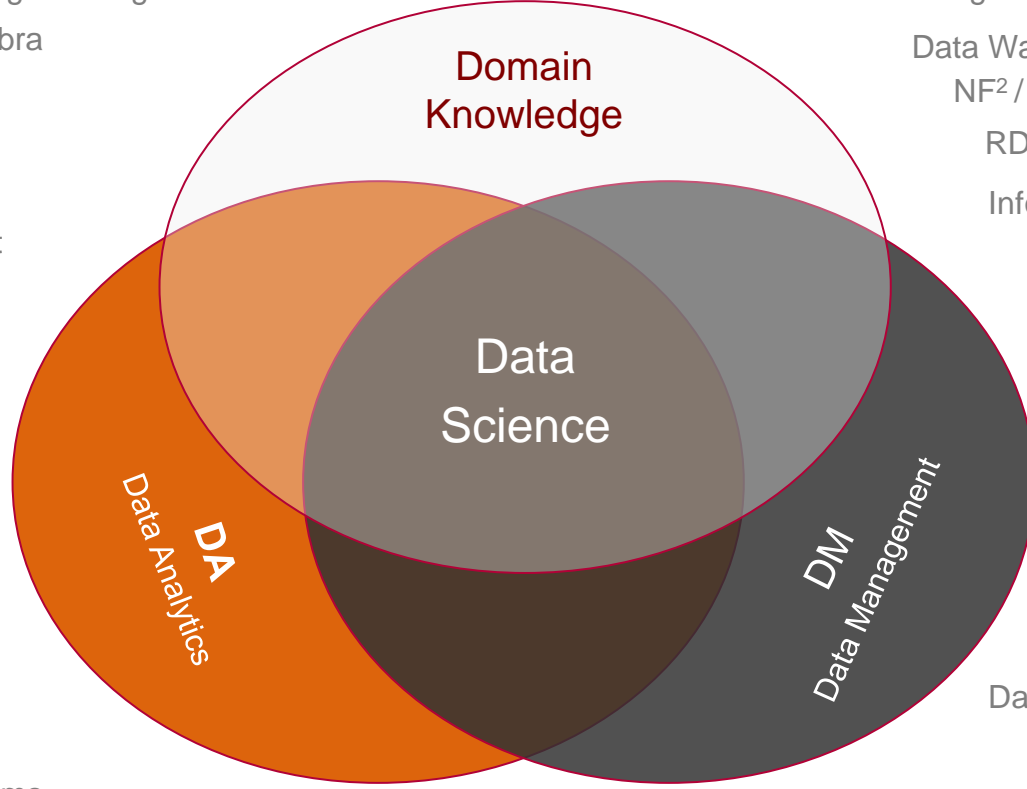
https://www.youtube.com/watch?v=3PjNgRWmv90&list=LLbLaqsrSDDURdv_ZV75-AMQ&index=6&t=0s



Domain Expertise (e.g., Industry 4.0, Medicine, Physics, Engineering, Energy, Logistics)

Mathematical Programming

Relational Algebra / SQL



Data Warehouse/OLAP

NF² / XQuery

RDF / SparQL

Information Integration

Information Extraction

Visual Analytics

Privacy

Memory Management

Parallelization

Scalability

Memory Hierarchy

Fault Tolerance

Security

Data Analysis Languages

Query Optimization

Real-Time

Indexing

- Linear Algebra
- Statistics
- Text Mining
- Graph Mining
- Signal Processing
- Stochastic Gradient Descent
- Machine Learning
- Error Estimation
- Active Sampling
- Monte Carlo
- Regression
- Predictive Analytics
- Sketches
- Data Obfuscation
- Convergence
- Decoupling
- Iterative Algorithms

Curse of Dimensionality

Legal Aspects

Control Flow

Business Models

Data Flow

Motivation: “Management” Data Management

Data Analytics

“The ability to effectively extract and calculate various kinds of information from data!”

- Structural information
- Explicit information
- Implicit/derived information

Data Management

“The ability to efficiently read, transform, and store large amounts of data!”

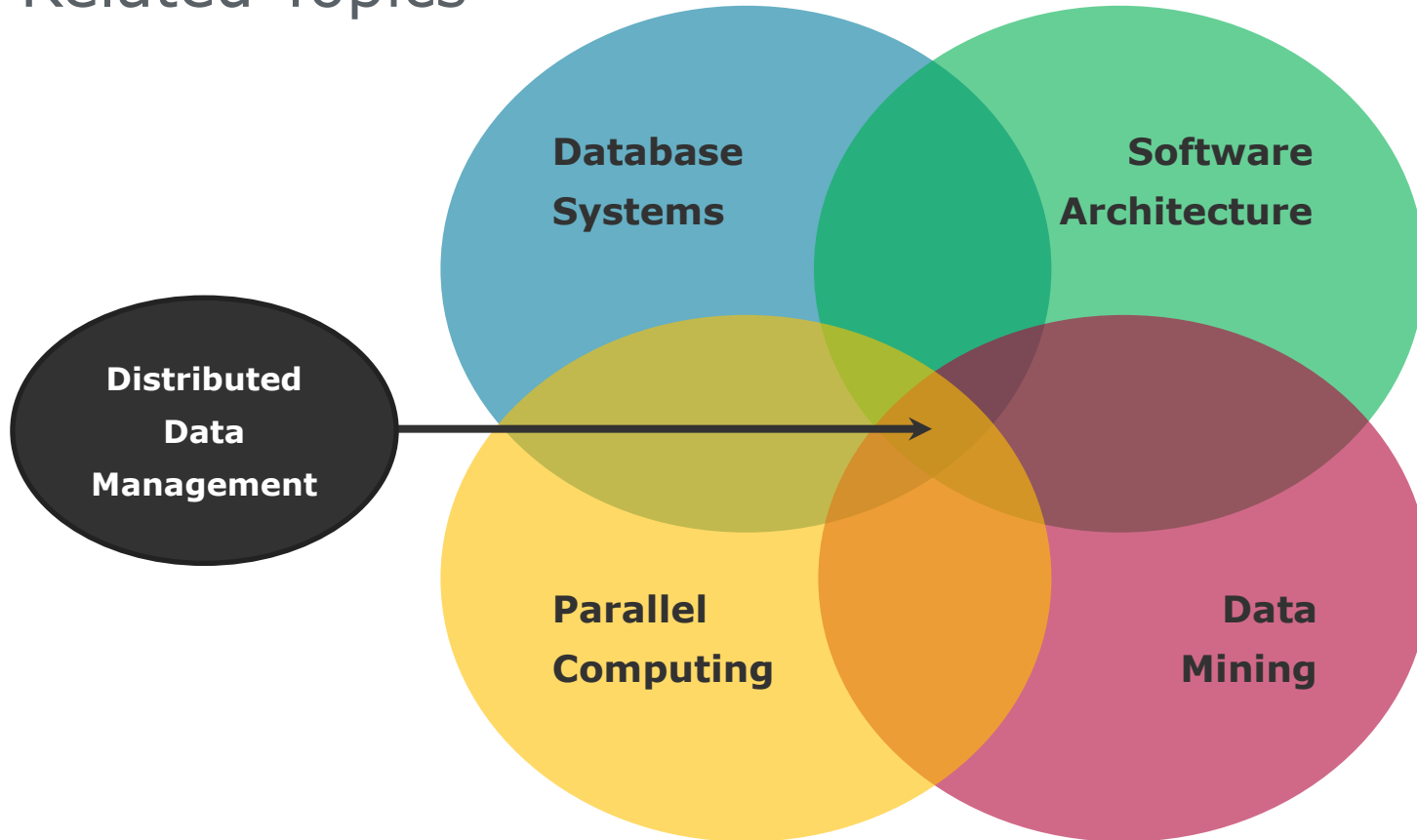
- Static (block) data
- Volatile (streaming) data

Distributed Data Management

Introduction

Motivation: "Management"

Related Topics



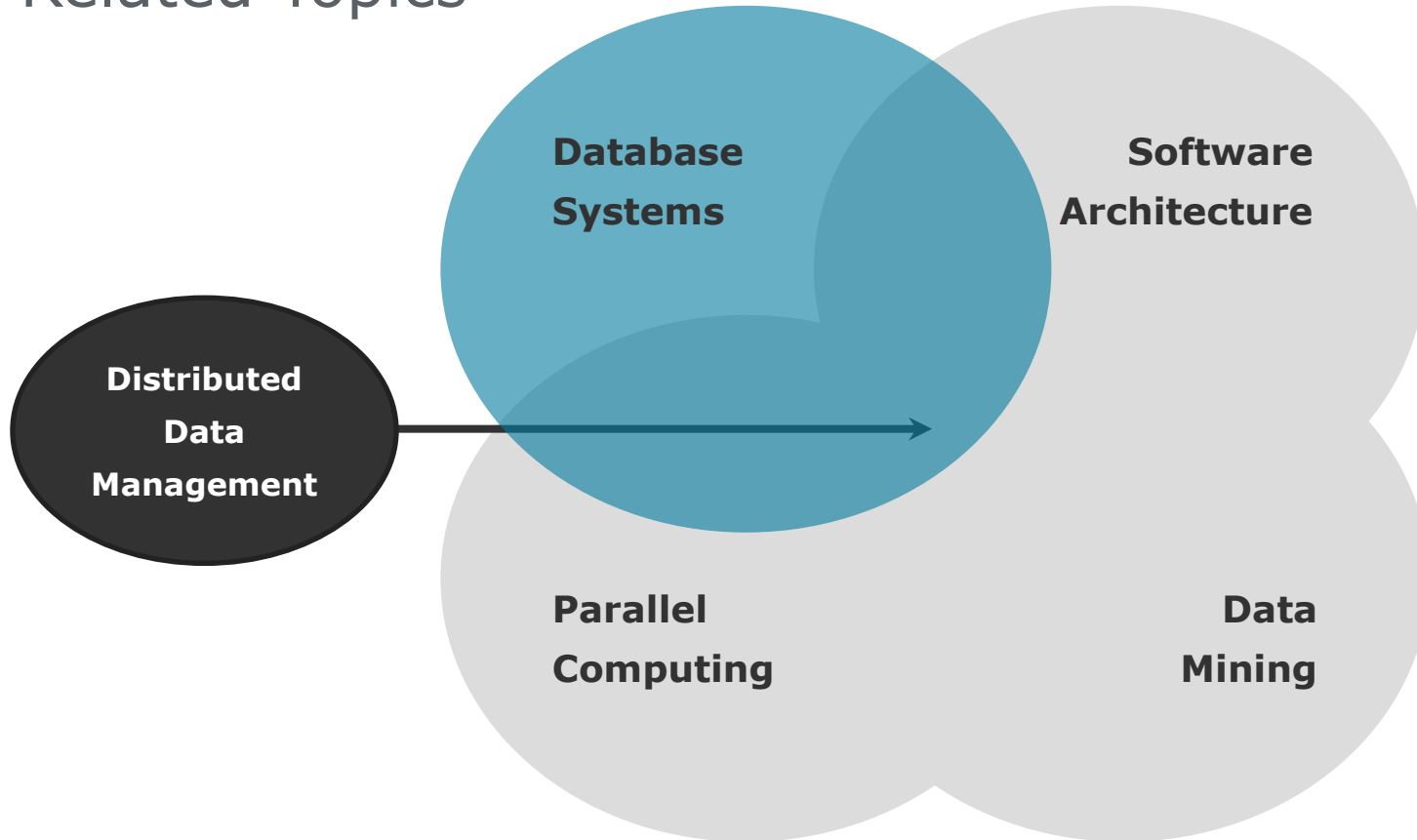
**Distributed Data
Management**

Introduction

ThorstenPapenbrock
Slide **53**

Motivation: "Management"

Related Topics



**Distributed Data
Management**

Introduction

ThorstenPapenbrock
Slide **54**

Motivation: “Management” Database Systems

Touch points

- Data models, query languages, and consistency guarantees
- Distributed storage and retrieval of data
- Index structures

Not in this lecture

- Physical data storage
- Foundations on transaction management and logging
- Core database technology, e.g., query optimizer

More focused lectures

- Database Systems I + II (Prof. Naumann)
- Trends and Concepts in Software Industry (Prof. Plattner)

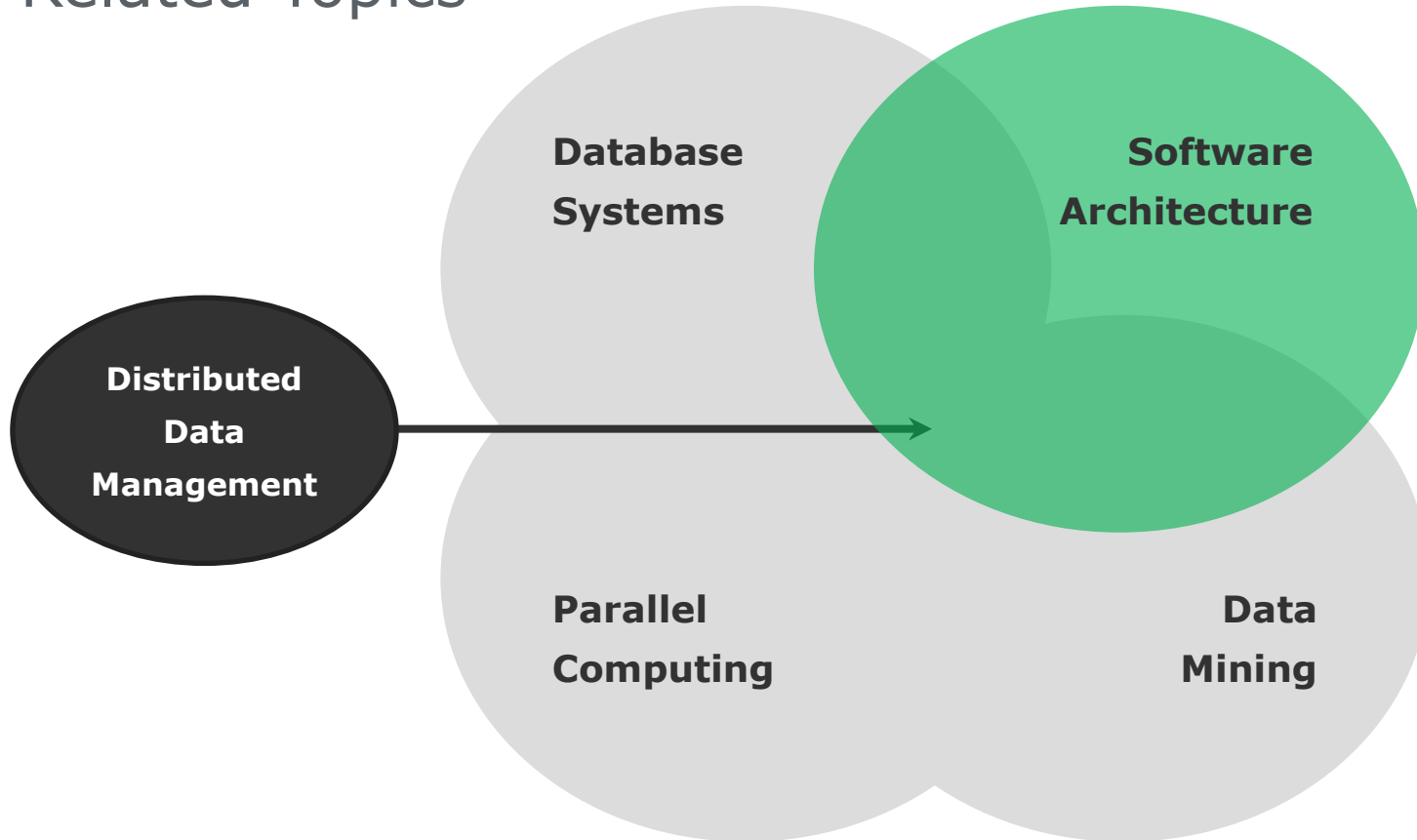
Distributed Data Management

Introduction

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Slide **55**

Motivation: "Management"

Related Topics



Distributed Data Management

Introduction

Motivation: “Management” Software Architectures

Touch points

- Requirements, design, and architecture of distributed systems
- Pros and cons of different technologies for distributed systems

Not in this lecture

- Non-distributed systems
- Agile software development techniques
- Software patterns

More focused lectures

- Software Architecture (Dr. Uflacker)
- Software Technique (Dr. Uflacker)

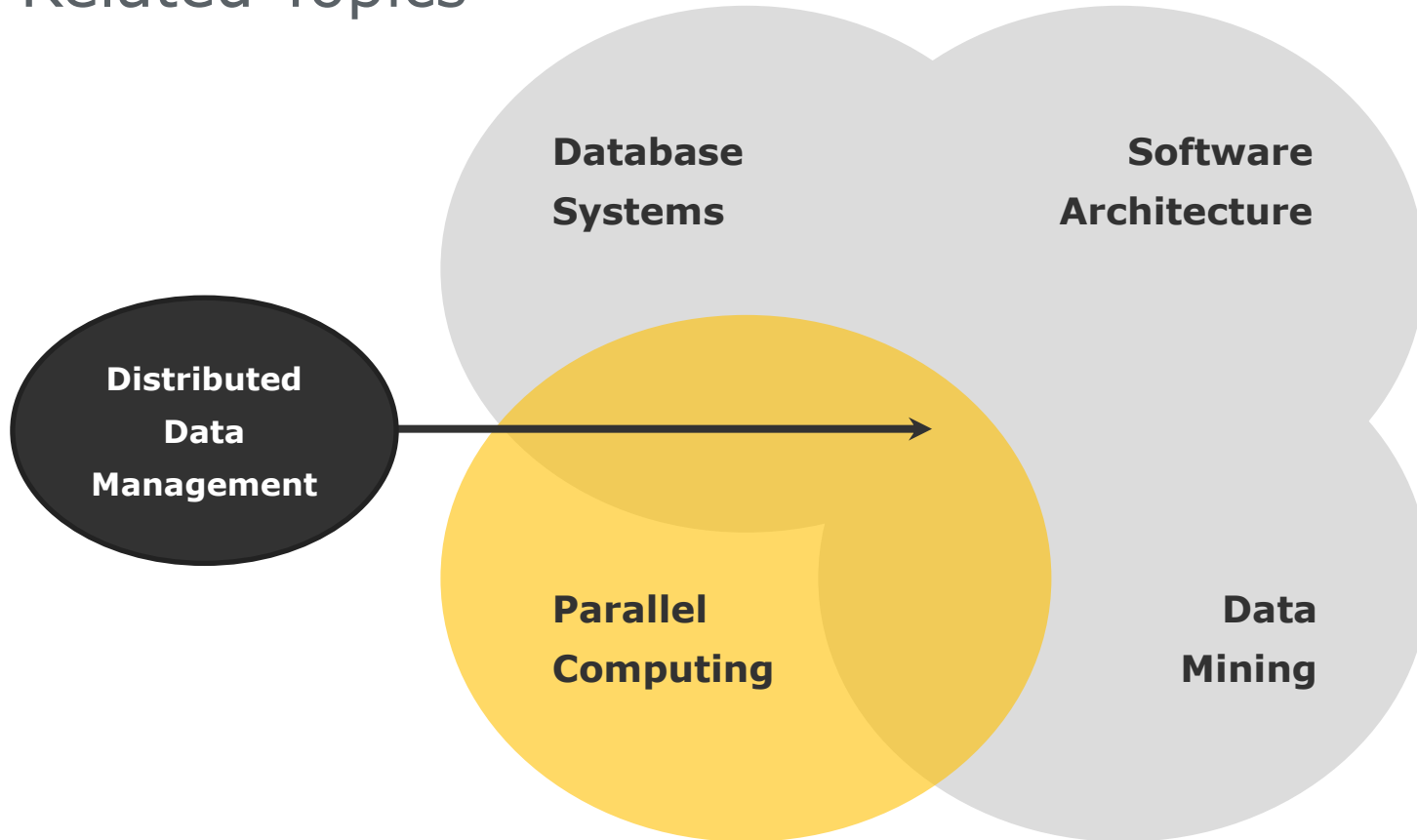
Distributed Data Management

Introduction

Thorsten Papenbrock
Slide **57**

Motivation: "Management"

Related Topics



**Distributed Data
Management**

Introduction

ThorstenPapenbrock
Slide **58**

Motivation: “Management”

Parallel Computing

Touch points

- Distributed data storage concepts
- Distributed programming models, e.g., actor programming and MapReduce

Not in this lecture

- Parallel, non-distributed programming languages, e.g., CUDA or OpenMP
- Core parallel computing concepts, e.g., scheduling or shared memory
- Processor architectures, cache hierarchies, GPU programming, ...

More focused lectures

- Parallel Programming (Dr. Tröger)
- Programmierung paralleler und verteilter Systeme (Dr. Feinbube)

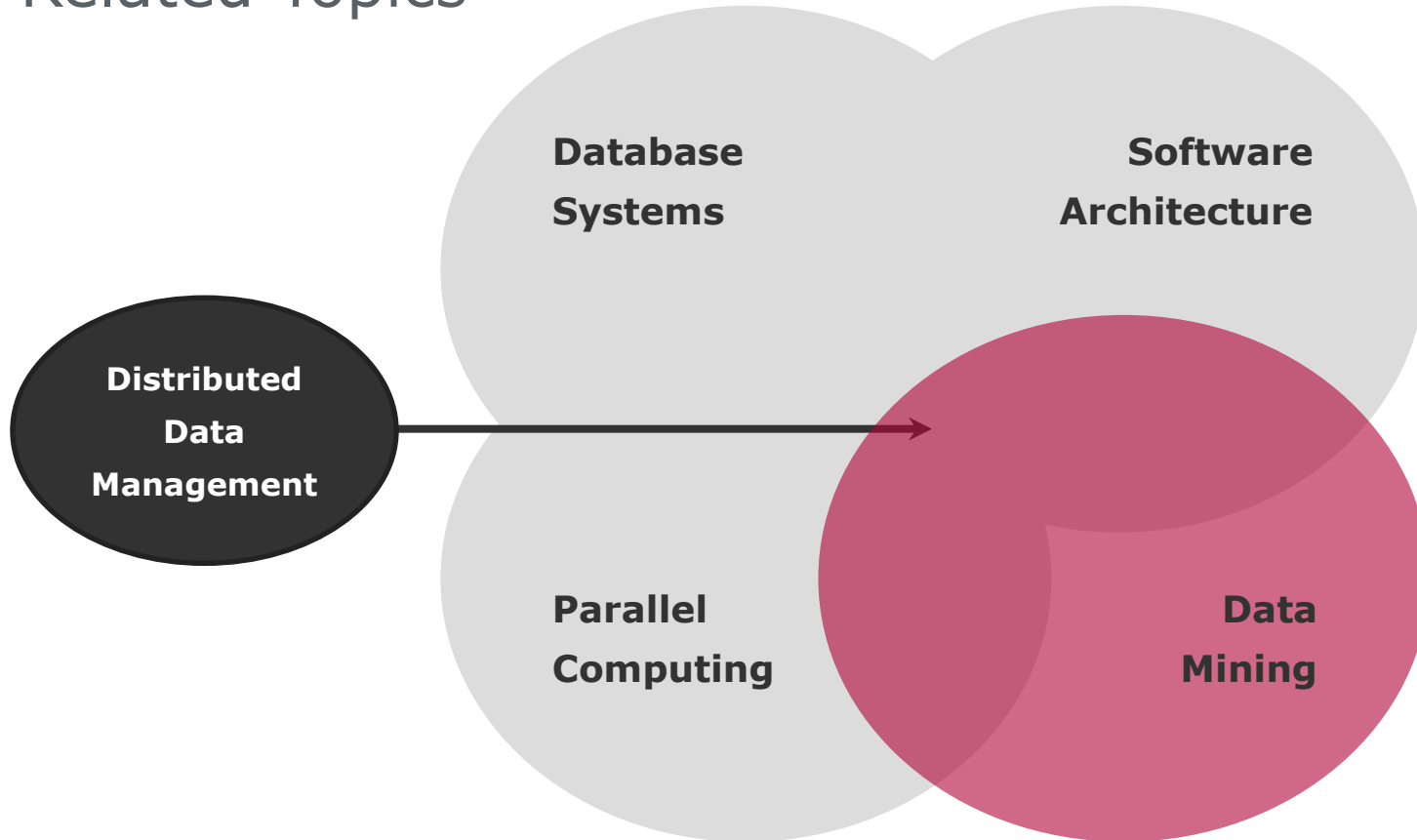
Distributed Data Management

Introduction

Thorsten Papenbrock
Slide **59**

Motivation: "Management"

Related Topics



**Distributed Data
Management**

Introduction

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Slide **60**

Motivation: “Management” Data Mining

Touch points

- Data analytics: aggregation queries and basic data mining algorithms

Not in this lecture

- Detailed introduction to machine learning, e.g., neuronal networks, (un)supervised learning, or Bayesian classification
- Statistics, linear algebra, and most sophisticated mining algorithms

More focused lectures/seminars

- Data Analysis in R (Lippert, Konigorski, Schurmann)
- Selected Topics in Data Analytics (Döllner, Hagedorn)
- Machine Learning for Data Steams (Albrecht)
- Neuro Design (Von Thienen)

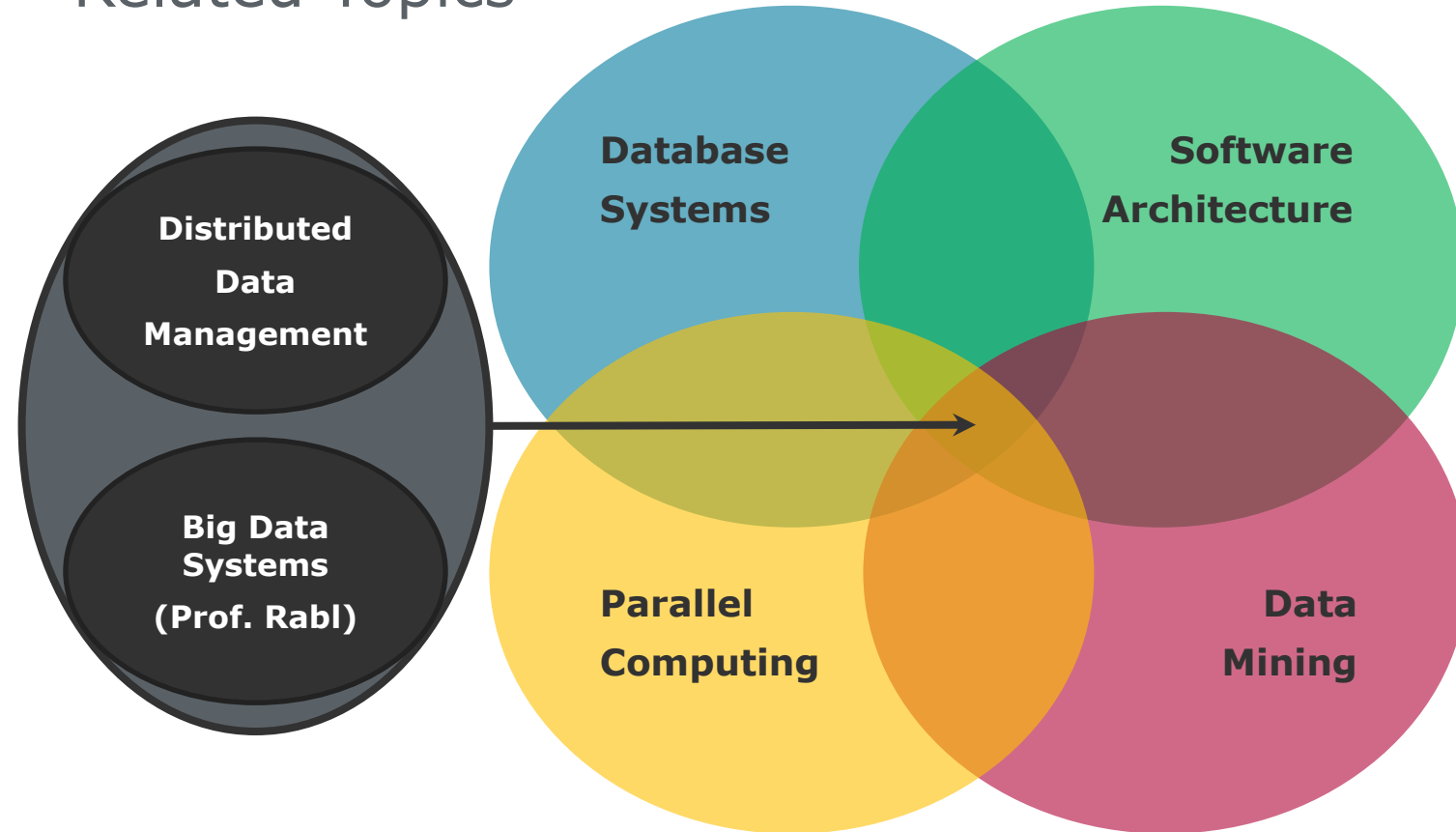
**Distributed Data
Management**

Introduction

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Motivation: "Management"

Related Topics



Distributed Data Management

Introduction

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Motivation: "Management"

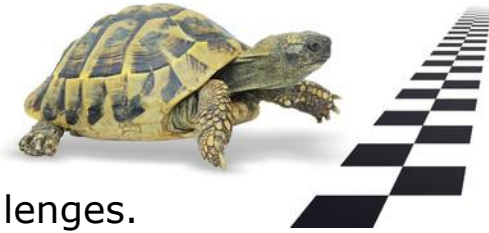
Lecture Goals

Sorting the buzzwords

- NoSQL, Big Data, OLAP, Web-scale, ACID, Sharding, MapReduce, Scale-out...

Understanding distributed systems

- You know how state-of-the-art distributed systems work.
- You know core technologies and techniques to solve distributed challenges.
- You know the advantages and disadvantages of important systems.
- You know how to handle data in distributed settings.



Exercising in distributed data management and analytics

- You can implement distributed algorithms and applications.
- You can solve problems that arise in distributed setups.
- You can write data-parallel and task-parallel jobs.

**Distributed Data
Management**

Introduction

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Slide **63**

“Dark Magic”

- With **distributed computing** we can utilize incredible amounts of compute power!
 - At the cost of harder programming (e.g. fault tolerance, testing and protocols)
 - At the cost of additional energy (e.g. communication and redundancy)
- Efficient, fault resistant code matters all the more, because inefficiency and failures scale, too!



“Dark Magic”

- “Around 10% of the world’s total electricity consumption is being used by the internet.”

Swedish KTH

<https://www.insidescandinavianbusiness.com/article.php?id=356>

<https://www.sciencedirect.com/science/article/pii/S2214629618301051>

- “The Internet’s data centers alone may already have the same CO2 footprint as global air travel.”

Global e-Sustainability Initiative

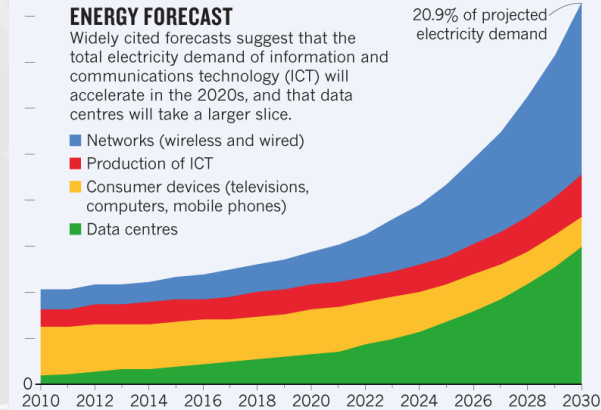
<https://internethealthreport.org/2018/the-internet-uses-more-electricity-than/>

- “Data centres [...] consume about 3% of the global electricity supply [...] accounting for about 2% of total greenhouse gas emissions” in 2016.

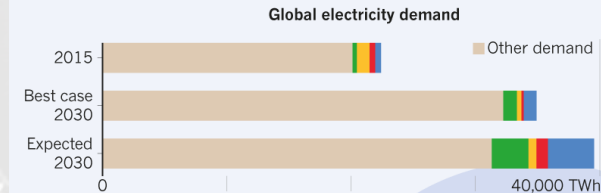
Independent

<https://www.independent.co.uk/environment/global-warming-data-centres-to-consume-three-times-as-much-energy-in-next-decade-experts-warn-a6830086.html>

9,000 terawatt hours (TWh)



The chart above is an ‘expected case’ projection from Anders Andrae, a specialist in sustainable ICT. In his ‘best case’ scenario, ICT grows to only 8% of total electricity demand by 2030, rather than to 21%.



INTERNET EXPLOSION

Internet traffic* is growing exponentially, and reached more than a zettabyte (ZB, 1×10^{21} bytes) in 2017.



*Traffic to and from data centres.

†TB, terabyte (10^{12} bytes); PB, petabyte (10^{15} bytes); EB, exabyte (10^{18} bytes).

DESIGNING Data-Intensive Applications
The big ideas behind reliable, scalable & maintainable systems

RELIABILITY **SCALABILITY** **MAINTAINABILITY**

RELIABILITY
Tolerating hardware & software faults
Human error

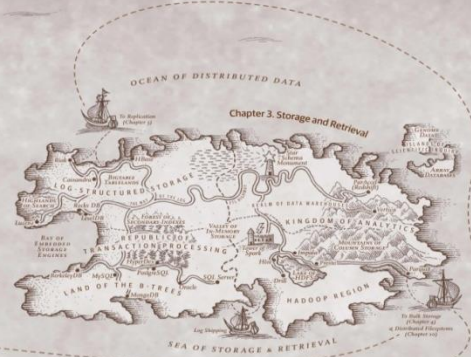
SCALABILITY
Measuring load & performance
Latency
Throughput

MAINTAINABILITY
Operability
Simplicity & evolvability

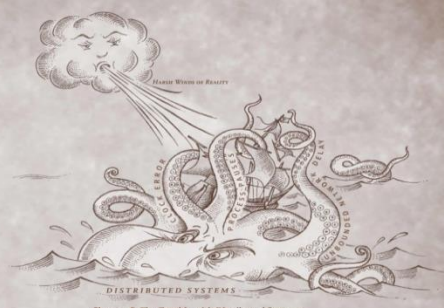
Chapter 1. Reliable, Scalable, and Maintainable Applications



Chapter 2. Data Models and Query Languages



Chapter 3. Storage and Retrieval



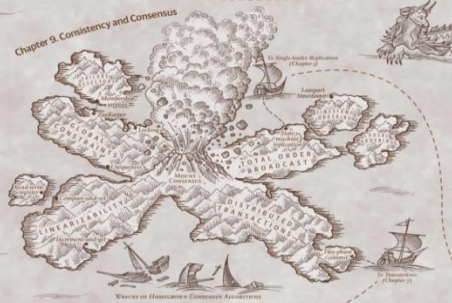
Chapter 8. The Trouble with Distributed Systems



Chapter 7. Transactions



Chapter 4. Encoding and Evolution



Chapter 9. Consistency and Consensus



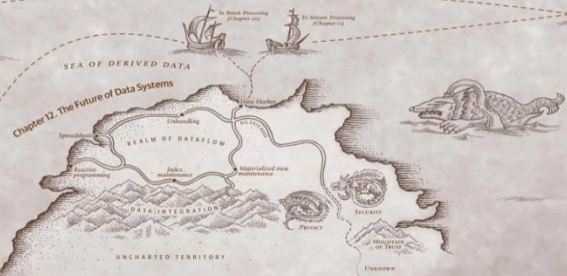
Chapter 5. Replication



Chapter 6. Partitioning



Chapter 10. Batch Processing



Chapter 12. The Future of Data Systems

O'REILLY

Designing Data-Intensive Applications

THE BIG IDEAS BEHIND RELIABLE, SCALABLE, AND MAINTAINABLE SYSTEMS

Martin Kleppmann