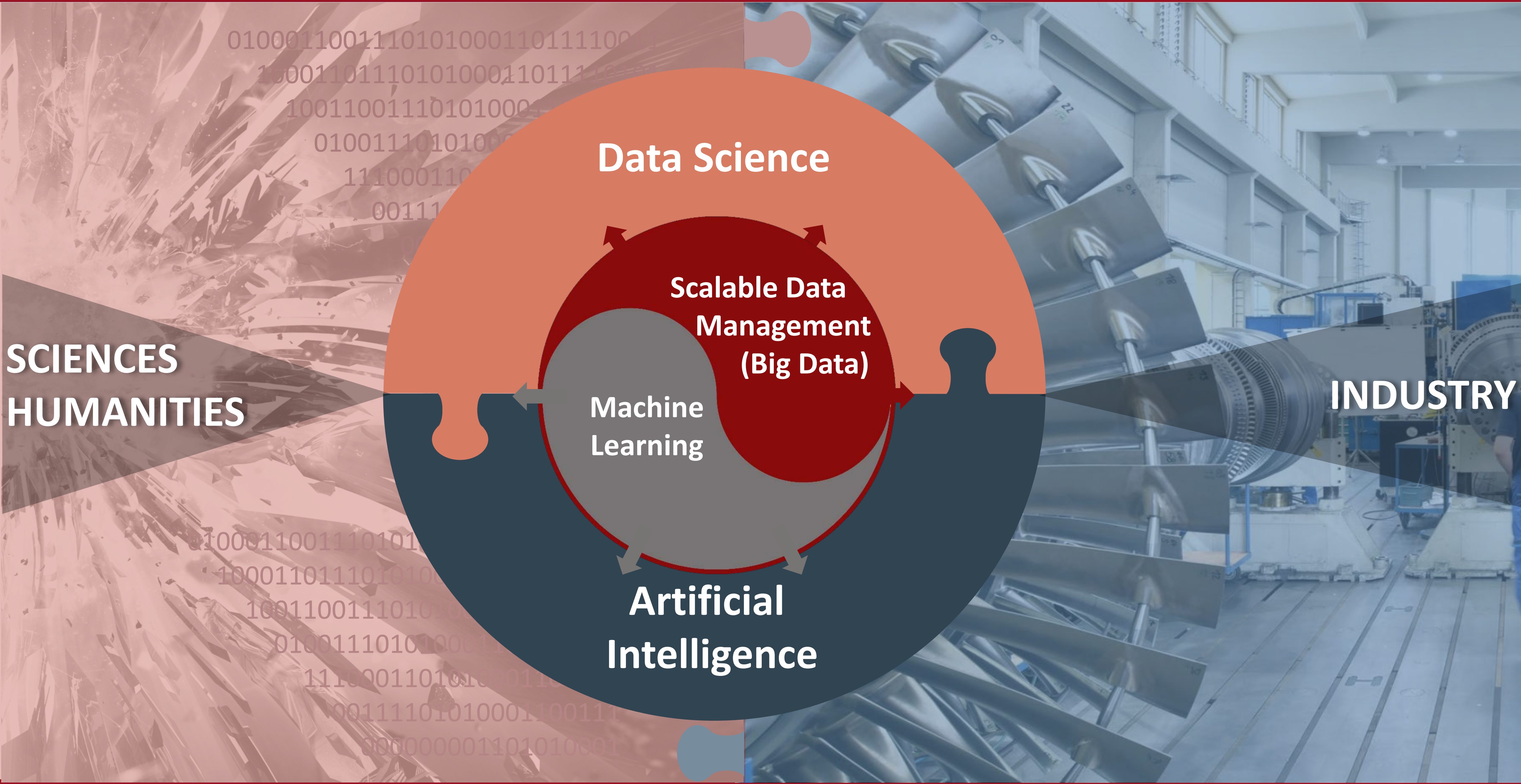
Mosaics in Big Data

Stratosphere, Apache Flink, and Beyond

Prof. Dr. Volker Markl

Technische Universität Berlin and the German Research Center for Artificial Intelligence (DFKI)


Data Science
Scalable Data Management (Big Data)
Machine Learning
Artificial Intelligence
SCIENCES
HUMANITIES
INDUSTRY

The Fourth Paradigm – A New Standard for Research

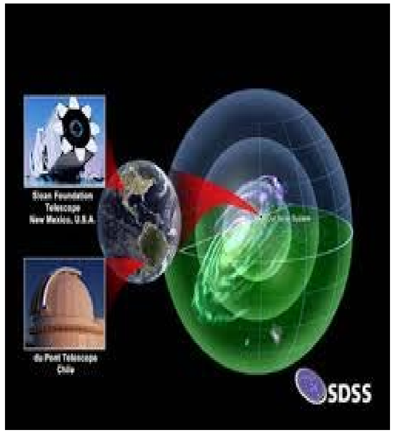
❶ 1000 Years Ago: **Empirical**
- ✓ Description of Natural Phenomena

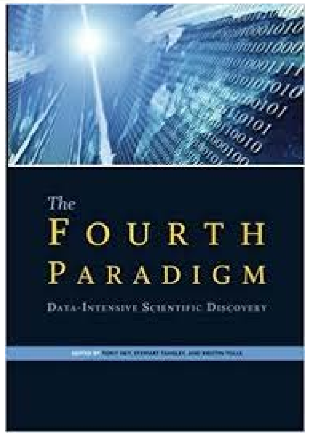
❷ The Last 100 Years: **Theoretical**
- ✓ Modeling and Generalizations

❸ The Last Decades: **Computational**
- ✓ Simulation of Complex Phenomena

❹ Nowadays: **Data Intensive**
- ✓ Massive Data Amounts Generated by Measurements and Simulation
- ✓ Data Exploration Through Software
- ✓ Information and Knowledge Stored On Computers
- ✓ Scientists Employ Databases/Files, Perform Data Management, Conduct Statistical Analysis

$$\begin{aligned} \nabla \cdot \mathbf{D} &= \rho \\ \nabla \cdot \mathbf{B} &= 0 \\ \nabla \times \mathbf{E} &= -\frac{\partial \mathbf{B}}{\partial t} \\ \nabla \times \mathbf{H} &= \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t} \end{aligned}$$





https://www.microsoft.com/en-us/research/publication/fourth-paradigm-data-intensive-scientific-discovery
https://blogs.technet.microsoft.com/dataplatforminsider/2016/03/10/mapping-the-universe-with-sql-server/

Data & Analysis: Increasingly Complex!

scalability DM

data volume too large	***V**olume*
data rate too fast	***V**elocity*
data too heterogeneous	***V**ariability*
data too uncertain	***V**eracity*

ML algorithms

Data

Reporting	Aggregation, Selection
Data Cubes/Ad-Hoc Queries	SQL, XQuery
ETL/ELT	MapReduce
Data Mining	MATLAB, R, Python
Predictive/Prescriptive	MATLAB, R, Python

DM scalability

ML algorithms

Analysis

Big Data: A New Standard for Data Analytics

Systems Research | **Algorithms Research**

Data Source Identification

- Structured Data
- Unstructured Data
- Complex Events
- Sensor Networks
- Data Streams
- Multimodalities

Data Integration and Processing

- Data Source
- Data Enrichment
- Annotation
- Info. Extraction
- Data Validation
- Deduplication
- Handle Updates
- Ensure Consistency

Data Management and Processing

- Data Curation
- On Premise
- SQL / NoSQL
- In Memory
- Cloud
- Spatially Distributed
- Massively Parallel
- Compression

Data Analysis & Model Building

- Preprocessing
- Semantic Analysis
- Setting Analysis
- Data Correlation
- Pattern Recognition
- Real-time Analysis
- Machine Learning
- Artificial Intelligence

Analysis Results Usage and Visualization

- Real-time Decision Support
- Forecasting
- Simulation
- Exploration
- Modeling
- Monitoring
- Control

Applications

Data Analytics: Ranging from simple queries on a data source, structured data, or relational data models, to complex analysis of disparate, decentralized data sources and data models, with diverse data types and modalities, high data generation and arrival rates, unsecured data, and incomplete data.

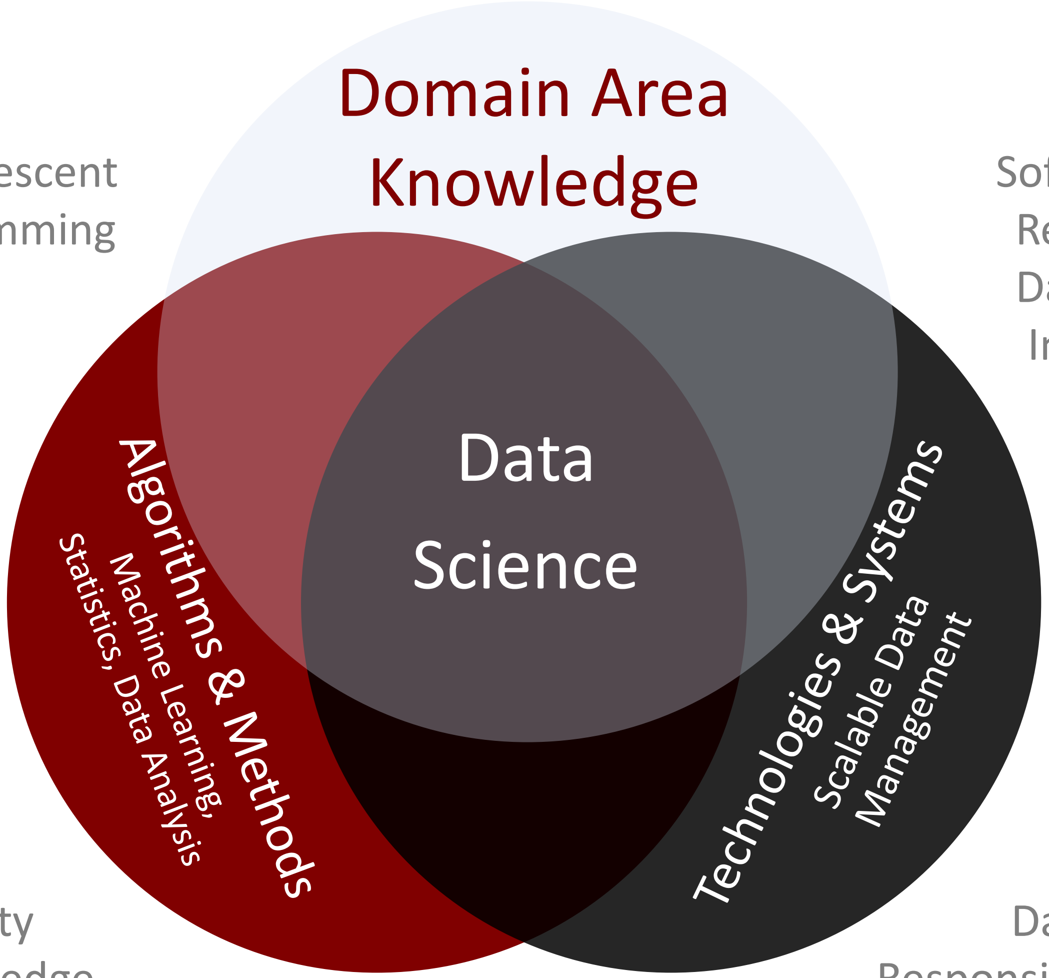
► **Higher complexity can potentially introduce new sources of error and new possibilities for data manipulation!**

► **Poor data quality and statistical pitfalls are fundamental problems that persist (even more so at larger scales)!**

Excessive Demands on Data Scientists

logistics, medicine, physics, mechanical engineering, energy, etc.

Stochastic Gradient Descent
Mathematical Programming
Explainable AI
Linear Algebra
Monte Carlo
Sparse Data
Regression
Statistics
Visualization
Hashing
Deep Learning
Convergence
Logics and Planning
Curse of Dimensionality
Exploiting Prior Knowledge

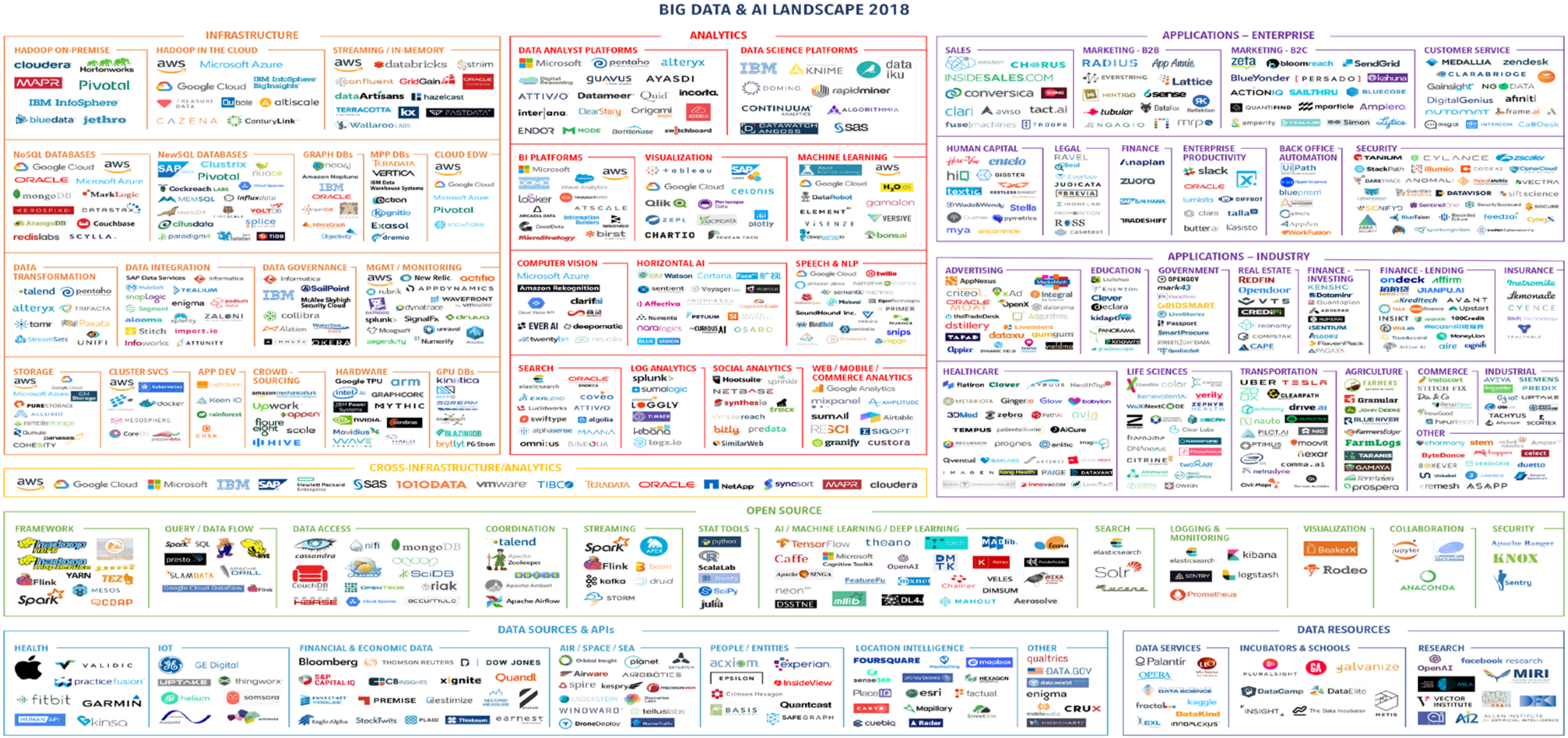


Software Engineering 2.0
Relational Algebra / SQL
Data Warehouse / OLAP
Information Integration
Information Extraction
Distributed Processing
Security
Compilers
Architectures
Parallelization
Reproducibility
Scalability / Latency
Storage Management
Data Analysis Languages
Responsible Data Management

Conclusion: Data scientists must be talented all around.

http://www.bbdc.berlin/news-events/blog-articles/

A Zoo of Technologies



http://mattturck.com/wp-content/uploads/2018/07/Matt_Turck_FirstMark_Big_Data_Landscape_2018_Final.png

Pitfalls of Big Data Analytics

Errors

- confirmation bias
- sampling bias
- outliers
- Simpson‘s paradox
- overfitting
- spurious correlations
- non-normal distributed data
- erroneous assumptions
- wrong conclusions

▶ **Data Fundamentalism?**
▶ **Accountability?**

Manipulation

- result oriented data trimming
- "bias" in algorithm training
- business influence
- algorithm bias by design
- visual distortion of the results

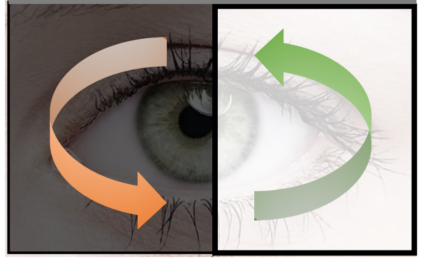
▶ **Increased influence on consumption, politics, the public**
▶ **Trust?**

Attacks

- data leaks
- data breaches
- reliability
- software errors
- security/safety
- cyber attacks

▶ **Vulnerability of companies, people, society?**

Dual Use/Misuse



- unlawful
- appropriate use
- discrimination
- monitoring/surveillance
- data protection
- personal rights violations
- espionage
- terrorism

▶ **Enforceable ethical principles?**
▶ **How should hazards be assessed?**

Data Monopolies

- self-reinforcing feedback loop of superior services and data collections
- controlling data usage is hard
- lack of access / fairness
- some companies may become more powerful than governments

▶ **Preventable via regulations?**

Example: Wrong Conclusions in Machine Learning

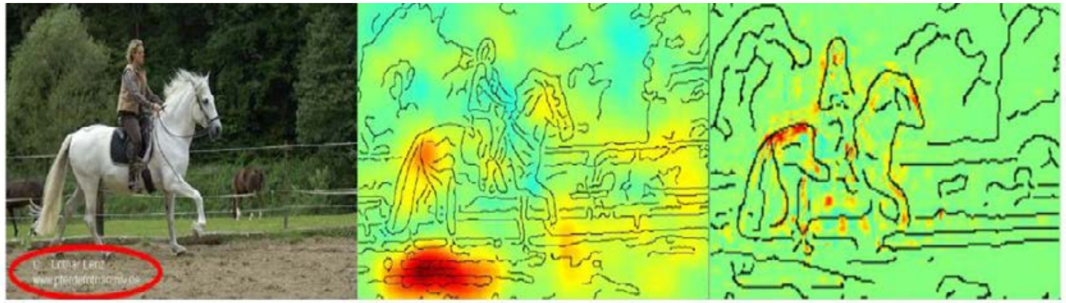
- Learning success depends on many parameters (e.g., learning method, features, configuration)
- Role of the parameters is not always directly apparent
- Validation and explanation are difficult

Conclusion: Learning methods may not learn and capture the intended behavior!

Test error for various classes:

	aeroplane	bicycle	bird	boat	bottle	bus	car
Fisher	79.08%	66.44%	45.90%	70.88%	27.64%	69.67%	80.96%
DeepNet	88.08%	79.69%	80.77%	77.20%	35.48%	72.71%	86.30%
	cat	chair	cow	diningtable	dog	horse	motorbike
Fisher	59.92%	51.92%	47.60%	58.06%	42.28%	80.45%	69.34%
DeepNet	81.10%	51.04%	61.10%	64.62%	76.17%	81.60%	79.33%
	person	pottedplant	sheep	sofa	train	tvmonitor	mAP
Fisher	85.10%	28.62%	49.58%	49.31%	82.71%	54.33%	59.99%
DeepNet	92.43%	49.99%	74.04%	49.48%	87.07%	67.08%	72.12%

Image FV DNN



Lapuschkin, S., Binder, A., Montavon, G., Muller, K. R., & Samek, W. (2016). *Analyzing classifiers: Fisher vectors and deep neural networks*. Proceedings of the IEEE Conference on Computer Vision & Pattern Recognition - CVPR (pp. 2912-2920)

Example: Data Monopolies

- Generation and storage of big data is expensive
- Incentives to share information are not always given
- Can lead to data monopolies or oligopolies and lead to conflicts of interest

Conclusion: Equal opportunities and scientific progress can be inhibited by information monopolies!

The Research Parasite Awards: http://researchparasite.com/

Big Data Infrastructures

A Big Data Analytics Infrastructure for the 4th Paradigm

… is not the same as open data silos.
- Open data does not explicitly provide a means to analyze and correlate massive datasets or data streams.
- Open data neither includes a scalable processing infrastructure, nor access to private/restricted data.

… is **very different** from **HPC infrastructures**.
- It requires SW/HW co-design and must employ database systems principles for access and management.
- It requires efficient I/O handling and must store the data efficiently to minimize data transfer.

… is **distinct** from **relational DBMS**.
- It must handle data of different modalities and offer a programming model beyond relational algebra.

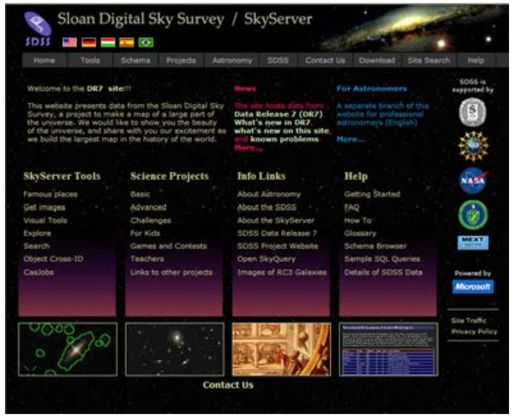
… is **logically central**.
- … comprised of a large-scale physical architecture and federated drill-through.
- … enabling data and code availability to communities via web-based interfaces.
- … supporting declarative languages, query optimizers, data caching, indexing, and data management.

… must **cover** the **entire data value chain**.
- … from source selection, over information extraction and integration, analysis and model building, to model application and visualization.

Sloan Digital Sky Survey / SkyServer

- “The Cosmic Genome Project” – multi-spectral imaging and spectroscopic redshift survey using a dedicated 2.5m wide-angle optical telescope at Apache Point Observatory in New Mexico, USA
- The SDSS made its entire data set available through **SkyServer** database – an online portal for public use, and invited volunteer contributions to scientific research.
- 150^{+} TB data – over 220 million galaxies and 260 million stars
- 2.9B web hits over a 17 year period
- 425M external SQL queries
- 7,000 refereed papers and 450K citations
- 4,000,000 distinct users vs. 15,000 astronomers
- Emergence of the “Internet Scientist”
- World’s most used astronomy facility today
- Collaborative server-side analysis done by 9,000 astronomers
- Serves as a model for other scientific communities
- Demonstrated that databases can be very powerful tools for science

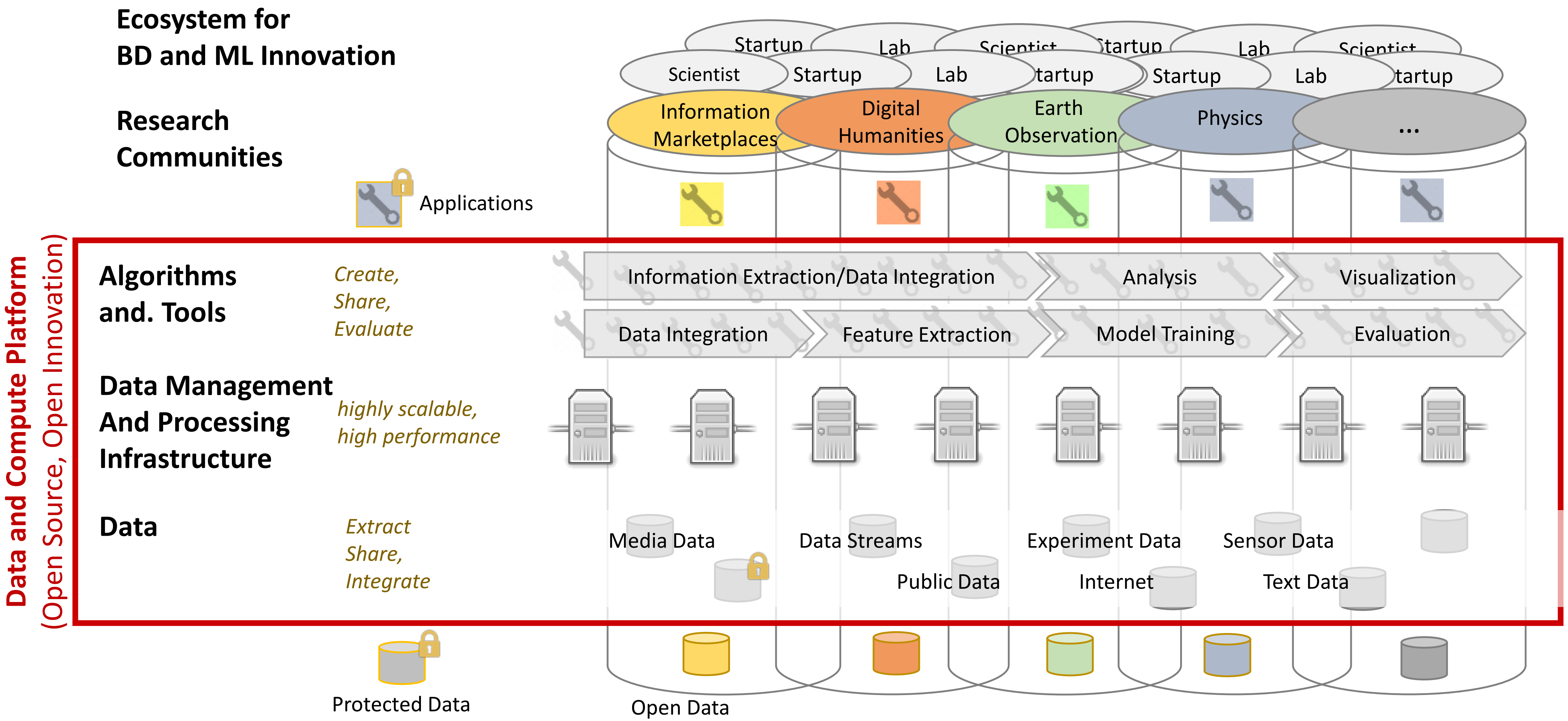
Slide: Due to Dr. Alex Szalay, Johns Hopkins University



https://www.sdss.org

Photo: The Late Jim Gray, 1998 Turing Award Winner

A Data Analytics Ecosystem



Responsible Data Management

Challenges

- Fairness
- Diversity
- Neutrality and Access
- Transparency
- Privacy Protection

Technical Solutions

- Testing and Verification
- Ensuring Properties
- Traceability
- Reproducibility
- Open Data and Open Source

http://dataresponsibly.com/

The Berlin Big Data Center (BBDC)

Vision

Research and development of methods and technologies for data science
at the intersection of data management and machine learning

DATA MANAGEMENT

Declarative Languages | Automatic Adaption
Scalable Processing

DM

BBDC

ML

MACHINE LEARNING

Feature Engineering | Representation
Algorithms (SVM, EM, etc.)

Think ML-Algorithms
in a Scalable Way

Declarative

Process ML-Algorithms
in a Scalable Way

Relational Algebra ▶ UDF ▶ Iteration/Recursion

▶ Linear Algebra / Graph Algebrae etc.

Stratosphere:
General Purpose Programming + Database Execution

Draws on
Database Technology

- Relational Algebra
- Declarativity
- Query Optimization
- Robust Out-of-core

Adds

- Iterations
- Advanced Dataflows
- General APIs
- Native Streaming

Draws on
MapReduce Technology

- Scalability
- User-defined Functions
- Complex Data Types
- Schema on Read

A. Alexandrov, D. Battré, S. Ewen, M. Heimel, F. Hueske, O. Kao, V. Markl, E. Nijkamp, D. Warneke: Massively Parallel Data Analysis with PACTs on Nephele. PVLDB 3(2): 1625-1628 (2010)
D. Battré, S. Ewen, F. Hueske, O. Kao, V. Markl, D. Warneke: Nephele/PACTs: a programming model and execution framework for web-scale analytical processing. SoCC 2010: 119-130
A. Alexandrov, R.Bergmann, S. Ewen, et al: The Stratosphere platform for big data analytics. VLDB J. 23(6): 939-964 (2014)

From Stratosphere to Flink

June 2, 2008

StratoSphere
Above the Clouds

Aug 26, 2014

Apache Flink

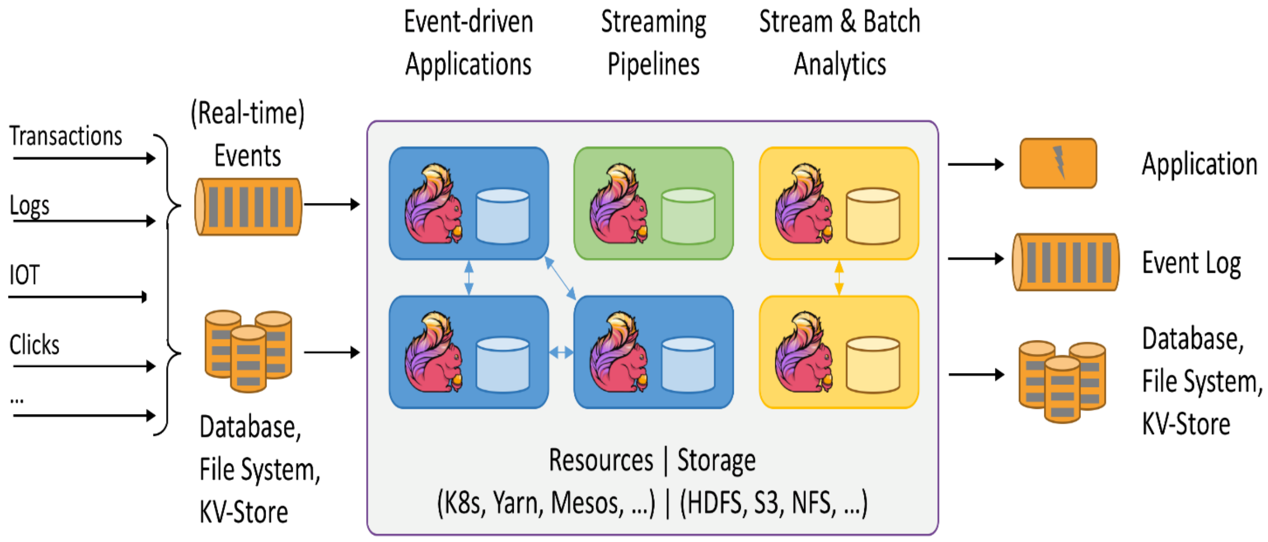
Flink

http://flink.apache.org/

Apache Flink® is an open-source stream processing framework for distributed, high-performing, always-available, and accurate data streaming applications, originating from the Stratosphere Project at TU Berlin.

Key Features

- Bounded and unbounded data
- Event time semantics
- Stateful and fault-tolerant
- Running on thousands of nodes with very good throughput and latency
- Exactly-once semantics for stateful computations.
- Flexible windowing based on time, count, or sessions in addition to data-driven windows



http://flink.apache.org

Key Publications

P. Carbone, A. Katsifodimos, S. Ewen, V. Markl, S. Haridi, K. Tzoumas:
Apache Flink™: Stream and Batch Processing in a Single Engine. IEEE Data Eng. Bull. 38(4): 28-38 (2015)
A. Alexandrov, R. Bergmann, S. Ewen, J.-C. Freytag, F. Hueske, A. Heise, O. Kao, M. Leich, U. Leser, V. Markl, et al:
The Stratosphere platform for big data analytics. The VLDB Journal. 23 (6): 939-964 (2014)

Technologies in Flink

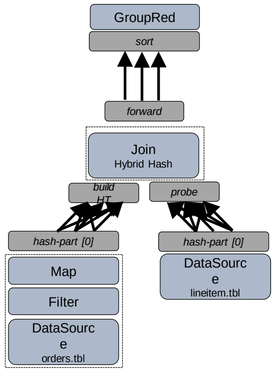
```
case class Path (from: Long, to:
Long)
val tc = edges.iterate(10) {
  paths: DataSet[Path] =>
    val next = paths
      .join(edges)
      .where("to")
      .equalTo("from") {
        (path, edge) =>
          Path(path.from, edge.to)
      }
      .union(paths)
      .distinct()
    next
  }
```

Program

Type Extraction Stack

Cost-based Optimizer

Pre-flight (Client)



Dataflow Graph

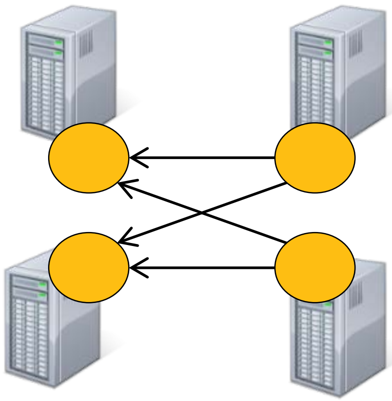
Recovery Metadata

Task Scheduling

Master

deploy operators

track intermediate results



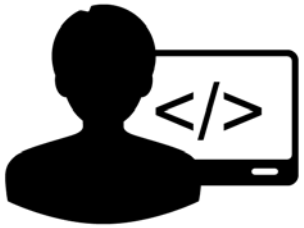
Workers

Memory Manager | Out-of-Core Algos

Batch & Streaming | State & Checkpoints

D. Battré, S. Ewen, F. Hueske, O. Kao, V. Markl, D. Warneke:
Nephele/PACTs: a programming model and execution framework for web-scale analytical processing. SoCC 2010: 119-130

Effect of Optimization



Hash vs. Sort
Partition vs. Broadcast
Caching
Reusing partition/sort

Execution
Plan A

Execution
Plan B

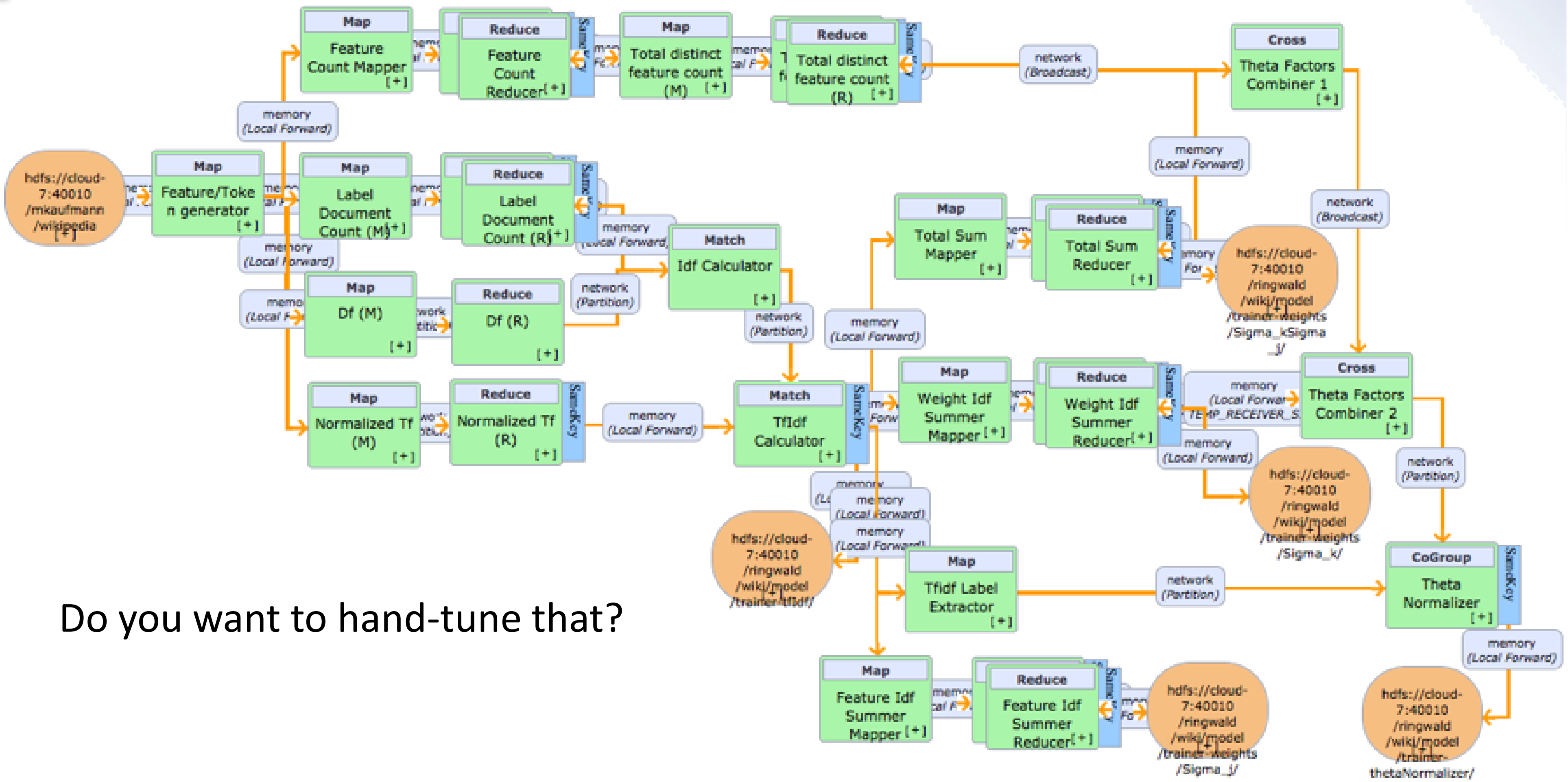
Execution
Plan C

Run a sample
on a laptop

Run large files
on a cluster

Run a month later, after
the data has evolved

Why Optimization?



Do you want to hand-tune that?

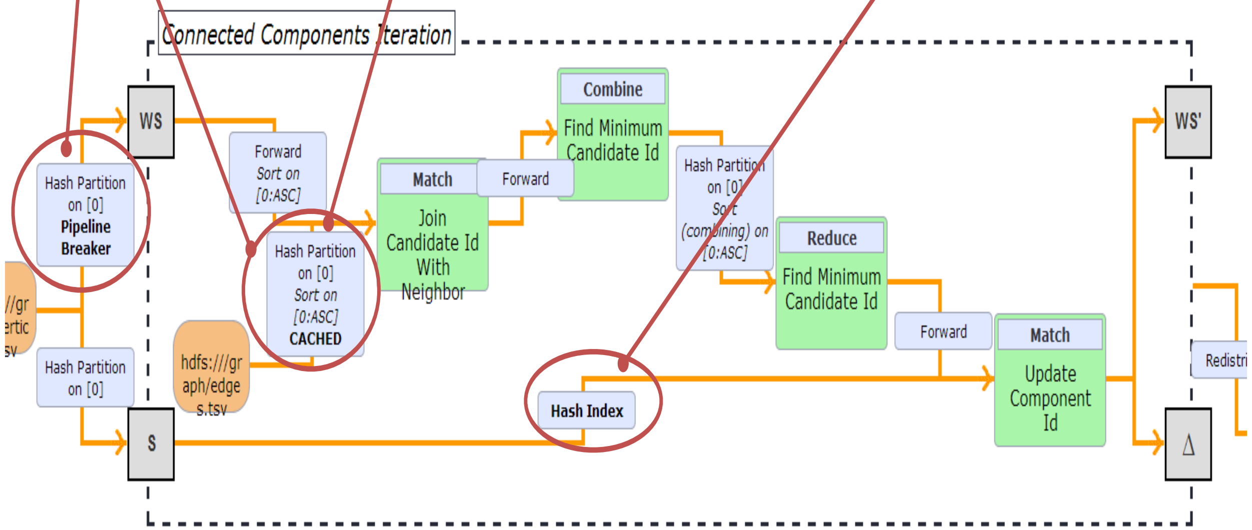
F. Hueske, M. Peters, A. Krettek, M. Ringwald, K. Tzoumas, V. Markl, J.C. Freytag: Peeking into the optimization of data flow programs with MapReduce-style UDFs. ICDE 2013: 1292-1295

Processing Iterative Data Analysis Programs

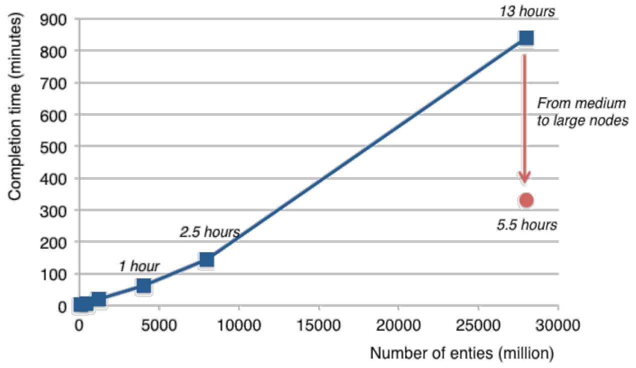
Pushing work „out of the loop“

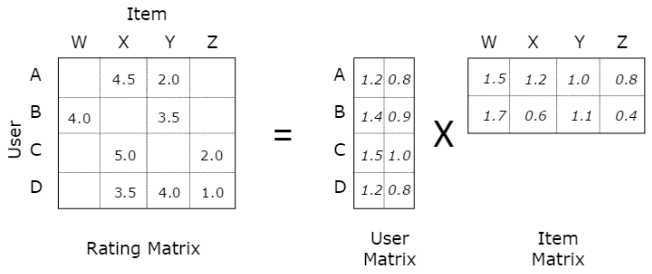
Caching Loop-invariant Data

Maintain state as index



Factorizing a matrix with 28 billion ratings for recommendations



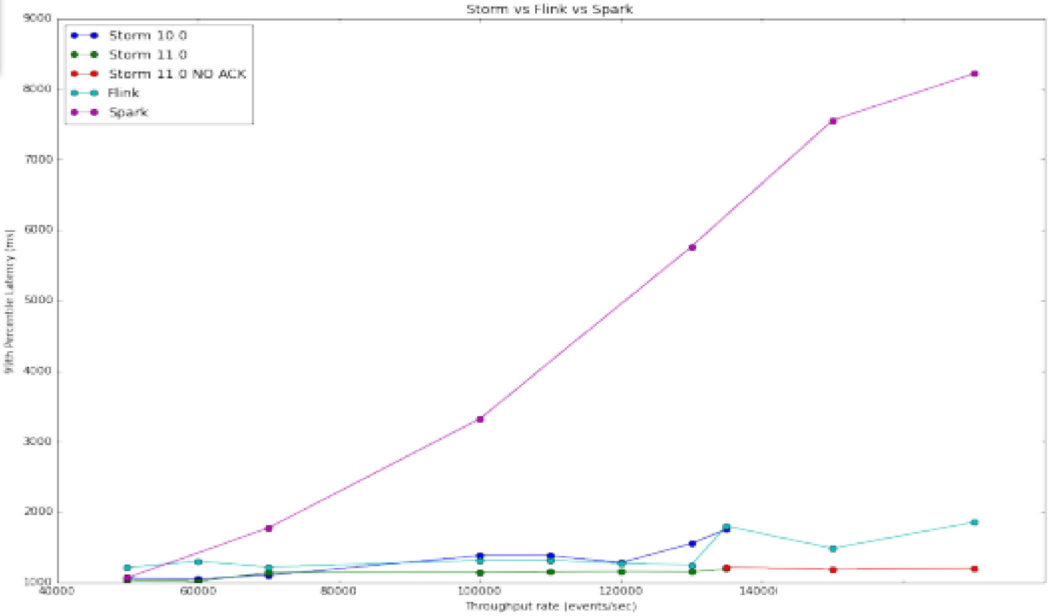


(Scale of Netflix or Spotify)

More at: http://data-artisans.com/computing-recommendations-with-flink.html

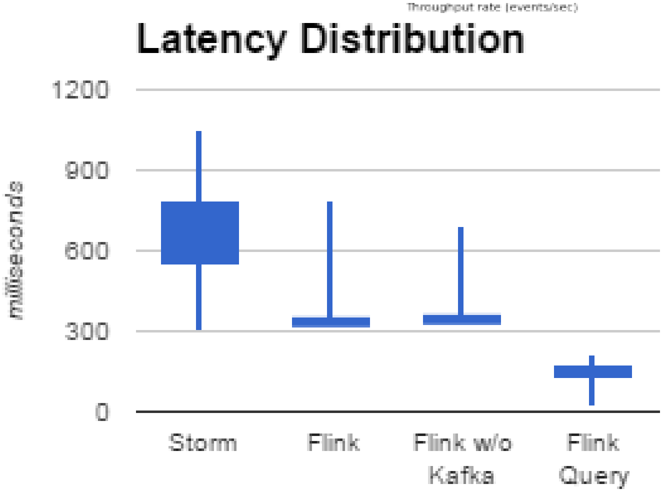
S. Ewen, S. Schelter, K. Tzoumas, D. Warneke, V. Markl:
Iterative Parallel Data Processing with Stratosphere: an Inside Look. SIGMOD 2013
S. Ewen, K. Tzoumas, M. Kaufmann, V. Markl:
Spinning Fast Iterative Data Flows. PVLDB 5(11): 1268-1279 (2012)

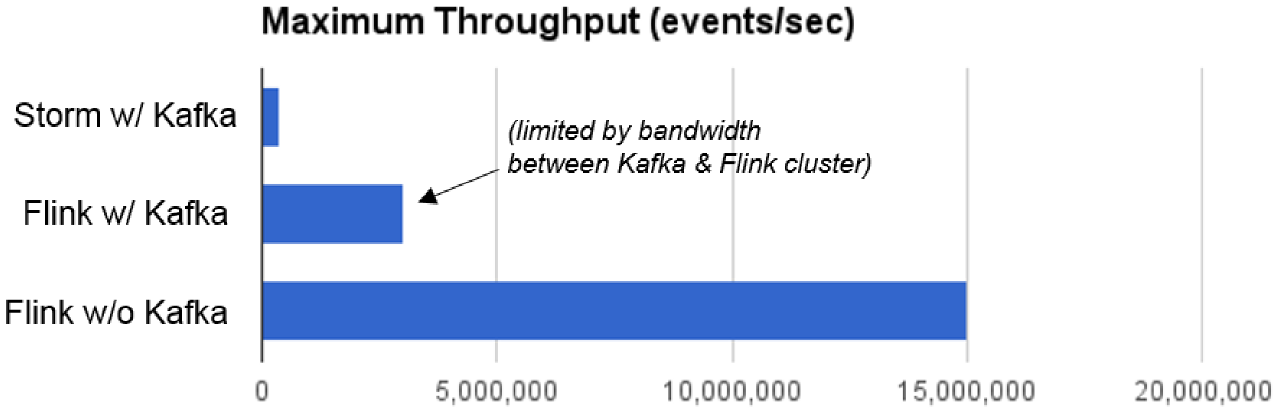
Streaming: Some Benchmark Results



Initially performed by Yahoo! Engineering

[..]Storm 0.10.0, 0.11.0-SNAPSHOT and Flink 0.10.1 show sub- second latencies at relatively high throughputs[..]. Spark streaming 1.5.1 supports high throughputs, but at a relatively higher latency.



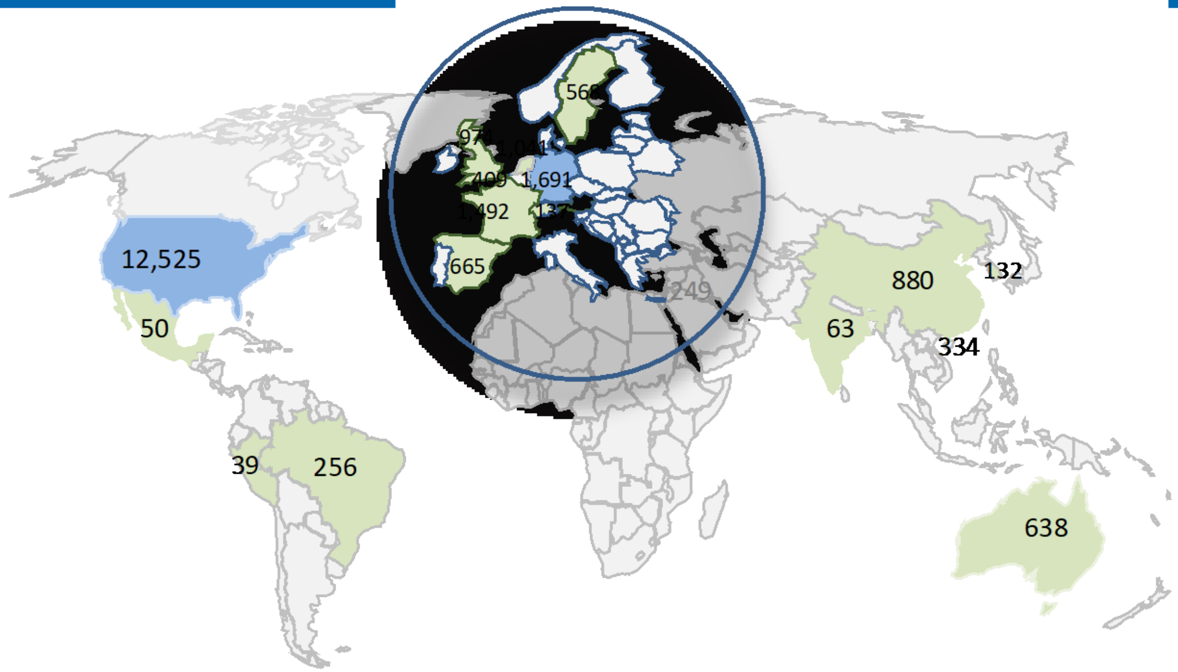


http://yahooeng.tumblr.com/post/135321837876/benchmarking-streaming-computation-engines-at
https://data-artisans.com/extending-the-yahoo-streaming-benchmark/

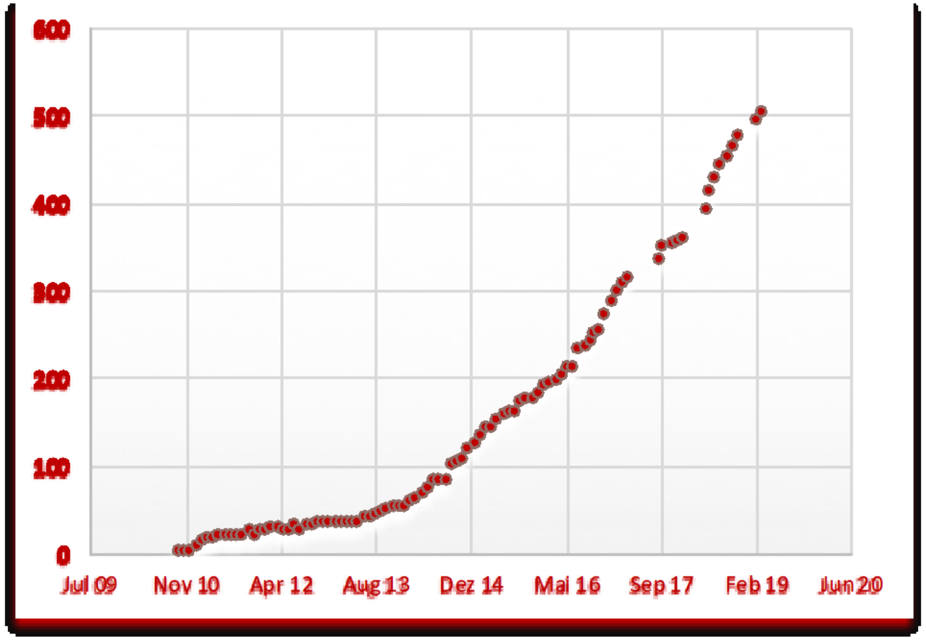
Apache Flink

https://www.meetup.com/topics/apache-flink/
https://flink.apache.org/poweredby.html
https://github.com/apache/flink

Flink Community



Flink Contributors



22,150+	**Meetup Members Worldwide**	**18**	**Countries that Regularly Hold Meetups**
500+	**Open Source Contributors/Developers**	**48+**	**Companies using Apache Flink**
41	**Meetup Groups Worldwide**		**Startup data Artisans, founded in 2014**

Some Highly Engaged Users

Largest job has > 20 operators, runs on > 5000 vCores in 1000-node cluster, processes millions of events per second

Complex jobs of > 30 operators running 24/7, processing 30 billion events daily, maintaining state of 100s of GB with exactly-once guarantees

30 Flink applications in production for more than one year. 10 billion events (2TB) processed daily

Courtesy of Kostas Tzoumas

Apache Flink Users

aeris
alephd We help publishers
Alibaba Group
amadeus
Atos
BetterCloud
Tencent 腾讯
altice

bouygues TELECOM
Capital One
dataArtisans
DRIVETRIBE
EURA NOVA
ERICSSON
FIRELAYERS
aws

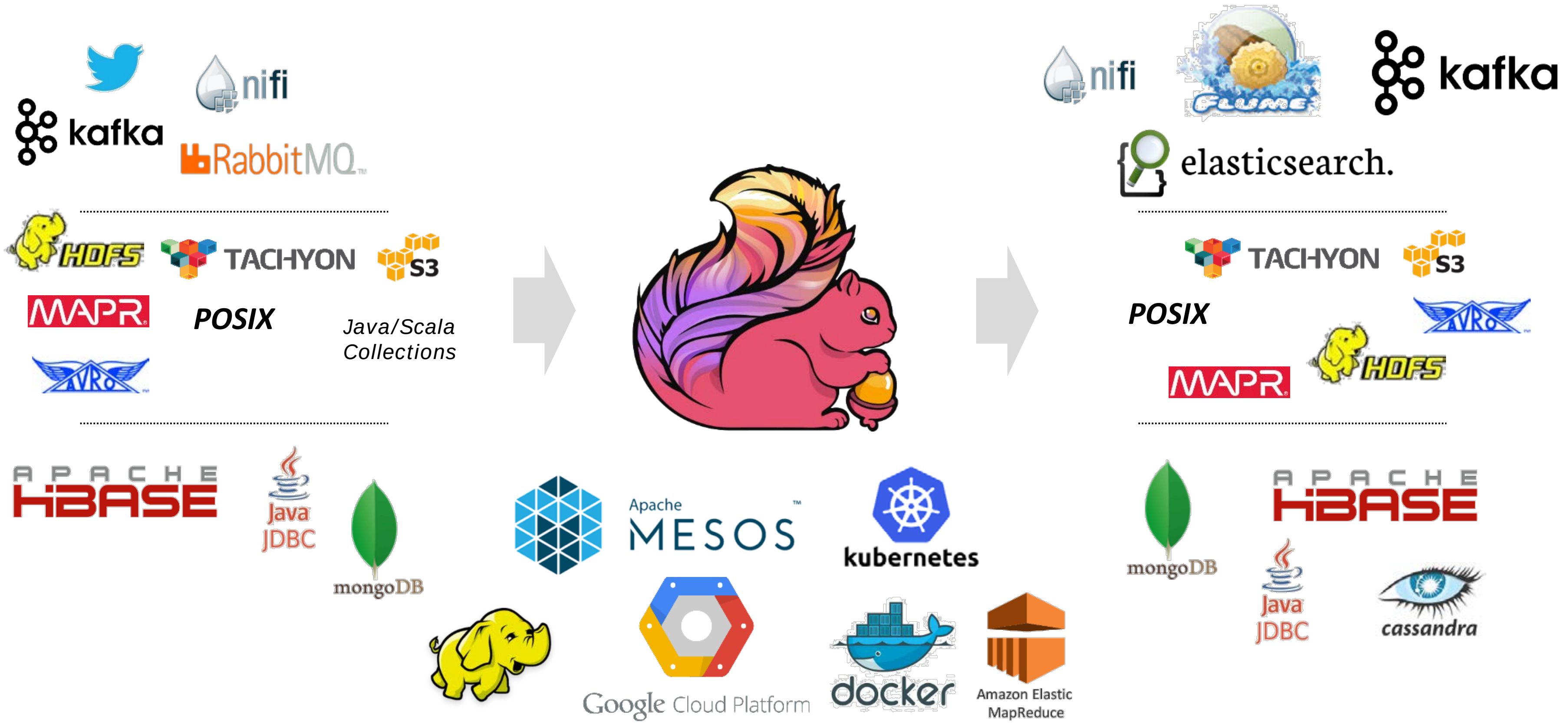
HUAWEI
IMR INTERNET MEMORY RESEARCH
ING
KEEDIO
King
LINE
mbrtargeting
MediaMath
MUX
KLAVIYO

NETFLIX
N MUSIC
OKKAM
otto group
Pragsis Bidoop Big Data Analytics
RADICALBIT Deep, Different, Disruptive.
InnoGames

ResearchGate
lyft
THIRD WATCH
treelogic
UBER
zalando
LIMEROAD New. Every day.
ROVIO

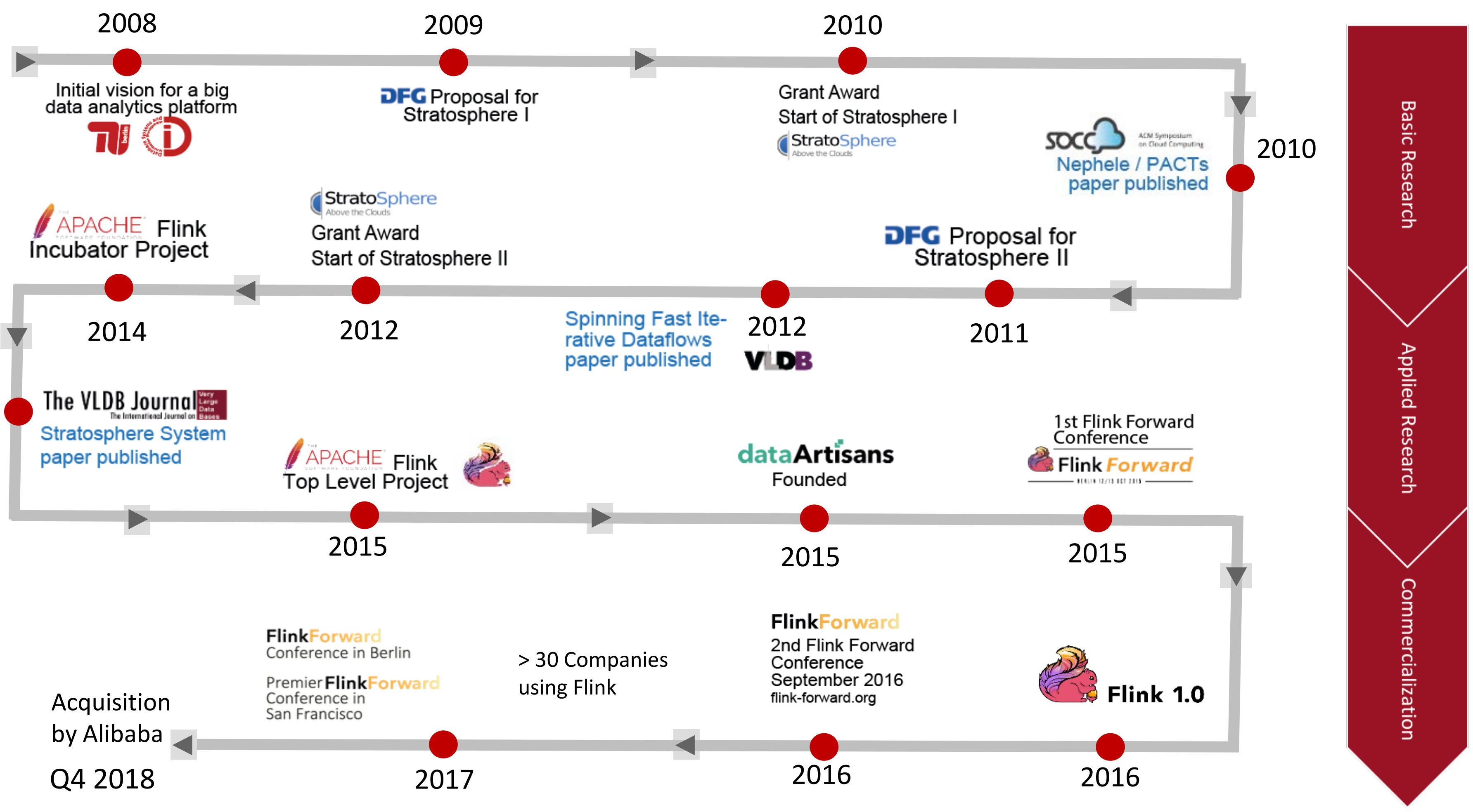
bol.com
Styx
yelp
COMCAST
ebay
Telefónica
Touk

Flink in the Ecosystem

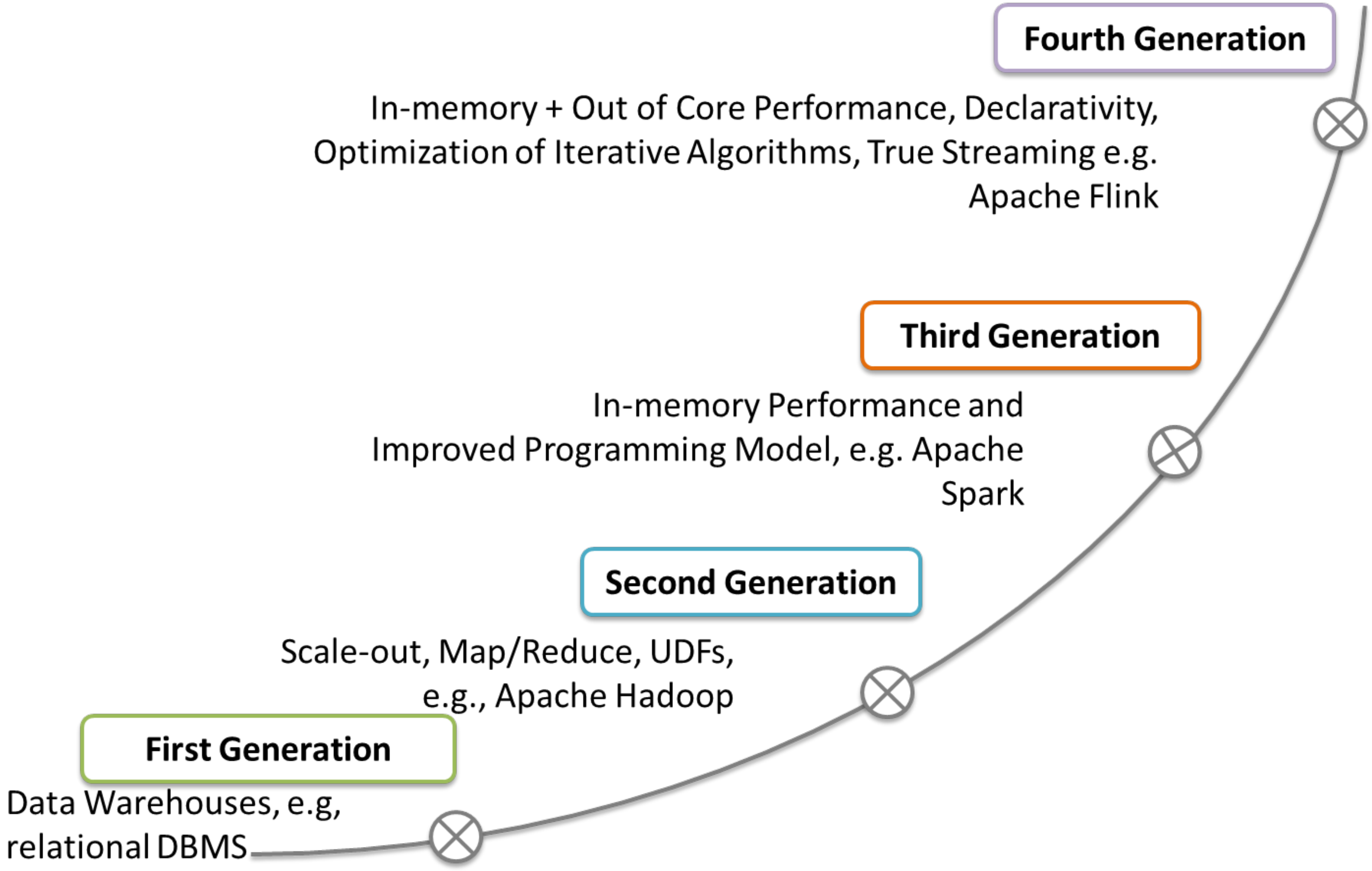


By courtesy of Kostas Tzoumas

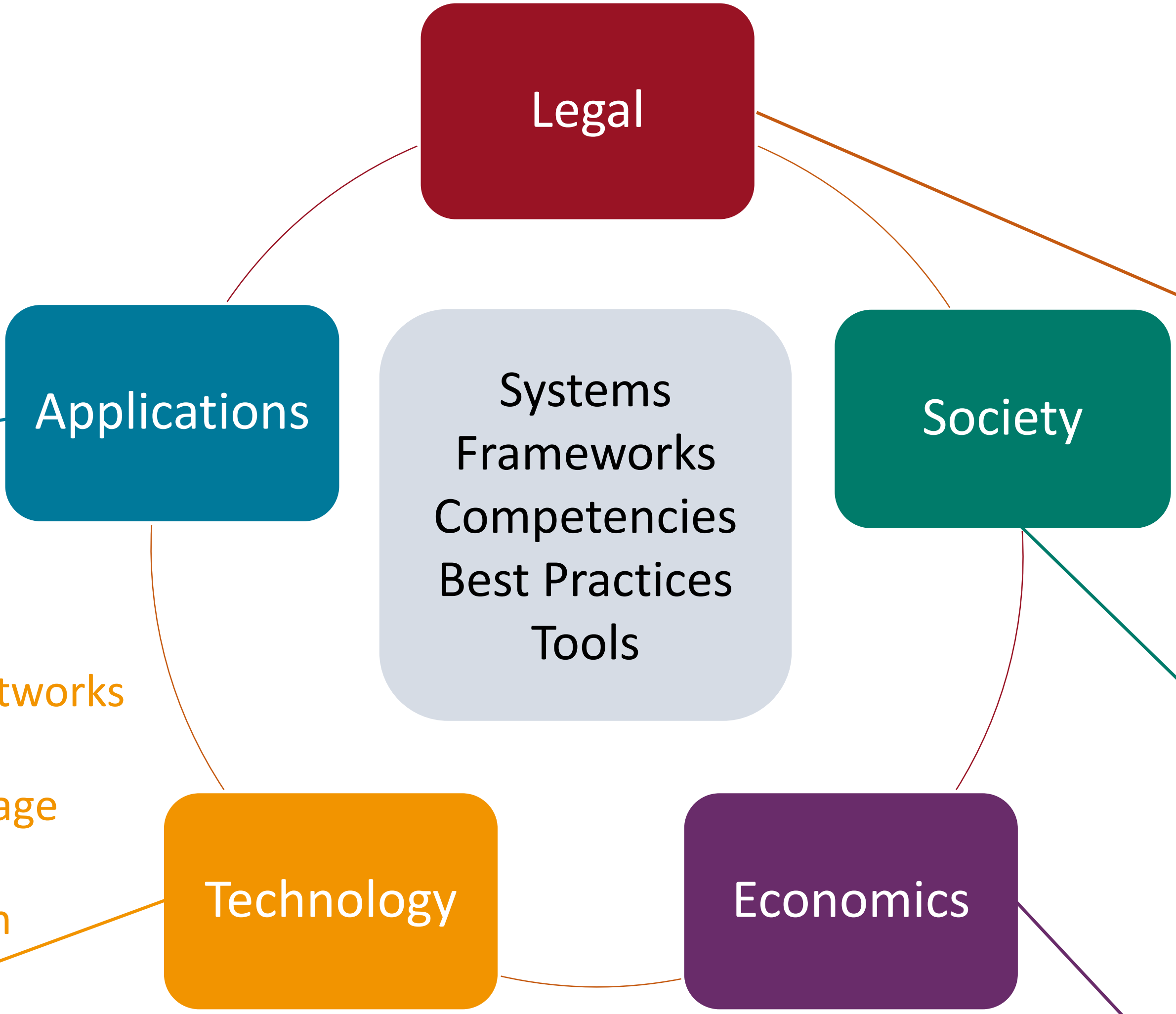
The Innovation Pipeline from Stratosphere to Flink



Evolution of Big Data Platforms



The Five Dimensions of Big Data and Data Science



Applications
- Engineering
- Humanities
- Medicine
- Economy
- Politics
- Sciences

Technology
- Data Management
- Distributed Systems / Networks
- Statistics, ML and AI
- Linguistics / Text / Language
- Security
- Interaction / Visualization
- Signal Processing

Legal
- Property
- Copyright
- Liability
- Bankruptcy Law
- Data Protection

Society
- Ethical Principles
- Common Good
- Social Processes
- Political Processes
- Xollaboration

Economics
- Benchmarking of Business Models
- Open Source and Open Data
- Distribution Models
- Information Pricing
- Information Marketplaces

http://www.bbdc.berlin/news-events/blog-articles/

Join us!

Berlin, the (digital) capital of Germany, is a **young, cosmopolitan, international city** in the heart of Europe, with a very large research and science industry as well as a dynamic and **thriving startup scene**, in particular in the creative and information technology space.

Pursue a DATA MANAGEMENT, DATA SCIENCE, AND DATA ENGINEERING career within

✓ **Doctoral and postdoctoral positions**

Questions and application submissions (including cover letter, CV, transcripts, and copies of your academic degrees) should sent to: jobs@dima.tu-berlin.de.

Reference Pages

The DIMA Research Group, http://www.dima.tu-berlin.de

The Berlin Big Data Center, http://big-data-berlin.dima.tu-berlin.de/home/

Prof. Volker Markl, http://www.user.tu-berlin.de/marklv