Architecture of ML Systems (AMLS)
01 Introduction and Overview

Prof. Dr. Matthias Boehm
Technische Universität Berlin
Berlin Institute for the Foundations of Learning and Data
Big Data Engineering (DAMS Lab)

Last update: Apr 17, 2025

Announcements / Org

- **#1 Hybrid & Video Recording**
  - Hybrid lectures (in-person, zoom) with optional attendance
    https://tu-berlin.zoom.us/j/9529634787?pwd=R1ZsN1M3SC9BOU1OcFdmem9zT202UT09
  - Zoom **video recordings**, links from website
    https://mboehm7.github.io/teaching/ss25_amls/index.htm

- **#2 Course Registrations**
  - TU Berlin ISIS registrations as of Apr 17
  - Bachelor/Master/PhD ratio? CS/others ratio?

~300

#3 Faculty IV - Team Awareness and Antidiscrimination

https://www.tu.berlin/eecs/awan

- **Goal**
  - **Low-barrier approachability** for spectrum of awareness and antidiscrimination issues
- **Team**
  - **Irene Hube-Achter** (MTSV)
  - **Matthias Boehm** (professors)
  - **Nadine Karsten** (scientific personnel)
  - **Tom Hersperger** (students)




- **Mission Statement**
  - Account for heterogeneity and complexity of modern societies at TU Berlin
  - All employees and students are committed to
    - **#1** Treat all persons with fairness and respect
    - **#2** Ensure a safe environment for all
    - **#3** Comply with our duty of care towards others
    - **#4** Actively support the implementation of the above guidelines and contribute

Contact: private email, eecs-TB-awareness@win.tu-berlin.de, or AwAn@dams.tu-berlin.de

Agenda

- FG Big Data Engineering (DAMS Lab)
- Motivation and Goals
- Course Organization and Logistics
- Course Outline, and Projects
- Apache SystemDS and DAPHNE

FG Big Data Engineering (DAMS Lab)

https://www.tu.berlin/dams

About Me

- **Since 09/2022 TU Berlin**, Germany
  - University professor for Big Data Engineering (DAMS)
- **2018-2022 TU Graz**, Austria
  - BMK endowed chair for data management + research area manager
  - **Data management for data science** (DAMS), **SystemDS & DAPHNE**
- **2012-2018 IBM Research – Almaden**, CA, USA
  - Declarative large-scale machine learning
  - Optimizer and runtime of **Apache SystemML**
- **2007-2011 PhD TU Dresden**, Germany
  - Cost-based optimization of integration flows
  - Time series forecasting / in-memory indexing & query processing

TECHNISCHE UNIVERSITÄT BERLIN

TU Graz

KNOW Center

IBM

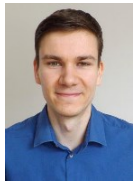
TECHNISCHE UNIVERSITÄT DRESDEN
DB group

BIFOLD

FG Big Data Engineering (DAMS Lab) – Team

- **Secretary** (09/2023)
  Sarah Hashmi

- **Postdoc** (01/2021)
  Patrick Damme



- **Postdoc** (04/2019)
  Arnab Phani

- **PhD Student** (01/2020)
  Sebastian Baunsgaard

Graduating 2024/25

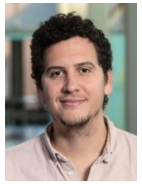
- **PhD Student** (10/2023)
  Christina Dionysio

- **PhD Student** (10/2023)
  Philipp Ortner
  → FONDA

- **PhD Student** (03/2023)
  David Justen
  → BIFOLD GS

- **PhD Student** (01/2024)
  Ramon Schöndorf
  Agility Project

- **PhD Student** (02/2023)
  Carlos E. Muniz Cuza
  → Agility Project



- **PhD Student** (10/2024)
  Grigorii Turchenko
  BIFOLD GS w/ Steffen Zeuch

- **PhD Student** (04/2021)
  Saeed Fathollahzadeh
  external

- **PhD Student** (01/2025)
  Martin Seyferth
  external

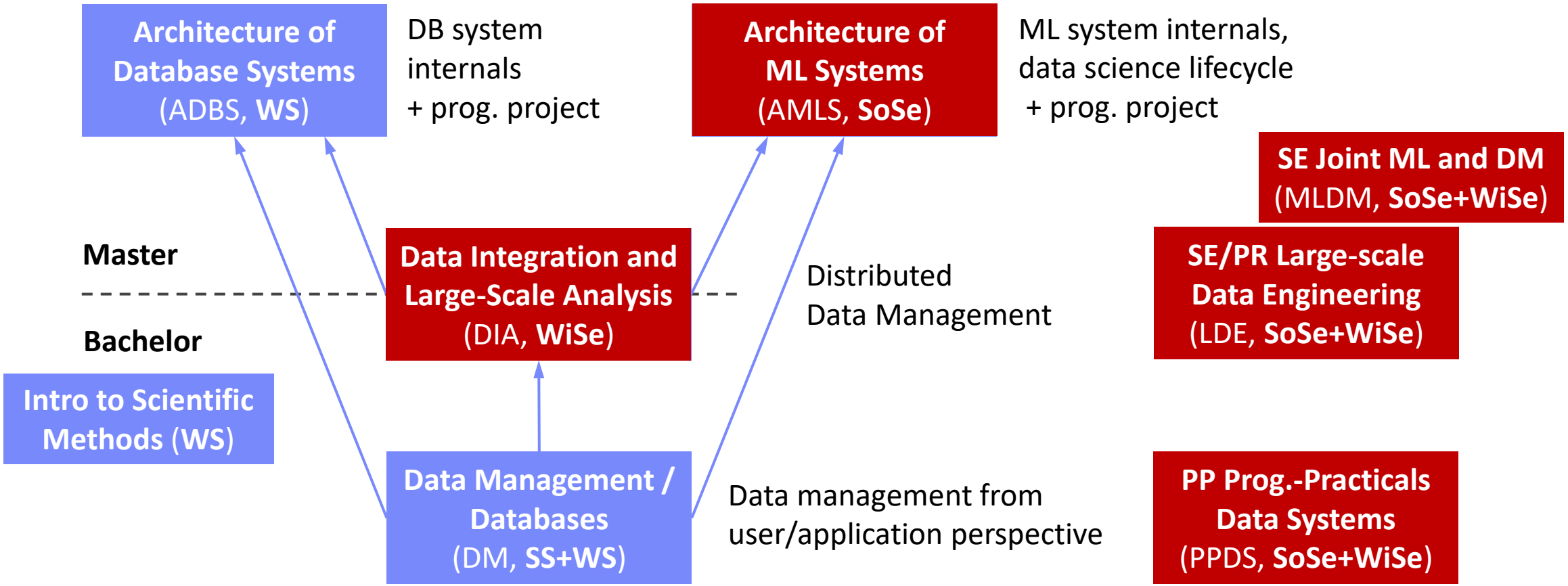
- **PhD Student** (02/2025)
  Alexander Wolotschai
  external

- **PhD Student** (04/2025)
  Martin Moesmann
  external

- **3x Student Assistants**
- **25x Bachelor/Master Students**
- **3x Interns and Visitors**

FG Big Data Engineering (DAMS Lab) – Teaching

Successfully Established TUB Teaching Portfolio (modules, slides)



Motivation and Goals

Example ML Applications (Past/Present)

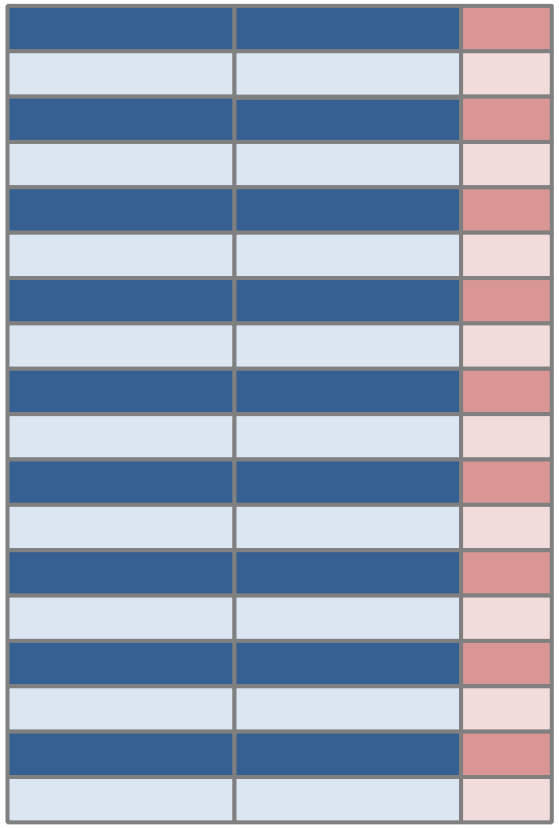
- **Transportation / Space**
  - **Lemon car detection and reacquisition** (classification, seq. mining)
  - **Airport passenger flows from WiFi data** (time series forecasting)
  - **Data analysis for driving assistance** (blind spot detection, emergency braking, lane centering)
  - **Automotive vehicle development** (ML-assisted simulations, hyper-parameter tuning, ejector optimization)
  - Earth observation and **local climate zone classification** and monitoring, reproducibility, compression
- **Finance**
  - **Insurance claim cost per customer** (model selection, regression)
  - **Financial analysts survey correlation** (bivariate stats w/ new tests)
- **Health Care**
  - **Breast / lunch / stomach cancer from histopathology images** (classification)
  - **Glucose trends and warnings** (clustering, classification)
  - Emergency room diagnosis / patient similarity (classification, clustering)
  - Patient survival analysis and prediction (Cox regression, Kaplan-Meier)

A Car Reacquisition Scenario

Warranty Claims

Repair History

Diagnostic Readouts



Machine Learning Algorithm

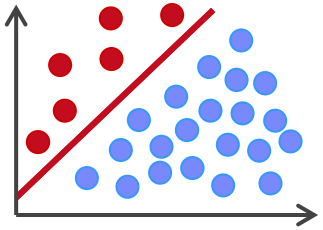
Algorithm

Algorithm

Algorithm

- Class skew
- Low precision

Predictive Models



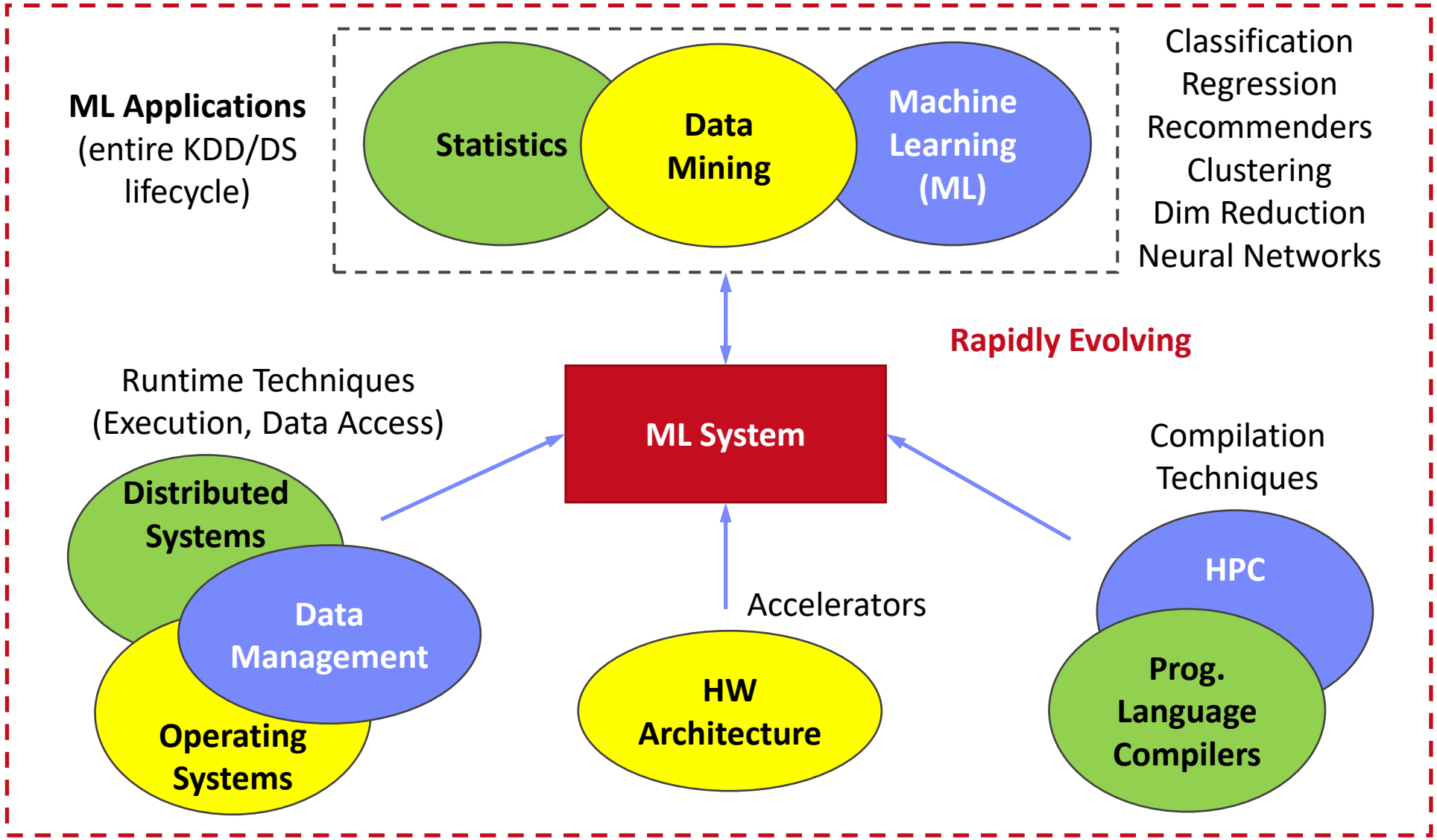
➔ 25x improved precision

+ custom loss functions
+ hyper-parameter tuning

Example ML Applications

- **Production/Manufacturing**
  - Paper and fertilizer production (regression/classification, anomalies)
  - Semiconductor manufacturing (ion beam tuning), and material degradation modeling (survival analysis)
  - Mixed waste stream sorting and recycling (composition, alignment, quality)
- **Other Domains**
  - Machine data: errors and correlation (bivariate stats, seq. mining)
  - Smart grid: energy demand/RES supply, weather models (forecasting)
- **Information Extraction**
  - NLP contracts → rights/obligations (classification, error analysis)
  - PDF table recognition and extraction, OCR (NMF clustering, custom)
  - Learning explainable linguistic expressions (learned FOL rules, classification)
- **Algorithm Research** (+ various state-of-the art algorithms)
  - User/product recommendations via various forms of NMF; word-embeddings via orthogonalized skip-gram
  - Localized, supervised metric learning (dim reduction and classification)

What is an ML System?



What is an ML System?, cont.

- **ML System**
  - **Narrow focus:** SW system that executes ML applications
  - **Broad focus:** Entire system (HW, compiler/runtime, ML application)

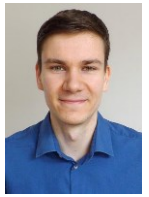
  ➔Trade-off **runtime/resources** vs **accuracy**

  ➔Early days: no standardizations (except some exchange formats), lots of different languages and system architectures, but many shared concepts

- **Course Objectives**
  - Architecture and internals of modern (large-scale) ML systems
    - **Microscopic view** of ML system internals
    - **Macroscopic view** of ML pipelines and data science lifecycle
  - **#1** Understanding of characteristics → **better evaluation / usage**
  - **#2** Understanding of effective techniques → **build/extend ML systems**

Course Organization and Logistics

Basic Course Organization


- **Staff**
  - Lecturer: Prof. Dr. Matthias Boehm (replacement: Dr. Patrick Damme)
  - Teaching Assistants: M.Sc. Sebastian Baunsgaard (projects/exercises)
- **Language**
  - Lectures and slides: **English**
  - Communication and examination: **English**/**German**
- **Course Format**
  - TU Berlin: VL+UE 3+2 SWS, **6 ECTS** (3x 1 ECTS + 2x 1.5 ECTS), master / TU Graz: VU 3 SWS, 5 ECTS
  - **Weekly lectures** (**start 4.15pm sharp**, including **Q&A**), **attendance optional**
  - **Mandatory programming project** or exercises (~3 ECTS)
  - **Recommended papers** for additional reading on your own
- **Prerequisites (preferred)**
  - Basic courses: **data management**/databases, distributed systems, **applied ML**
  - Completed bachelor (not mandatory)

Course Logistics

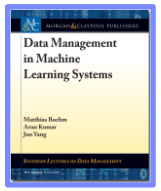
- **Website**
  - https://mboehm7.github.io/teaching/ss25_amls/index.htm
  - All course material (lecture slides) and dates
- **Video Recording / Live Streaming Lectures (zoom)**
- **Communication**
  - **Informal language** (first name is fine)
  - Please, **immediate feedback** (unclear content, missing background)
  - **ISIS forum** for offline questions, after lecture, and via email/PR discussions
  - **Office hours:** Tue 4pm-5.30pm (Sebastian in B 119) or after lecture
- **Exam**
  - **Completed project / exercise** (checked by me/staff, **no plagiarism** incl *-GPT)
  - **Final exam** (written exam or delegated oral exams, if >70 students take the exam)
  - **Grading** (project/exercises completion, 100% exam) → **new: +5 exam points if exercises >=90 points**

Course Logistics, cont.

- **Course Applicability TU Berlin**
  - Master programs computer engineering, computer science, electrical engineering, information systems management
    - Area Data and Software Engineering
    - Area Cognitive Systems
    - Area Distributed Systems
- **Course Applicability TU Graz** (remote – **offered in exceptions**)
  - Master programs computer science (CS), as well as software engineering and management (SEM)
    - Catalog Data Science (compulsory course in major, and elective)
    - Catalog Machine Learning (elective course)
    - Catalog Interactive and Visual Information Systems (elective course)
    - Catalog Software Technology (elective course)
  - PhD CS doctoral school list of courses
- **Free subject course in any other study program**

Outline and Projects

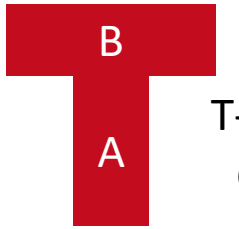
Created SoSe 2019, partially based on



[Matthias Boehm, Arun Kumar, Jun Yang: Data Management in Machine Learning Systems. Synthesis Lectures on Data Management, Morgan & Claypool Publishers 2019]

Major updates in SoSe 2020 – SoSe 2025

Part A: Overview and ML System Internals



T-shaped course layout

- **01 Introduction and Overview** [Apr 17]
- **02 Languages, Architectures, and System Landscape** [Apr 24]

- **03 Size Inference, Rewrites, and Operator Selection** [Fri, May 02]
- **04 Operator Fusion and Runtime Adaptation** [Fri, May 09]
- **05 Data- and Task-Parallel Execution** [May 15]
- **06 Parameter Servers** [May 22]
- **07 LLM Training and Inference** [Jun 05]

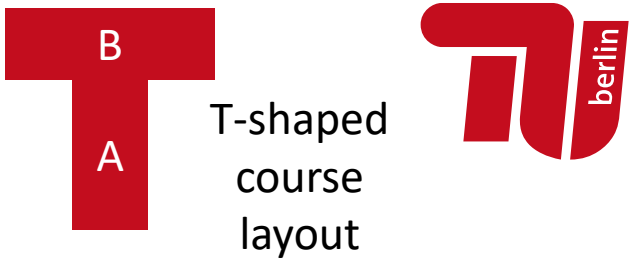
Labor Day May 01

80y EoWW2 May 08

Ascension of Jesus May 29

- **08 Hybrid Execution and HW Accelerators** [Jun 12]
- **09 Caching, Partitioning, Indexing, and Compression** [Jun 19]

Part B: ML Lifecycle Systems



- **10 Data Acquisition, Cleaning, and Preparation** [Jun 26]
- **11 Model Selection and Management** [Jul 03]
- **12 Model Debugging, Fairness, and Explainability** [Jul 10]
- **13 Model Serving Systems and Techniques** [Jul 17]
  - Incl Q&A and Exam Preparation

- **Planned Written Exams**
  - **Thu Jul 24, 4pm** (in ???)
  - **Thu Jul 31, 4pm** (in ???)
  - **Thu Aug 14, 4pm** (in ???)

Programming Projects

- **Open-Source Projects**
  - Programming project in context of open-source projects
    - **Apache SystemDS:** https://github.com/apache/systemds
    - **DAPHNE:** https://github.com/daphne-eu/daphne
    - Other OSS projects possible, but harder to merge PRs
  - Commitment to **open source and open communication** (PRs, mailing list)
  - **Remark:** Don't be afraid to ask questions / develop code in public

Apache SystemML™

DAPHNE

Lists of projects
available on website

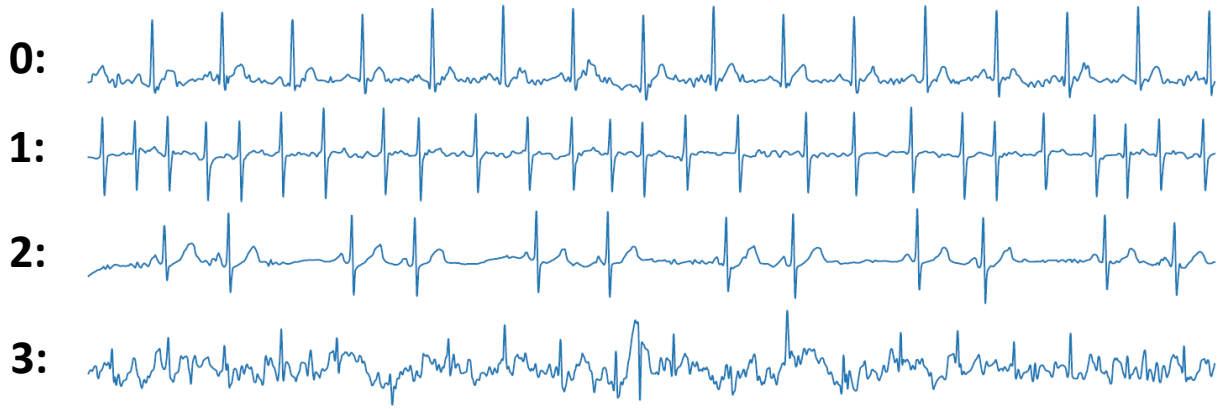
- **Objectives**
  - Non-trivial feature in an ML system (**3 ECTS → 75-90 hours**)
  - **OSS processes:** Break down into subtasks, code/tests/docs, one or more pull-requests per project, code review, incorporate review comments, etc

Project/Exercise Selection by May 01 EOD:
https://tinyurl.com/yeyrjyxw

- **Team**
  - Individuals or up to **three-person teams** (w/ separated responsibilities)

Alternative Exercise (published: Apr 12, submission: Jul 15)

- **Task: ECG Time Series Classification**
  - **Task Description:** https://mboehm7.github.io/teaching/ss25_amls/AMLS_2025_Exercise.pdf
  - **Data Exploration (15):** data acquisition, data characteristics, train/validation splits
  - **Modeling (40):** train ML models for classifying the ECG time series; hyper-parameter tuning
  - **Data Augmentation and Feature Engineering (30)**
  - **Data Reduction (15):** sampling, compression, others



0 .. Normal heart rhythm
1 .. Tachyarrhythmia
2 .. Other 3 .. Noisy

- **Objectives**
  - End-to-end development of an ML pipeline for ECG data
  - Handle data exploration, modeling and tuning, data augmentation, and compression

- **Team**
  - Individuals or up to **three-person teams** (w/ separated responsibilities)

Apache SystemDS and DAPHNE

https://github.com/apache/systemds

https://github.com/daphne-eu/daphne

Apache SystemDS: A Declarative ML System for the End-to-End Data Science Lifecycle

https://github.com/apache/systemds

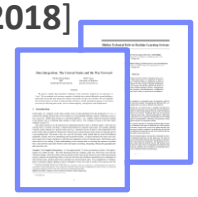
Landscape of ML Systems

- **Existing ML Systems**
  - **#1 Numerical computing** frameworks
  - **#2 ML Algorithm libraries** (local, large-scale)
  - **#3 Linear algebra ML systems** (large-scale)
  - **#4 Deep neural network** (DNN) frameworks
  - **#5 Model management, and deployment**

- **Exploratory Data-Science Lifecycle**
  - **Open-ended problems** w/ underspecified objectives
  - Hypotheses, data integration, run analytics
  - **Unknown value** → lack of system infrastructure
    → **Redundancy of manual efforts and computation**

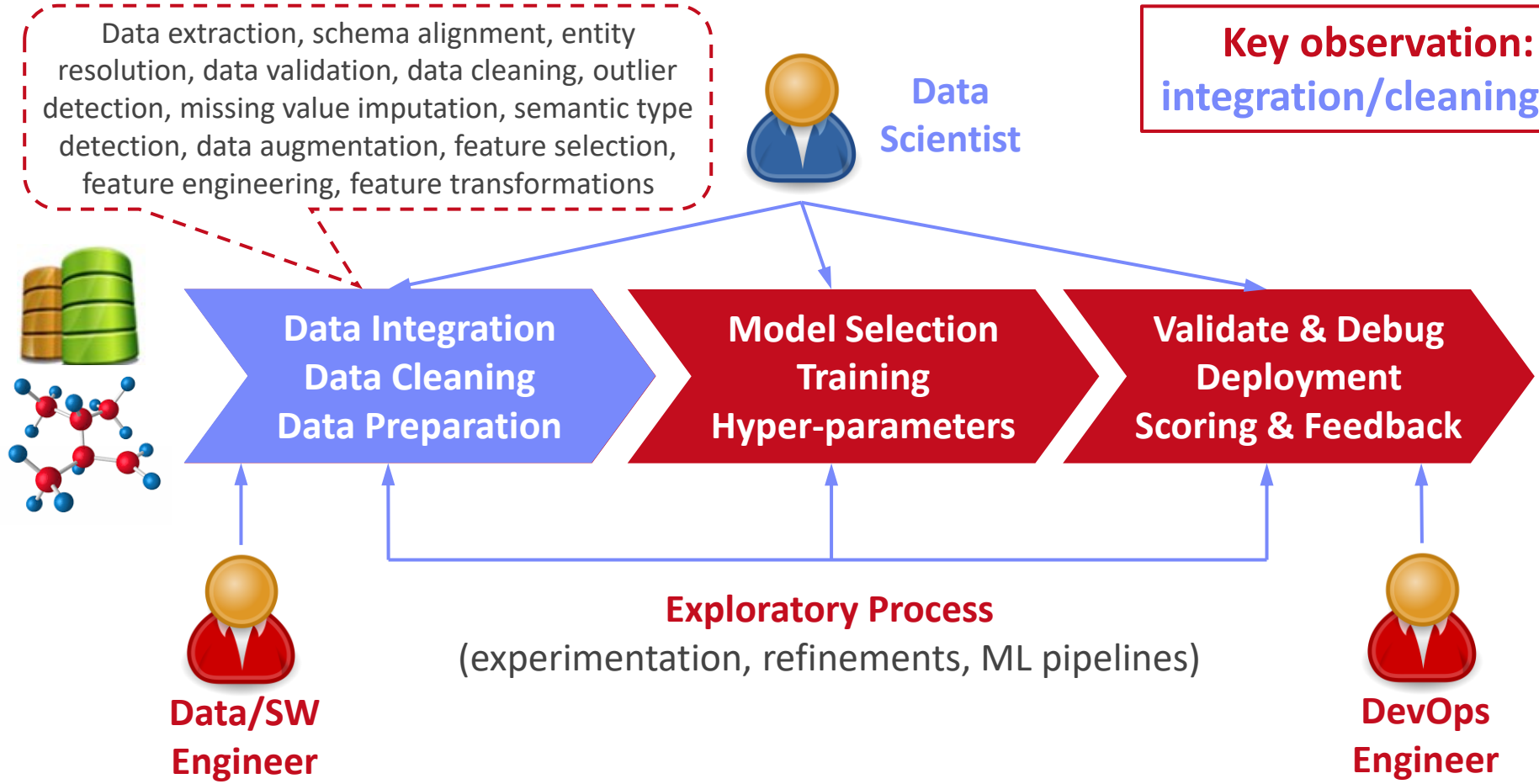
"Take these datasets and show value or competitive advantage"

[NIPS 2015]
[DEBull 2018]

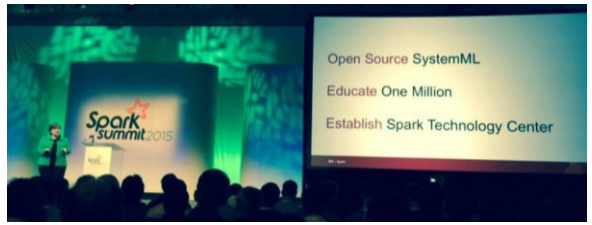


- **Data Preparation Problem**
  - **80% Argument:** 80-90% time for finding, integrating, cleaning data
  - Diversity of tools → boundary crossing, lack of optimization

The Data Science Lifecycle (aka KDD Process, aka CRISP-DM)



Apache SystemDS [https://github.com/apache/systemds]



APIs: Command line, JMLC, Python Spark MLContext, Spark ML, (Scalable Algorithms + Primitives)

DML Scripts

Language

Compiler

Runtime

Write Once, Run Anywhere

[SIGMOD'15,'17,'19,'21abc,'23abc,'24ab]
[PVLDB'14,'16ab,'18,'22]
[ICDE'11,'12,'15]
[EDBT'25][BTW'25ab]
[CIDR'17,'20]
[VLDBJ'18]
[CIKM'22]
[DEBull'14]
[PPoPP'15]

Apache SystemML™

07/2020 Renamed to **Apache SystemDS**
05/2017 Apache Top-Level Project
11/2015 Apache Incubator Project
08/2015 Open-Source Release

In-Memory Single Node
(scale-up)

Java

since 2012

Hadoop or Spark Cluster
(scale-out)

since 2010/11

since 2015

Federated
(LA progs, PS)

since 2019

In-Progress:

GPU

since 2014/16

Others:
Netezza
Apache Flink

Language Abstractions and APIs

Data Independence + Impl-Agnostic Ops
➔ **"Separation of Concerns"**

- **Example:** Stepwise Linear Regression

User Script

```
X = read('features.csv')
Y = read('labels.csv')
[B,S] = steplm(X, Y,
  icpt=0, reg=0.001)
write(B, 'model.txt')
```

Built-in Functions

```
m_steplm = function(...) {
  while( continue ) {
    parfor( i in 1:n ) {
      if( !fixed[1,i] ) {
        Xi = cbind(Xg, X[,i])
        B[,i] = lm(Xi, y, ...)
    } }
    # add best to Xg
    # (AIC)
} }
```

Feature Selection

```
m_lm = function(...) {
  if( ncol(X) > 1024 )
    B = lmCG(X, y, ...)
  else
    B = lmDS(X, y, ...)
}
```

ML Algorithms

```
m_lmCG = function(...) {
  while( i<maxi&nr2>tgt ) {
    q = (t(X) %*% (X %*% p))
      + lambda * p
    beta = ... }
}
```

```
m_lmDS = function(...) {
  l = matrix(reg,ncol(X),1)
  A = t(X) %*% X + diag(l)
  b = t(X) %*% y
  beta = solve(A, b) ...}
```

Linear Algebra Programs

Facilitates optimization across data science lifecycle tasks

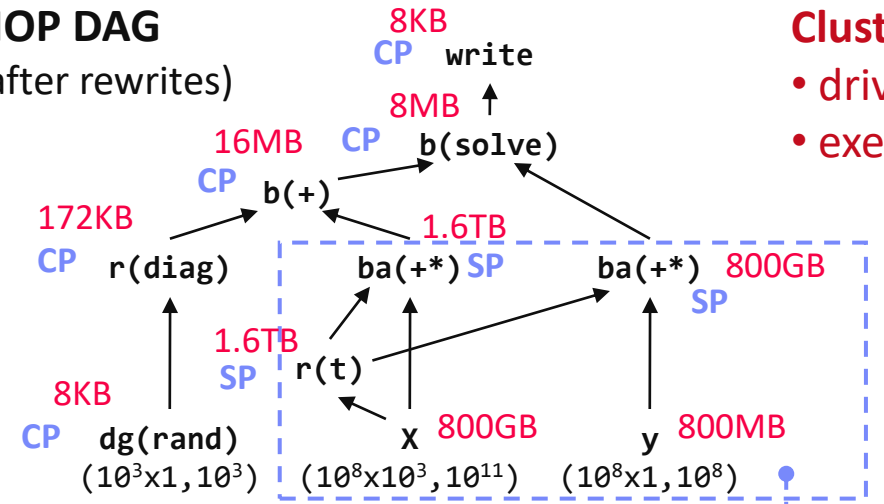
Basic HOP and LOP DAG Compilation

LinregDS (Direct Solve)

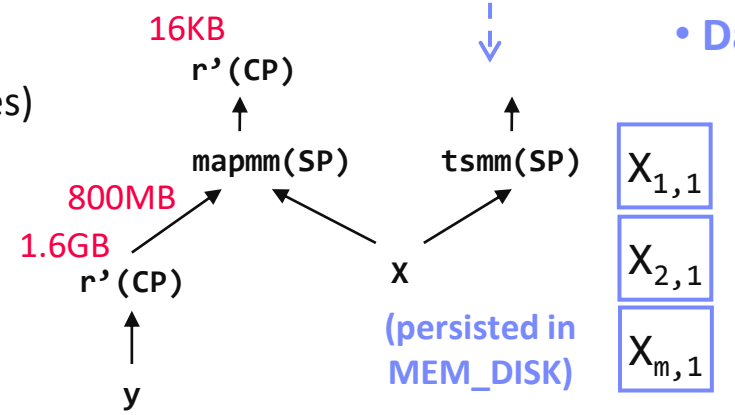
```
X = read($1);
y = read($2);
intercept = $3;
lambda = 0.001;
...
if( intercept == 1 ) {
  ones = matrix(1, nrow(X), 1);
  X = append(X, ones);
}
I = matrix(1, ncol(X), 1);
A = t(X) %*% X + diag(I)*lambda;
b = t(X) %*% y;
beta = solve(A, b);
...
write(beta, $4);
```

Scenario:
X: 10^8 x 10^3, 10^{11}
y: 10^8 x 1, 10^8

HOP DAG
(after rewrites)



LOP DAG
(after rewrites)



$X_{1,1}$
$X_{2,1}$
$X_{m,1}$

Cluster Config:
- driver mem: 20 GB
- exec mem: 60 GB

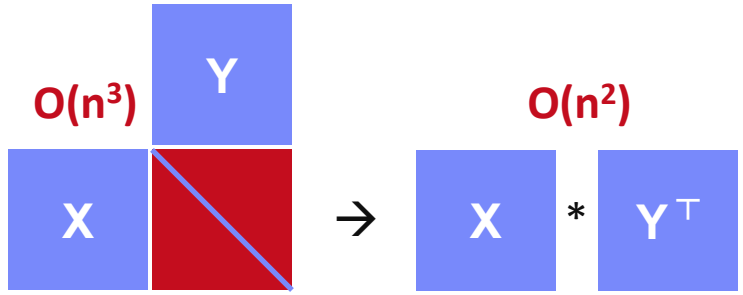
➔ **Distributed Matrices**
- Fixed-size matrix blocks
- Data-parallel operations

➔ **Hybrid Runtime Plans:**
- Size propagation / memory estimates
- Integrated CP / Spark runtime
- Dynamic recompilation during runtime

Static and Dynamic Rewrites

- **Example Static Rewrites** (size-independent)
  - Common Subexpression Elimination
  - Constant Folding / Branch Removal / Block Sequence Merge
  - Static Simplification Rewrites
  - Right/Left Indexing Vectorization
  - For Loop Vectorization
  - Spark checkpoint/repartition injection

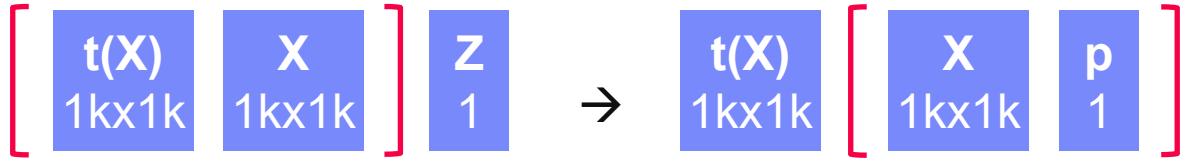
`trace(X%*%Y)` → `sum(X*t(Y))`



`sum(λ*X)` → `λ*sum(X)`
`sum(X+Y)` → `sum(X)+sum(Y)`

- **Example Dynamic Rewrites** (size-dependent)
  - Dynamic Simplification Rewrites
  - Matrix Mult Chain Optimization

`rowSums(X)` → `X, iff ncol(X)=1`
`sum(X^2)` → `X%*%t(X), iff ncol(X)=1`



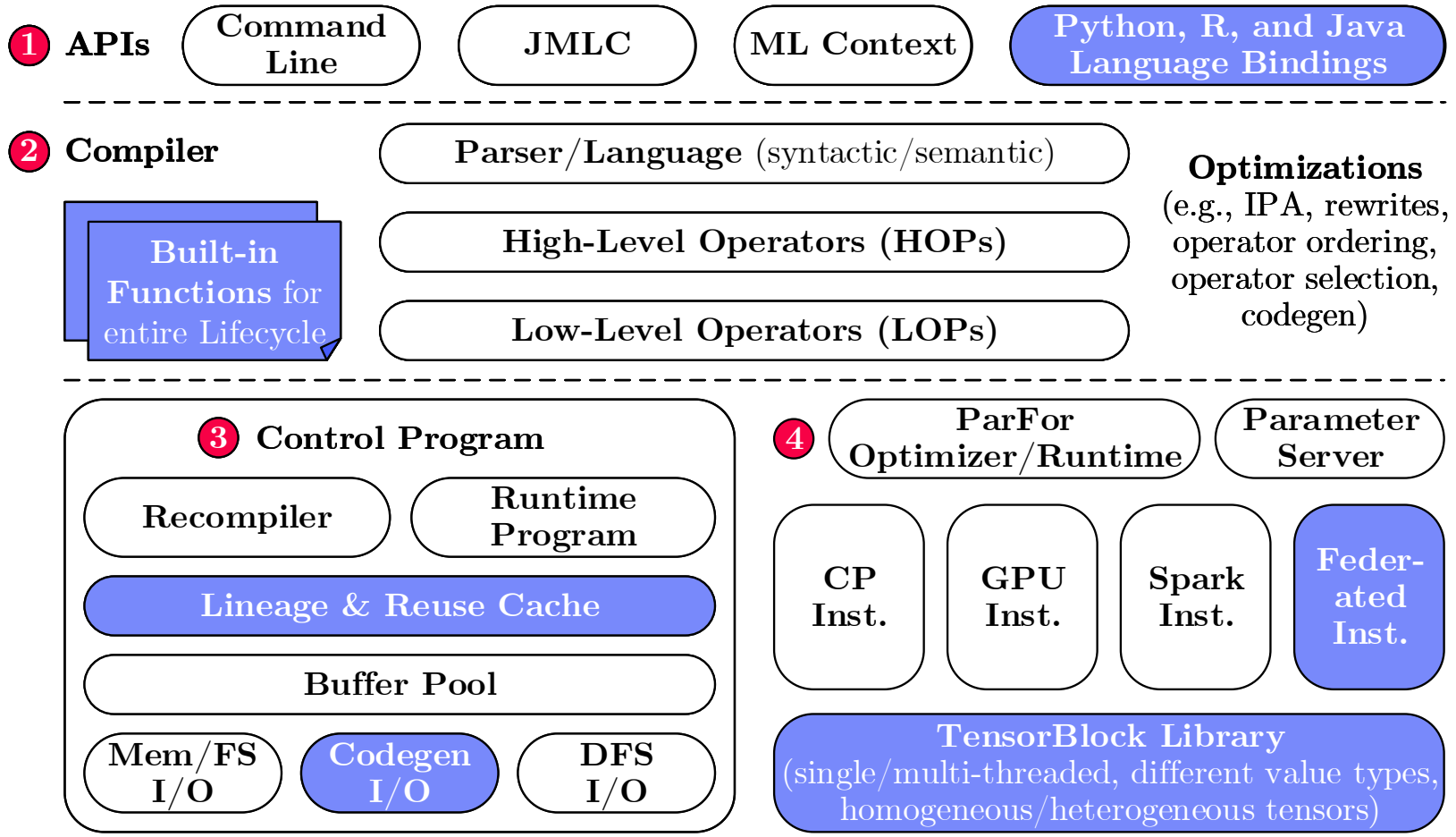
2,002 MFLOPs **4 MFLOPs**

Size propagation and sparsity estimation

Sparsity Estimation & Sparse DP Enum [SIGMOD'19]

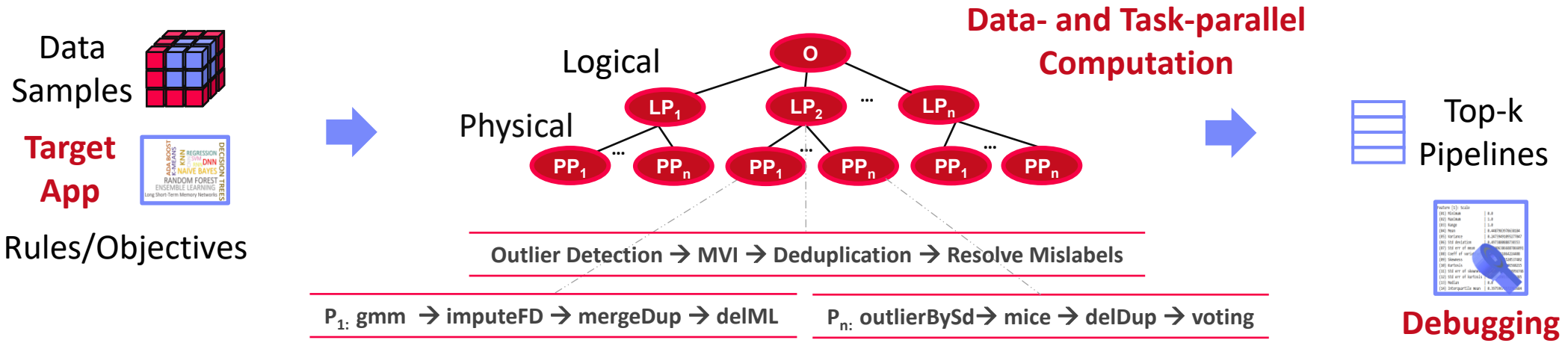
Apache SystemDS Architecture [CIDR'20]

> 500K tests
> 10K DSL tests



Data Cleaning Pipelines [SIGMOD'24, under submission]

- **Automatic Generation of Cleaning Pipelines**
  - Library of robust, parameterized **data cleaning primitives**
  - **Enumeration of DAGs** of primitives & **hyper-parameter optimization** (evolutionary, HB)



University	Country
TU Graz	Austria
TU Graz	Austria
TU Graz	Germany
IIT	India
IIT	IIT
IIT	Pakistan
IIT	India
SIBA	Pakistan
SIBA	null
SIBA	null

Dirty Data

University	Country
TU Graz	Austria
TU Graz	Austria
TU Graz	Austria
IIT	India
IIT	India
IIT	India
IIT	India
SIBA	Pakistan
SIBA	Pakistan
SIBA	Pakistan

After **imputeFD(0.5)**

A	B	C	D
0.77	0.80	1	1
0.96	0.12	1	1
0.66	0.09	null	1
0.23	0.04	17	1
0.91	0.02	17	null
0.21	0.38	17	1
0.31	null	17	1
0.75	0.21	20	1
null	null	20	1
0.19	0.61	20	1
0.64	0.31	20	1

Dirty Data

A	B	C	D
0.77	0.80	1	1
0.96	0.12	1	1
0.66	0.09	17	1
0.23	0.04	17	1
0.91	0.02	17	1
0.21	0.38	17	1
0.31	0.29	17	1
0.75	0.21	20	1
0.41	0.24	20	1
0.19	0.61	20	1
0.64	0.31	20	1

After **MICE**

SliceLine for Model Debugging [SIGMOD'21b, BTW'25b]

sliceline

[**Credit:** sliceline, Silicon Valley, HBO]

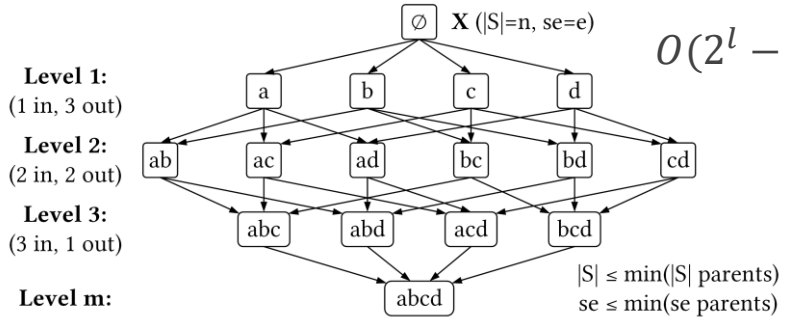
- **Problem Formulation**
  - Intuitive slice scoring function
  - Exact top-k slice finding
  - $|S| \geq \sigma \wedge sc(S) > 0, \alpha \in (0,1]$

$$sc = \alpha\left(\frac{\bar{e}(S)}{\bar{e}(X)} - 1\right) - (1-\alpha)\left(\frac{|X|}{|S|} - 1\right)$$

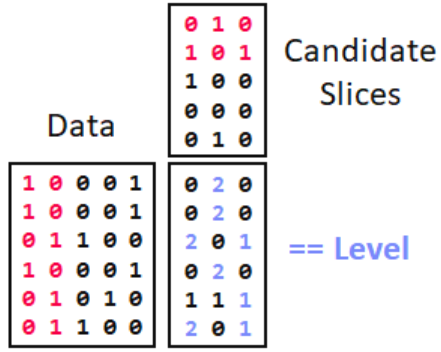
$$= \alpha\left(\frac{|X|}{|S|} \cdot \frac{\sum_{i=1}^{|S|} es_i}{\sum_{i=1}^{|X|} e_i} - 1\right) - (1-\alpha)\left(\frac{|X|}{|S|} - 1\right)$$

slice error slice size

- **Properties & Pruning**
  - Monotonicity of slice sizes, errors
  - Upper bound sizes/errors/scores
    → pruning & termination



$$O(2^l - \sum_{j=1}^{m} 2^{d_j} + l + m)$$



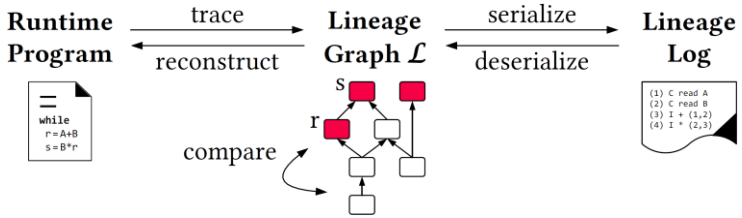
- **Linear-Algebra-based Slice Finding**
  - Recoded/binned matrix **X**, error vector e
  - Vectorized implementation in linear algebra (join & eval via sparse-sparse matmult)
  - Local and distributed task/data-parallel execution

BIFOLD

Multi-level Lineage Tracing & Reuse

[CIDR'20, SIGMOD'21a, EDBT'25]


- **Lineage as Key Enabling Technique**
  - Trace lineage of ops (incl. non-determinism), dedup for loops/funcs
  - Model versioning, data reuse, incr. maintenance, autodiff, debugging

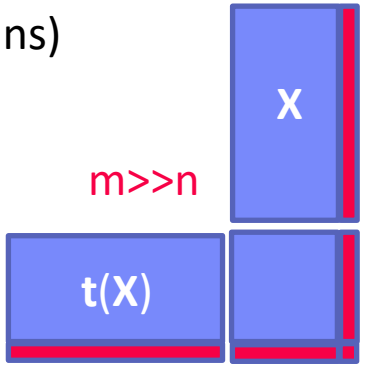


- **Full Reuse of Intermediates**
  - Before executing instruction, probe output lineage in cache
    `Map<Lineage, MatrixBlock>`
  - Cost-based/heuristic caching and eviction decisions (compiler-assisted)

```
for( i in 1:numModels )
  R[,i] = lm(X, y, lambda[i,], ...)
```

```
m_lmDS = function(...) {
  l = matrix(reg,ncol(X),1)
  A = t(X) %*% X + diag(l)
  b = t(X) %*% y
  beta = solve(A, b) ...}
```

- **Partial Reuse of Intermediates**
  - **Problem:** Often partial result overlap
  - Reuse partial results via dedicated rewrites (compensation plans)
  - Example: steplm



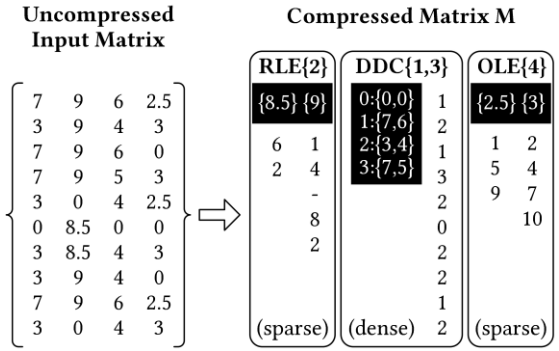

```
m_steplm = function(...) {
  while( continue ) {
    parfor( i in 1:n ) {
      if( !fixed[1,i] ) {
        Xi = cbind(Xg, X[,i])
        B[,i] = lm(Xi, y, ...)
    } }
    # add best to Xg (AIC)
} }
```

- **Extensions:** multi-backend (Local, GPU, Spark), unified memory management

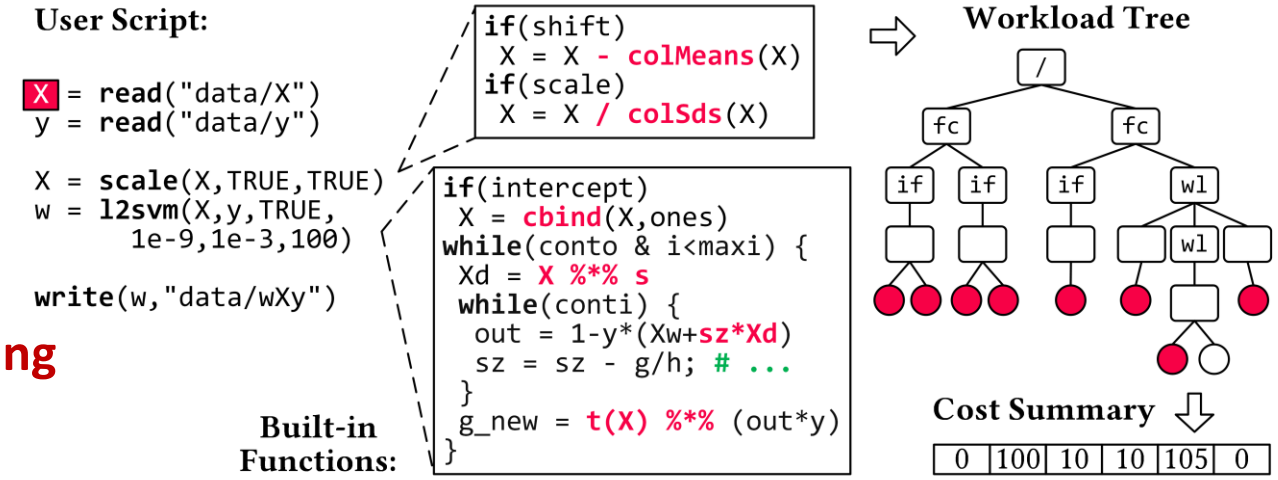
Compressed Linear Algebra Extended

[PVLDB'16a, VLDBJ'18, SIGMOD'23a, under submission]

- **Lossless Matrix Compression**
  - Improved general applicability (adaptive compression time, new compression schemes, new kernels, intermediates, workload-aware)
  - Sparsity → Redundancy exploitation (data redundancy, structural redundancy)



- **Workload-aware Compression**
  - Workload summary → compression
  - Compressed Representation → execution planning

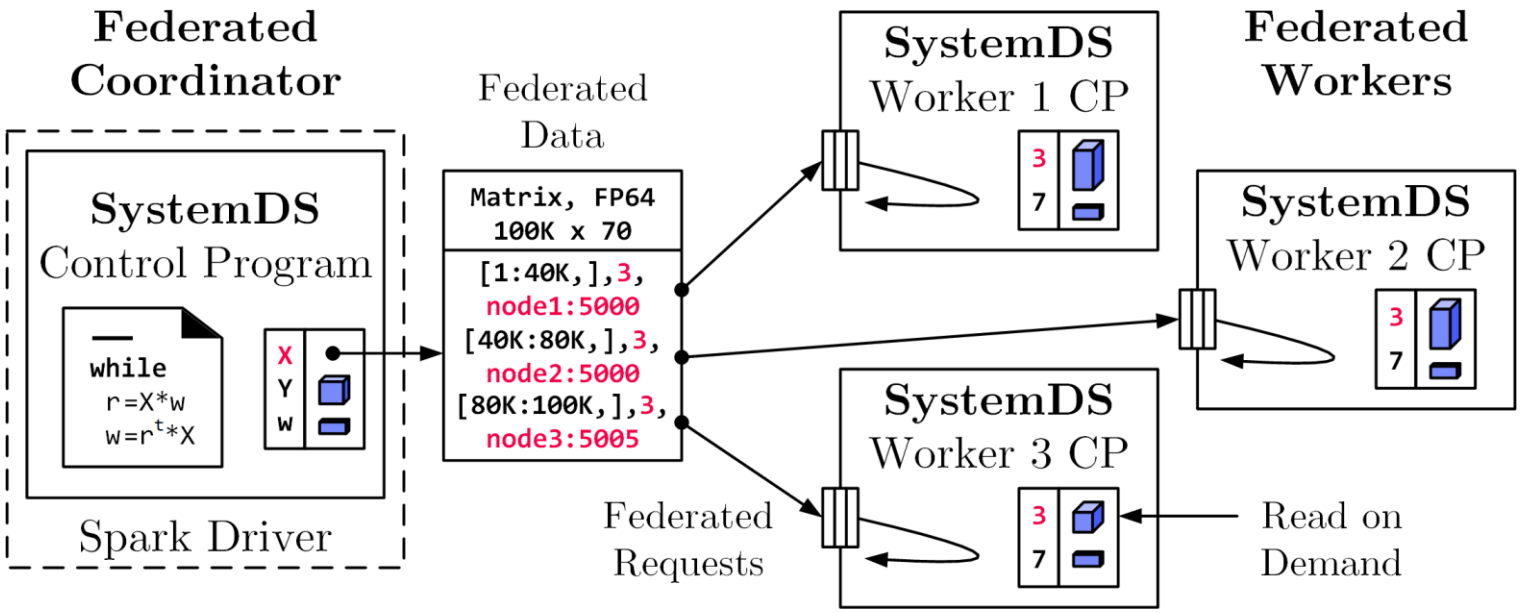


- **BWARE: Compressed Feature Engineering**
  - Frame compression, compressed I/O
  - Compressed feature transformations
  - Morphing of compressed data

Federated Learning [SIGMOD'21c]

- **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`

➔ **Design Simplicity:**
(1) reuse instructions
(2) federation hierarchies

DAPHNE: An Open and Extensible System Infrastructure for Integrated Data Analysis Pipelines

https://github.com/daphne-eu/daphne

DAPHNE

Motivation

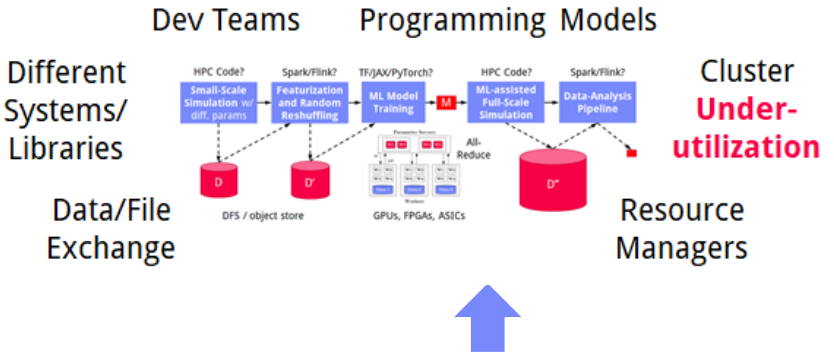
➔ DAPHNE Overall Objective: Open and extensible system infrastructure

- **Integrated Data Analysis Pipelines**
  - Open data formats, query processing
  - Data preprocessing and cleaning
  - ML model training and scoring
  - HPC, custom codes, and simulations

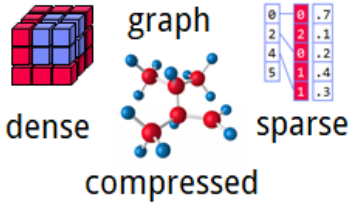
- **Hardware Challenges**
  - DM+ML+HPC share compilation and runtime techniques / converging cluster hardware
  - **End of Dennard scaling:** $P = \alpha CFV^2$ (power density 1)
  - **End of Moore's law**
  - **Amdahl's law:** sp = 1/s

  ➔ Increasing Specialization

Deployment Challenges



#1 Data Representations



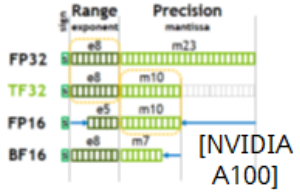
Sparsity Exploitation from Algorithms to HW

#2 Data Placement

Local vs **distributed**

#3 Data (Value) Types

FP32, FP64, INT8, INT32, INT64, UINT8, BF16, TF32, FlexPoint

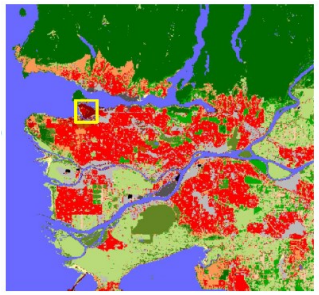


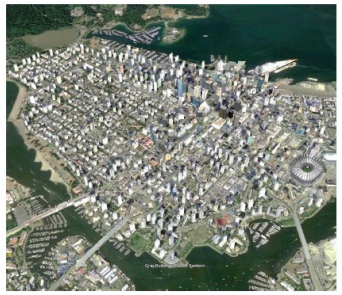
DAPHNE Use Cases

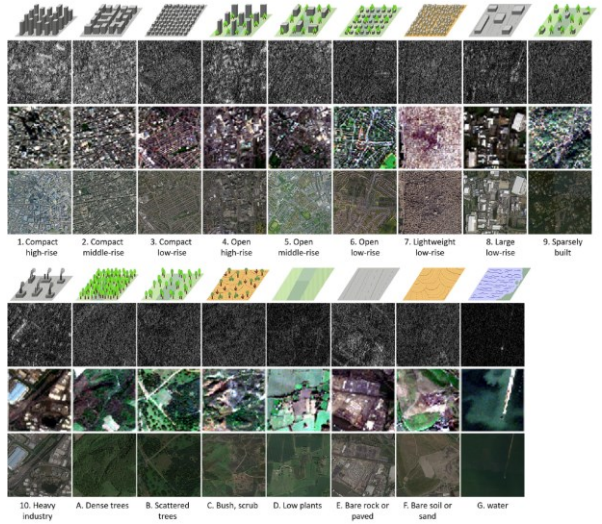
[Xiao Xiang Zhu et al: So2Sat LCZ42: A Benchmark Dataset for the Classification of Global Local Climate Zones. **GRSM 8(3) 2020**]

[So2Sat LC42: https://mediatum.ub.tum.de/1454690]

- **DLR Earth Observation**
  - **ESA Sentinel-1/2** datasets → 4PB/year
  - Training of local climate zone classifiers on **So2Sat LCZ42** (15 experts, 400K instances, 10 labels each, 85% confidence, ~55GB H5)
  - **ML pipeline:** preprocessing, ResNet20, climate models



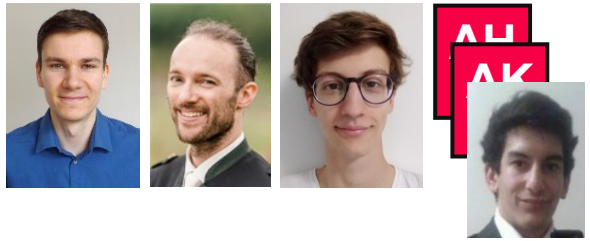


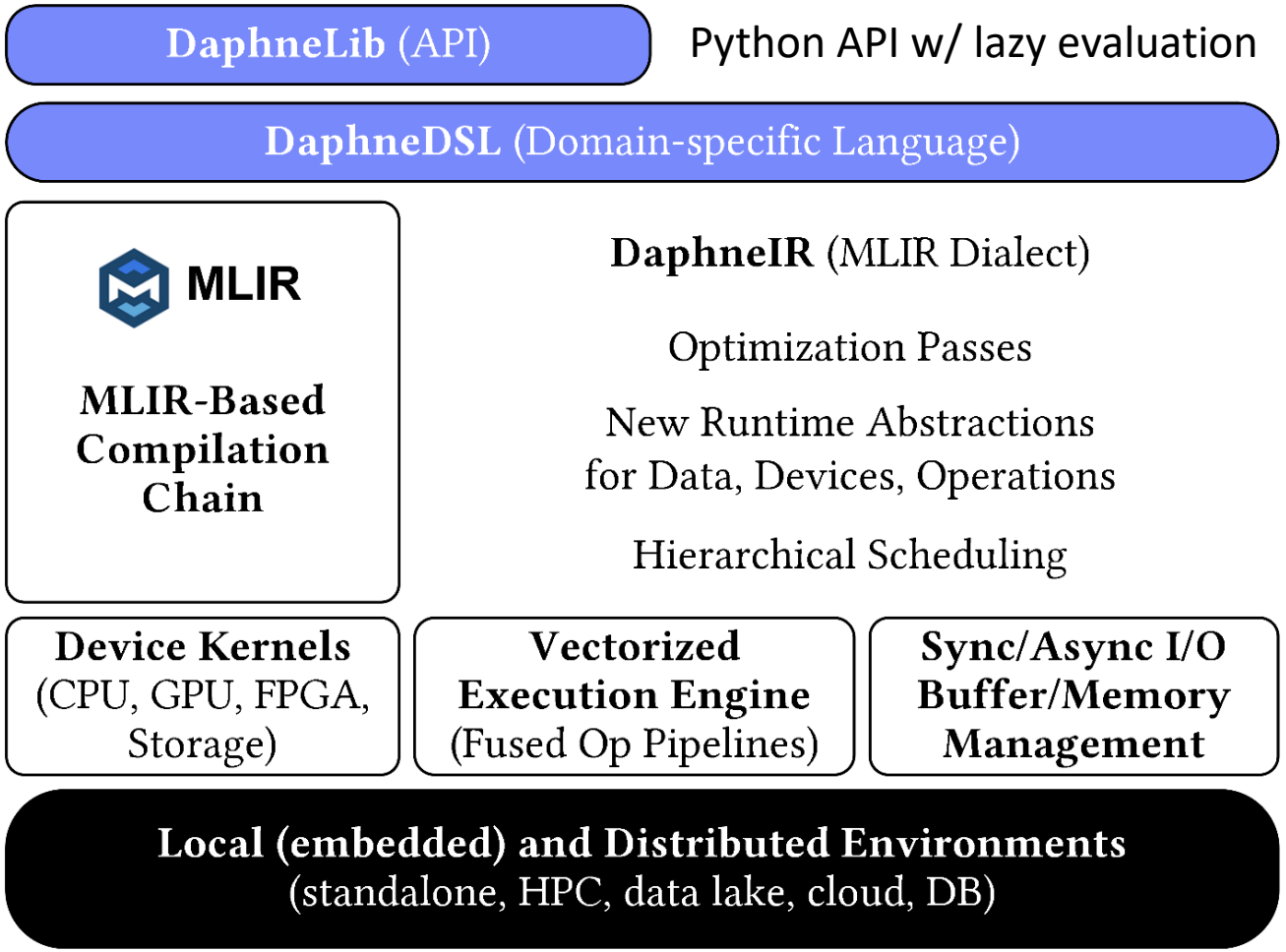


- **IFAT Semiconductor Ion Beam Tuning**
- **KAI Semiconductor Material Degradation**
- **AVL Vehicle Development Process (ejector geometries, KPIs)**

- **ML-assisted simulations, data cleaning, augmentation**

DAPHNE System Architecture [CIDR'22]





Extensible Infrastructure

MLIR Dialects, Extension Catalog (new data types, kernels, scheduling algs)

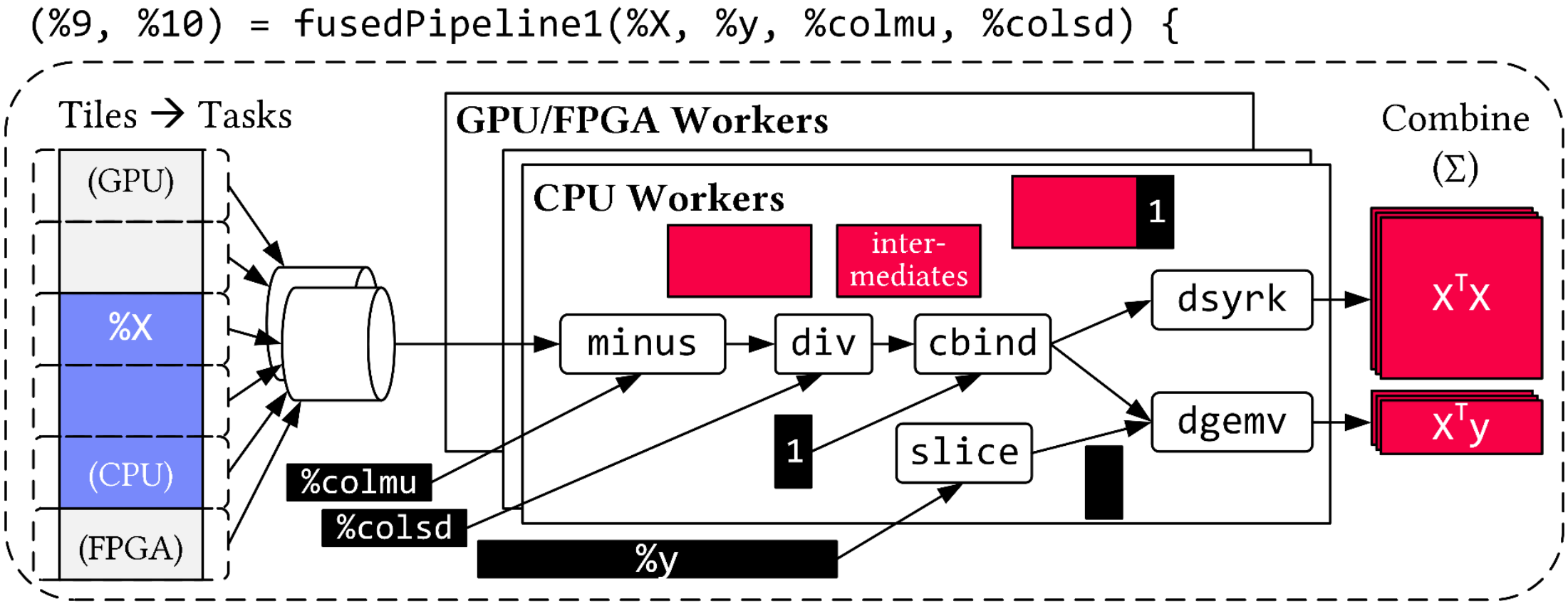
Multi-level Compilation/ Runtime

Sideways Entry, DSL-level constraints (e.g., data/op placement)

Fine-grained Fusion and Parallelism

Integration w/ Resource Mgmt & Prog. Models

Vectorized (Tiled) Execution



Default Parallelization
Frame & Matrix Ops

Locality-aware,
Multi-device Scheduling

Fused Operator Pipelines
on Tiles/Scalars + Codegen

Summary & QA

Thanks

- **FG Big Data Engineering (DAMS Lab)**
- **Motivation and Goals**
- **Course Organization and Logistics**
- **Course Outline, and Projects**
- **Apache SystemDS and DAPHNE**

Programming Projects in SystemDS/DAPHNE, or Alternative Exercise Project/Exercise Selection by **May 01 EOD**:
https://tinyurl.com/yeyrjyxw

- **Next Lectures (Part A)**
  - **02** Languages, Architectures, and System Landscape [Apr 24]
  - **03** Size Inference, Rewrites, and Operator Selection [May 02]
  - **04** Operator Fusion and Runtime Adaptation [May 09]
  - **05** Data- and Task-Parallel Execution [May 15]
  - **06** Parameter Servers [May 22]
  - **07** LLM Training and Inference [Jun 05]