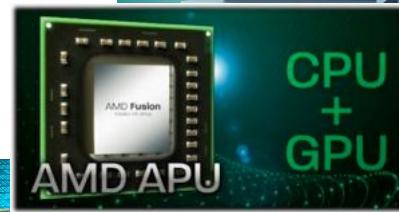
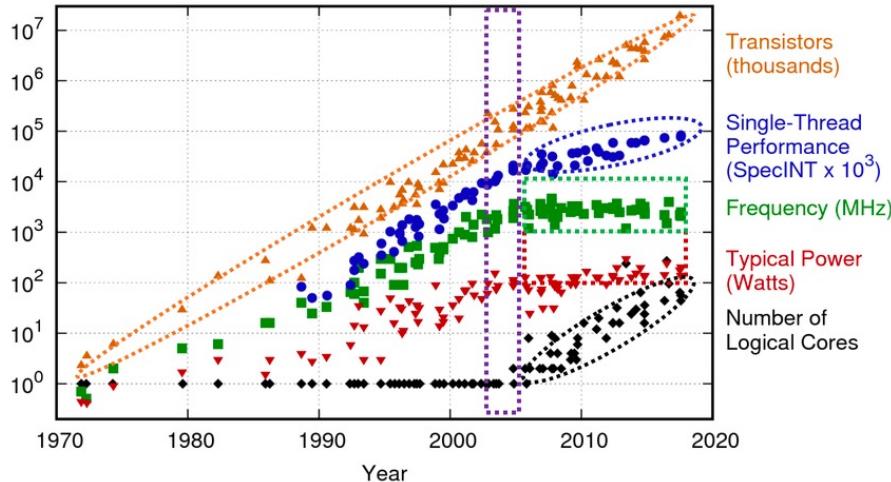


Data Processing System on Modern Hardware

Shuhao Zhang
Assistant Professor
School of Computer
Science and Engineering

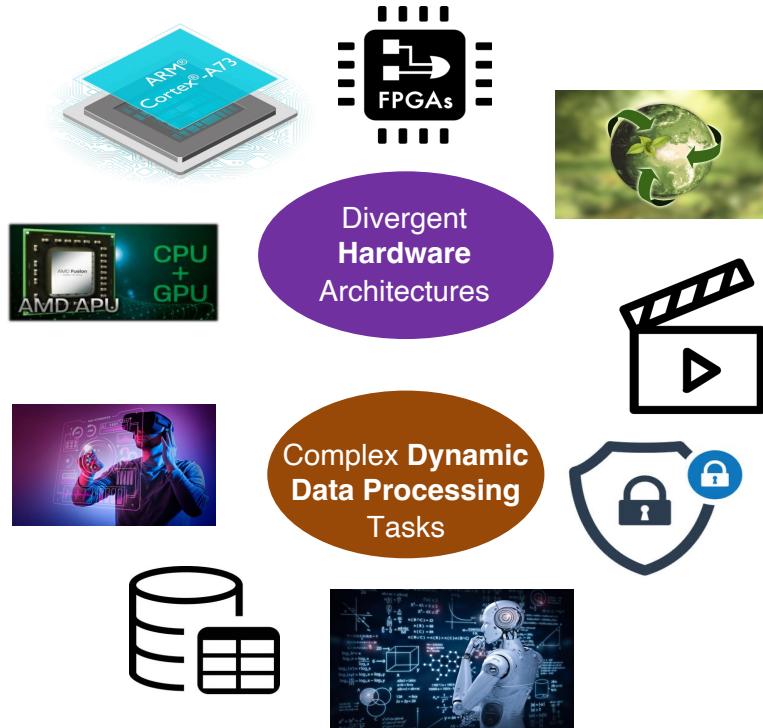


Introduction



Source: BACKUS: Comprehensive High-Performance Research Software
Engineering Approach for Simulations in Supercomputing Systems, 2019

Motivation



Data Challenges:

- Volume: Massive datasets
- Velocity: Rapid data streams
- Variety: Diverse data types

Our past focus

Traditional Architecture Limits:

- Scalability
- Efficiency
- Flexibility

Modern Hardware Solutions:

- Processors: Multicore CPUs, GPUs, FPGAs, ASICs
- Memory: NVRAM, HBM
- Network: RDMA



| Our Research Contributions

❑ Journal

IEEE TPDS '16/ '17/ '21, IEEE TKDE '21,
ACM SIGMOD Rec. '19, VLDBJ '22/ '23

❑ Conference

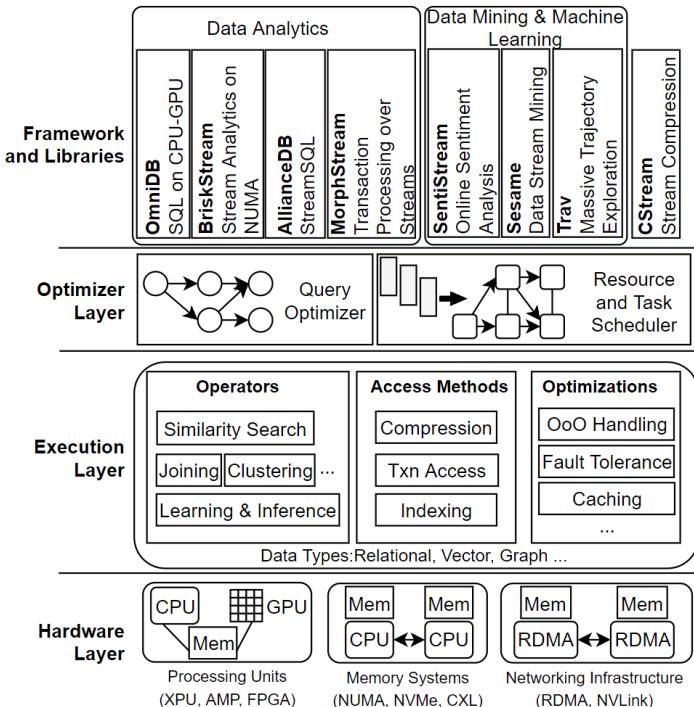
SIGMOD '19/ '21/ '23(x2)/ '24(x2), ICDE
'17(x2)/ '20/ '23(x3), VLDB '13, EMNLP'23, SC '16,
IJCAI '20, USENIX ATC '20, DEBS '23 (vision)

❑ System demo and Workshop

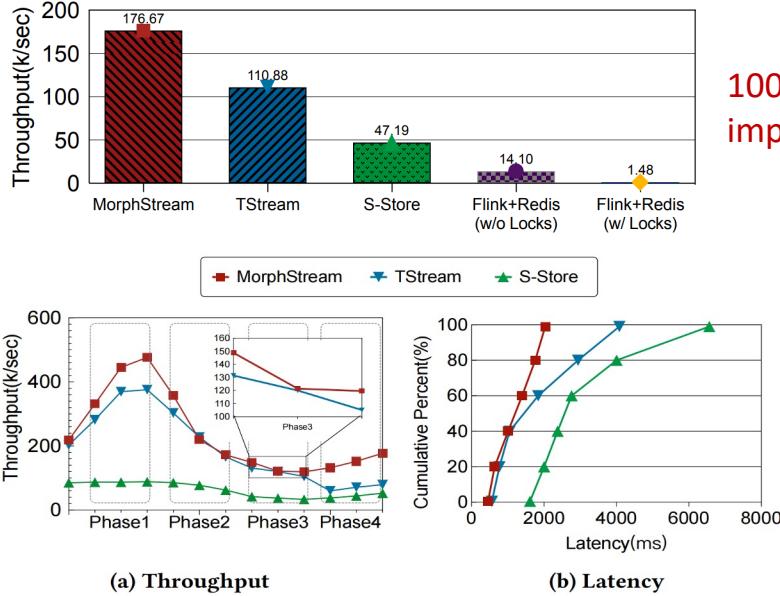
VLDB '13, IEEE BIGMM '19, VLIoT '20,
ICDE'24

❑ Code distribution

- BriskStream - First authored patents registered in USA
- MorphStream
- ...



System Development and Optimization

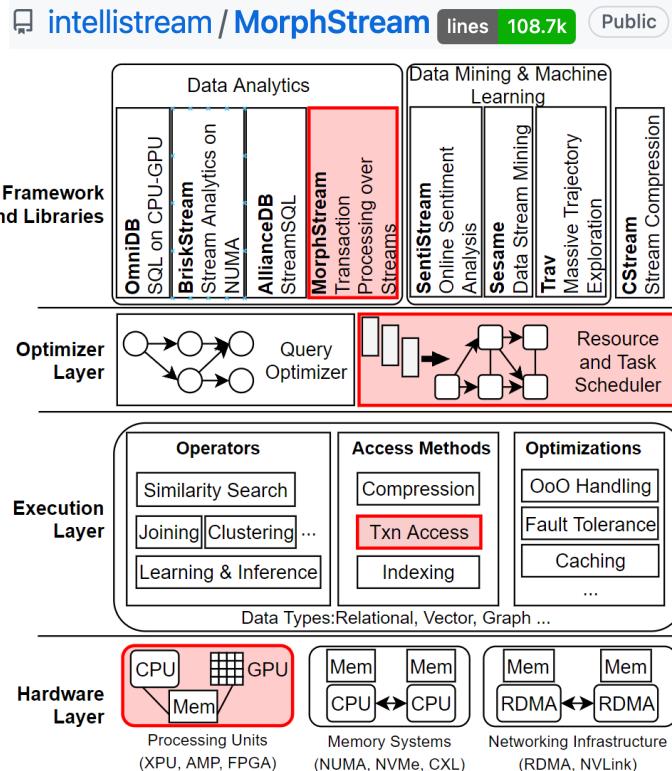


100x performance improvement

(a) Throughput

(b) Latency

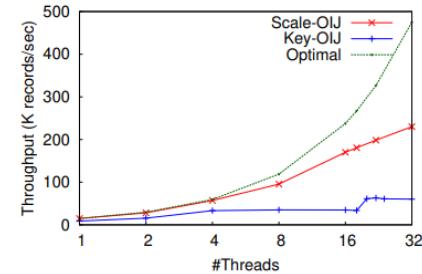
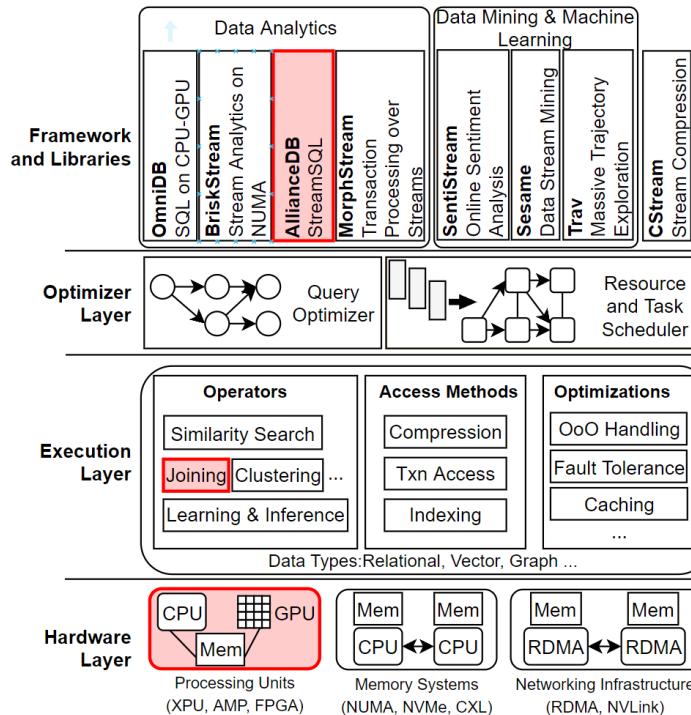
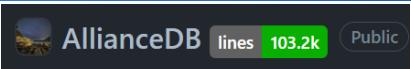
Always select a better-performing scheduling strategy under changing workloads



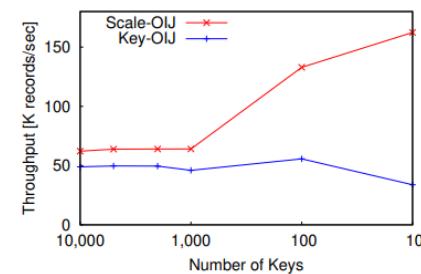
Yancan Mao, Jianjun Zhao, Shuhao Zhang, Haikun Liu, and Volker Markl. 2023. MorphStream: Adaptive Scheduling for Scalable Transactional Stream Processing on Multicores. Proc. ACM Manag. Data 1, 1, Article 59 (May 2023), 26 pages.



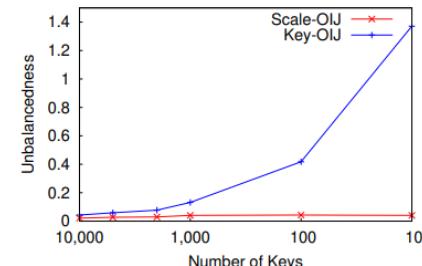
Algorithmic Innovations



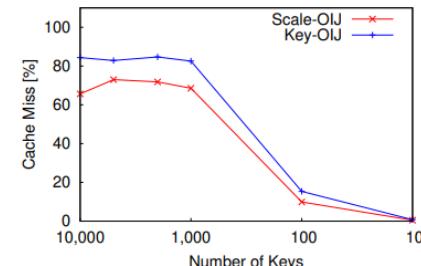
(a) Scalability under 10 Unique Keys



(b) Throughput



(c) unbalancedness

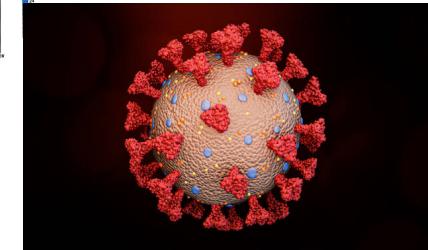
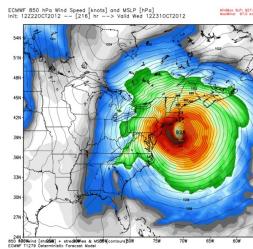


(d) LLC Load Miss

H. Zhang, X. Zeng, S. Zhang, X. Liu, M. Lu and Z. Zheng, "Scalable Online Interval Join on Modern Multicore Processors in OpenMLDB," 2023 IEEE 39th International Conference on Data Engineering (ICDE), Anaheim, CA, USA, 2023, pp. 3031-3042, doi: 10.1109/ICDE55515.2023.00232.

| Real-world Applications

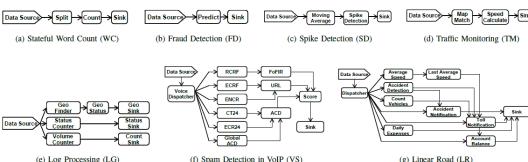
- ❑ Stream Compression on Drone [ICDE'23]
- ❑ Accelerating On-line decision augmentation (OLDA) [ICDE'23, SIGMOD'24]
- ❑ Video Database View Materialization [SIGMOD'24]
- ❑ Sentiment Analysis in Data Streams [EMNLP'23]
- ❑ ...



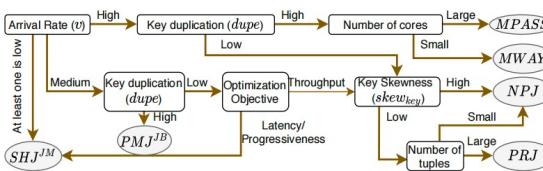
Current Research Direction: System-Wise

Data Management on New Hardware (DaMoN)

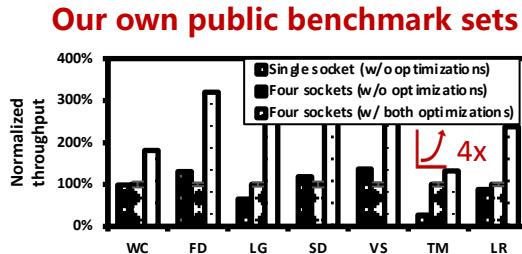
A) Profiling and benchmarking:
to understand the gaps between
new hardware and current DB
algorithms & systems



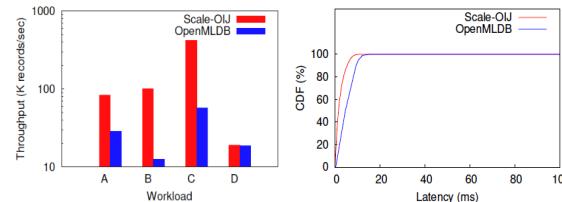
B) Algorithm Optimization:
Optimizing data processing
algorithms, e.g., Join, Aggregation,
Clustering on modern hardware



Decision Model for Join over Streams on Multicores

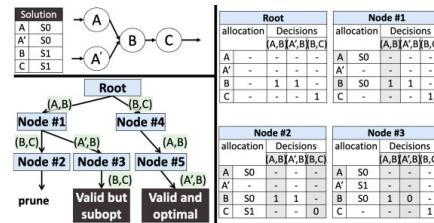


Discovered major issues of open-sourced stream processing systems

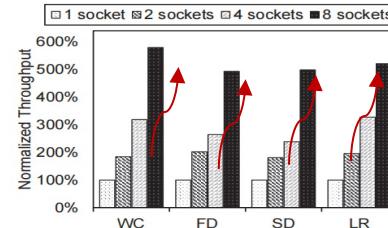


Improves commercial database system (OpenMLDB) with 8x higher throughput

C) System Optimization: Optimizing data processing systems, e.g., MapReduce, DB, Stream engine on modern hardware



NUMA-aware Query Planner



Almost linearly scalable on NUMA architecture



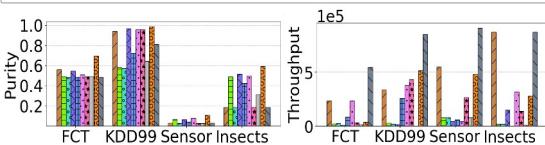
Current Research Direction: App-Wise

Database meets Artificial Intelligence (DB4AI & AI4DB)

A) Benchmarking: to understand the gaps among current DB algos & systems and AI applications and new hardware

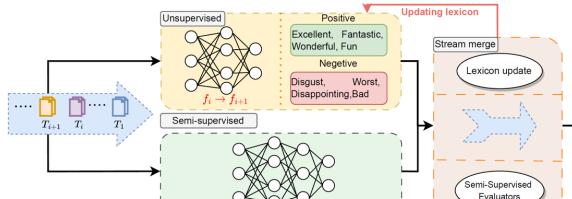
Algorithm	Year	Summarizing Data Structure		Window Model	Outlier Detection	Offline Refinement
		Name	Catalog			
BIRCH [57]	1996	CFT	Hierarchical	LandmarkWM	OutlierD	NoRefine
CluStream [5]	2003	MCS	Partitional	LandmarkWM	OutlierD-T	Refine
DenStream [1]	2006	MCS	Partitional	DampedWM	OutlierD-BT	Refine
DStream [13]	2007	Grids	Partitional	DampedWM	OutlierD-T	NoRefine
StreamKM++ [4]	2012	CoreT	Hierarchical	LandmarkWM	NoOutlierD	Refine
EDMStream [18]	2016	MCS	Partitional	DampedWM	OutlierD-T	Refine
DBStream [19]	2017	DPT	Hierarchical	DampedWM	OutlierD-BT	NoRefine
SL-KMeans [9]	2020	AMS	Partitional	SlidingWM	NoOutlierD	NoRefine

Decomposing Stream clustering algorithms into 4 dimension

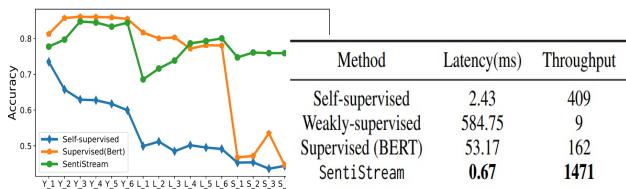


Discovered reconfigurable algorithm to meet dynamic requirements

B) DB4AI: bring (HW-accelerated) database system technologies into AI to enhance their training and/or inferring efficiency

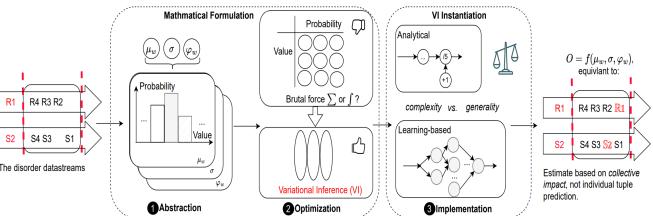


Bring stream pipeline to NLP

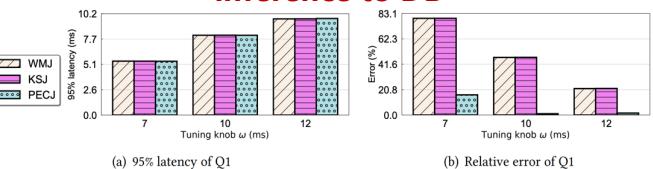


High accuracy (**80%**), high performance (**0.7ms, Tpt = 1.4K**) self-learning systems

C) AI4DB: bring AI into (HW-accelerated) DB to enhance their processing capabilities on complex situations that can be hardly handled with simple models



Bring learning-based variational inference to DB



Low processing latency with ~1% marginal error when handling disordered data streams



Challenges and Future Directions

Things are getting
complicated...



REQUIREMENT



HARDWARE



APPLICATION

- Scalability:** Keeping up with data growth.
- Complexity:** Managing diverse data types and processing demands.
- Energy Efficiency:** Reducing the carbon footprint.

| Conclusion and Q&A



Emphasis on **Modern Hardware** for data processing challenges.



Innovative Techniques in execution plan optimization and state management.



Real-World Applications showcasing our research impact.



Future Directions highlighting unexplored areas and potential advancements.



Call for Collaboration to push the boundaries further.

Thank You
shuhao.zhang@ntu.edu.sg

