Towards ML-driven resource orchestration in disaggregated memory systems: Challenges and Opportunities

Dimosthenis Masouros

National Technical University of Athens, Greece

May 19th 2023

Invited Talk – 2nd Workshop on Composable Systems

Co-located with IPDPS 2023

"ToC"

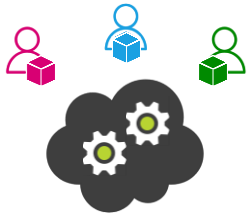
ML for (disaggregated) systems

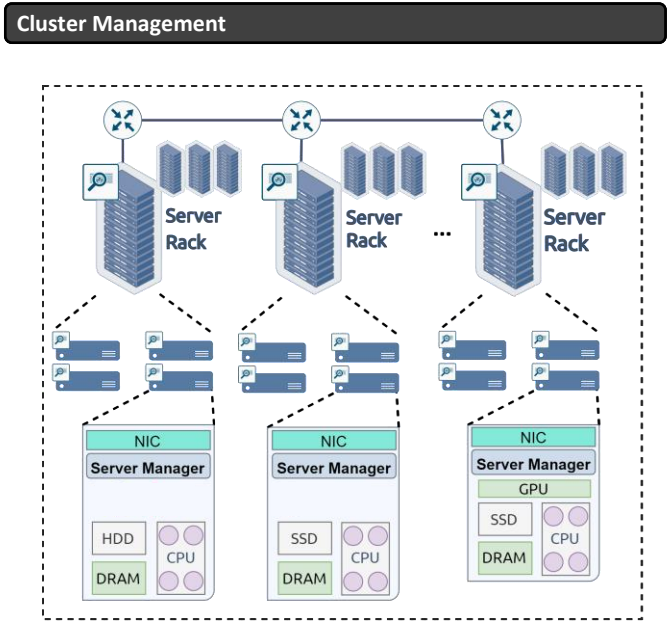
Adrias

Interference-Aware Memory Orchestration for Disaggregated Cloud Infrastructures

Introduction

- Rise of applications executed in the Cloud
- Application co-location (multi-tenancy)
  - Resource interference ➔ performance degradation
- Traditional infrastructures ➔ static architecture
  - Servers with fixed number of CPUs and RAM + HW accelerators
- Several issues/challenges w.r.t. resource efficiency
  - Fragmentation of resources
  - Handling of HW failures
  - Integration of new HW devices



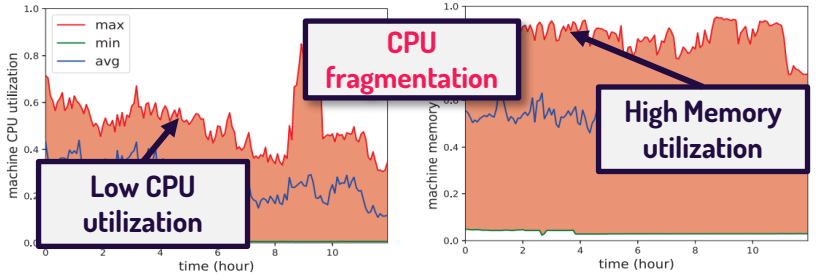


Why Memory Disaggregation?

- Memory is a major factor w.r.t. resource fragmentation
  - Memory shortage
  - Memory stranding
- Memory disaggregation to the rescue!
  - Allocate memory either locally or from neighboring nodes over network

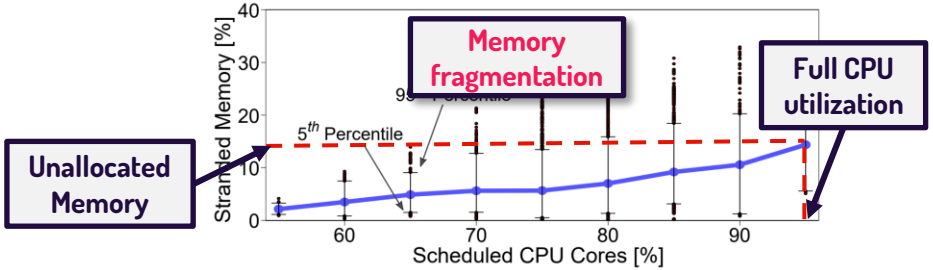
Imbalance in the cloud: An analysis on Alibaba cluster trace

Chengzhi Lu, Kejiang Ye, +2 authors Tongxin Bai • Published 1 December 2017 • Computer Science •
2017 IEEE International Conference on Big Data (Big Data)



Pond: CXL-Based Memory Pooling Systems for Cloud Platforms

Huaicheng Li, Daniel S. Berger, +10 authors R. Bianchini • Published 1 March 2022 • Computer Science •
Proceedings of the 28th ACM International Conference on Architectural Support for Programming Languages and Operating Systems



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  - Memory disaggregation and multi-tier memory architectures infiltrating the Cloud world

Towards an Adaptable Systems Architecture for Memory Tiering at Warehouse-Scale

Padmapriya Duraisamy, Wei Xu, +15 authors A. Vahdat • Published 25 March 2023 • Computer Science •
Proceedings of the 28th ACM International Conference on Architectural Support for Programming Languages and Operating Systems

Design Tradeoffs in CXL-Based Memory Pools for Public Cloud Platforms

Daniel S. B

Pond: CXL-Based Memory Pooling Systems for Cloud Platforms

Huaicheng Li, Daniel S. Berger, +10 authors R. Bianchini • Published 1 March 2022 • Computer Science •
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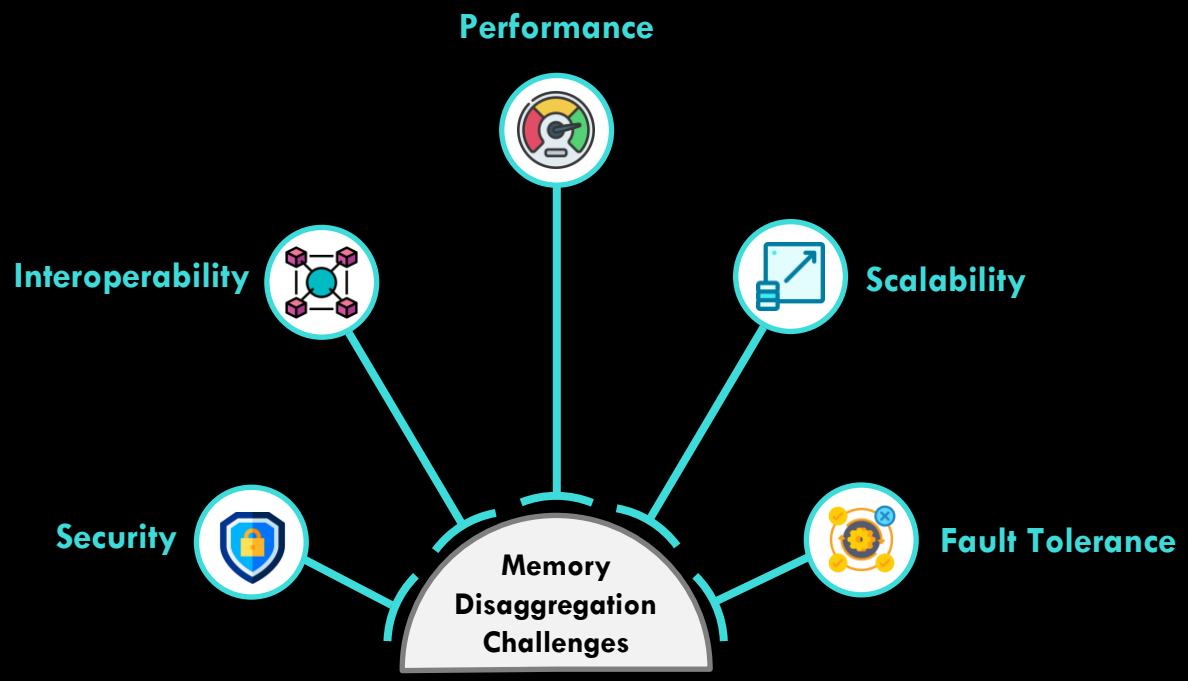
Challenges of Memory Disaggregated Cloud systems



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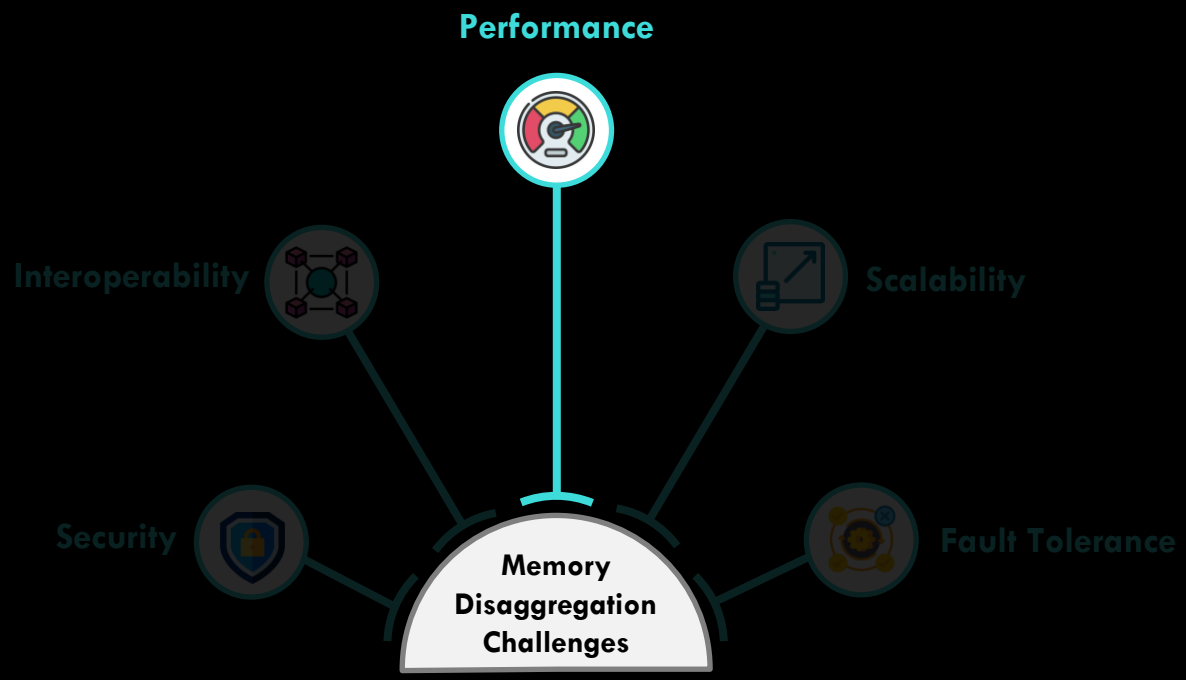


Performance Implications of Memory Disaggregation

- Performance degradation by design **(OR NOT?)** 🤔
  - Network Latency/Bandwidth & Protocol overheads

➢ **20% average performance degradation** for Spark apps

➢ Not akin across all benchmarks

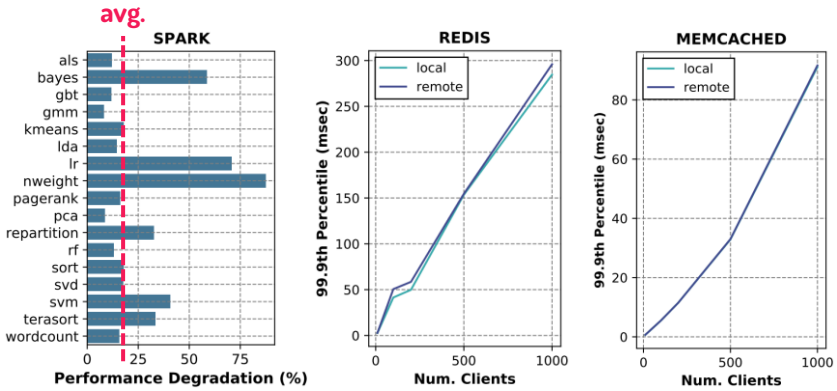
➢ **LC apps insensitive to remote memory**

Adrias: Interference-Aware Memory Orchestration for Disaggregated Cloud Infrastru

Dimosthenis Masouros
2023 IEEE International

ThymesisFlow: A Software-Defined, HW/SW co-Designed Interconnect Stack for Rack-Scale Memory Disaggregation

Christian Pinto, D. Syrivelis, +4 authors H. P. Hofstee • Published 1 October 2020 • Computer Science •
2020 53rd Annual IEEE/ACM International Symposium on Microarchitecture (MICRO)



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- Interference complicates things
  - Huge performance chasm between local and remote
  - Stacking interference effects

➢ **Up to x4 worst performance** under memory bandwidth and LLC interference

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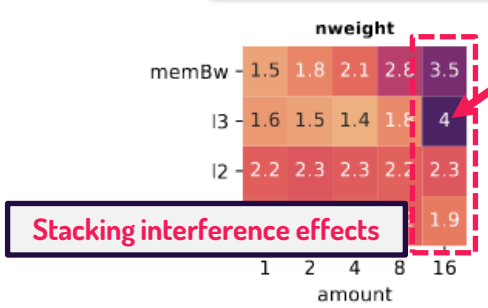

Up to x4 worst performance when stressing L3 cache

Stacking interference effects

Values show the slowdown of remote memory vs. local for the same amount of applied interference (**higher is worse**)

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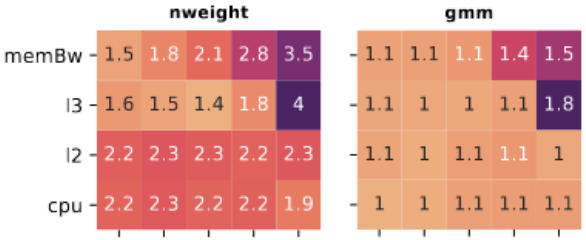

Not similar behavior across different benchmarks

Values show the slowdown of remote memory vs. local for the same amount of applied interference (**higher is worse**)

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➢ **LC apps sensitive to memory bandwidth interference**

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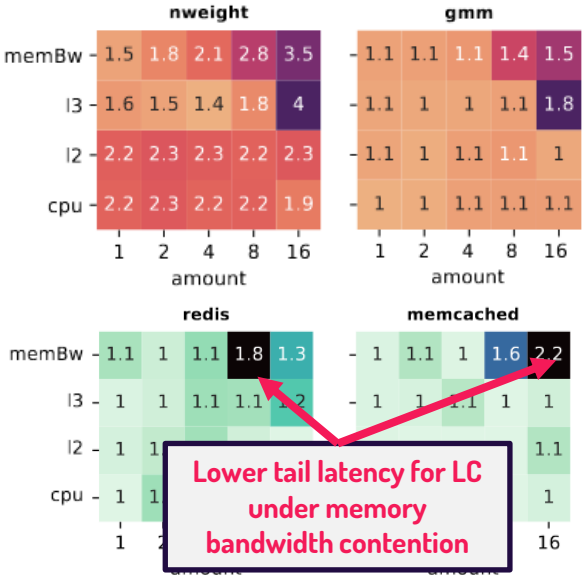

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Potential Use of ML for Resource Management

- Naïve use of remote memory ➔ huge performance degradation
- "Intelligent" memory mapping of applications
  - Allocate "remote-memory friendly" apps on disaggregated pool
  - Minimize shared resource interference
  - Minimize data travelling back & forth through the network

Fundamental Questions

WHERE ?

HOW ?

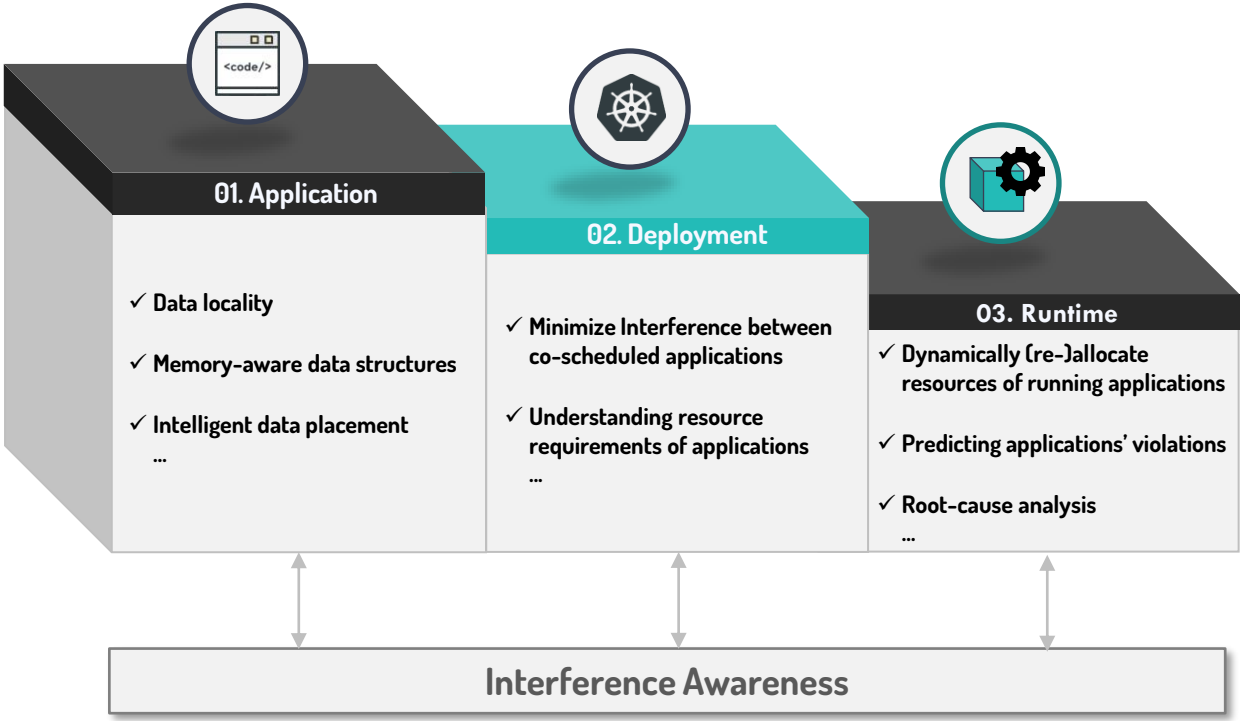
Fundamental Questions

WHERE ?

HOW ?

Levels of Applying ML Solutions

Software



Hardware

Prior works to be considered

Towards making the most of NLP-based device mapping optimization for OpenCL kernels
Petros Vavaroutsos, Ioannis Oroutzoglou, +1 author D. Soudris • Published 1 August 2022 • Computer Science •
2022 IEEE International Conference on Omni-layer Intelligent Systems (COINS)

End-to-End Deep Learning of Optimization Heuristics
Chris Cummins, Pavlos Petoumenos, +1 author H. Leather • Published 9 September 2017 • Computer Science •
Parallel Architectures and Compilation Techniques (PACT)

CodeBERT: A Pre-Trained Model for Programming and Natural Languages
Zhangyin Feng, Daya Guo, +8 authors Ming Zhou • Published 19 February 2020 • Computer Science • ArXiv

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Sinan: ML-based and QoS-aware resource management for cloud microservices
Yanqi Zhang, Weizhe Hua, +3 authors WeizheHua • Published 19 April 2021 • Computer Science •

FIRM: An Intelligent Fine-Grained Resource Management Framework for SLO-Oriented Microservices
Subho Sankar Banerjee, +2 authors R. Iyer • Published in USENIX Symposium on Operating... 19 August 2020 •

Resource Central: Understanding and Predicting Workloads for Improved Resource Manageme in Large Cloud Platforms
Eli Cortez C. Vilarinho, Anand Bonde, +3 authors R. Bianchini • Published 14 October 2017 • Computer Science •
Proceedings of the 26th Symposium on Operating Systems Principles

Paragon: QoS-aware scheduling for heterogeneous datacenters
Christina Delimitrou, C. Kozyrakis • Published in International Conference on... 16 March 2013 • Computer Science

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Learning Memory Access I
Milad Hashemi, Kevin Swersky, +5 authors Parthasarathy Ranganatha
Published in International Conference on... 6 March 2018 • Computer

Adjacent LSTM-Based Page Sch Hybrid DRAM/NVM Memory Sy
Manolis Katsaragakis, Konstantinos Stavrakakis, +2 authors D. Soudris • Published

Coeus: Clustering (A)like Patterns for Practical Machine Intelligent Hybrid Memory Management
Thaleia Dimitra Doudali, Ada Gavrilovska • Published 1 May 2022 • Computer Science •
2022 22nd IEEE International Symposium on Cluster, Cloud and Internet Computing (CCGrid)

Kleio: A Hybrid Memory Page S Machine Intelligence
Thaleia Dimitra Doudali, S. Blagodurov, +2 authors Ada Gavrilovska • Published 1
Proceedings of the 28th International Symposium on High-Performance Parallel and

Nimble Page Management for Tiered Memory Systems
Zi Yan, Daniel Lustig, +1 author A. Bhattacharjee • Published 4 April
Proceedings of the Twenty-Fourth International Conference on Architec
Systems

Utility-Based Hybrid Memory Management
Y. Li, Saugata Ghose, +3 authors O. Mutlu • Published 1 September 2017 • Computer Science •
2017 IEEE International Conference on Cluster Computing (CLUSTER)

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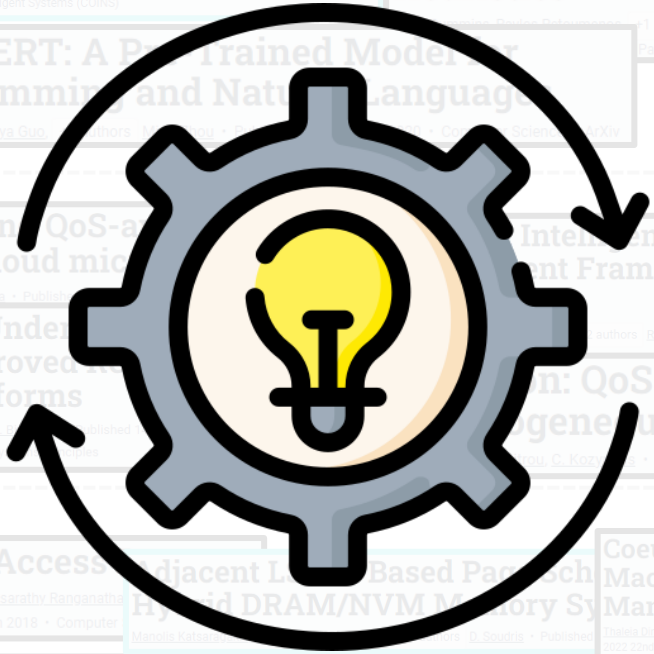


Fundamental Questions

WHERE ?

HOW ?

How to use ML?

Things to consider when deciding how to exploit ML in cloud resource management:

- What should the ML model do?
- What inputs should the ML model receive?
- What should the ML model's architecture be?
- How quickly and often should the ML do predictions?

…

Exploring the opportunities to use ML, the possible designs, and our experience with Microsoft Azure.

BY RICARDO BIANCHINI, MARCUS FONTOURA, ELI CORTEZ, ANAND BONDE, ALEXANDRE MUZIO, ANA-MARIA CONSTANTIN, THOMAS MOSCIBRODA, GABRIEL MAGALHAES, GIRISH BABLANI, AND MARK RUSSINOVICH

Toward ML-Centric Cloud Platforms

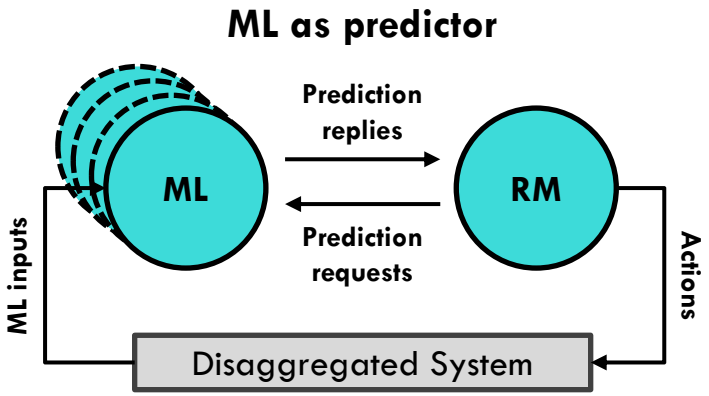
ML Integration Approaches

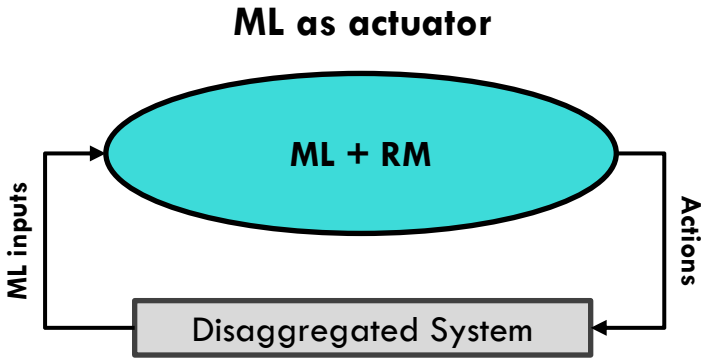
ML model's purpose:

- Behavioral predictions (predictor)
- Actual management actions (actuator)

ML modeling approach:

- One model per application / memory type
  + More accurate (probably)
  - Less scalable
- One model to rule them all!





What Inputs to Use?

- Application-specific (high-level) metrics
  - Accurate (real) performance
  - Difficult to acquire
  - Developers have to instrument apps with monitoring tools (e.g., AWS Cloudwatch)
- System-wide (lower-level) metrics
  - Imperfect proxy for performance
  - Always available to providers
  - Can be used to "predict" performance

Rusty: Runtime Interference-Aware Predictive Monitoring for Modern Multi-Tenant Systems
Dimosthenis Masouros, S. Xydis, D. Soudris • Published 1 January 2021 • Computer Science •
IEEE Transactions on

Characterizing Job Microarchitectural Profiles at Scale: Dataset and Analysis
Kangjin Wang, Ying Li, +8 authors Liping Zhang • Published 29 August 2022 • Computer Science •

SOL: safe on-node learning in cloud platforms
Ya-wen Wang, D. Crankshaw, +3 authors R. Bianchini • Published 25 January 2022 • Computer Science •
Proceedings of the 27th ACM International Conference on Architectural Support for Programming Languages and Operating Systems

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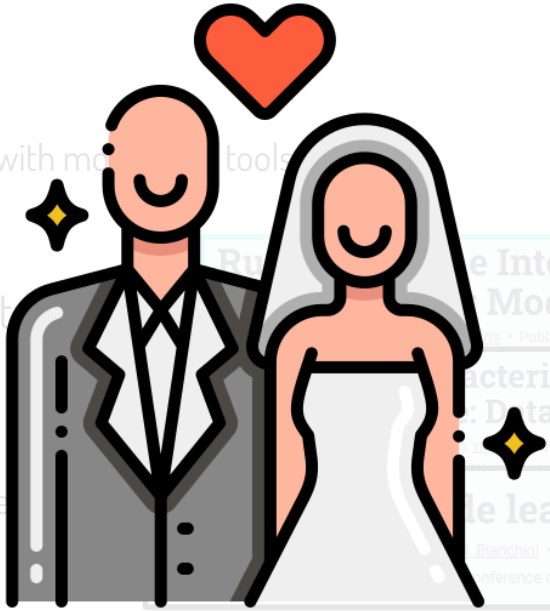

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Adrias

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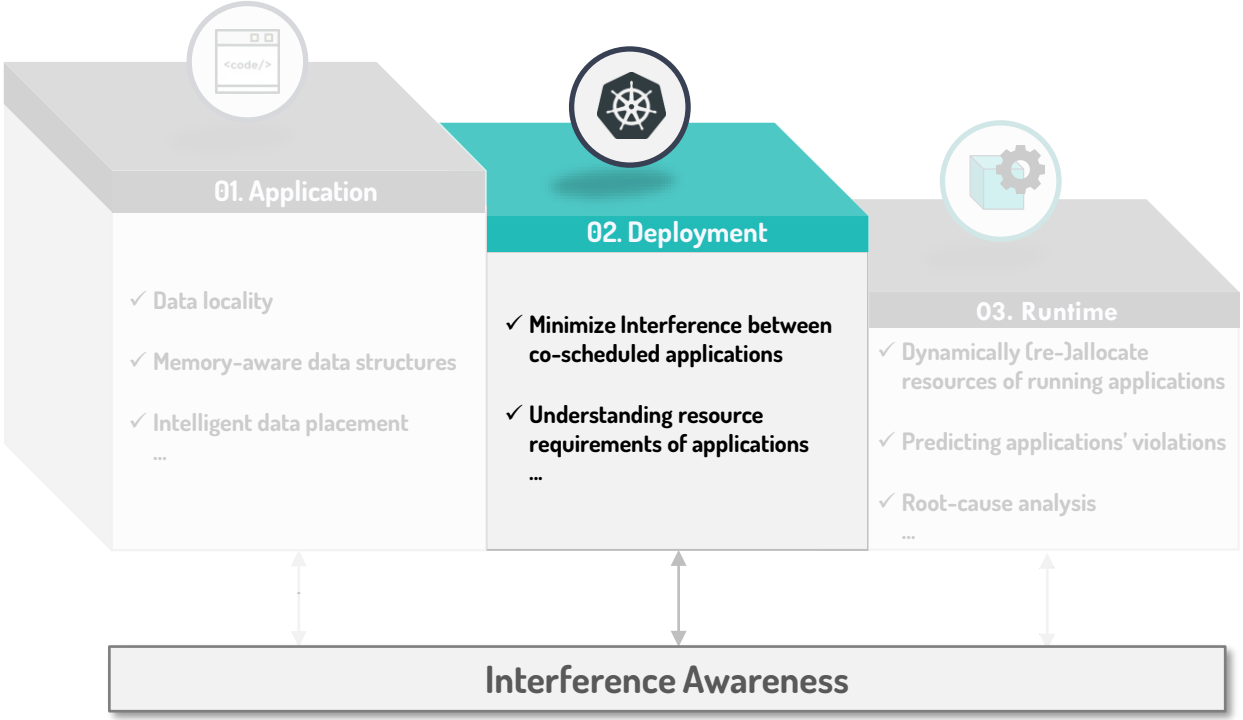
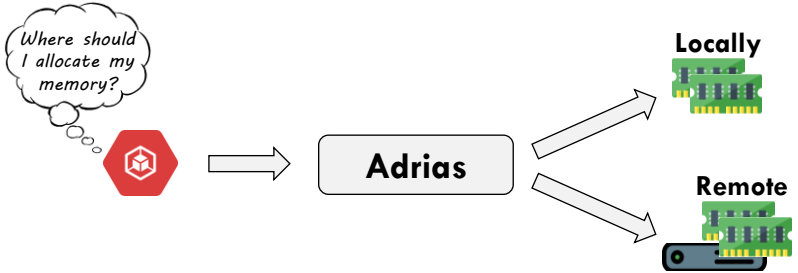
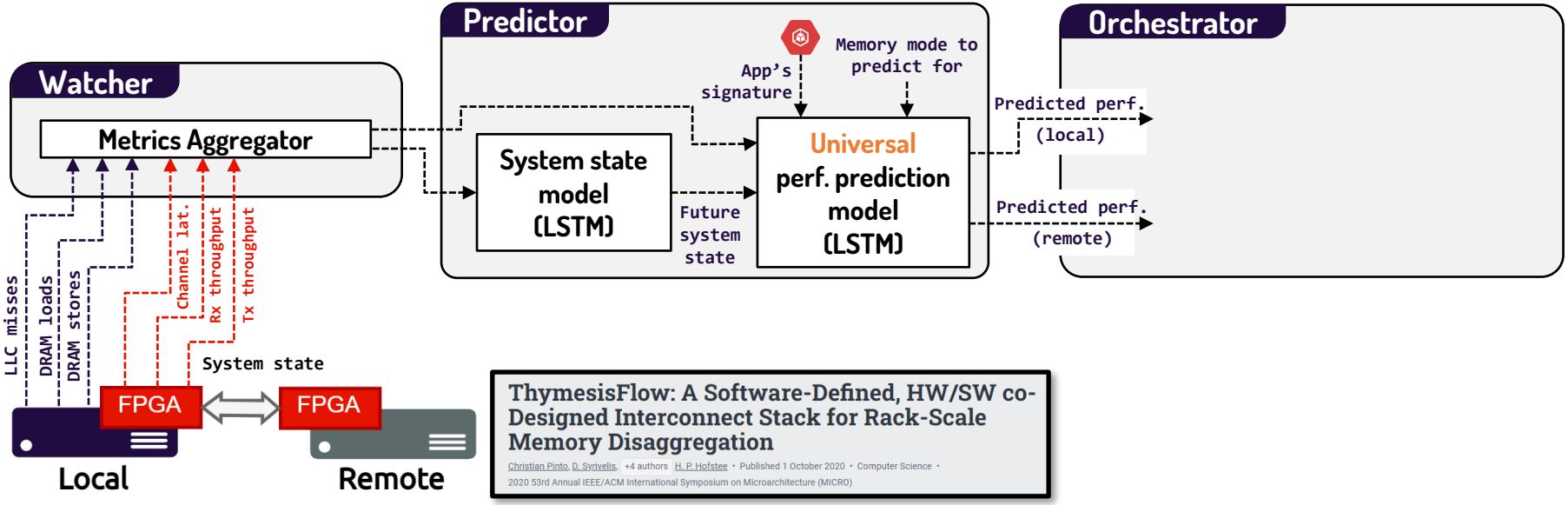


Hardware

(really abstract) Overview

Goal: Adrias aims to efficiently **place all memory allocations of incoming applications either on local or remote memory**





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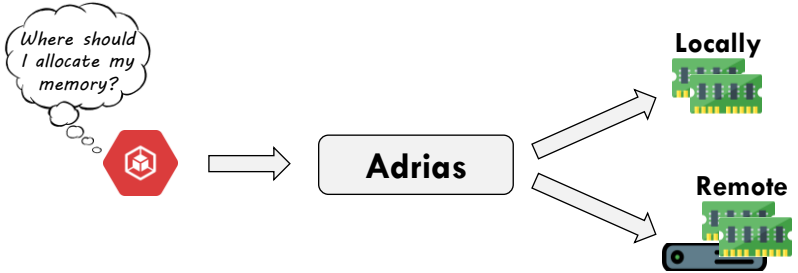
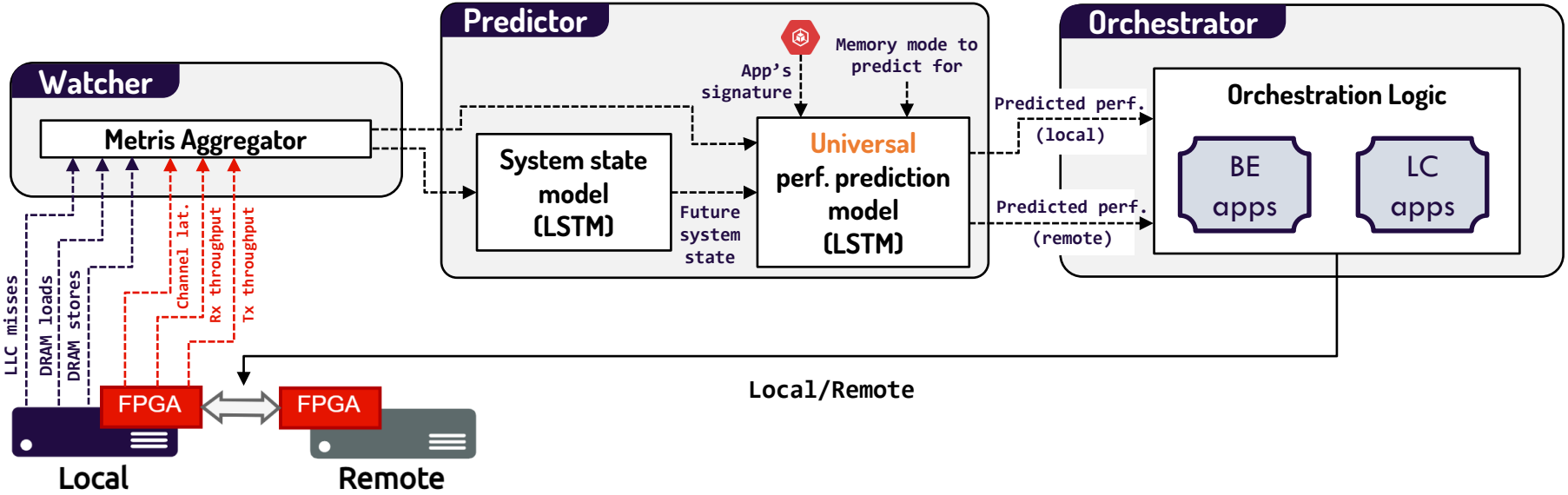


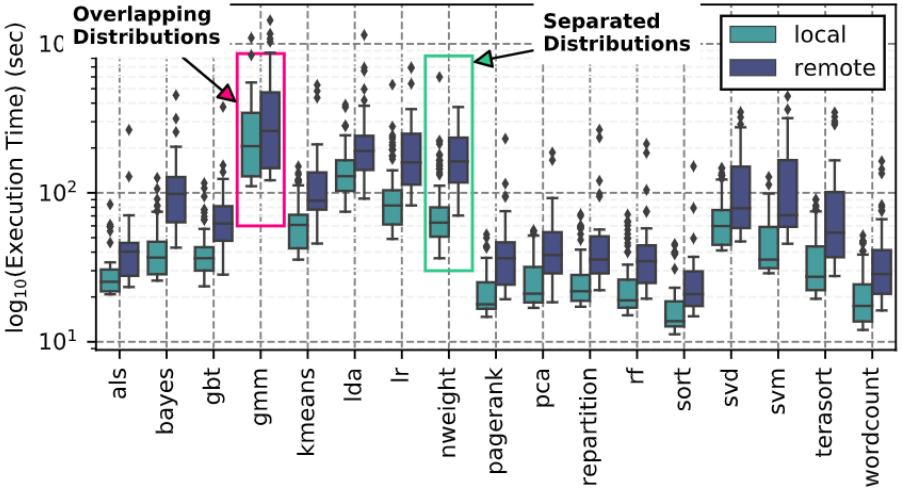


Data collection

- 72 random 1-hour scenarios deployed
  - Random applications arriving at random intervals

Scenarios' Insights

- **Overlapping performance distributions** (e.g., gmm)
  - Remote memory could be beneficial in certain interference scenarios
  - Sacrifice performance for leveraging remote memory
- **Separated performance distributions** (e.g., nweight)
  - Use of remote memory prohibitive due to stacking interference effects

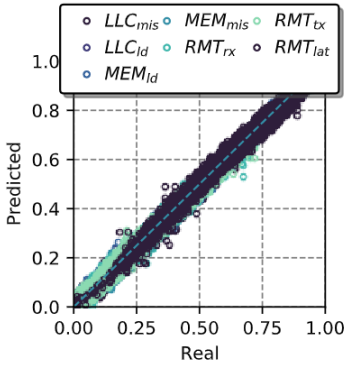


Evaluation Results

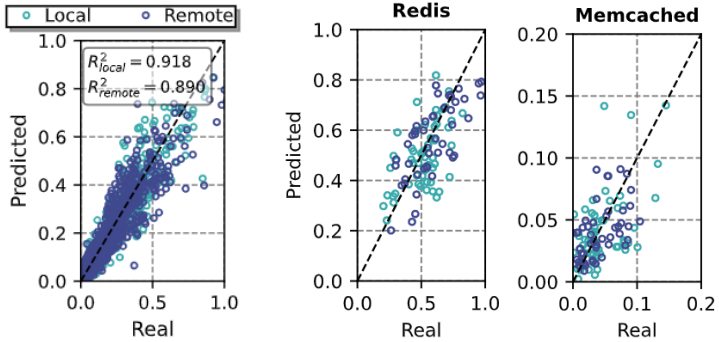
- System state model
  - **~0.99** R^2 score* for all predicted metrics
- Performance prediction model
  - **0.94 average** R^2 score* for performance prediction of both BE and LC on local and remote
- Orchestration logic
  - Outperforms Random and Round-Robin schedulers
  - Allocates 10%-35% to remote memory with 0.5%-15% median performance degradation
  - Up to 55% less traffic on the network channel
  - Aligns with scenarios' insights

*Values closer to 1 are better

Predicted vs. Real (system state model)



Predicted vs. Real (perf. prediction model)



For More Results…

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Dimosthenis Masouros, Christian Pinto, +2 authors D. Soudris • Published 1 February 2023 • Computer Science •
2023 IEEE International Symposium on High-Performance Computer Architecture (HPCA)

Conclusions

- Memory disaggregation is the next big thing (in the Cloud)
- Memory disaggregation + interference ➔ huge performance variability and unpredictability
- ML for systems can be a strong tool (tailored to our needs)
- Rethink and adapt current ML solutions

Adrias showed the potential of ML in disaggregated memory systems

- Separated ML and Orchestration logic
- Able to leverage remote memory with minimal performance impact

Q & A

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