Pufferfish: Container-driven Elastic Memory Management for Data-intensive Applications

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Outline

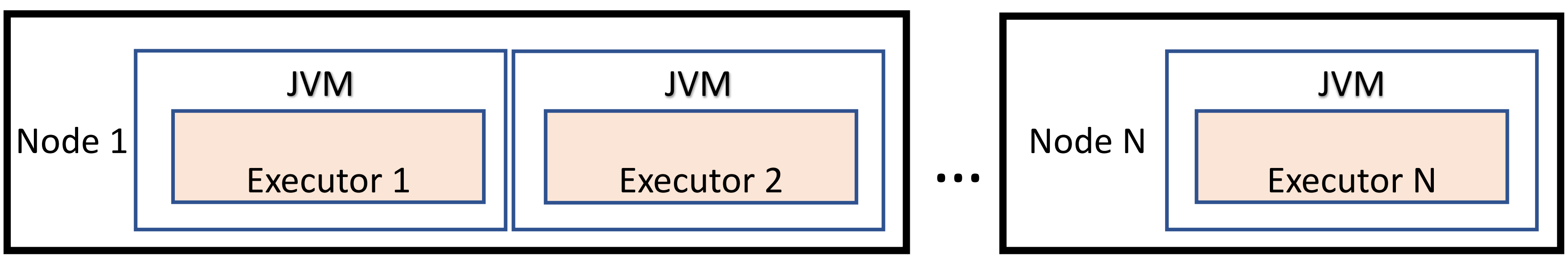
- Introduction to data-intensive applications
- Memory problems and opportunities
- Pufferfish mechanisms
- Pufferfish architecture
- Evaluation
- Conclusion

Data-intensive applications

- Data analytics applications are extensively used in both industry and academia
- Most of the frameworks run on JVM

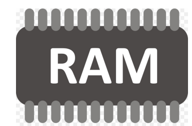
Data-intensive applications in clusters

- Executor memory is bounded by JVM heap size
- All executors of the same application share the same configuration
- Memory adjustment cannot be done at runtime



State-of-the-art

- JVM heap management
  - Analysis of data-intensive application behaviors
  - Improved garbage collection
  - ROLP[Eurosys'19], FACADE[SOSP'15], Yak[OSDI'16]
- Memory elasticity



  - Dynamically adjust memory allocation at runtime
  - C. Iorgulescu et al. [ATC'17], J. Wang et al. [ATC'17]
- Memory ballooning for virtual machines
  - Memory elasticity of virtual machines

Memory problems in clusters

- Garbage collection degrades job performance
- Memory under-utilization
- Out of memory error
  - Mis-configuration
  - Data skew
  - Load imbalance
  - …

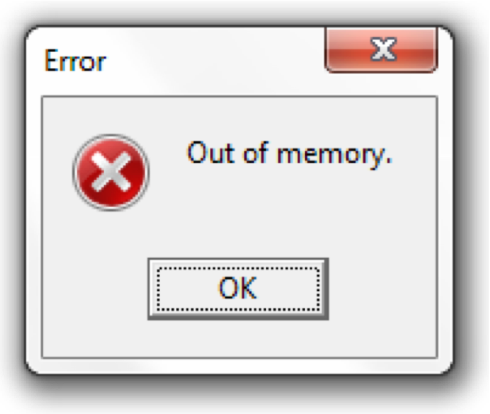
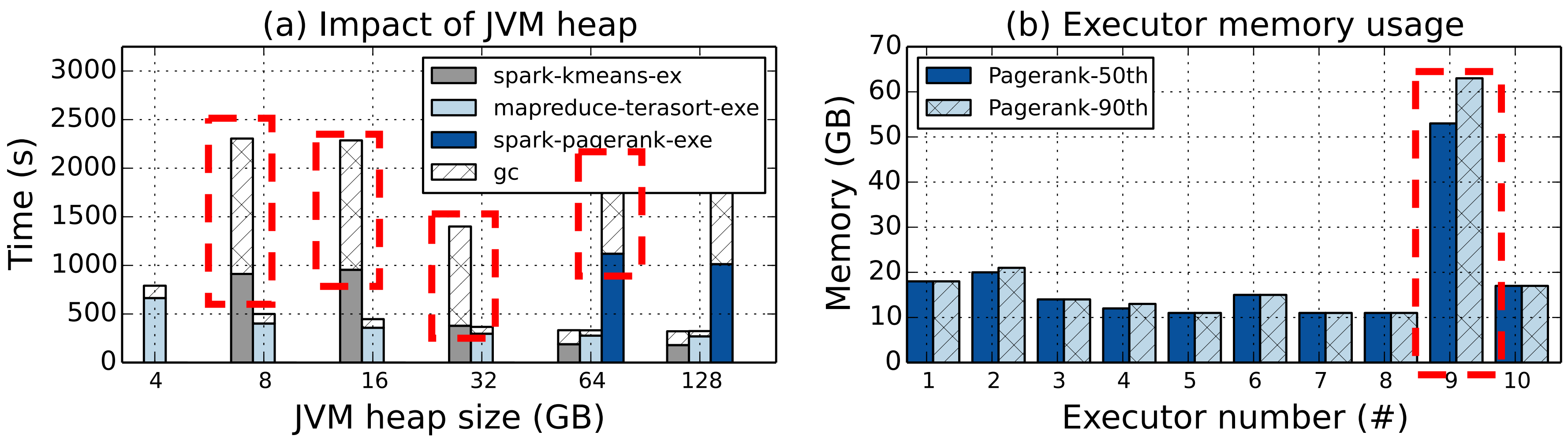


Illustration of memory problems



- Expensive garbage collection degrades performance
- Heterogeneous memory usage across executors in an application

Opportunities

- Memory heterogeneity
  - Memory is provisioned for the largest executor of the workload
  - Memory underutilization for small executors

- Memory Dynamics
  - Memory usage is dynamic during execution of a executor
  - Transient idle memory can be exploited

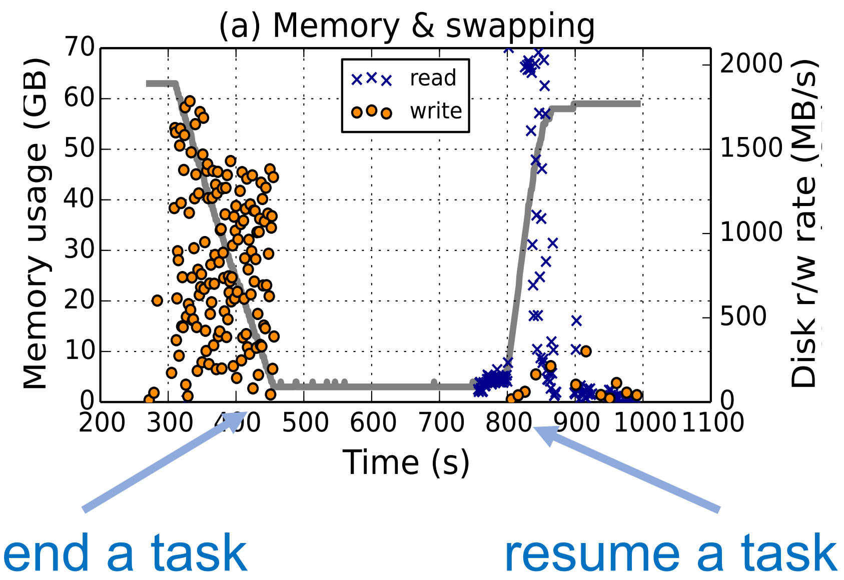
Pufferfish mechanisms

- Configure executors with a large JVM heap size.
- Configure executors with a small Docker memory limit
- Container-based executor memory management
  - **Puff** (increase) container memory limit on demand
  - **Suspend** an *Out-of-Container-Memory* container
  - **Resume** a task when memory is available

- A large JVM heap size always presents sufficient memory to executors
- Executors under memory pressure are swapped into disks instead of Out-Of-Memory error
  - Preserve job progress

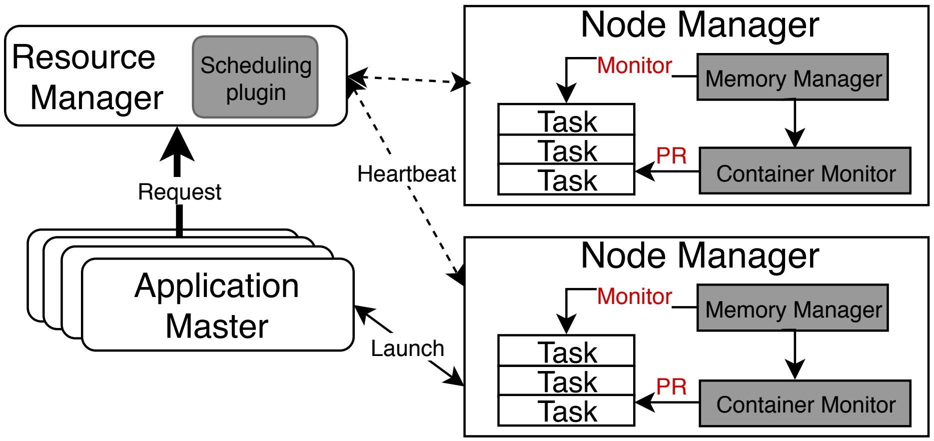
Executor suspension and resumption

- An *Out-of-Container-Memory* executor incurs extensive disk I/O due to swapping
- Heuristic: Suspend the executor by throttling its CPU usage to 1% when it is out of its container memory



- Tasks under suspension are still alive
- I/O activities are throttled

Pufferfish architecture

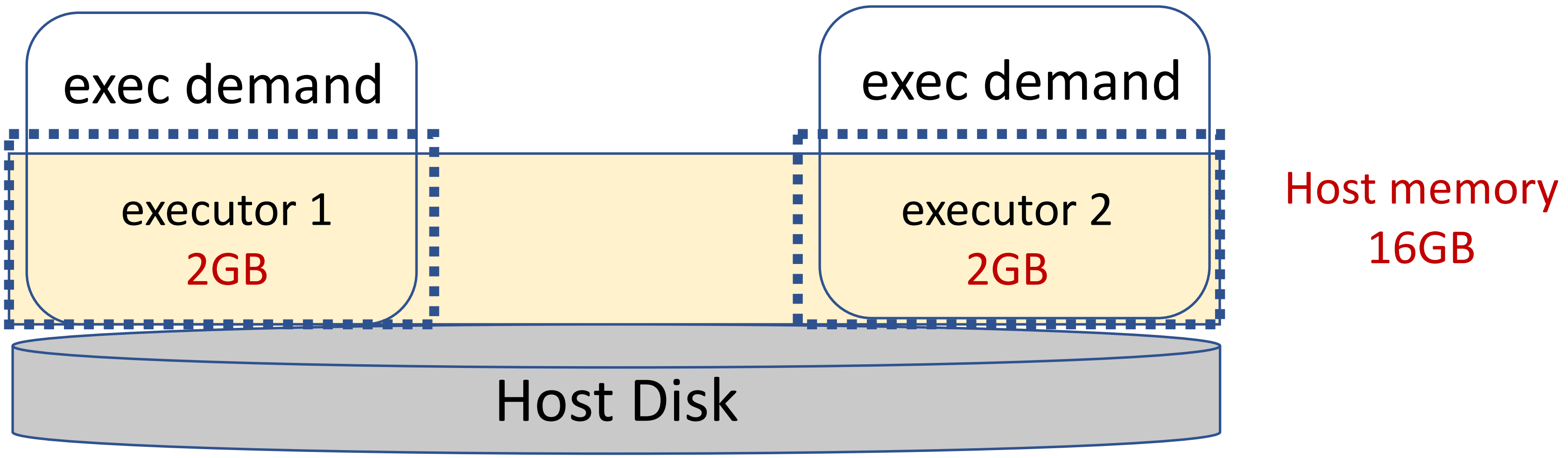


- Container monitor
  - Performs container suspend and resume operations on FLEX containers
- Memory manager
  - Decides how much memory should be allocated to each container
- Resource scheduler plugin
  - Enforce fairness when taking account of different types of workloads

FLEX container

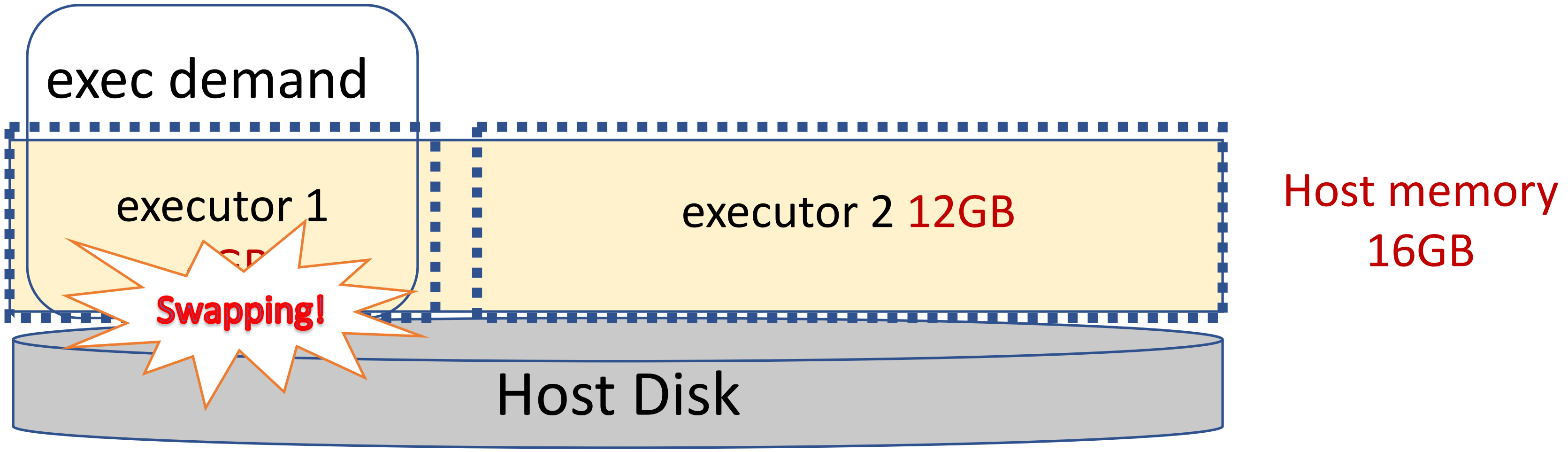
- FLEX container: a type of flexible container
- FLEX containers are set with a large JVM heap size
- FLEX containers are started the same small container memory limit
- FLEX containers are allowed to puff when its memory demand is larger than the container memory limit

Container monitor: an example



- Both executor 1 and executor 2 are configured with 16GB JVM heap and 2 GB container memory limit
- Container memory grows from 2GB with the increase of executor memory demand

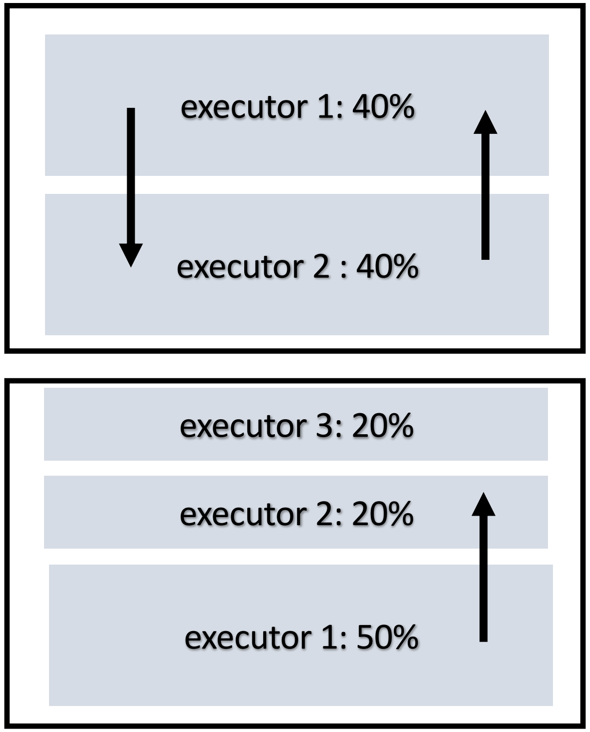
Container monitor: an example



- Container constrains the actual physical memory
- Executor 1 demands 8GB, suspended at 4GB.
- Executor 2 demands 12GB, fully satisfied.

Memory manager

- Address memory contention
- Backoff-based puff
  - Increase the container size according to their priorities
- Kill the container with the lowest priority when memory is used up



Pufferfish scheduling plugin

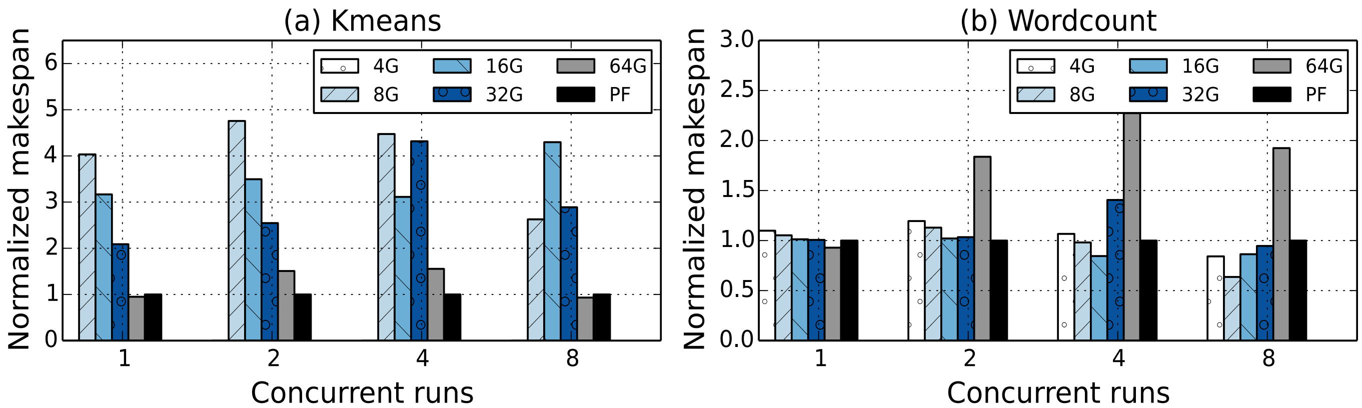
- Scheduling Plugin
  - Exposes physical memory usage of each node
  - Balances the physical memory usage across nodes

- Prioritization Policies
  - Earliest Job First (EJF) : Puff the earliest submitted job first
  - Shortest Job First (SJF) : Puff the shortest job first

Evaluation setup

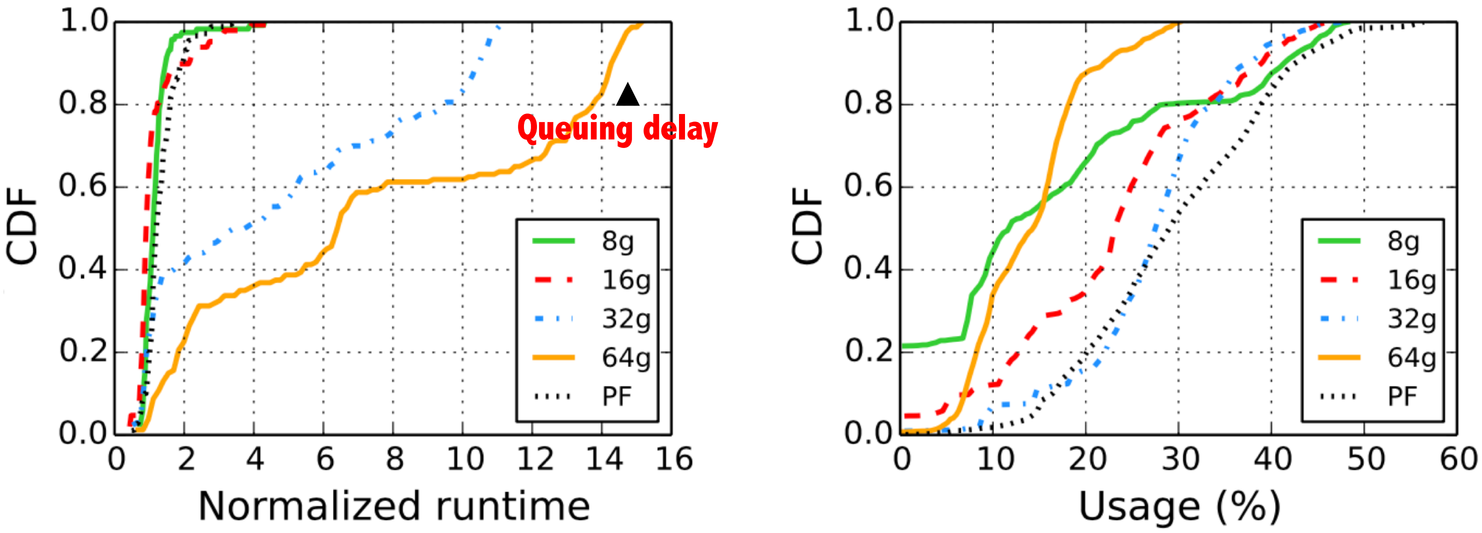
- Setup
  - 26-node cluster with Ubuntu-16.04
  - 32 cores, 128GB RAM, RAID-5 HDDs
  - Cluster is connected by 10Gbps Ethernet
  - Hadoop-2.7.2, Spark-2.0.1, Docker-1.12.1
- Workloads
  - HiBench as batch workloads
  - TPC-H on Spark-SQL as latency-critical workloads

Single node



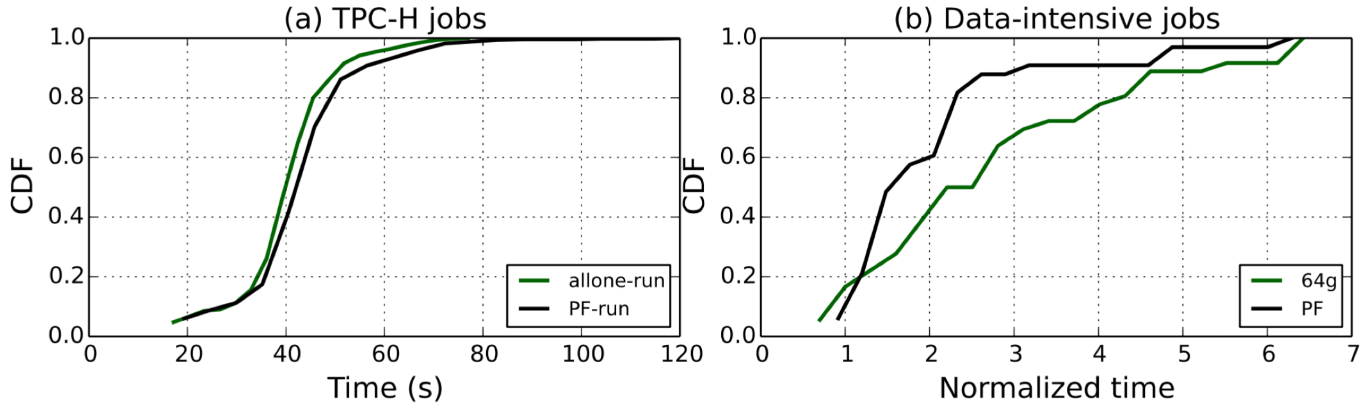
- Workloads: Kmeans and Wordcount
- Pufferfish vs. Yarn with different heap sizes
- Pufferfish achieves the best performance for **Kmeans**
  - **Kmeans** is dominated by GC and is CPU intensive
- Pufferfish achieves close-optimal performance for **Wordcount**
  - **Wordcount** is I/O intensive
  - Higher parallelism outweighs a larger heap size

Production trace



- Replay a subset of Google trace in the 26-node cluster
- Pufferfish completes all workloads without OOM
- Pufferfish achieves the highest memory utilization

Mixed workloads



- Workloads
    - 38 data-intensive jobs as batch jobs
    - 576 TPC-H jobs as latency-critical jobs
- For **latency-critical** workloads, Pufferfish achieves almost the same performance as stand-alone execution
- For **batch workloads**, Pufferfish outperforms default Yarn with 64GB heap by adaptive parallelism

Conclusion

- Data-intensive applications suffer from memory issues OOM and suboptimal memory utilization.
- Pufferfish is an elastic memory manager that leverage **OS containers** to achieve dynamical memory allocation: puff/suspend/reclaim
- Pufferfish can avoid OOM, preserve job performance and improve cluster memory utilization

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Thank you!

Q & A