



# Running Spark on a High-Performance Cluster using RDMA Networking and NVMe Flash

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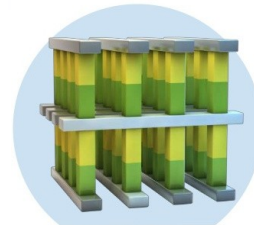
# Hardware Trends

community  
target

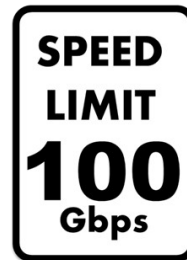
	2010	2017
Storage	100 MB/s 100ms	1000 MB/s 200us
Network	1Gbps 50us	10Gbps 20us
CPU	~3GHz	~3GHz

# Hardware Trends

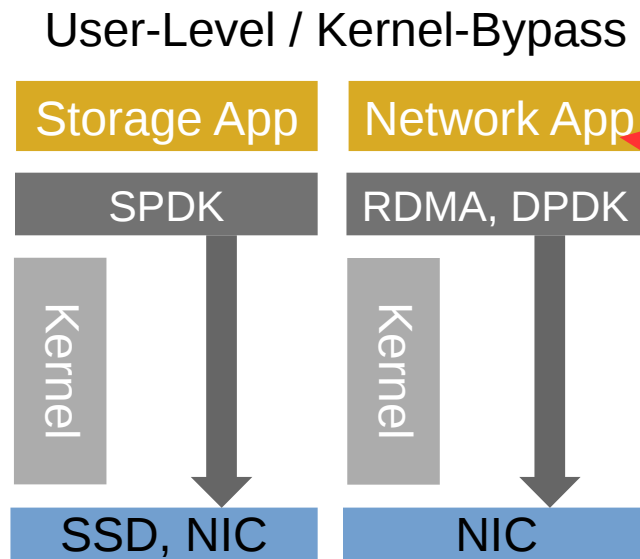
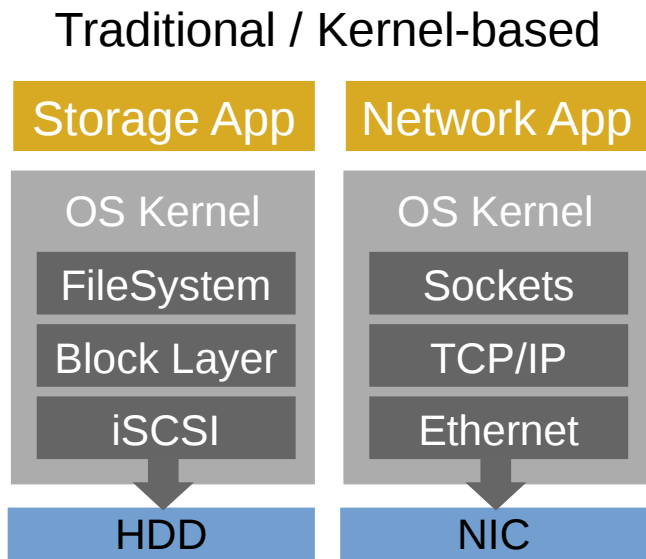
		community target	our target
	2010	2017	2017
Storage	100 MB/s 100ms	1000 MB/s 200us	10 GB/s 50us
Network	1Gbps 50us	10Gbps 20us	100Gbps 1us
CPU	~3GHz	~3GHz	☹



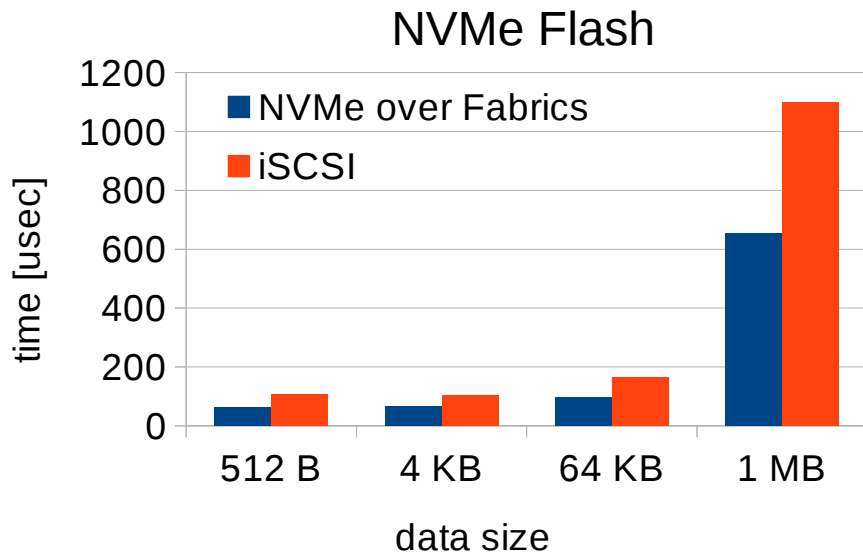
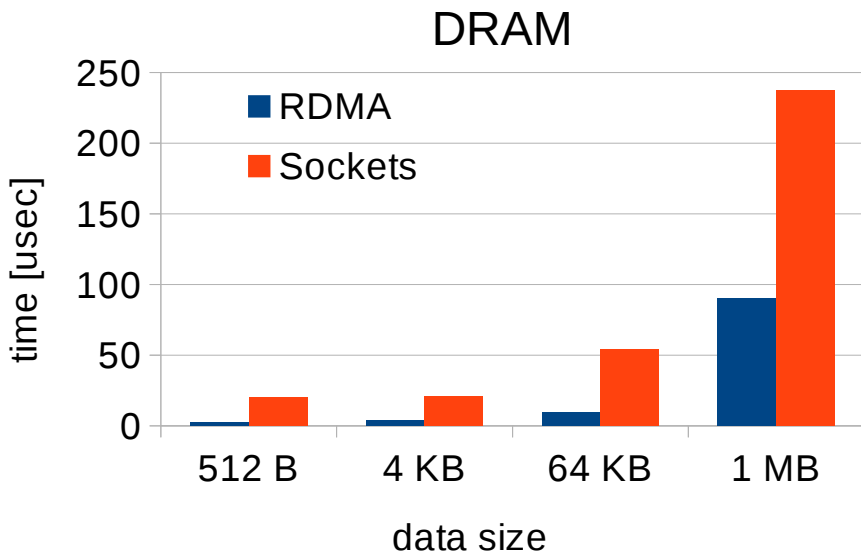
3D XPoint



# User-Level APIs

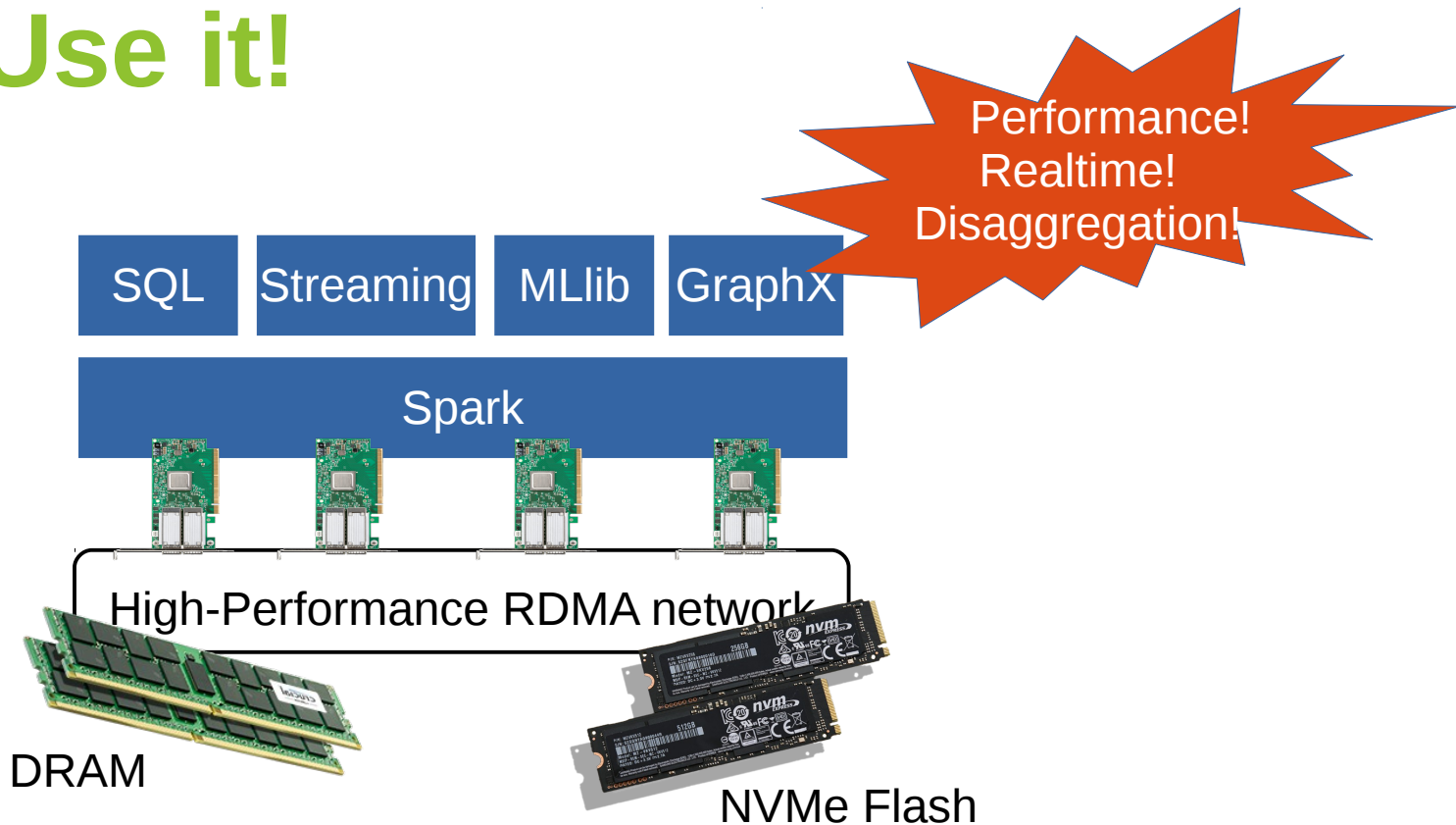


# Remote Data Access

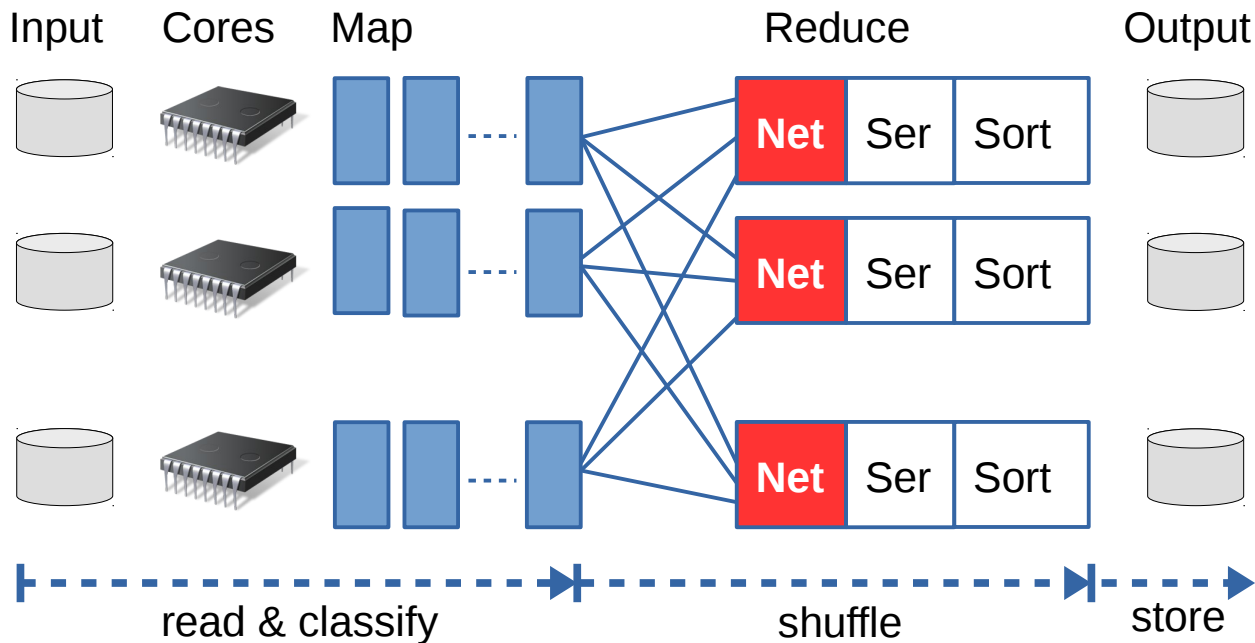


User-level APIs offer 2-10x better performance than traditional kernel-based APIs

# Let's Use it!

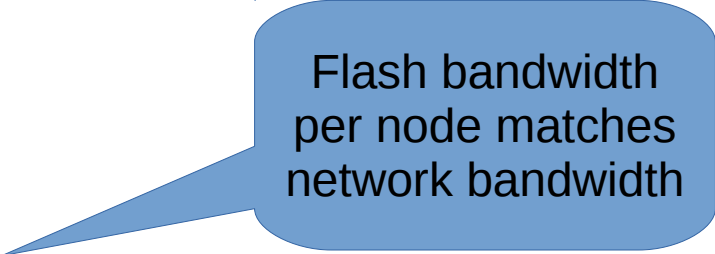


# Case Study: Sorting in Spark



# Experiment Setup

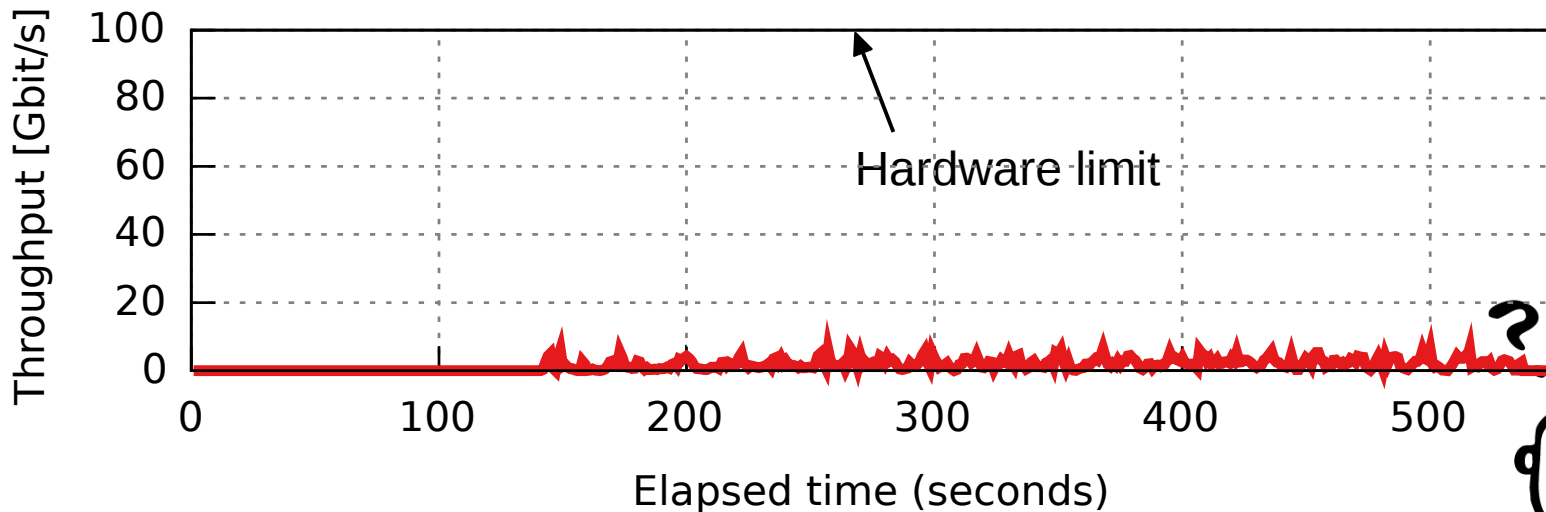
- Total data size: 12.8 TB
- Cluster size: 128 nodes
- Cluster hardware:
  - DRAM: 512 GB DDR 4
  - Storage: 4x 1.2 TB NVMe SSD
  - Network: 100GbE Mellanox RDMA



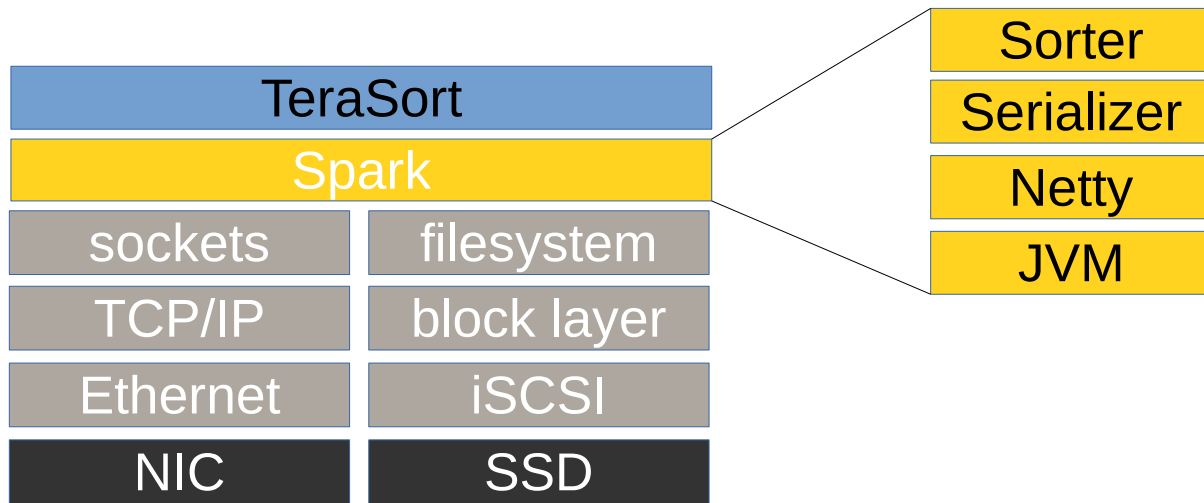
Flash bandwidth  
per node matches  
network bandwidth



# How is the Network Used?



# What is the Problem?

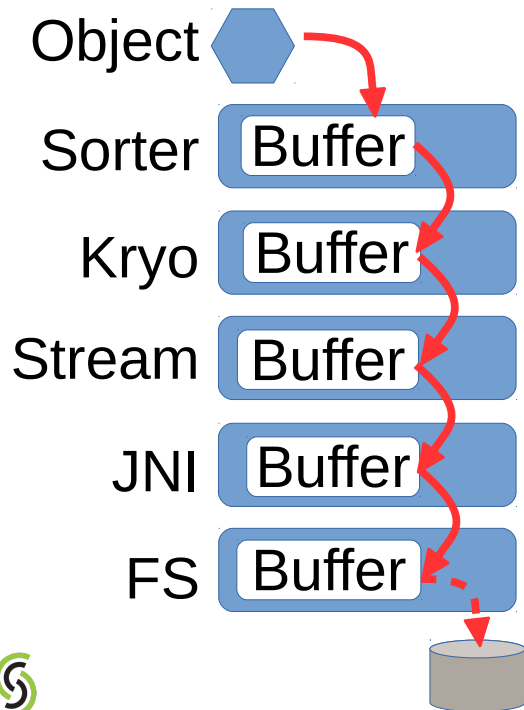


- Spark uses legacy networking and storage APIs: no kernel-bypass
- Spark itself introduces additional I/O layers: Netty, serializer, sorter, etc.

# Example: Shuffle (Map)



# Example: Shuffle (Map)



# Example: Shuffle (Map+Reduce)



# Example: Shuffle (Map+Reduce)



# How can we fix this...

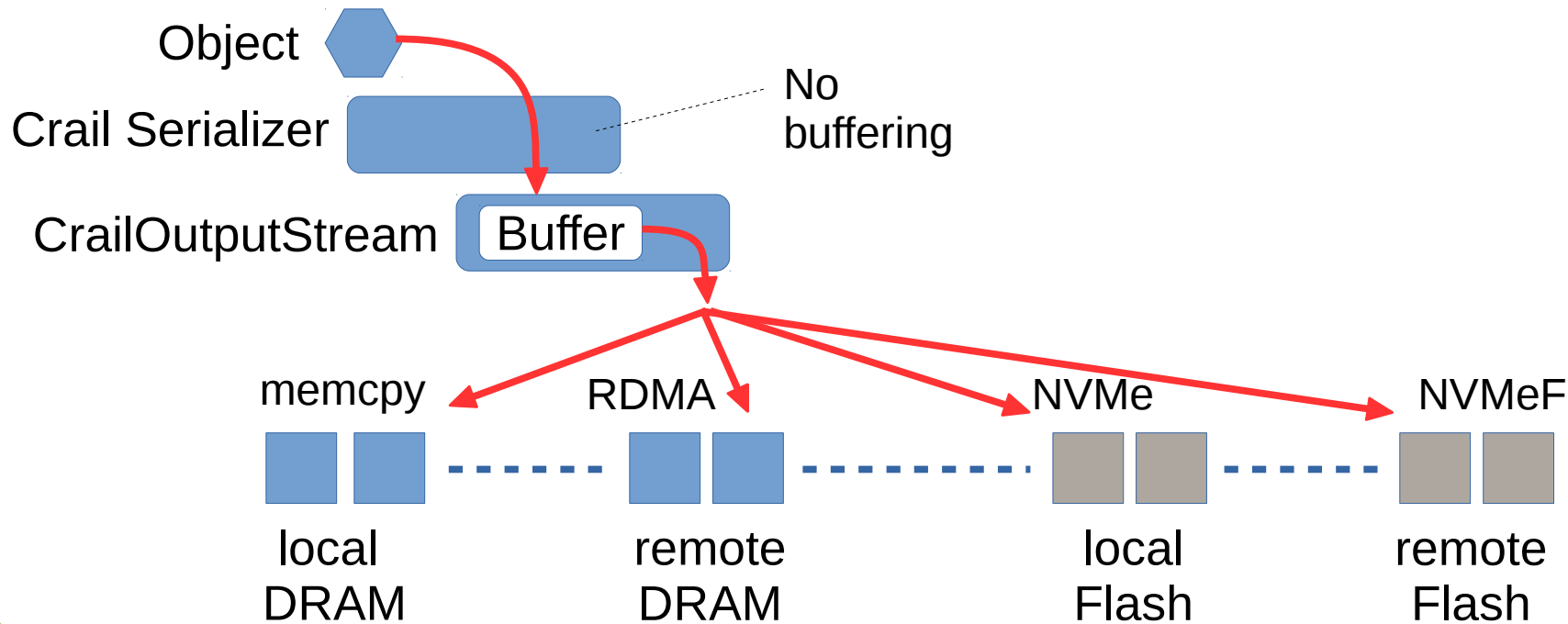
- Not just for shuffle
  - Also for broadcast, RDD transport, inter-job sharing, etc.
- Not just for RDMA and NVMe hardware
  - But for any possible future high-performance I/O hardware
- Not just for co-located compute/storage
  - Also for resource disaggregation, heterogeneous resource distribution, etc.
- Not just improve things
  - Make it perform at the hardware limit

# The CRAIL Approach

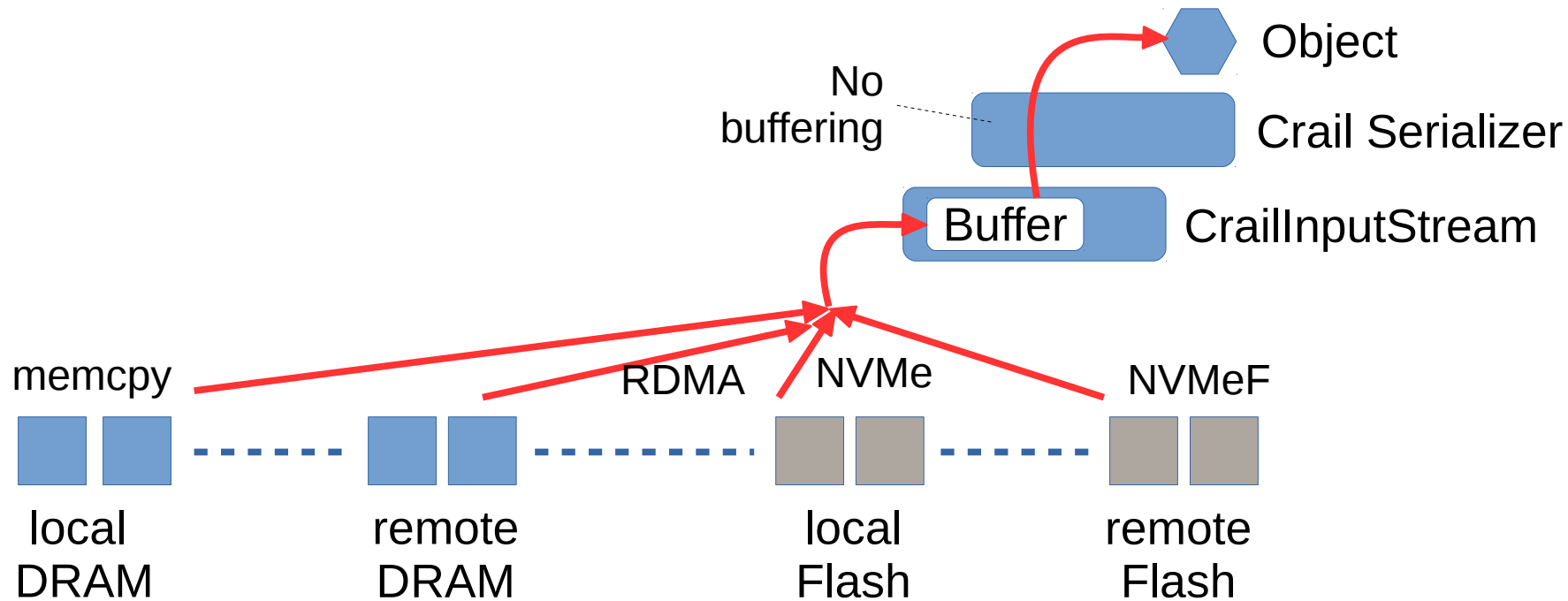




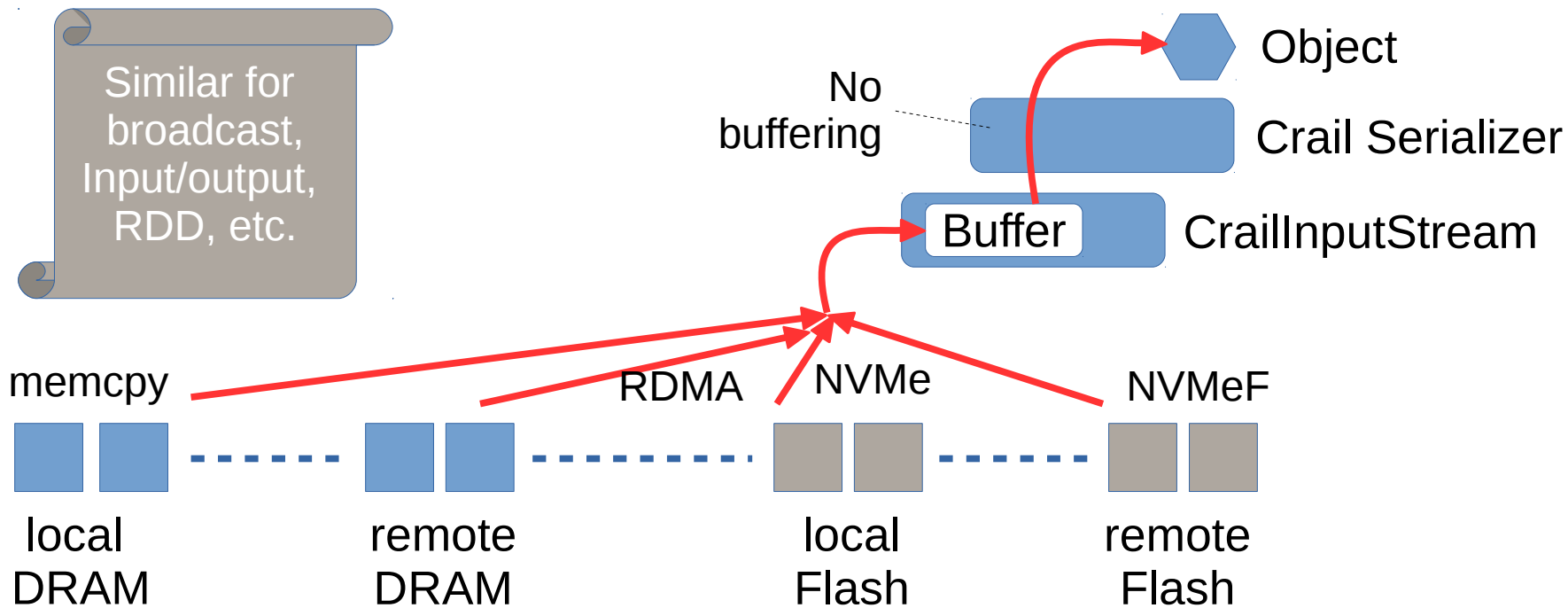
# Example: Crail Shuffle (Map)



# Example: Crail Shuffle (Reduce)



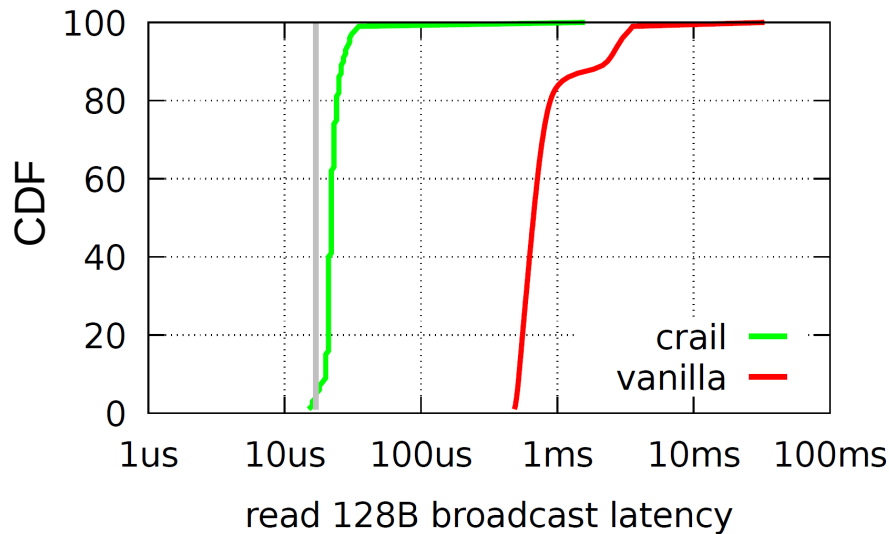
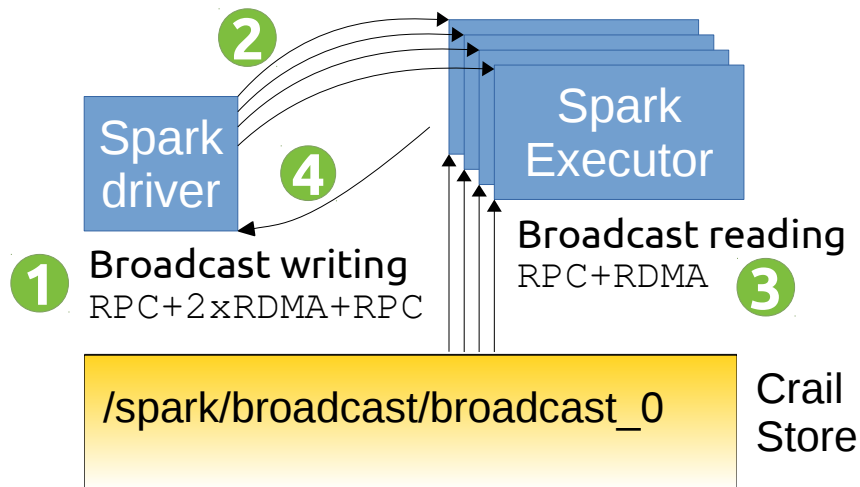
# Example: Crail Shuffle (Reduce)



# Performance: Configuration

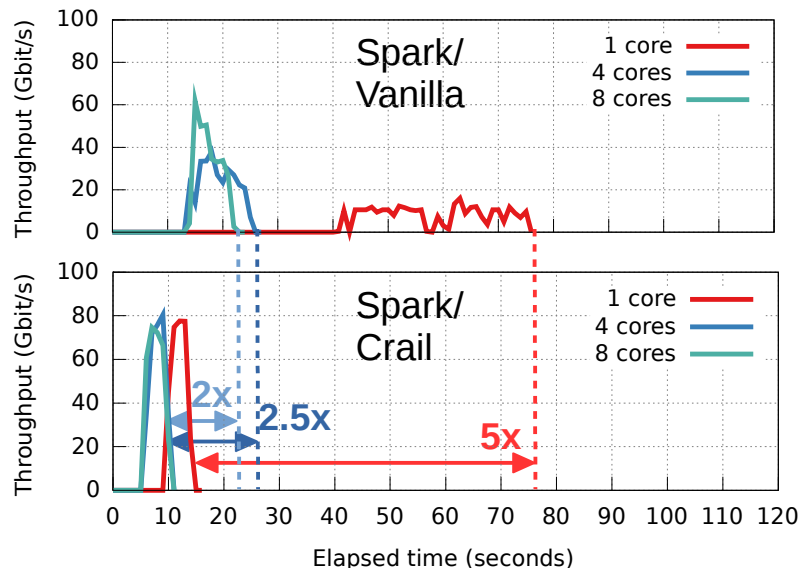
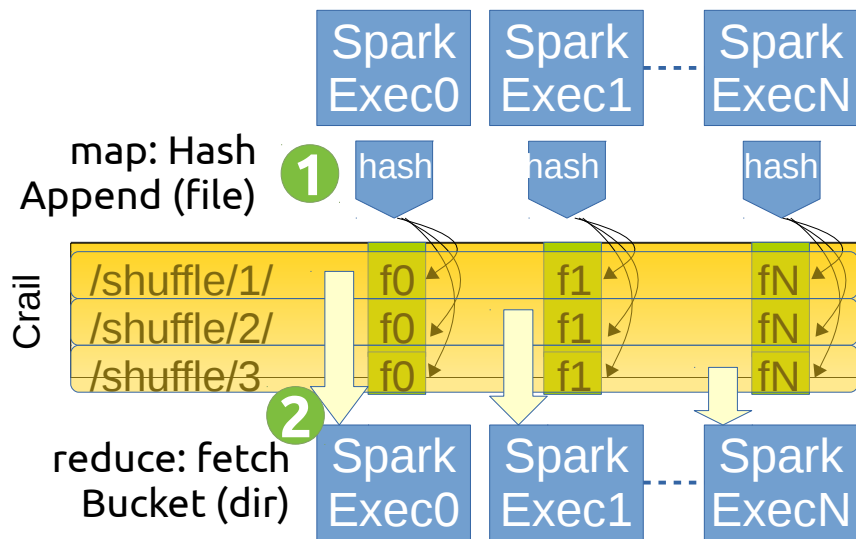
- Experiments
  - Memory-only: Broadcast, GroupBy, Sorting, SQL
  - Memory/Flash: disaggregation, tiering
- Cluster size: 8 nodes, except Sorting: 128 nodes
- Cluster hardware:
  - DRAM: 512 GB DDR 4
  - Storage: 4x 1.2 TB NVMe SSD
  - Network: 100GbE Mellanox RDMA
- Spark 2.1.0, Alluxio 1.4, Crail 1.0
- Hadoop.tmp.dir: RamFS for microbenchmarks, flash SSD for workloads

# Spark Broadcast



```
val bcVar = sc.Broadcast(new Array[Byte](128))
sc.parallelize(1 to tasks, tasks).map(_ => {
  bcVar.value.length
}).count
```

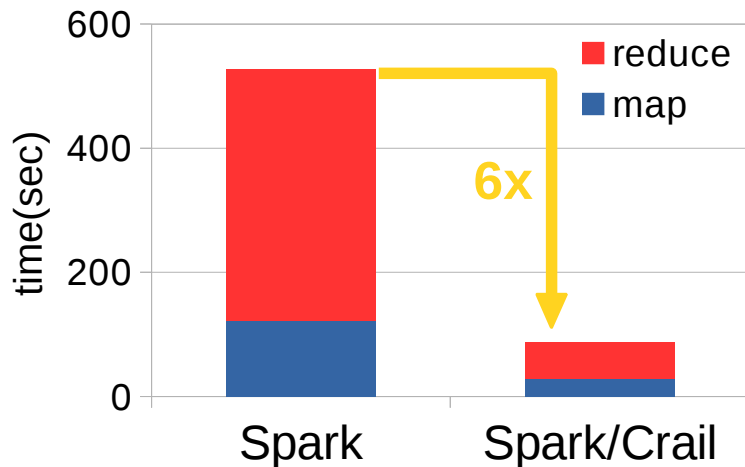
# Spark GroupBy (80M keys, 4K)



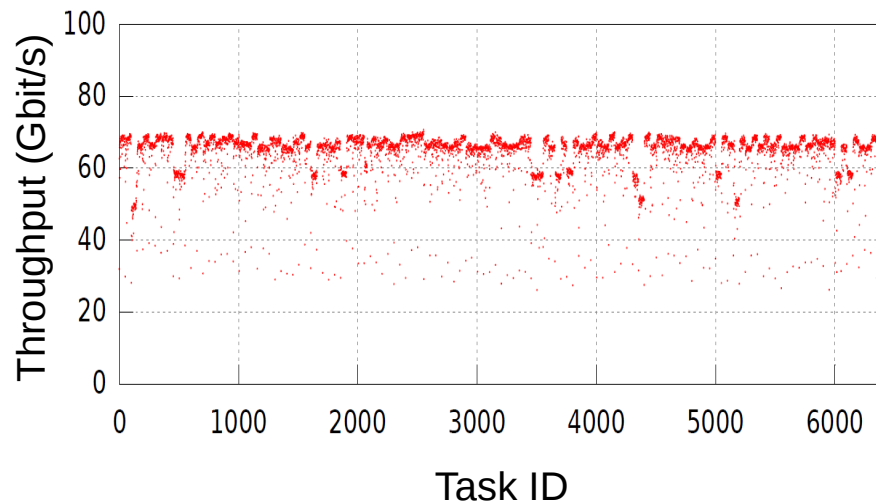
```
val pairs = sc.parallelize(1 to tasks, tasks).flatMap(_ => {  
  var values = new array[Long,Array[Byte]](numKeys)  
  values = initValues(values)  
}).cache().groupByKey().count()
```

# Sorting 12.8 TB on 128 nodes

Sorting Runtime



Spark/Crail Network Usage



# How fast is this?

[www.sortingbenchmark.org](http://www.sortingbenchmark.org)

Spark

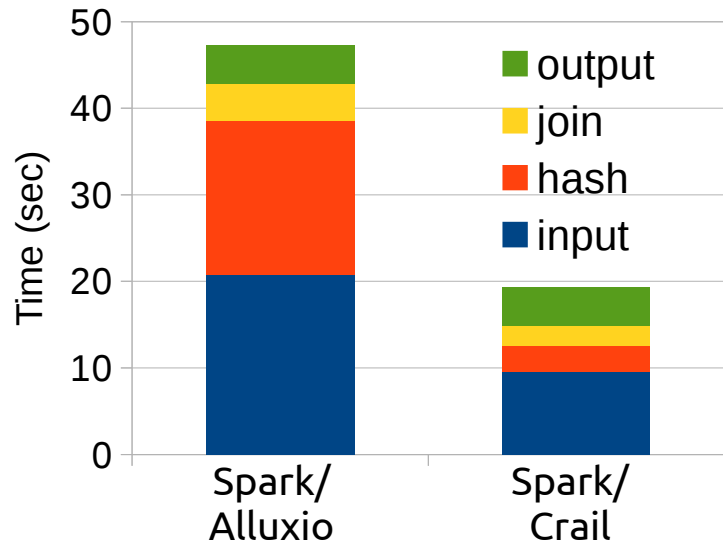
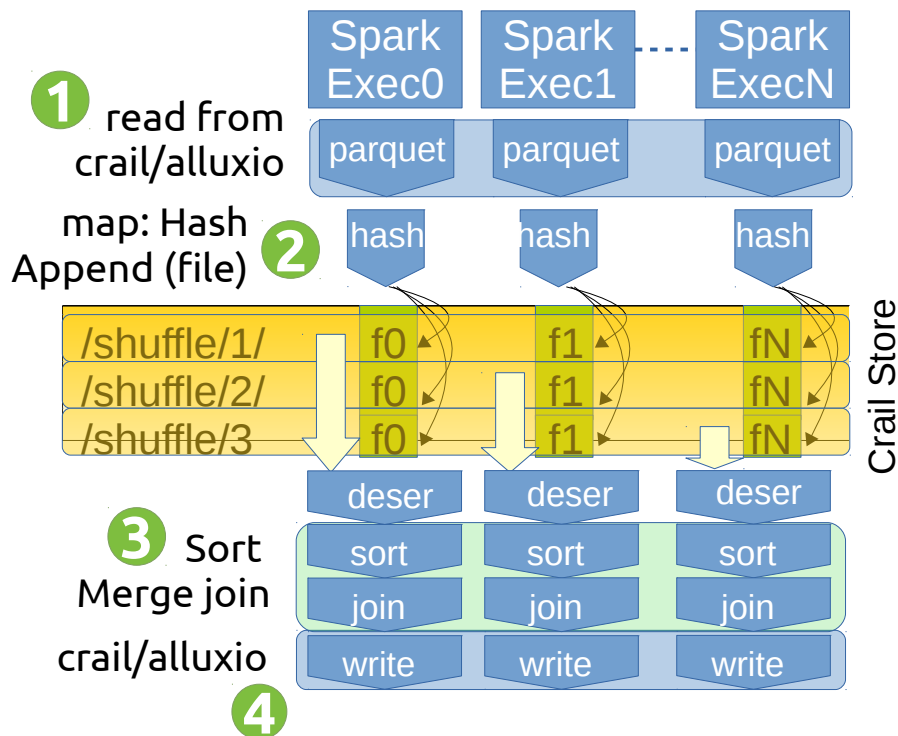
Native C  
distributed  
sorting  
benchmark

	Spark/Craill	Winner 2014	Winner 2016
Size (TB)	12.8	100	100
Time (sec)	98	1406	134
Total cores	2560	6592	10240
Network HW (Gbit/s)	100	10	100
Rate/core (GB/min)	3.13	0.66	4.4

Sorting rate of  
Craill/Spark only 27%  
slower than rate of  
Winner 2016

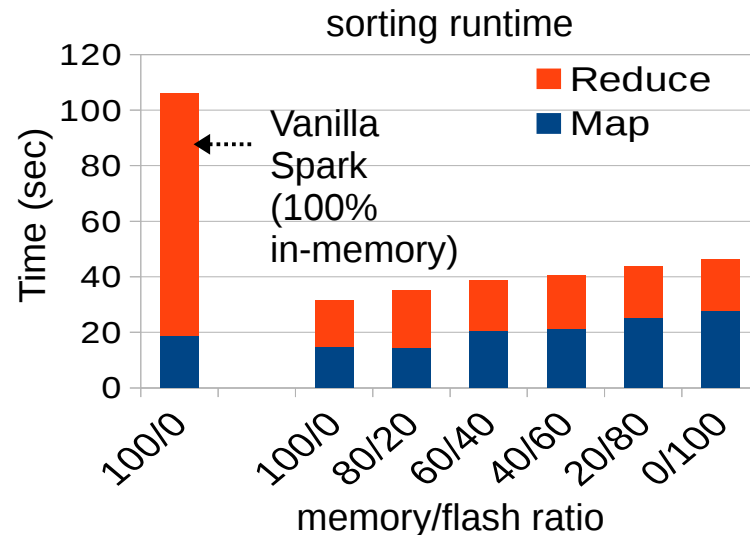
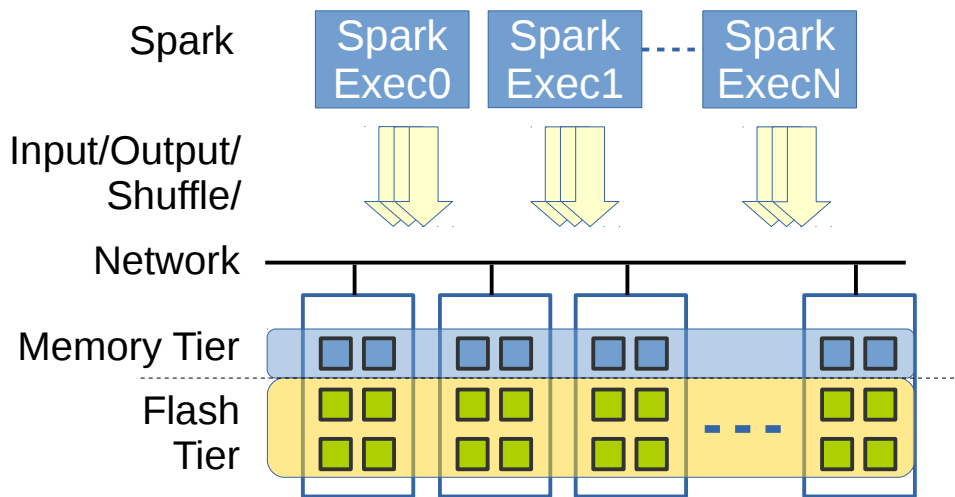


# Spark SQL Join



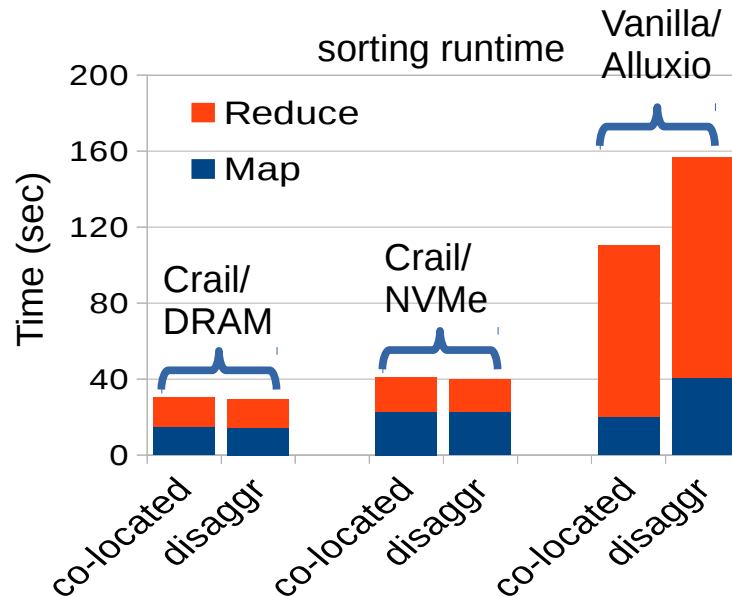
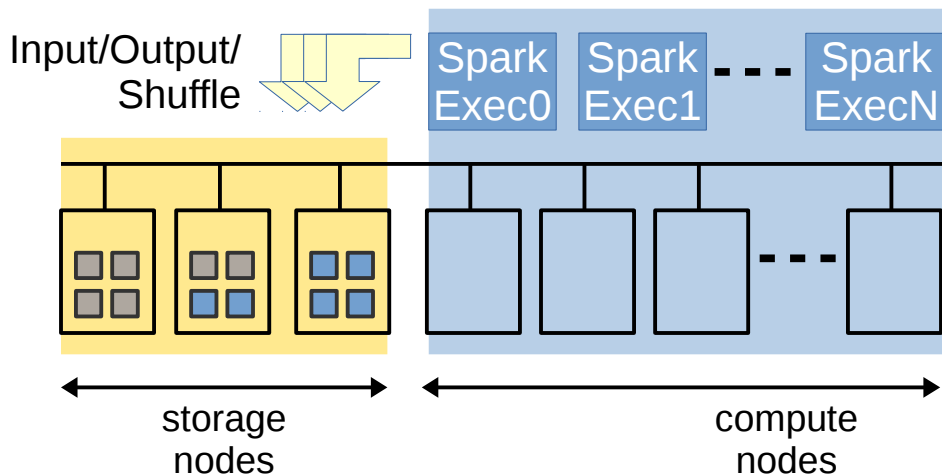
```
val ds1 = sparkSession.read.parquet(...) //64GB dataset
val ds2 = sparkSession.read.parquet(...) //64GB dataset
val resultDS = ds1.joinWith(ds2, ds1("key") === ds2("key")) //~100GB
resultDS.write.format("parquet").mode(SaveMode.Overwrite).save(...)
```

# Storage Tiering: DRAM & NVMe



With Crail, replacing memory with NVMe flash for storing input/output/shuffle reduces the 200GB sorting runtime by only 48%

# DRAM & Flash Disaggregation



Using Crail, a Spark 200GB sorting workload can be run with memory and flash disaggregated at no extra cost

# Conclusions

- Effectively using high-performance I/O hardware in Spark is challenging
- Crail is an attempt to re-think how data processing frameworks (not only Spark) should interact with network and storage hardware
  - User-level I/O, storage disaggregation, memory/flash convergence
- Spark's modular architecture allows Crail to be used seamlessly

# Crail for Spark is Open Source



[www.crail.io](http://www.crail.io)



[github.com/zrlio/spark-io](https://github.com/zrlio/spark-io)



[github.com/zrlio/crail](https://github.com/zrlio/crail)



[github.com/zrlio/parquetgenerator](https://github.com/zrlio/parquetgenerator)



[github.com/zrlio/crail-terasort](https://github.com/zrlio/crail-terasort)



# Thank You.

## Contributors:

Animesh Trivedi, Jonas Pfefferle, Michael Kaufmann, Bernard Metzler, Radu Stoica, Ioannis Koltsidas, Nikolos Ioannou, Christoph Hagleitner, Peter Hofstee, Evangelos Eleftheriou, ...