



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

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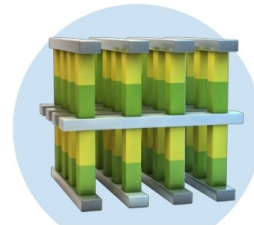
Hardware Trends

community
target

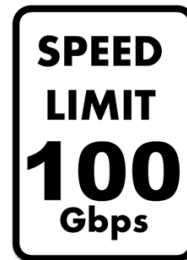
	2010	2017
Storage	100 MB/s 100ms	1000 MB/s 200us
Network	1Gbps 50us	10Gbps 20us
CPU	~3GHz	~3GHz

Hardware Trends

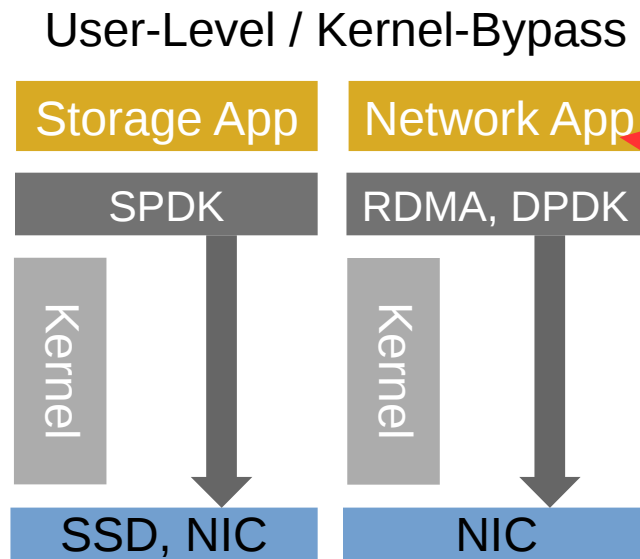
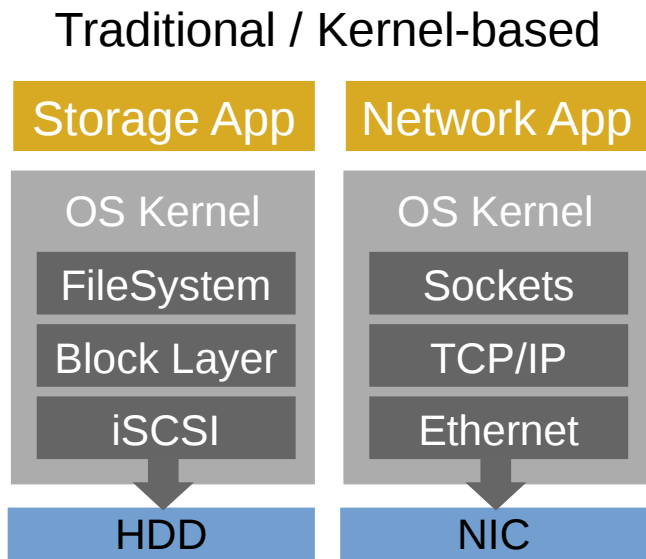
		community target	our target
	2010	2017	2017
Storage	100 MB/s 100ms	1000 MB/s 200us	10 GB/s 50us
Network	1Gbps 50us	10Gbps 20us	100Gbps 1us
CPU	~3GHz	~3GHz	☹️



3D XPoint



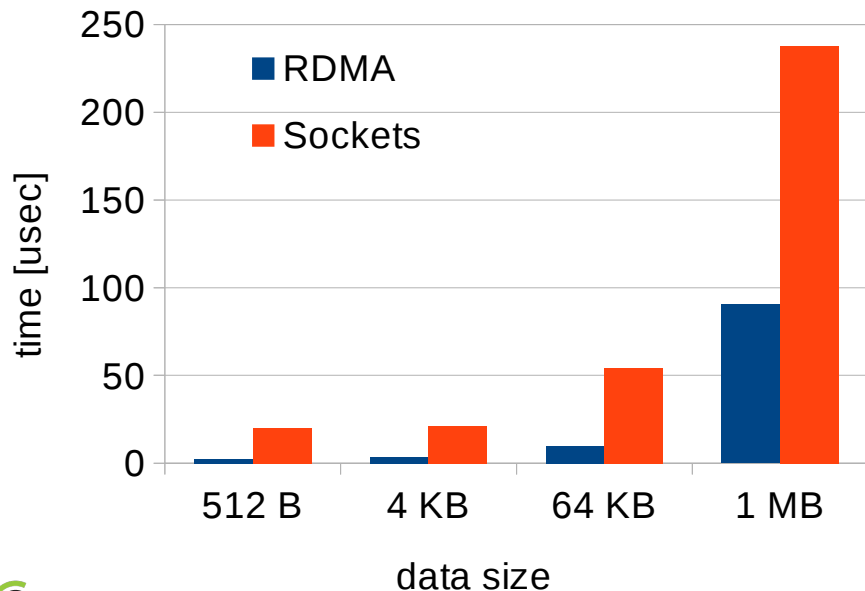
User-Level APIs



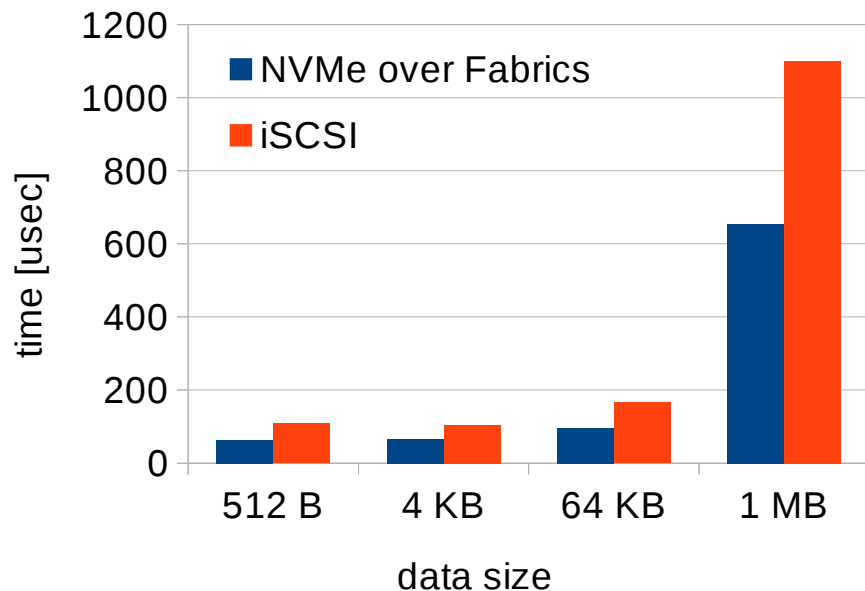
Needed to
achieve
1us RTT!

Remote Data Access

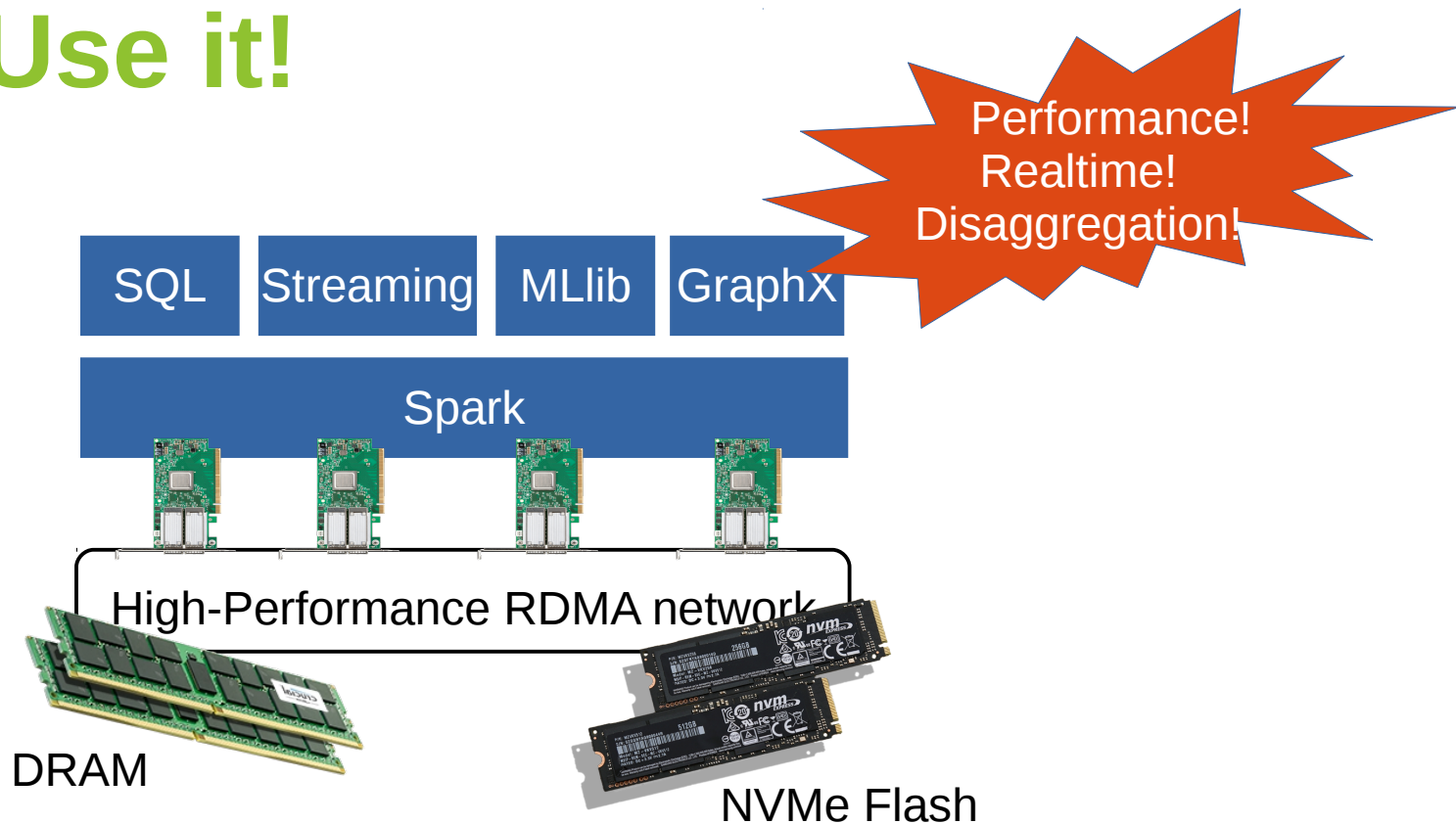
DRAM



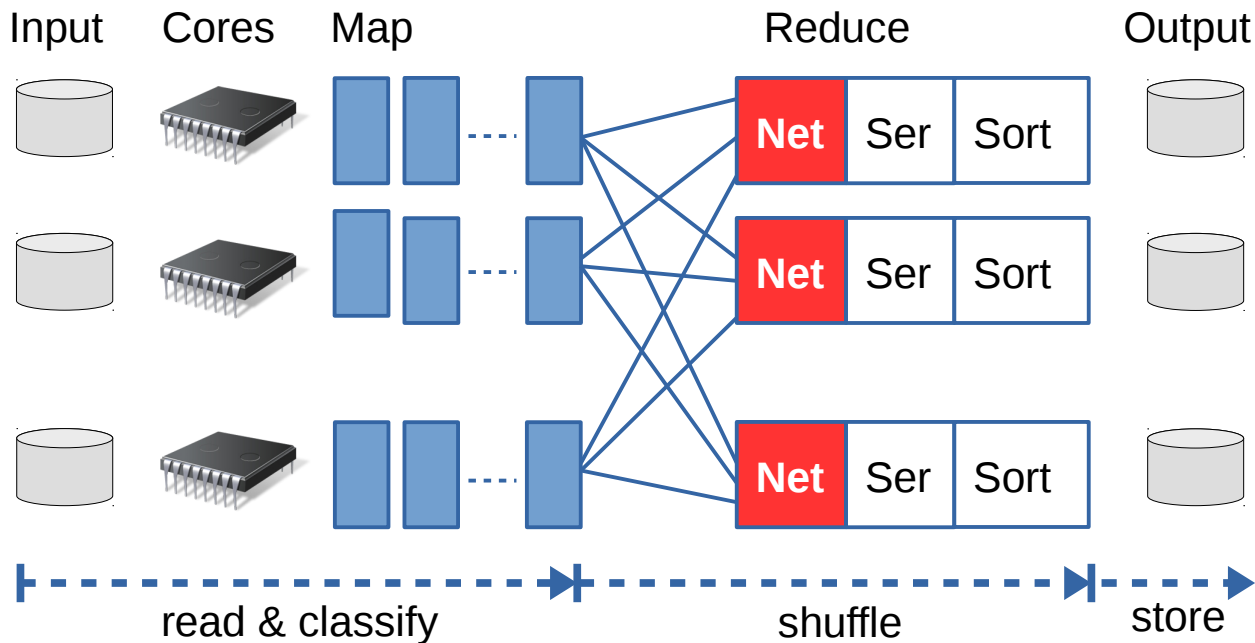
NVMe Flash



Let's Use it!

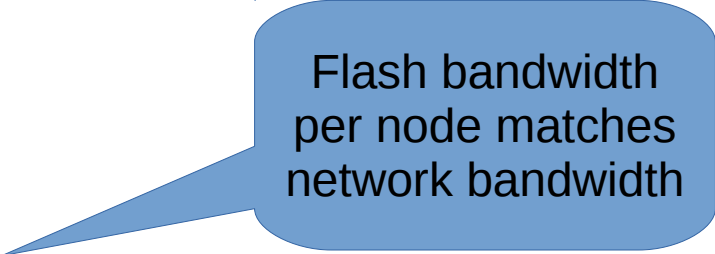


Case Study: Sorting in Spark



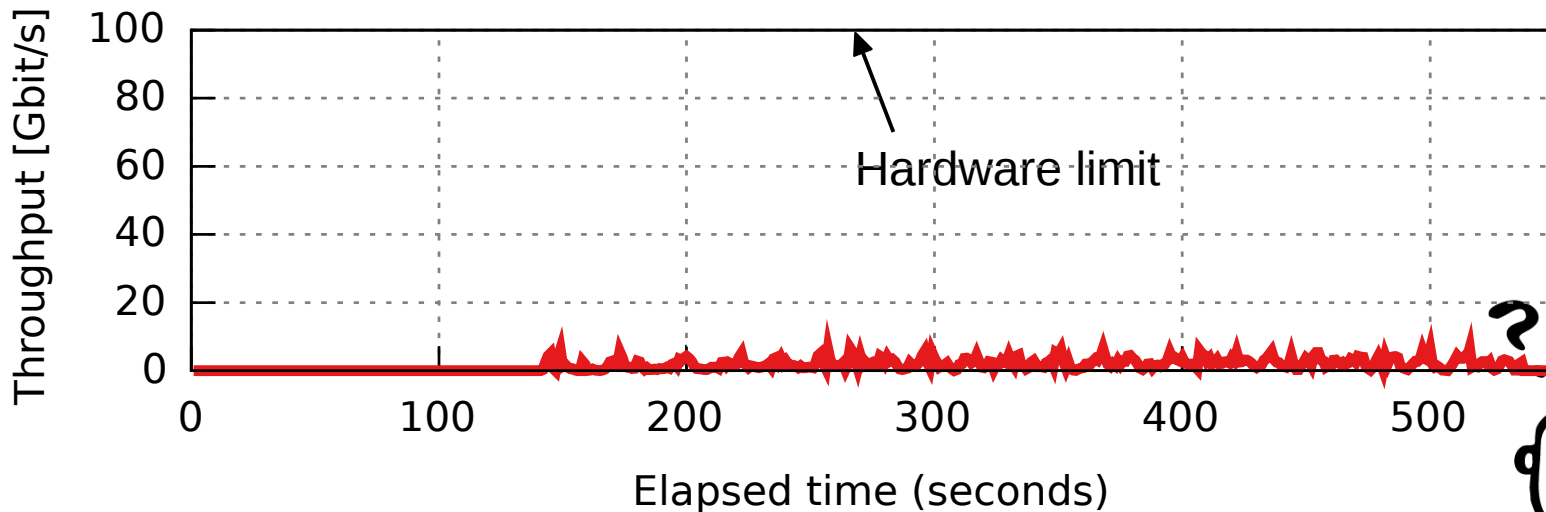
Experiment Setup

- 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

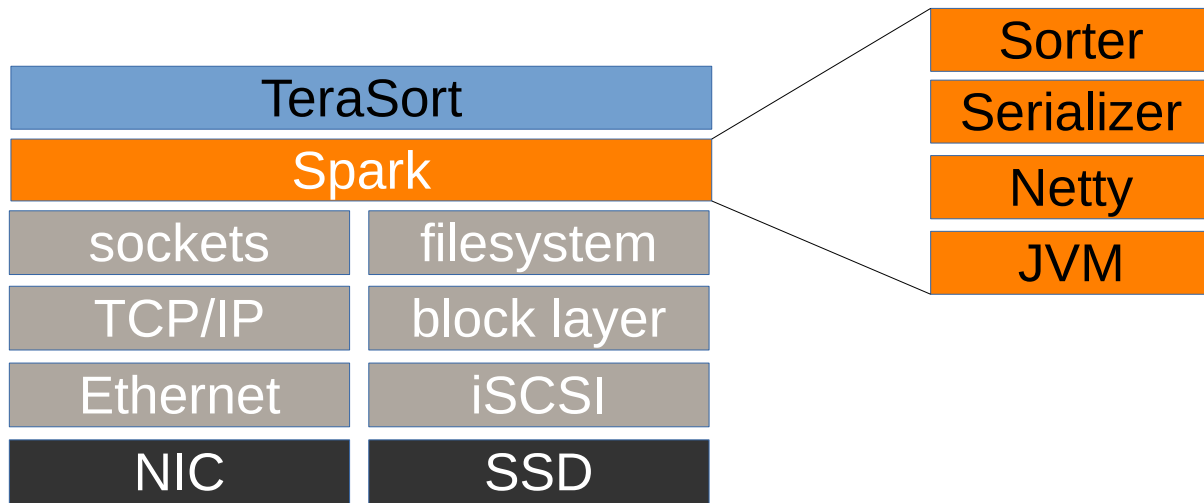


Flash bandwidth
per node matches
network bandwidth

How is the Network Used?



What is the Problem?

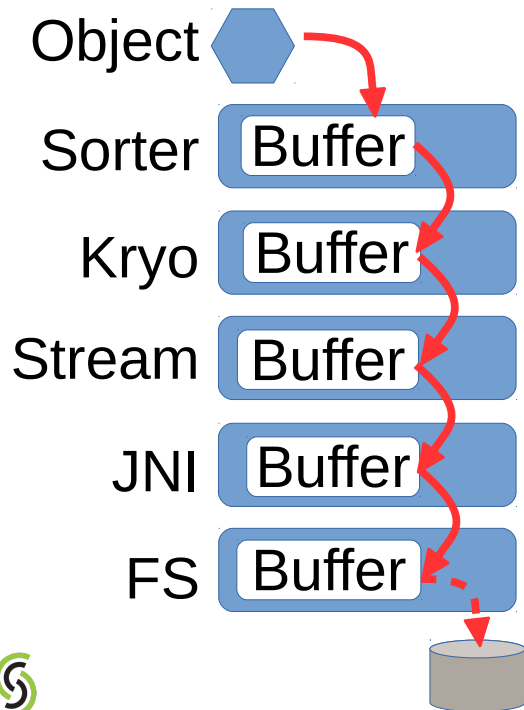


- Spark uses legacy networking and storage APIs: no kernel-bypass
- Spark itself introduces additional I/O layers: Netty, serializer, sorter, etc.

Example: Shuffle (Map)



Example: Shuffle (Map)



Example: Shuffle (Map+Reduce)



Example: Shuffle (Map+Reduce)



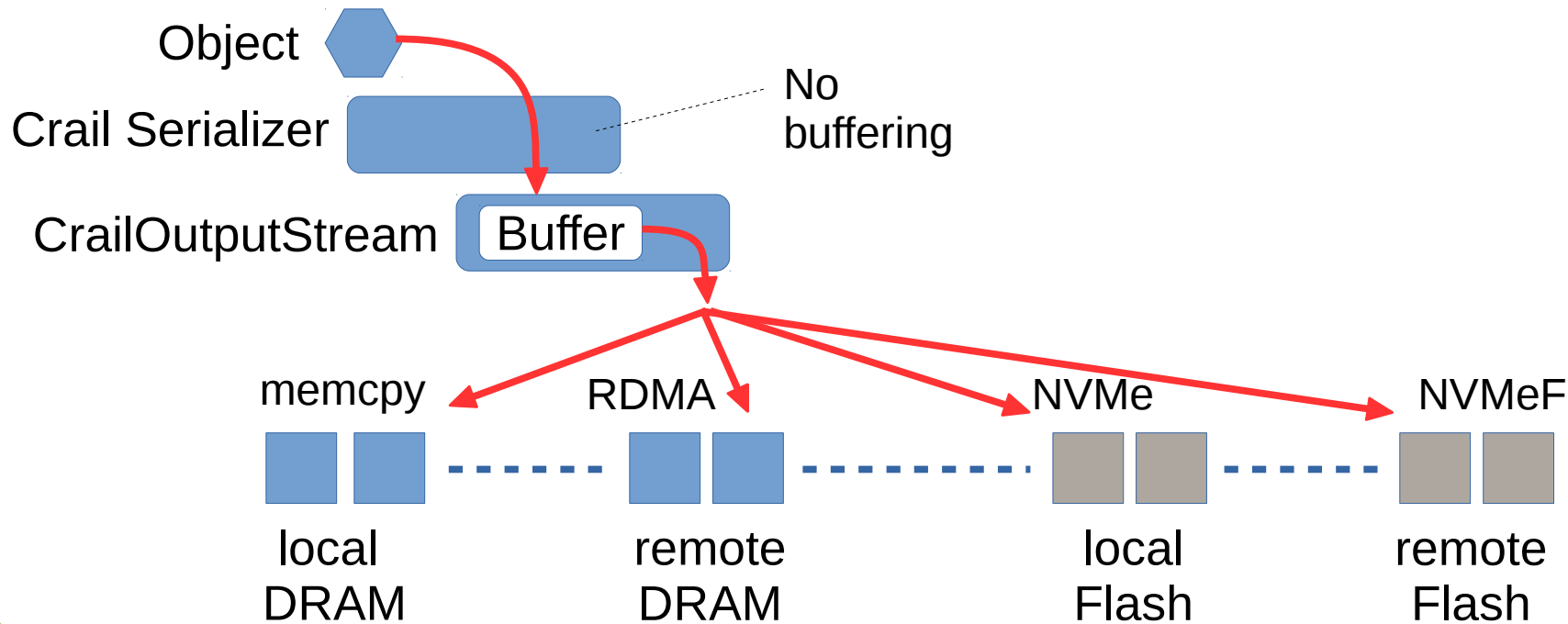
How can we fix this...

- 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

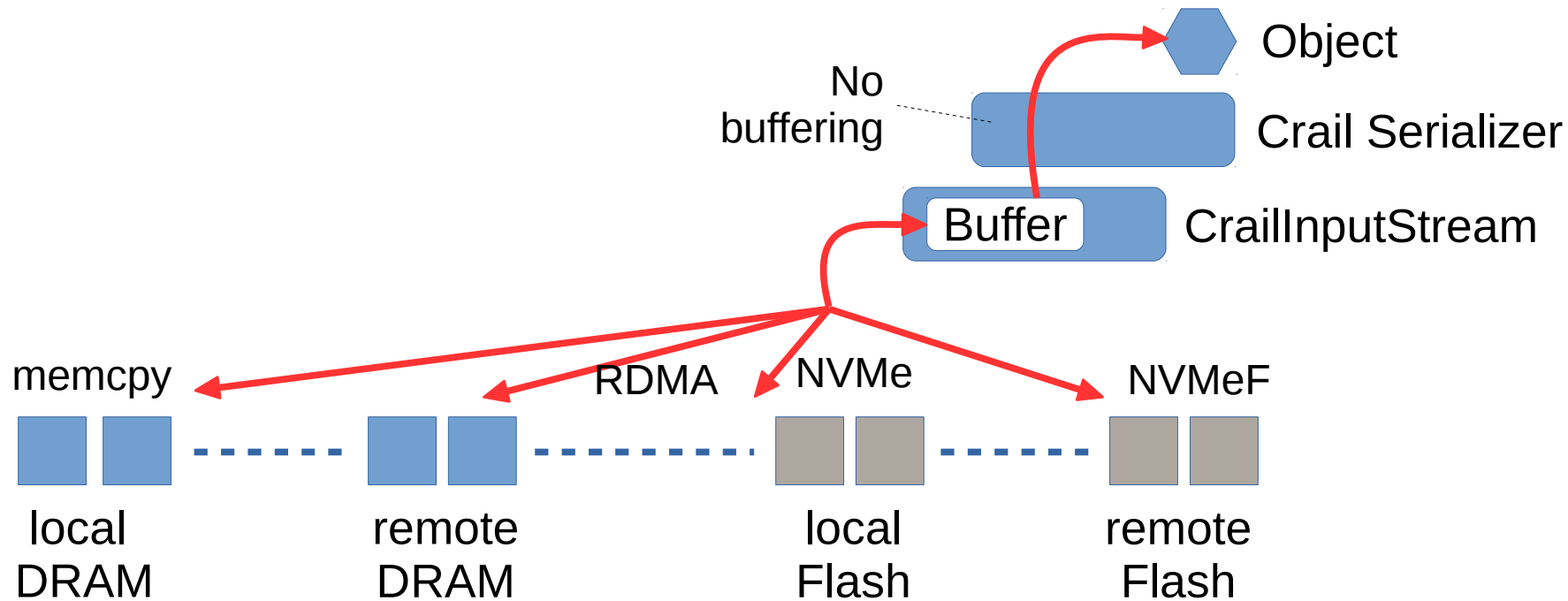
The CRAIL Approach



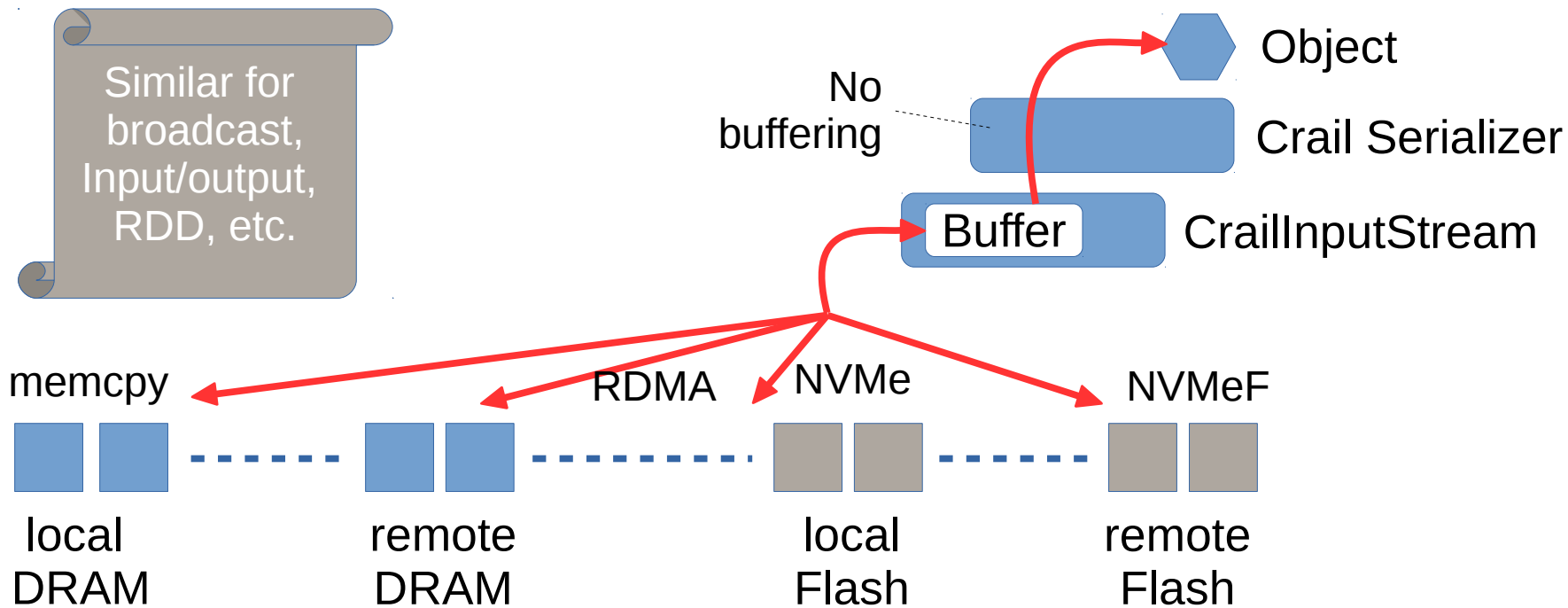
Example: Crail Shuffle (Map)



Example: Crail Shuffle (Reduce)



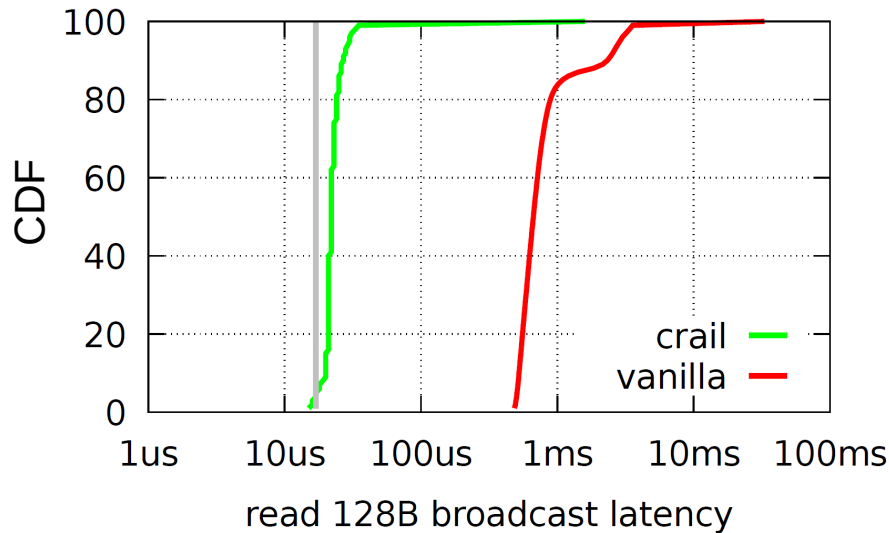
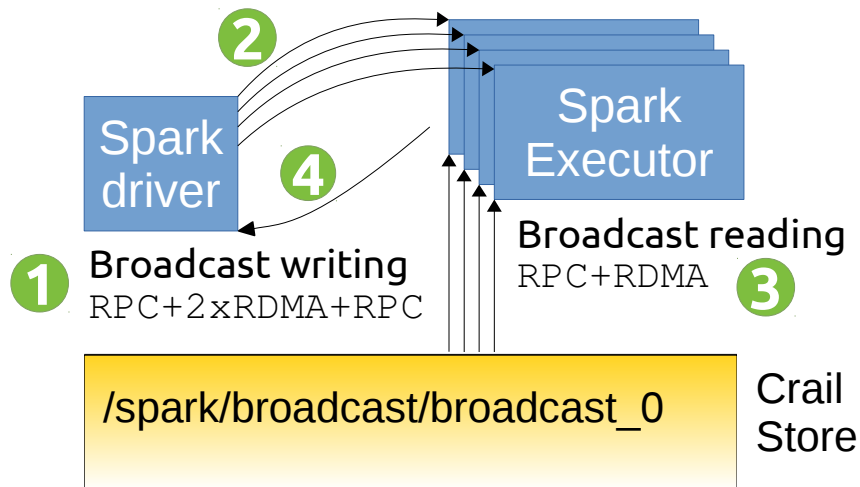
Example: Crail Shuffle (Reduce)



Performance: Configuration

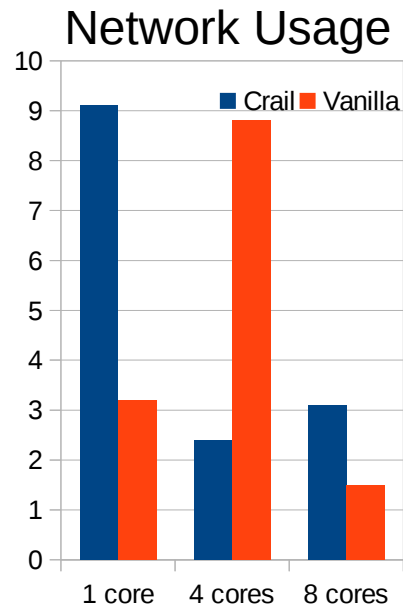
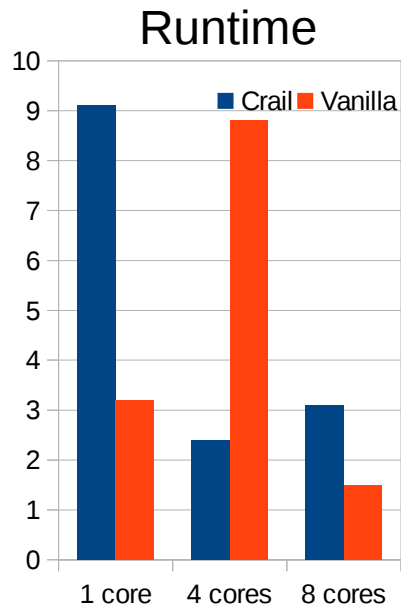
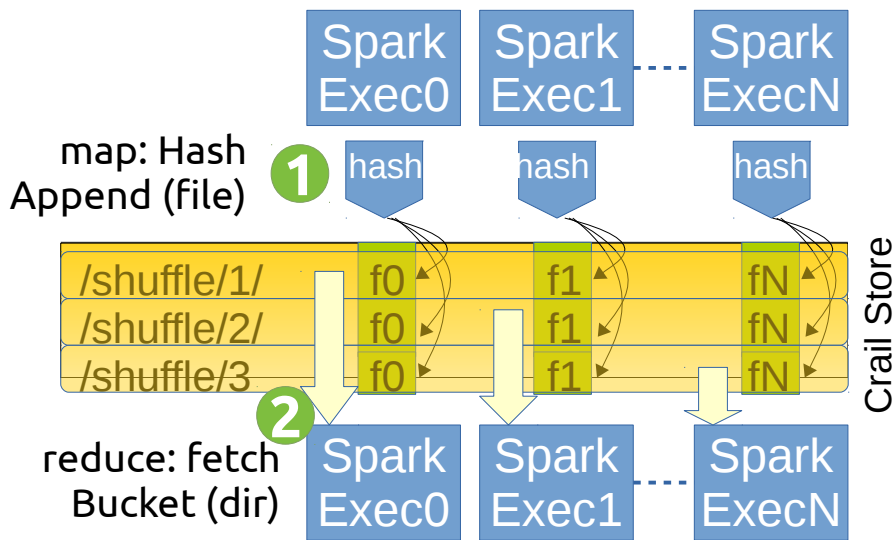
- Experiments
 - Performance: Broadcast, GroupBy, Sorting, SQL (memory)
 - Disaggregation, tiering: Sorting (memory/flash)
- Cluster size: 8 nodes, except TeraSort: 128 nodes
- Cluster hardware:
 - DRAM: 512 GB DDR 4
 - Storage: 4x 1.2 TB NVMe SSD
 - Network: 100GbE Mellanox RDMA

Spark Broadcast



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

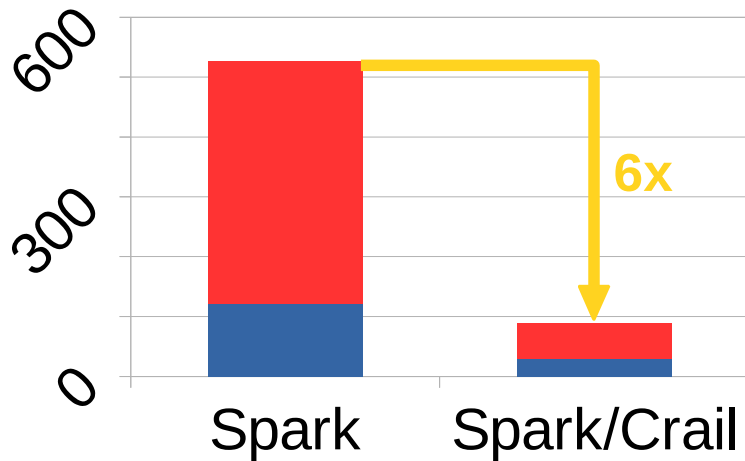
Spark GroupBy (240GB)



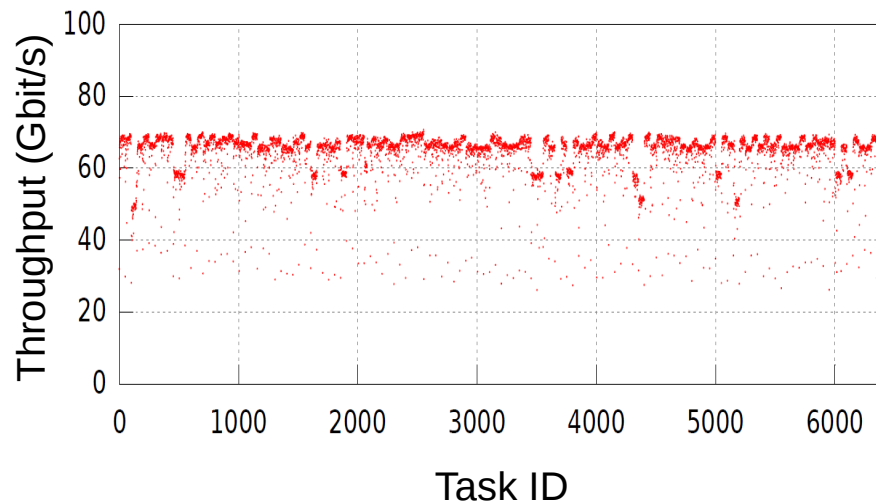
```
val pairs = sc.parallelize(1 to tasks, tasks).flatMap(_ => {  
  var values = new array[Long,Array[Byte]](numKeys)  
  values = initValues(values)  
}).cache().groupByKey().map(v => v._1).count()
```

Sorting 12.8 TB on 128 nodes

Sorting Runtime



Spark/Crail Network Usage



How fast is this?

www.sortingbenchmark.org

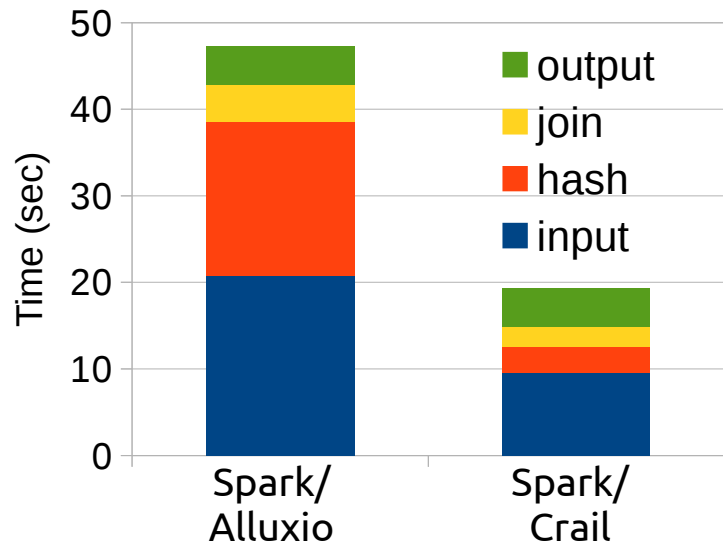
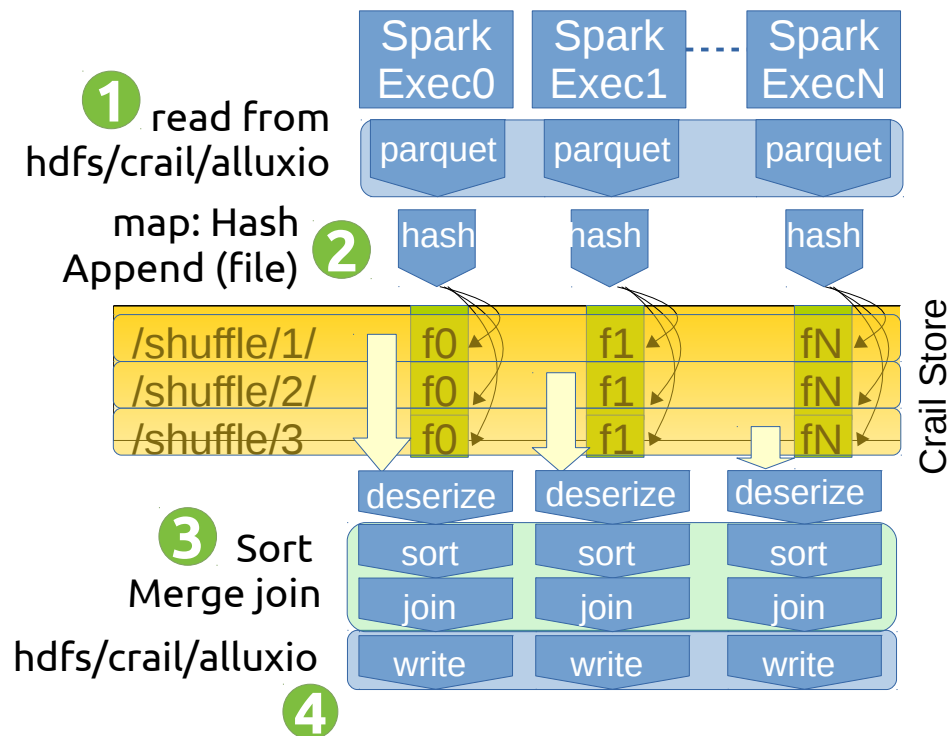
Spark

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

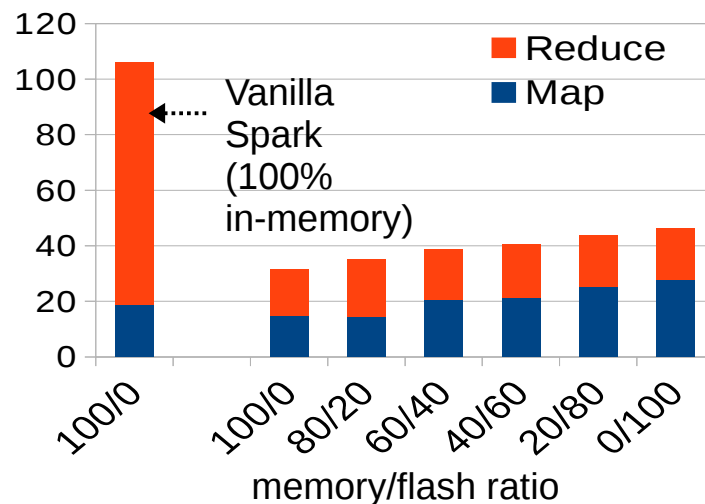
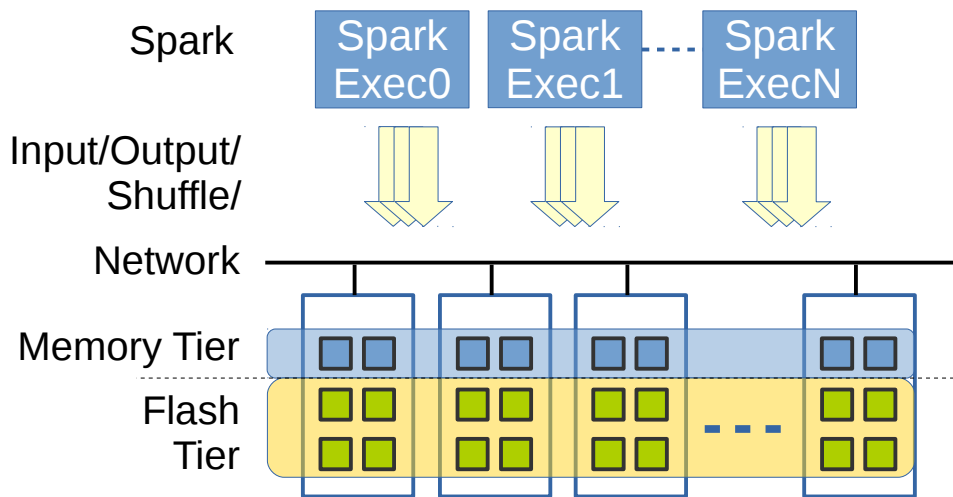
Sorting rate of
Craill/Spark only 27%
slower than rate of
Winner 2016

Spark SQL Join



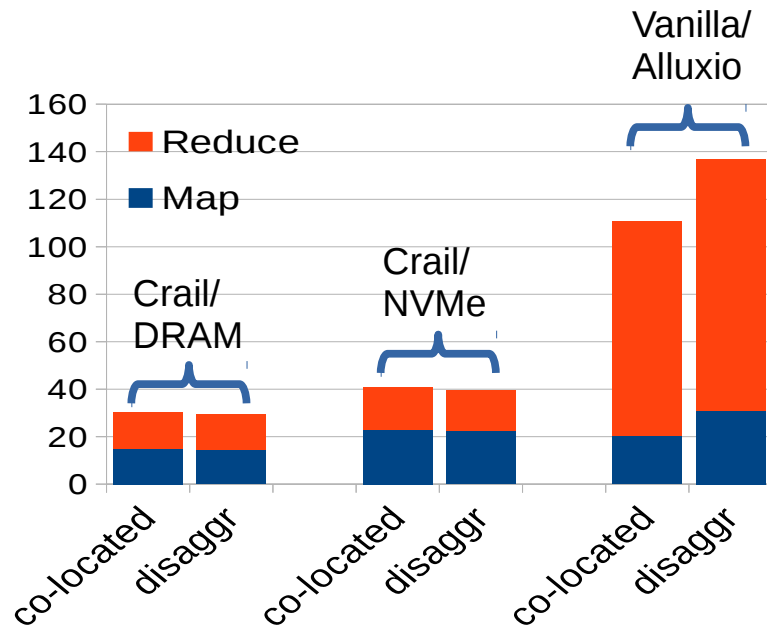
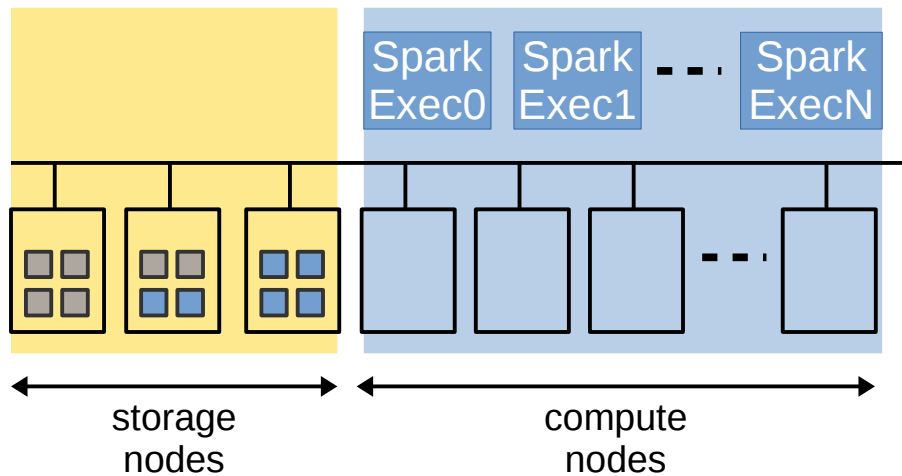
```
val ds1 = spSess.read.parquet(...) //100GB dataset
val ds2 = spSess.read.parquet(...) //100GB dataset
val resultDS = ds1.joinWith(ds1, ds1(key) === ds2(key))
resultDS.write.format("parquet").mode(SaveMode.Overwrite).save(...)
```

Storage Tiering: DRAM & NVMe



Using NVMe flash instead of memory for input/output/shuffle data results in only 48% performance cost

DRAM & Flash Disaggregation



With Crail, Spark sorting workload can be run both with memory and flash disaggregated without performance 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

Crail for Spark is Open Source



www.crail.io



github.com/zrlio/spark-io



github.com/zrlio/crail



github.com/zrlio/parquetgenerator



github.com/zrlio/crail-terasort



Thank You.

The CRAIL Approach

