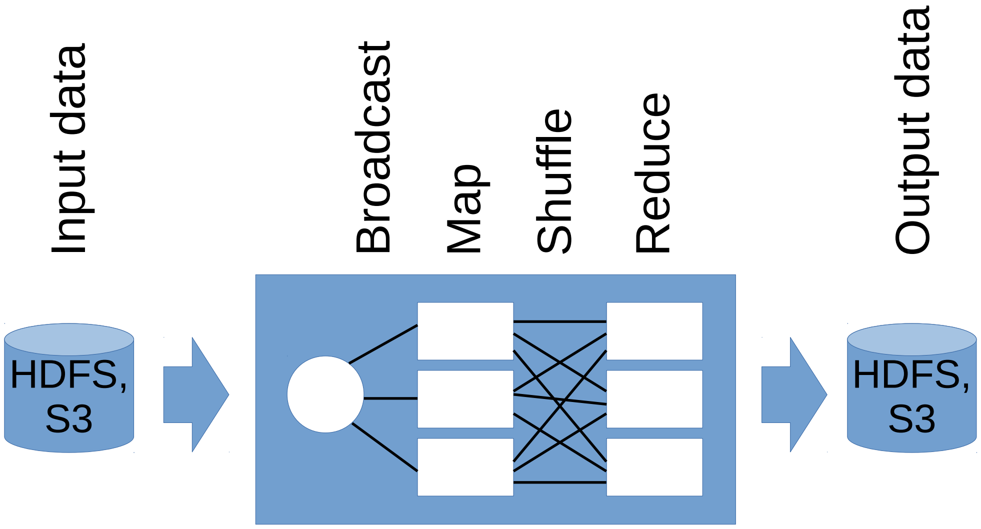
Unification of Temporary Storage in the NodeKernel Architecture

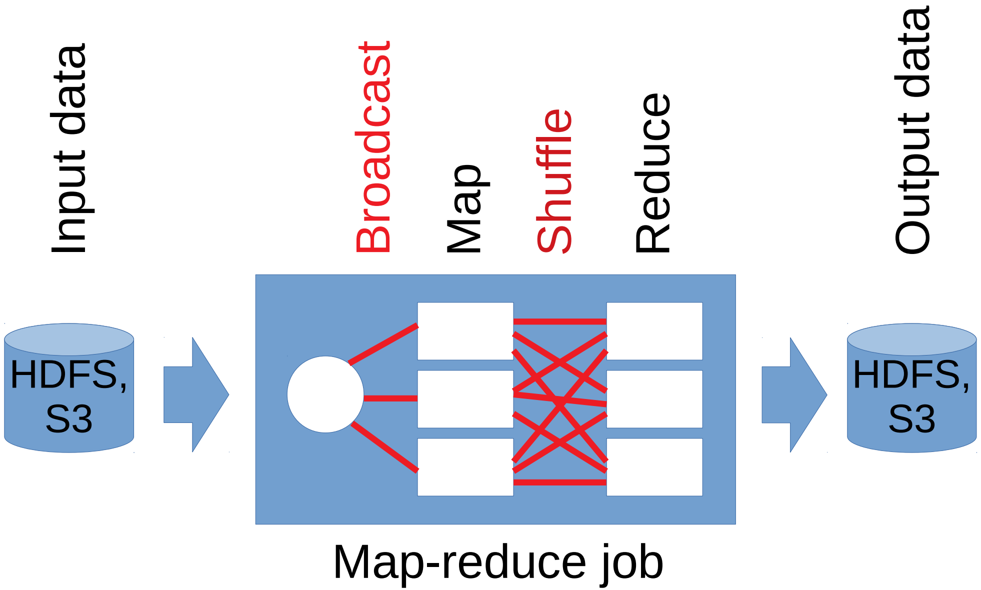
Patrick Stuedi, Animesh Trivedi, Jonas Pfefferle, Ana Klimovic, Adrian Schuepbach, Bernard Metzler

Temporary/Intermediate Data



Map-reduce job

Temporary/Intermediate Data



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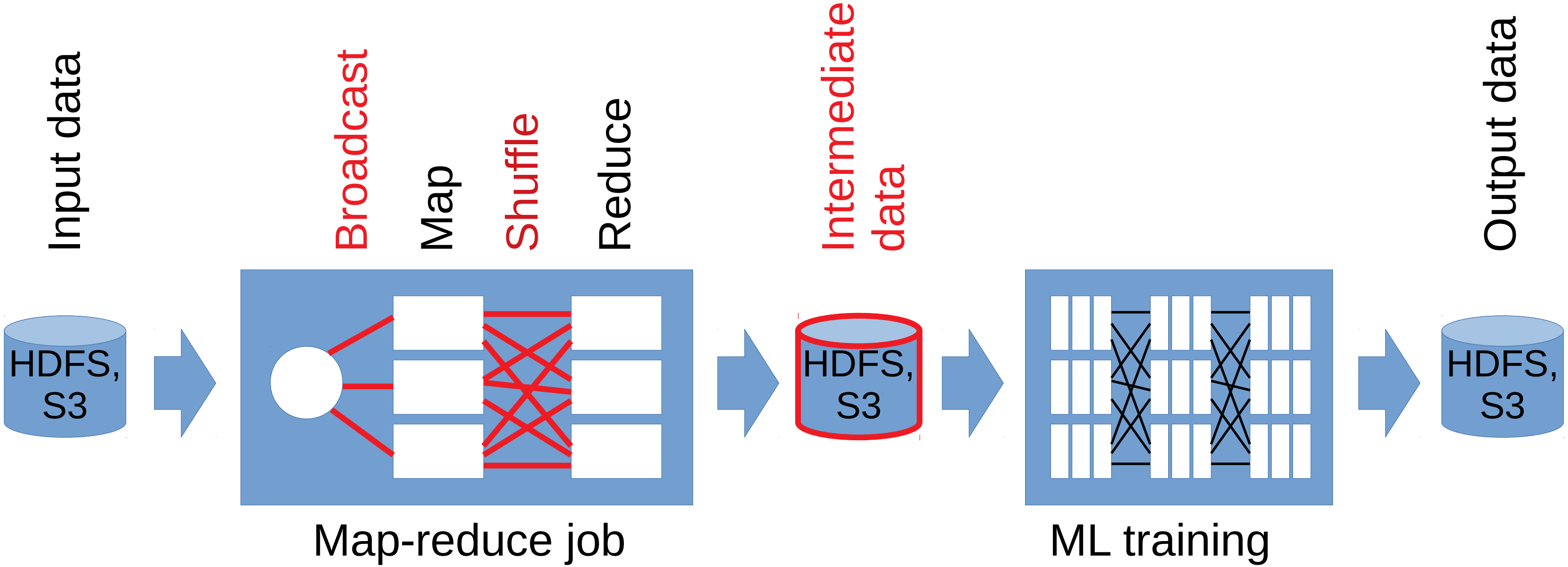

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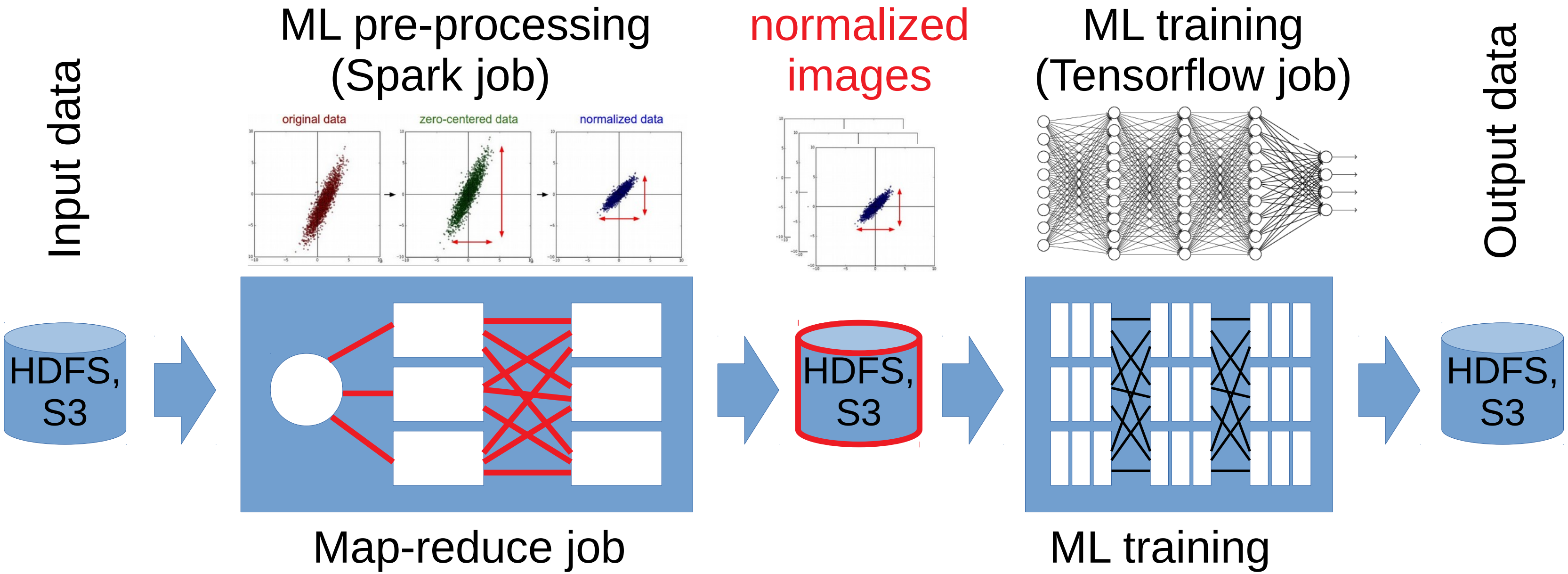


Input data

ML pre-processing
(Spark job)

normalized
images

ML training
(Tensorflow job)

Output data

HDFS,
S3

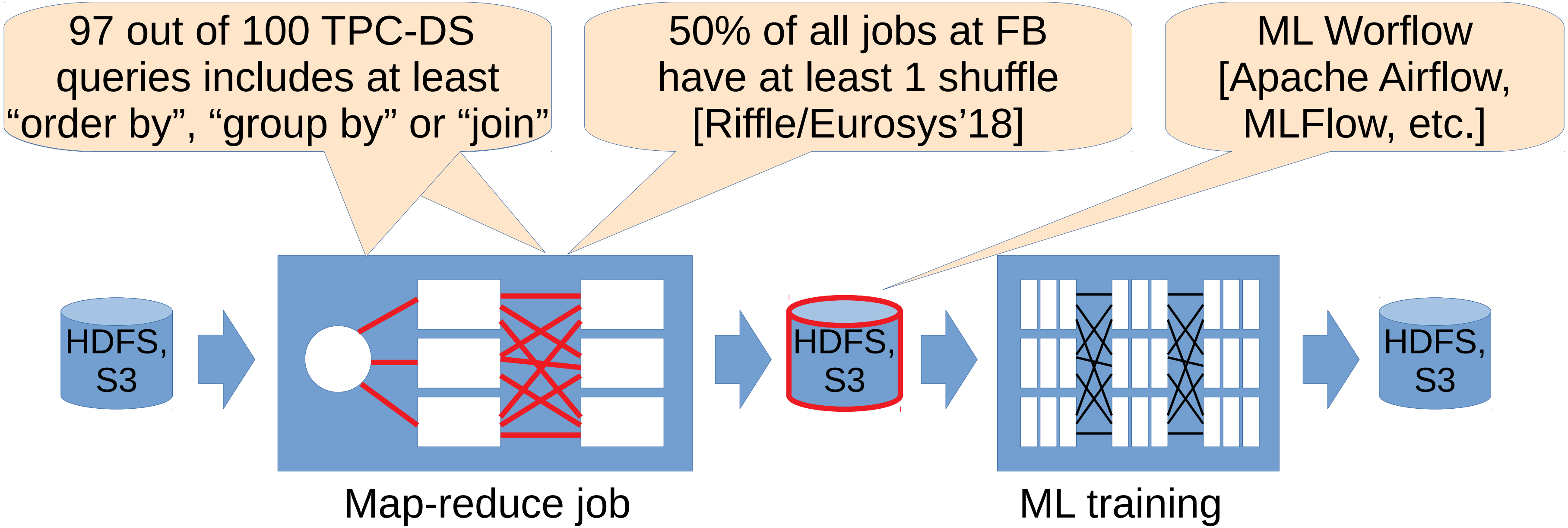
HDFS,
S3

HDFS,
S3

Map-reduce job

ML training

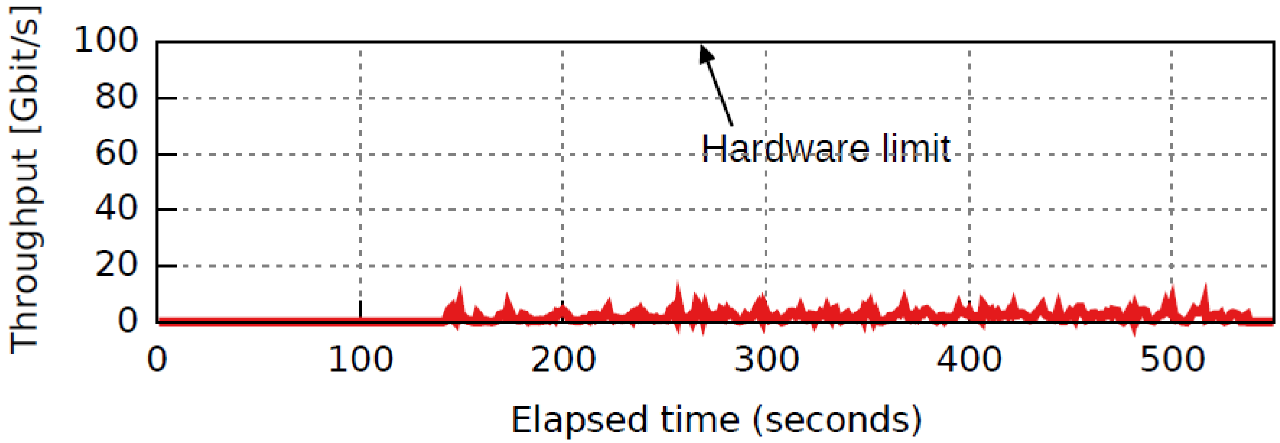
Temporary/Intermediate Data

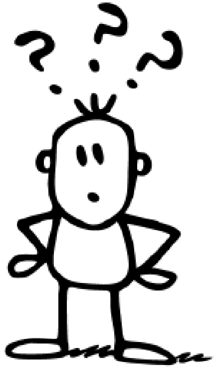


Temporary data is an important class of data for data processing workloads

Shortcomings of Temporary Data Storage

- Inefficient:
  - Difficult to leverage modern networking and storage hardware (e.g., 100 Gb/s Ethernet, NVMe Flash, etc.)





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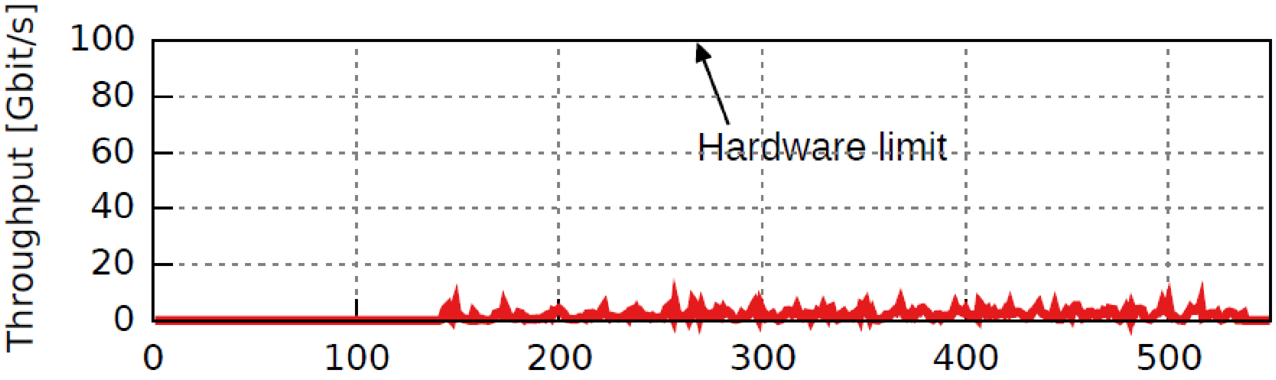
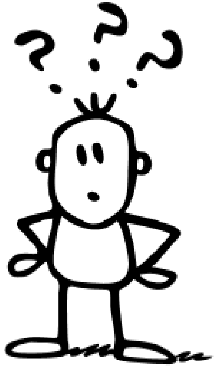


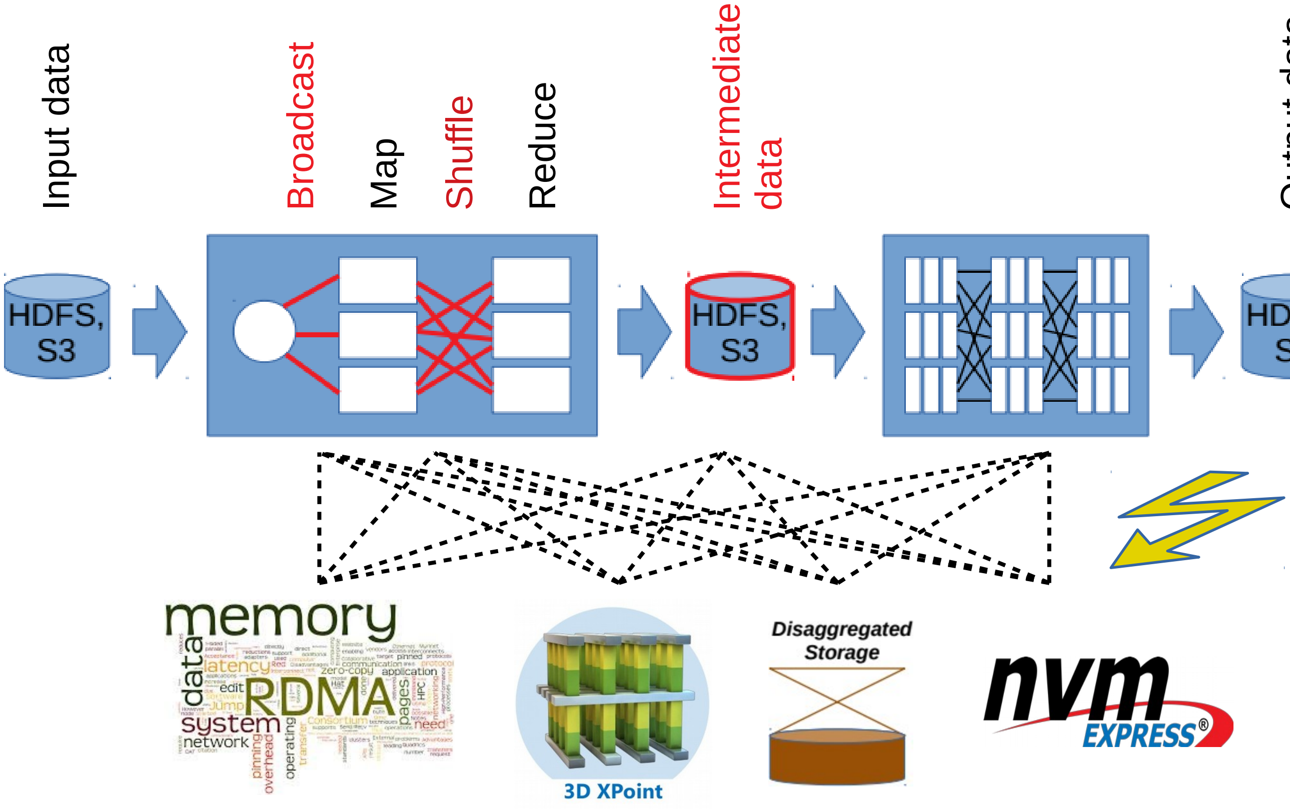


Ousterhout/NSDI’16 **Trivedi/HotCloud’16**

Shortcomings of Temporary Data Storage

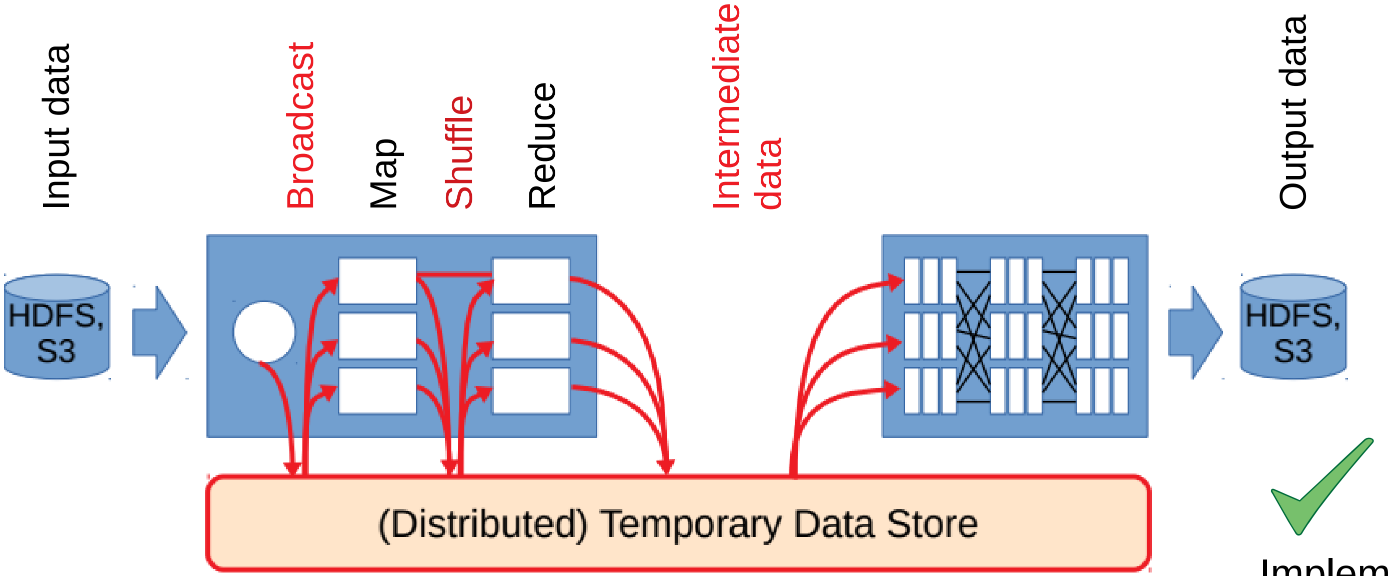
- Inefficient:
  - Difficult to leverage modern networking and storage hardware (e.g., 100 Gb/s Ethernet, NVMe Flash, etc.)
- Inflexible:
  - Temporary data management hard-wired with data processing framework
  - Difficult to change deployment (e.g., disaggregation, tiered storage, etc.)

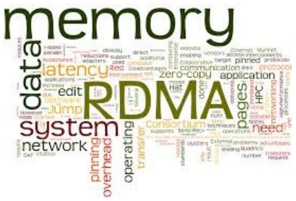
Instead of this...

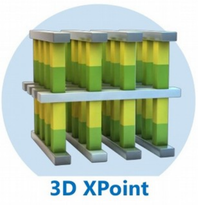


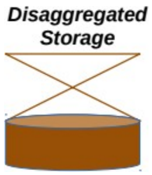
Can’t implement every operation for all the different hardware and deployment options

...better do this







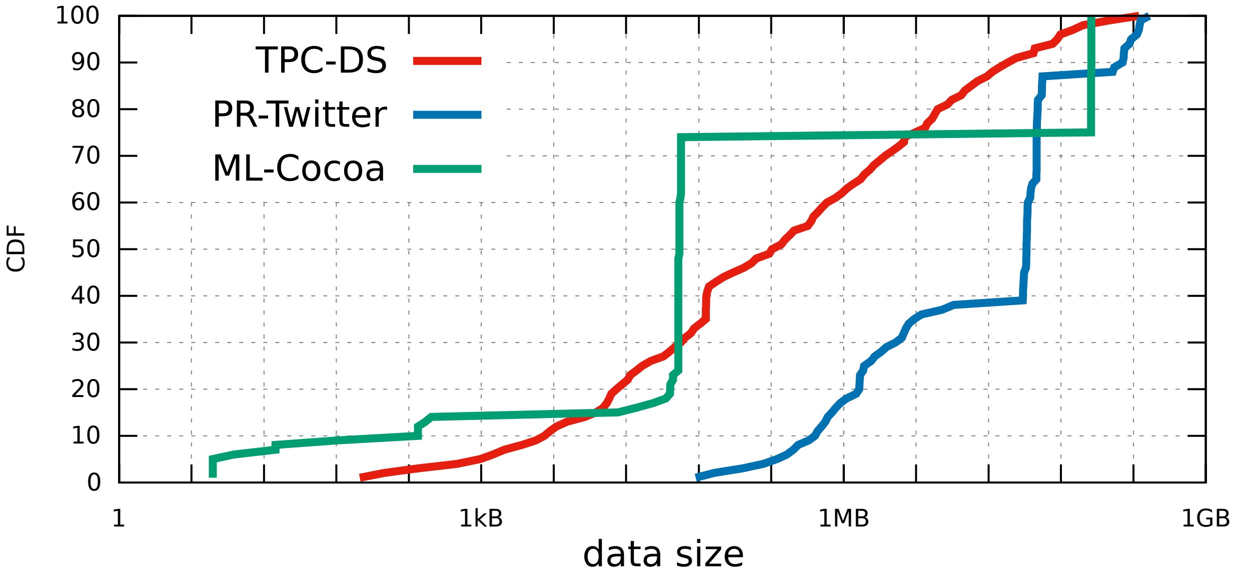


Implement hardware support once and support different operations and frameworks

How should the temporary data store look?

Can we use an existing storage platform, e.g., KV store, FS, etc.?

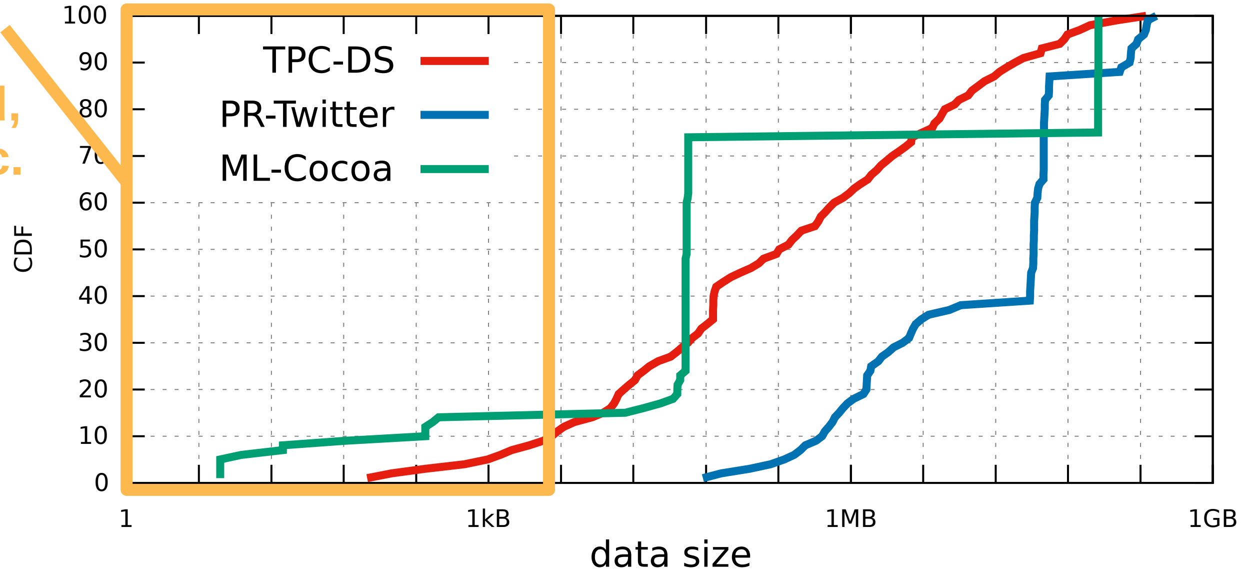
Temporary data distribution



Wide range of data sets (per task)

Temporary data distribution

KV-Store regime: RAMCloud, ccKVS, etc.



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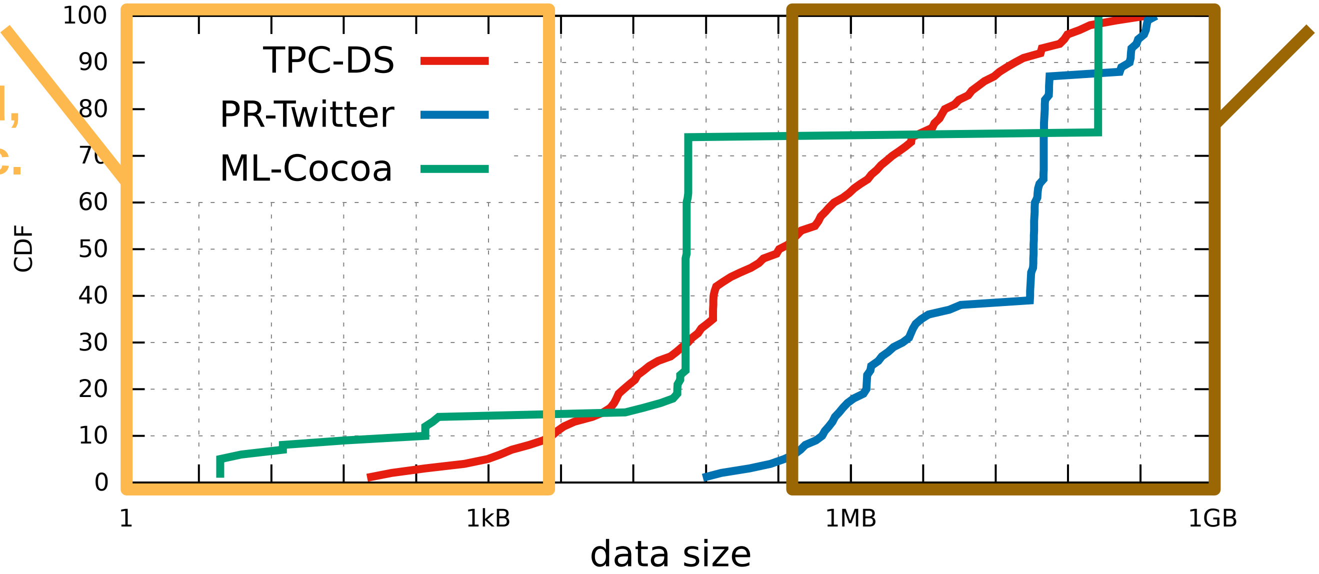

Filesystem regime: Octopus, Gassyfs, etc.

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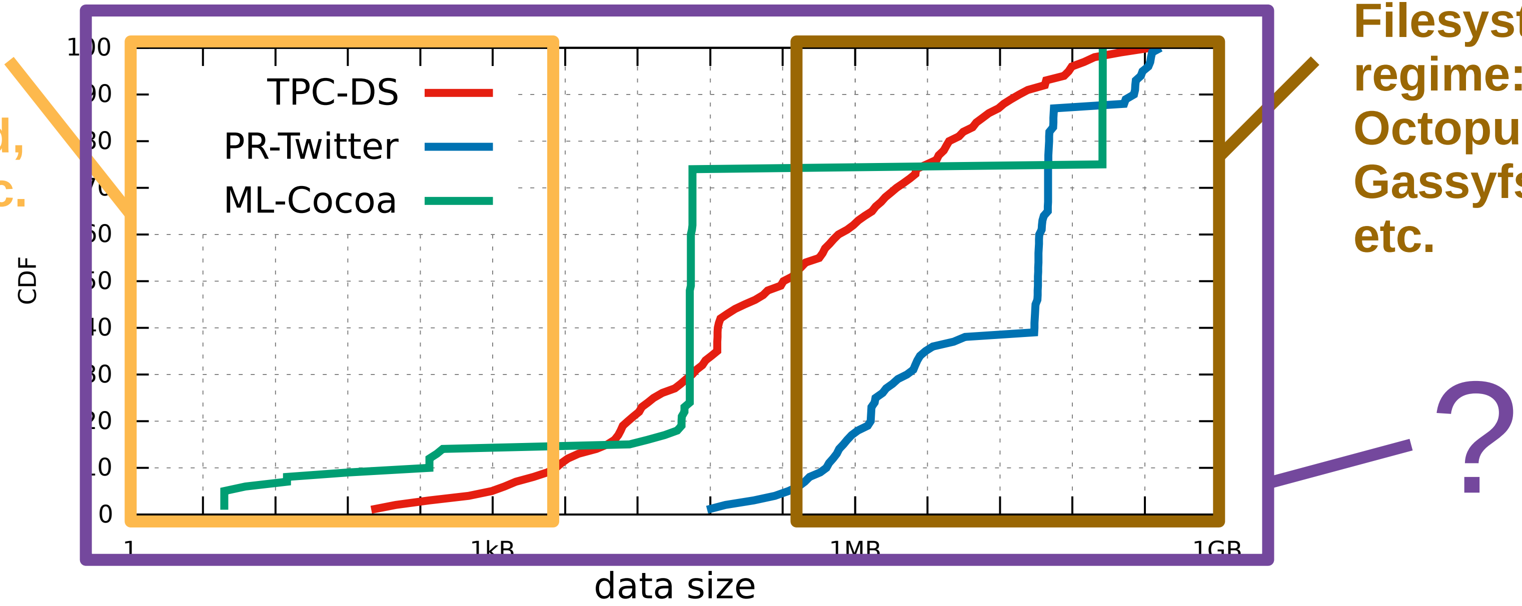

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Temporary Data Storage Requirements

- Perform well for wide range of data sizes
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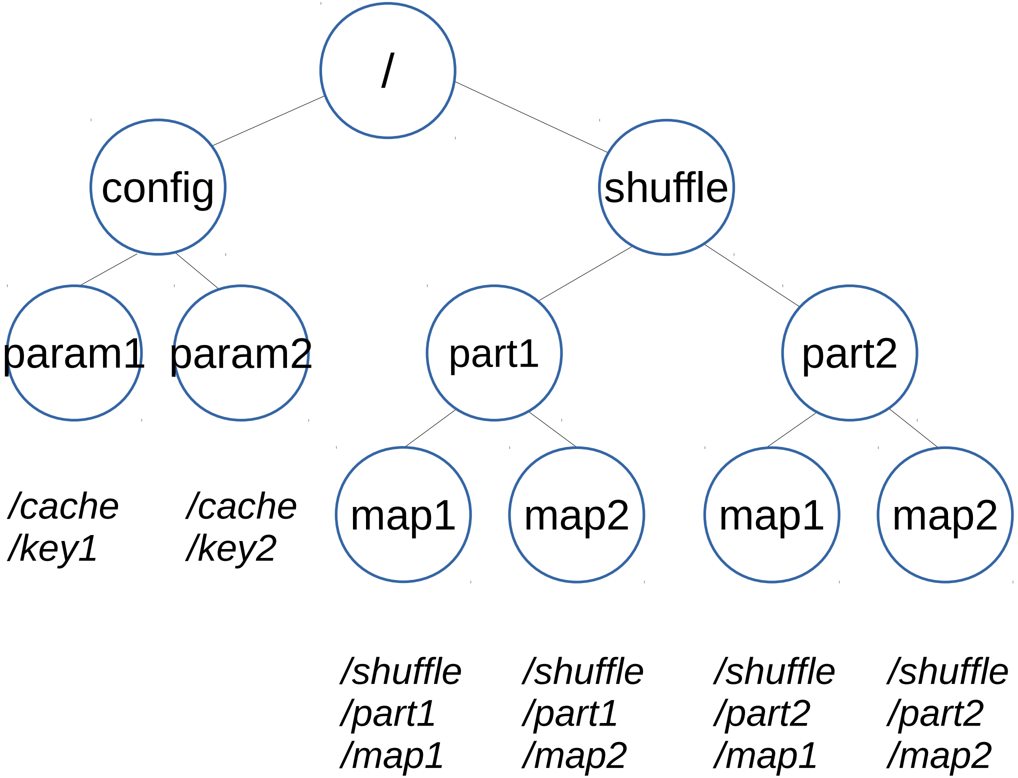
- Scalability
- Fault-tolerance, Durability
  - **Temporary data is short-lived, can we use coarse grained recovery?**

NodeKernel

- Distributed storage architecture for temporary data
- Fusion of filesystem and key-value semantics
- Designed for high-performance hardware

NodeKernel: Data Model



CreateNode()
LookupNode()
RemoveNode()
RenameNode()

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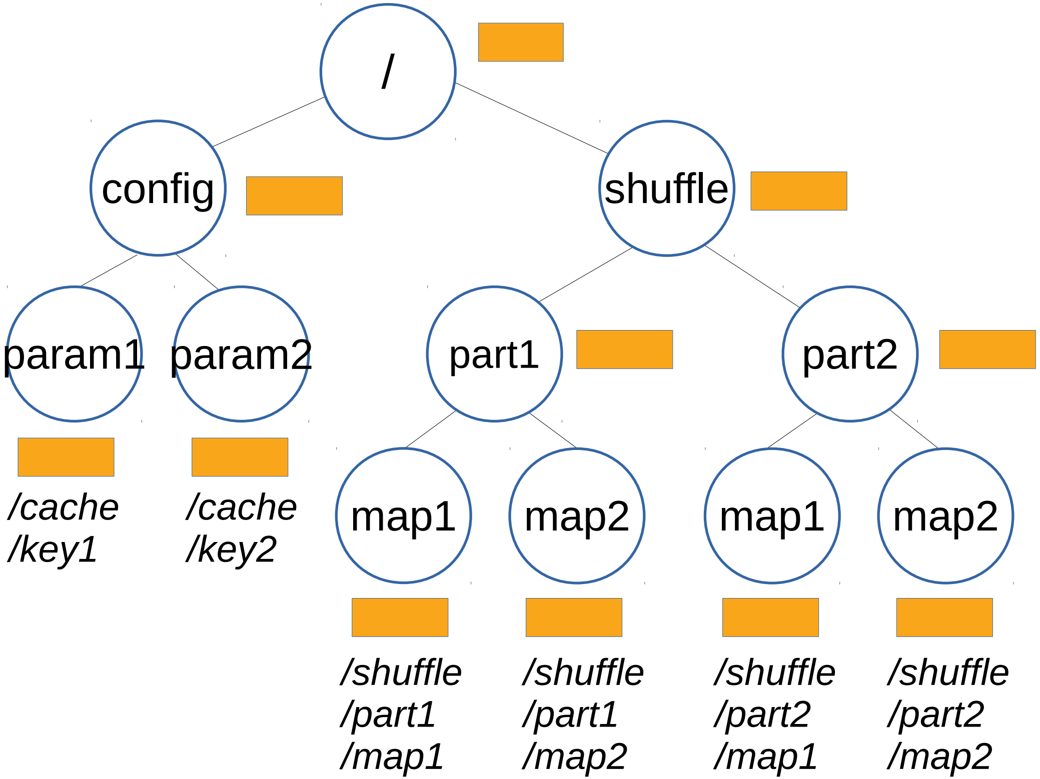
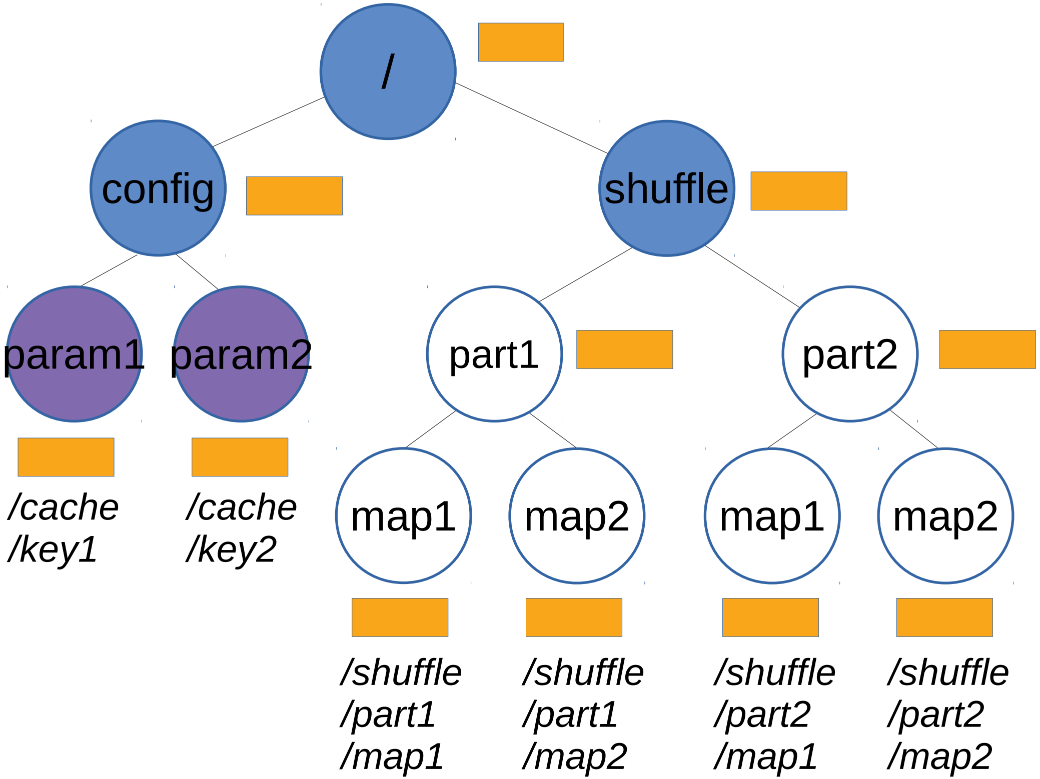


CreateNode()
LookupNode()
RemoveNode()
RenameNode()

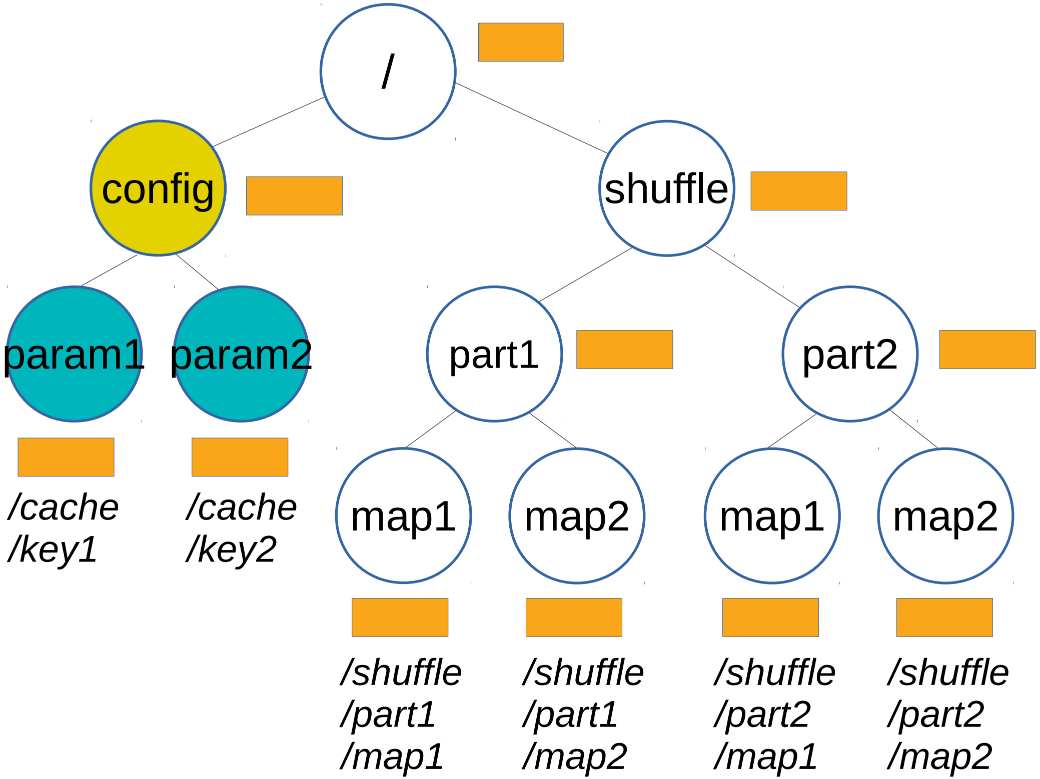
Node {
AppendData()
UpdateData()
ReadData()
}

NodeKernel: Node Types



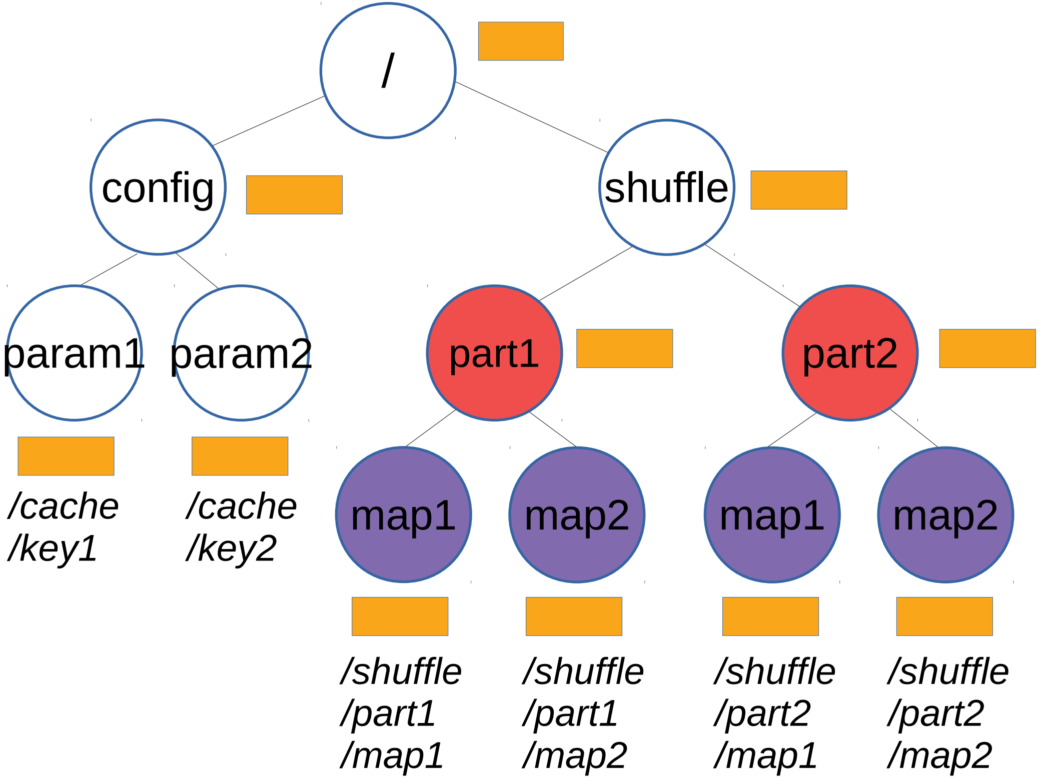
```
Directory : Node {
  Enumerate()
}
File : Node {
  Read()
  Append()
}
```

NodeKernel: Node Types



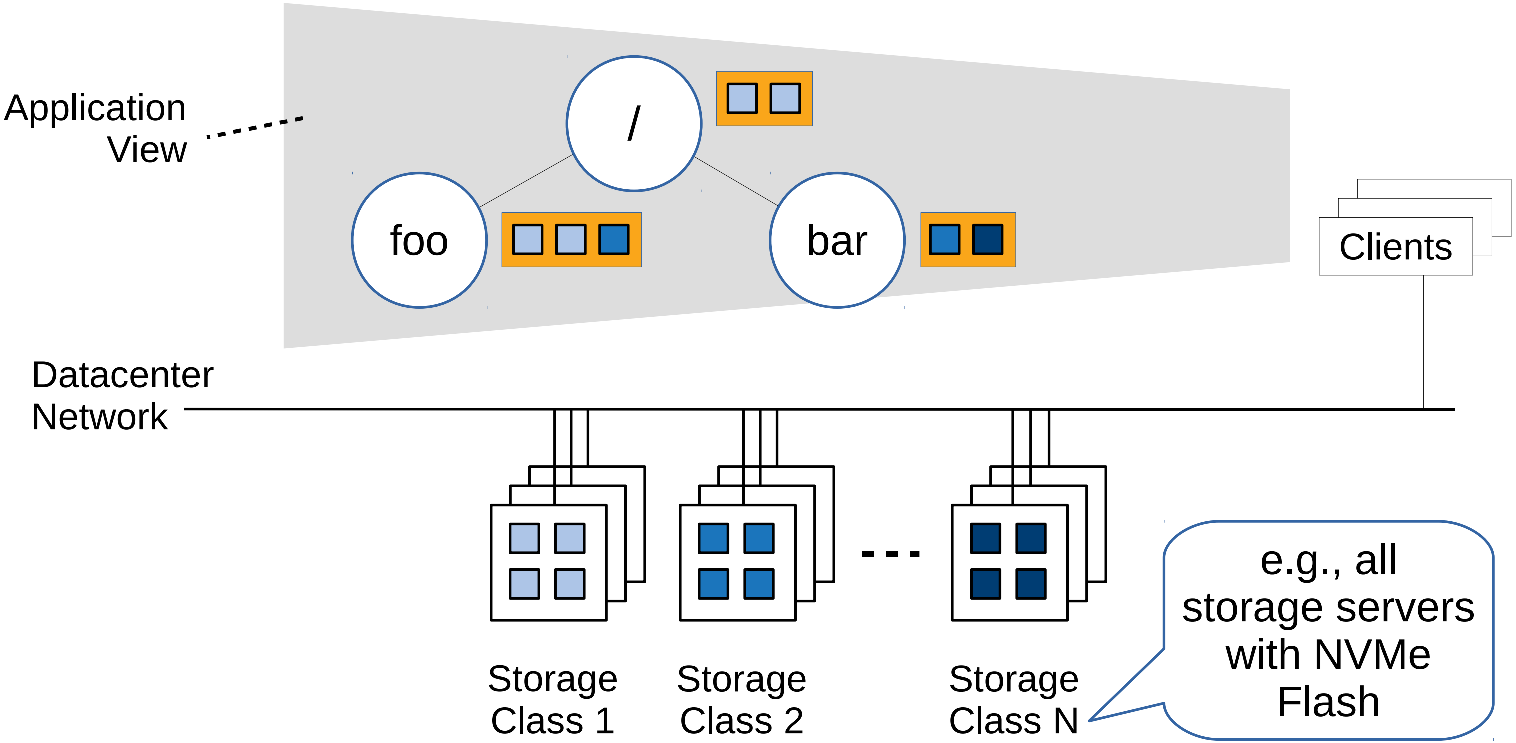
```
Table : Node {
  Put()
  Get()
}
KeyValue : Node {
  Append()
  Read();
}
```

NodeKernel: Node Types



```
Bag : Node {
  readSubtree()
}
File : Node {
  Read()
  Append()
}
```

NodeKernel: System Architecture



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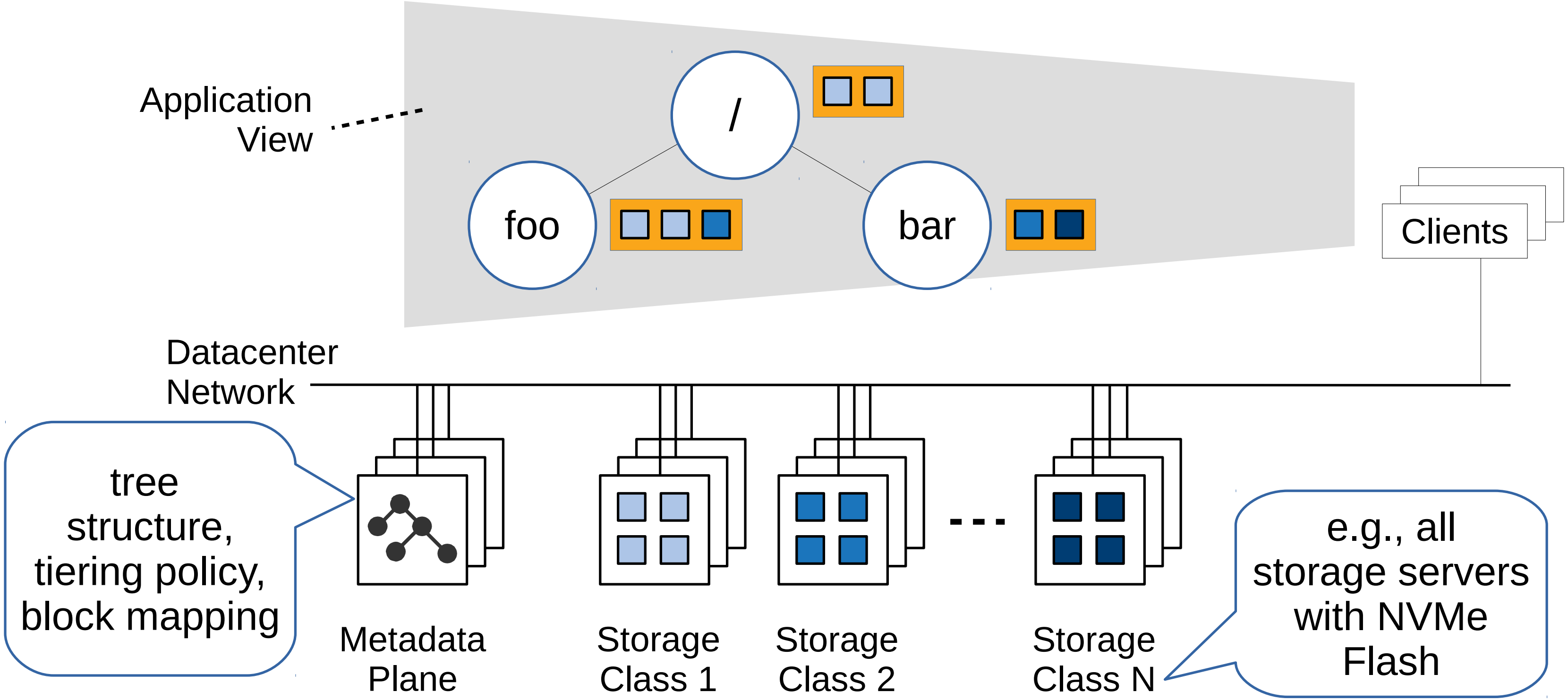

tree structure, tiering policy, block mapping

e.g., all storage servers with NVMe Flash

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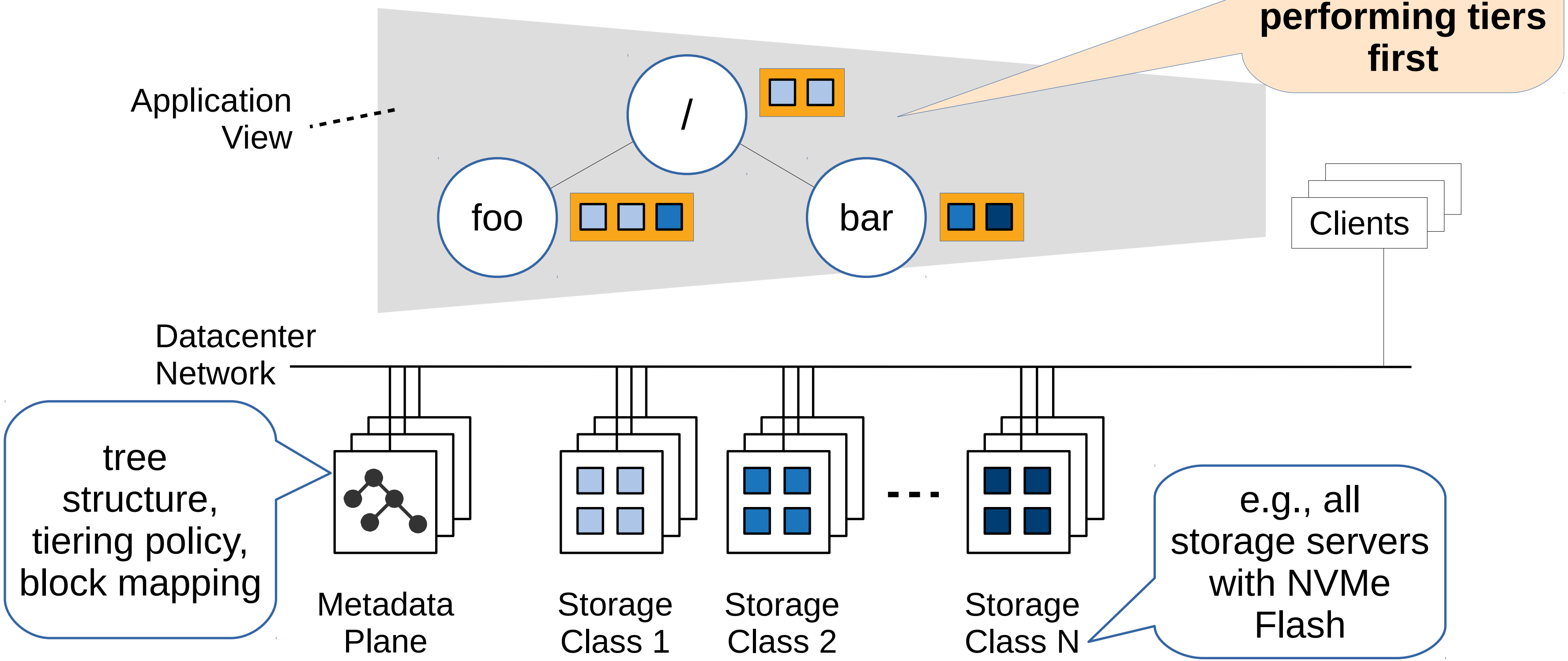

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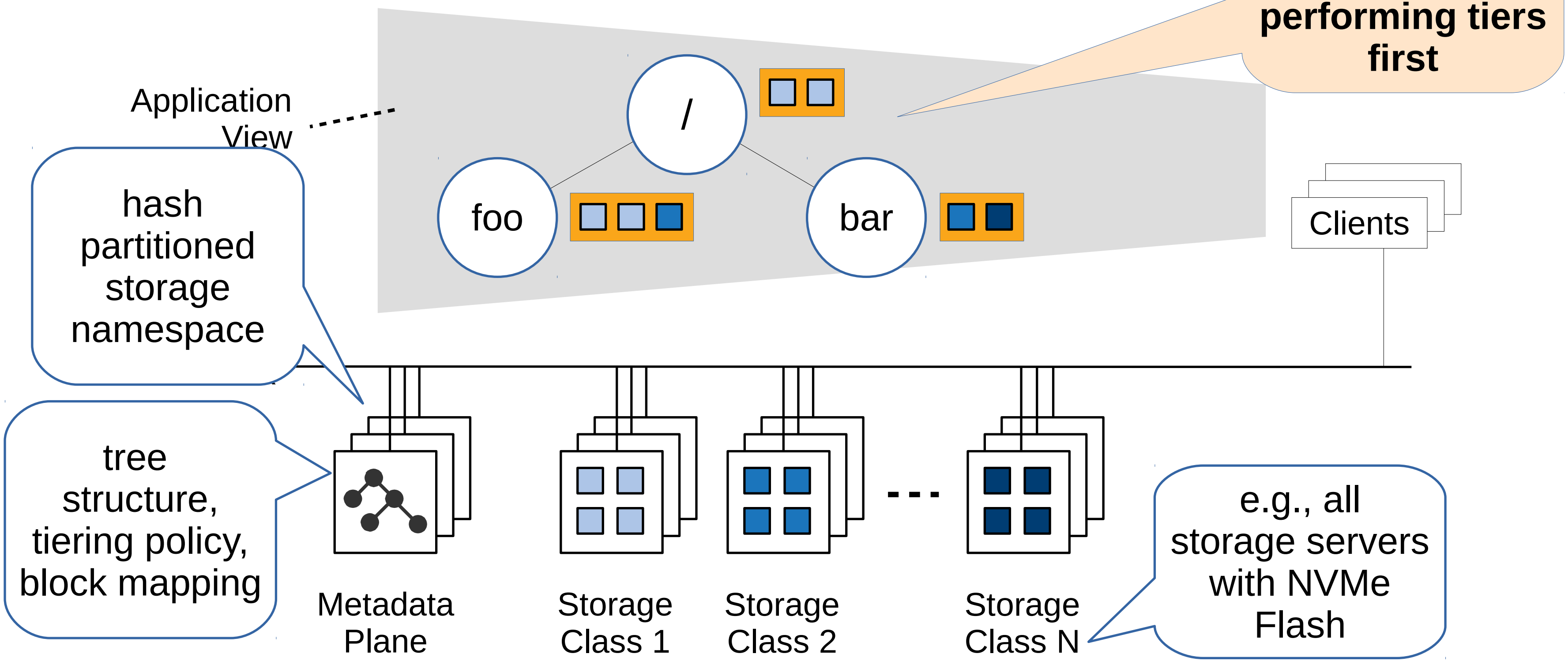

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hash partitioned storage namespace

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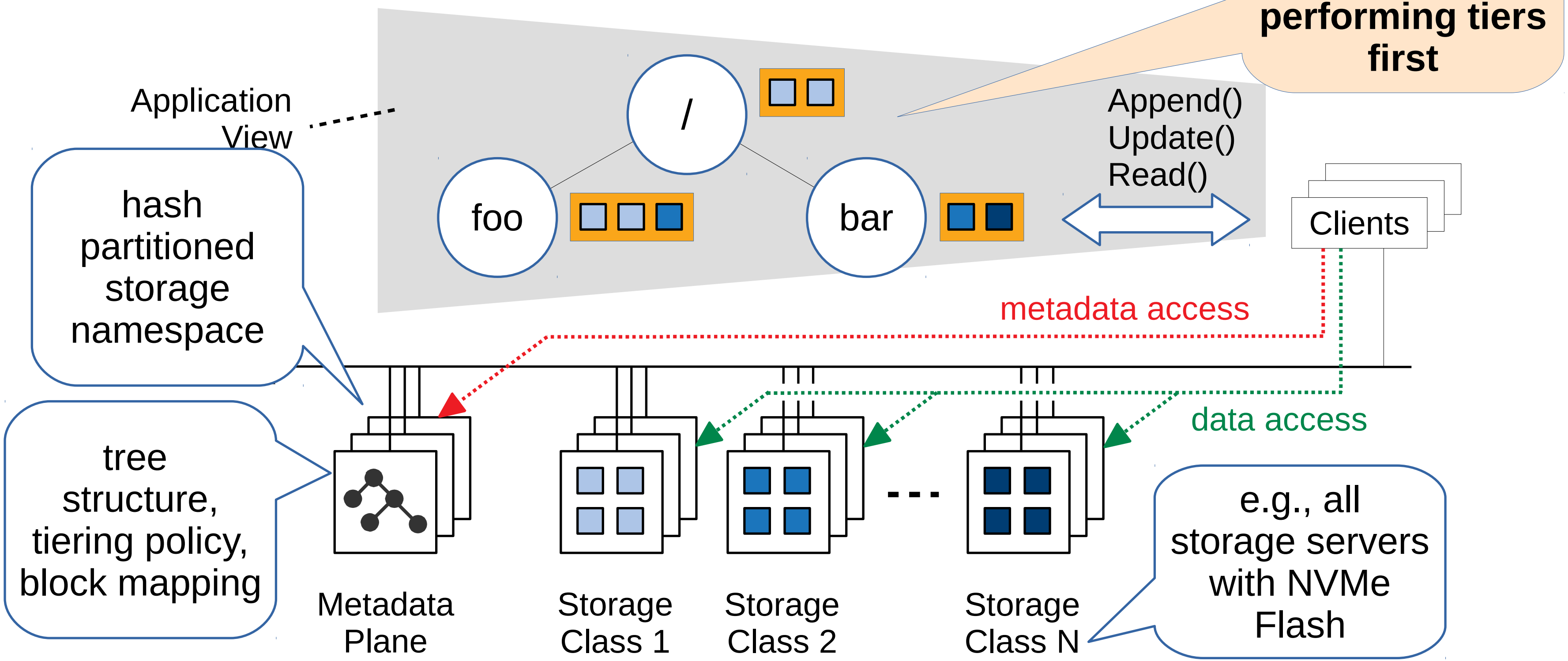

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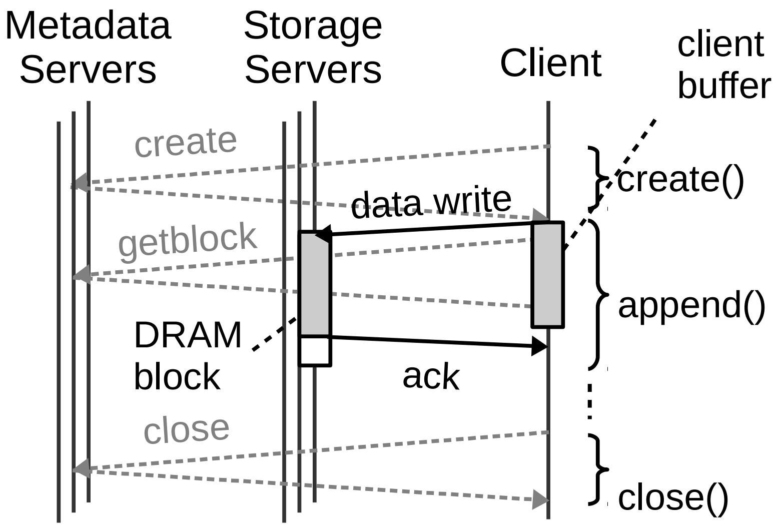
Example: KeyValue PUT



NodeKernel

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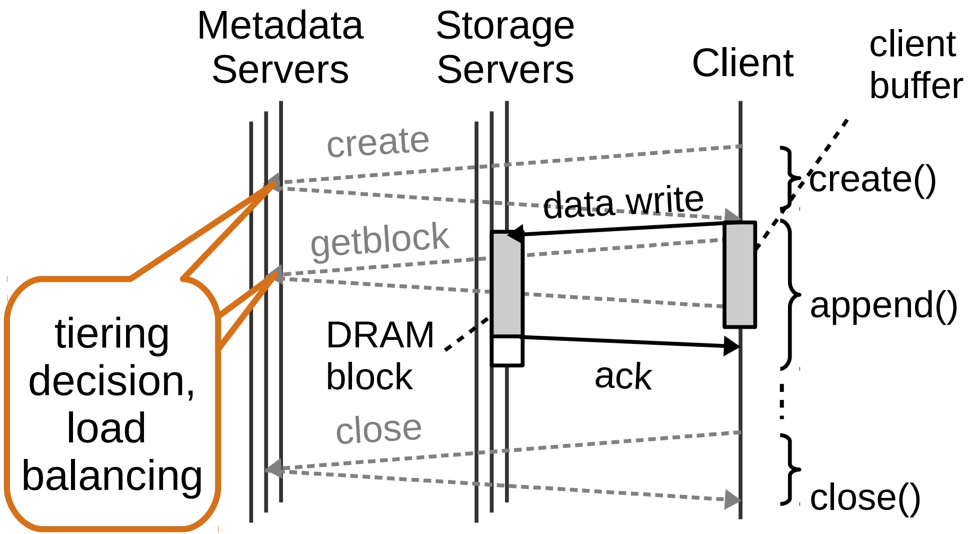
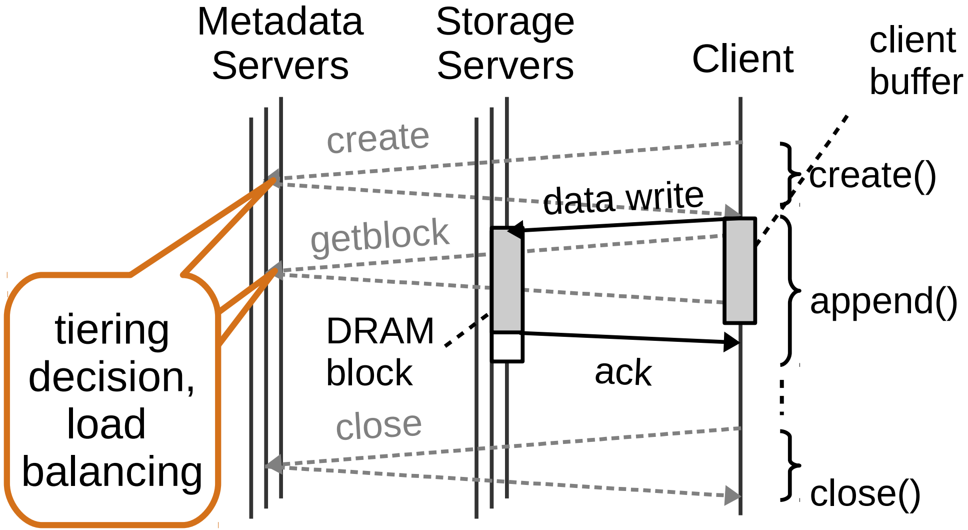


NodeKernel

Separating metadata from data adds **flexibility**

Example: KeyValue PUT



Metadata Servers

Storage Servers

Client

client buffer

create

data write

getblock

DRAM block

ack

close

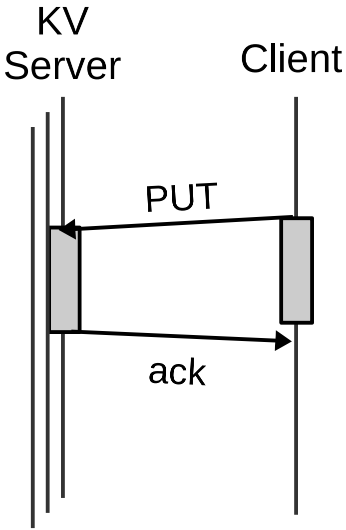
create()

append()

close()

tiering decision, load balancing

NodeKernel



KV Server

Client

PUT

ack

Traditional KVS

Separating metadata from data adds **flexibility**
but requires low-latency metadata operations

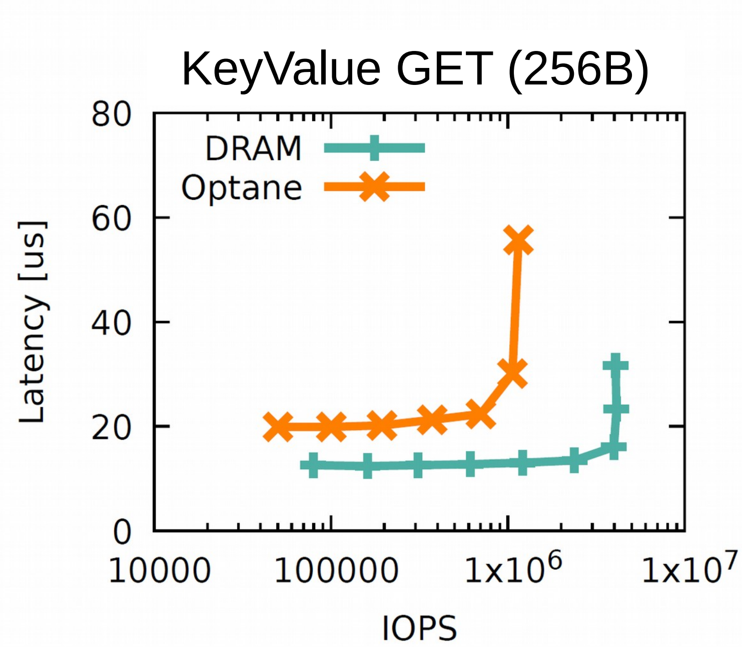
Apache Crail

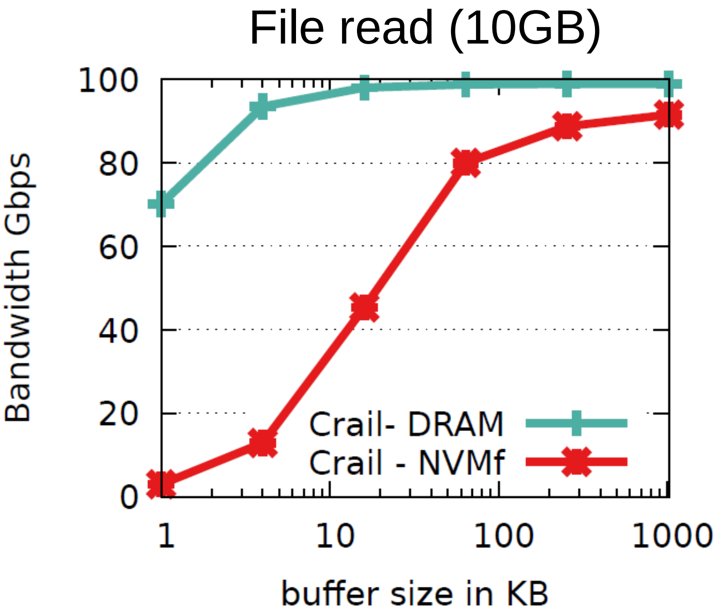
- **Implementation** of the NodeKernel architecture
- Low-latency RDMA-based RPC between client and metadata servers
- Two storage classes:
  - Flash accessed via NVM-over-Fabrics
  - DRAM accessed via RDMA
- Open source: crail.apache.org

Evaluation

- 16 node cluster, machine hardware:
  - 100 Gb/s RDMA RoCE
  - 256 GB DRAM
  - Intel Optane NVMe SSD
- Evaluation questions:
  - **Any size:** how well is Crail performing for different object sizes?
  - **Modern hardware:** are we able to accelerate workloads?
  - **Flexibility:** what benefits we get by decoupling data processing and temporary data storage?
  - **Abstractions:** Are KeyValue, File and Bag abstractions helpful?

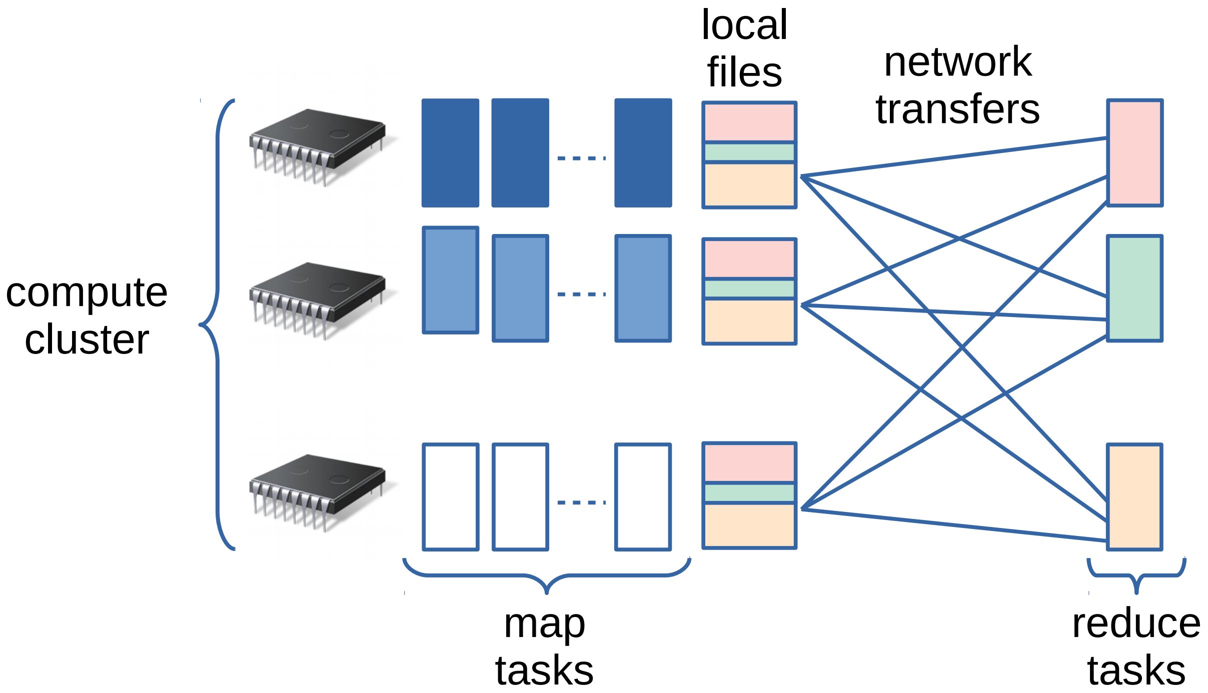
Small and Large Data Sets





Crail serves small and large data sets close to the hardware limit
(latency RDMA: 3us, latency Optane 15us, bandwidth RDMA: 100 Gb/s)

Spark Shuffle



compute cluster

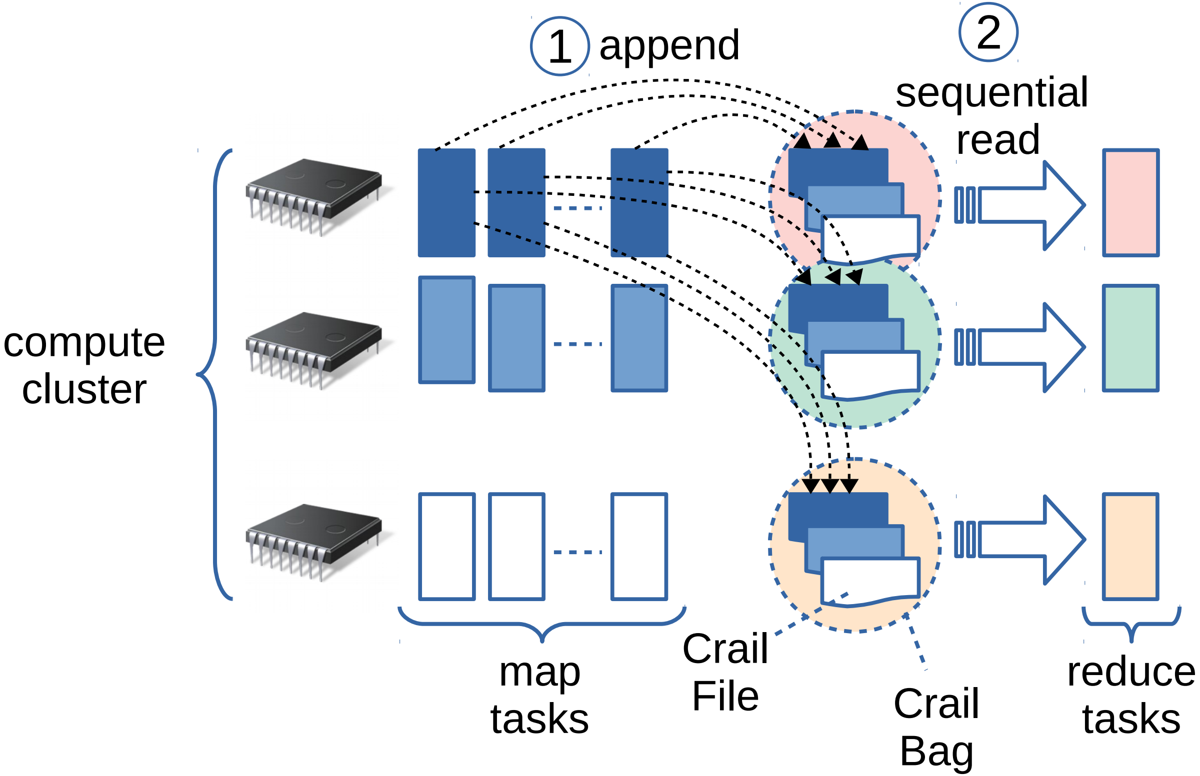
map tasks

local files

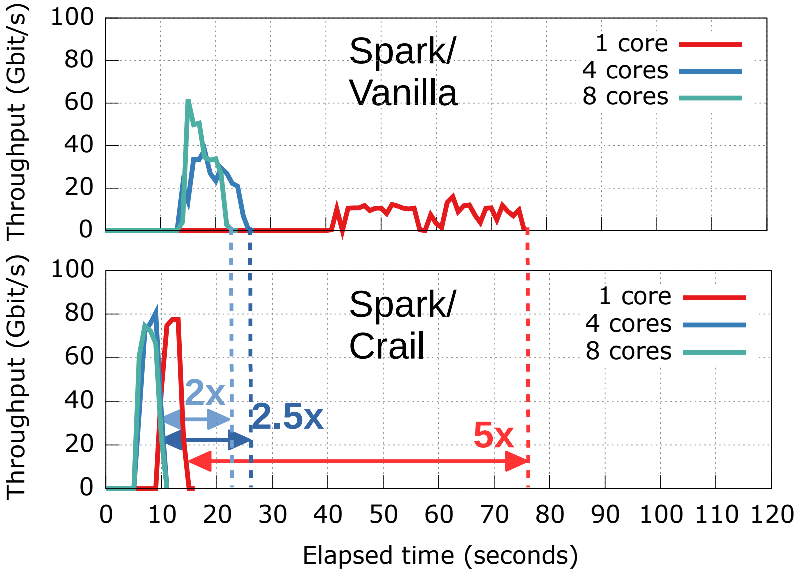
network transfers

reduce tasks

Spark Shuffle using Crail::Bag

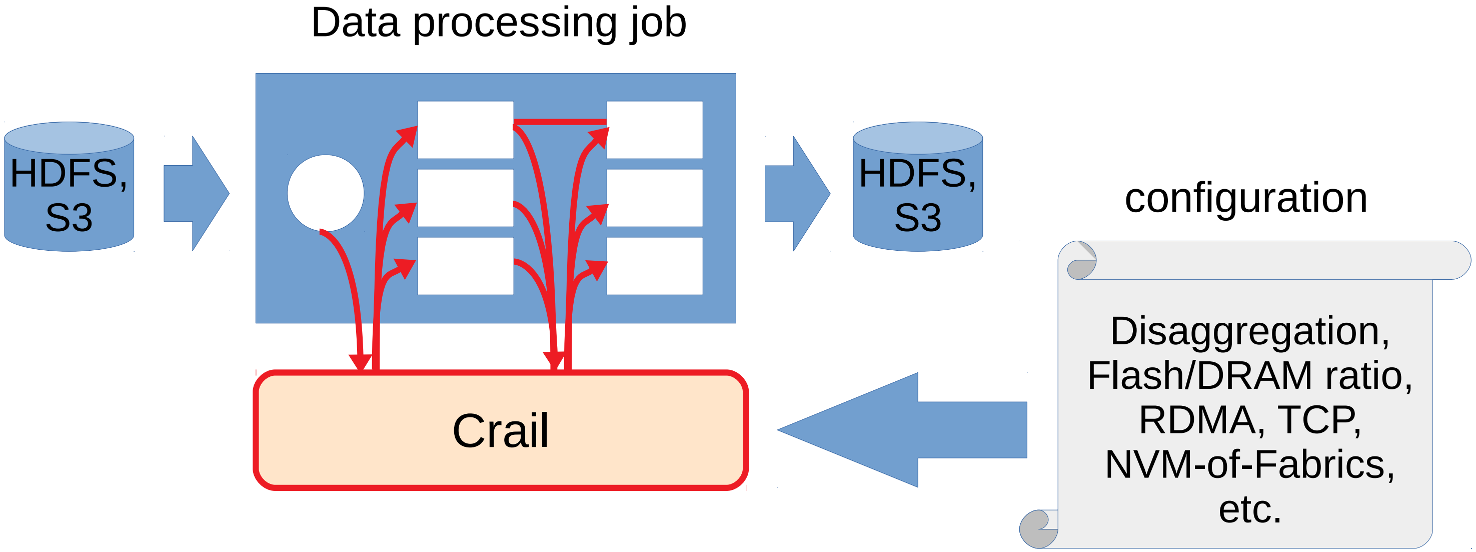


Spark GroupBy (80M keys, 4K)



Spark shuffling via Crail on a single core is 2x faster
than vanilla Spark on 8 cores per executor (8 executors)

Flexible Deployment



Data processing job

HDFS,
S3

HDFS,
S3

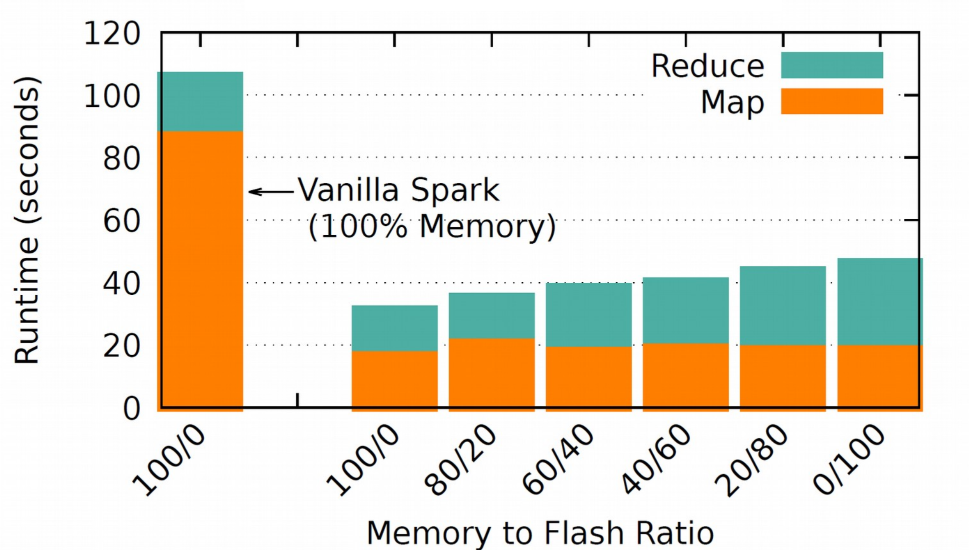
Crail

configuration

Disaggregation,
Flash/DRAM ratio,
RDMA, TCP,
NVM-of-Fabrics,
etc.

DRAM / Flash Ratio

200GB Sorting



Flexible deployment: Crail permits trading performance for cost

Conclusions

- Sharing temporary efficiently in data processing workloads is challenging
  - Inefficient in deployments with modern hardware
  - Inflexible: difficult to use storage tiering, disaggregation, etc.
- NodeKernel: distributed storage architecture for temporary data storage
  - Fusion of Filesystem and Key-Value semantics in single storage namespace
- Apache Crail: Implementation of NodeKernel for RDMA and NVMf
  - Accelerates temporary data storage on modern hardware
  - Enable flexible deployment: storage tiering, disaggregation, etc.

Open Source

- Crail:

  https://github.com/apache/incubator-crail
- Crail shuffler:

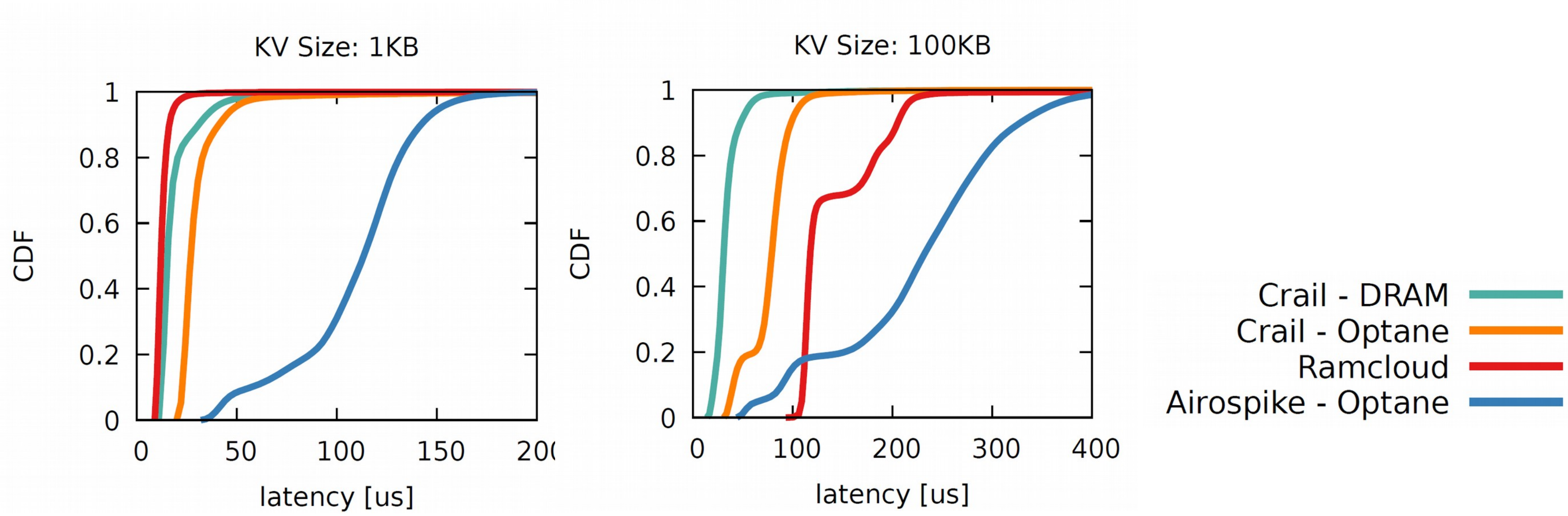
  https://github.com/zrlio/crail-spark-io
- YCSB benchmark:

  https://github.com/brianfrankcooper/YCSB

  (includes Crail)

Backup

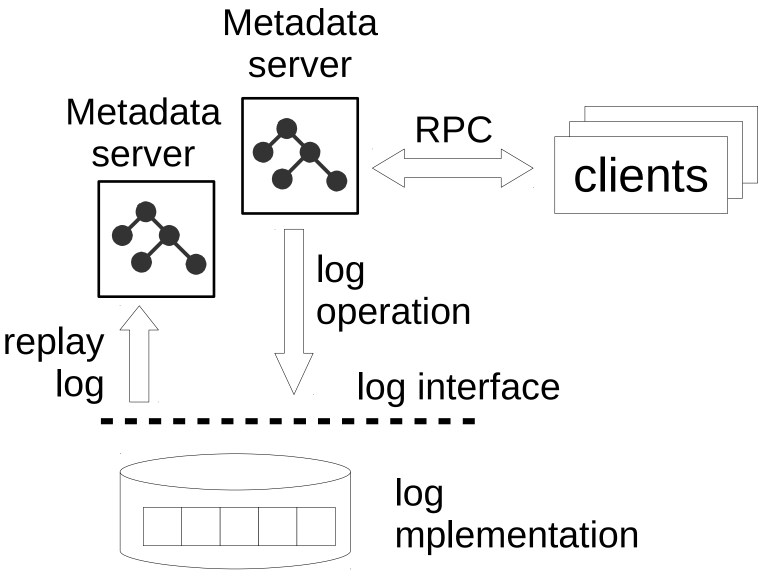
YCSB Benchmark: GET Latency



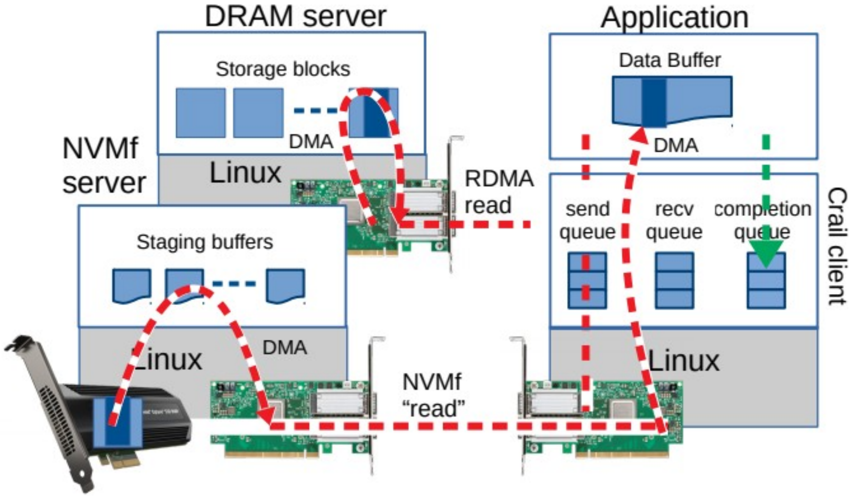
1KB KV pairs: ~12us (DRAM) and 30us (NVMe)
100KB KV pairs: ~30us (DRAM) and 40us (NVMe)

Persistence & Fault Tolerance

- Data plane
  - No replication
  - Graceful handling of faulty or crashed storage servers (signaled at client during read/write ops)
- Meta data plane
  - Persist metadata state using operation logging
  - Shutdown and replay log to re-create state
- Pluggable log device
  - Current log is on local FS
  - Could be a distributed log: maintain a hot standby metadata server



Crail Data Plane



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Future<Node> fut = crail.create("/a.dat", CrailType.File);
//...do work
CrailFile file = fut.get().asFile();
CrailOutputStream stream = file.getDirectOutputStream();
ByteBuffer buffer = crail.allocateBuffer();
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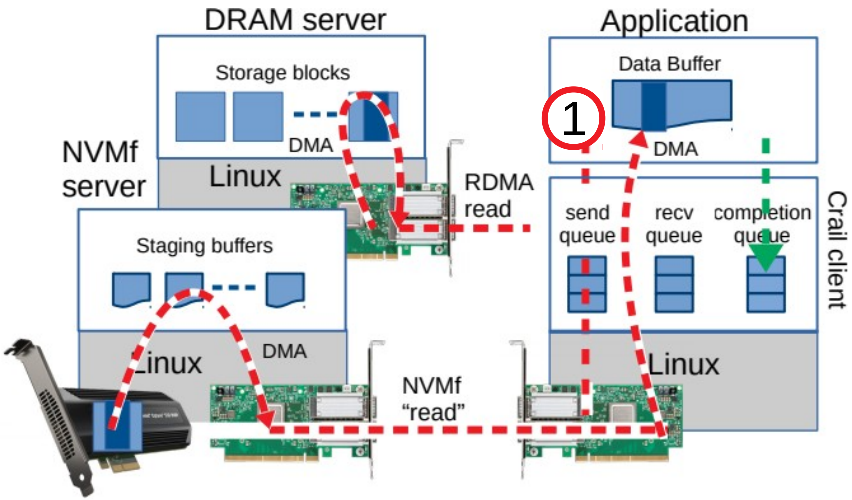

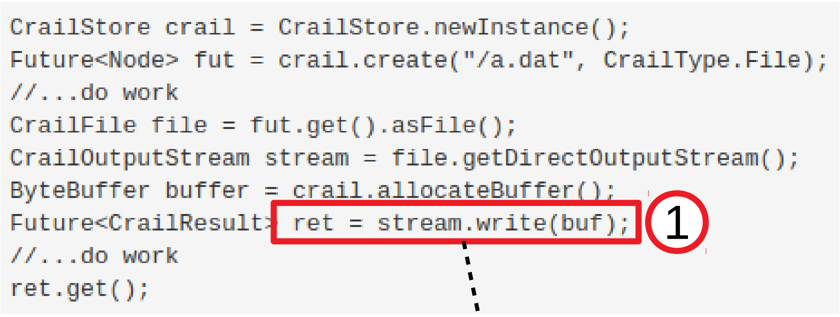

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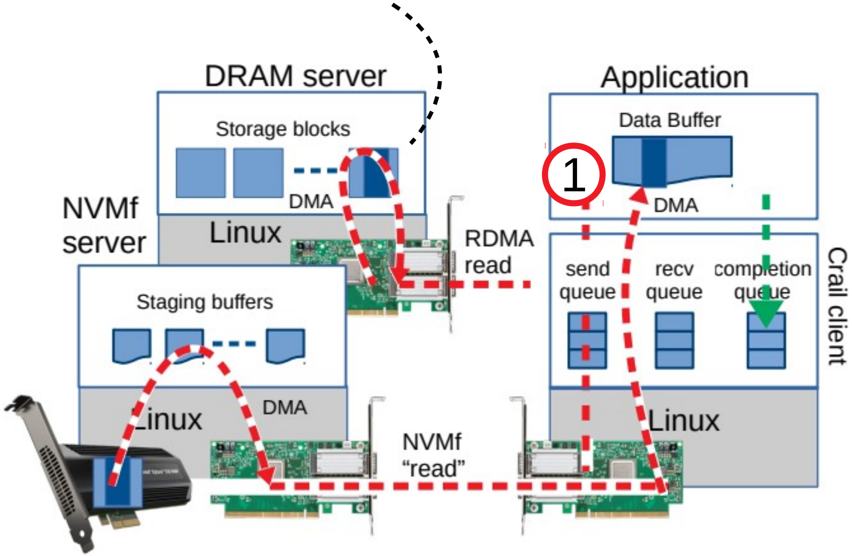
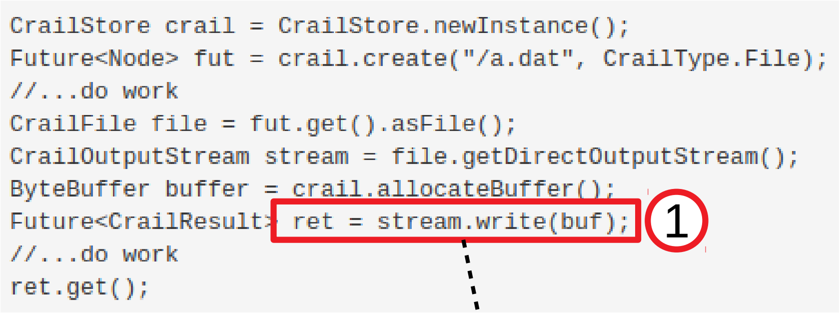
asynchronous API

Crail Data Plane

zero copy
data movement





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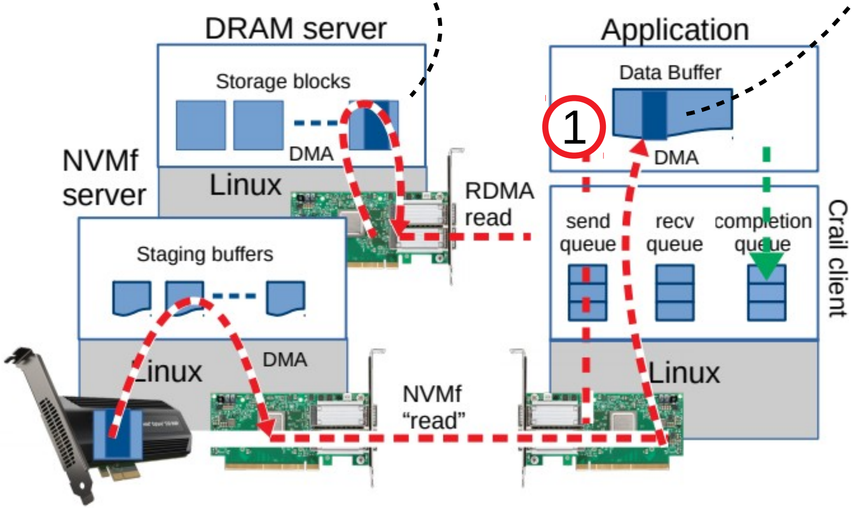
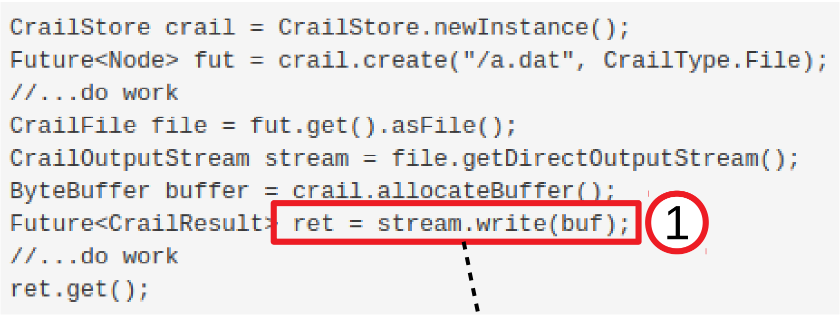


direct
data placement



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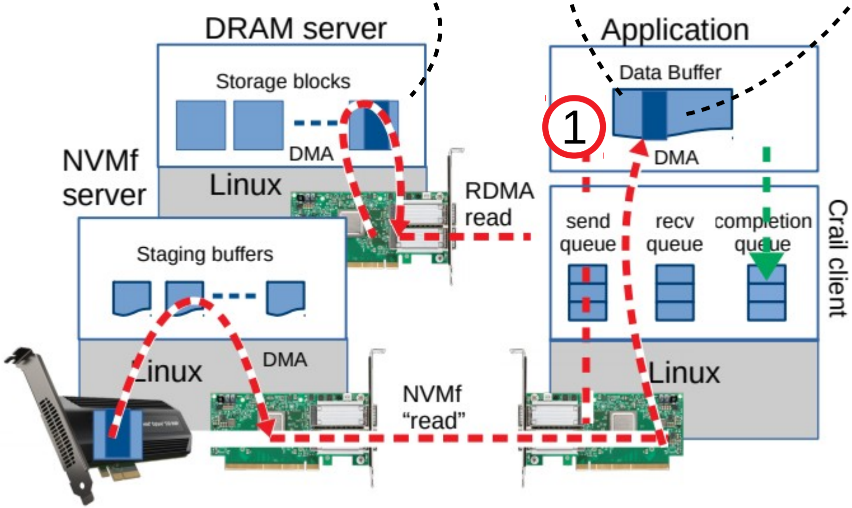
asynchronous
API

Crail Data Plane

zero copy
data movement

transfer only
data requested

direct
data placement



```
CrailStore crail = CrailStore.newInstance();
Future<Node> fut = crail.create("/a.dat", CrailType.File);
//...do work
CrailFile file = fut.get().asFile();
CrailOutputStream stream = file.getDirectOutputStream();
ByteBuffer buffer = crail.allocateBuffer();
Future<CrailResult> ret = stream.write(buf); ①
//...do work
ret.get();
```

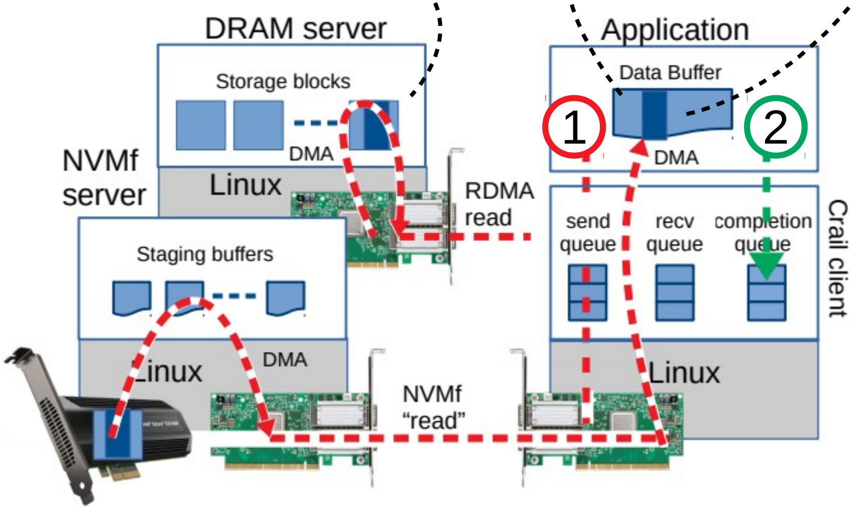
asynchronous
API

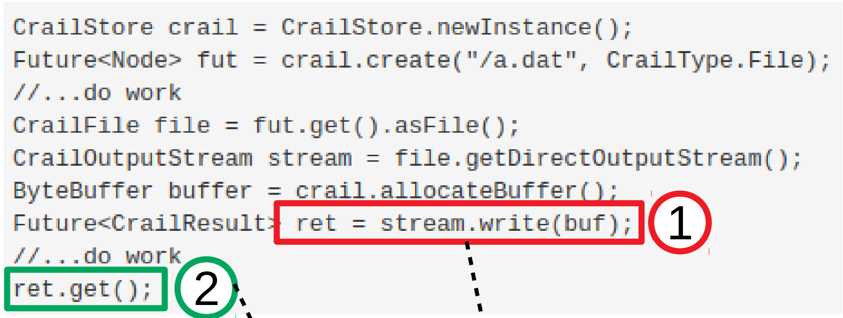
Crail Data Plane

zero copy
data movement

transfer only
data requested

direct
data placement





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①
②

synchronous
call

asynchronous
API