Accelerating Complex Data Transfer for Cluster Computing

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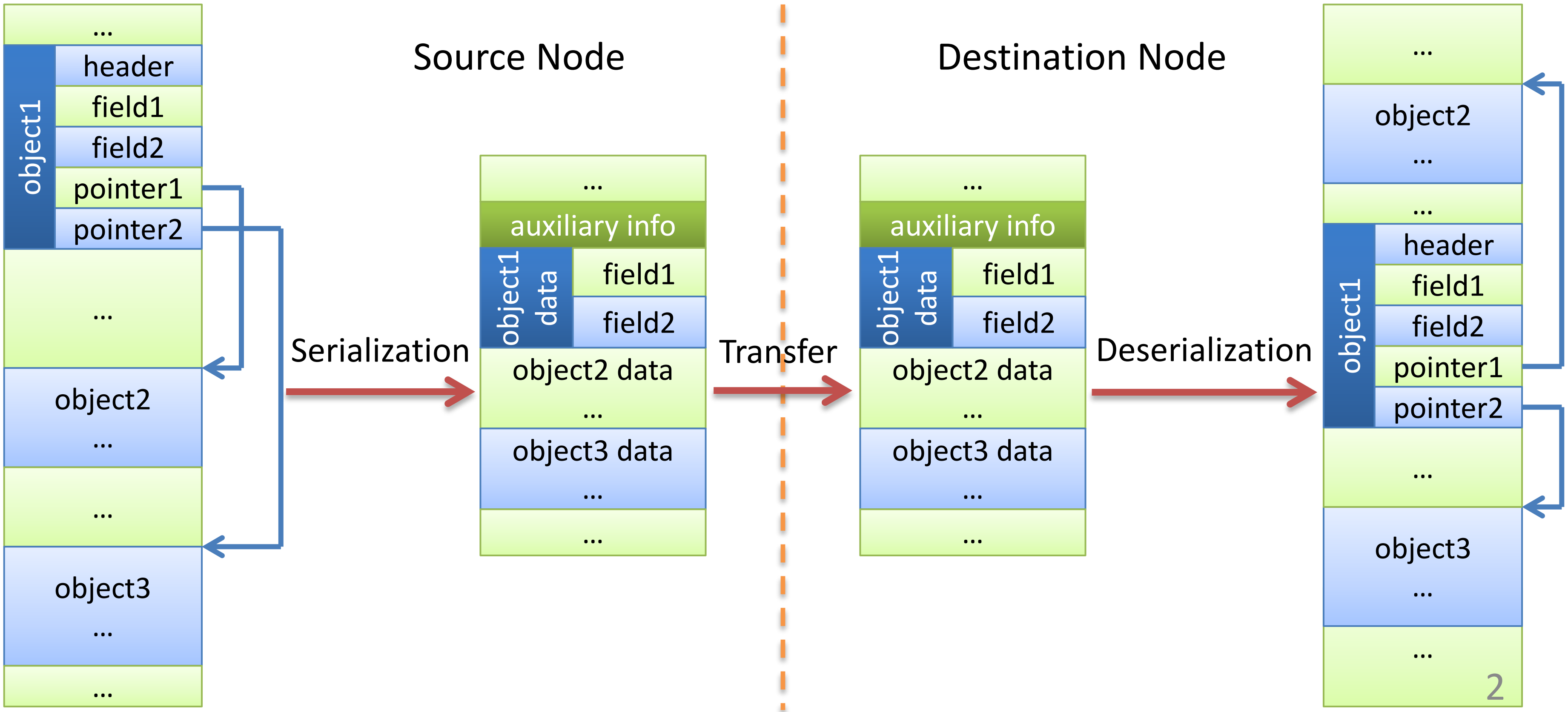
Motivation

- Data processing is now CPU-bound
- Software layers can’t leverage fast datacenter networks
  - network responsible for as low as 2% of overall performance

    [Ousterhout, K. et al., “Making sense of performance in data analytics frameworks”, NSDI’15]
- Data [de]serialization is one of the bottlenecks
  - up to 26% of total CPU time

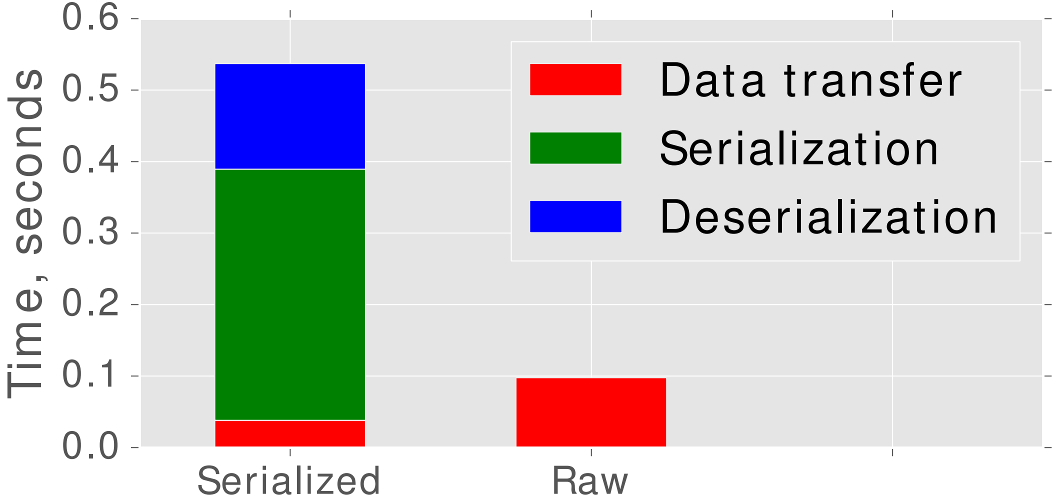
    [Trivedi, A. et al., “On the [ir]relevance of network performance for data processing”, HotCloud’16]
  - prevents from fully leveraging RDMA

Serialized data transfer



Transfer time breakdown: complex data

TreeMap; size: 64 MB raw, 24 MB serialized; 10 Gbit/s



80% overhead
(for 100 Gbit/s – 97%)

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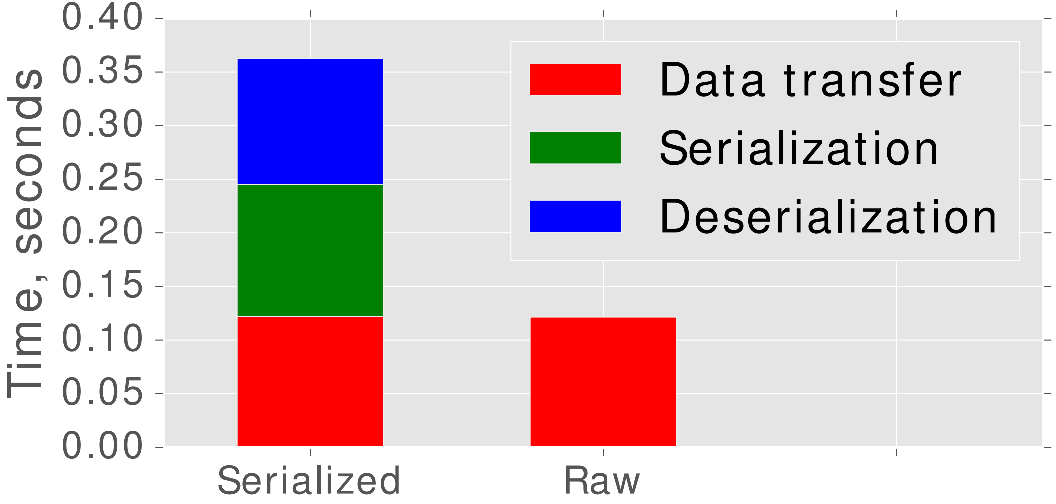
Transfer time breakdown: simple data

double[]; size: 80 MB; 10 Gbit/s

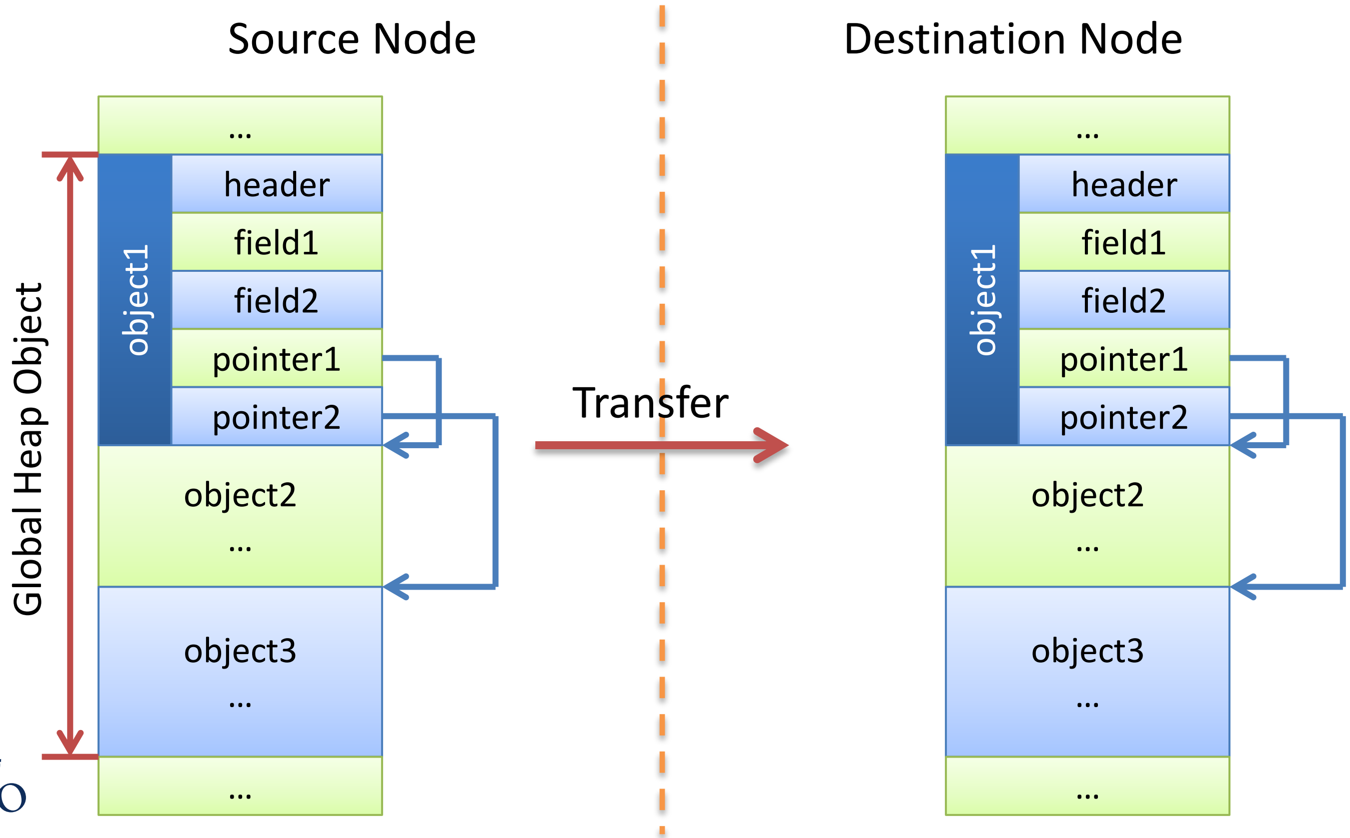


65% overhead

Eliminating data [de]serialization

- Reason: pointer-based data structures become invalid when copied directly to another address space
  - other reasons (e.g. different endianness) are irrelevant: assume that all nodes have the same architecture
- General idea: shared cluster-wide virtual address space
- Compact allocation of objects to be copied together
  - continuous regions copied in a single operation – RDMA-friendly

Compact object format and Direct transfer



Cluster-wide shared address space

- Virtual address space is huge -> can be shared
  - 128 TB (2^{47}), potentially 2^{63} bytes
- Limited version of DSM (distributed shared memory)

- DSM original goal: trade off performance for transparency / ease of programming
- We use DSM to *improve* performance (but increase programming complexity)

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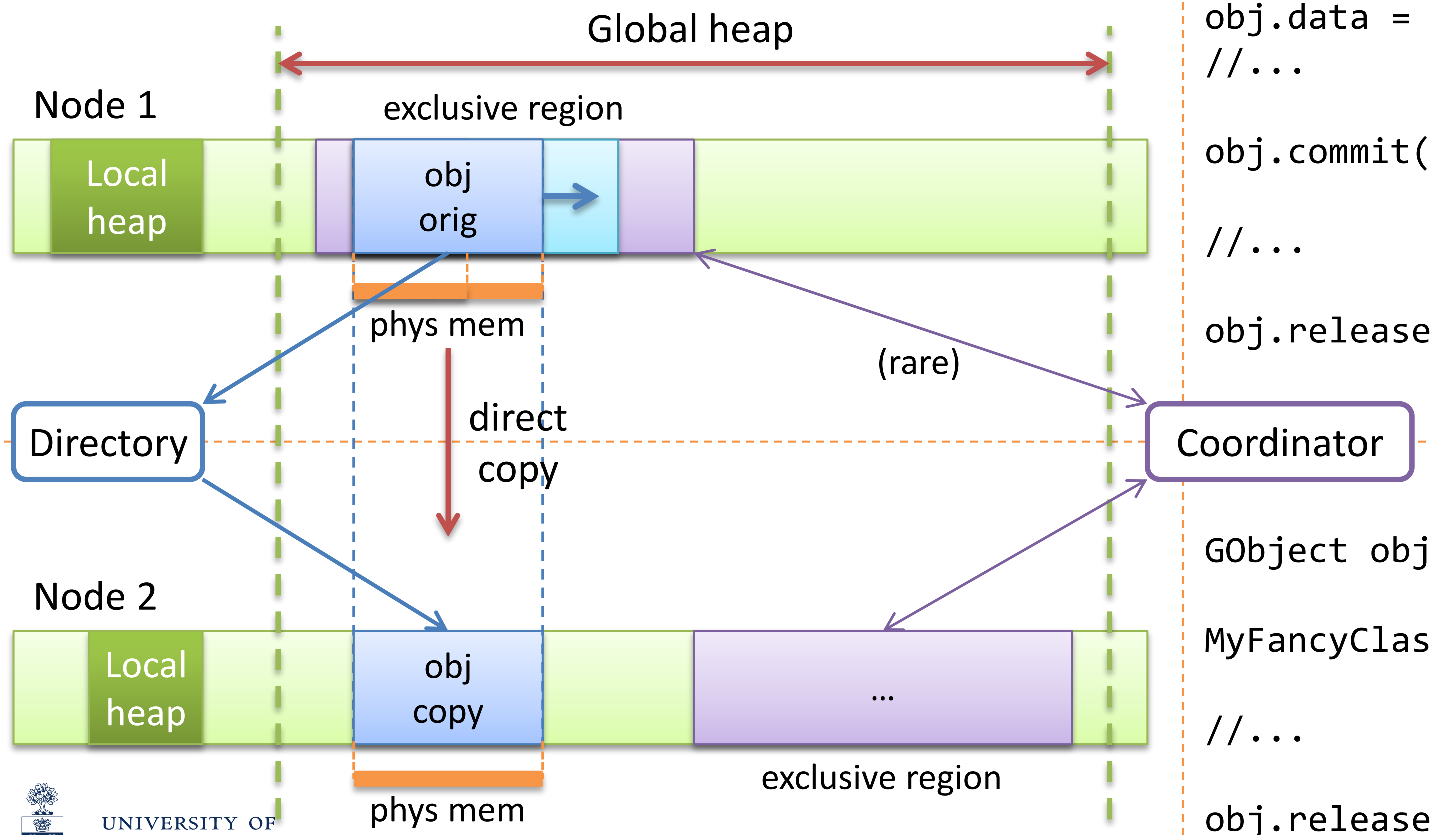
Assumptions

- Immutable shared objects
  - – modifications of the original are not propagated
  - – not very restrictive: e.g. immutable RDDs in Spark

- No need to be completely transparent to programmer
  - – explicit management of global objects
  - – possible to hide most of the details inside the framework

Architecture



```
GObject obj = new GObject(...);

obj.data = new MyFancyClass(...);
//...

obj.commit("key");

//...

obj.release();
```

```
GObject obj = GHeap.get("key");

MyFancyClass data = obj.data;

//...

obj.release();
```

Global heap architecture

- Huge *virtual* address space region; the same on all nodes
- Partitioning: nodes allocate objects in own exclusive regions
  - minimal amount of coordination required
- Mapping to physical memory on demand
- Objects identified by keys mapped to <node, vaddr>
- 3-stage object creation: (1) reserve space; (2) populate with data; (3) commit (make available to other nodes)
- Explicit release of objects

JVM-based implementation

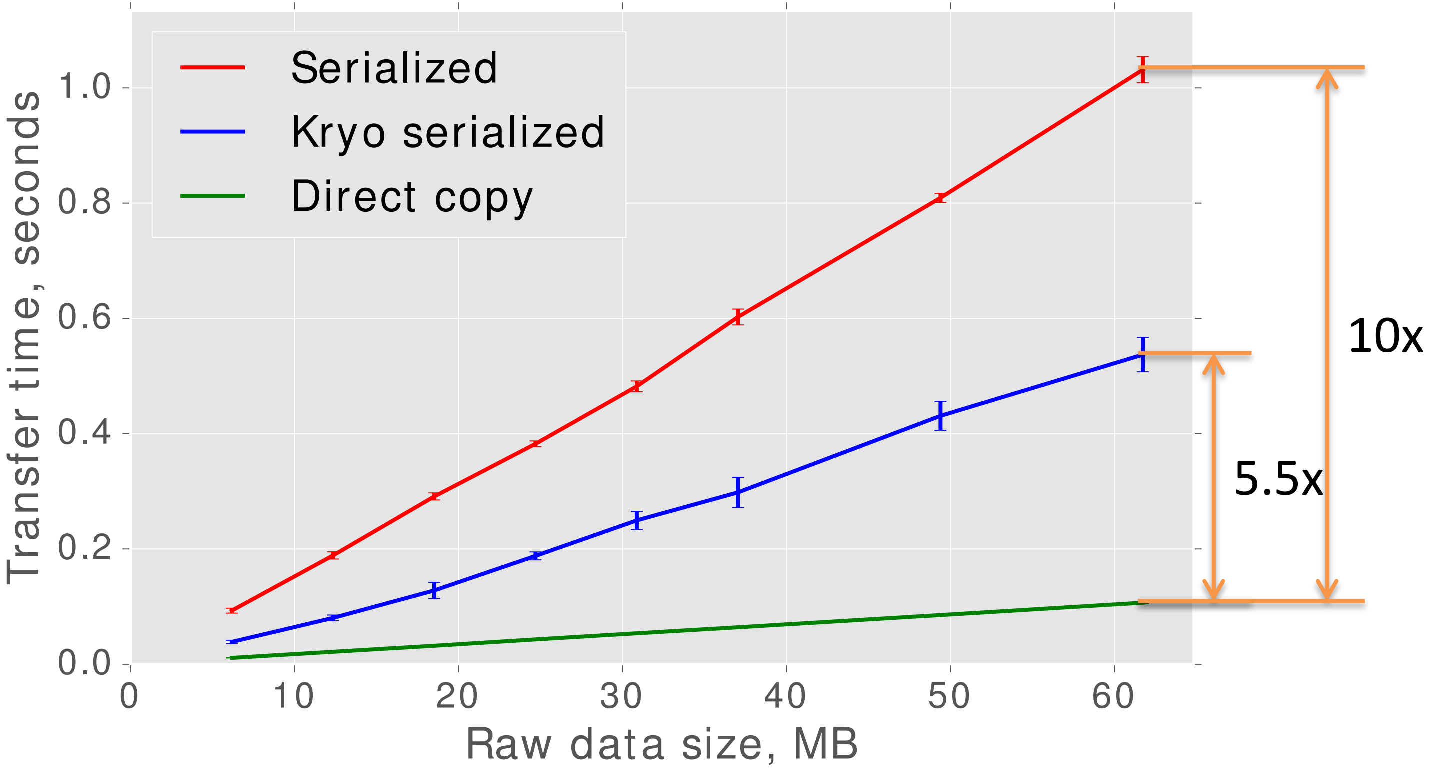
- Prototype based on JamVM
  - HotSpot ("standard" JVM) – in progress
- Most of functionality implemented in native methods
- Still need some JVM modifications
  - memory allocator / garbage collector
  - object header format
  - bytecode interpreter / JIT compiler
- Details: in the paper

Evaluation

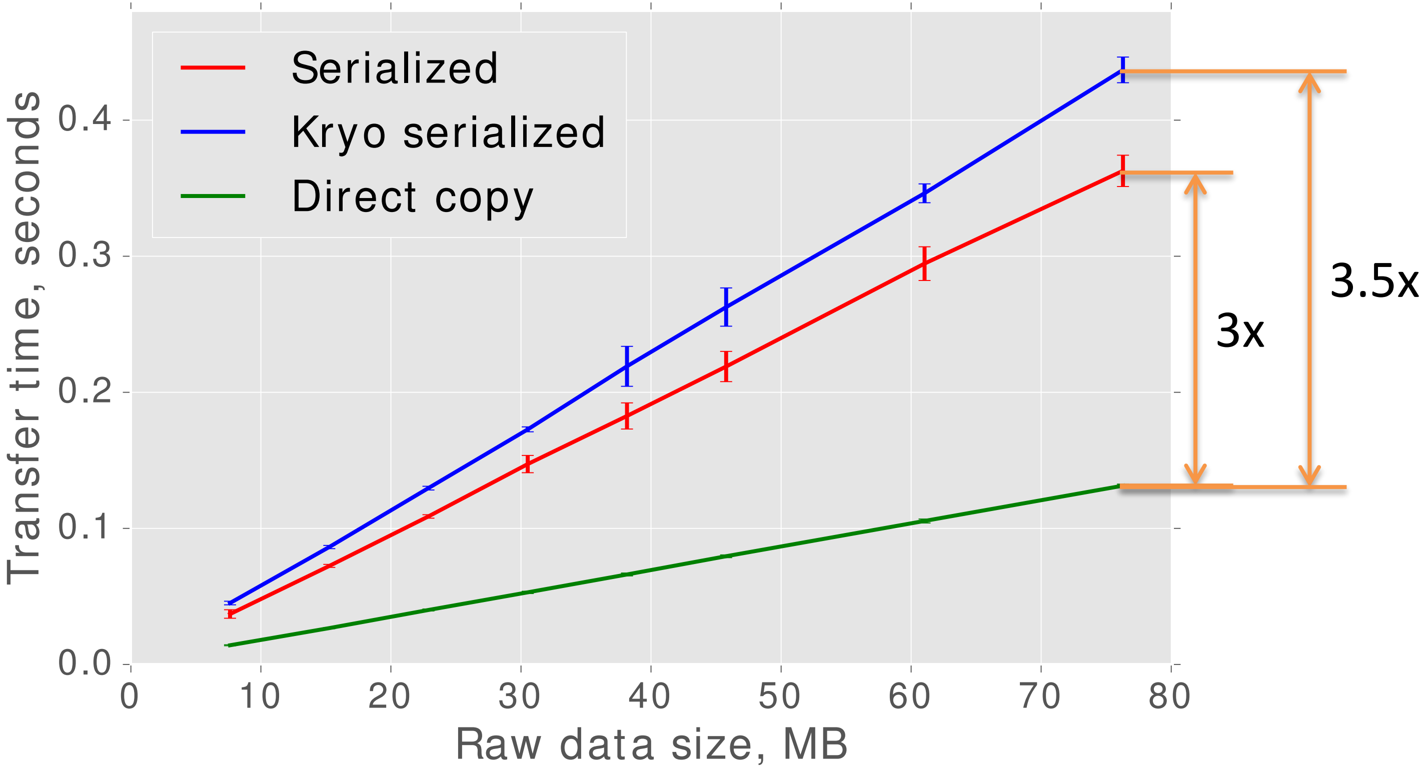
- Microbenchmark (performance of the mechanism alone)
- Transfer objects between 2 identical nodes
- Direct copy vs. serialized
  - both standard Java serialization and Kryo
- HotSpot for serialized measurements,
  JamVM for direct copy
- TCP transport, 10 Gbit/s; expect better results with RDMA

- Overhead of JVM modifications: within 1%

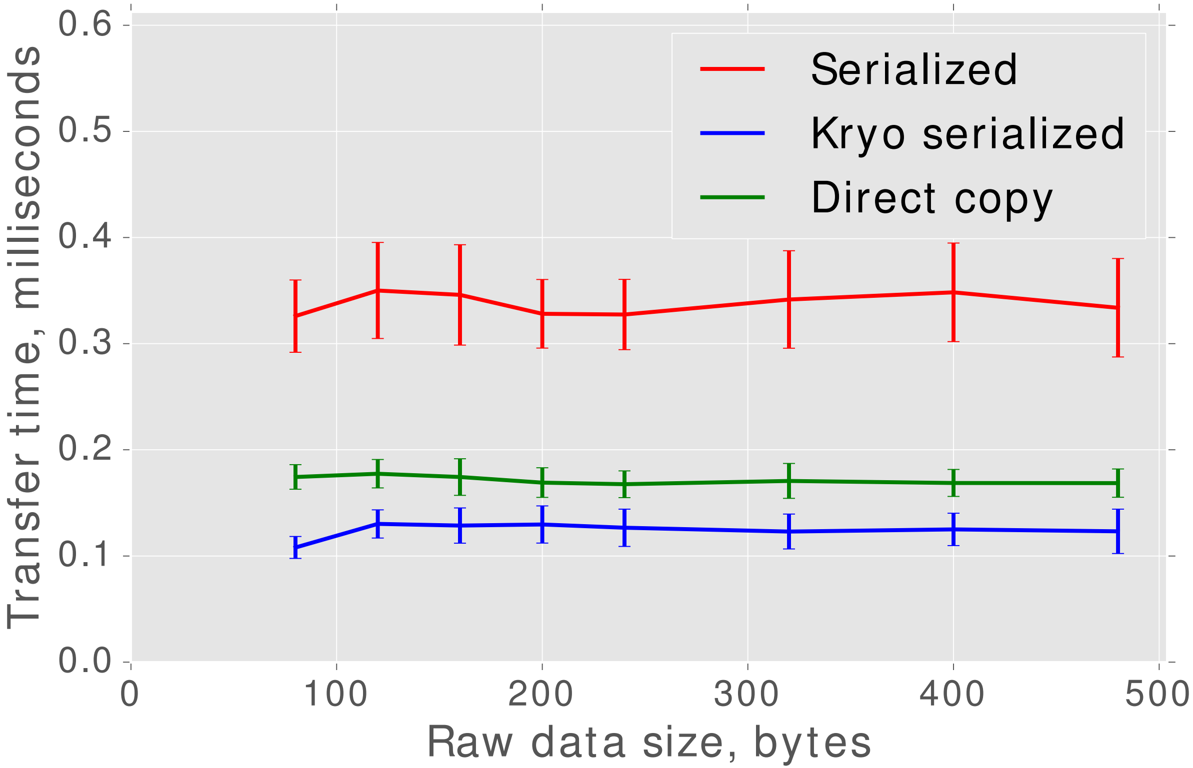
Evaluation: complex data (TreeMap)



Evaluation: simple data (double[])



Evaluation: small simple objects



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Proposed applications

- Data processing frameworks: Spark, Hadoop, etc.
  - optimize shuffle stages (data exchange between all nodes)
  - possible scheduling improvements; data migration is now cheaper
- Distributed in-memory storage
  - store complex data efficiently
  - reduce latency of set/get operations
- Fast IPC and RPC
  - zero-copy within one machine (using shared memory)

Current and future work directions

- Applications and macrobenchmarks
- RDMA
- Reliability / fault tolerance
- Storage considerations (spills to disk)
- Multiple address spaces for extremely large datasets
- Global heap space management,
  other implementation details…

Conclusion

- Data [de]serialization is a bottleneck;
  doesn't let us fully leverage fast network
- Designed a data transfer mechanism to avoid serialization
  - main idea: shared cluster-wide virtual address space
- Use DSM to improve performance,
  trading off increased programming complexity
- Evaluation shows significant (up to 10x) speedup of data transfer
- Will explore applications that can benefit from this mechanism

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Questions?