Grappa: enabling next-generation analytics tools via latency-tolerant distributed shared memory

Jacob Nelson, Brandon Myers, Brandon Holt, Vincent Lee, Daniel Halperin, Bill Howe, Preston Briggs, Luis Ceze, Simon Kahan, Mark Oskin
{nelson, bdmyers, bholt, vlee2, dhalperi, billhowe, preston, luisceze, skahan, oskin}@cs.washington.edu
University of Washington

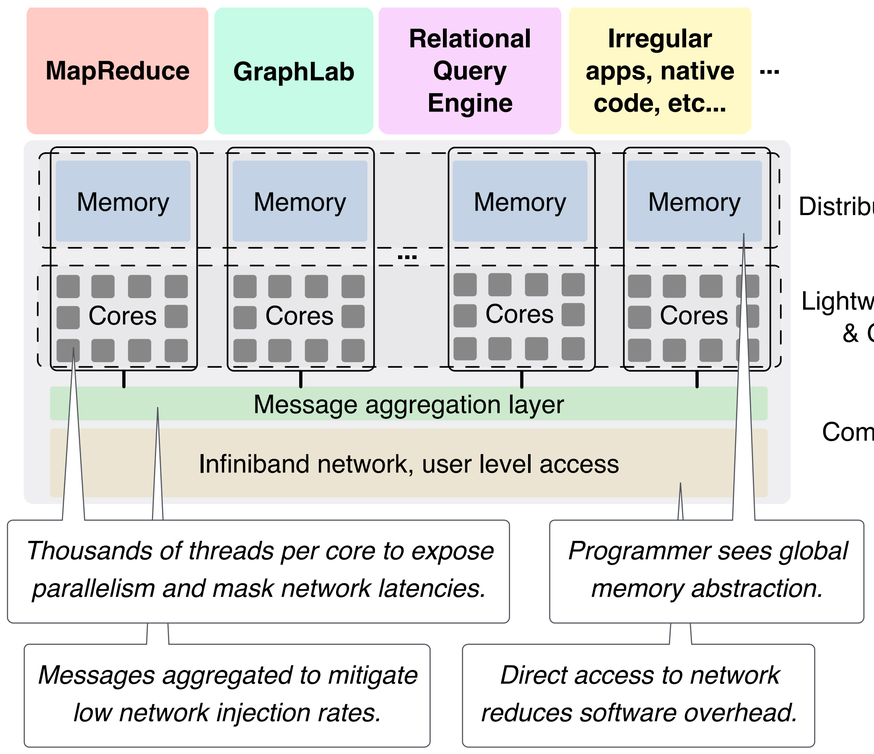
More info, papers, code:
http://grappa.io

Grappa is a modern take on software distributed shared memory, tailored to *exploit parallelism* inherent in data-intensive applications to overcome their poor locality and input-dependent load distribution.

Grappa differs from traditional DSMs in three ways:

- Instead of minimizing per-operation latency for performance, Grappa *tolerates latency* with concurrency (latency-sensitive apps need not apply!)
- Grappa *moves computation to data* instead of caching data at computation
- Grappa operates at *byte granularity* rather than page granularity

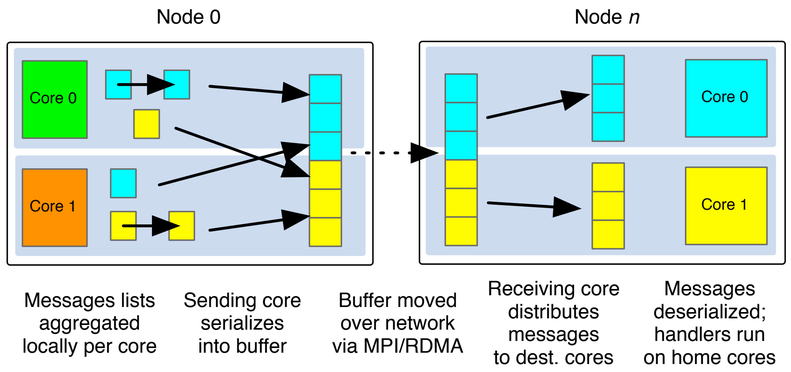
Latency tolerance has been applied successfully in hardware for nanosecond latencies (e.g., superscalar processors and GPUs). This project explores the application of this idea at distributed system scales with millisecond latencies.

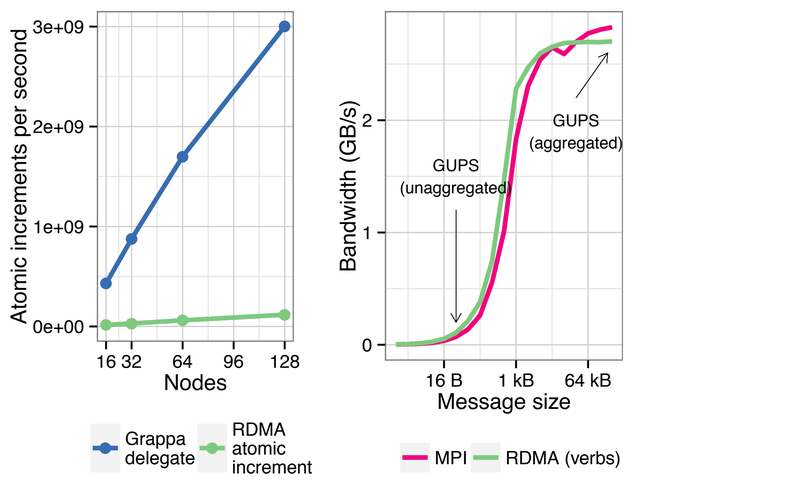


Grappa's current target is small, ~128 node clusters and does not yet implement fault tolerance. Work is ongoing.

Key feature: Message Aggregation

Commodity networks have a limited message injection rate, so building up larger packets from unrelated tasks is essential for small-message throughput (fine-grained random access to global memory).





Experiments run at Pacific Northwest National Laboratory on PAL cluster (1.9GHz AMD Interlagos processors, Mellanox ConnectX-2 InfiniBand network)

Selected publications

Latency Tolerant Distributed Shared Memory (USENIX ATC 2015)

A 10G NetFPGA Prototype for In-Network Aggregation (WARP 2015)
Explores increasing small-message throughput by doing aggregation in network switches.

Compiling Efficient Query Plans for Distributed Shared Memory (UW CSE tech report 2014)
Explores distributed database implementation techniques that exploit PGAS and latency tolerance.

Alembic: Automatic Locality Extraction via Migration (OOPSLA 2014)
Describes a compiler pass that automatically finds and extracts delegate operations from ordinary code.

Pomace: A Grappa for Non-Volatile Memory (NVMW 2013)
Explores approaches for providing high random access rates with non-volatile memory.

Flat Combining Synchronized Global Data Structures (PGAS 2013)
Distributed data structures that combine operations to reduce communication while remaining consistent.

Programming example

Grappa's familiar multithreaded C++ programming model enables easier development of analysis tools for terabyte-scale data. We provide sequential consistency for race-free programs using RPC-like atomic *delegate operations*, along with standard multithreading synchronization primitives.

Here's an example of building a distributed parallel word-count-like application with a simple hash table:

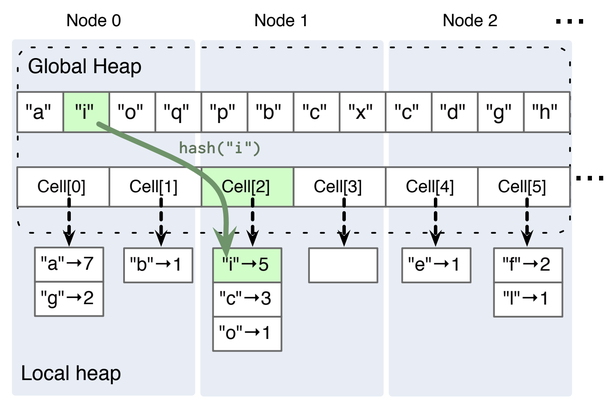
Grappa C++11 (*library-only*)

```
// distributed input array
GlobalAddress<char> chars;

// distributed hash table
using Cell = map<char,int>;
GlobalAddress<Cell> cells;

forall(chars, nchars, [=](char c) {
  // hash the char to determine destination
  size_t idx = hash(c) % ncells;

  delegate(cells+idx, [=](Cell& cell)
  { // runs atomically
    if (cell.count(c) == 0) cell[c] = 1;
    else cell[c] += 1;
  });
});
```



With *Alembic* C++ compiler

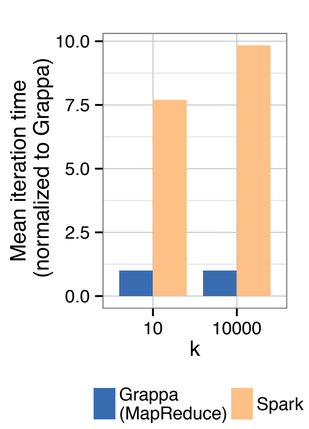
```
char global* chars;
Cell global* cells;
forall(chars, nchars, [=](char c) {
  Cell global& cell = cells[hash(c) % ncells];
  // compiler-inferred delegate:
  if (cell.count(c) == 0) cell[c] = 1;
  else cell[c] += 1;
});
```

Three prototype data analytics tools

In-memory MapReduce

~150 lines of code, implemented with forall loop over inputs followed by forall over keys

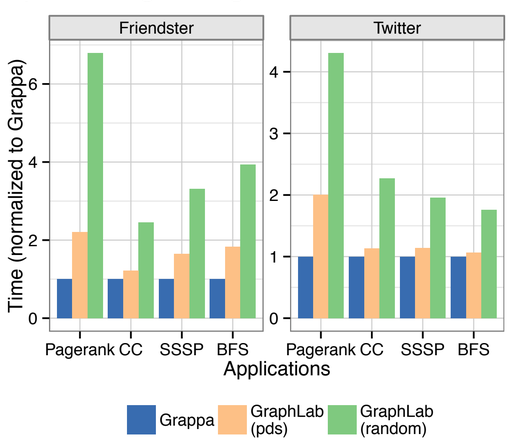
K-Means computation with 64 nodes on SeaFlow flow cytometry dataset with two different k values, compared with Spark using MEMORY_ONLY fault tolerance



GraphLab-like API

~60 lines of code, implementing:
- Synchronous engine with delta caching
- Random graph partition with no replication

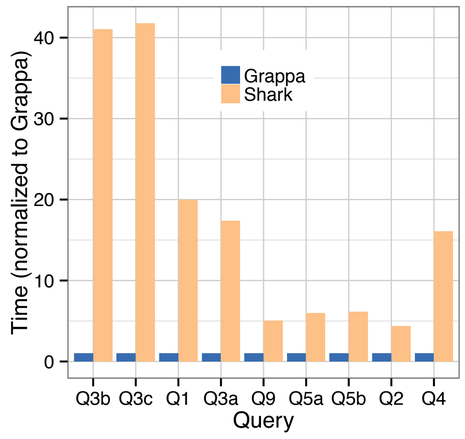
Benchmarks run on 31 nodes using 1.8B edge Friendster social network graph and 1.4B edge Twitter follower dataset, compared with GraphLab using two partitioning strategies



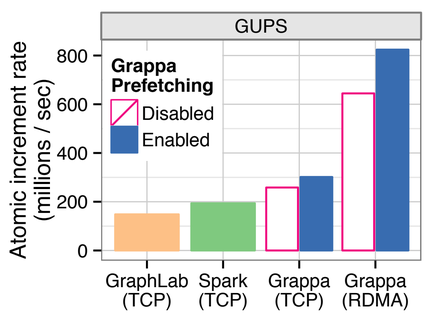
Backend for Raco relational query compiler

~700 lines of code, translating physical query plan into C++11 code using Grappa forall loops

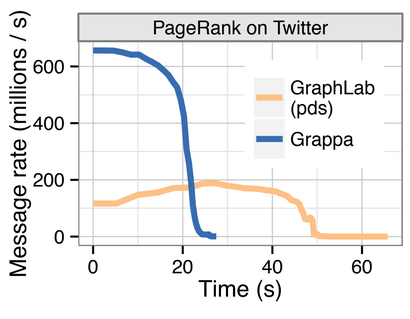
SP²Bench benchmark run on 16 nodes, compared with Shark distributed query engine



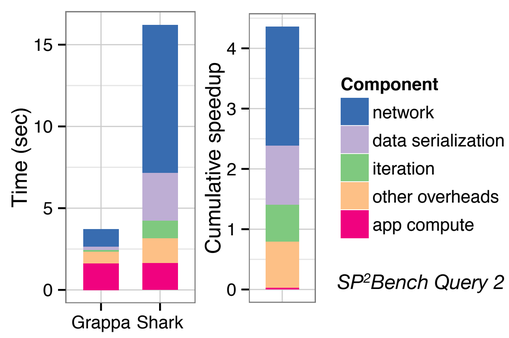
Performance breakdown (or *"why is Grappa faster?"*)



Kernel-bypass communication with cache-aware data placement.



High-concurrency program phases enable aggregation and thus high message rates.



More efficient network layer, lower serialization cost.