User Application Optimizations

Chapel versions 1.21 / 1.22

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chapel-lang.org

@ChapelLanguage

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CRAY CHAPEL

User Applications: Background

- Chapel has seen an uptick in users with substantial applications

https://chapel-lang.org/poweredby.html

The Chapel Parallel Programming Language

- Home
- What is Chapel?
- What's New?
- Upcoming Events
- Job Opportunities
- How Can I Learn Chapel?
- Contributing to Chapel
- Download Chapel
- Try Chapel Online
- Documentation
- Release Notes
- Performance
- Powered by Chapel

Powered by Chapel

The following projects use Chapel. Click the arrows for details.

- **Arkouda (αρκούδα):** NumPy-like Arrays at Massive Scale for Python
- **CHAMPS:** Chapel Multi-Physics Simulations
- **CHGL:** Hypergraph Analytics in Chapel
- **ChOp:** Chapel-based Optimization
- **ChplUltra:** Simulating Ultralight Dark Matter
- **CrayAI:** Distributed Machine Learning Workflow Libraries
- **Your Project Here?** If you're using Chapel in interesting ways, let us know!

- Has resulted in optimization/tuning collaborations with the Chapel team

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Outline

- DistributedFFT (from ChplUltra)
- Arkouda

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DistributedFFT (from ChplUltra)

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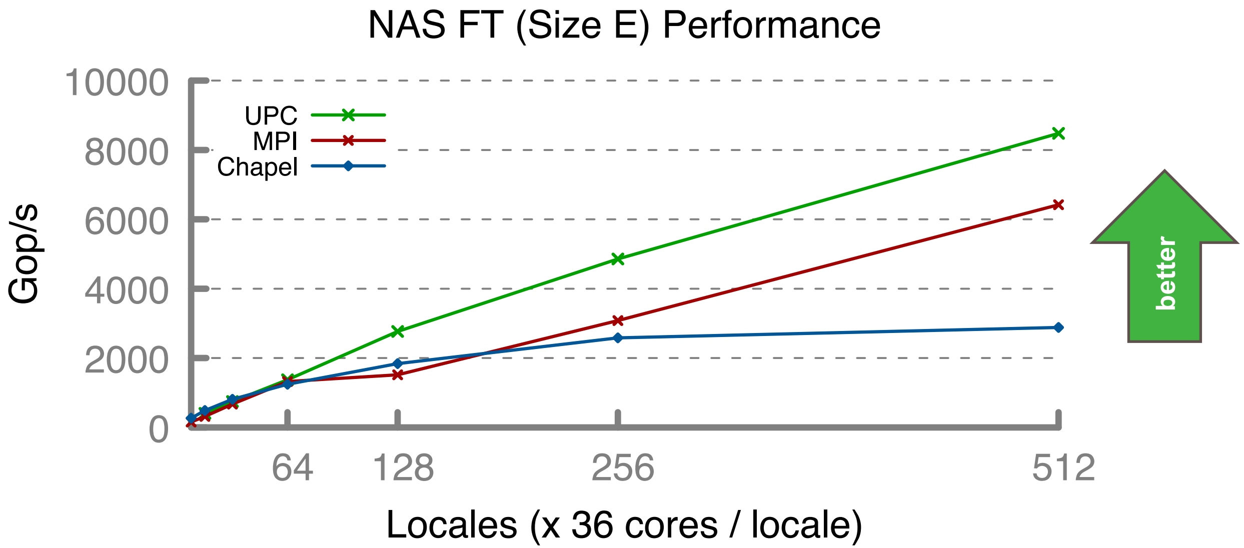
DistributedFFT: Background

- DistributedFFT provides a distributed 3D FFT
  - https://github.com/npadmana/DistributedFFT
- Used as the foundation for an Ultralight Dark Matter (ULDM) Simulation
  - Originally used Python/pyFFTW, but problem size soon exceeded single node
  - Chapel was chosen for distributed nature and high performance
- Chapel port uses FFTW for serial FFT computations
  - Chapel is responsible for data distribution, parallelism, and communication
  - Showcases Chapel’s interoperability features

DistributedFFT: Background

- Initial Chapel port provided significant performance improvements over Python
  - Added NAS-FT benchmark to validate and compare to traditional HPC
    - Performance was decent, though lagged UPC/MPI at 64 nodes or more



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DistributedFFT: This Effort

- Implemented several algorithmic optimizations
  - FFTW batching and plan caching, added comm/compute overlap

- Identified Chapel performance bottlenecks
  - Point-to-point array slice assignment has overhead
    - Only optimized for 'A = B', not 'A[locale0] = B[locale1]'
  - Local array assignment is not parallelized (uses serial 'memcpy')

- Opened Chapel issues for performance issues, worked around in the meantime
  - Using comm primitives (PUT/GET), manually parallelizing array assignment

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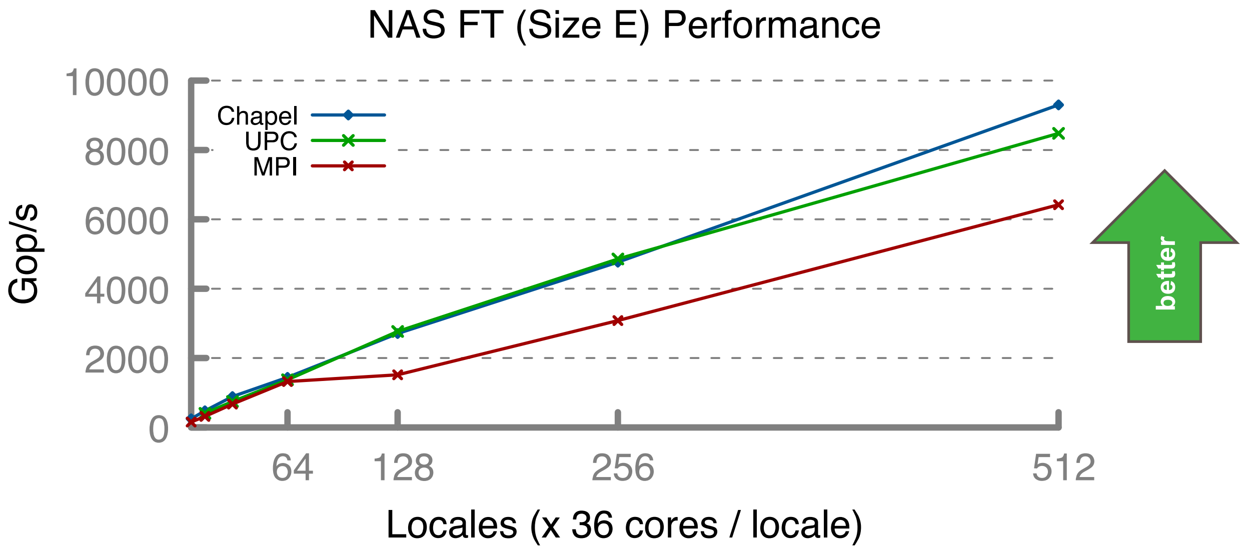
DistributedFFT: Impact

- Significantly improved performance and scalability (3x faster at 512 nodes)
  - Performance ahead of MPI
  - On par with highly optimized non-blocking UPC



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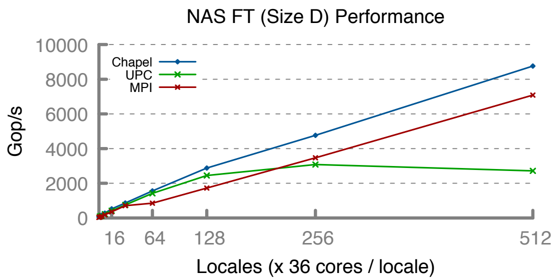
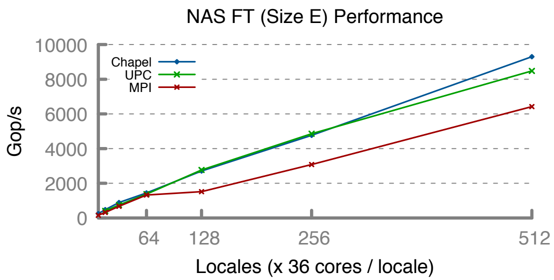
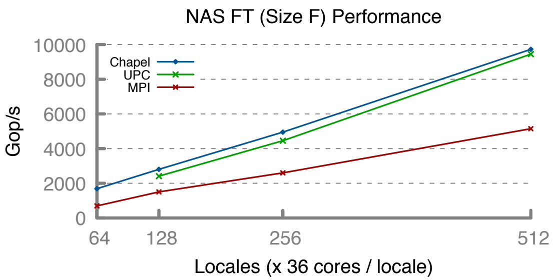
DistributedFFT: Impact

- Good performance across small, medium, and large problem sizes
  - Due to data decomposition, one-sided overlapping comm, FFTW batching







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DistributedFFT: Next Steps

- Implement fixes for upstream Chapel performance issues
- Explore using cuFFT to offload FFT computations to GPUs

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Arkouda

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Arkouda: Background

- Arkouda provides NumPy-like arrays at HPC scale
  - A NumPy/Pandas Python interface, backed by Chapel
    - https://github.com/mhmerrill/arkouda
  - One of the largest open-source projects using Chapel
- Widespread adoption requires performing well on a wide variety of platforms
  - Has motivated several improvements to the Chapel compiler and runtime
- Some key operations use fine-grained communication (many 8-byte messages)
  - Cray Aries can achieve high rates for small messages
  - Other networks have much lower rates for small messages

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Arkouda Aggregation: Background

- Previously, Arkouda used 'unorderedCopy()' for fine-grained messages
  - On Cray Aries, bulk copies achieve 8000 MB/s
    - unorderedCopy achieves 1000 MB/s (1/8 of bulk copy rate)
  - On 56 Gb FDR InfiniBand, bulk copies achieve 6000 MB/s
    - unorderedCopy only achieves 3 MB/s per node (1/2000 of bulk copy rate)

- In order to get performance on IB, small message aggregation is needed
  - Room for improvement on Aries as well

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Arkouda Aggregation: This Effort

- Added copy aggregators to Arkouda
  - Aggregators must be created for each task
  - Have to specify type and whether source or destination is remote

```
  forall i in D do
    unorderedCopy(revA[n-i], A[i]);
=>
  forall i in D with (var agg = new DstAggregator(int)) do
    agg.copy(revA[n-i], A[i]);
```

Arkouda Aggregation: Impact

- Significant performance improvements for operations with fine-grained comm
  - Following results are from:
    - 32-node Cray CS with 56 Gb InfiniBand network
    - 512-node Cray XC with Aries network
  - Per-node hardware is similar for both systems
    - 36-core Broadwell CPU
    - 128 GB RAM

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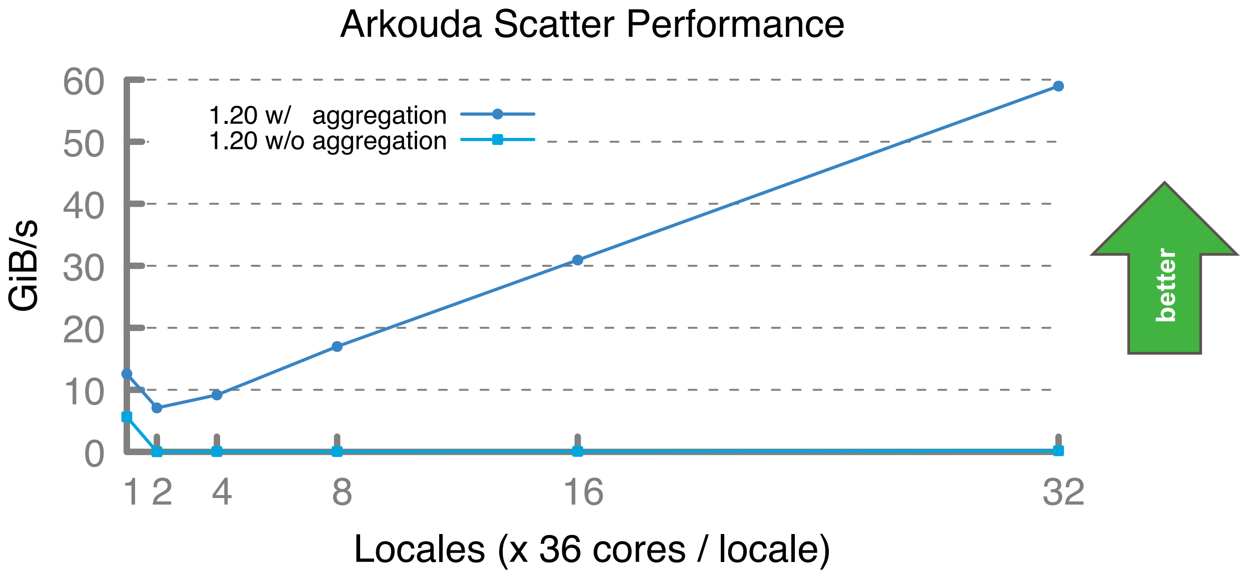
Arkouda Aggregation: Cray CS Impact

- Significant performance improvements for operations with fine-grained comm
  - 300x speedup for scatters on 32 CS nodes



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Arkouda Aggregation: Cray CS Impact

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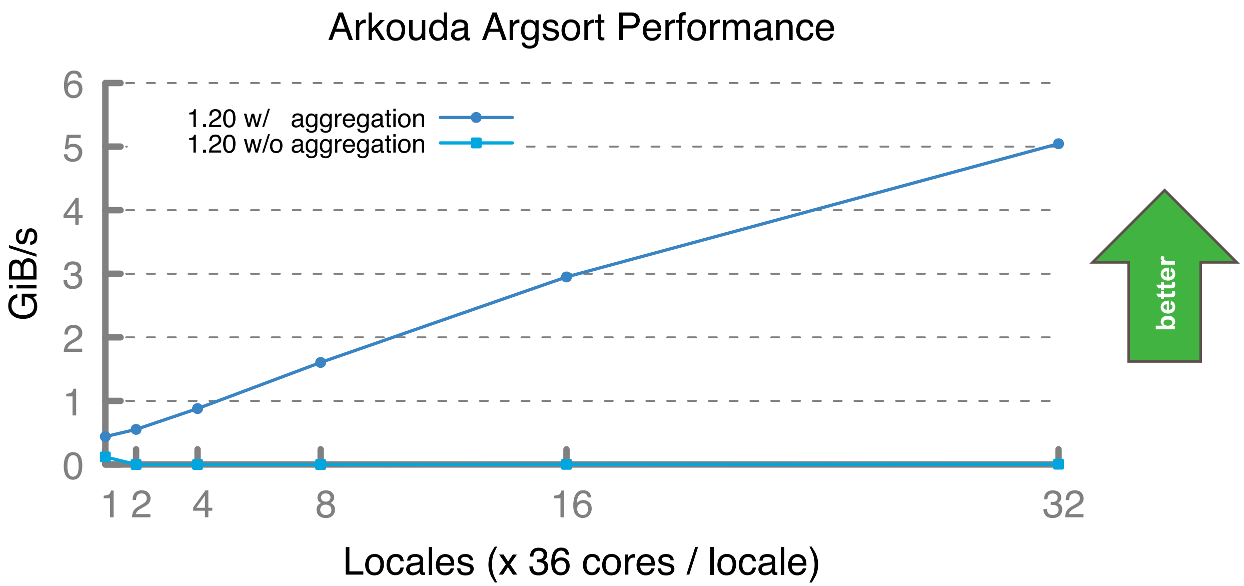
- Significant performance improvements for operations with fine-grained comm
  - 1200x speedup for sorting on 32 CS nodes



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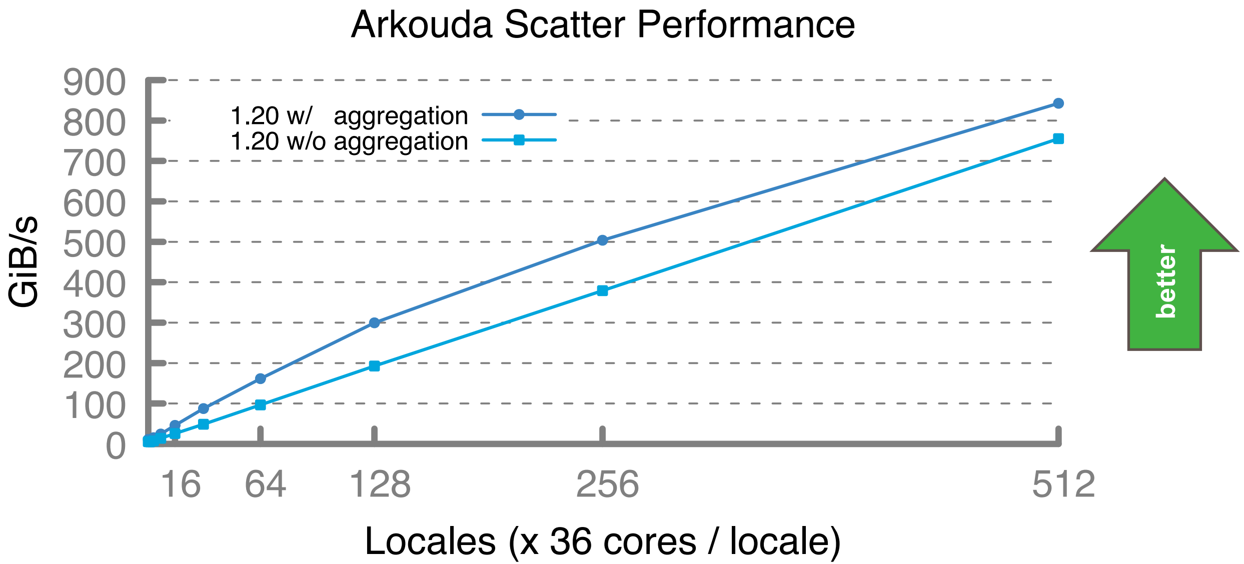
Arkouda Aggregation: Cray XC Impact

- Significant performance improvements for operations with fine-grained comm
  - 10% speedup for scatters on 512 XC nodes



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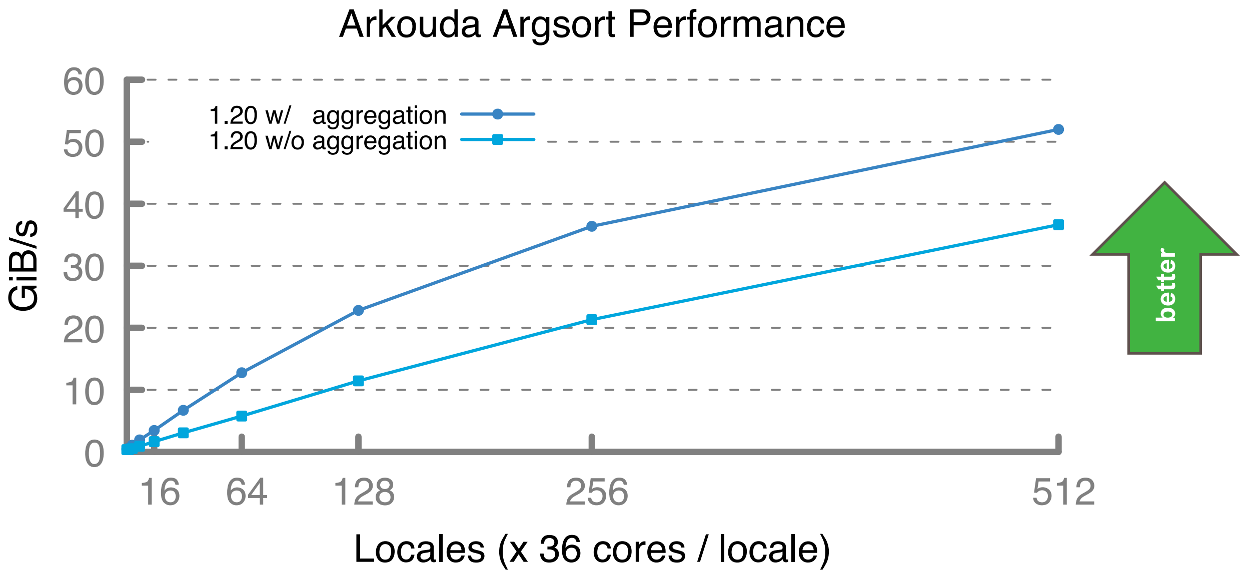
Arkouda Aggregation: Cray XC Impact

- Significant performance improvements for operations with fine-grained comm
  - 40% speedup for sorting on 512 XC nodes



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Arkouda Aggregation: Next Steps

- Optimize aggregation performance and reduce memory footprint
  - Current implementation is simple, lots of optimization opportunity
- Improve aggregation ease-of-use
  - Add utility functions for common idioms (gather/scatter)
  - Possibly enable with automatic unordered compiler optimization
- Add aggregation to Chapel’s standard library

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Arkouda Chapel Performance: This Effort

- Many 1.21 optimizations were motivated by, and benefitted, Arkouda
  - Optimizing on-statements for InfiniBand networks benefitted aggregation
  - Optimizing distributed array/domain creation benefitted most operations
  - Extending fast-followers improved array binary operations

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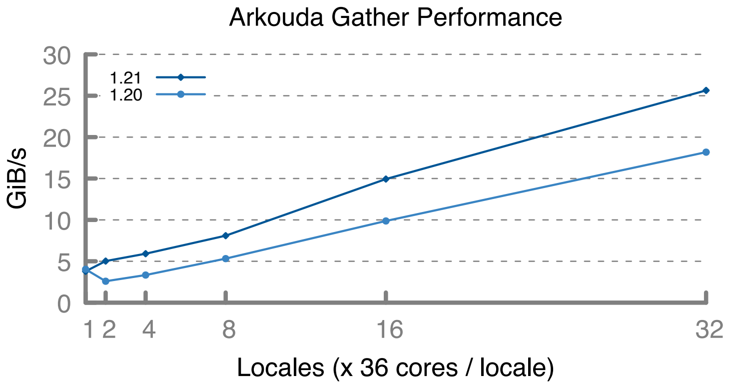
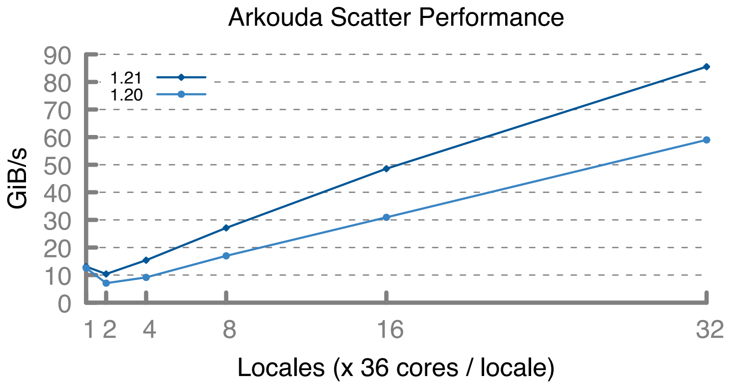
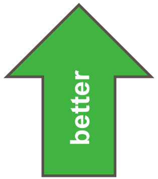
Arkouda Chapel Performance: Cray CS Impact

- Significant performance improvements on Cray CS (FDR InfiniBand)
  - At 32 locales: 40% faster Gather, 45% faster Scatter







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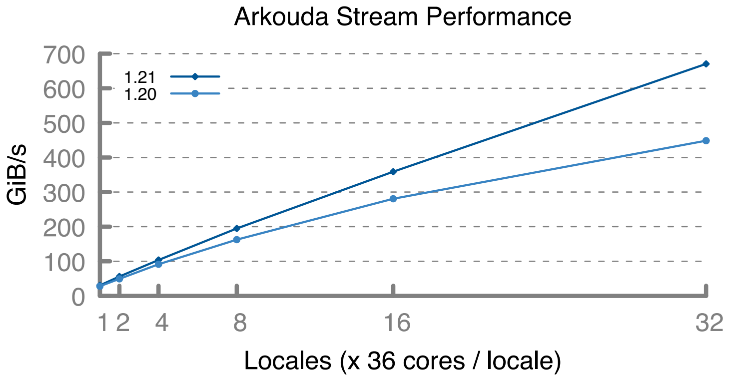
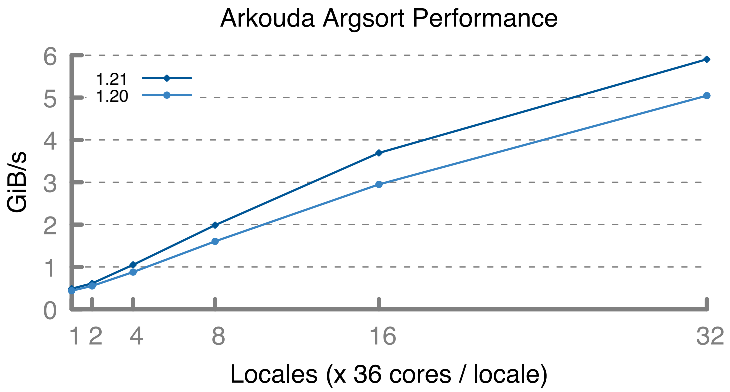
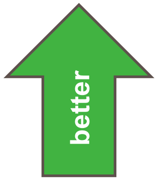
Arkouda Chapel Performance: Cray CS Impact

- Significant performance improvements on Cray CS (FDR InfiniBand)
  - At 32 locales: 50% faster Stream, 15% faster Argsort







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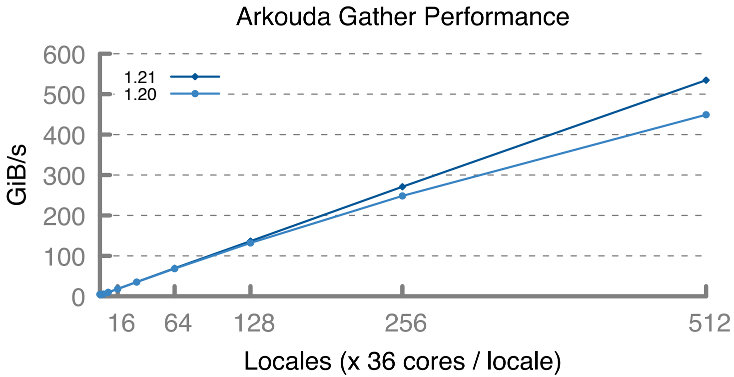
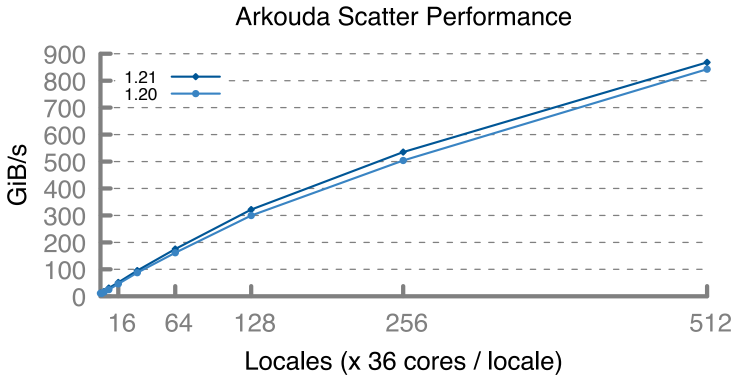
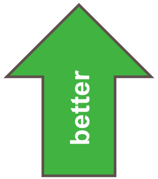
Arkouda Chapel Performance: Cray XC Impact

- Significant performance improvements on Cray XC (Aries)
  - At 512 locales: 20% faster Gather, 5% faster Scatter







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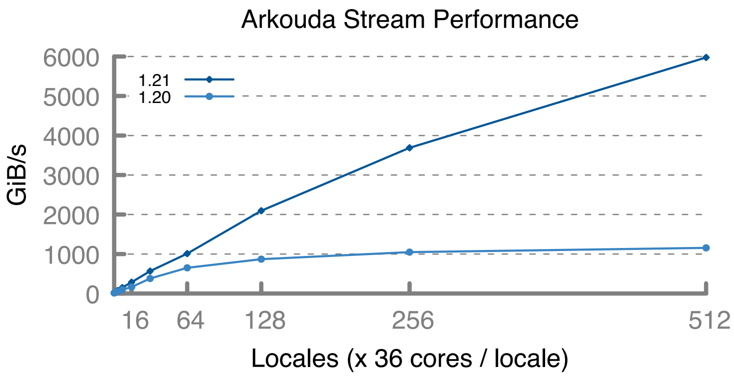
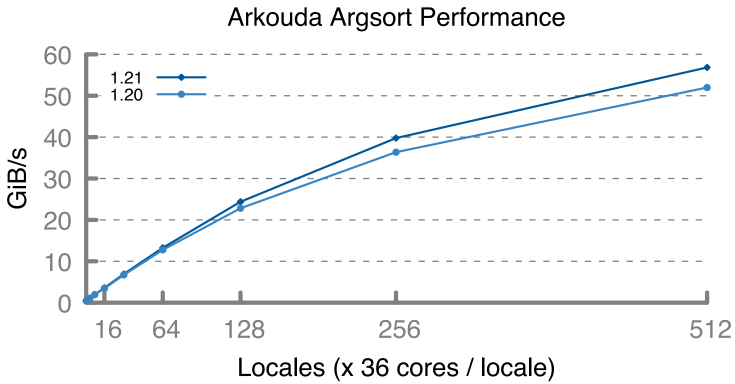
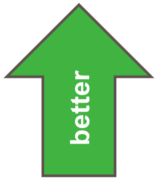
Arkouda Chapel Performance: Cray XC Impact

- Significant performance improvements on Cray XC (Aries)
  - At 512 locales: 525% faster Stream, 10% faster Argsort







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Arkouda: Additional Performance Improvements

- A few other Arkouda-specific optimizations were contributed upstream
  - Eliminated overhead for sorting negative integers
  - Optimized hashing used for string sorting
    - Requires extremely fast serial performance and scalable operations
    - Showcases Chapel's ability to program in the small and large

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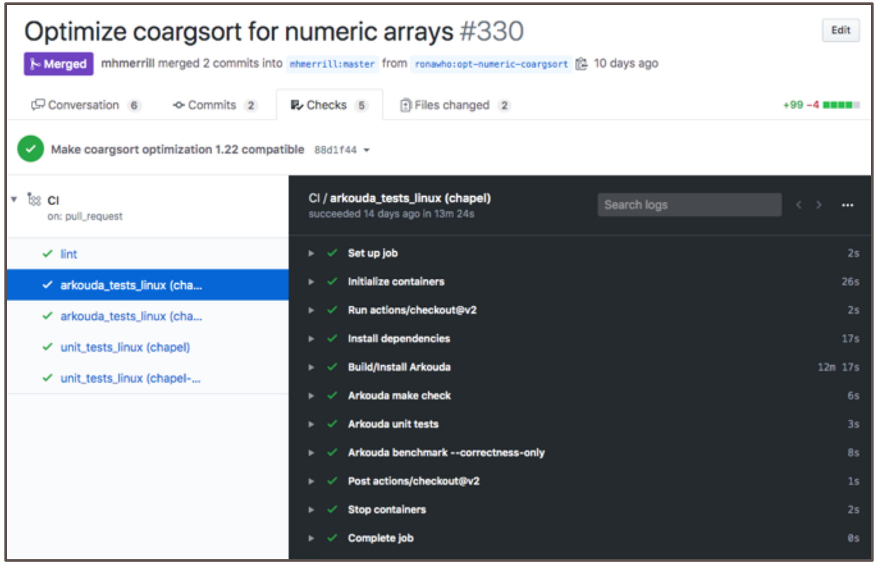
Arkouda: CI Testing

- Added continuous integration (CI) testing
  - Build and test Arkouda for each Pull Request



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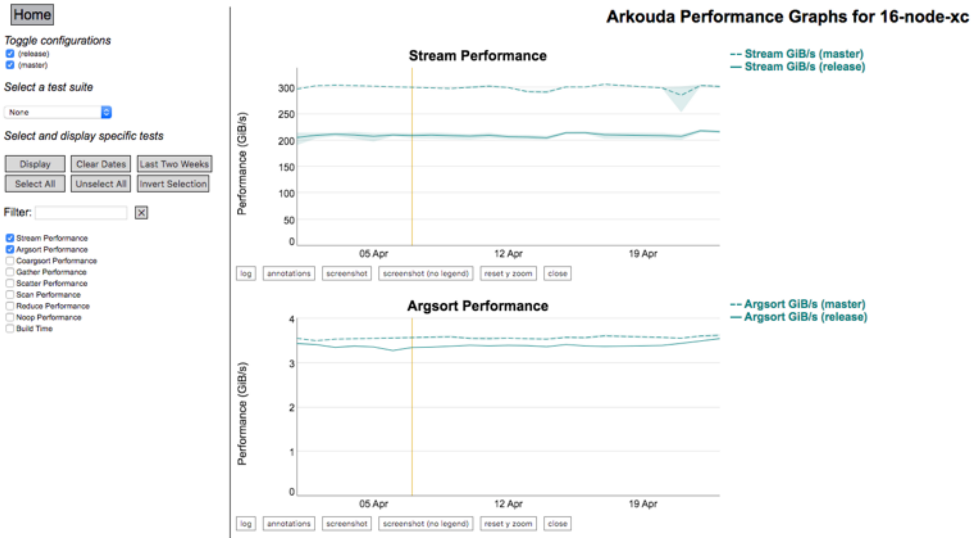
Arkouda: Performance testing

- Added benchmarking infrastructure and nightly performance testing
  - Runs single-node, 16-node CS, and 16-node XC
  - https://chapel-lang.org/perf/arkouda/



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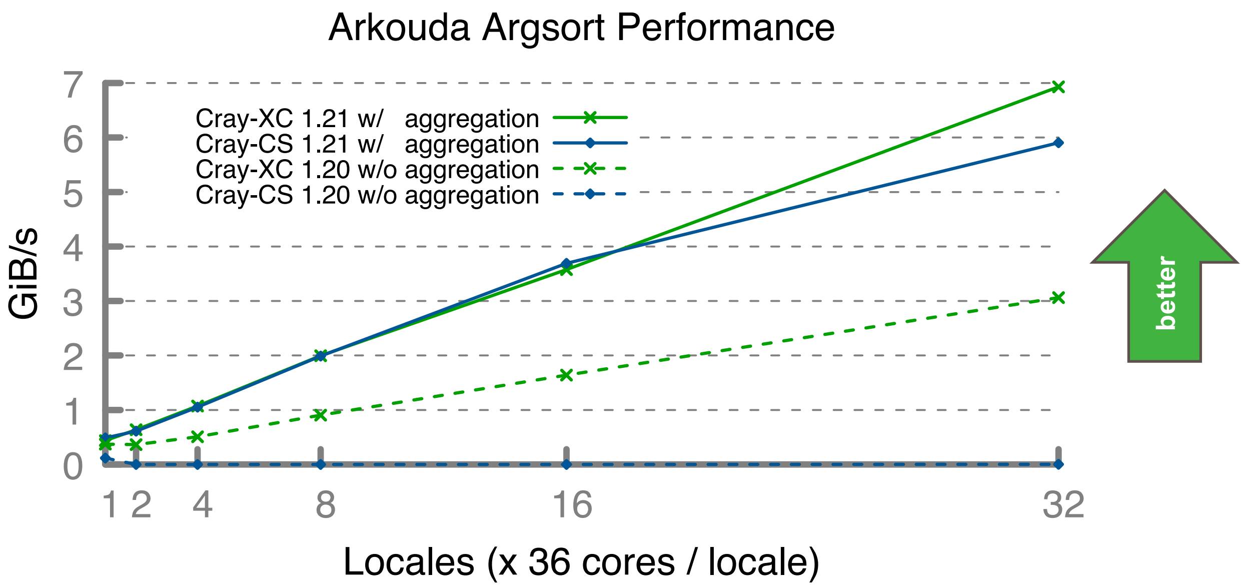
Arkouda: Summary

- Arkouda performance has significantly improved
  - Particularly on InfiniBand, which is now comparable to Aries



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User Applications: Next Steps

- Continue to support user efforts
  - Please feel free to contact us if your Chapel code needs tuning
- Develop better tooling for profiling and performance investigation
- Improve tooling for building/testing/releasing Chapel packages and applications
  - i.e. improve Mason

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