User Application Optimizations

Chapel versions 1.21 / 1.22
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User Applications: Background

- Chapel has seen an uptick in users with substantial applications
  
  https://chapel-lang.org/poweredby.html

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

• DistributedFFT (from ChplUltra)
• Arkouda
DistributedFFT (from ChplUltra)
DistributedFFT: Background

• DistributedFFT provides a distributed 3D FFT
  • [https://github.com/npadmana/DistributedFFT](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
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
DistributedFFT: Impact

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

![Graph showing NAS FT (Size E) Performance](image)
DistributedFFT: Impact

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

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

• Arkouda provides NumPy-like arrays at HPC scale
  • A NumPy/Pandas Python interface, backed by Chapel
    • [https://github.com/mhmerrill/arkouda](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
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
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
Arkouda Aggregation: Cray CS Impact

• Significant performance improvements for operations with fine-grained comm
  • 300x speedup for scatters on 32 CS nodes
Arkouda Aggregation: Cray CS Impact

- Significant performance improvements for operations with fine-grained comm
  - 1200x speedup for sorting on 32 CS nodes
Arkouda Aggregation: Cray XC Impact

- Significant performance improvements for operations with fine-grained comm
  - 10% speedup for scatters on 512 XC nodes
Arkouda Aggregation: Cray XC Impact

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

Arkouda Argsort Performance

[Graph showing Arkouda Argsort Performance with two lines: 1.20 w/ aggregation and 1.20 w/o aggregation. The graph shows a clearer performance with aggregation.]
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
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
Arkouda Chapel Performance: Cray CS Impact

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

![Graphs showing Arkouda Gather and Scatter performance with improvements at 32 locales.](image)
Arkouda Chapel Performance: Cray CS Impact

• Significant performance improvements on Cray CS (FDR InfiniBand)
  • At 32 locales: 50% faster Stream, 15% faster Argsort
Arkouda Chapel Performance: Cray XC Impact

• Significant performance improvements on Cray XC (Aries)
  • At 512 locales: 20% faster Gather, 5% faster Scatter
Arkouda Chapel Performance: Cray XC Impact

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

• Added continuous integration (CI) testing
  • Build and test Arkouda for each Pull Request
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/](https://chapel-lang.org/perf/arkouda/)
Arkouda: Summary

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

![Arkouda Argsort Performance Diagram](image)
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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