Hewlett Packard Enterprise

CHAPEL 1.31/1.32 RELEASE NOTES: SS-11 / IB PERFORMANCE STATUS

Chapel Team

June 22, 2023 / September 28, 2023

OUTLINE

RECENT SCALABILITY HIGHLIGHTS

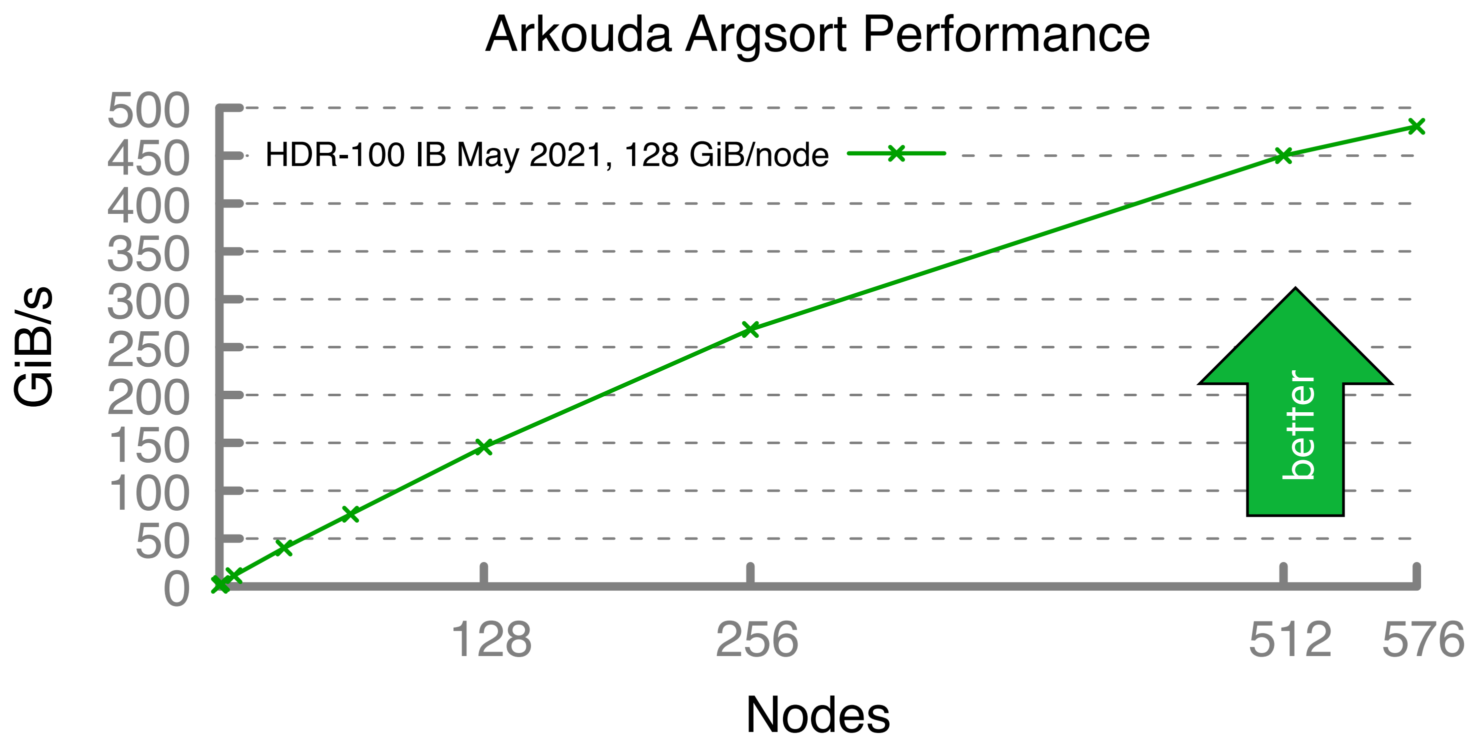
SCALABILITY HIGHLIGHTS BACKGROUND

- We had brief access to larger machines to evaluate performance at higher scales
  - In May 2021 we had access to a 576 node HDR-100 InfiniBand machine
    - Collected Arkouda argsort results
  - In May 2023 we had access to an 8,192 node Slingshot-11 machine
    - Collected Arkouda argsort and Bale indexgather results
- All Chapel results are with 1 process per node using a single NIC

ARKOUDA SCALABILITY HIGHLIGHTS

HPE Apollo (May 2021)

- HDR-100 Infiniband network (100 Gb/s)
- 576 compute nodes
- 72 TiB of 8-byte values
- ~480 GiB/s (~150 seconds)



A notable performance achievement in ~100 lines of Chapel

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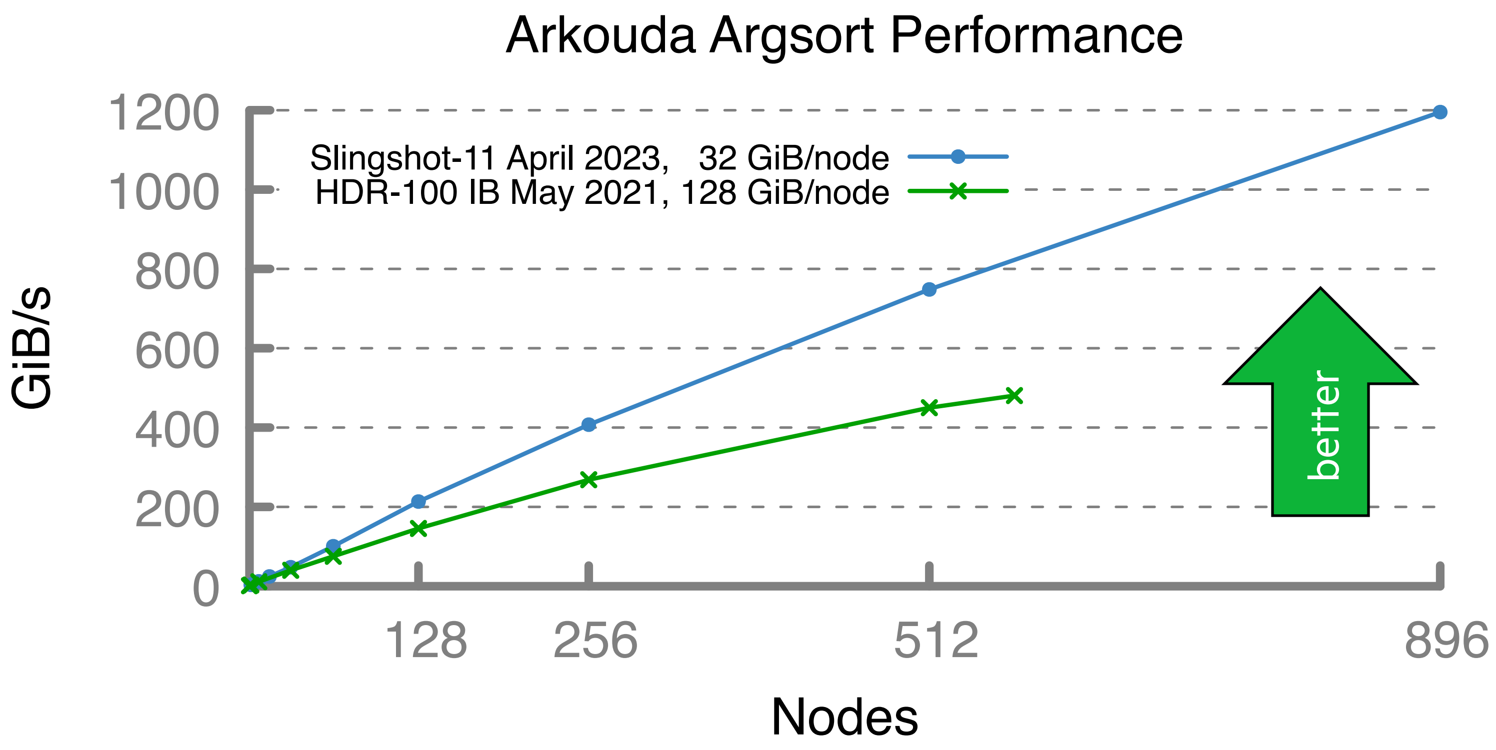
HPE Cray EX (April 2023)

- Slingshot-11 network (200 Gb/s)
- 896 compute nodes
- 28 TiB of 8-byte values
- ~1200 GiB/s (~24 seconds)



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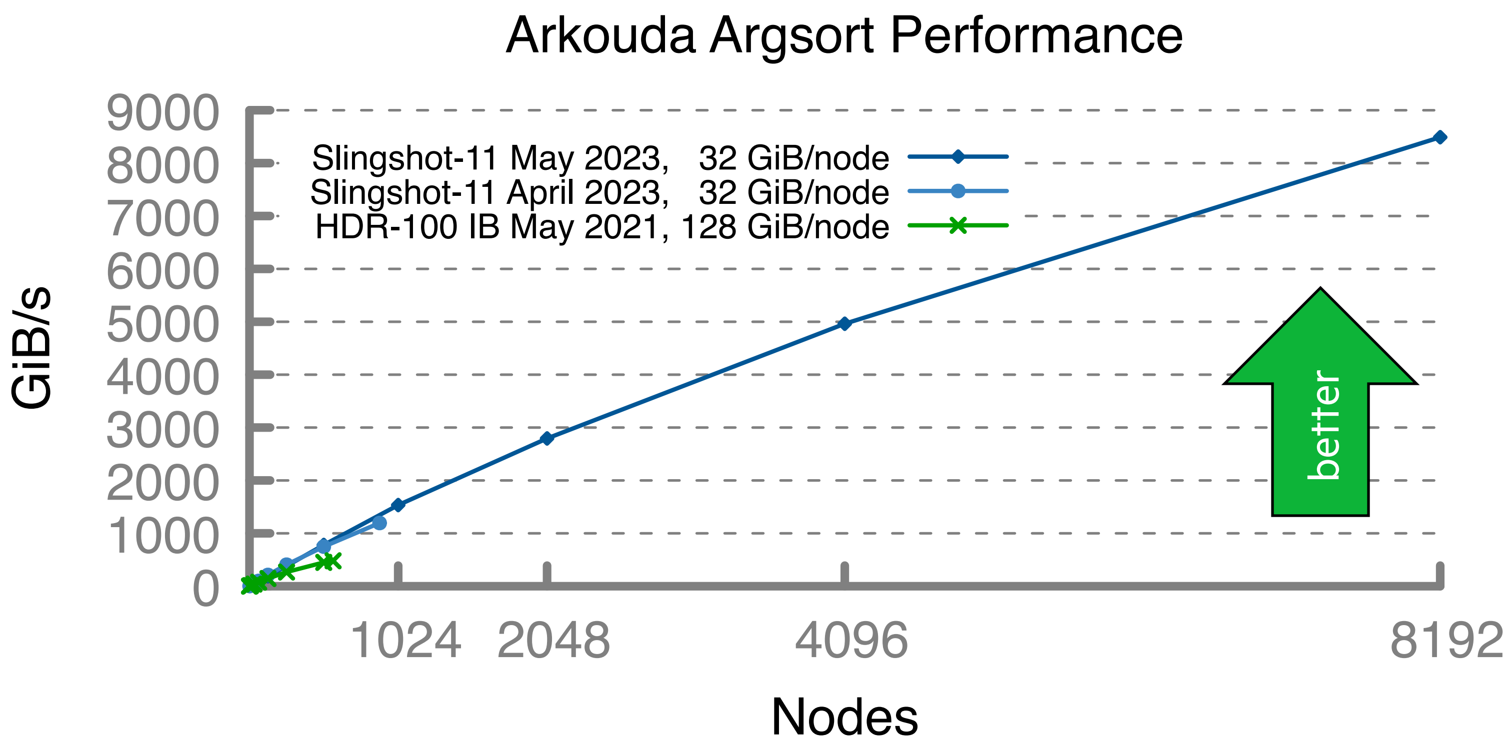
HPE Cray EX (May 2023)

- Slingshot-11 network (200 Gb/s)
- 8192 compute nodes
- 256 TiB of 8-byte values
- ~8500 GiB/s (~31 seconds)



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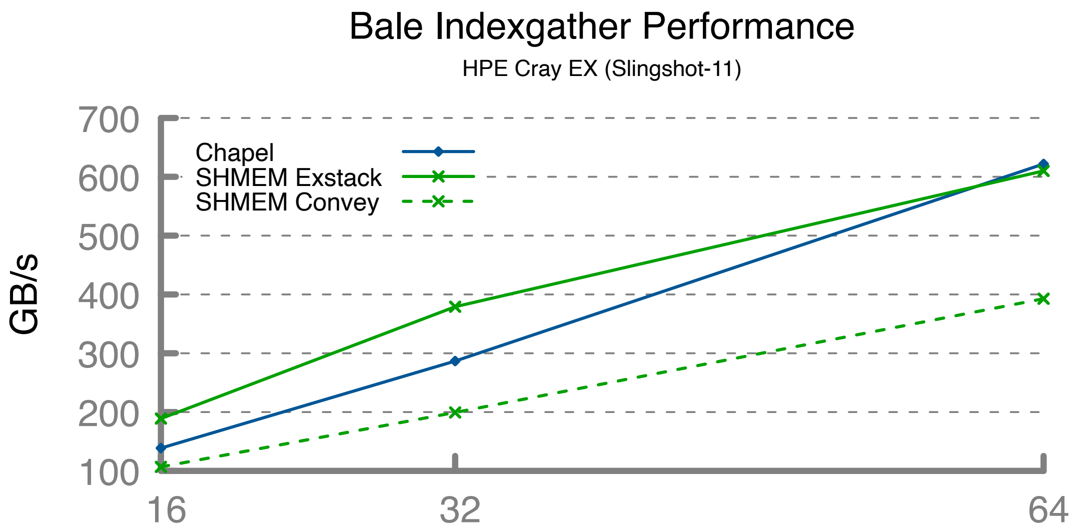
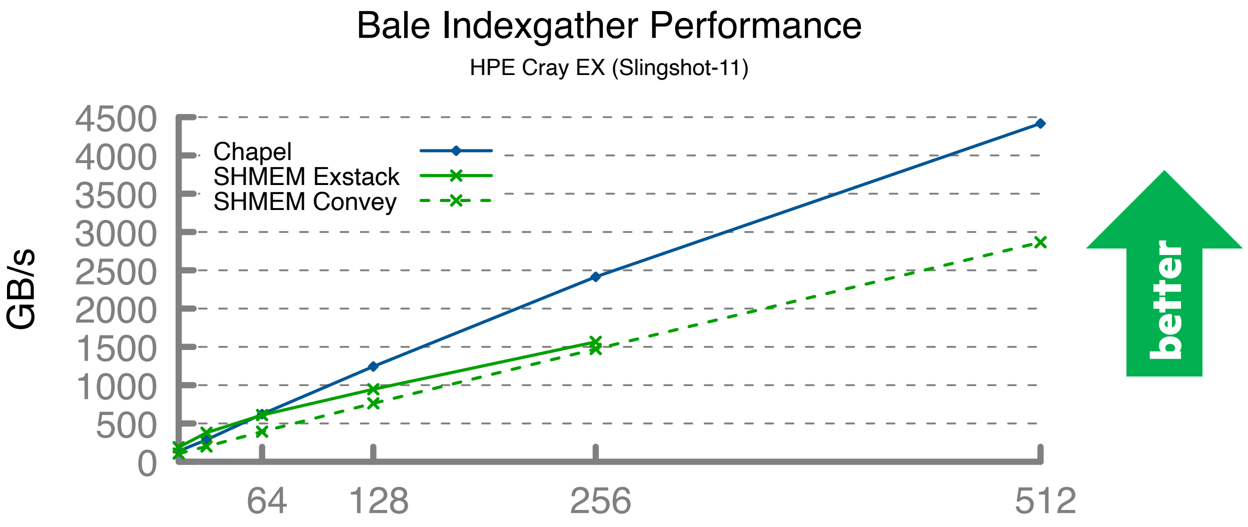
INDEXGATHER SCALABILITY HIGHLIGHTS

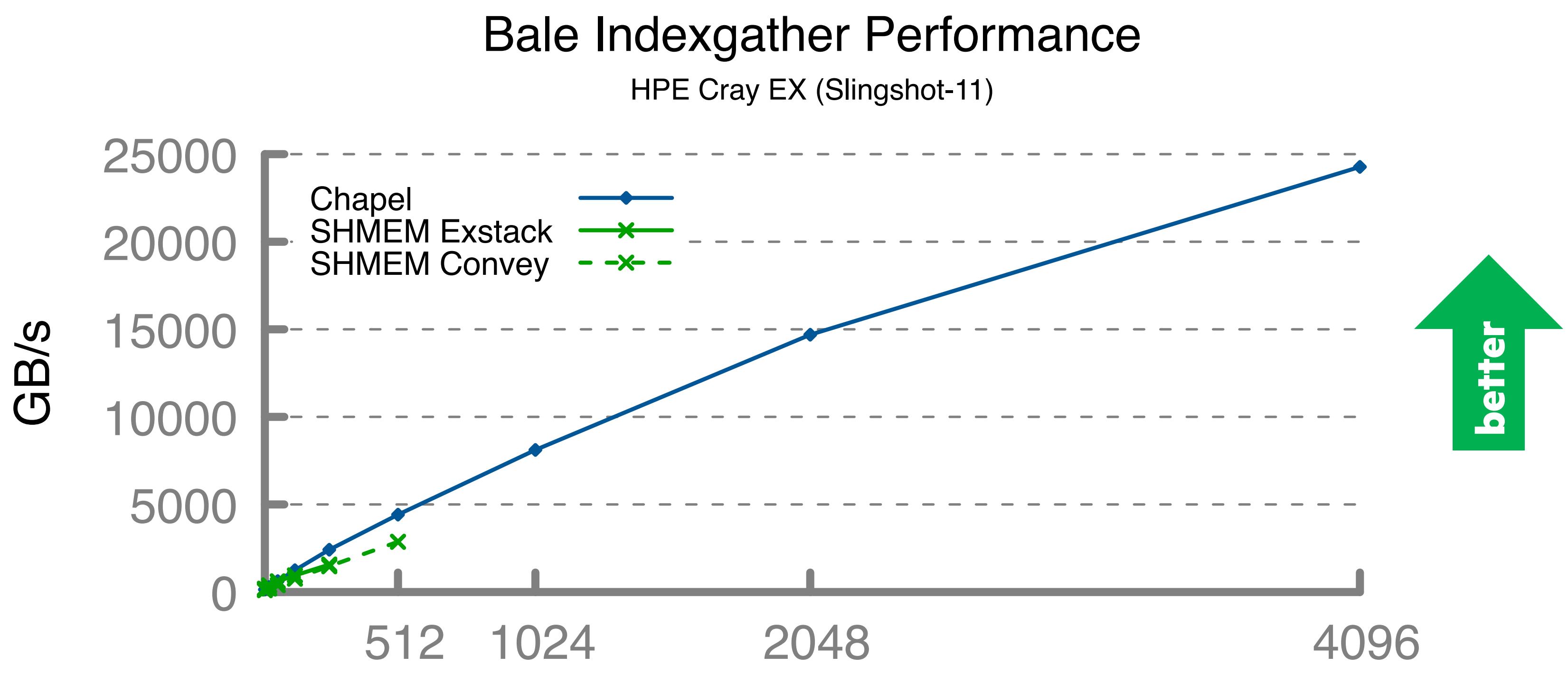
- Exstack performance is ahead up to 64 nodes, but Chapel is ahead above that
  - Exstack library and Conveyors implementation of indexgather only support a fixed number of PEs
    - – Conveyors can be adjusted to support more, but only determined that later





INDEXGATHER SCALABILITY HIGHLIGHTS

- Chapel indexgather runs and scales up to 4K nodes
  - Timed out gathering results, but uses same aggregators as Arkouda so expected to scale to 8K nodes as well



SCALABILITY HIGHLIGHTS SUMMARY

- We are happy with these scalability results, but they are Arkouda/aggregation focused
  - Aggregation only covers a relatively narrow set of network operations
- We wanted to take a step back and evaluate overall performance using our core benchmarks
  - These cover a broader range of HPC idioms

PERFORMANCE BACKGROUND

PERFORMANCE BACKGROUND
Platforms

- We want benchmark results to evaluate Chapel's performance on InfiniBand and Slingshot networks
  - As well as some reference MPI/SHMEM figures to get a sense of what the hardware is capable of

- We have only been optimizing for InfiniBand and Slingshot-11 since 2020
  - Prior to that, we focused on performance for Cray XC systems with the Aries network
    - Intent was to ensure Chapel had the right language features/semantics first, then optimize for other networks

- Hardware has changed dramatically between XC systems and modern InfiniBand/Slingshot systems
  - Typical XC was dual socket with ~36 intel cores per node and a single NIC per node
    - Penalty for getting NUMA affinity wrong was relatively low (1.5-2x)
  - Modern systems we've run on are dual socket with 128+ AMD cores or 72+ Intel cores, often with multiple NICs
    - Penalty for getting NUMA affinity wrong can be quite high (~10x)
    - Hard to target multiple NICs from a single process/locale

PERFORMANCE BACKGROUND
Co-locales

- Historically, Chapel ran with a process/locale per node, multithreading within a node
  - This worked well on single-NIC systems with lower cross-socket NUMA penalties
  - Especially when we could provide first-touch for large arrays on Aries systems
- Modern hardware performs best with a process per socket or even NUMA domain
  - Due to high cost of getting NUMA affinity wrong and benefit of targeting multiple NICS from different processes
- Much of our recent work has been to support running Chapel with multiple processes/locales per node
  - We refer to this as co-locales: co-located / cooperative locales running on the same node
  - Initial work has focused on a process per socket, but have foundations to support more arbitrary mappings
- Results will include data for 1 and 2 locales per node (LPN)

PERFORMANCE BACKGROUND

System Configurations

- We wanted to collect core benchmark results on systems with similar per-node hardware
  - Have easy access to single-NIC systems, so no multi-NIC results, but allows easier comparison between IB/SS
- Slingshot-11/InfiniBand hardware
  - Dual-socket Milan (128-cores total)
  - Single 200 Gbps NIC (HDR-200 and Slingshot-11)
- Historical Cray XC hardware
  - Dual-socket Intel (36-cores total)
  - Single Aries NIC

PERFORMANCE BACKGROUND
Benchmark Description

- Core Benchmarks
  - Stream: No communication, NUMA affinity sensitive
  - ISx: Concurrent bulk communication over wide address range, NUMA affinity sensitive
  - RA: Concurrent random fine-grained communication over wide address range
  - Indexgather: Concurrent bulk communication between small address range
- Arkouda argsort
  - Concurrent bulk communication between small address range, some NUMA affinity sensitivity

- Unless otherwise noted, results show weak scaling (fixed problem size per node)

PERFORMANCE BACKGROUND

Reference Background

- Collecting reference numbers on HPE/Cray systems is straightforward
  - cray-mpich and cray-openshmemx/cray-shmem are tuned and readily available
  - SHMEM expects multiple NICs, might not be fully tuned for single
    - Even so, still a useful comparison point to see if Chapel performance is way off
- We hit challenges collecting InfiniBand reference numbers that we could feel confident in
  - No vendor-supported MPI/SHMEM implementation on the particular system we ran on
    - Tried MPICH, OpenMPI and MVAPICH2 for MPI; MVAPICH2 had best performance but still seemed low
    - OpenMPI was the only available SHMEM implementation, but performance was quite poor
  - Opted to not include reference numbers for InfiniBand at this time

ARIES PERFORMANCE

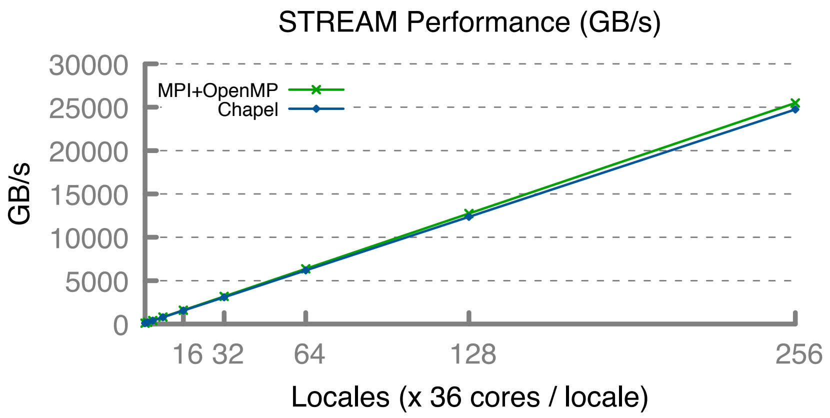
ARIES PERFORMANCE
Implementation Background

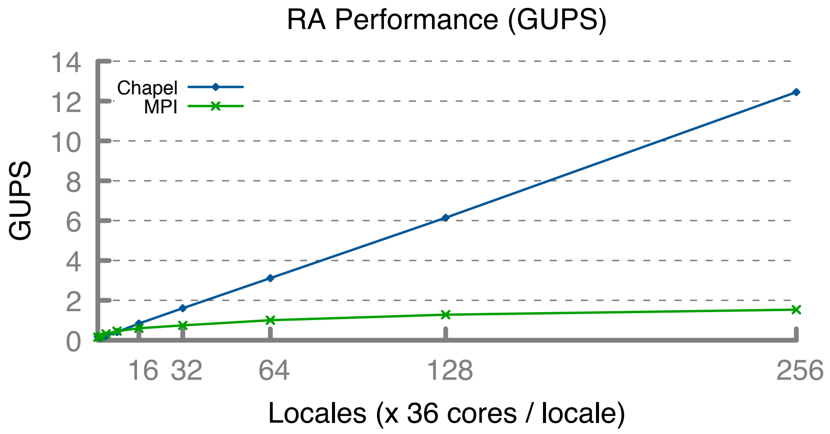
- We use ‘CHPL_COMM=ugni’ to target Aries
  - Dynamically allocates large arrays from the OS and registers them at allocation time
    - Enables first-touch for each array, provides good NUMA affinity and limits fragmentation
    - Communication is fast since all memory is registered, able to achieve hardware bandwidth injection rates
  - Each runtime thread has a communication endpoint
    - Enables concurrent and uncontended injection, achieves hardware injection rates for small messages
  - Has support for network atomics
  - Uses a blocking active-message handler, avoids interference when there are no incoming AMs

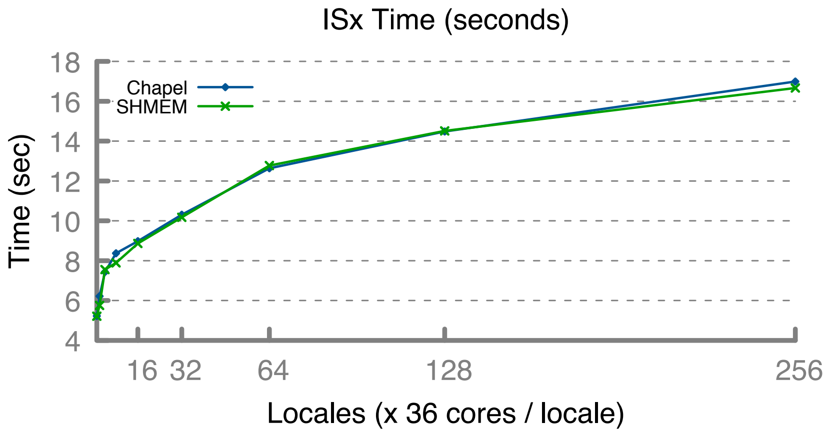
- In general, our core benchmarks were competitive with or ahead of reference MPI/SHMEM codes
  - Core benchmarks tested up to 256 nodes
  - Previous scaling studies done up to 2048 nodes

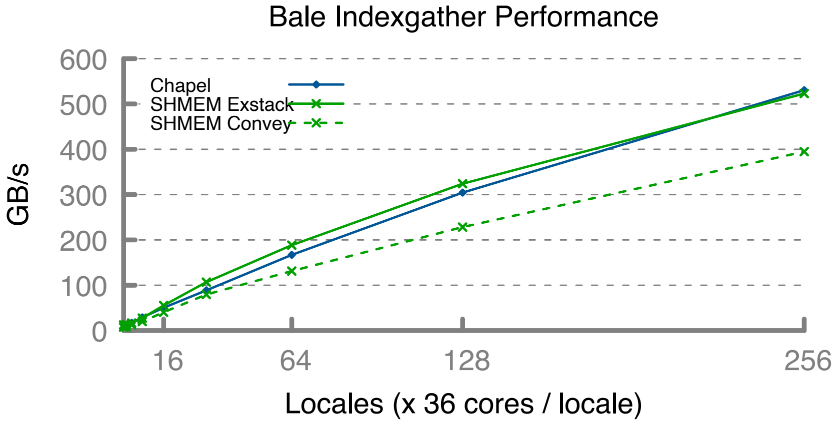
ARIES PERFORMANCE

Performance Results









SLINGSHOT-11 PERFORMANCE

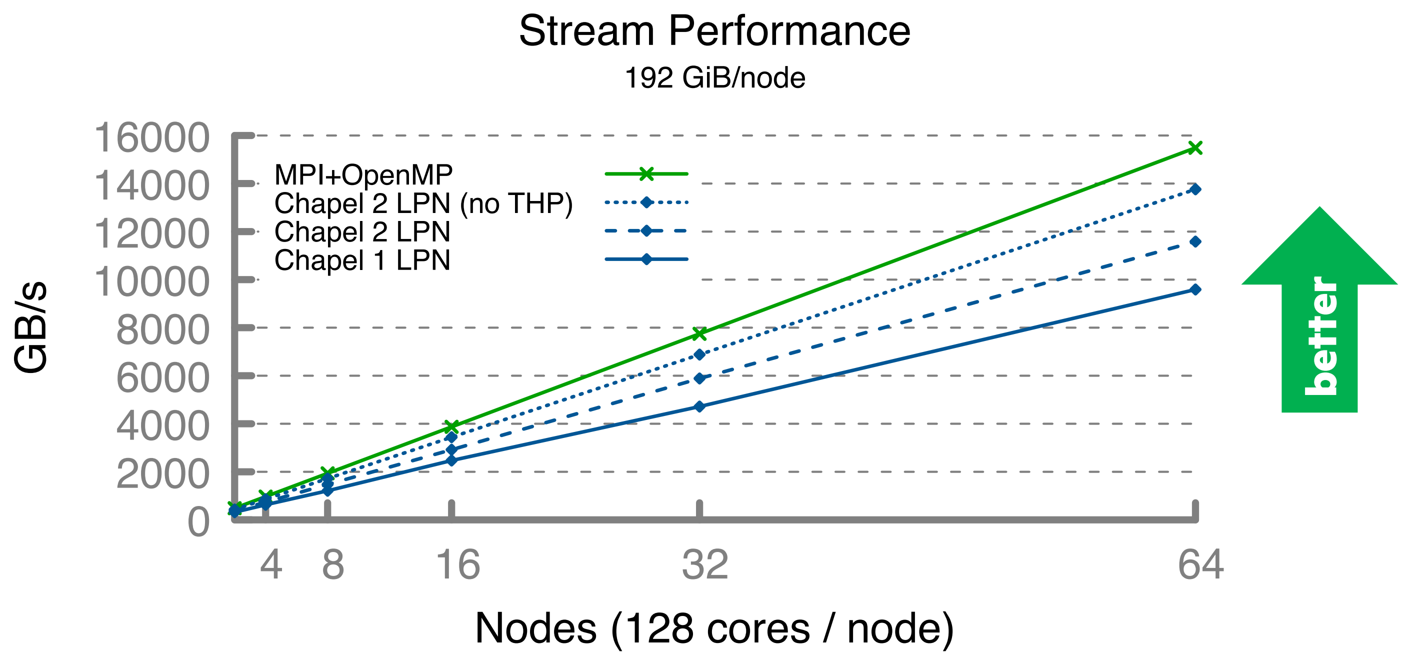
SLINGSHOT-11 PERFORMANCE
Implementation Background

- We use ‘CHPL_COMM=ofi’ with the cxi provider to target Slingshot-11
  - Uses a fixed and statically registered heap
    - Memory is interleaved across the NUMA domains that a locale is running on
    - Static registration makes RDMA trivial (all memory registered at program startup)
  - Supports running a process per socket
    - Limits interleaving to a single socket
    - Does not currently support shared memory bypass for co-located locales
  - Each runtime thread has a communication endpoint
    - Enables concurrent and hopefully uncontended injection (fast concurrent fine-grained communication)
  - Has support for network atomics
  - Uses a polling active-message handler, can cause interference even when there are no incoming AMs

SLINGSHOT-11 PERFORMANCE

Stream Results

- 1-locale-per-node performance is limited by the fixed heap being interleaved across sockets
- Expected locale-per-socket to achieve near peak performance (like we saw with gasnet-ibv on IceLake)
  - However, additional NUMA behavior within AMD CPUs seems to limit performance
    - Additionally, seeing even worse performance when using transparent huge pages (THP)



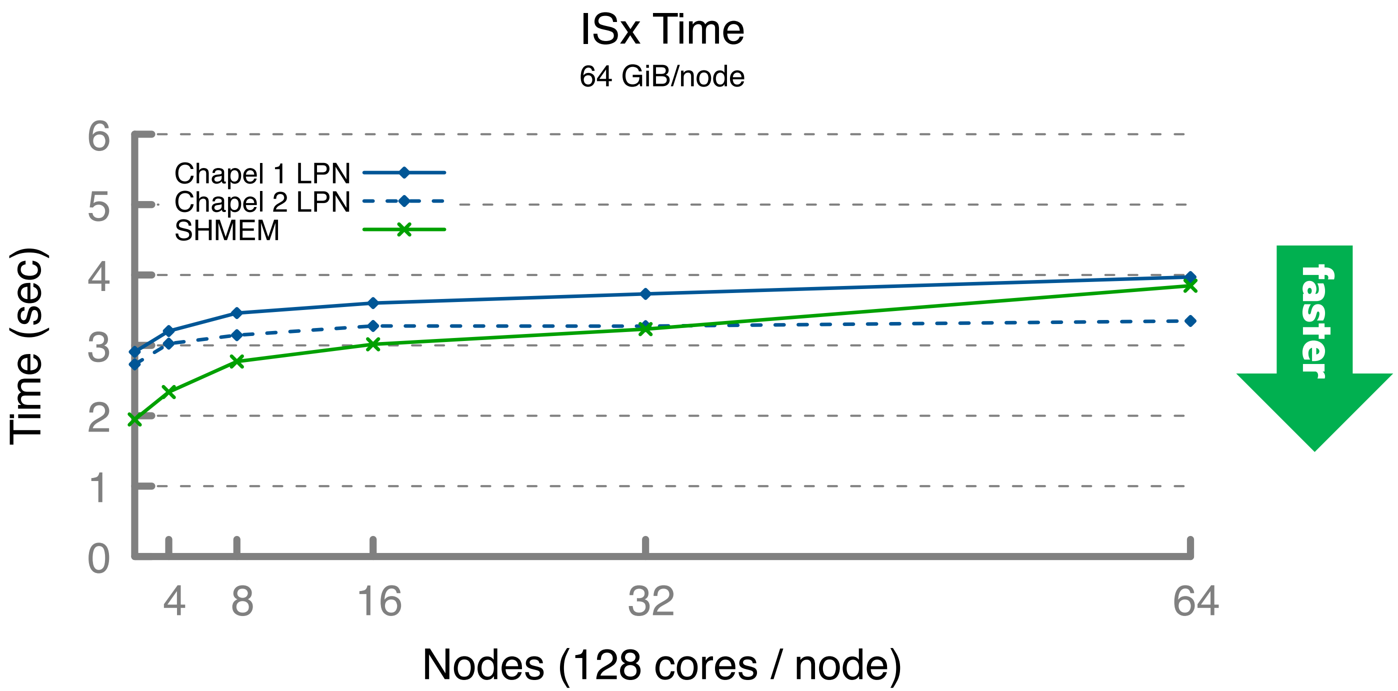
SLINGSHOT-11 PERFORMANCE

Stream Next Steps

- Investigate performance differences from transparent huge pages
- Add support for dynamic heap/registration, enabling first-touch affinity
- Add support for running with a locale per NUMA domain
  - Results in ideal NUMA affinity without requiring first-touch
  - But increases number of AM handlers and number of peers

SLINGSHOT-11 PERFORMANCE
ISx Results

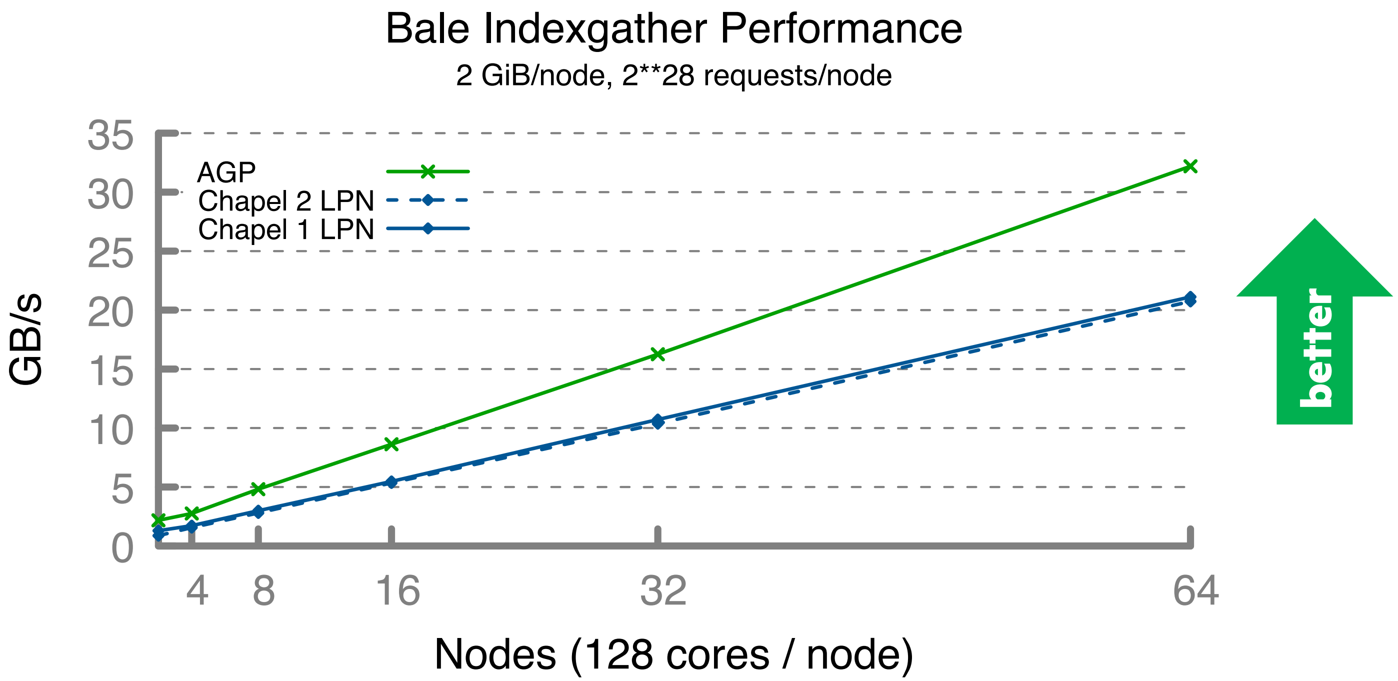
- ISx performance is fairly competitive, slightly behind under 32 nodes
  - Believe communication patterns are optimized, likely cause is imperfect NUMA affinity



SLINGSHOT-11 PERFORMANCE

Fine-grained Indexgather Results

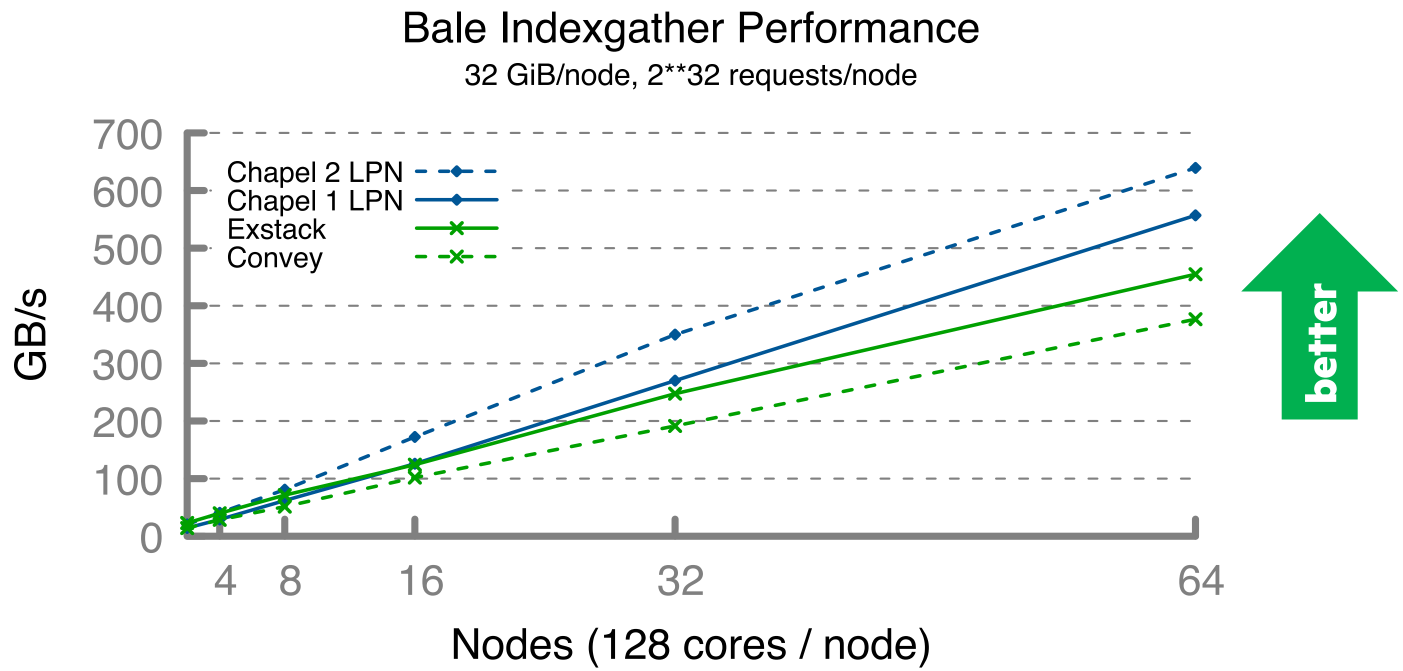
- Fine-grained indexgather performance is behind SHMEM
  - Root cause unknown, need to investigate



SLINGSHOT-11 PERFORMANCE

Aggregated Indexgather Results

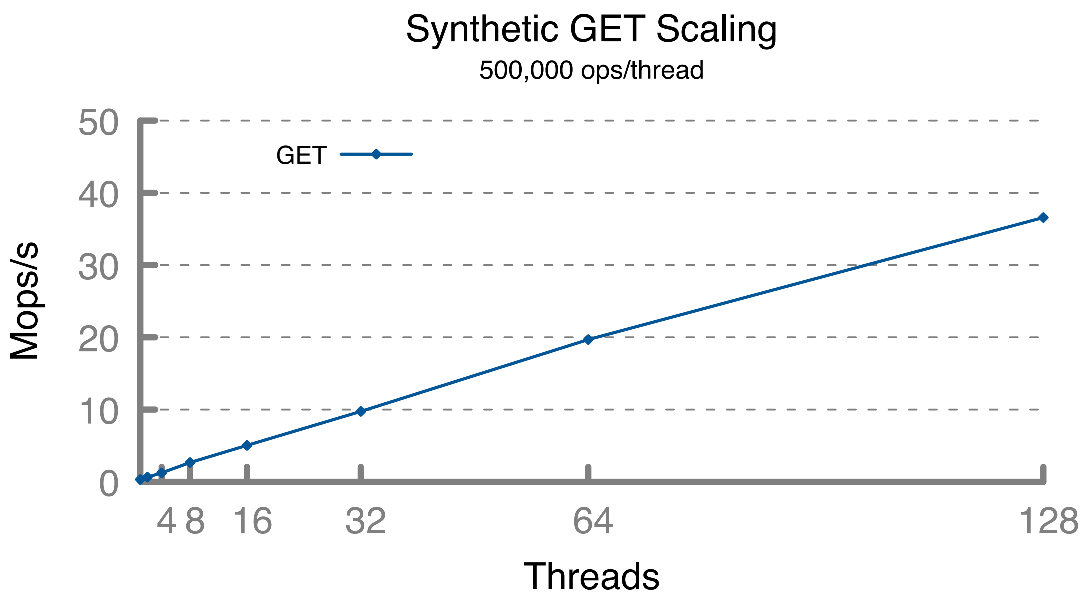
- Aggregated indexgather performance is generally ahead of SHMEM
  - Chapel implementation is more asynchronous, and task-based runtime enables trivial comm/compute overlap
  - Additionally, Chapel using a process per node/socket reduces number of peers, enabling fewer and larger buffers

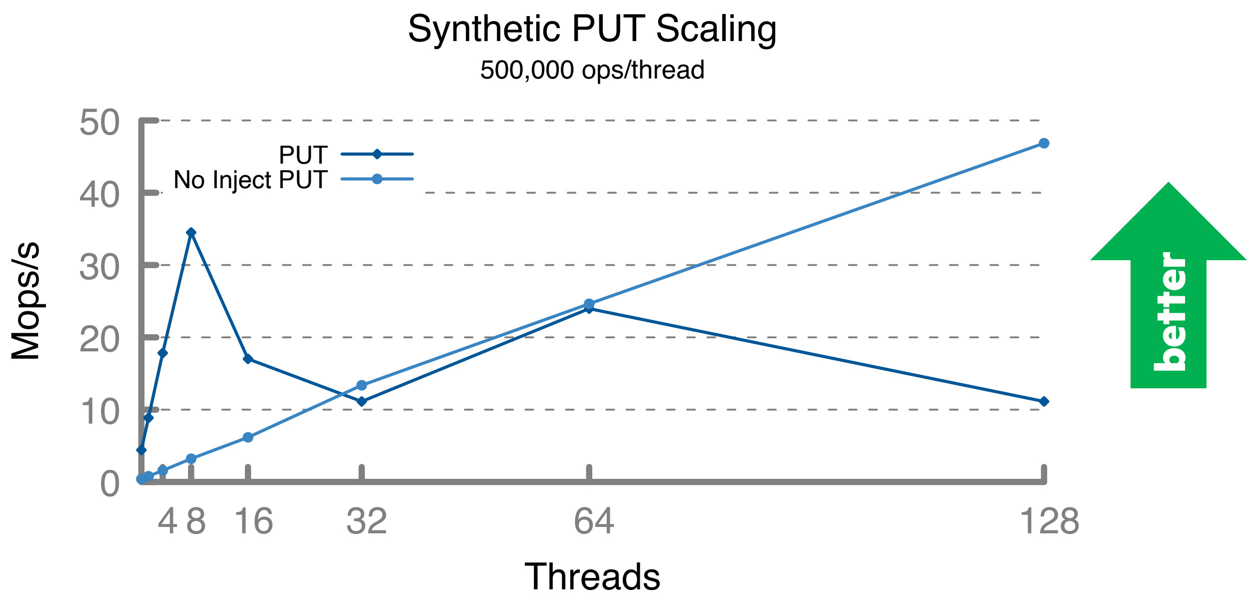


SLINGSHOT-11 PERFORMANCE

Thread Scaling Results

- GETs have good thread scaling, but PUTs have poor scaling when using FI_INJECT
  - Likely caused by some resource exhaustion; debug messages show running out of resources for FI_INJECT
    - Running without inject we see better scaling, but low per-core rate
  - Have some leads, but root cause is not fully understood





INFINIBAND PERFORMANCE

INFINIBAND PERFORMANCE

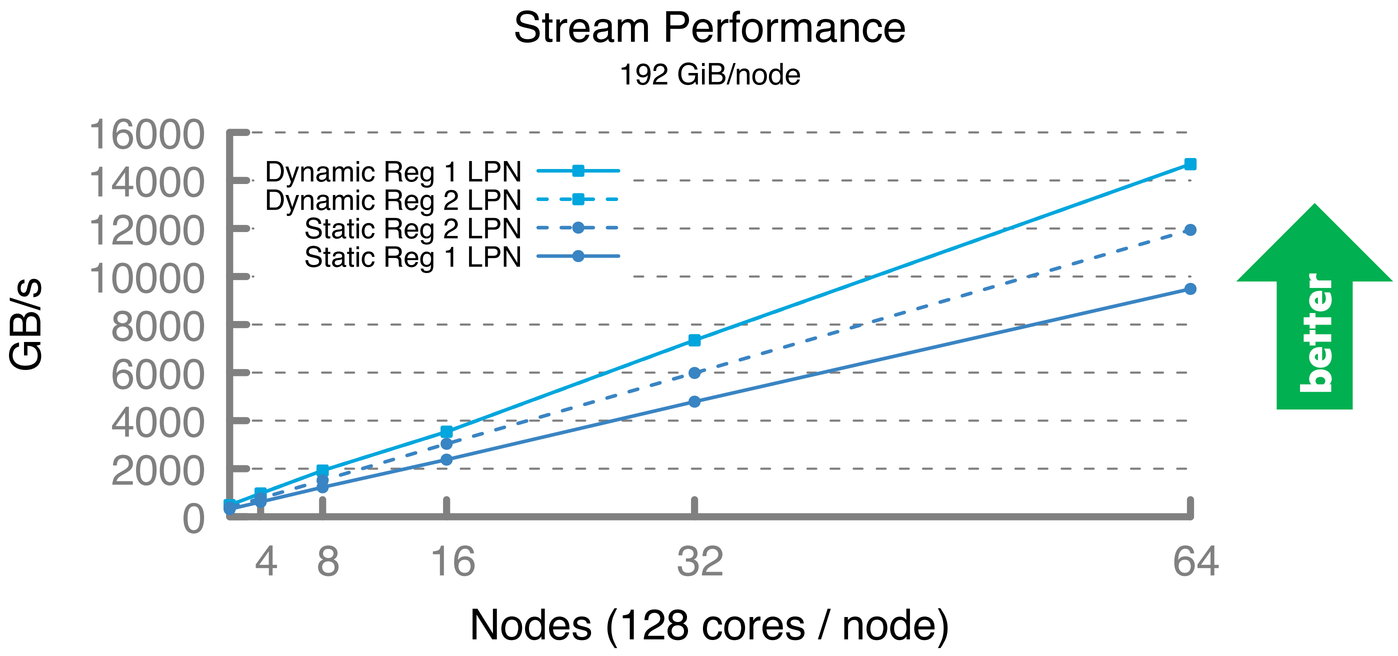
Implementation Background

- We use 'CHPL_COMM=gasnet' with the ibv conduit to target InfiniBand
  - Two production mechanisms for registering memory
    - Segment fast (like SS-11): fixed heap, all memory is registered at program startup
      - Memory is interleaved
      - Static registration enables fast communication
    - Segment large (default): fixed heap, but memory is registered at communication time in 128K chunks
      - Global first-touch (fixed heap results in memory reuse)
      - Dynamic registration in small chunks can limit communication performance
  - Supports running a process per socket
    - We currently disable GASNet shared memory bypass for co-located locales (would prevent blocking AM handler)
  - Runtime threads share a single communication endpoint
    - Serializes communication injection, hurts fine-grained communication
  - Not currently utilizing the GASNet-EX remote atomic API
    - And GASNet does not currently offload atomics on InfiniBand anyway
  - Uses a blocking active-message handler, avoids interference when there are no incoming AMs

INFINIBAND PERFORMANCE

Stream Results

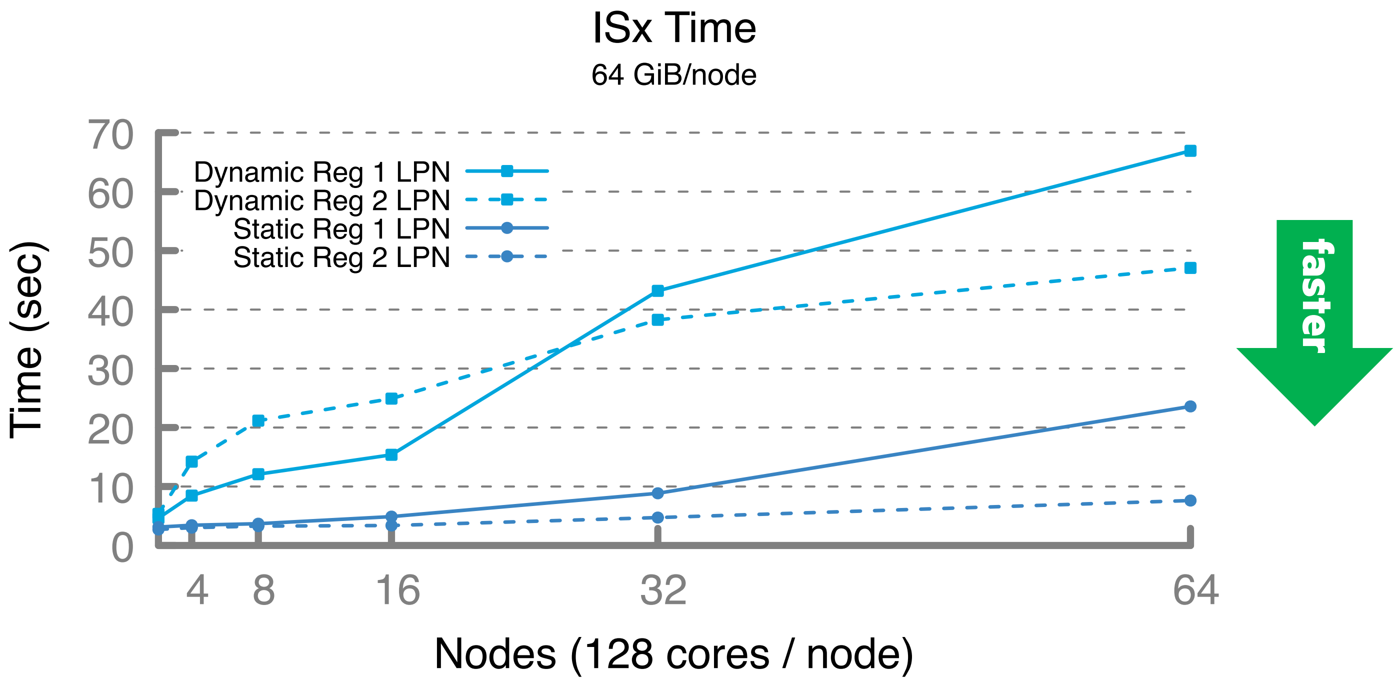
- Dynamic registration can achieve peak stream performance
  - Static registration suffers from the same NUMA penalties as SS-11 (including THP issues)



INFINIBAND PERFORMANCE

ISx Results

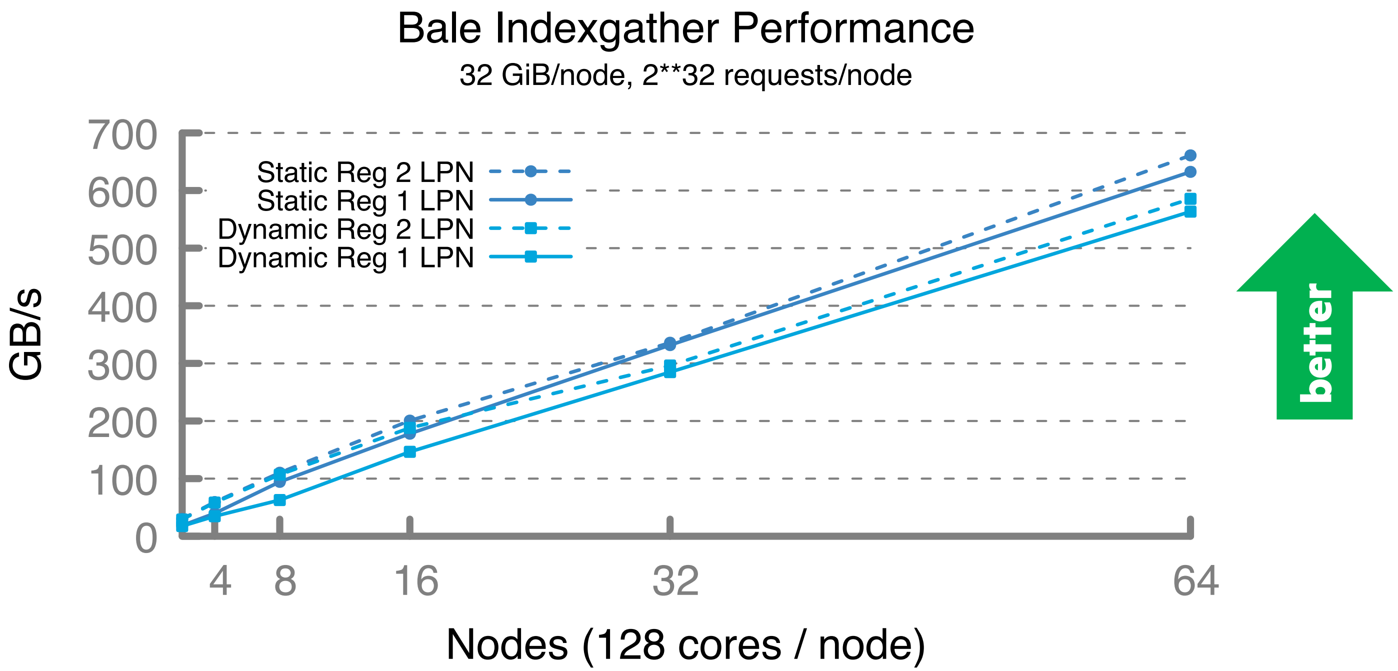
- ISx performance suffers with dynamic registration
  - Registration at comm time and 128K chunking limits bandwidth over a wide address range
- Performance with static registration is much better
  - Locale per socket improves affinity and increases communication concurrency



INFINIBAND PERFORMANCE

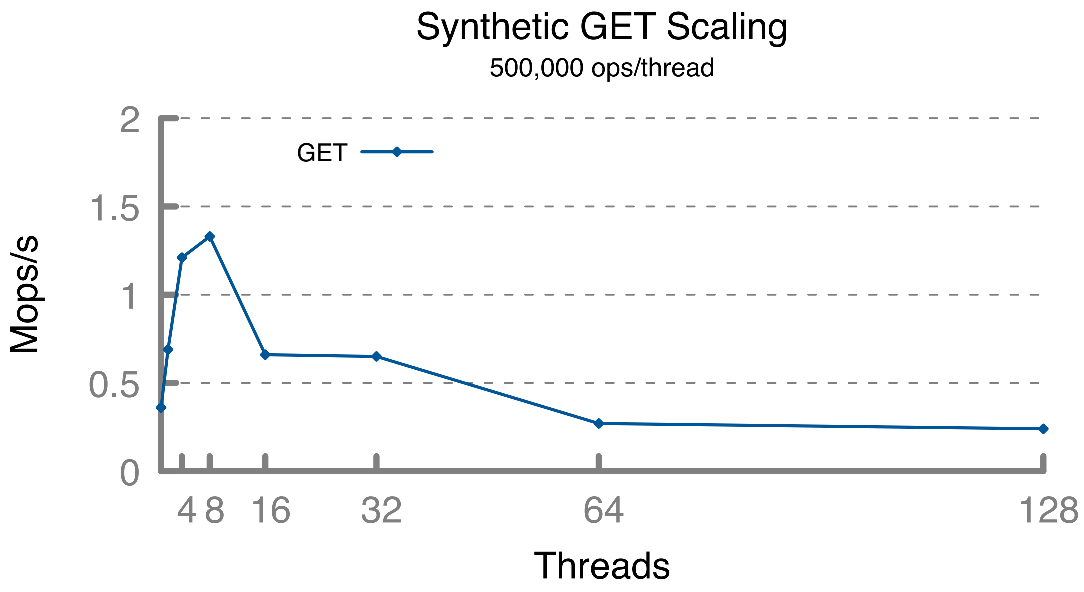
Indexgather Results

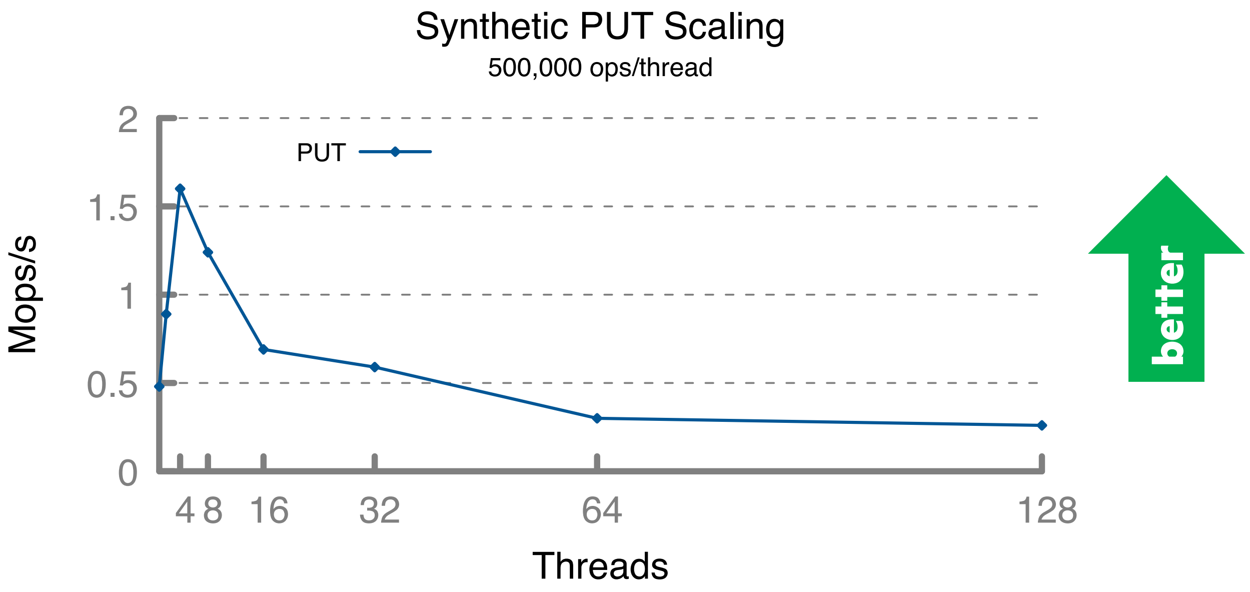
- Indexgather is largely unimpacted by registration type
  - Lots of communication, but between same addresses so dynamic registration overhead is amortized



INFINIBAND PERFORMANCE
Thread Scaling Results

- GETs and PUTs have poor thread scaling
  - Due to injection serialization

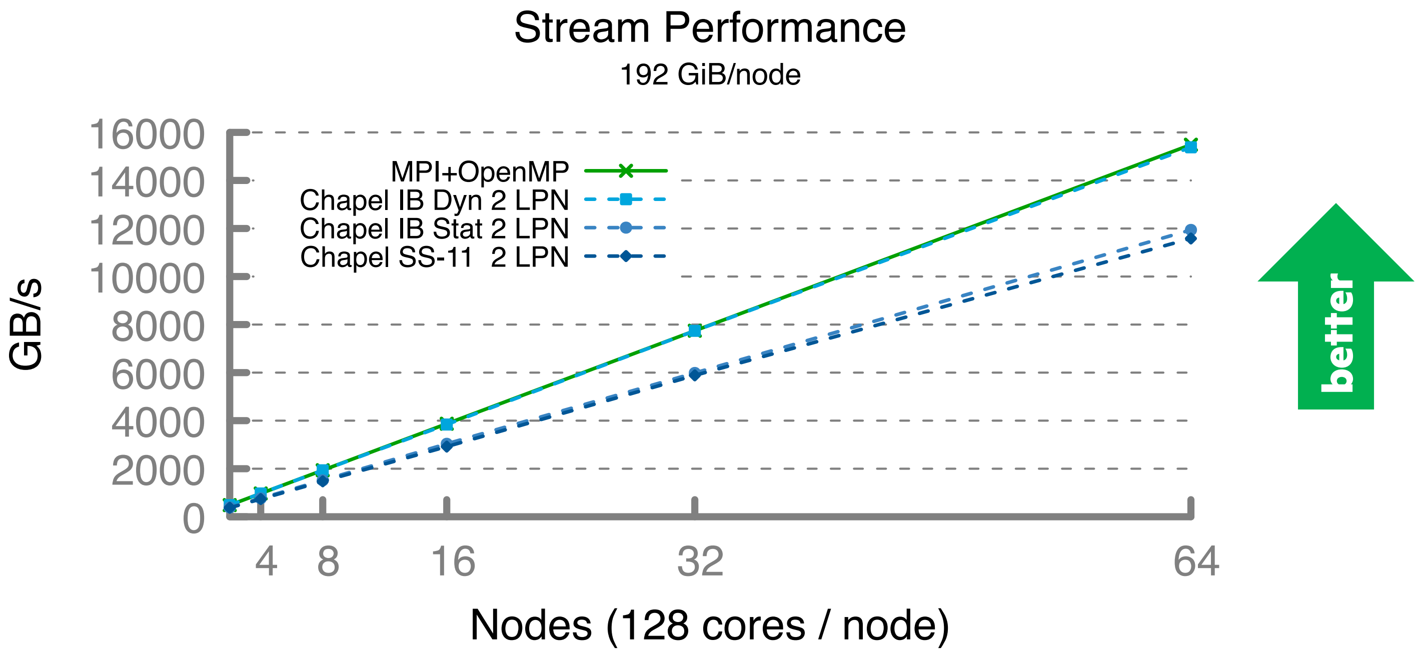




SLINGSHOT VS INFINIBAND

SLINGSHOT VS INFINIBAND
Stream Results

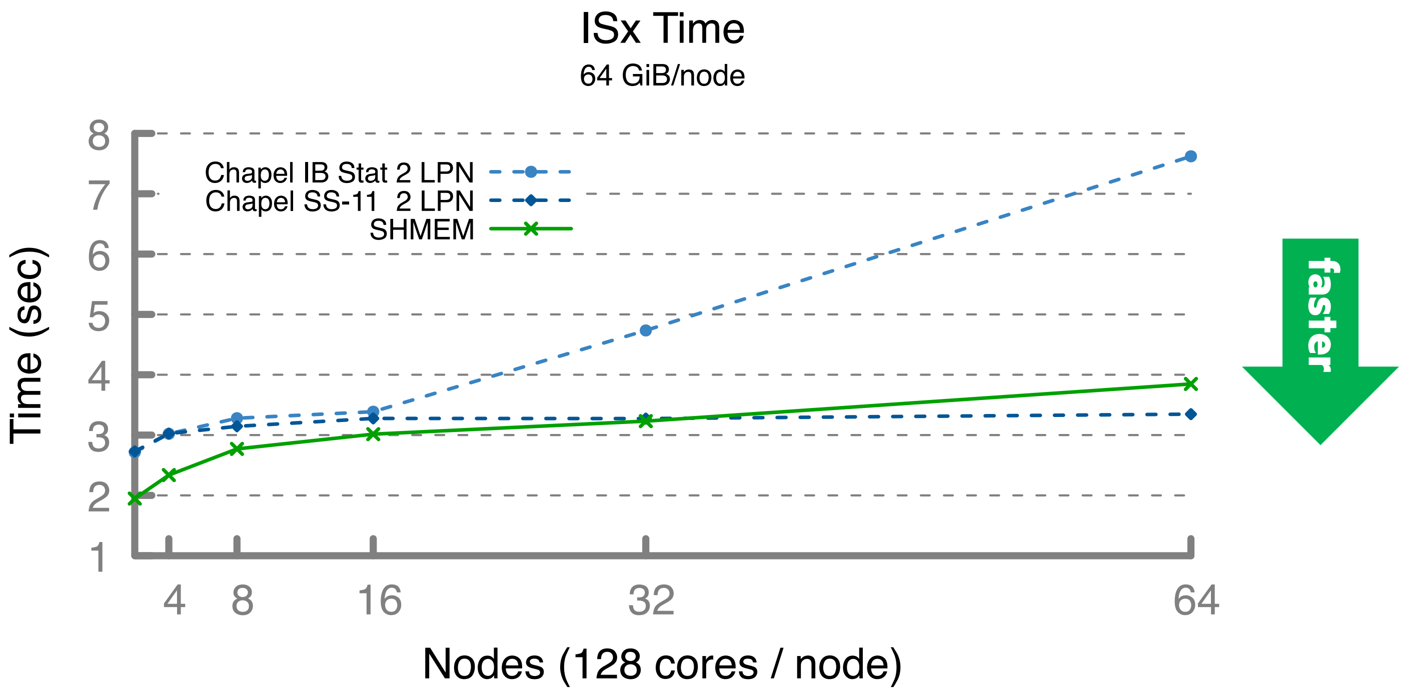
- GASNet dynamic registration matches reference
  - Static registration suffers from suboptimal NUMA affinity



SLINGSHOT VS INFINIBAND

ISx Results

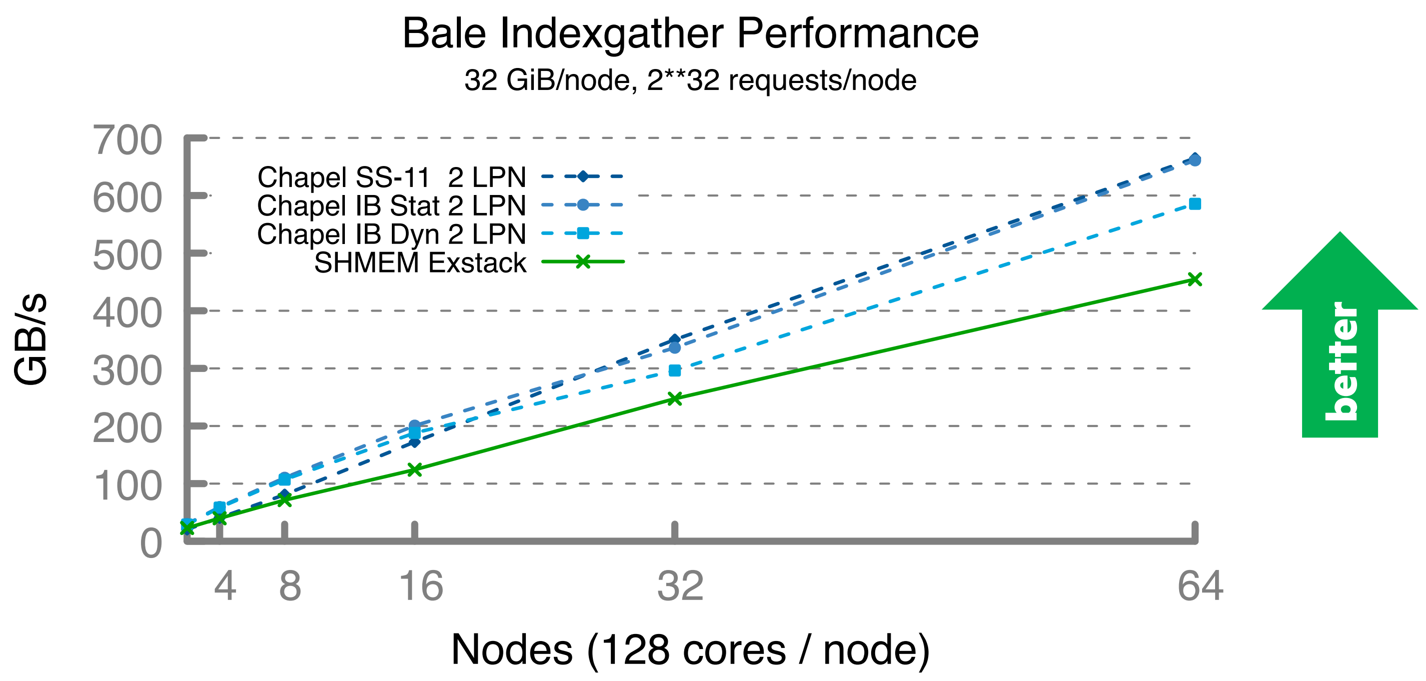
- ISx performance is similar on InfiniBand and Slingshot-11 up to 16 nodes
  - InfiniBand falling off above that, need to investigate root cause
    - Reminder that InfiniBand dynamic registration (not shown) had substantially worse performance



SLINGSHOT VS INFINIBAND

Indexgather Results

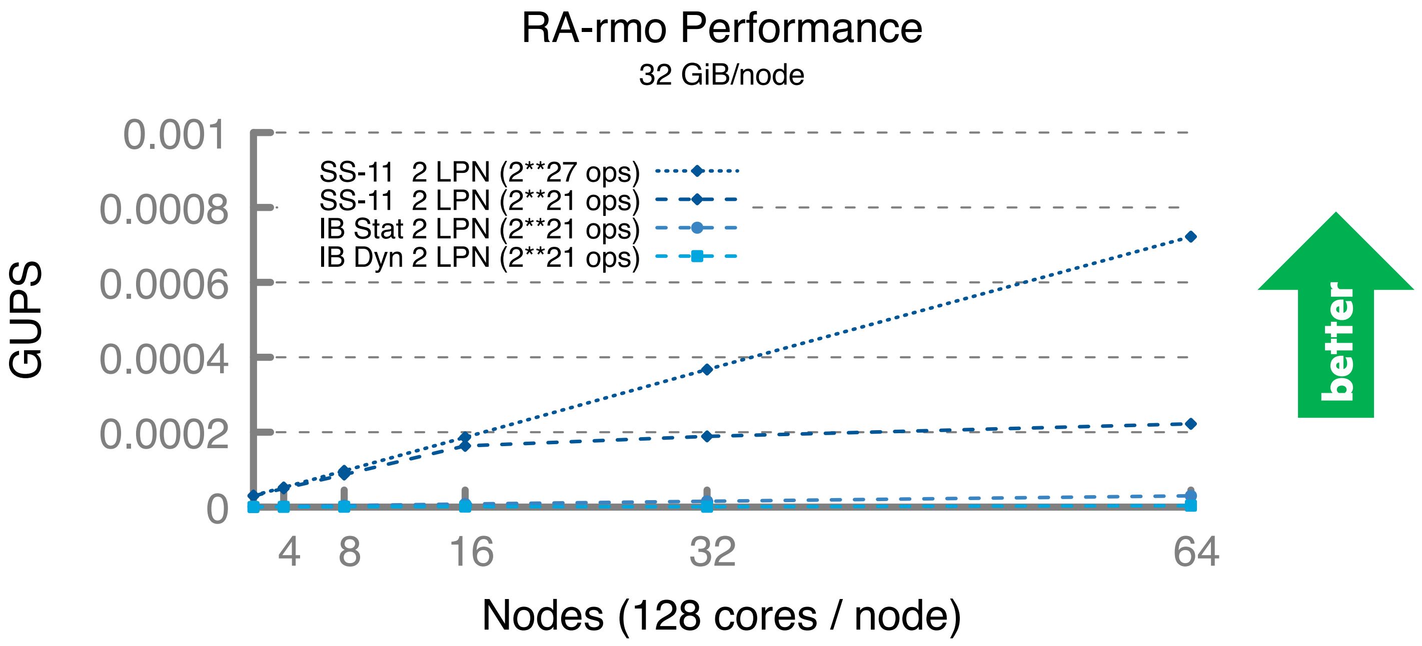
- Indexgather performance is similar on InfiniBand and Slingshot-11



SLINGSHOT VS INFINIBAND

Random Access (RMO) Results

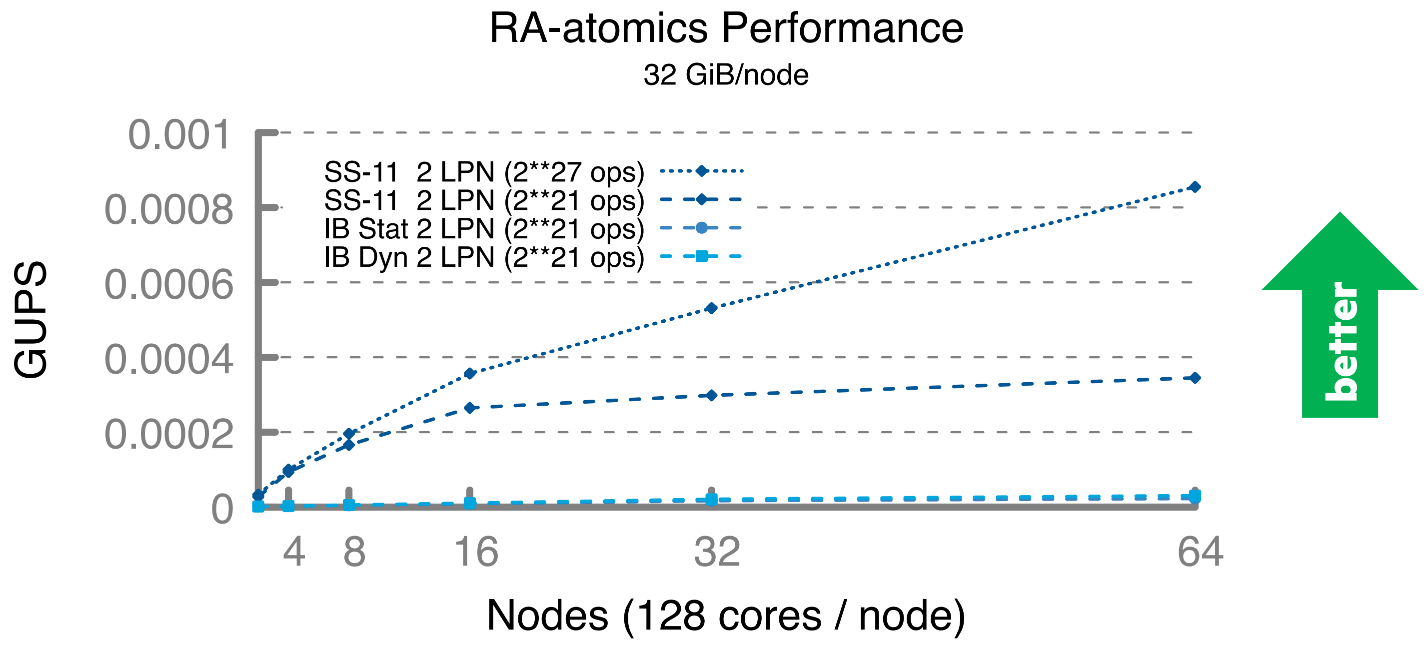
- Injection serialization limits fine-grained performance for gasnet-ibv
  - Dynamic registration further limits performance for operations over a wide address range



SLINGSHOT VS INFINIBAND

Random Access (atomics) Results

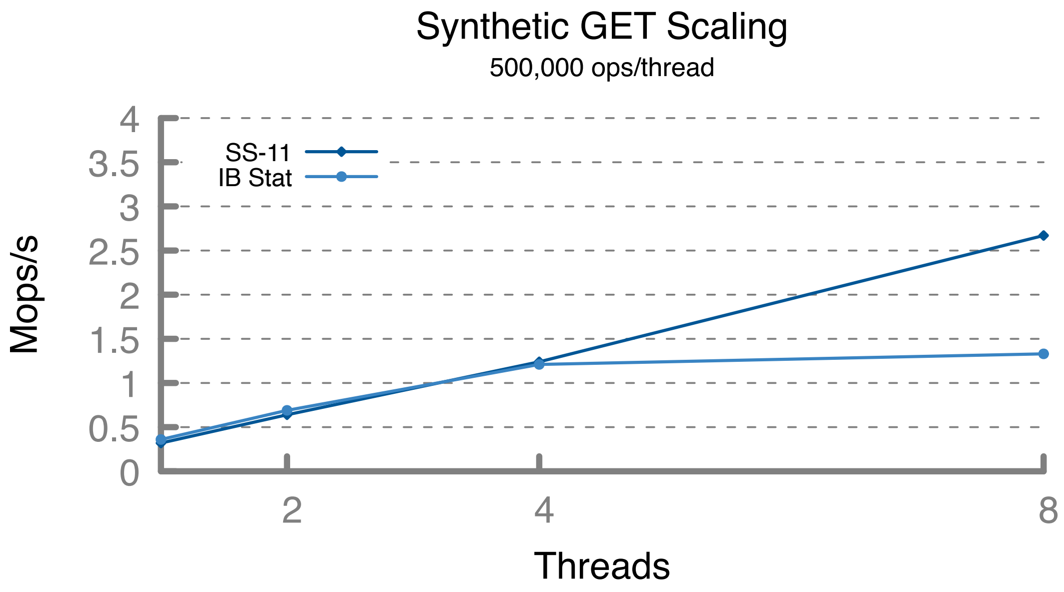
- Injection serialization and lack of offloaded atomics hurts gasnet-ibv performance

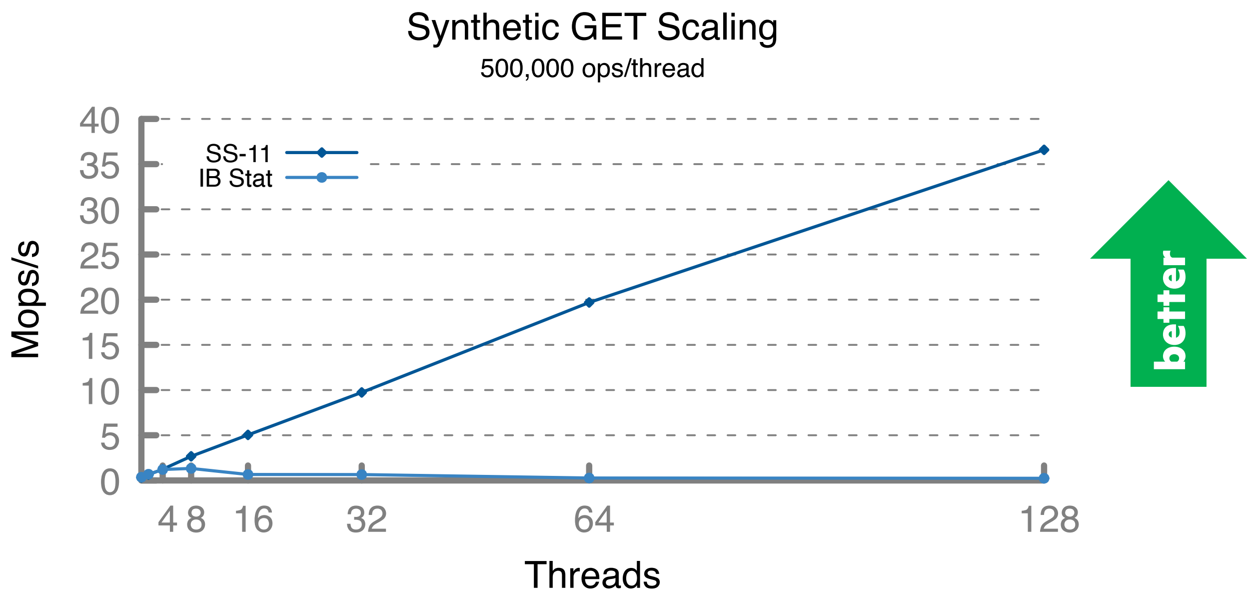


SLINGSHOT VS INFINIBAND

Thread Scaling Results

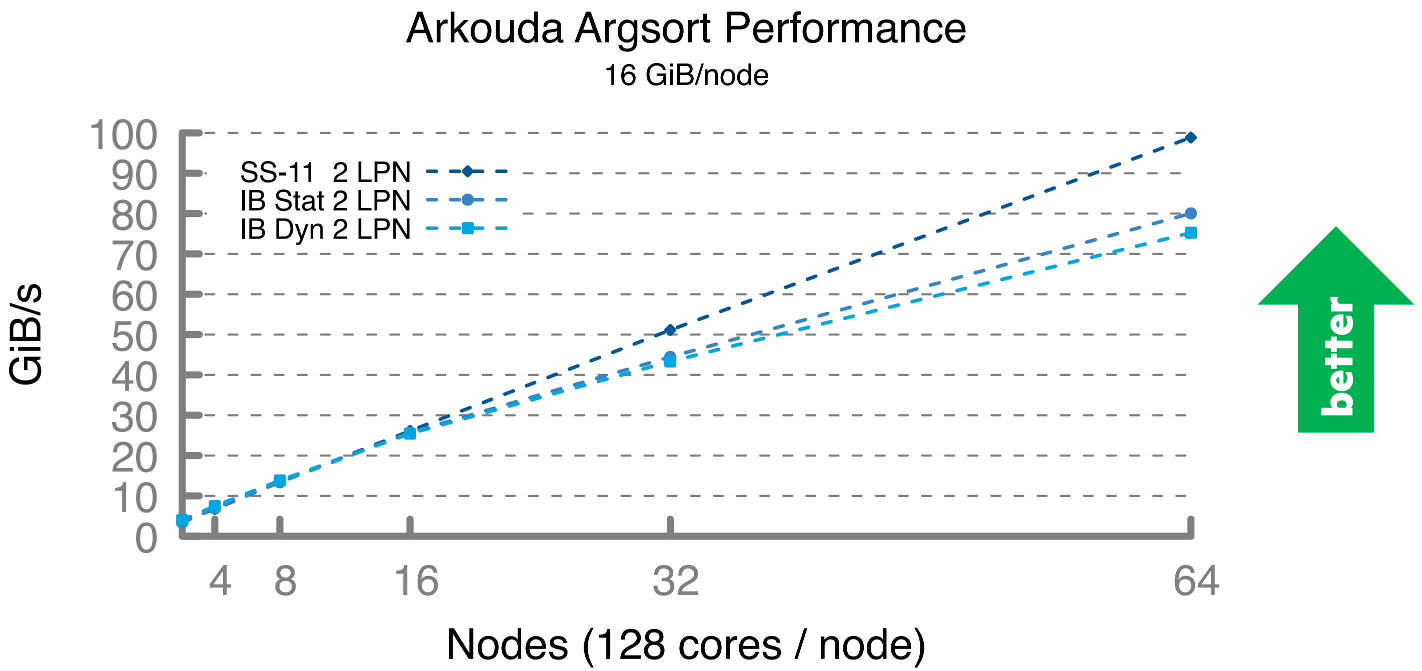
- Serial and up to 4 thread GET rates are similar on InfiniBand and Slingshot-11
  - Only higher InfiniBand thread counts start to fall off from serialization





SLINGSHOT VS INFINIBAND
Arkouda Results

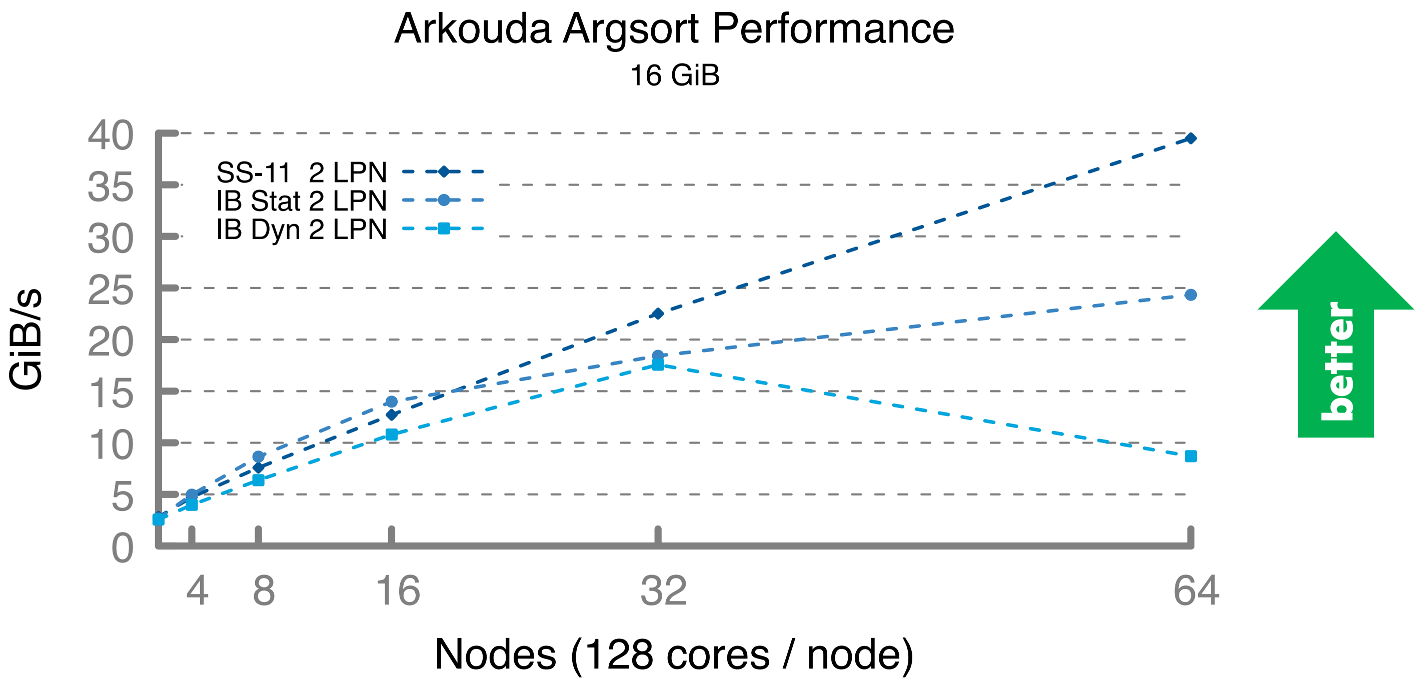
- For larger problem sizes, Arkouda performance is similar on InfiniBand and Slingshot-11



SLINGSHOT VS INFINIBAND

Arkouda Strong Scaling Results

- For smaller problem sizes (or strong scaling) gasnet-ibv performance falls off
  - Smaller transfers start seeing overhead of injection serialization
  - Fewer transfers inhibits amortization of dynamic registration cost



NEXT STEPS

NEXT STEPS
Benchmarks

- Automate performance scaling runs using new ‘chplExperiment’ framework
  - Publish scripts so users can run on their systems too
- Run additional core benchmarks and gather more reference numbers
  - Collect Chapel and reference results for PRK Stencil and NAS FT
  - Collect reference results for Random Access
- Collect reference numbers on InfiniBand
  - Requires figuring out installs or running on a machine with vendor tuned implementations
- Run core benchmarks at higher scales
- Run core benchmarks on multi-NIC systems
- Run additional user applications like CHAMPS
- Port additional benchmarks like Bale, PRKs

NEXT STEPS
Slingshot-11

- Investigate and improve stream performance on transparent huge pages
- Resolve fine-grained performance thread scaling issues
- Add allocation-time dynamic registration and explore ODP
- Evaluate and tune multi-NIC performance
- Expand co-locale support to allow an arbitrary number of locales per node
  - And add support for shared memory bypass
- Explore possibility of using a blocking active message handler

NEXT STEPS
InfiniBand

- Complete and merge code co-developed with GASNet team to upgrade to GASNet-EX API
  - Minimal transliteration of existing GASNet code—does not make use of new features
- Use GASNet-EX remote atomics (ideally with more offload support from GASNet)
- Improve thread scaling by using GASNet-EX multi-endpoint API (also requires GASNet work)
- Evaluate performance of UCX conduit
- Improve registration story, preferably 1 good default instead of being application-dependent
  - Ideally want either allocation time dynamic registration (with a new GASNet API to register) or ODP
    - But ODP (on demand paging) requires good hardware/firmware support, which we're not confident about
- Expand co-locale support to allow an arbitrary number of locales per node
  - And enable GASNet's existing support for shared memory bypass
    - Either requires polling active-message handler or collaboration with GASNet team to only bypass GETs/PUTs

THANK YOU

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