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ECP
EXASCALE COMPUTING PROJECT

U.S. DEPARTMENT OF ENERGY

Efficient Active Message RMA in GASNet Using a Target-Side Reassembly Protocol

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Parallel Applications Workshop, Alternatives to MPI+X (PAW-ATM)
Held in conjunction with SC19
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Overview

- Introduce GASNet-EX
- Introduce Active Messages
- Discuss protocols for implementing Active Messages
- Measure a new “target-side reassembly” protocol for Active Messages on the Cray XC’s Aries network

GASNet-1: Overview

- Started in 2002 to provide a portable network communication runtime for three PGAS languages:
  - UPC, CAF and Titanium
- Primary features:
  - Non-blocking RMA (one-sided Put and Get)
  - Active Messages (simplification of Berkeley AM-2)
- Motivated by semantic issues in (then current) MPI-2.0
  - Dan Bonachea, Jason Duell, "Problems with using MPI 1.1 and 2.0 as compilation targets for parallel language implementations", IJHPCN 2004. **doi.org/10.25344/S4JP4B**

GASNet: Adoption and Portability

- Client runtimes

UPC++
Berkeley UPC
GCC/UPC
Clang UPC
Chapel

Legion
Titanium
Rice Co-Array Fortran
OpenUH Co-Array Fortran
OpenCoarrays in GCC Fortran

OpenSHMEM reference impl.
Omni XcalableMP
At least 7 others known to us

- Network conduits

OpenFabrics Verbs (InfiniBand)
Mellanox MXM and VAPI (InfiniBand)
Cray uGNI (Gemini and Aries)
Intel PSM2 (OmniPath)

UDP (any TCP/IP network)
MPI 1.1 or newer

IBM PAMI (BG/Q and others)
IBM DCMF (BG/P)
IBM LAPI (Colony and Federation)
Cray Portals3 (Seastar)

OFI/libfabric
Sandia Portals4

SHMEM (Cray X1 and SGI Altix)
Quadric elan3/4 (QsNet I/II)
Myricom GM (Myrinet)
Dolphin SISCI

Shared memory (no network)

- Supported platforms
  - Over 10 compiler families, 15 operating systems and dozens of architectures

* These lists and counts include both current and past support

GASNet-EX: Overview

- GASNet-EX is the next generation of GASNet
  - Addressing needs of newer programming models such as UPC++, Legion and Chapel
  - Incorporating over 15 years of lessons learned
  - Provides backward compatibility for GASNet-1 clients
- Motivating goals include
  - Support more client asynchrony
  - Enable more client adaptation
  - Decrease memory footprint
  - Improve threading support
  - Support offload to network h/w
  - Support multi-client applications
  - Support for device memory

GASNet-EX: Status

- GASNet-EX is still evolving
  - Not every new feature has been implemented yet
  - Most have - with benefits shown in prior work
- Four prominent clients actively adopting GASNet-EX
  - UPC++ and Berkeley UPC Runtime require GASNet-EX
  - Chapel embeds GASNet-EX
  - Legion has started work to use EX-specific features

GASNet-EX: New Features Include

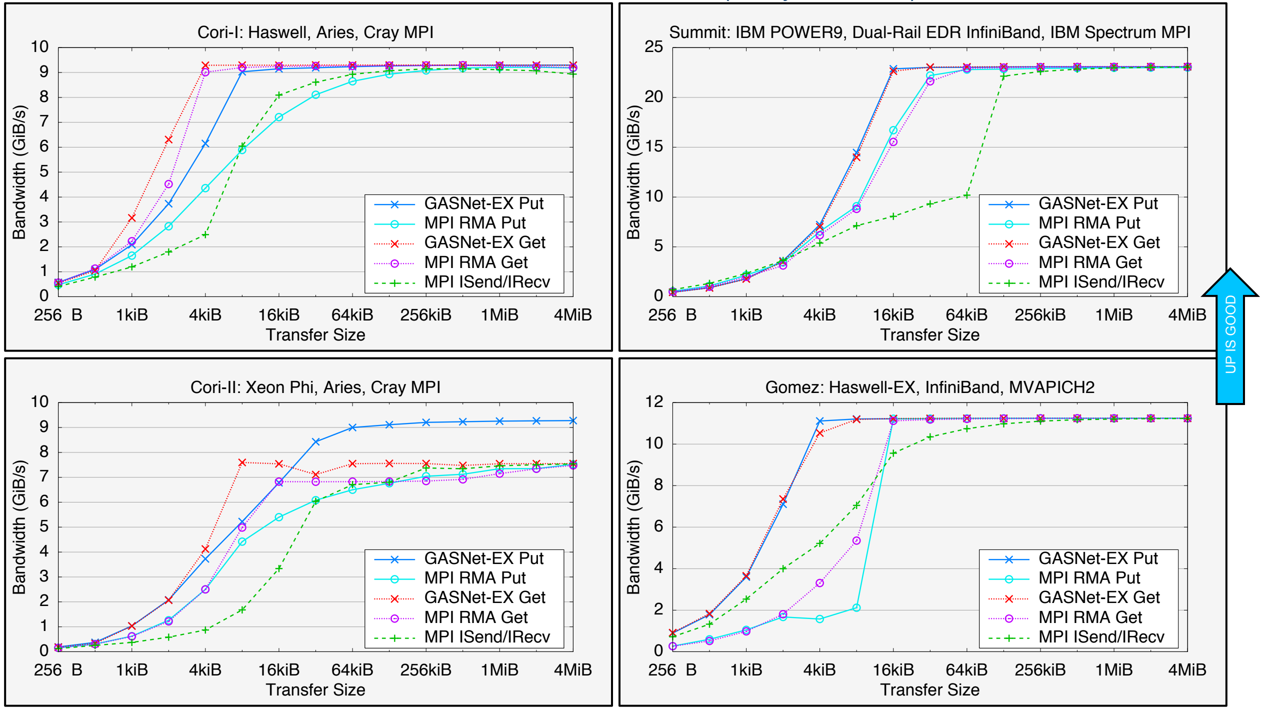
- Local completion control
  - Improved control over buffer lifetime to increase overlap
- Immediate-mode injection
  - Avoid stalls in low-resource conditions
- Negotiated-payload Active Messages
  - Construct messages in GASNet's buffers to avoid **`memcpy()`**
- Remote atomic operations
  - Utilize offload capabilities in modern network interfaces
- Subset teams
- Numerous small API additions and improvements

For details see Languages and Compilers for Parallel Computing (LCPC'18). **doi.org/10.25344/S4QP4W**

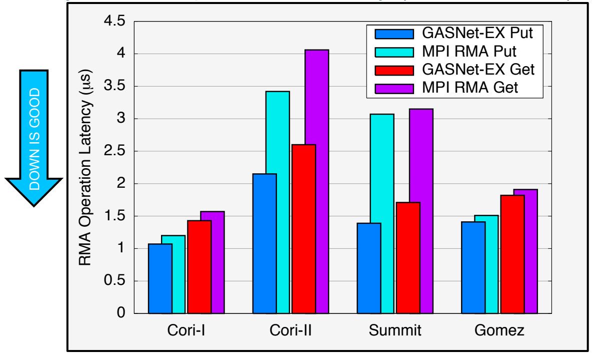
Status: GASNet-EX RMA Performance Versus MPI

- Three different MPI implementations
- Two distinct network hardware types
- On four systems the performance of GASNet-EX matches or exceeds that of MPI RMA and message-passing:
  - 8-byte Put latency 6% to 55% better
  - 8-byte Get latency 5% to 45% better
  - Better flood bandwidth efficiency, typically saturating at ½ or ¼ the transfer size

Uni-directional Flood Bandwidth (many-at-a-time)



8-Byte RMA Operation Latency (one-at-a-time)



GASNet-EX results from v2018.9.0 and v2019.6.0. MPI results from Intel MPI Benchmarks v2018.1.
For more details see Languages and Compilers for Parallel Computing (LCPC'18).
doi.org/10.25344/S4QP4W

More recent results on Summit here replace the paper's results from the older Summitdev.

Active Messages (AM)

- AM is a *restricted* form of remote procedure call
  - Executes code (handler) on a remote node
  - Request handler may *only* send back an optional Reply
  - No other communication is permitted in AM handlers
- Request and Reply APIs take
  - Integer “handler index” (which table entry to run)
  - Zero or more 32-bit integer arguments
  - Optional bulk data payload
- These arguments and payload are provided to handler

AM Payloads / Problem Statement

- Three “categories” depending on presence and handling of the optional payload
  - Short: No payload
  - Medium: Payload buffered by implementation
  - Long: Payload delivered to client-specified address
    AM delivery coupled with RMA payload Put
- AM Long presents implementation challenge: to both...
  - Leverage RDMA h/w for most efficient payload transfer
  - Ensure the payload is in-place before handler runs

AM Long Protocol Tuning

Evaluating alternatives on the Cray XC's Aries network

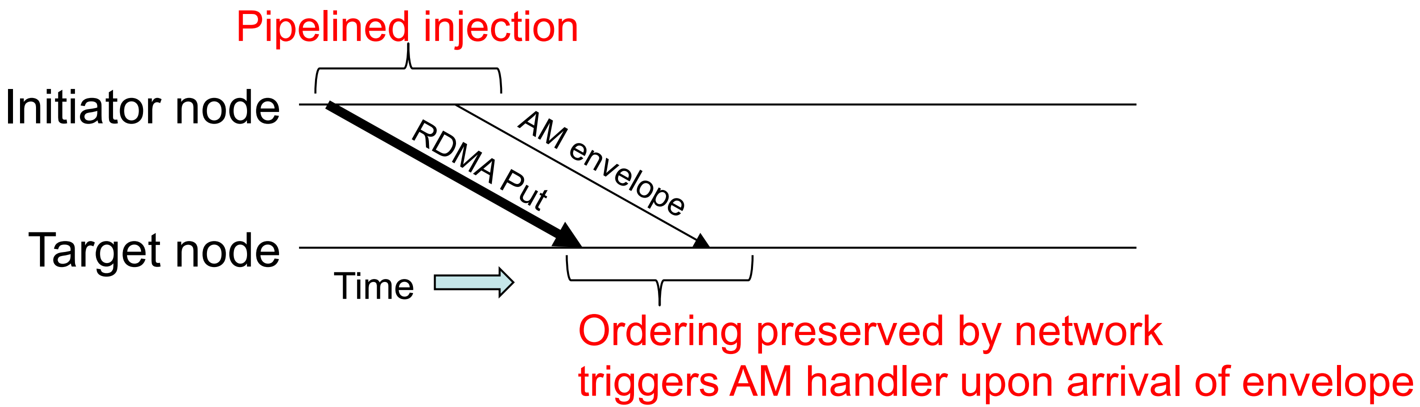
- Latency between initiator and target
- Overheads (CPU use on initiator and target)
- Bandwidth between initiator and target
- Sensitivity to attentiveness
  - Is more than one library entry needed to complete?
- Timely signaling of local completion
  - Allows initiator to reuse or free payload source memory

"L", "o" and "g" of LogP model

AM Long Protocols 1

Ordered Networks (including selectively ordered)

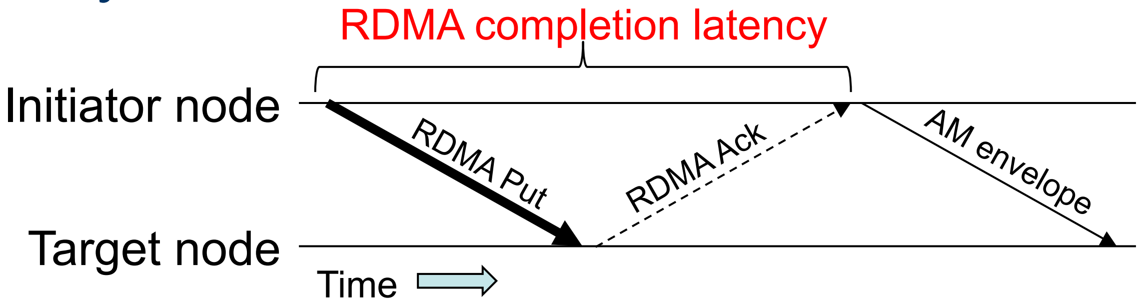
- Simple if available, but seldom “free”
- Aries provides only at cost of defeating multi-pathing



AM Long Protocols 2

Initiator Chaining

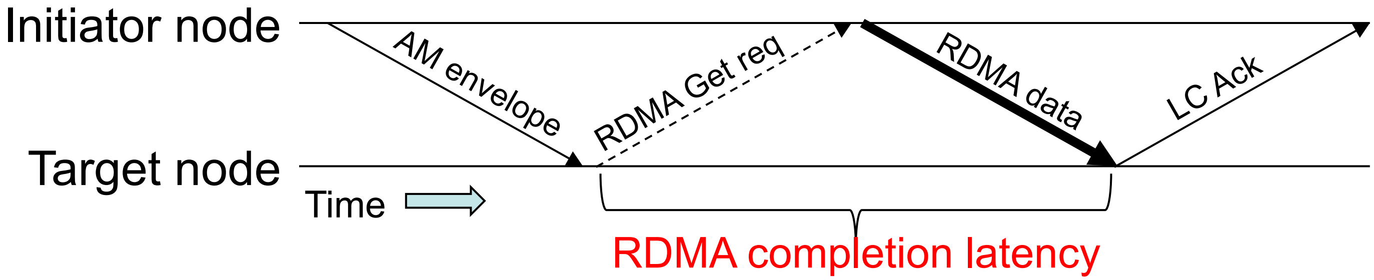
- Simplest but also poor by most of our metrics
- Synchronous variant (aka “put-sync-send”) ties up injector until Put is complete [aries used this previously]
- Asynchronous variant relies on attentiveness



AM Long Protocols 3

Rendezvous Get

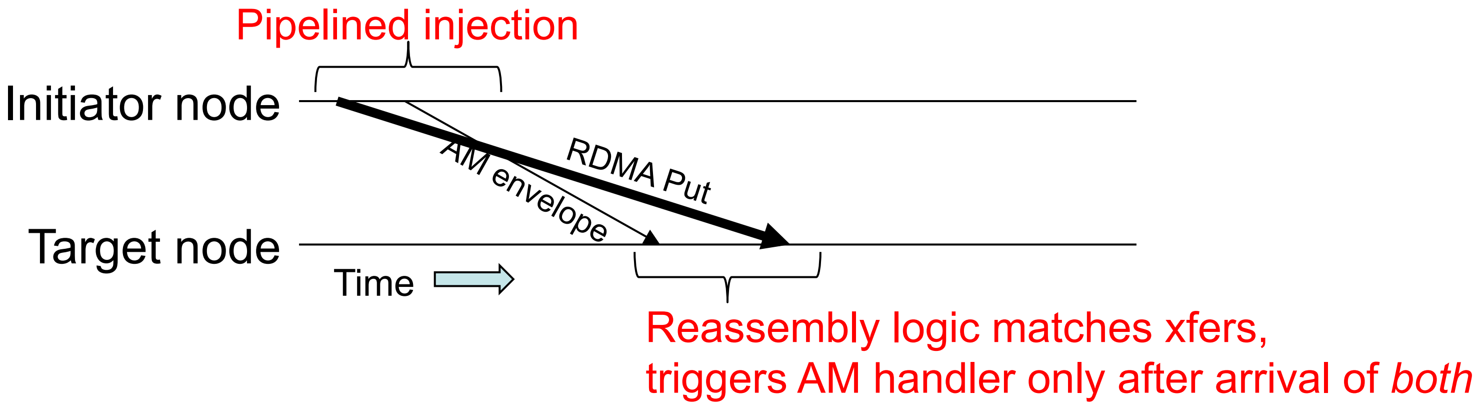
- Initiator adds source address to the message envelope
- Target uses an RDMA Get for the payload
- Adds a round-trip latency
- Also delays notification of local completion



AM Long Protocols 4

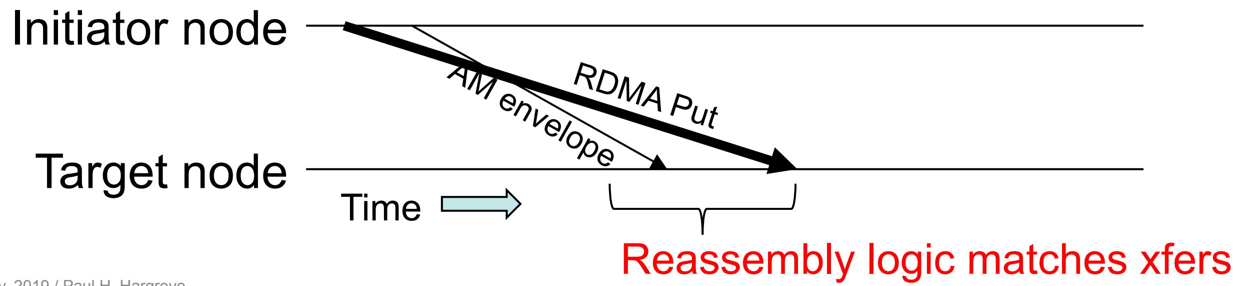
Target-Side Reassembly

- Subject of this presentation
- At very high level:
  - Payload and envelope injected into *unordered* network
  - Logic at target is *tolerant* of any reordering



Target-side Reassembly

- Both envelope and payload sent without delay
  - Can leverage multiple paths of networks like Aries
  - No attentiveness problem on either end
  - No network round-trips, and thus no stalls
  - No delays in signaling of local completion
  - However, additional network-specific metadata is required to allow target to match them



Target-side Reassembly On Aries

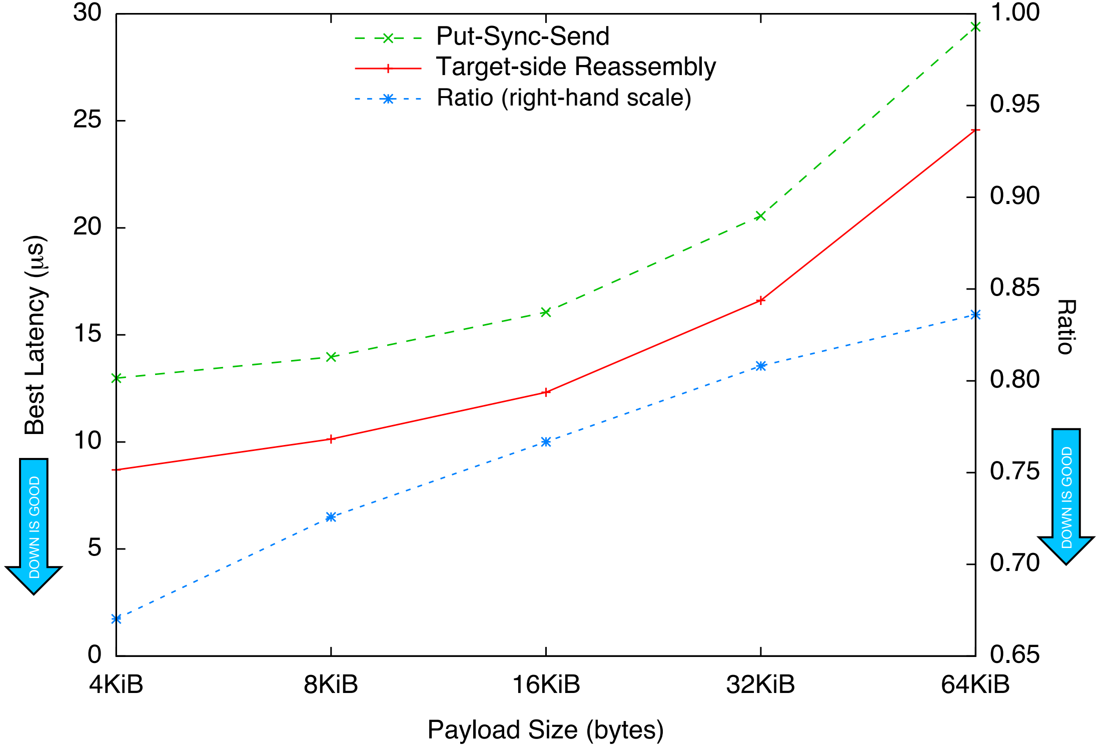
- Target needs a “nonce” to match AM envelope + payload
- Fairly simple to add a field to AM envelope
  - But we didn’t actually need to in this case
    - An existing buffer management field “fits the bill”
- Not always simple to deliver a nonce with an RDMA Put
  - Other network APIs have “Put with immediate data”
  - uGNI API for Aries has a 32-bit source identifier
    - Under software control, allowing us to steal some bits

Performance Results

- Measurements on NERSC's Cori Phase II
  - Cray XC30
  - 1.4GHz Xeon Phi CPUs
- First results: AM Long ping-pong latency
  - At most one message in flight at any time:
    - Node 0 sends Request of given size
    - Node 1 issues Reply of same size
  - Report average time to complete many iterations

AM Long Ping-Pong Latency

- Figure shows the range 4KiB – 64KiB
- At 4KiB
  - Old: 13.0µs
  - New: 8.7µs
  - Ratio: 33% faster
- 4KiB – 1MiB range: reductions between 3.7µs and 6.1µs



Measuring One-way Injection Overhead

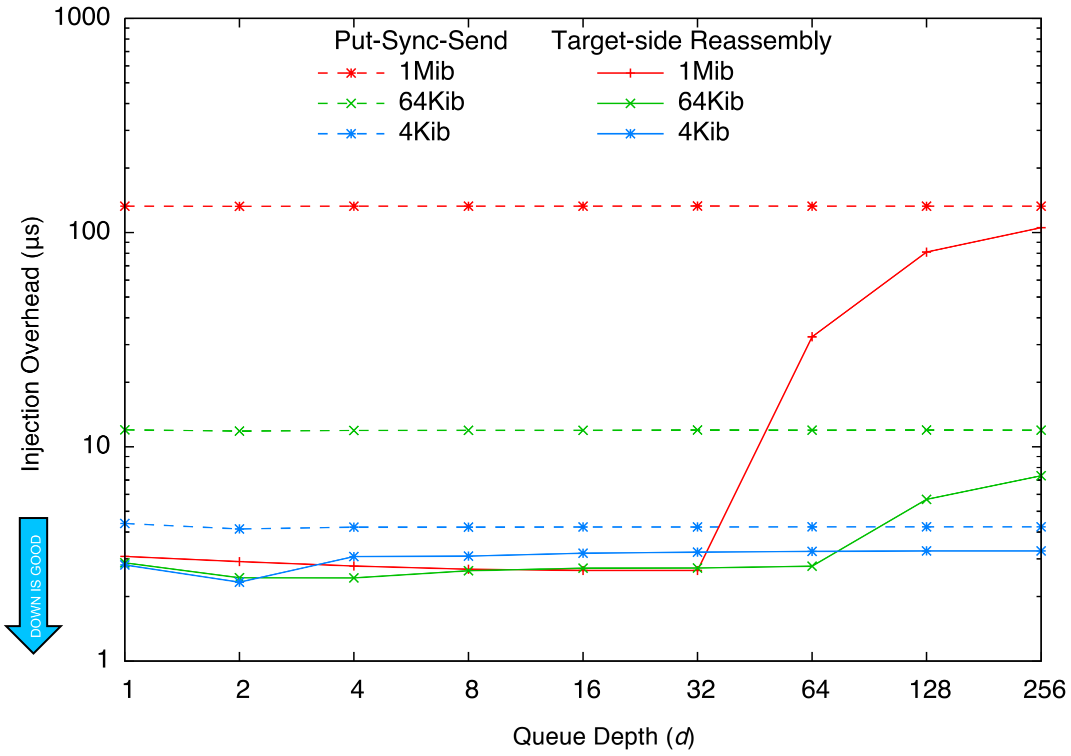
- Where put-sync-send must block for payload RDMA, target-side reassembly can return immediately
  - Reduced injection overhead ➔ more overlap
- Report the average time for many repetitions of

```
start timer
for (int i=0; i < d; ++i)
        gex_AM_RequestLong(..., size, ...);
end timer
drain network
```

- Report for various values of queue depth *d* and *size*

Reduced Injection Overhead

- Time to inject *d* AMs of a given *size*
  - *d:* on the x-axis
  - *size:* color & symbol
  - old/new: dashed/solid
- Average injection time is up to **50x** faster
- Remains faster when flow-control sets in



Conclusions

- Presented several algorithms for AM Long on Aries
- Identified “target-side reassembly” as most promising
- Overcame challenge of coupling nonce with payload
- Presented microbenchmarks showing improvement
- We believe this algorithm is a good choice for other networks with similar properties
- New implementation released in GASNet-EX 2019.9.0

THANK YOU

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GASNet-EX

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