Intel and PGAS: Our Multifaceted PGAS Activities and Community Engagements

Ulf Hanebutte and James Dinan

OpenSHMEM Workshop
August 5, 2015

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Intel and PGAS

We've been busy:

- Looking at PGAS and engaging with this community
- Internalizing PGAS usage models and requirements
- Participating in the development of OpenSHMEM

We aim to:

1. Ensure PGAS models can access to full capabilities of Intel HPC offerings
2. Advocate for needs of PGAS users within Intel
3. Participate in community effort to improve parallel programming models

In this talk:

- Skip the typical boring product spiel
- Give an overview of some recent PGAS work at Intel

Talk Outline

Extensions to OpenSHMEM and issues they address:

1. *Contexts*: comm./computation overlap and multithreading
2. *Counting puts*: point-to-point synchronization
3. *One-sided append*: receiver buffer management
4. *Federations*: topology-aware mapping

Open Fabrics Interface:

- New industry standard low-level communication API
- Aligned with PGAS features and performance targets
- Intel is a key partner in industry consortium

Communication Contexts

Enables programmer to express multiple independent streams of communication

Key programming model challenges addressed:

- Improve support for communication/computation overlap
- Improve efficiency of communication from multithreaded PEs

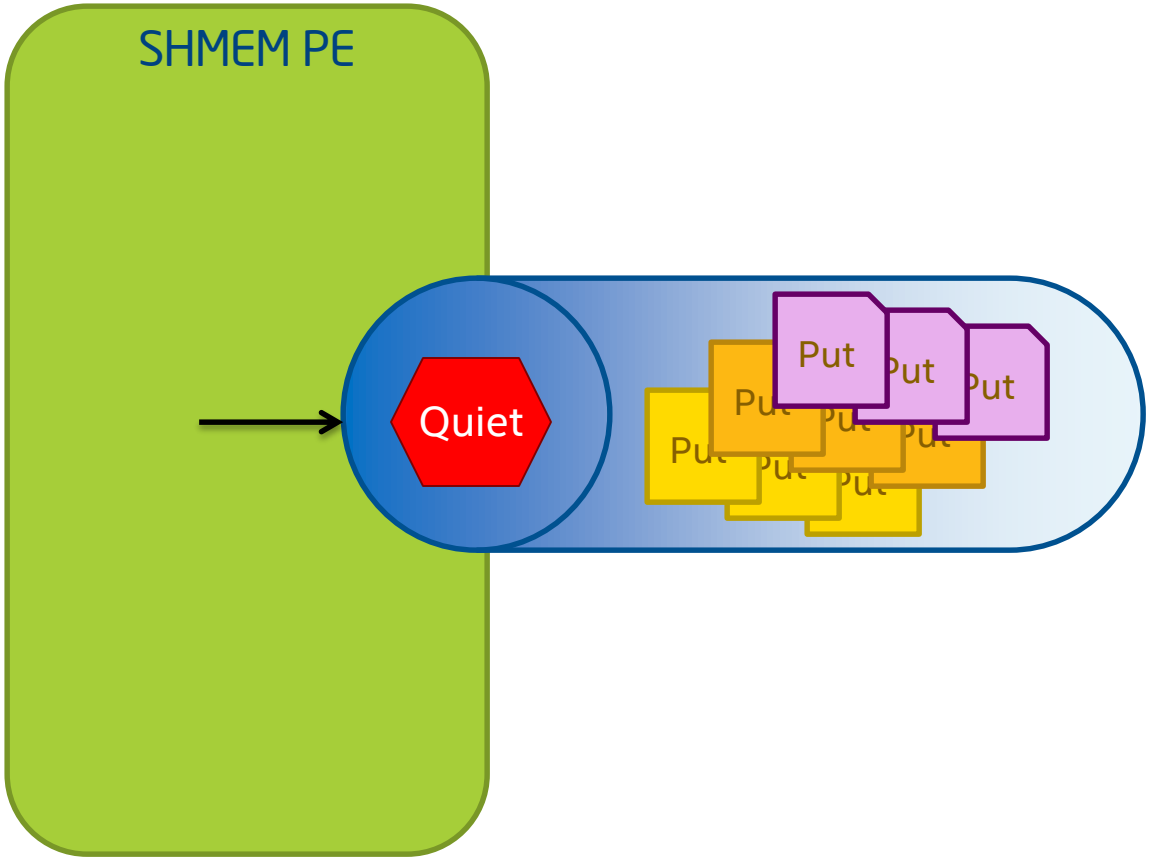
Simple, thread-safety solutions are inefficient

- SHMEM has a single communication stream for each PE, as a result
- Communication overlap across threads is not possible; fence/quiet affects all threads
- Threads share resources within the runtime system, resulting in synchronization overheads

More information:

- Formal proposal and API: https://github.com/jdinan/openshmem-contexts
- Redmine #177: http://bongo.cs.uh.edu/redmine/issues/177

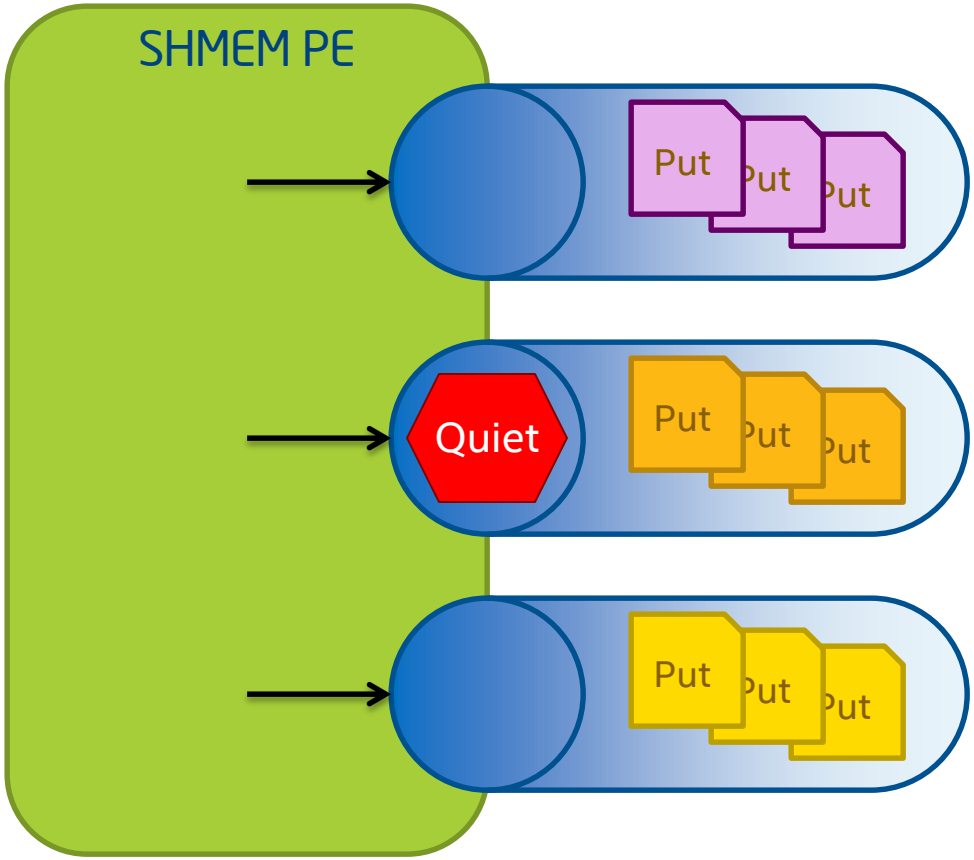
Communication in OpenSHMEM 1.x



Not possible to choose which operations are impacted by the quiet

Not possible for subset of operations to overlap with the quiet

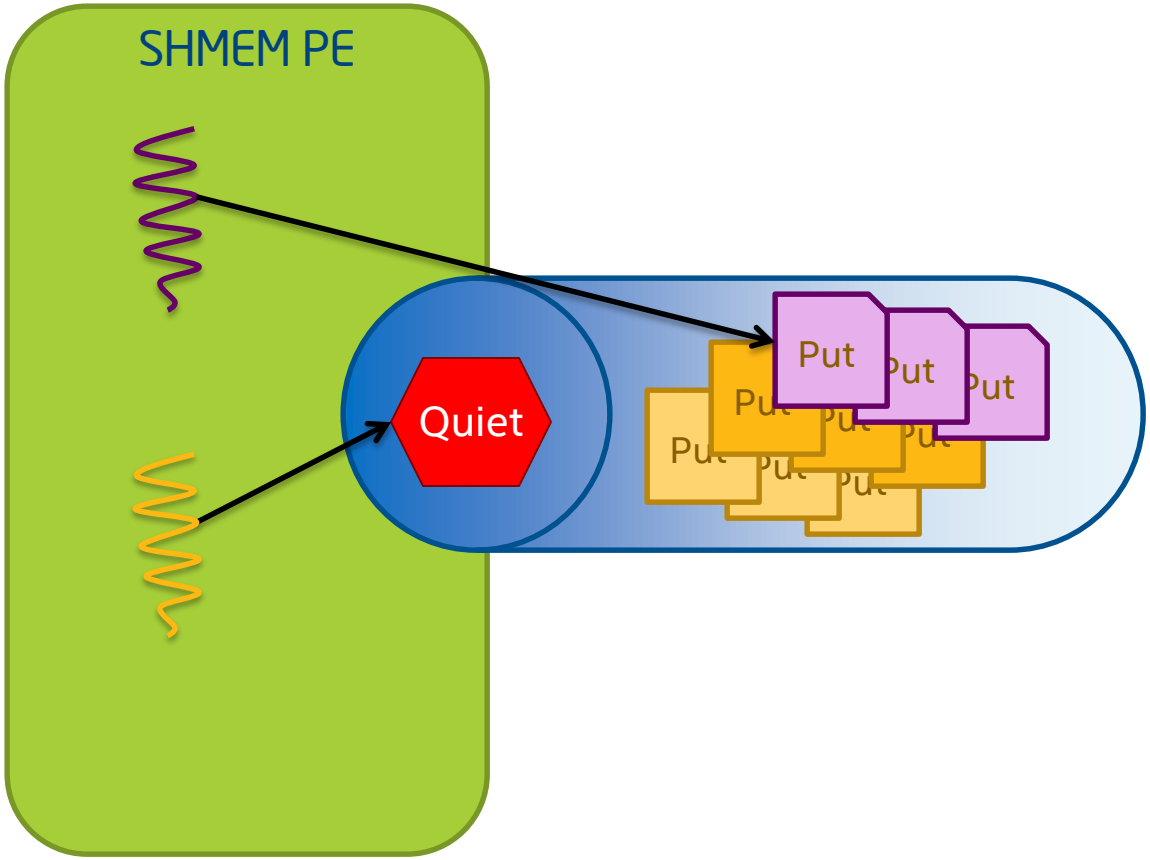
Communication Contexts and PEs



Contexts can be used to isolate streams of communication ops from a PE

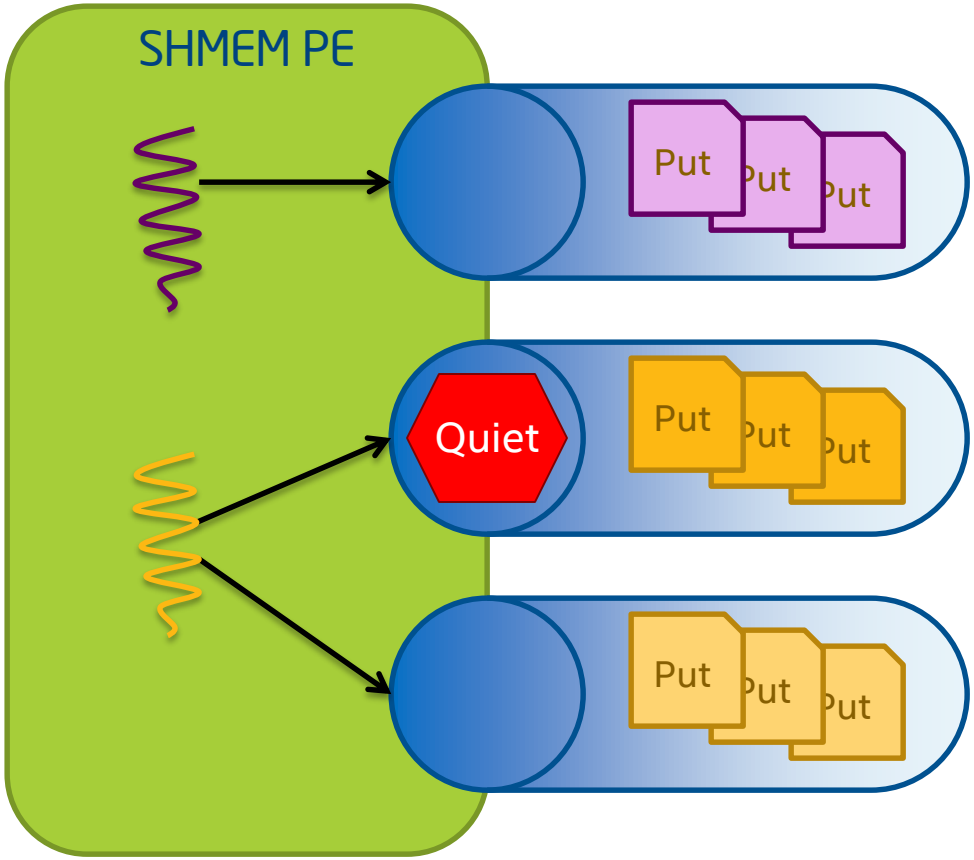
Enable communication/computation overlap and pipelining

Simple, Thread-Safe Communication



Quiet from one thread interacts with other thread's communication

Communication Contexts and Threads



Contexts can be used to isolate streams of communication ops from threads

Threads can further isolate streams by using multiple contexts

Multithreaded Prog. with Contexts

1. OpenSHMEM resource domain: shmem_domain_t
   - User creates a local resource domain to represent each thread
   - Single-threaded codes can use existing SHMEM_DOMAIN_DEFAULT
   - Allows implementation to assign resources to thread
   - Used to eliminate resource sharing and synchronization

2. OpenSHMEM communication context: shmem_ctx_t
   - Threads create contexts on their resource domain
   - Each context is a separate unit of overlap

3. Context object passed to one-sided communication operations
   - Context object rather than thread-local storage (TLS)
   - Eliminates lookup overhead and avoids threading package dependence

NAS Integer Sort (IS) Benchmark

Key Exchange Code

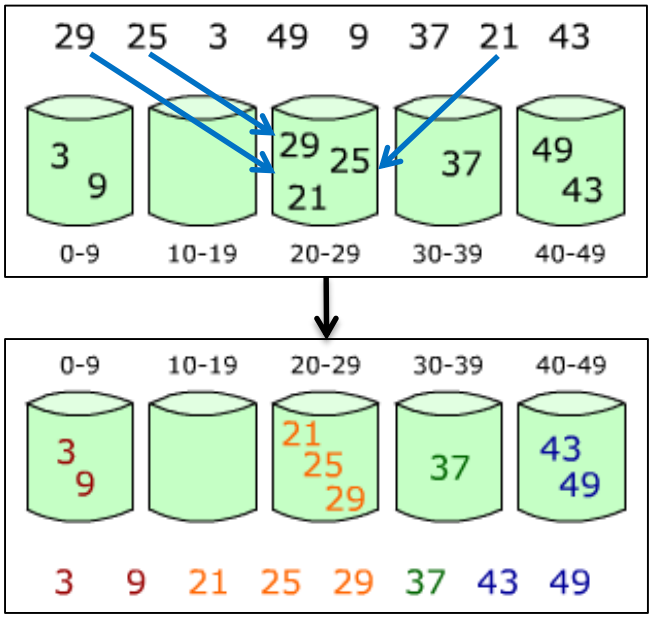
```
shmem_barrier_all();

for (i = 0; i < num_pes; i++) {
  int k1 = send_offset[i];
  int k2; // target offset

  shmemx_ctx_int_get(ctx[0], &k2,
            &recv_offset[me], 1, i);

  shmemx_ctx_int_put_nb(ctx[1],
            key_buff2+k2, key_buff1+k1,
            send_count[i], i);
}

shmem_barrier_all();
```



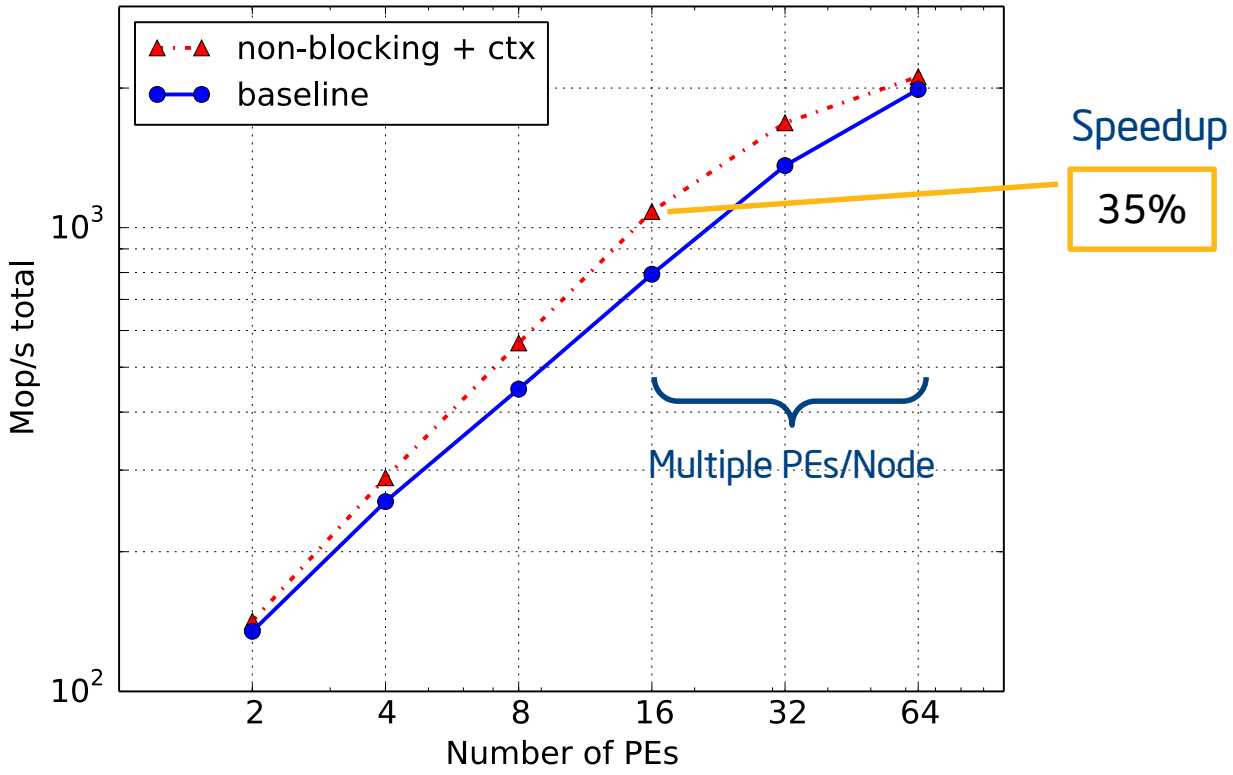
Picture Credit: Wikipedia

Parallel bucket sort on a set of small integers

- Single-threaded benchmark, show impact of contexts on overlap control
- Contexts allow blocking gets to overtake nonblocking puts

Key exchange is the main contributor to communication

NAS IS Strong Scaling



Significant speedup from added overlap control via contexts

Speedup decreases when number of PE/Node increases

- All-to-all communication volume in the fabric increases as square of num. PEs
- Loss of speedup caused by sharing the underlying Portals/InfiniBand network

OpenSHMEM 1.x Pt-to-Pt Synchronization

Consistent Barrier

```
for (pe = 0; pe < NPES; pe++)
  shmem_putmem(data, PE);

shmem_barrier_all();
```

Point-to-Point Flags

```
for (pe = 0; pe < NPES; pe++)
  shmem_putmem(data, PE);

shmem_fence();

for (pe = 0; pe < NPES; pe++)
  shmem_int_add(flag, -1, PE);

shmem_int_wait_until(flag, EQ, 0);
```

Strong ordering semantic

- Remote completion of all operations

Globally synchronizes PEs

- Ensure next phase can reuse buffers
- Expensive

Point-to-point synchronization

- O(P) messages for pt-to-pt
- O(log P) for barrier

Sync. not visible to runtime system

- Limits ability to optimize

Bundling Communication and Sync.

```
shmem_ct_create(&ct);

for (pe = 0; pe < NPES; pe++)
  shmem_put_ct(ct, data, …, PE);

shmem_ct_wait(ct, NPES);
```

Bundle comm. and synchronization together in a single operation

- Counter is incremented at the target after the operation has completed
- The receiver can do the increment in ct_get/wait, using completion events

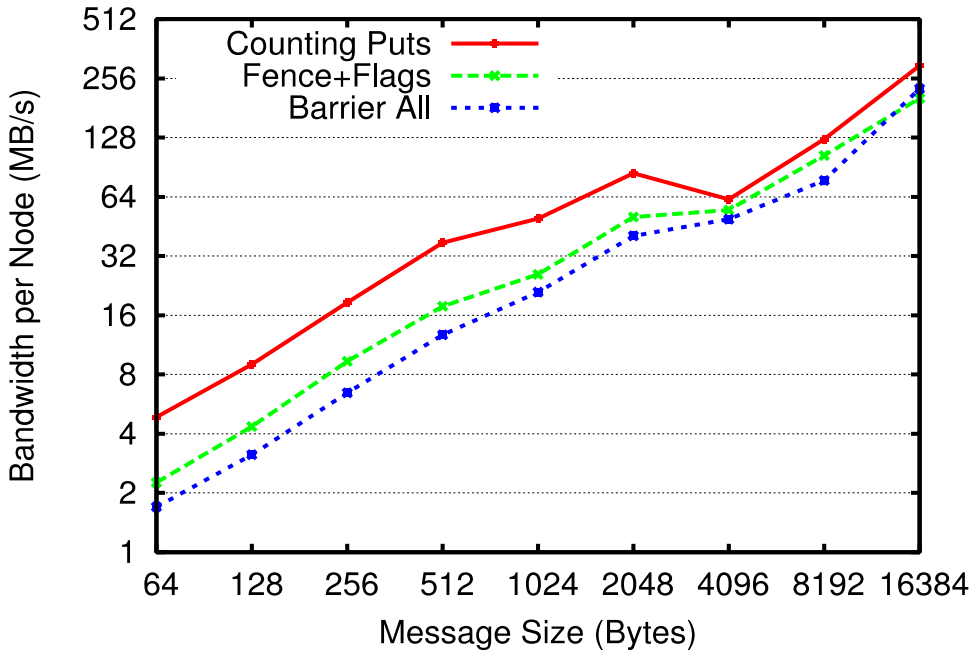
Bundling enables implementation optimizations

- Leverage hardware capabilities (ordering, bundling, events, …)

Enables a receiver-managed implementation

- Can eliminate flag update communication

All-to-All Bandwidth (180 PEs)



Measure bandwidth achieved in all-to-all

- 15 Node QDR InfiniBand cluster
- Bandwidth shown is aggregated per-node / physical network endpoint

Bandwidth improvement of >2x for small messages

- Fence + flags approach sends O(P) additional messages
- Barrier synchronizes all PEs, only as fast as the slowest PE

One-Sided Append

```
/* SHMEM Offset Counter (OCT) object management (collective) */
void shmem_oct_create(shmem_oct_t *oct, void *buffer, size_t len);
void shmem_oct_destroy(shmem_oct_t *oct);

/* Appending put, a.k.a. "push", one-sided communication */
void shmem_push(shmem_oct_t oct, const void *src, size_t len, int pe);

/* Offset counter update/query routines (local) */
void shmem_oct_reset(shmem_oct_t oct);
size_t shmem_oct_get(shmem_oct_t oct);
```

Push: One-sided operation appends sender's data to receiver's buffer

Introduces "offset counter", which is atomically updated during push

Can be used in conjunction with other proposed extensions:

- Contexts, counting puts, nonblocking communication, …

NAS Integer Sort (IS) Key Exchange

```
int dst_buf[DST_BUF_SIZE]; /* Symmetric buffer for RX of keys */
int counter = 0;           /* Symmetric integer offset counter */
...
for (i = 0; i < num_pes; i++) {
  int dst_off;

  dst_off = shmem_int_fadd(&counter, cnt[i], i);
  shmem_int_put(dst_buf+dst_off, src_buf+src_off[i], cnt[i], i);
}
```

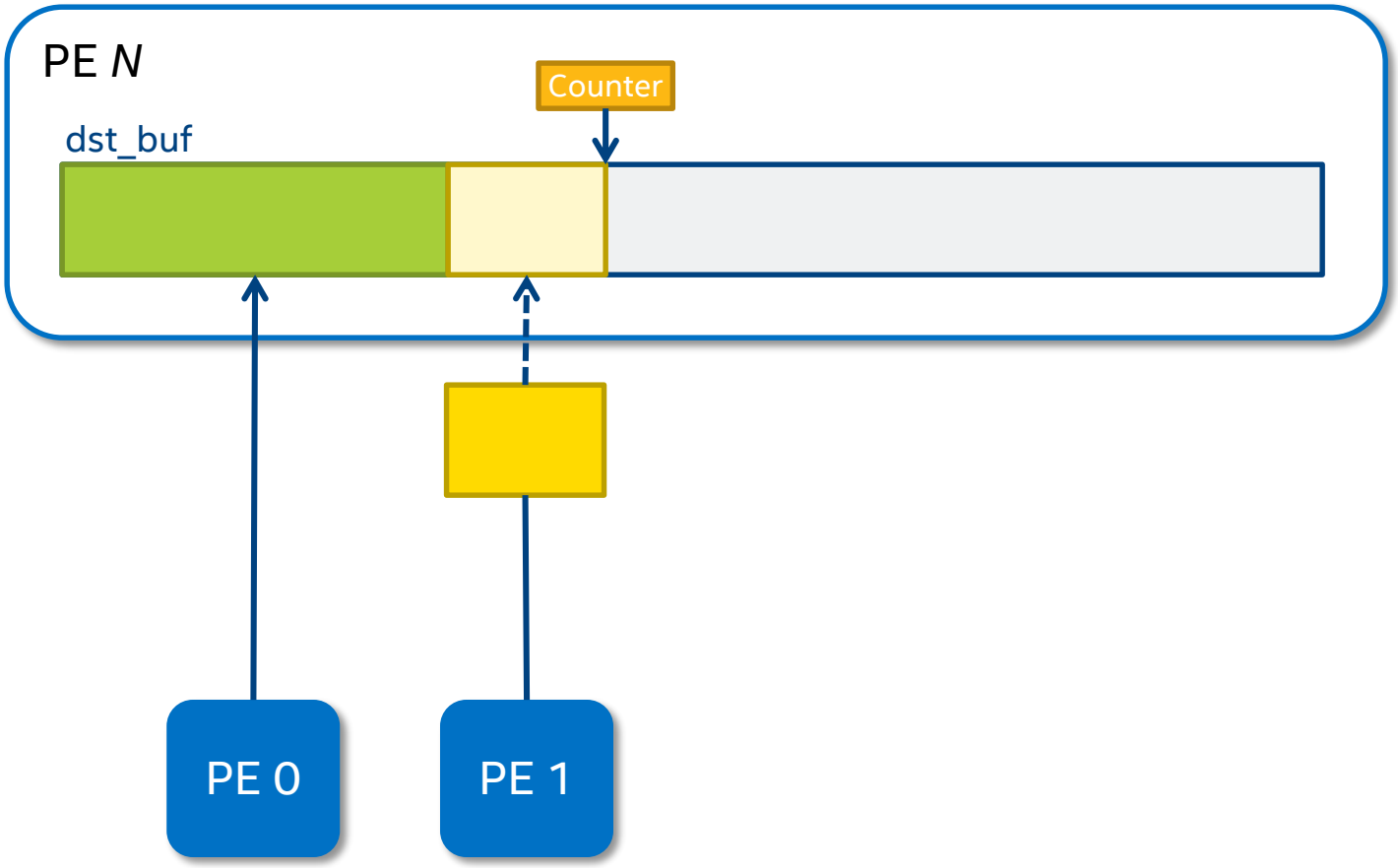
Key-exchange portion of integer bucket sort algorithm

Receiver's buffer management is done by the sender

- Requires additional fetch-add message from the sender
- Alternative is to pre-arrange buffer space

Sidebar: Iterations can be overlapped with nonblocking ops

One-Sided Append in Key Exchange



NAS IS Key Exchange (Push)

```
int dst_buf[DST_BUF_SIZE]; /* Symmetric buffer for RX of keys */
shmem_oct_create(&keys_oct, dst_buf, DST_BUF_SIZE);
...
for (i = 0; i < num_pes; i++) {
  shmem_int_push(keys_oct, src_buf+src_off[i], cnt[i], i);
}
...
shmem_oct_free(&keys_oct);
```

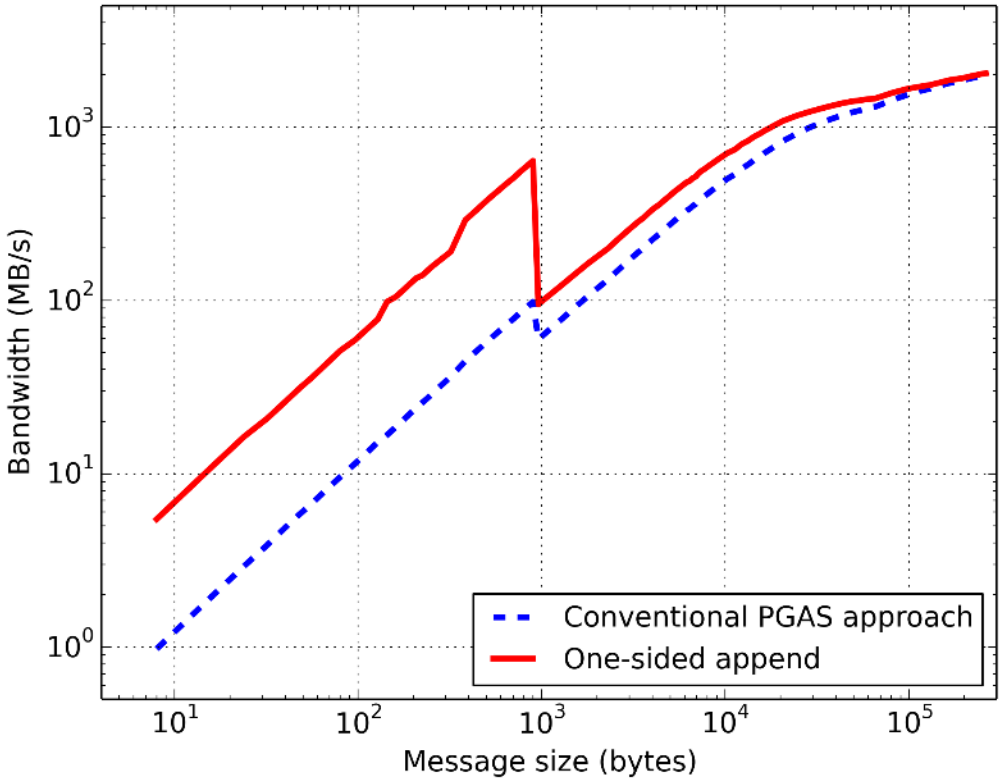
Key-exchange portion of integer bucket sort algorithm

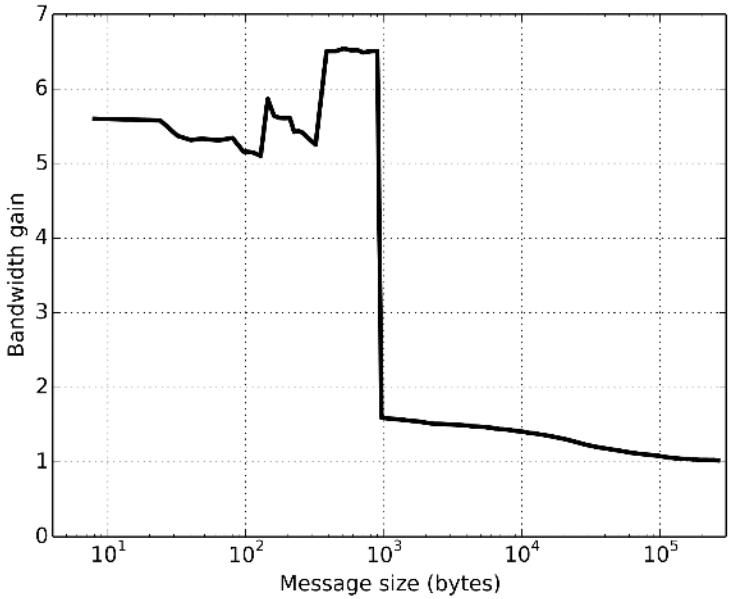
Destination buffer addressed using the offset counter (OCT)

- Allows receiver-managed implementation
- Receiver can calculate effective target address

Sidebar: Iterations can be overlapped with nonblocking ops

Early Perf. Evaluation of Key Exchange

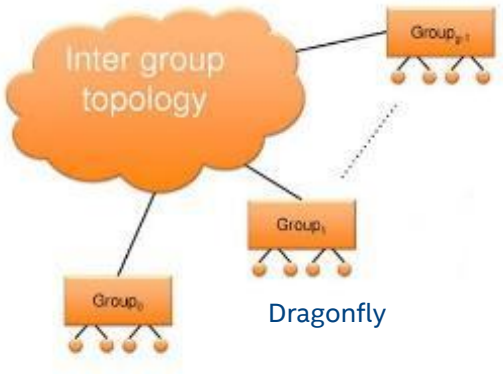




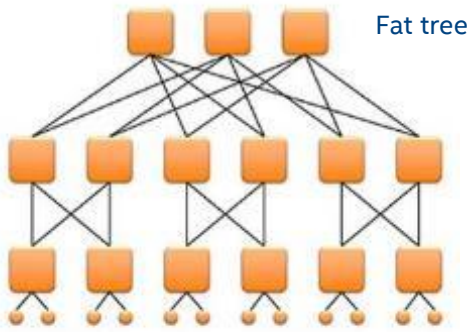
InfiniBand® Cluster: 16 nodes, 16 PEs; OpenSHMEM over Portals 4 over IB

Drop-off at Portals *max_volatile_size* (buffering converts blocking to NB)

Federations – a System-Centric View



Dragonfly



Proposal of a teams interface that can be used to expose detailed system topology information to the application.

- Supports conventional communication groups
- Exposes evolving network topology and heterogeneous node architecture

Integration with system management and runtime

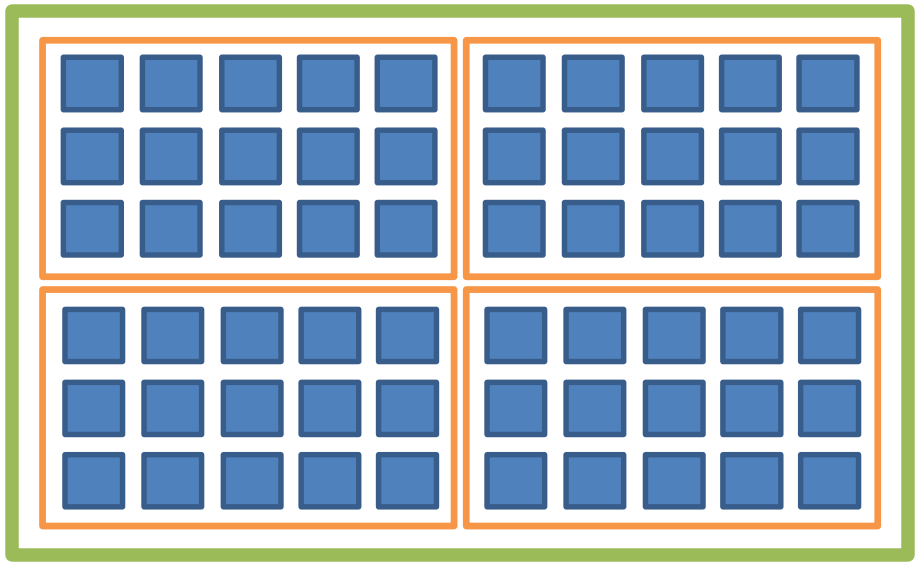
- E.g. integration with PMIx, hwloc, netloc; (see open-mpi.org)

Facilitates Topology-aware parallel decomposition

Enables definition of communication patterns aligned with topologies

Picture Credit: web search see notes

Federations



SHMEM_TEAM_WORLD

Federation of Nodes

Federation of Neighborhoods

Examples:

- Leaf switch nodes (fat tree)
- All2all connected nodes (dragonfly)

Federations created by split operations performed on SHMEM_TEAM_WORLD

A federation contains set of all teams created during split

System topology derived federations via split keys, similarly to those used in the MPI_Comm_split_type operation

Introducing a new shmem_federation_t type

PE-Centric Viewpoint

Cray proposed SHMEM Teams extension* to manage PE subsets

Takes a PE-centric view, supporting intra-team communication

Created with collective `shmem_team_split`, grouping PEs into new teams based on the value supplied in color argument

Limitations:

- Can't provide global view
- No support for topology based colors
- Application's responsibility to set color value and to track it
- Limited query functions only about the teams a given PE is member of
- Two baseline teams: `SHMEM_TEAM_WORLD` and `SHMEM_TEAM_NODE`

Federations proposal builds upon the Cray proposal

* ten Bruggencate, M.: Cray SHMEM update. Presented to OpenSHMEM Workshop (March 2014)

User Level Federation library and APIs

- Discover teams (system and application initiated teams)
- Query team membership (for my_PE and for any other PE)
- Select code path based on team membership (e.g. support 2 cyclic red/black iterations)
- Operate on, map and translate teams and team members
- Intra team communications: particularly collectives
- Inter team communications (similar to MPI neighborhood collectives)

Provide a common framework through UL-Federation library and relieve application from explicit team management

Federations: Conclusions

Propose a two-stage approach to extending OpenSHMEM

- Foundational team APIs defined for the OpenSHMEM standard
- Reference user-level library to demonstrate a proposed, rich set of APIs exposing greater degree of information via federations interface

Provide rich set of Federations/Teams APIs to application, while keeping OpenSHMEM standard nimble

Create evolutionary path for teams in OpenSHMEM standard

Separate system specifics from OpenSHMEM standard

New capability for application to see a complete picture of how the given job maps to the system topology

- Ability to adjust data, computation, and communication patterns to optimize for the given system

Open Fabrics Alliance

Enabling High-Performance Networking

Defined a set of SHMEM requirements

Influences various vendors fabric interface

Created **OFIWG**

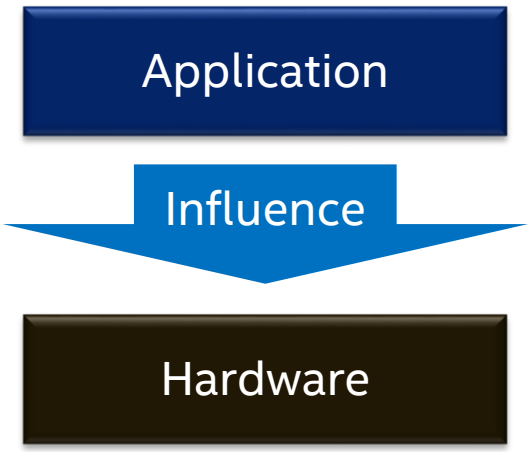
- **Developed OFI "Open Fabric Interface"**

Goal:

Redefining Fabric Mapping:

Top Down Approach

"OFI"



Open Fabric Interface

OFI: a high performance open source network interface

- Open Fabrics Alliance networking standard
- Goals: scalability, implementation independence, decreased software overhead

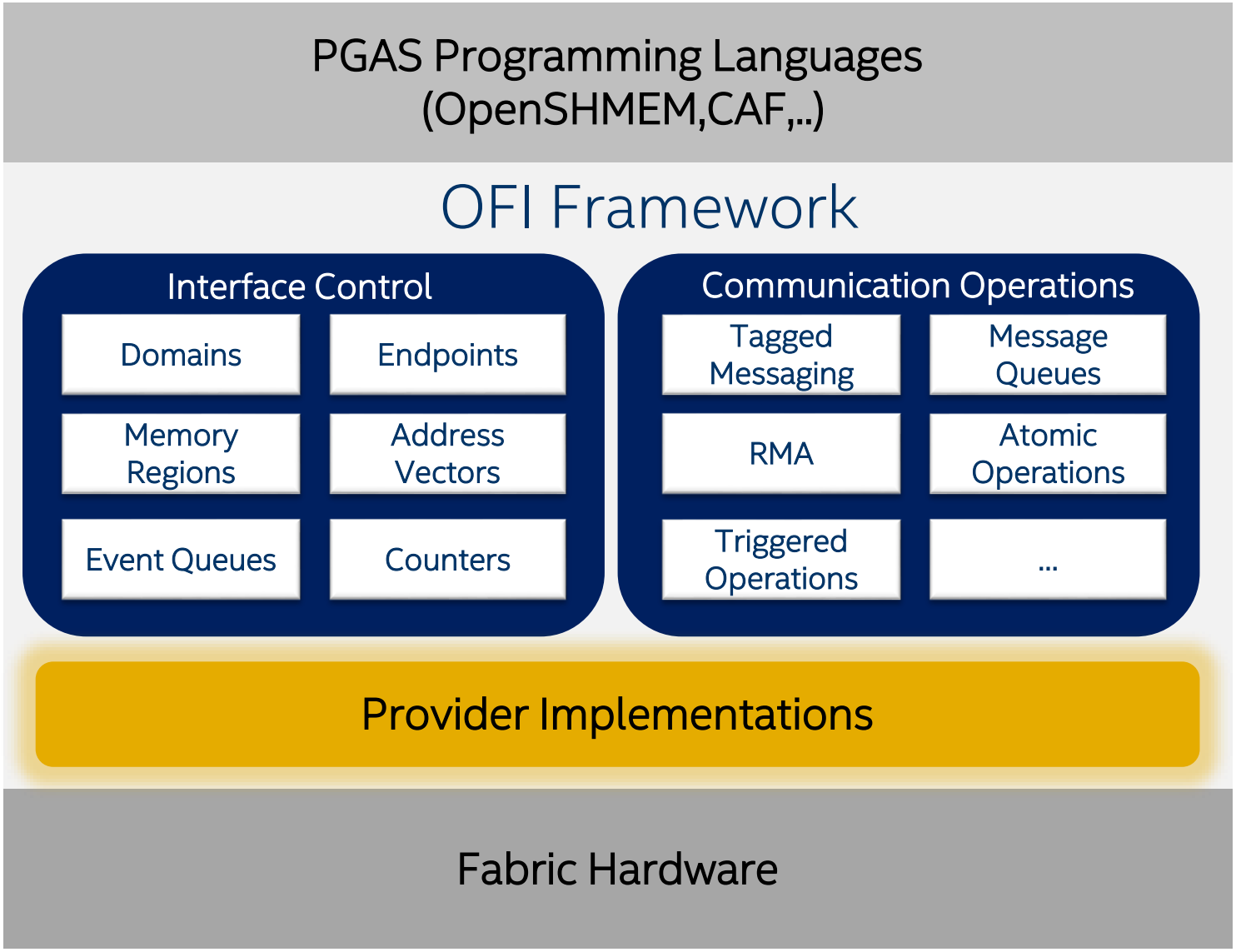
Papers

- PGAS 2014, HOTI 2015

OFI WG is open participation

- Contact the ofiwg mail list ofiwg@lists.openfabrics.org
- Source code available through github.com/ofiwg

OFI Framework



SHMEM-OFI: Components

Endpoint

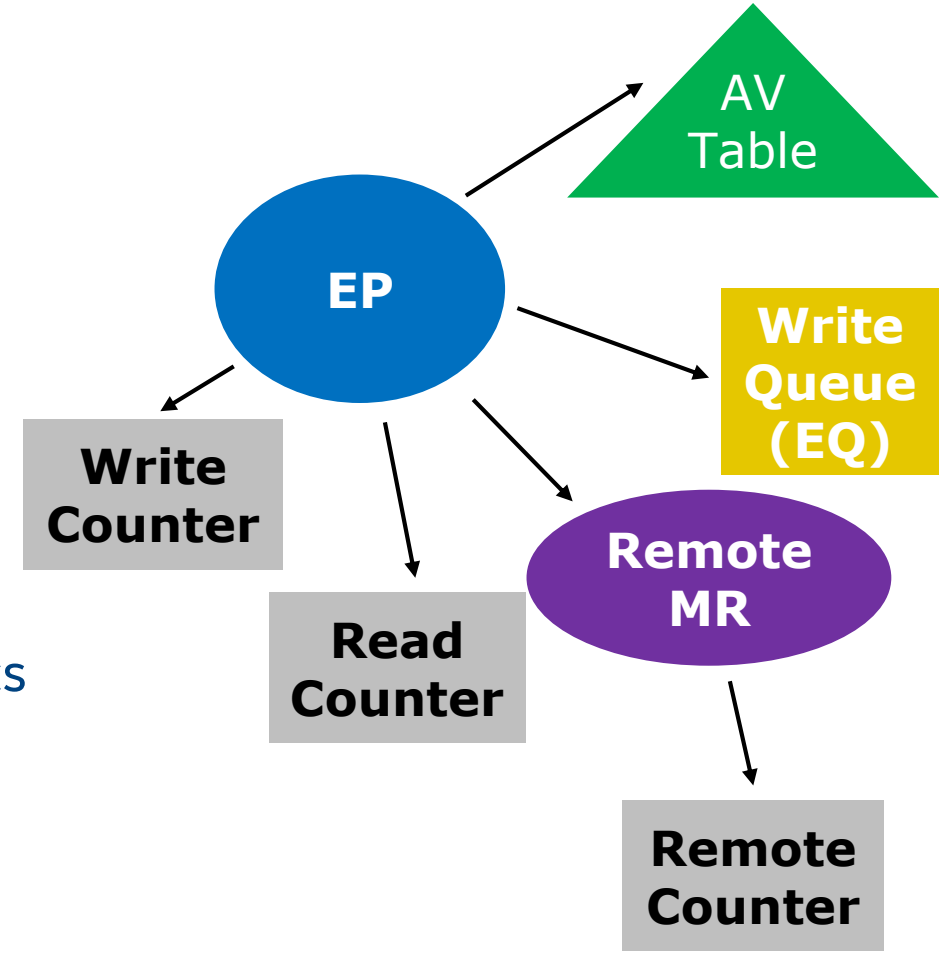
- Full address space, single universal key
- Remote completion enabled

Counters

- Write: outgoing put/atomics
- Read: outgoing reads/atomics
- Remote: incoming messages

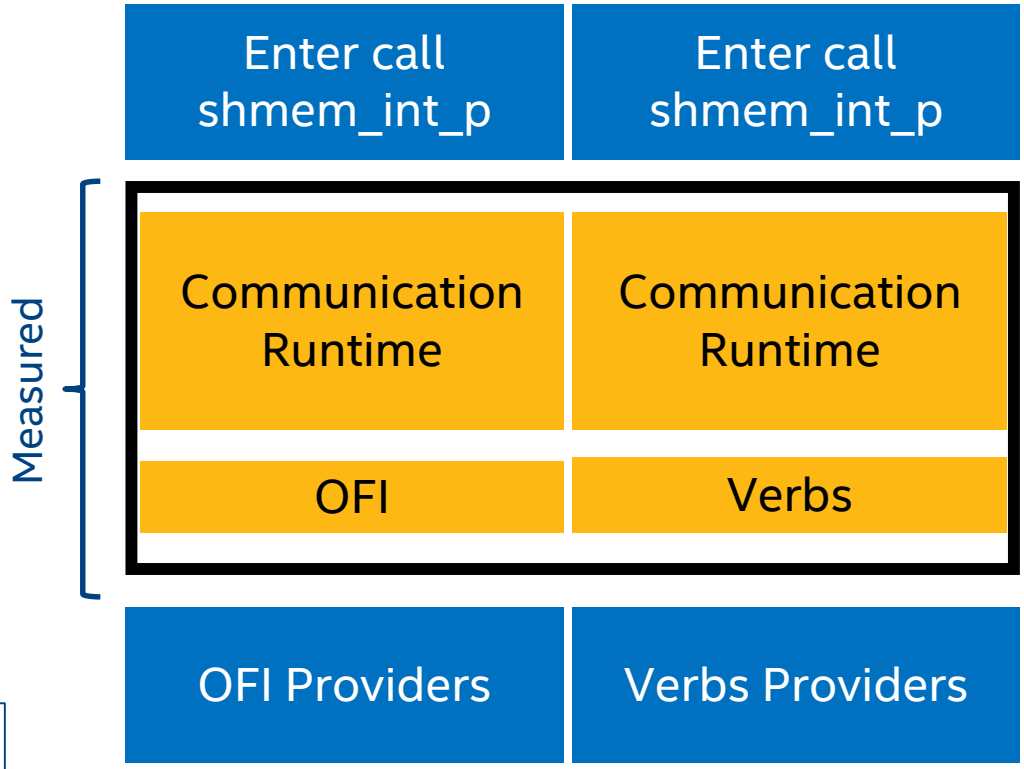
MR: Incoming messaging

EQ: enable “non-blocking” writes



SHMEM-OFI and IB Verbs Comparison Methodology

- Semantic match measured in instructions
- Mapping overhead: instructions in fabric communication middleware
- Single Operation: put/sync/fence
- 2 nodes
- Lower instruction count=less software overhead



The evaluation is done on two dual socket nodes containing Intel® Xeon® X5570 Quad-core Nehalem CPUs, running at 2.93GHz with 12GB of host memory. The nodes are connected by a Mellanox QDR/10GigE ConnectX InfiniBand HCA (MT26428). The nodes are running Red Hat Linux 6.5, with kernel version 2.6.32-431.el6.x86 64. The Intel® C++ Composer XE 2013 SP1 (Intel® C++ compiler 14.0) is used with "-O3 -ipo" flags. GASNet 1.22.4 and MVAPICH2-X 2.0 are utilized for the evaluation. We use a variation of the Intel® Pin for generating instruction traces for accurate measurement.

Results SHMEM-OFI and IB Verbs

SHMEM-OFI

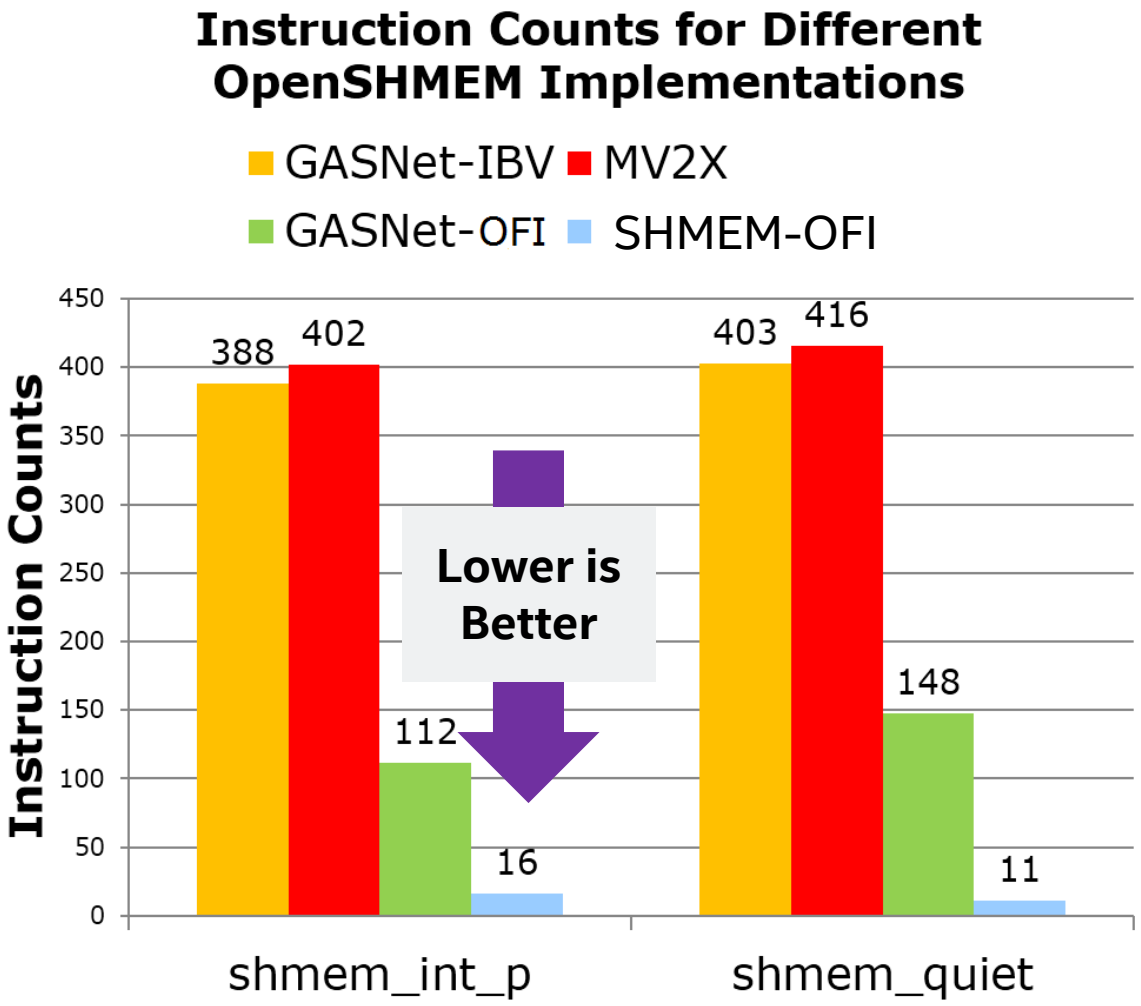
- **95%~** software Overhead reduction
- Improved Memory registration/usage
- Put: Inject feature
- Quiet: counters

SHMEM-GASNet

- segmented address space lookup

MVAPICH2-X

- Registration key lookup



Right abstraction can yield more efficient mapping from programming model to device

Scalability Improvements Examples

Comparison of OFI to IB Verbs (from HotI 2015 paper)

Addressing: 77% memory footprint reduction

- 36 bytes metadata libibverbs vs. 8 bytes OFI
- OFI AV: address data best handled by fabric
  - OFI encodes subnet path in unused addressing bits

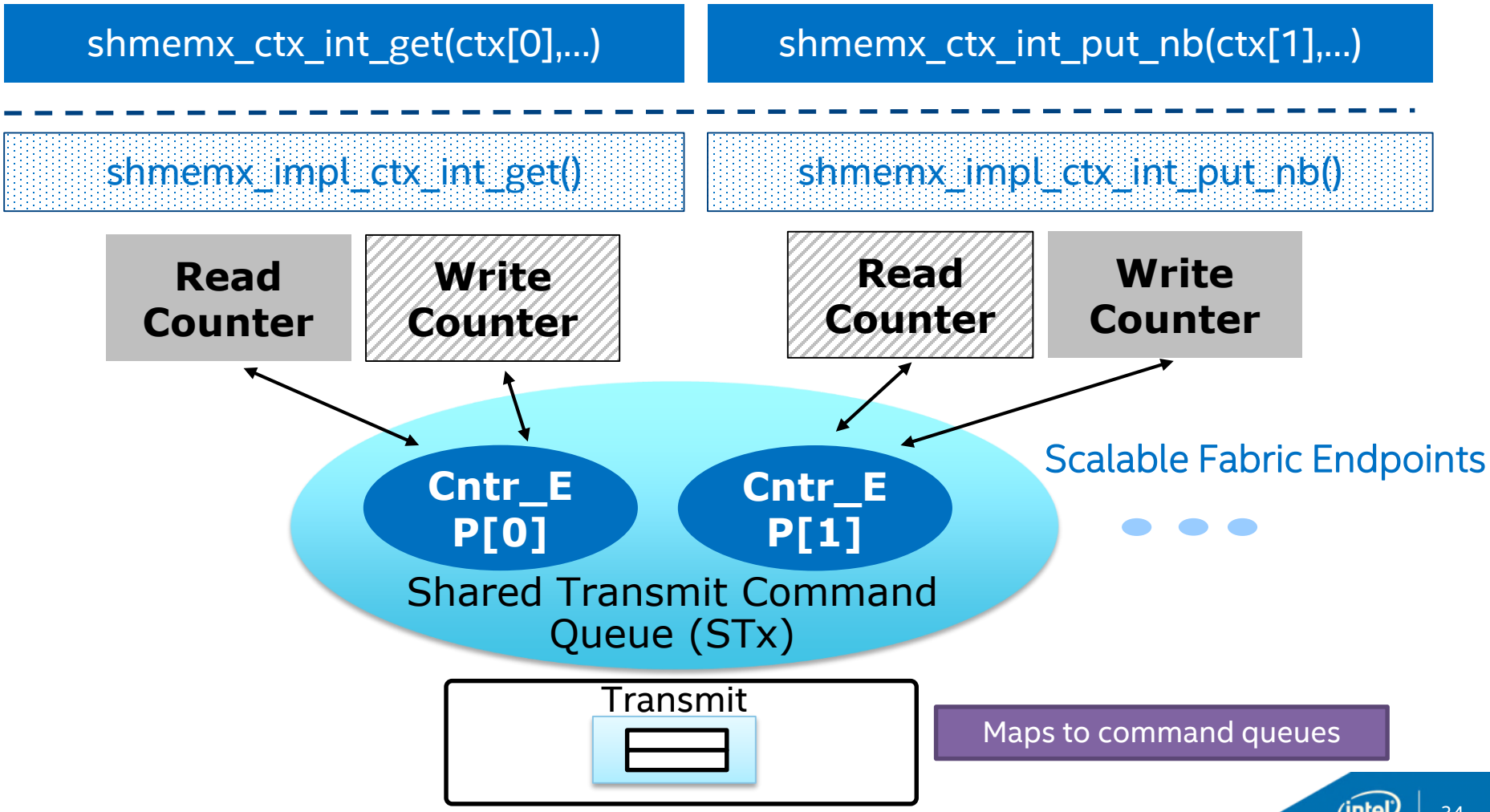
Transmit code Path: 52% memory footprint reduction

- Arg size for a write: 84 bytes libibverbs vs. 40 OFI
- OFI transmit interface definition is simpler
  - Endpoint customization -> fewer branches
  - Multi-entry points for different messaging types (RMA vs. MSG vs. Tagged)

OFI for PGAS – Functionality Highlights

- Scalable endpoint enumeration: 0(1) memory usage and no lookups, can enumerate PE's with integers
- Scalable memory usage/registration: enables upfront full VA registration, remote VA
- Remote completion for RMA/atomics no extra sync communication: lightweight fence/quiet
- Exposes counters: lightweight completion mechanism
- Rich atomic set: full SHMEM coverage, enables optimizations and synchronization algorithms
- Instruction count minimization: lightweight path with direct provider usage

OpenSHMEM Contexts Extension Mapping in OFI



PGAS – OFI implementations

GASNet-OFI conduit

- Enables UPC-GASNet-OFI
- *OFI enables*: lightweight polling overhead and memory management
- Submitted to Lawrence Berkeley Lab. for review

SHMEM-OFI

- *OFI enables:* lightweight memory registration and counter completion, full atomic breadth
- Internal prototyping and testing extensions: context

References

1. *Reducing Synchronization Overhead Through Bundled Communication.* James Dinan, Clement Cole, Gabriele Jost, Stan Smith, Keith Underwood, Robert W. Wisniewski. First OpenSHMEM Workshop: Experiences, Implementations, and Tools. 2013.
2. *Contexts: A Mechanism for High Throughput Communication in OpenSHMEM.* James Dinan and Mario Flajslik. Proc. Eighth Conf. on Partitioned Global Address Space Programming Models (PGAS). Eugene, OR. Oct 2014.
3. *One-Sided Append: A New Communication Paradigm For PGAS Models.* James Dinan and Mario Flajslik. OpenSHMEM User Group Meeting. Eugene, OR. October 7, 2014.
4. *Early Evaluation of Scalable Fabric Interface for PGAS Programming Models.* Miao Luo, Kayla Seager, Karthik S. Murth, Charles J. Archer, Sayantan Sur, and Sean Hefty. Proc. Eighth Conf. on Partitioned Global Address Space Programming Models (PGAS). Eugene, OR. Oct 2014.
5. *A Brief Introduction to the OpenFabrics Interfaces - A New Network API for Maximizing High Performance Application Efficiency.* P. Grun, S. Hefty, S. Sur, D. Goodell, R. Russell, H. Pritchard and J. Squyres. 23rd Symp. on High-Performance Interconnects (HotI). August, 2015.

Intel and PGAS Wrap Up

Participants in the PGAS community:

- Ensure PGAS models can access to full capabilities of Intel HPC offerings
- Advocate for needs of PGAS users within Intel
- Participate in efforts to improve and define parallel programming models

Areas of engagement:

- Tackling key programming model challenges to OpenSHMEM
  - Multithreading and communication/computation overlap
  - Point-to-point synchronization and data dependence
  - Coordination and buffer management
- Open Fabrics Interface
  - Community effort to define new low-level communication API
  - General purpose, optimizable, and aligned with parallel programming models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