Reducing Synchronization Overhead Through Bundled Communication

James Dinan, Clement Cole, Gabriele Jost, Stan Smith, Keith Underwood, and Robert W. Wisniewski

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SHMEM Synchronization Gap

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
- Can be expensive
- Load Imbalance, noise, etc.

Point-to-point ordering

- Weaker than remote completion

Point-to-point synchronization

- O(P) messages, vs O(log P) for barrier

Comm/sync are split up

- Limits optimizations in the runtime

Bundling Communication and Synchronization

```
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
- Weak counting semantic: the receiver can do the increment in get/wait

Bundling enables implementation optimizations

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

Enables a receiver-managed implementation

- Can significantly reduce communication involved in synchronization

Counting Puts Interface

```
void shmem_ct_create(shmem_ct_t *ct);
void shmem_ct_free(shmem_ct_t *ct);

long shmem_ct_get(shmem_ct_t ct);
void shmem_ct_set(shmem_ct_t ct, long value);
void shmem_ct_wait(shmem_ct_t ct, long greater_or_equal_val);

void shmem_putmem_ct(shmem_ct_t ct, void *target, …, int pe);
...
```

Creation / free is collective

- Every PE needs a handle to refer to the counter
- Individual counter created on each PE

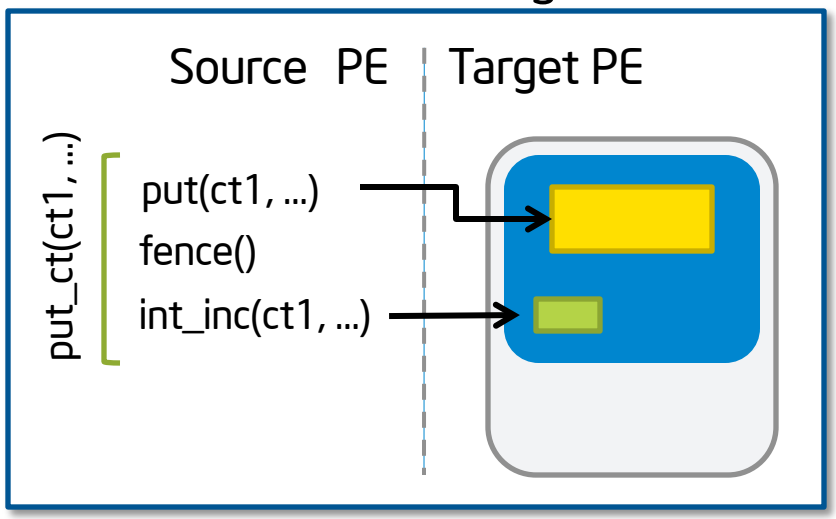
Query functions are local

- Read, write, or wait on a counter
- Counter updates can be delayed until query

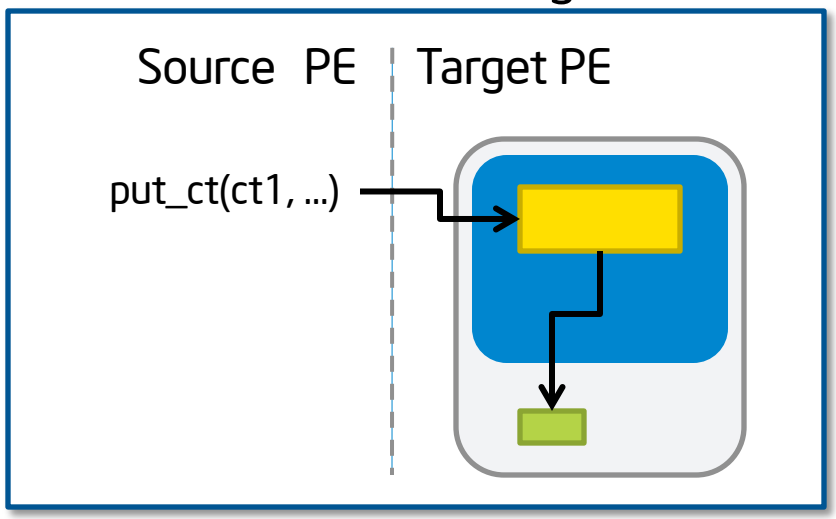
Add “counting” versions of one-sided communication operations

Counting Puts Implementation

Sender-Managed



Receiver-Managed



Implementation on top of SHMEM

- Put, fence, increment flag

Shared memory implementation

- Similar to implementation on SHMEM
- Copy, membar, atomic increment flag

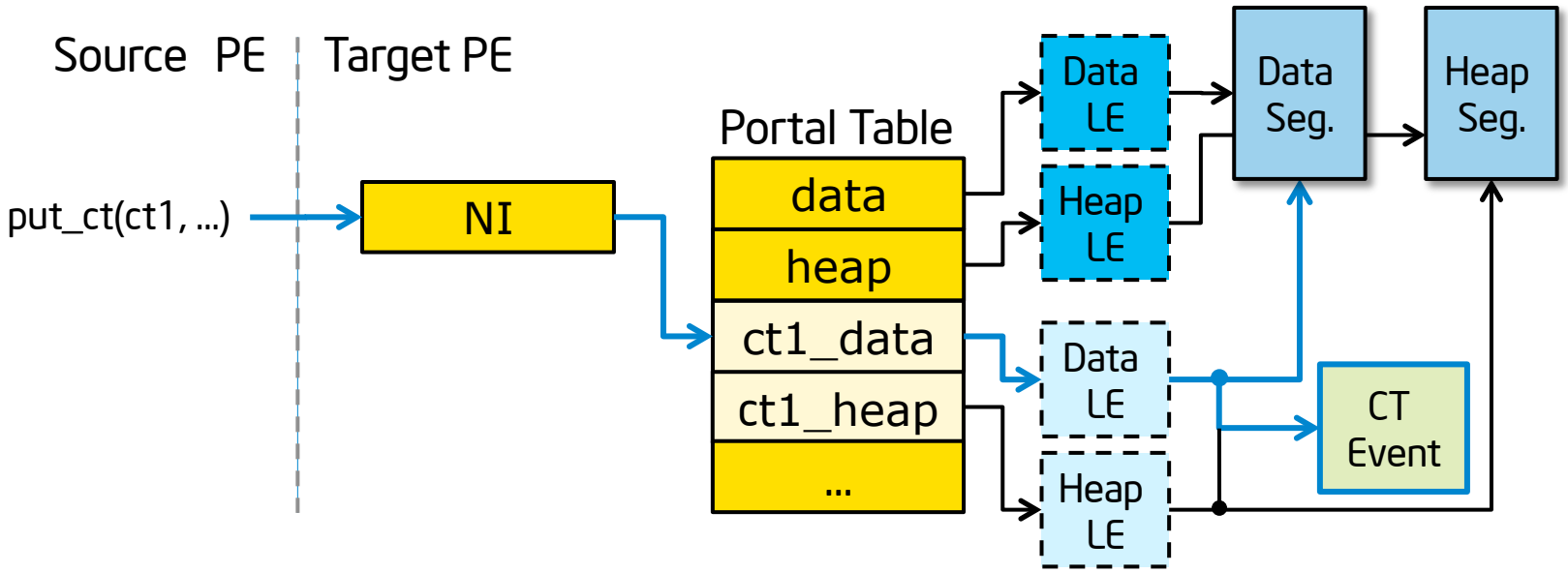
Use communication events

- Portals network – counting events, counter triggered by communication
- Other networks – completion events, update counter in query function

Piggyback info in message header

- UDP, PSM, etc...

Signaling Puts in Portals SHMEM



Create separate portal table entries for each counter

- Non-matching entries, list entry (LE) points to memory segment
- Isolates counters from each other

Portals counting event is attached to LE on counting PTE

- Automatically incremented when the operation completes

Direct counting puts to corresponding CT PTE, others to generic PTE

Empirical Evaluation

Implemented and available in Portals-SHMEM

- http://code.google.com/p/portals-shmem/

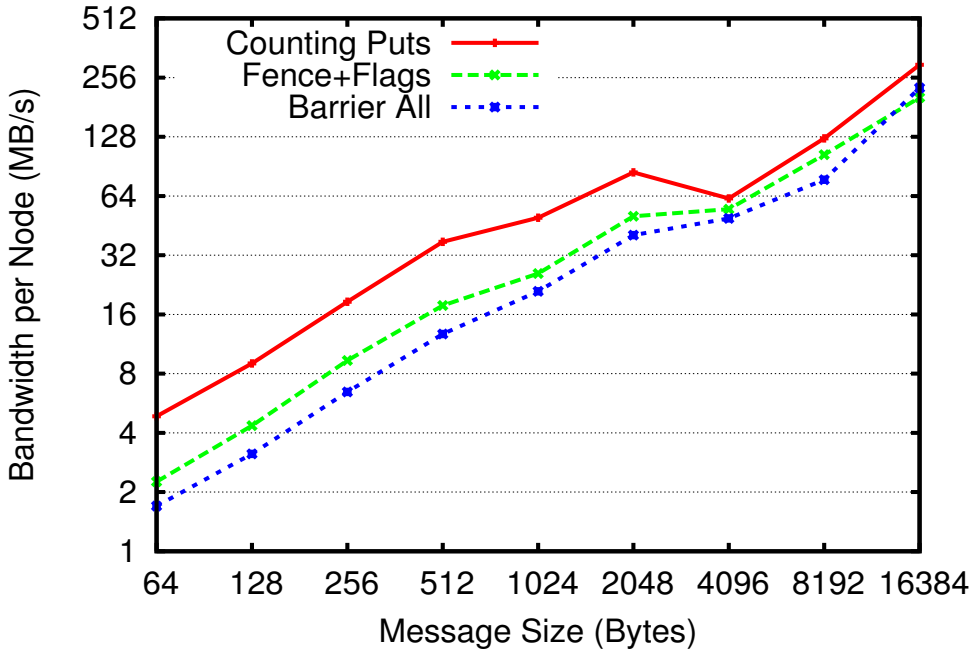
Evaluation system:

- Mellanox QDR InfiniBand, single switch
- Intel® Xeon® X5680 x 2, 24 GB memory
- 15 nodes, 12 cores per node = 180 PEs
- Open source Portals-IB, Portals-SHMEM

Benchmarks and highlights:

- All-to-all (bandwidth)
  - 2x bandwidth for small messages
- Ping-pong (latency)
  - ½ latency for small messages
- Pipelined parallel stencil kernel (overlap)
  - More than 2x improvement

All-to-All Bandwidth (180 PEs)



Measure bandwidth achieved in all-to-all

- 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

Large messages amortize cost of sync messages (Amdahl)

Ping-Pong Benchmark

Fence + Flags

Sender

```
shmem_putmem(rcv, snd, msg_len, pe);
shmem_fence();
shmem_int_inc(&flag, target);
```

Receiver

```
shmem_int_wait(&flag, 0);
flag = 0;
```

Counting Puts

Sender

```
shmem_putmem_ct(ct, rcv, snd, msg_len, pe);
```

Receiver

```
shmem_ct_wait(ct, 1);
shmem_ct_set(ct, 0);
```

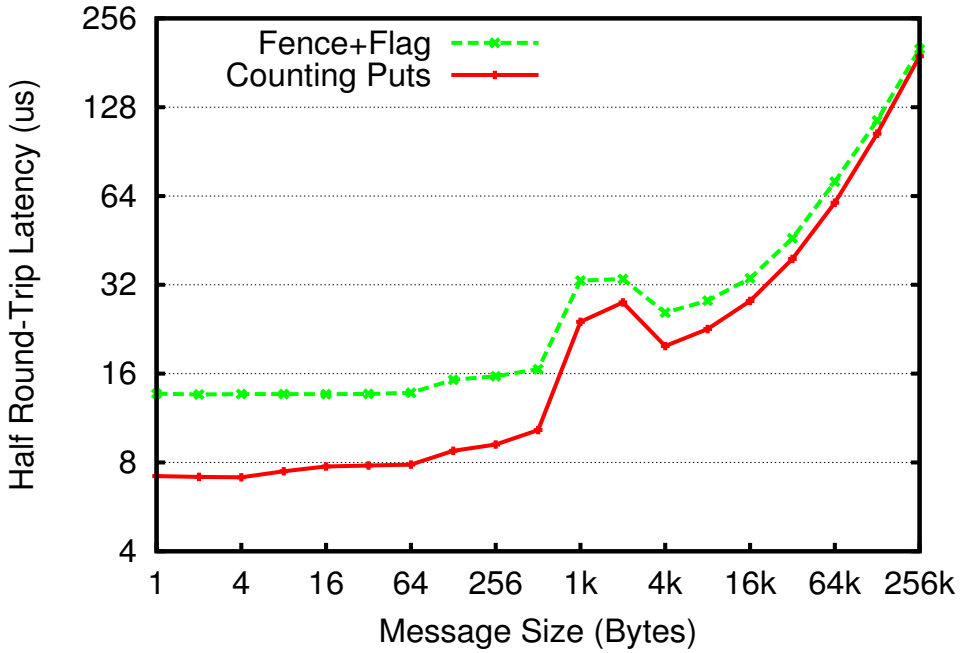
Bundle sender's operations

- Put, fence, and atomic increment are combined
- Weaker than fence, only ensures that this put is visible to receiver

Experiment:

- PEs switch sender/receiver roles every iteration
- Sweep message length parameter

Half Round-Trip Latency (2 PEs)



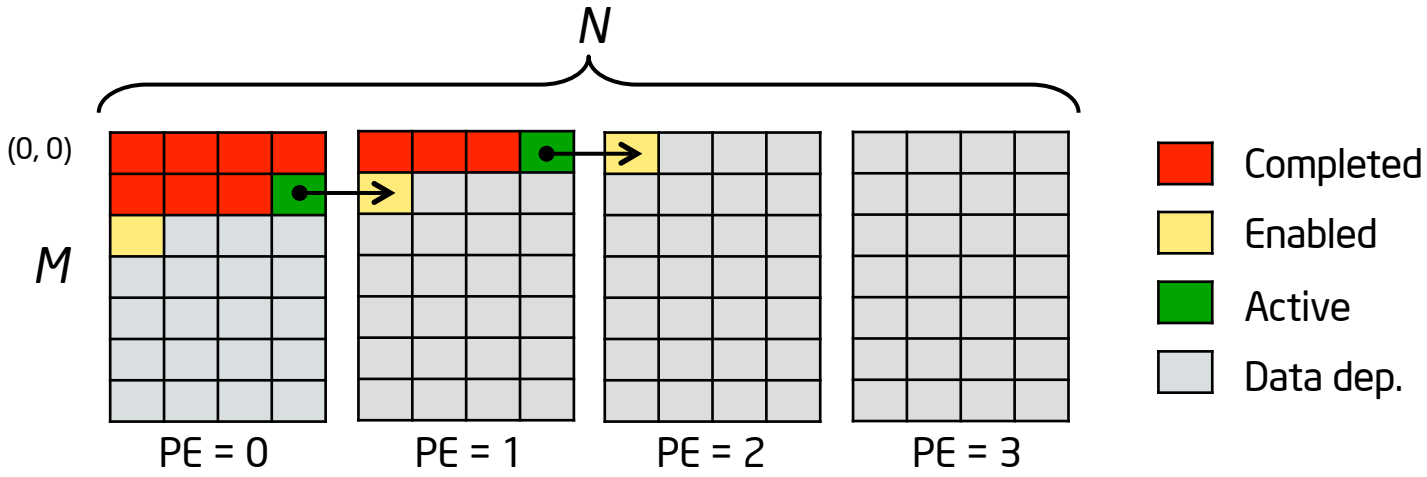
Counting puts eliminate atomic increment message

- Halves latency for small message sizes
- Large messages amortize sync. cost (Amdahl)

Explicit fence is also eliminated

- Removes waiting for completion at the sender
- We can fire and forget the counting put, through a bounce buffer

Pipelined Parallel Stencil Benchmark



Stencil update rule

- A(i, j) = A(i-1, j) + A(i, j-1) - A(i-1, j-1)

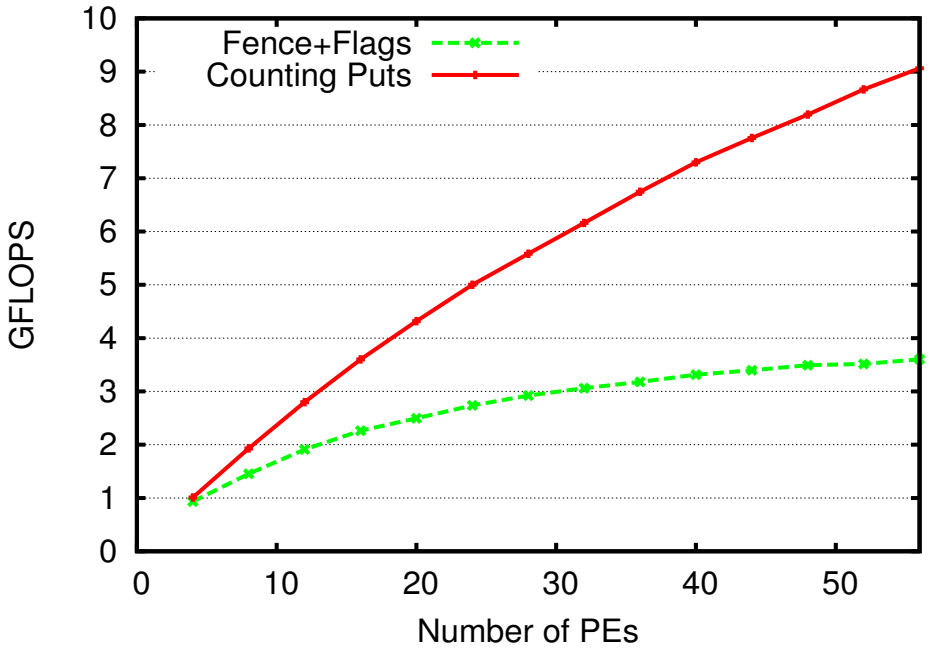
Domain decomposition along j-dimension

- Data dependence – West, North, Northwest
- Pipelined parallelism
- Put data to neighbor's ghost cell and notify them

Intel Parallel Research Kernels, Synch_p2p benchmark

- Tim Mattson, Rob van der Wijngaart (http://github.com/ParRes)

Sync_P2P Strong Scaling



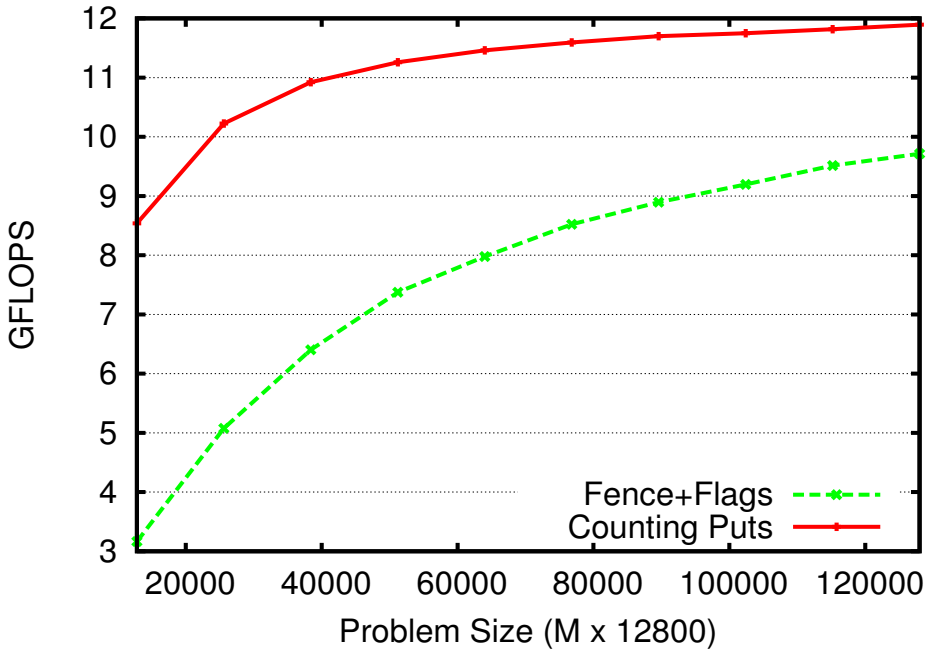
Dataset is *A[M, N]* = 12800 x 1280

- Executed using 4 PEs per node
- GFLOPS = Total FLOPs at all PEs / exec. time (notably comm. time)

Small messages (single element) result in high comm. overheads

- Flags double the number of small messages that are sent
- Benchmark is communication bound on small messages

Synch_P2P Weak Scaling (48 PEs)



Dataset is *A[M, N]* = *M* x 12800

- Run on 4 PEs per node, 48 PEs total

Shows impact of pipelining startup, shutdown latency

- Large values of M amortize this cost
- More efficient point-to-point sync. reduces pipelining overhead

Related Work

UPC semaphores proposal (Bonachea, et al.)

- Similar idea in UPC
- Could use receiver-managed implementations

Split-C signaling store

- Wait for a specific number of bytes to arrive
- One counter per process

MPI point-to-point communication

- Send/recv, data movement and sync. are conjoined

Full/empty bits

- Tera MTA, Cray XMT, Chapel, …

Put-with-flag

- ARMCI_Put_flag(), GASPI write-and-notify

Aggregate synchronization from multiple operations

Synchronize individual operations

SHMEM Synchronization Discussion

Bundling can improve efficiency of point-to-point synchronization

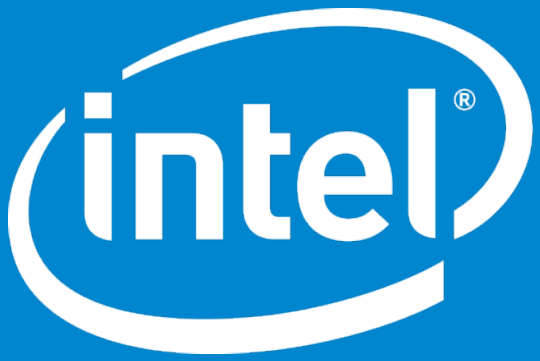
- Enables implementation optimizations
- Leverage hardware capabilities, e.g. communication events

Variety of interfaces for bundled comm. and synchronization

- Opaque flag object
  - Pro: Better enabling of receiver-managed implementations
  - Con: Requires additional API to query remotely
- Integer flag
  - Pro: Fits into existing API, can be queried remotely
  - Con: Restricts implementation options, e.g. hard to use counting events
- Update rule: increment vs. set
  - Increment: aggregates synchronizations to a single object
  - Set: fine-grain, can require many flags, e.g. scalability challenge for all-to-all

Additional synchronization operations for investigation

- Control-only barrier – counting puts already synchronized data
- Split-phase barrier and non-blocking synchronizations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