Optimizing Charm++ over MPI

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The Charm++ stack

- Runtime goodies sit on top of **LRTS**, an abstraction of the underlying network API.
  - LrtsSendFunc
  - LrtsAdvanceCommunication
  - Choice of native API (uGNI, DCMF, etc) and MPI.

(Sun et al., IPDPS '12)
Why use MPI as the network engine

- Vendor-tuned MPI implementation from day 0.
  - Continued development over machine's life-time.
- Prioritizing development.
  - Charm's distinguishing features sit above this level.
- Reduce resource usage redundancy in MPI interoperability.
Why not use MPI as the network engine

- Unoptimized default machine layer implementation.
  - In non-SMP, communication will stall computation on the rank.
    - Many chares are mapped to the same MPI rank.
  - In SMP, incoming messages are serialized.

- Charm++'s semantics don't play well with MPI's.
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Why not use MPI as the network engine
Why not use MPI as the network engine

3-neighbor on Blue Gene/Q (256 nodes, ppn = 1)

Lower is better for MPI.
The inadequacy of MPI matching for Charm++

- Native APIs have no concept of source/tag/datatype matching
  - Neither does Charm, but MPI doesn't know it (if using Send/Recv)
  - One-sided semantics avoid matching.
    - Can write directly to desired user buffer.
    - Same for rendezvous-based two-sided MPI, but with a receiver synchronization trade-off.
    - Most importantly, it can happen with little to no receiver-side cooperation.
Leveling the field

- Analyzed implementation inefficiencies and semantic mismatches.
  1. MPI implementation issues
     1. MPI's unexpected message queue ✗
     2. Charm++ over MPI implementation issues
     1. MPI Progress frequency ✗
     2. Using MPI `Send/Recv` vs. MPI one-sided ✓
  3. Semantics mismatches
     1. MPI tuning for expected vs. unexpected messages ✓
1) Length of MPI's unexpected message queue

- Unexpected messages (no matching `Recv`) have a twofold cost.
  - `memcpy` from temp to user buffer.
  - Unnecessary message queue searches.
  - Part of why there's an eager and a rendezvous protocol.

- Tested using `MPI_T`, a new MPI-3 interface for performance profiling and tuning.
  - Internal counter keeps track of queue length.
  - Refer to section 14.3 of the standard.
1) Length of MPI's unexpected message queue

- Arguably has no significant impact on performance.
  - Default uses `MPI_ANY_TAG` and `MPI_ANY_SOURCE`, meaning `MPI_Recv` only looks at the head.
  - No need for dynamic tag shuffling (another option in the machine layer).
  - Only affects eager messages.
    - Bulk of rendezvous messages is handled as if expected.
1) **Mprobe/Mrecv instead of Iprobe/Recv.**

- In schemes with multiple tags, `MPI_Iprobe + MPI_Recv` walks the queue twice.
- `MPI_Mprobe` instead deletes entry from queue and outputs a handle to it, used by `MPI_Mrecv`.
- No advantage with double wildcard matching.
- Reduced critical section may help performance with multiple commthreads.
In Charm, failed `Iprobe` calls drive MPI's progress engine. 
- Pointless spinning around if there are no incoming messages.

Tried reducing calling frequency to 1/16-1/32th of the default rate. 
- Reduces unexpected queue length. 
- Little to no benefit. 
  - Network may need it to kickstart communication.
3) Eager/rendezvous threshold

NAMD on Cray XE6 (40 nodes; ppn = 24)
3) Eager/rendezvous threshold

- **Builds on idea of asynchrony.**
  - Rendezvous needs active participation from receiver.
- Forces use of preregistered temp buffers on some machines.
- Environment vars aren't the appropriate granularity.
  - Implemented per-communicator threshold on MPICH.
    - Specified using info hints (section 6.4.4).
    - Each library may tune their communicator differently.
    - Particularly useful with hybrid MPI/charm apps.
    - Available starting from MPICH 3.0.4.
4) Send/Recv vs one-sided machine layer

- **Implemented machine layer** using MPI-3 RMA to generalize what native layers do.
  - Dynamic windows (attaching buffers non-collectively);
  - Multi-target locks (MPI_Win_lock_all);
  - Request-based RMA Get (MPI_Rget).
  - Based on “control message” scheme.
    - Sends small messages directly; larger ones happen via MPI-level RMA.
  - Handles multiple incoming messages concurrently.
  - Can't be tested yet for performance.
    - IBM and Cray MPICH don't currently support MPI-3.
Current workarounds using MPI-2

- **Blue Gene/Q**: use the *pamilrts buffer pool* and *preposted MPI_Irecvs* (toggle `MPI_POST_RECV` on `machine.c` to 1).
  - Interconnect seems to be more independent from software for RDMA
    - Preposting `MPI_Irecv` help it handle multiple incoming messages.

- **Cray XE6 (and InfiniBand clusters)**: increase *eager threshold* to a reasonably large size.
  - Cray's eager (E1) and rendezvous (R0) protocols differ mostly in their usage of preregistered buffers.
Nearest-neighbors results

3-neighbor on Blue Gene/Q (256 nodes, ppn = 1)

- PAMI (SMP + buffer pool)
- MPI (SMP + buffer pool)
- PAMI/MPI speedup (with buffer pool)

Lower is better

iteration duration (us)

speedup (%)
Nearest-neighbors results

3-nearest neighbor on Blue Gene/Q (256 nodes, ppn = 1)

- PAMI (SMP + buffer pool)
- MPI (SMP + buffer pool)
- MPI (SMP + preposted irecv)
- PAMI/MPI speedup (preposted irecv)

Lower is better
Nearest-neighbors results

NAMD on Cray XE6 (ppn = 16)

- Baseline MPI (non-SMP)
- Tuned MPI (non-SMP)
- uGNI (SMP)
- Tuned MPI/uGNI speedup

Lower is better

Higher is better for MPI

ms/step

# of cores

1024 2048 4096 8192 16384 32768
Future work.

- Fully integrate one-sided machine layer with charm.
- No convincing explanation yet for ibverbs/MVAPICH difference.
- Hybrid benchmark for per-communicator eager/rendezvous threshold on Cray.
Conclusions

- There's more to MPI slowdown than just “overhead”.
  - Mismatch of MPI with Charm semantics is a better story.
- Specific MPI-2 techniques per machine.
  - May not be portable, like eager/rendezvous threshold for Cray XE6 vs preposted IRrecv for Blue Gene/Q.
- Send/Recv machine layer should be replaced with one-sided version once MPI-3 is broadly available.
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3) Send/Recv vs one-sided machine layer

- One-sided communication better suits charm's asynchrony.
  - Send/Recv puts too much burden on receiver.
  - All native machine layers take advantage of this.

(Sun et al., IPDPS ’12)
3) Send/Recv vs one-sided machine layer

- Vendor-supplied MPI implementations already do this internally.
- Two-sided matching semantics are just inappropriate.
  - “Tuned” for expected messages.
  - Blue Gene/Q suffers from serialization because of Send/Recv.

(Cray Inc., PRACE ‘12)