UPC++: Asynchronous RMA and RPC Communication for Exascale Applications

WBS 2.3.1.14

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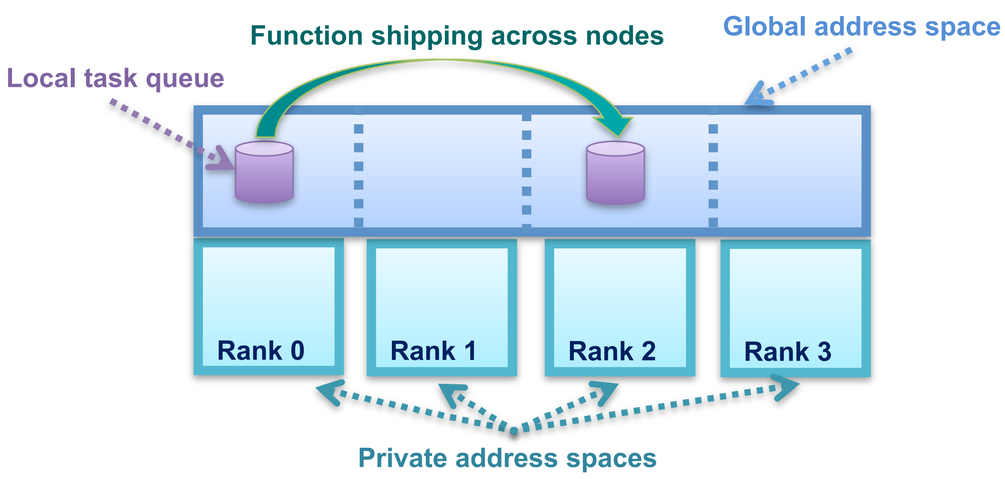
UPC++ at Lawrence Berkeley National Lab (upcxx.lbl.gov)

- UPC++ is a C++11 PGAS library
  - Lightweight, asynchronous, one-sided communication (RMA)
  - Asynchronous remote procedure call (RPC)
  - Data transfers may be non-contiguous
  - Futures manage asynchrony, enable communication overlap
  - Collectives, teams, remote atomic updates
  - Provides building blocks to construct irregular data structures
- Latest software release: September 2019
  - Runs on systems from laptops to supercomputers
- Easy on-ramp and integration
  - Enables incremental development
  - Selectively replace performance-critical sections with UPC++
  - Interoperable with MPI, OpenMP, CUDA, etc.



- **Integration efforts with ExaBiome (WBS 2.2.4.04)**
  - ExaBiome's HipMer 1.2.1 release (September 2019)
    - The k-mer counting step rewritten from MPI to UPC++
    - UPC++ RPC is a better fit to the problem
    - Reduces code size by roughly ½
      - More readable and maintainable
    - Lower memory requirements and better scaling
  - Current work-in-progress
    - Previous UPC stages of HipMer pipeline rewritten in UPC++
    - Approximately 85% reduction in code size
    - ExaBiome team's initial results:
      - Comparable genome assembly results
      - Lower memory requirements and better performance
- **Integration efforts with ExaGraph (WBS 2.2.6.07)**
  - Worked with PNNL team to develop two UPC++ versions of a graph matching problem from their IPDPS'19 paper
    - RMA version uses Puts to communicate among processes
    - RPC version uses asynchronous remote procedure calls to execute logic on remote parts of the graph
  - Initial results on NERSC Cori Haswell (3.6B-edge Friendster):
    - Both UPC++ versions competitive with (or better than) best MPI versions up to at least 4,096 processes
    - At 4,096 processes: UPC++ RMA version is 4.3x faster than best MPI-3 (RMA+neighborhood collective) version

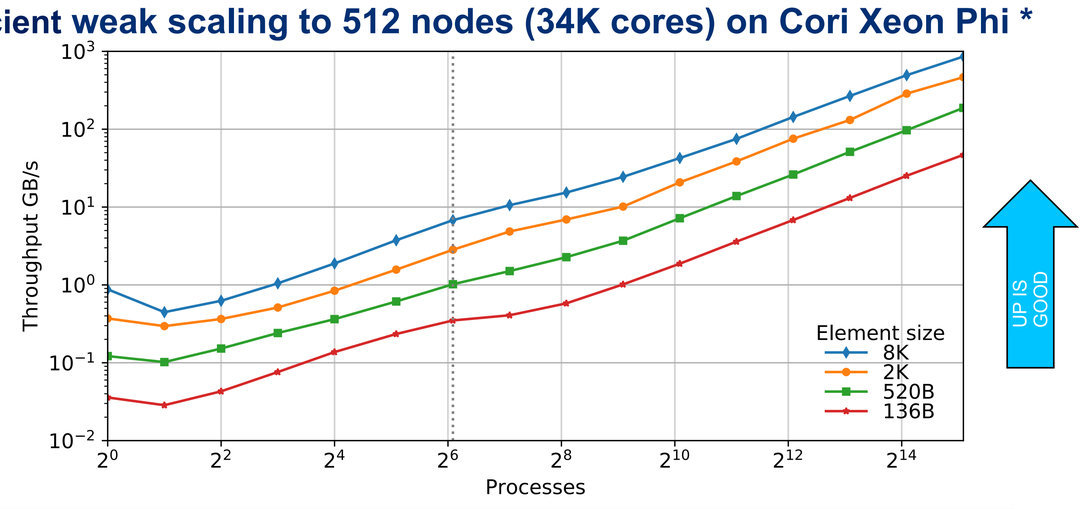
Case 1: Easy Distributed Hash-Table via Function Shipping and Futures

- **Distributed hash-table design is based on function shipping**
  - RPC inserts the key metadata at the target
  - Once the RPC completes, an attached callback issues a one-sided RMA Put (rput) to store the value data

```
// C++ global variables correspond to rank-local state
std::unordered_map<uint64_t, global_ptr<char>> local_map;
// insert a key-value pair and return a future
future<> dht_insert(uint64_t key, char *val, size_t sz) {
 future<global_ptr<char>> fut =
     rpc(key % rank_n(),              // RPC obtains location for the data
             [key,sz]() -> global_ptr<char> {    // lambda invoked by RPC
               global_ptr<char> gptr = new_array<char>(sz);
               local_map[key] = gptr;              // insert in local map
               return gptr;
             });
 return fut.then(                    // callback executes when RPC completes
       [val,sz](global_ptr<char> loc) -> future<> {
           return rput(val, loc, sz); });    // RMA Put the value payload
}
```

- **Benefits:**
  - Use of **RPC** simplifies distributed data-structure design
    - Argument passing, remote queue management and progress engine are factored out of the application code
  - Asynchronous execution enables overlap

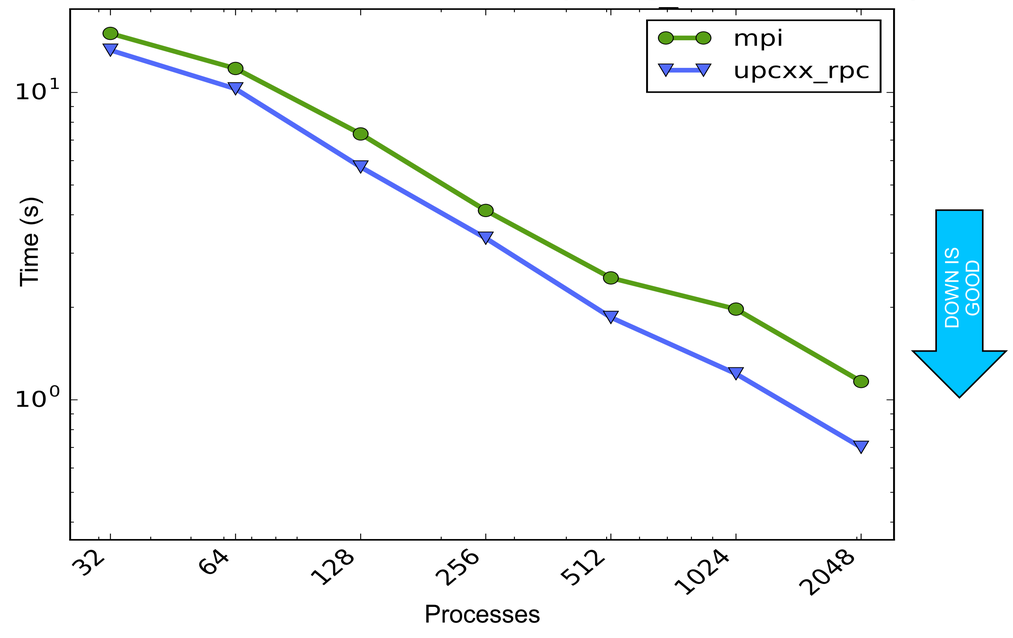
Efficient weak scaling to 512 nodes (34K cores) on Cori Xeon Phi *



Case 2: Asynchronous Sparse Matrix Solvers

- **A time consuming operation in multifrontal sparse solvers:**
  - ***Extend-add:*** update a distributed sparse matrix, scattering the packed data source
- **Challenge:**
  - This operation has low computational intensity and exhibits irregular communication patterns
- **Solution**:
  - UPC++ **function shipping** via RPC enables efficient communication and asynchrony, increasing overlap and improving performance of ***Extend-add***
- **Impact:**
  - UPC++ enhances overlap in ***Extend-add***, yielding up to a 1.63x speedup over MPI collective and 3.11x over MPI message-passing implementations. The green line in the figure corresponds to the fastest of these two variants.

Strong scaling comparison of the UPC++ implementation of Extend-add using RPC and an MPI variant for the audikw_1 matrix on NERSC Cori Xeon Phi (using 64 cores/node) *



*** For more details see IPDPS'19. https://doi.org/10.25344/S4V88H**

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