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Can There Be a Common Communication Runtime System?

William Gropp and Darius Buntinas
Mathematics and Computer Science Division

THE UNIVERSITY OF CHICAGO
Office of Science
U.S. DEPARTMENT OF ENERGY
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Overview of Pros and Cons

- Pro
  - Share development work
  - Encourage interoperability of programming models
  - Provide portability for HPCS languages (ubiquity)

  } Why develop a common runtime?
- Con
  - Match to programming model (duplicate the "MPI effect" — constrain models into CCS semantics)
  - Match to hardware (particularly hardware that is expensive to emulate in software, e.g., full/empty bits or remote atomic updates)
  - Runtime overhead may be unsuitable for load-store operations
  - RISC vs CISC (small and simple vs large and rich)
- Short answer:
  - Maybe …

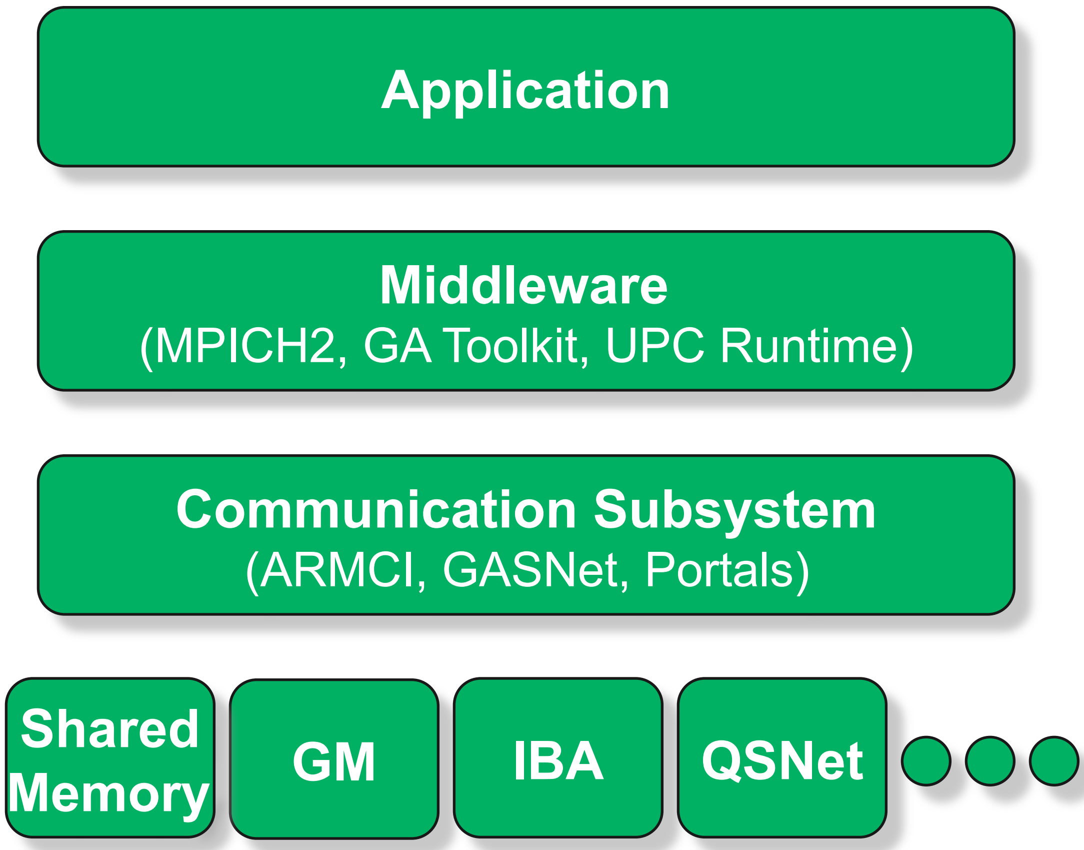
Some Issues

- What memory may be used in zero-copy mode?
  - Special memory? Statically allocated memory? Stack?
  - Alternately, which classes of RMA memory does the programming model require:
    - *RMA memory defined collectively at init time*
    - *RMA memory defined collectively at any time*
    - *RMA memory defined non-collectively at any time*
    - *All of process memory*
- How are remote addresses specified?
  - Require "symmetric allocation"?
  - Prior initialization?
- Are stores ordered? What is the consistency model?
- Is the model scalable? Is it scalable to subsets of processes (teams)?
- What data alignments are supported efficiently?
- Are there remote atomic operations? Fetch and increment? Compare and swap? Load-link/store conditional? Queue insert and extract?
- How is progress managed (polling verses interrupt/non-polling/thread/separate hardware)?
- We examined these issues and others for MPI in the context of some existing runtime systems
  - These other systems are well-optimized for *their* programming models
  - This illustrates some of the challenges in a common model — the devil *is* in the details

Motivation

- We worked on implementing a hybrid MPI-UPC programming environment
  - Port MPICH2 over the GASNet communication subsystem
  - GASNet couldn't efficiently support all that was needed by MPICH2
    - *And MPI can't efficiently support what is needed by UPC*
- While there are many common features
  - E.g., RMA operations, bootstrapping
- Communication subsystems are typically designed to support a specific middleware library or runtime system
- Previously analyzed the requirements of various programming model middleware and the communication subsystems that support them
  - There are no existing communication subsystems that efficiently support all middleware
  - There are no mutually exclusive requirements

Software Layers of a High-Performance Computing System



Design Issues for Communication Subsystems for MPI

- Required features (for the MPI programming model)
  - Remote Memory Access operations
  - MPI-2 RMA support
  - GAS language and remote-memory model support
  - Efficient transfer of large MPI two-sided messages
- Desired features
  - Active messages
  - In-order message delivery (to simplify support for MPI "envelope" ordering)
  - Noncontiguous data (not just contiguous or strided)

Summary of Features Supported by Current Communication Subsystems

	RMA operations	MPI-2 active-mode RMA	MPI-2 passive-mode RMA	GAS language support	Transfer of large MPI messages	Active messages	In-order message delivery	Noncontiguous data*	Portability
ARMCI	●		●	●				V,S	●
GASNet	●		●	●		●			●
LAPI	●	●	●	●	●	●		V	
Portals	●	●	●	●	●		●		●
MPI-2	●	●	●		●		●	V,S,B	●

* V = I/O vector; S = strided; B = block-indexed

An Example Communication Subsystem – CCS

- CCS (Common Communication Subsystem) is based on
  - Nonblocking RMA operations
    - *For efficient data transfer*
  - Active messages
    - *For small messages, control and invocation of remote operations*

- Outline
  - Active messages
  - Remote memory access operations
  - Efficient transfer of large MPI two-sided messages
  - In-order message delivery
  - Noncontiguous data

Active Messages

- CCS provides active messages
  - Sender specifies handler function with parameters
    - *Handler is executed on receiver when message is received*
  - Provide flexibility to upper layer developers
  - Intended for small messages, so should be optimized for latency
- Depending on implementation, handlers will be called from within a CCS function, or asynchronously
  - CCS provides locks which can safely be called from within handlers
  - CCS provides a mechanism to prevent a handler from interrupting the current thread
- CCS allows multiple upper layer libraries to use CCS at the same time
  - Each library allocates a *context*
    - *Uniquely identifies a set of handler functions*

Remote Memory Access Operations

- CCS provides nonblocking RMA operations
  - Use the interconnect's native RMA operations to maximize performance
  - If native RMA operations are not available, use active messages
    - *E.g., Get : active message + put*
  - Support for GAS language and remote-memory models
    - *Concurrent accesses are allowed*
- CCS uses callback functions for completion notification
  - A callback function pointer and parameter are specified in the call to the RMA operation
  - The callback is called when the RMA operation completes remotely
  - This can be used to implement fence operations
- Lower-level interconnect libraries have different requirements for RMA memory
  - CCS provides different functions to meet these requirements
    - *Registration of existing memory to be used for RMA*
    - *RMA memory allocation*

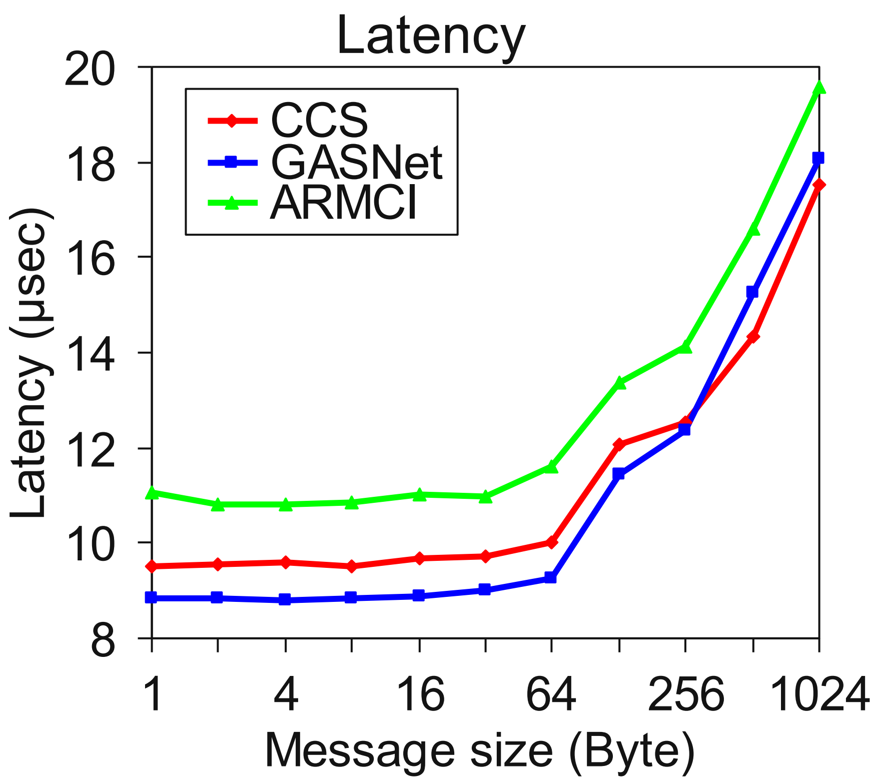
RMA Memory

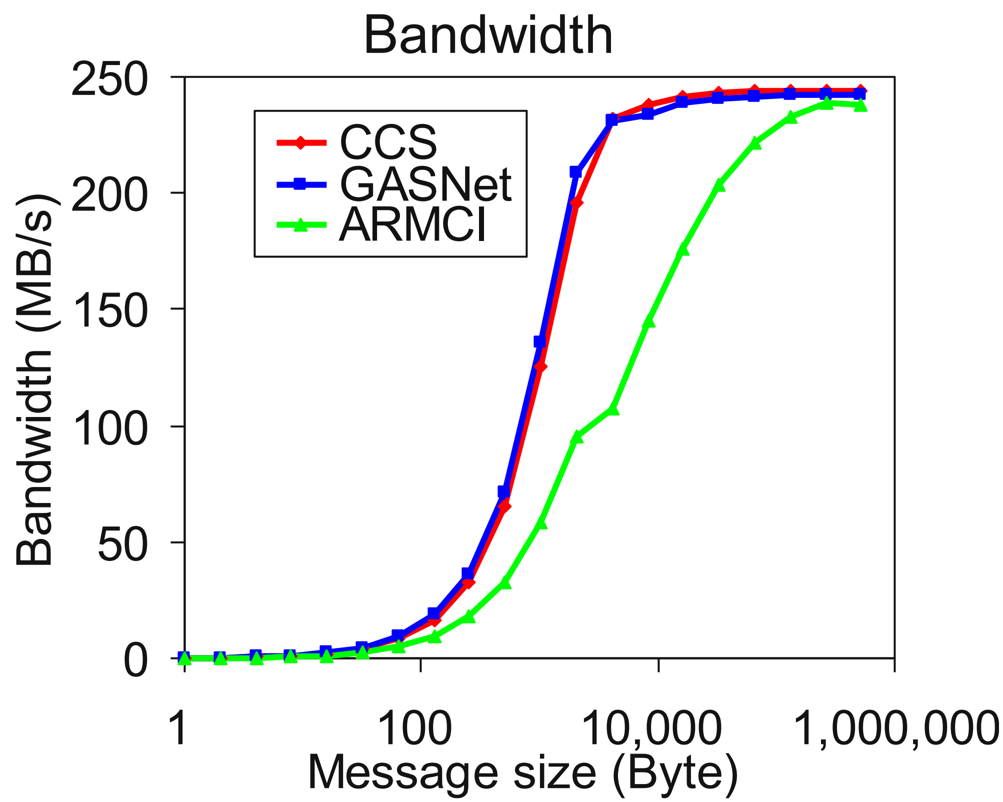
- Registration of existing memory to be used for RMA
  - Most user-level communication libraries require registration
  - CCS will manage which pages to register with communication library
    - *Communication library may limit the number of registered pages*
    - *Not all pages registered with CCS need be registered with the communication library*
  - Note that there are many well-known problems with user-mode registration caches (if user/OS/middleware releases memory)
- Allocation of RMA memory
  - Some architectures don’t support registration of existing pages
    - *E.g., Solaris can’t pin existing pages*
  - What if the implementation communicates using shared memory?
    - *Can’t make existing memory shared memory*
  - CCS provides methods to allocate RMA memory
    - *E.g., allocate a shared memory region to which others can attach*

Noncontiguous Data

- CCS supports noncontiguous data using *datadescs*
  - Similar to MPI Datatypes
  - Defined recursively
    - *But unrolled into component loops rather than use recursive procedure calls*
  - Basic datadescs
    - *Contiguous*
    - *Vector – blocks of data at regular intervals*
    - *Struct – like a C struct of different datadescs*
    - *Indexed – similar to I/O vector*
    - *Block-indexed – like indexed, but each segment is the same length*
- Datadescs
  - Along with native datatype info (e.g, int, double) can be used to implement MPI Datatypes
  - LAPI I/O vectors can be implemented with *Indexed* datadesc
  - ARMCI
    - *"Strided" can be implemented with* Vector *datadesc*
    - *"Vector" can be implemented with* Indexed *datadesc*

Preliminary Performance Results (over GM2)





- 4-Byte latencies:
  - GASNet 8.8 µs =21120 cycles
  - CCS 9.6 µs
  - ARMCI 10.8 µs
- Max bandwidth:
  - GASNet 242 MBps
  - CCS 244 MBps
  - ARMCI 238 MBps

Implications for a Common Runtime System

- A "classic" runtime library is unlikely to satisfy all needs
  - There may be too many differences at both the hardware and programming model level to bridge while maintaining performance
  - We have an example in the BLAS and sparse BLAS
    - *BLAS for small matrices slower than simple Fortran code*
      - Overhead dominates for latency-sensitive sizes
    - *Sparse BLAS have had little impact*
      - Rich but still a mismatch to hardware and/or "programming model" (application data structures)
- What can we do?
  - After all, BLAS are useful in the right place …

Some Steps Toward a Common Communication Runtime

- Like the beginnings of MPI, there are a number of high-quality systems targeting different parts of the general space
- Methods could be shared for specific operations
- Initialization of runtime systems could be arranged to allow different systems to interoperate
- Source "templates" could be used as "executable documentation" of best practice and used as input in creating custom runtimes
- An extensible common core could be defined
  - Define required architectural abilities
    - *Part of MPI RMA model complexity results from accommodating non-cache-coherent systems; other complexity from weak consistency model*
  - Consider allowing several "progress" alternatives
    - *Picking one model is guaranteed to drive away some systems*
  - Consider following the graphics engine model (basic ops plus optional special features)
  - Start from scratch (don't start from anyone's existing system)
- No matter what you do, by definition it will be a Greatest Common Denominator system