The Grass is Always Greener: Reflections on the Success of MPI and What May Come After

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Some Context

- Before MPI, there was chaos – many systems, but mostly different names for similar functions.
  - Even worse – similar but not identical semantics
- Same time(ish) as attack of the killer micros
  - Single core per node for almost all systems
- Era of rapid performance increases due to Dennard scaling
  - Most users could just wait for their codes to get faster on the next generation hardware
  - MPI benefitted from a stable software environment
    - Node programming changed slowly, mostly due to slow quantitative changes in cache, instruction sets (e.g., new vector instructions)
- The end of Dennard scaling unleashed architectural innovation
  - And imperatives – more performance requires exploiting parallelism or specialized architectures
  - (Finally) innovation in memory – at least for bandwidth

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Why Was MPI Successful?

- It addresses all of the following issues:
  - Portability
  - Performance
  - Simplicity and Symmetry
  - Modularity
  - Composability
  - Completeness
- For a more complete discussion, see "Learning from the Success of MPI",
- https://link.springer.com/chapter/10.1007/3-540-45307-5_8

Portability and Performance

- Portability does not require a “lowest common denominator” approach
  - Good design allows the use of special, performance enhancing features without requiring hardware support
  - For example, MPI’s nonblocking message-passing semantics allows but does not require “zero-copy” data transfers
- MPI is really a “Greatest Common Denominator” approach
  - It *is* a “common denominator” approach; this is portability
    - To fix this, you need to change the hardware (change “common”)
  - It *is* a (nearly) greatest approach in that, within the design space (which includes a library-based approach), changes don’t improve the approach
    - Least suggests that it will be easy to improve; by definition, any change would improve it.
    - Have a suggestion that meets the requirements? Lets talk!

Simplicity and Symmetry

- MPI is organized around a small number of concepts
  - The number of routines is not a good measure of complexity
    - E.g., Fortran
      - Large number of intrinsic functions
    - C/C++, Java, and Python runtimes are large
    - Development Frameworks
      - Hundreds to thousands of methods
  - This doesn't bother millions of programmers

- Exceptions are hard on users
  - But easy on implementers — less to implement and test
- Example: MPI_Issend
  - MPI provides several send modes
  - Each send can be blocking or non-blocking
  - MPI provides all combinations (symmetry), including the "Nonblocking Synchronous Send"
    - Removing this would slightly simplify implementations
    - Now users need to remember which routines are provided, rather than only the concepts

Modularity and Composability

- Many modern algorithms are hierarchical
  - Do not assume that all operations involve all or only one process
  - Provide tools that don't limit the user
- Modern software is built from components
  - MPI designed to support libraries
    - "Programming in the large"
  - Example: communication contexts
- Environments are built from components
  - Compilers, libraries, runtime systems
  - MPI designed to "play well with others"*
- MPI exploits newest advancements in compilers
  - … without ever talking to compiler writers
  - OpenMP is an example
    - MPI (the standard) required **no changes** to work with OpenMP

Completeness

- MPI provides a complete parallel programming model and avoids simplifications that limit the model
  - Contrast: Models that require that synchronization only occurs collectively for all processes or tasks
- Make sure that the functionality is there when the user needs it
  - Don't force the user to start over with a new programming model when a new feature is needed

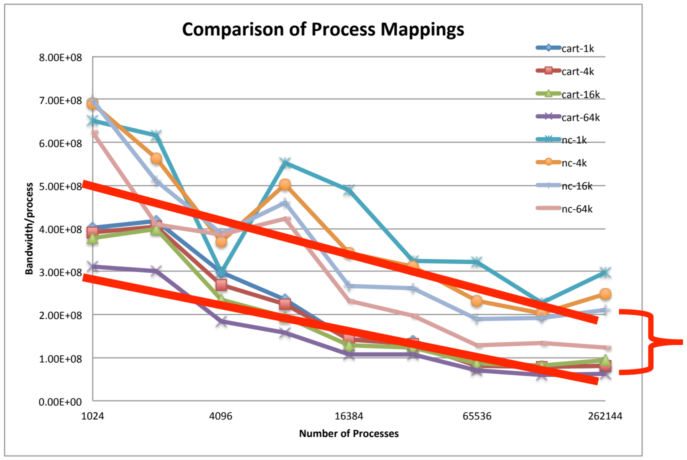
I can do “Better”

- “I don’t need x, and can make MPI faster/smaller/more elegant without it”
  - Perhaps, for you
  - Who will support you? Is the subset of interest to enough users to form an ecosystem?
- My hardware has feature x and MPI *must* make it available to me
  - Go ahead and use your non-portable HW
  - Don’t pretend that adding x to MPI will make codes (performance) portable

- Major fallacy – measurements of performance problems with an MPI implementation do *not* prove that MPI (the standard) has a problem
  - All too common to see papers claiming to compare MPI to x when they do no such thing
    - Instead, the compare an implementation of MPI to an implementation of x.
  - Why this is bad (beyond being bad science and an indictment of the peer review system that allows these) – focus on niche, nonviable systems rather than improving MPI implementations

Maybe you *Can* do Better

- There is a gap between the functional definition and the delivered performance
  - Not just an MPI problem – common in compiler optimization
    - Many (irresponsible) comments that the compiler can optimize better than the programmer
    - A true lie – true for simple codes, but often false once nested loops or more complex code; often false if vectorization expected
    - “If I actually had a polyhedral optimizer that did what it claimed…” – comment at PPAM17
  - In MPI:
    - Datatypes
    - Process topologies
    - Collectives
    - Asynchronous progress of nonblocking communication
    - RMA latency
    - Intra-node MPI_Barrier (I did 2x better with naïve code)
    - Parallel I/O performance
    - …



- Challenge for MPI developers:
  - Which is most important? Optimize for latency (hard) or asymptotic bandwidth?

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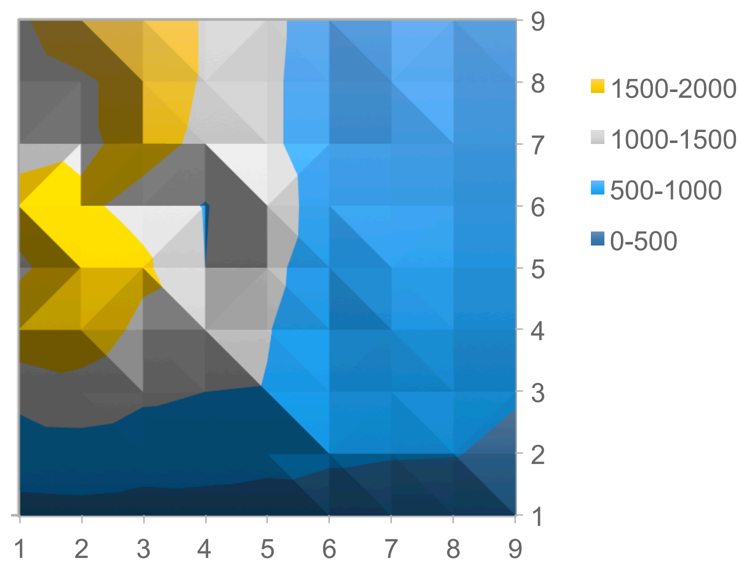
Why Ease of Use isn't the Goal

- Yes, of course I want ease-of-use
  - I want matter transmitters too – it would make my travel much easier
- Performance is the reason for parallelism
  - Data locality often important for performance
  - MPI forces the user to pay attention to locality
    - That "forces" is often the reason MPI is considered hard to use
- It is easy to define systems where locality is someone else's problem
  - "Too hard for the user – so the compiler/library/framework will do it automatically for the user!"
  - HPC compilers can't even do this for dense transpose (!) – why do you think they can handle harder problems?
  - Real solution is to work *with* the system – don't expect either user or system to solve the problem
- Making them useful is an unsolved problem



Simple, unblocked code compiled with O3 – 709MB/s

But What about the Programming Crisis?

- Use the right tools
- MPI tries to satisfy everyone, but the real strengths are in
  - Attention to performance and scalability
  - Support for libraries and tools
- Many computational scientists use frameworks and libraries built upon MPI
  - This is the right answer for most people
  - Saying that MPI is the problem is like saying C (or C++) is the problem, and if we just eliminated MPI (or C or C++) in favor of a high productivity framework *everyone's* problems would be solved
  - In some ways, MPI is *too* usable – many people can get their work done with it, which has reduced the market for other tools
    - Particularly when those tools don't satisfy the 6 features in the success of MPI

The Grass is Always Greener…

- You can either work to improve existing systems like MPI (or OpenMP or UPC or CAF) or create a new thing that shows off your new thing
- One challenge to fixing MPI implementations
  - Researchers receive more academic credit for creating a new thing (system y that is “better” than MPI) rather than improving someone else’s thing (here’s the right algorithm/technique for MPI feature y)

What Might Be Next

- Intranode considerations
  - SMPs (but with multiple coherence domains); new memory architectures
  - Accelerators, customized processors (custom probably necessary for power efficiency)
  - MPI can be used (MPI+MPI or MPI everywhere), but somewhat tortured
    - No implementation built to support SIMD on SMP, no sharing of data structures or coordinated use of the interconnect
- Internode considerations
  - Networks supporting RDMA, remote atomics, even message matching
  - Overheads of ordering
  - Reliability (who is best positioned to recover from an error)
- MPI is both high and low level (See Marc Snir's talk today) – can we resolve this?
- Challenges and Directions
  - Scaling at fixed (or declining) memory per node
    - How many MPI processes per node is "right"?
  - Realistic fault model that doesn't guarantee state after a fault
  - Support for complex memory models (MPI_Get_address ☺)
  - Support for applications requiring strong scaling
    - Implies very low latency interface and …
    - Low latency means paying close attention to the implementation
      - RMA latencies sometimes 10-100x point-to-point (!)
  - MPI performance in MPI_THREAD_MULTIPLE mode
  - Integration with code re-writing and JIT systems as an alternative to a full language

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Summary

- MPI was successful because
  - It focused on performance, the reason that most users go parallel
  - It focused on completeness, so that there would be a large enough user community to support it
  - It focused on clear and precise semantics, so it was clear what the operations *did*
  - It was pragmatic about not being a language, despite the benefits
  - It supports backwards compatibility, something no longer a goal for modern software ☹
  - It was developed in a truly open process by a diverse group of great people
- MPI should and can be augmented and/or replaced
  - But by something more, not less, capable
  - And as part of an ecosystem that provides both higher and lower level APIs