# MPI Evolution

Advanced Message-Passing Programming

# Reusing this material

# Overview

- History of the MPI Standard
  - Before MPI
  - MPI 1
  - MPI 2
- Present of the MPI Standard
  - MPI 3.1
- Future of the MPI Standard
  - MPI 4.0/Next
- MPI Implementations

# Before MPI

- Before MPI, many competing message passing libraries.
  - Most computer vendors developed their own proprietary libraries.
  - There were also various portable libraries:
    - These targeted a variety of systems/interconnects.
    - Mostly developed by academic groups.
    - Usually only optimised for a small subset of the supported platforms.
- Different libraries used different models of communication
- This made application development very hard
  - Applications often needed their own communication module to encapsulate the different message passing systems.
- MPI was an attempt to define a standard set of communication calls.

# MPI Forum

- Main web site at http://mpi-forum.org/meetings/
- The MPI Forum contains representatives from many of the vendors and academic library developers.
- This is one reason the specification is so large:
  - MPI supports many different models of communication, corresponding to various communication models supported by its predecessors.
- Much of the specification driven by the library developers.
  - leaves a lot of scope for optimised versions on different hardware.
  - many aspects of the MPI specification deliberately allow different implementations the freedom to work in different ways.
    - this makes it easy to port/optimise MPI for new hardware.
    - application developers need to be aware of this when writing code.
    - erroneous applications may work fine on one MPI implementation but fail using a different one.

# Early History of MPI

- MPI is an “Application Programming Interface” (API) specification.
  - it is a specification not a piece of code.
  - there are many different implementations of the MPI specification.
- The MPI Standard is defined by the MPI Forum
  - Work started 1992
  - V 1.0 in 1994 – basic point-to-point, collectives, data-types, etc
  - V 1.1 in 1995 – fixes and clarifications to MPI 1.0
  - V 1.2 in 1996 – fixes and clarifications to MPI 1.1
  - V 1.3 in 1997 – refers to MPI 1.2 after combination with MPI-2.0
  - V 2.0 in 1997 – parallel I/O, RMA, dynamic processes, C++, etc

# More recent History of MPI

- ... V 2.0 in 1997 – parallel I/O, RMA, dynamic processes, C++, etc

- Stable for 10 years
  - Version 2.1 in 2008 – fixes and clarifications to MPI 2.0
  - Version 2.2 in 2009 – small updates and additions to MPI 2.1
  - Version 3.0 in 2012 – neighbour collectives, unified RMA model, etc
  - Version 3.1 in 2015 – fixes, clarifications and additions to MPI 3.0
  - Version 4.0 in 2021 – persistent collectives

# MPI-2 One-sided communication

- Separates data transmission from process synchronisation
- All comms parameters specified by a single process
- Definitions: “origin” calls MPI, memory accessed at “target”

- Initialise by creating a “window”
  - A chunk of local memory that will be accessed by remote processes

- Open origin “access epoch” (and target “exposure epoch”)
  - Communicate: MPI_Put, MPI_Get, MPI_Accumulate
  - Synchronise: passive target (or active target)
  - Use data that has been communicated
- Tidy up by destroying the window – MPI_Win_free

# MPI 3.0

- Major new features
  - Non-blocking collectives, neighbourhood collectives
  - Improvements to one-sided communication
  - Added a new tools interface and new bindings for Fortran 2008
- Other new features
  - Matching Probe and Recv for thread-safe probe and receive
  - Non-collective communicator creation function
  - Non-blocking communication duplication function
  - “const” correct C language bindings
  - New MPI_Comm_split_type function
  - New MPI_Type_create_hindexed_block function
- C++ language bindings removed
  - previously deprecated functions removed

# MPI 3.0 – Changes to collectives

- Non-blocking versions of all collective communication functions added
  - MPI_Ibcast, MPI_Ireduce, MPI_Iallreduce, etc
    - There is even a non-blocking barrier, MPI_Ibarrier
  - They return MPI_Request like other non-blocking functions
    - The user code must complete the operation with (one of the variants of) MPI_Test or MPI_Wait
  - Multiple non-blocking collectives can be outstanding but they must be called in the same order by all MPI processes
- New neighbourhood collective functions added
  - MPI_Neighbor_allgather and MPI_Neighbor_alltoall (plus variants)
  - Neighbours defined using a virtual topology, i.e. cartesian or graph
  - Extremely useful for nearest-neighbour stencil-based computations
  - Allow a scalable representation for common usage of MPI_Alltoallv

# MPI 3.0 – Changes to One-sided

- New window creation functions
  - New options for where, when and how window memory is allocated
- New atomic read-modify-write operations
  - MPI_Fetch_and_op and MPI_Compare_and_swap

- New "unified" memory model
  - Old one still supported, now called "separate" memory model
  - Simplifies memory consistency rules on cache-coherent machines

- New local completion semantics for one-sided operations
  - MPI_Rput, MPI_Rget and MPI_Raccumulate return MPI_Request
  - User can use MPI_Test or MPI_Wait to check for local completion

# MPI 4.0: selected features

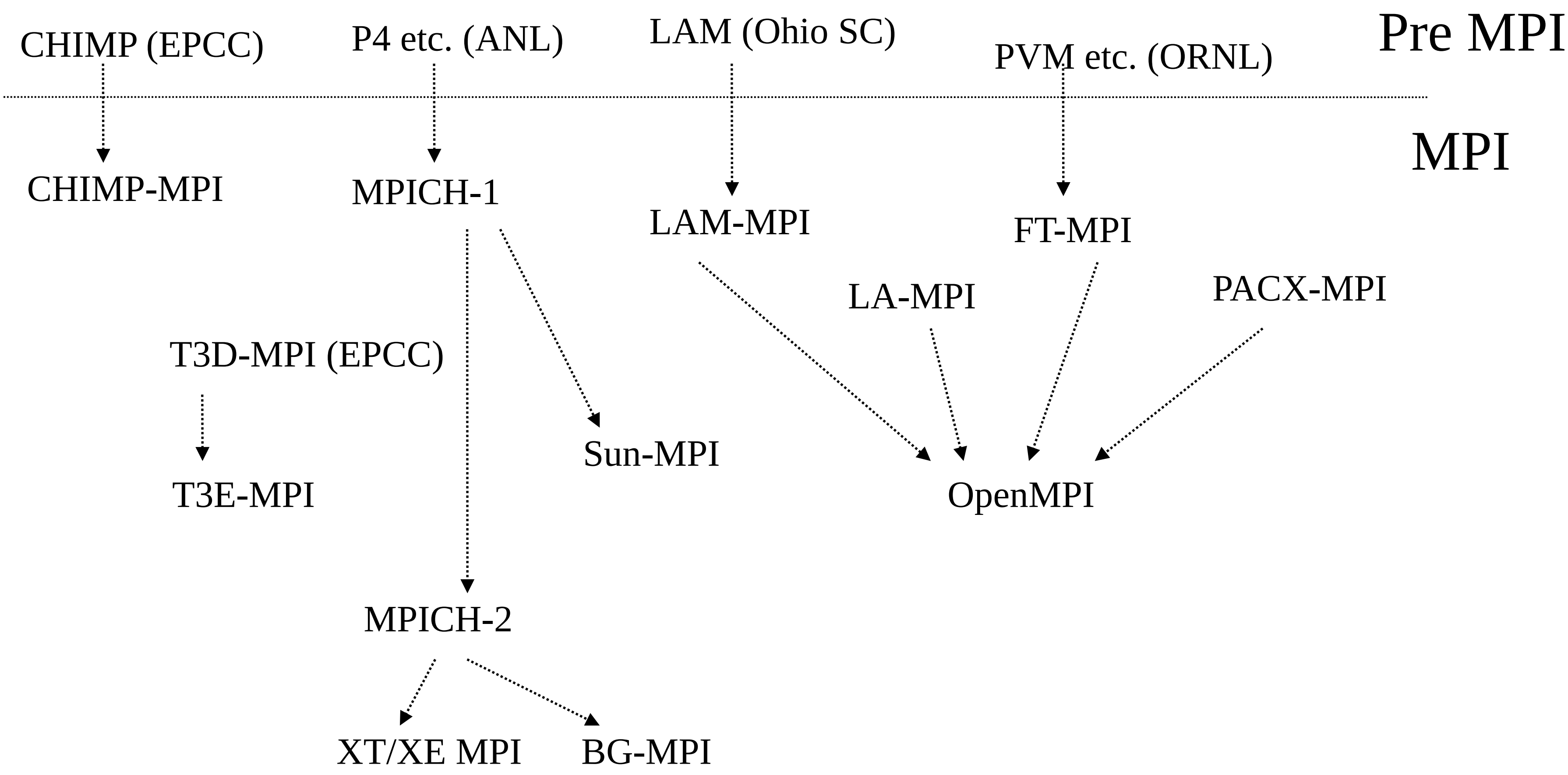
- Persistent collectives
  - Extends existing persistent point-to-point functions
  - Many more runtime optimisations are possible for collectives
- Fault-tolerance proposal – improved error-handling
  - Allow an MPI program to survive various types of failure
  - Node failure, communication link failure, etc
  - Notification: local process told particular operation will not succeed
  - Propagation: local knowledge of faults disseminated to global state
  - Consensus: vote for and agree on a common value despite failures
  - Low-level minimum functionality to support fault-tolerance libraries

- Fault tolerance does not appear to be in 4.0 standard

# MPI implementations

- There are many different implementations of the MPI specification.
- Many of the early ones were based on pre-existing portable libraries.
- Currently there are 2 main open source MPI implementations
  - MPICH
  - OpenMPI
- Many vendor MPI implementations are now based on these open source versions.

# MPI family tree (partial)



# MPICH

- Virtually the default MPI implementation
  - Mature implementation.
  - Good support for generic clusters (TCP/IP & shared memory).
  - Many vendor MPIs now based on MPICH.
- Original called MPICH (MPI-1 functionality only)
- Re-written from scratch to produce MPICH-2 (MPI-2)
- Incorporated MPI-3 and renamed back to MPICH again
- Ported to new hardware by implementing a small core ADI
  - ADI = Abstract Device Interface.
  - Full API has default implementation using the core ADI functions.
  - Any part can be overridden to allow for optimisation.

# OpenMPI

- New MPI implementation
  - Joint project between developers of
    - FT-MPI
    - LA-MPI
    - LAM/MPI
    - PACX/MPI
- Very active project
    - Special emphasis on support for infiniband hardware
    - Initially had an emphasis on Grid MPI
      - Fault tolerant communication
      - Heterogeneous communication
  - Current version supports MPI-3
  - Open Source project with large and varied community effort

# Summary

- Most MPI implementations use a common “superstructure”
  - lots of lines of code dealing with a whole range of MPI issues: datatypes, communicators, argument checking, …
  - will implement a number of different ways (protocols) of sending data
    - all hardware-specific code kept separate from the rest of the code, e.g. hidden behind an Abstract Device Interface
- To optimise for a particular architecture
  - rewrite low-level communication functions in the ADI
  - optimise the collectives especially for offload hardware
  - use machine-specific capabilities when advantageous
- Multi-core nodes
  - modern MPI libraries are aware of shared-memory nodes
    - already include optimisations to speed up node-local operations
  - uses multiple implementations of the same ADI in a single library