The MPI Message-passing Standard Practical use and implementation (V)

SPD Course

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Intracommunicators

COLLECTIVE COMMUNICATIONS

Collectives' Characteristics

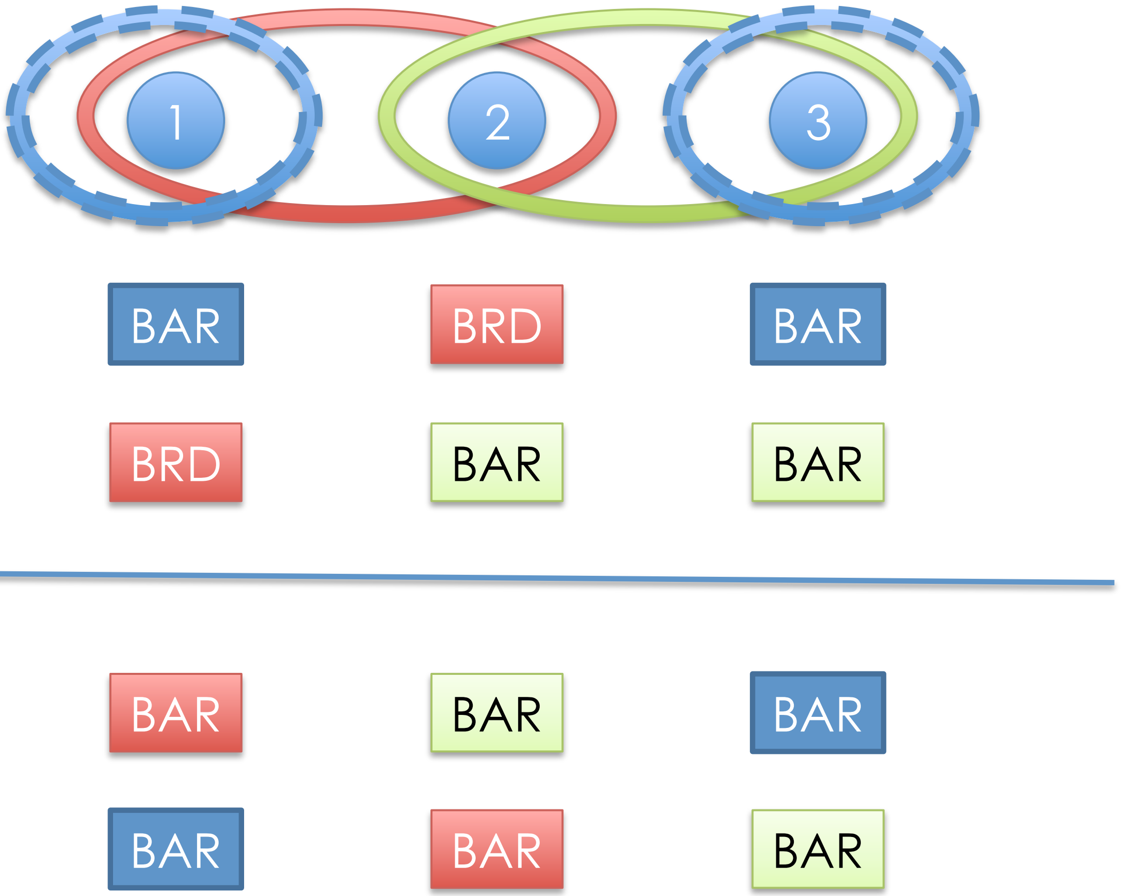
- Collective operations are called by ALL processes of a communicator
  - Still happen within a communicator like p-to-p
  - Use Datatypes to define message structure
  - Implement complex communication patterns
- Distinct semantics from point-to-point
  - No modes
  - Always blocking (* MPI 3 changes this *)
  - No unmatched variable-size data
  - No status parameters (would require many…)
  - Limited concurrency
- Still a lot of freedom left to implementers
  - E.g. actual pattern choice, low-level operations
  - Semantics carefully defined for this aim

Collective & Communicators

- Independence among separate communicators
- Independence with any p-to-point in same comm.
  - Although collectives may be implemented on top of p-to-point, e.g. by using a separate set of tags
- Collectives are serialized over a communicator
  - Obvious consequence of the semantics
  - Collectives must share the same actual call order from every process in the communicator
- Serialization **is not** synchronization
  - Blocking behaviour = after the call, local completion is granted and buffer / parameters are free to be reused
  - Globally, the collective may still be ongoing (and vice versa)
  - Example: broadcast on a binary support tree may complete on root process long before it is done
  - p-to-point primitives are concurrent with collective op.s
  - **Only** MPI_Barrier is granted to synchronize
- Serialization **is** a source of deadlocks

Example of deadlocks and errors

- Serialization **is** a source of deadlocks
  - 3 overlapping comm.s with collectives in conflicting order



Collective Primitives – High-level view

- Many of the primitives you already know
  - Synchronization:
    Barrier (*also an all-to-all*)
  - One-to-all: Bcast (*broadcast*), Scatter *
  - All-to-one: Gather *, Reduce
  - All-to-all: AllGather *, AllToAll *, AllReduce, ReduceScatter
  - Other (*computational-communication patterns* and *management primitives*):
    Scan (*parallel prefix*), Exscan
    Communicator-building operations
- More on this later on

Collectives: Semantics

- All processes send and/or receive data
  - If a structure is distributed, one piece is possibly sent/received by the same process
  - This in general includes the root process, if one is present
  - Semantics are symmetric to simplify the case where the root process dynamically changes at runtime
- Agreement on parameters among all processes
  - Which process is the root, if a root role is needed
  - Specific roles in communicator building, operators in computational collective
- Agreement on data to be transferred
  - Buffers defined at each process must match in size and type signature with what is required by the partner sending/receiving that data
    - Even if the actual communication may happen differently!
  - In some cases the same buffer is used for reading AND writing

Collectives: Semantics

- User-defined datatypes and type signatures are allowed
  - However, more constraints than in the p-to-p case
  - Type signatures should be compatible as always
  - *Writing* typemaps shall never be redundant
    - No ambiguity shall ever arise from typemap access order, which is free choice of the MPI library
  - Generally speaking, collective primitives should not read or write twice the same location
    - no location written twice by either the same or different processes inside a collective
    - can imply that no location is either **read** twice
    - **Not** discussing all cases, refer to the standard

Barrier & Broadcast

- `int MPI_Barrier(MPI_Comm comm)`
  - can be applied to intercommunicators
  - the only collective whose synchronization effects are guaranteed by the MPI standard

-
  ```
  int MPI_Bcast(void* buffer, int count,
          MPI_Datatype datatype, int root,
          MPI_Comm comm )
  ```
  - semantics: the specified communication is sent to all processes
    - equivalent descriptions always given in the standard
  - can use any underlying scheme (trivial, n-ary tree, spanning tree…)

Classifications of collectives

- MPI-3 has plenty of distinct collective comm. calls
  - Distinct == a different API function name and signature
  - 17 blocking and 17 non-blocking, + some more for communicator management

1. Classification by asymmetry
   - All to 1 many processes send to one
   - 1 to All one process sends to many
   - All to All all processes send and receive
2. by homogeneity of data exchange
   - "*normal*" = homogeneous communications
   - V "*variable*" = a count/size for each communication is specified by the process
3. By kind of pattern
   - Communication only
   - Communication **and** Computation (A-to-1, A-to-A)

Gather

- `int MPI_Gather(`
  ```
      const void* sbuf, int scount, MPI_Datatype sendtype,
      void* recvbuf, int recvcount, MPI_Datatype recvtype,
      int root, MPI_Comm comm)
  ```
  - All to 1
    - gather a distributed data structure at the root process
  - the send and recv type signatures must match
    - like a couple of point-to-point communication
    - all send specs must match the recv at the root
  - the actual recv buffer and data structure is N times bigger than the recv specification
    - where N is the number of processes in comm
  - process rank *i* will write at position *i* of this buffer
    - exact address is recvbuf+i*count*mpi_size(recvtype)
  - the receive buffer count and type is significant only at the root, an ignored on other processes
    - the root can use MPI_IN_PLACE for the send buffer

in-place Communication

- In collectives, all processes send or receive data, **including** the designed root
  - much like a send or receive to MPI_PROC_SELF
  - this means extra work and extra buffers
- MPI_IN_PLACE constant
  - to be specified as a buffer address
  - specifies that the input and output buffers at this process for this collective are the same
  - to be used as the send or receive buffer, depending on the collective
  - the associated count, datatype parameters are ignored
- why?
  - explicitly avoid useless data movement
  - simplify usage of collectives in many common cases (less parameters needed and less error prone)
  - avoid the limitation of languages that forbid aliasing of parameters (e.g. Fortran)

Scatter

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  ```
  int MPI_Scatter(const void* sendbuf,
      int sendcount, MPI_Datatype sendtype,
      void* recvbuf, int recvcount,
      MPI_Datatype recvtype,
      int root, MPI_Comm comm)
  ```
  - 1 to All
    - scatter a data structure from the root process onto the whole comm
  - the send and recv type signatures must match
    - like a couple of point-to-point communication
    - all send specs must match the recv at the root
  - the actual send buffer and data structure is N times bigger than the send specification
    - where N is the number of processes in comm
  - process rank *i* will read from at position *i* of this buffer
    - exact address is sendbuf+i*count*mpi_size(sendtype)
  - the send buffer count and type are significant only at the root, and ignored on other processes
    - the root can use MPI_IN_PLACE for the recv buffer

Gatherv = Gather Variable-length

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  ```
  int MPI_GatherV(
      const void* sbuf, int scount, MPI_Datatype sendtype,
      void* recvbuf, const int recvcounts[],
      const int displs[], MPI_Datatype recvtype,
      int root, MPI_Comm comm)
  ```
  – like Gather, but the parts of the gathered structure are allowed to be a different size each one
    - the receive count is now an array of integers
    - the send counts can vary, communications sizes are no longer bound to be the same on all processes
    - some counts can be zero

  – also: place in memory for received parts is given
    - process of rank *i* will write at position
      displs[*i*]*mpi_extent (recvtype) of recvbuf
    - the order of the received parts can be arbitrarily changed

  – the send and recv type signatures must **still** match on each couple of processes
    - more complex to check, but no real change

Variable-length : Scatterv

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  ```
  int MPI_Scatterv(const void* sendbuf,
      const int sendcounts[], const int displs[],
      MPI_Datatype sendtype,
      void* recvbuf, int recvcount,
      MPI_Datatype recvtype,
      int root, MPI_Comm comm)
  ```

- Analogous to the variable-length gather, but performing a scatter

Allgather

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  ```
  int MPI_Allgather(const void* sendbuf,
      int sendcount, MPI_Datatype sendtype,
      void* recvbuf, int recvcount,
      MPI_Datatype recvtype,
      MPI_Comm comm)
  ```
- Same semantics of gather, but all processes actually perform the gather operation and get the result (no root process specification)
- Semantics is the same as gather + broadcast, but the communication pattern may be optimized by MPI
- Also has a V form, **MPI_Allgatherv**

MPI_ALLTOALL

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  ```
  int MPI_Alltoall(const void* sendbuf,
      int sendcount, MPI_Datatype sendtype,
      void* recvbuf, int recvcount,
      MPI_Datatype recvtype,

      MPI_Comm comm)
  ```
- Further generalized communication, each process sends distinct data to all other processes
- All blocks of data have the same definition

MPI_ALLTOALLV

-
  ```
  int MPI_Alltoallv(const void* sendbuf,
      const int sendcounts[],
      const int sdispls[],
      MPI_Datatype sendtype,
      void* recvbuf, const,
      int recvcounts[], const int rdispls[],
      MPI_Datatype recvtype,
      MPI_Comm comm)
  ```
- Further generalized communication, each process sends distinct data in different amount to all other processes
- **MPI_Alltoallw** further generalizes the pattern, also allowing distinct receive and send datatypes for each distinct communication portion among a couple of processes

Changes! with MPI 3.0

- **MPI standard 3.0 released in September 2012**
  - Collective Communications **can** be non-blocking
  - In this course we will stick to the MPI 2.2 definition
- ***After*** studying the blocking version, it might worth to know about non-blocking collectives
  - names gain an "I" e.g. MPI_BCAST → MPI_IBCAST
  - blocking and non-blocking collectives **do not** match with each other
  - completion checked via all {WAIT * , TEST *} calls
  - multiple outstanding collectives allowed in same communicator
  - non-blocking behavior can avoid collective-related deadlock across communicators
    - interaction with collective serialization **is** significant
  - it is not allowed to cancel a non-bl. collective

Reference Texts

- MPI standard Relevant Material for 3rd lesson
  - Chapter 2:
    sec.
  - Chapter 3:
    sec. 3.2.5, 3.2.6, 3.6, 3.7, 3.11
  - Chapter 4:
    sec. 4.1.2, (skip 4.1.3, 4.1.4) , 4.1.5 – 4.1.7, 4.1.11
  - Chapter 5:
    sec.