Remote Memory Access

Getting started with RMA

Reusing this material

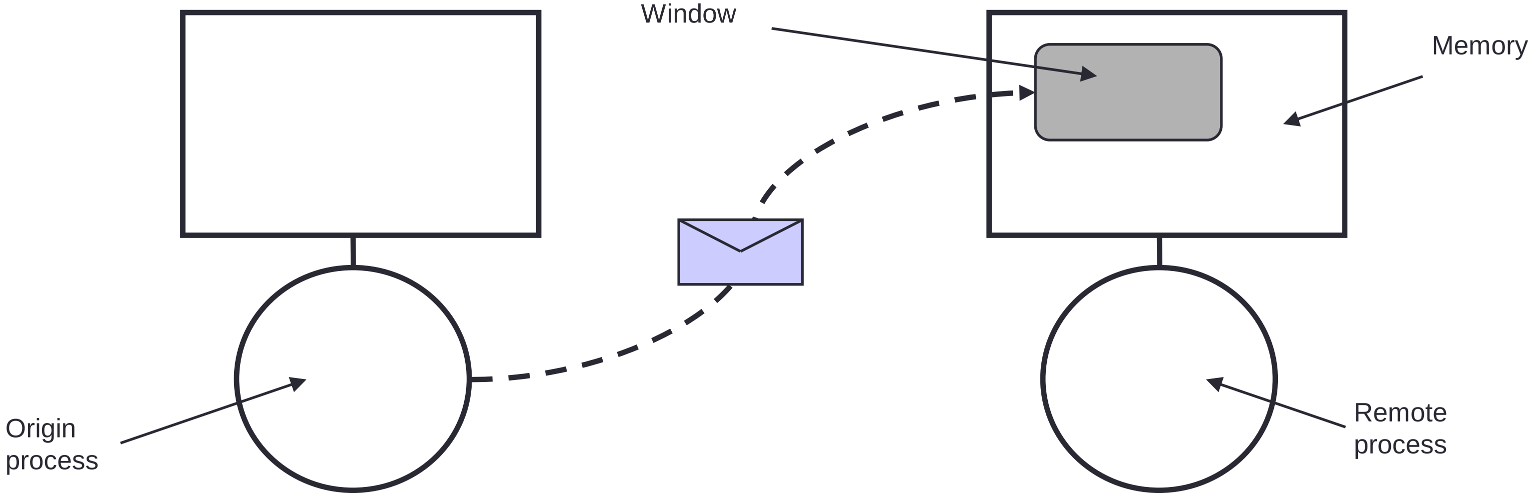
Outline

- MPI RMA Basic Concepts
  - Why RMA?
  - Terminology
  - Program flow
- Getting started with RMA
  - Management of windows
  - Fence synchronization
  - Moving data around
- Practical
  - Modifying P2P code to use RMA

MPI RMA Concepts

Single-Sided Model

- Remote memory can be read or written directly using library calls



- Remote process does not actively participate
  - No matching receive (or send) needs to be performed
  - Synchronisation is now a major issue

Motivation

- Why extend the basic message-passing model?
- Hardware
  - Many supercomputer networks support Remote Memory Access (RMA) in hardware
  - This is the fundamental model for SMP systems
  - Many users started to use RMA calls for efficiency
    - Lead to the development of non-portable parallel applications
- Software
  - Many algorithms naturally single-sided
    - e.g., sparse matrix-vector
  - Matching send/receive pairs requires extra programming
  - Even worse if communication structure changes
    - e.g., adaptive decomposition

Why RMA

- One-sided comms functions are an interface to MPI RMA
  - I think "one sided" is a confusing term because, as we will see, whilst the communication calls themselves are one sided often the synchronisation is issued on both sides

- Is a natural fit for some codes

- Can provide a performance/scalability increase for codes
  - Programmability reasons
  - Hardware (interconnect) reasons
  - But is not a silver bullet!

Terminology

- Origin is process initiating the request (performs the call)
  - Irrespective of whether data is being retrieved or written
- Target is the process whose memory is accessed
  - By the origin, either remotely reading or writing to this

- All remote access performed on windows of memory
- All access calls non-blocking and issued inside an *epoch*
  - The epoch is what forces synchronisation of these calls

RMA program flow

- Collectively initialise a window

  a) Start an RMA epoch (synchronisation)
  b) Issue communication calls
  c) Stop an RMA epoch (synchronisation)

  Repeat as many times as you want

- Collectively free the window

Getting started with RMA

Window management, fences and data movement

Window creation

- A collective call, issued by all processes in the communicator

```
int MPI_Win_create(void *base, MPI_Aint size, int disp_unit,
     MPI_Info info, MPI_Comm comm, MPI_Win *win)
```

- Each process may specify completely different locations, sizes, displacement units and info arguments.
- You can specify no memory with a zero size and NULL base
- The same region of memory may appear in multiple windows that have been defined for a process. But concurrent communications to overlapping windows are disallowed.
- Performance may be improved by ensuring that the windows align with boundaries such as word or cache-line boundaries.

Other window management

- Retrieving window attributes

```
int MPI_Win_get_attr(MPI_Win win, int win_keyval,
     void *attribute_val, int *flag)
```

  - `win_keyval` is one of `MPI_WIN_BASE`, `MPI_WIN_SIZE`, `MPI_WIN_DISP_UNIT`, `MPI_WIN_CREATE_FLAVOR`, `MPI_WIN_MODEL`
  - `Attribute_val` if the attribute is available and in this case (`flag` is true), otherwise `flag` will be false

- Freeing a window

```
int MPI_Win_free(MPI_Win *win)
```

  - All RMA calls must have been completed (i.e. the epoch stopped)

Fences

- Synchronisation calls required to start and stop an epoch
  - Fences are the simplest way of doing this where global synchronisation phases alternate with global communication

- Most closely follows a barrier synchronisation
  - A (collective) fence is called at the start and stop of an epoch

```
int MPI_Win_fence(int assert, MPI_Win win)
```

```
MPI_Win_fence(0, window);
```

Communication calls go here

```
MPI_Win_fence(0, window);
```

RMA can not be started until this first fence

All issued communication calls block here

Default value – no assertions

Fence attributes

- Attributes allow you to tell the MPI library more information for performance (but MPI implementations are allowed to ignore it!)
  - **MPI_MODE_NOSTORE** local window was not updated by local writes of any form since last synchronisation. *Can be different on processes*
  - **MPI_MODE_NOPUT** local window will not be updated by put/accumulate RMA operations until AFTER the next synchronisation call. *Can be different on processes*

  - **MPI_MODE_NOPRECEDE** fence does not complete any sequence of locally issues RMA calls. *Attribute must be given by all processes*
  - **MPI_MODE_NOSUCCEED** fence does not start any sequence of locally issued RMA calls. *Attribute must be given by all processes*

- Attributes can be or'd together, i.e.
  - `MPI_Win_fence((MPI_MODE_NOPUT | MPI_MODE_NOPRECEDE), window)` or `ior(MPI_MODE_NOPUT, MPI_MODE_NOPRECEDE)`

RMA Communication calls

- Three general calls, all non-blocking:
  - Get data from target's memory

```
int MPI_Get(void *origin_addr, int origin_count,
    MPI_Datatype origin_datatype, int target_rank,
    MPI_Aint target_disp, int target_count,
    MPI_Datatype target_datatype, MPI_Win win)
```

  - Put data into target's memory

```
int MPI_Put(const void *origin_addr, int origin_count,
    MPI_Datatype origin_datatype, int target_rank,
    MPI_Aint target_disp, int target_count,
    MPI_Datatype target_datatype, MPI_Win win)
```

  - Accumulate data in target's memory with some other data

```
int MPI_Accumulate(void *origin_addr, int origin_count,
    MPI_Datatype origin_datatype, int target_rank,
    MPI_Aint target_disp, int target_count,
    MPI_Datatype target_datatype, MPI_Op op, MPI_Win win)
```

RMA communication comments

- Similarly to non-blocking P2P one must wait for synchronisation (i.e. end of the epoch) until accessing retrieved data (*get*) or overwriting written data (*put/accumulate*)

- `target_disp` is multiplied by window displacement unit, `origin_count` and `target_count` are in units of data type

- Undefined operations:
  - Local stores/reads with a remote PUT in an epoch
  - Several origin processes performing concurrent PUT to the same target location
  - Single origin process performing multiple PUTs to same target location in a single epoch

- Accumulate supports the `MPI_Reduce` operations, but NOT user defined operations. Also supports `MPI_REPLACE` - Effectively the same as a put.

Generic Simple Approach

- Declare local storage on each rank
- Create a window including all storage: `MPI_Win_create()`
  - replaces the communicator in subsequent RMA calls
- Access data in local storage using normal array operations
- Synchronise so everyone is ready: `MPI_Win_fence()`
  - Issue remote reads / writes to from / to data on other processes
    - `MPI_Get()` and `MPI_Put()`
- Synchronise so everyone is finished: `MPI_Win_fence()`
- Can now access data in local storage as normal

Example

Based on an example at
cvw.cac.cornell.edu/MPIoneSided/fence

```
MPI_Win win;
int ctrlbuf[20], mybuf[20];
if (rank == 0) {
    MPI_Win_create(ctrlbuf, sizeof(int)*20, sizeof(int),
                   MPI_INFO_NULL, comm, &win);
} else {
    MPI_Win_create(NULL, 0, 1, MPI_INFO_NULL, comm, &win);
}
if (rank == 0) initialise(ctrlbuf);

MPI_Win_fence(MPI_MODE_NOPRECEDE,win);
if (rank != 0) {
    MPI_Get(mybuf, 20 , MPI_INT, 0, 0, 20, MPI_INT, win);
}
MPI_Win_fence(MPI_MODE_NOSUCCEED, win);

if (rank != 0) process(mybuf);
MPI_Win_free(&win)
```

Rank 0 creates a window of 20 integers, displacement unit = 4 bytes (= 1 integer)

Other ranks create a window but attach no local memory

Fence, no preceding RMA calls

Non-zero ranks get the 20 integers from rank 0, disp 0

Fence, complete all communications and no RMA calls in next epoch

RMA Memory model

- Public and private window copies
  - Public memory region is addressable by other processes (i.e. exposed main memory)
  - Private memory (i.e. transparent caches or communication buffers) which is only locally visible but elements from public memory might be stored.

- Coherent if updates to main memory are automatically reflected in private copy consistently
- Non-coherent if updates need to be explicitly synchronised

RMA Memory model

- MPI therefore has two models
  - Unified if public and private copies are identical – used if possible, realistic on cache coherent machines. *(This was added in MPI v3)*
  - Separate if they are not, here there is only one copy of a variable in process memory but also a distinct public copy for each window that contains it. The old model
- In the separate model a suitable synchronisation call (i.e. end of an epoch) must be issued to make these consistent. In the unified model some synchronisation calls might be omitted for performance reasons
- The window attribute tells you which model it follows

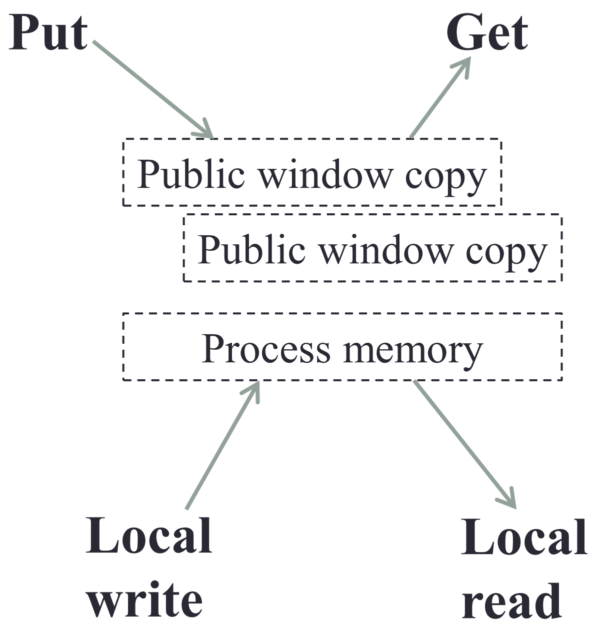


Illustration of separate model

Additional functionality

- You should be aware that:
  - you *can* do point-to-point synchronisation in MPI RMA as well as global synchronisation with fences
    - it is called “Post-Start-Complete-Wait” - PSCW
    - you do not need to know any more details than this!
  - you *can* lock windows
    - this is called “passive target synchronisation” as the target process does not need to make any RMA calls
    - model is something like: lock / put / unlock
    - you do not need to know any more details than this!

- Covered in detail in additional lecture
  - provided for info but you **do not need to learn this extra material**

Summary

- Model is quite simple
  - although syntax can be quite challenging

- Performance may not be very good
  - portability and flexibility requirements of MPI mean that latency may not be as small as you hoped

- However
  - windows are a key component of MPI shared-memory approach
  - see later ...