Lecture 34: One-sided Communication in MPI

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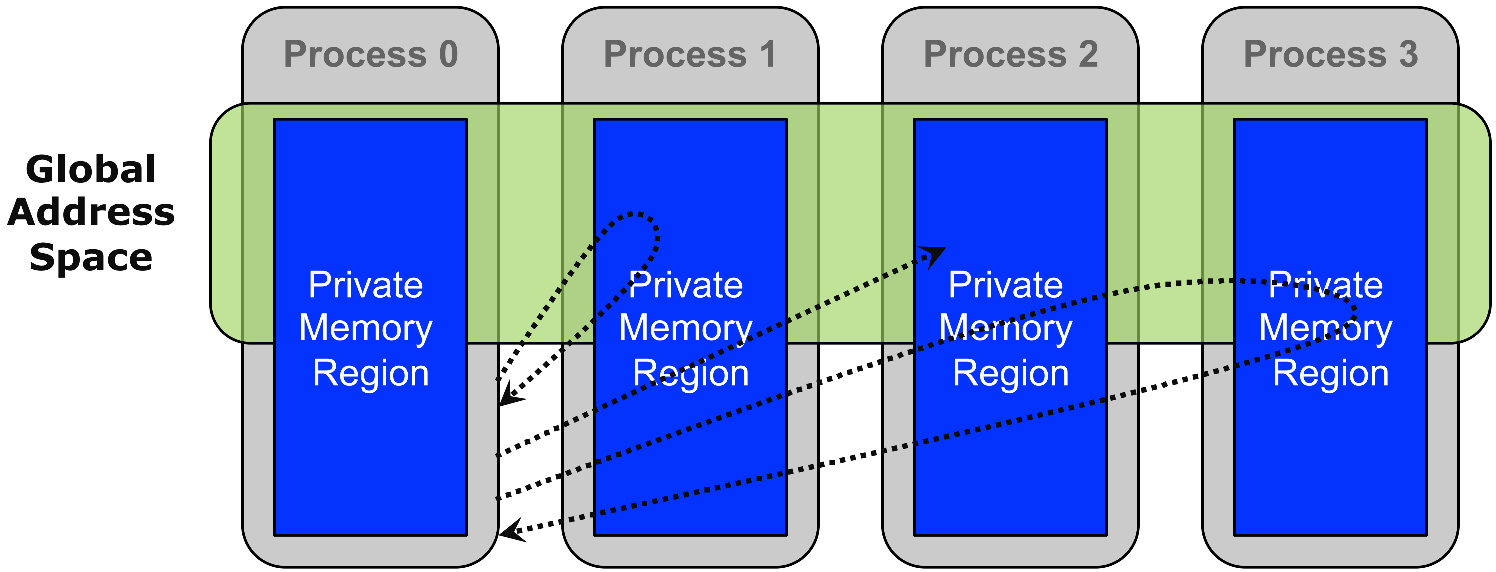
Thanks to

- This material based on the SC14 Tutorial presented by
  - Pavan Balaji
  - William Gropp
  - Torsten Hoefler
  - Rajeev Thakur

One-Sided Communication

- The basic idea of one-sided communication models is to decouple data movement with process synchronization
  - Should be able to move data without requiring that the remote process synchronize
  - Each process exposes a part of its memory to other processes
  - Other processes can directly read from or write to this memory



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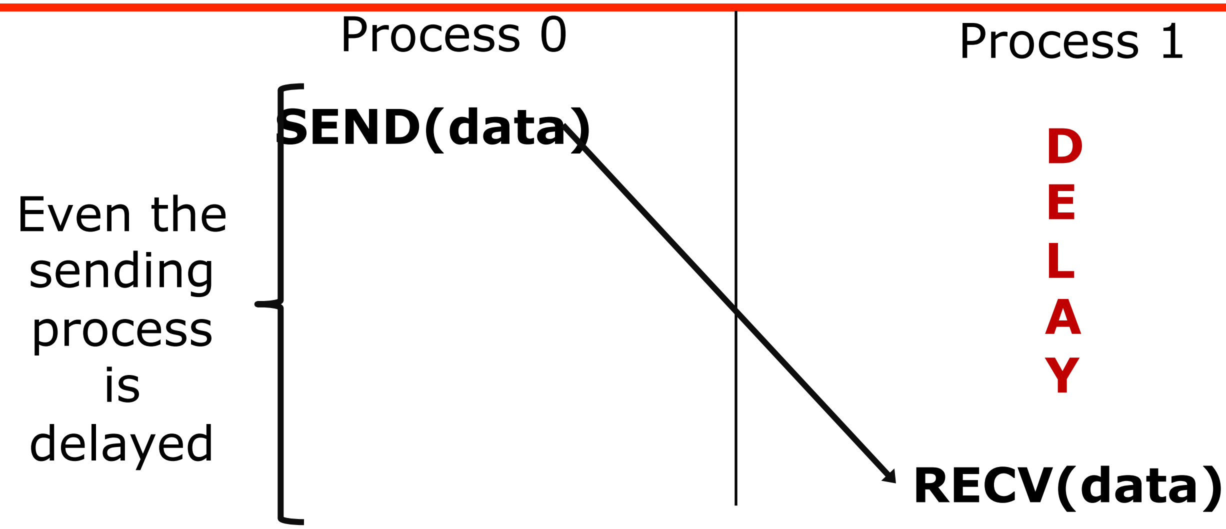
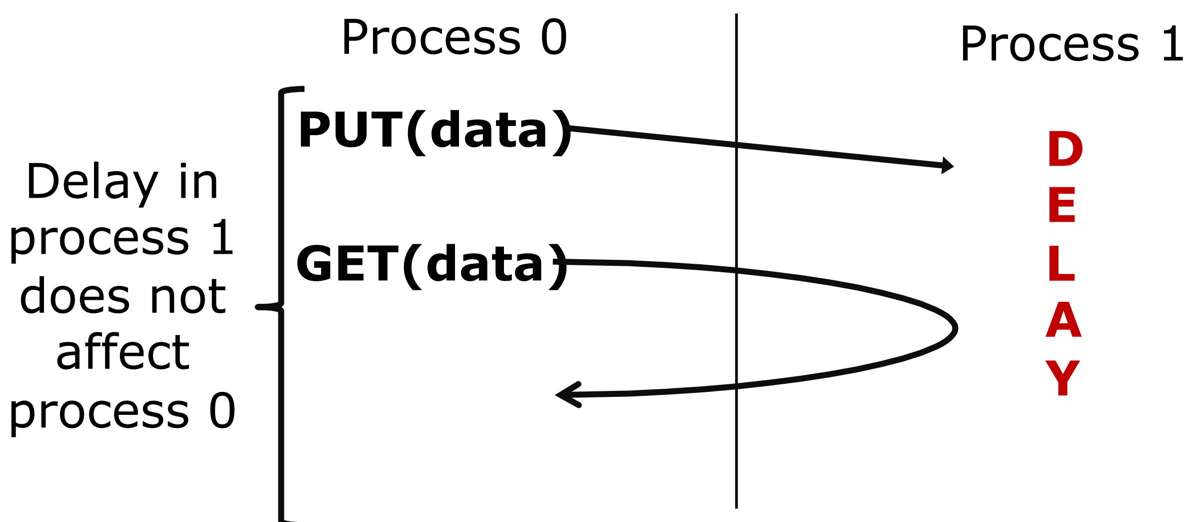
Comparing One-sided and Two-sided Programming





Advantages of RMA Operations

- Can do multiple data transfers with a single synchronization operation
  - like BSP model
- Bypass tag matching
  - effectively precomputed as part of remote offset
- Some irregular communication patterns can be more economically expressed
- Can be significantly faster than send/receive on systems with hardware support for remote memory access, such as shared memory systems

Irregular Communication Patterns with RMA

- If communication *pattern* is not known *a priori*, but the data locations are known, the send-receive model requires an extra step to determine how many sends-receives to issue
- RMA, however, can handle it easily because only the origin or target process needs to issue the put or get call
- This makes dynamic communication easier to code in RMA

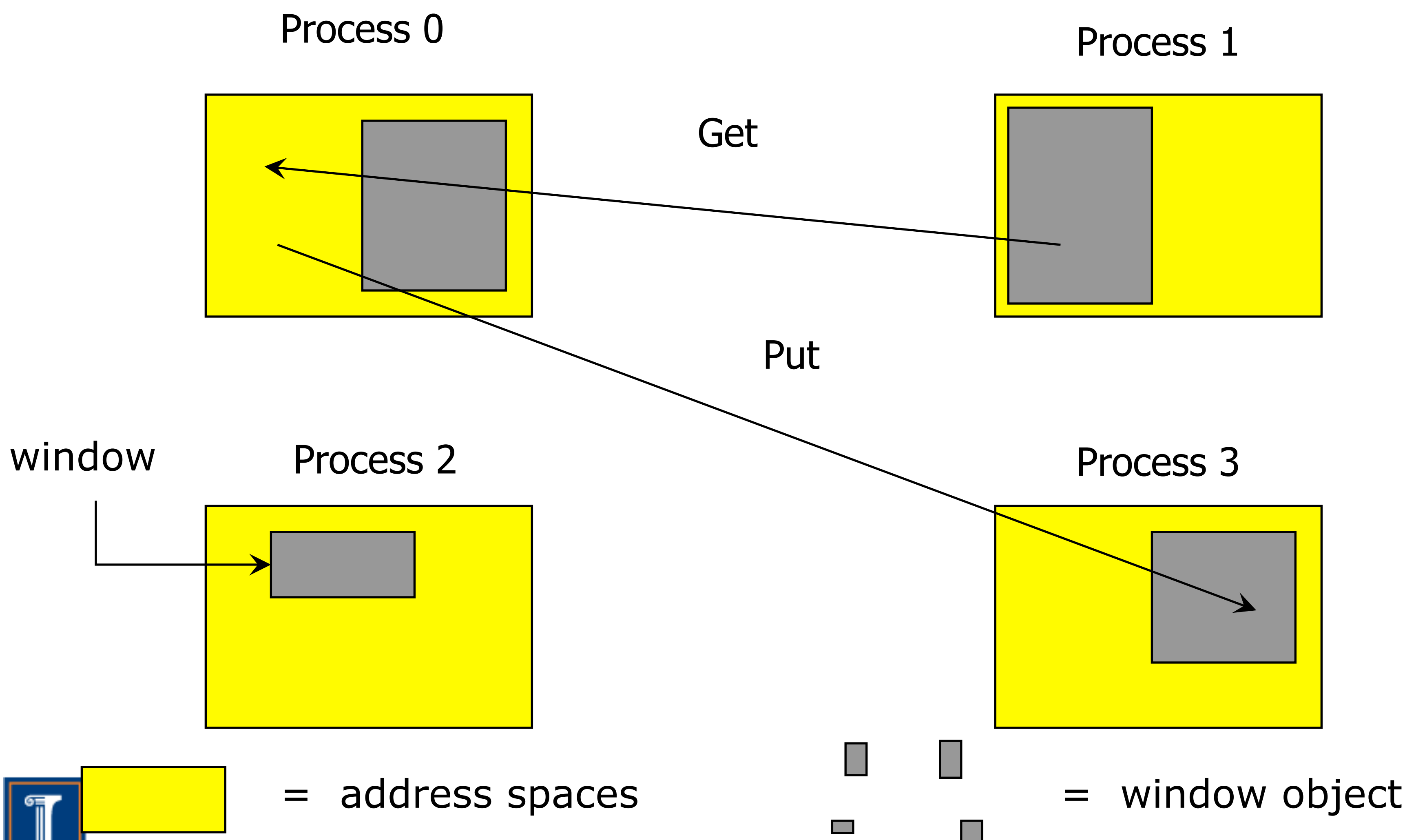
What we need to know in MPI RMA

- How to create remote accessible memory?
- Reading, Writing and Updating remote memory
- Data Synchronization
- Memory Model

Creating Public Memory

- Any memory created by a process is, by default, only locally accessible
  - X = malloc(100);
- Once the memory is created, the user has to make an explicit MPI call to declare a memory region as remotely accessible
  - MPI terminology for remotely accessible memory is a "window"
  - A group of processes collectively create a "window object"
- Once a memory region is declared as remotely accessible, all processes in the window object can read/write data to this memory without explicitly synchronizing with the target process

Remote Memory Access Windows and Window Objects



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Basic RMA Functions for Communication

- **`MPI_Win_create`** exposes local memory to RMA operation by other processes in a communicator
  - Collective operation
  - Creates window object
- **`MPI_Win_free`** deallocates window object

- **`MPI_Put`** moves data from local memory to remote memory
- **`MPI_Get`** retrieves data from remote memory into local memory
- **`MPI_Accumulate`** updates remote memory using local values
- Data movement operations are non-blocking
- **Subsequent synchronization on window object needed to ensure operation is complete**

Window Creation Models

- Four models exist
  - ♦ MPI_WIN_CREATE
    - You already have an allocated buffer that you would like to make remotely accessible
  - ♦ MPI_WIN_ALLOCATE
    - You want to create a buffer and directly make it remotely accessible
  - ♦ MPI_WIN_CREATE_DYNAMIC
    - You don't have a buffer yet, but will have one in the future
  - ♦ MPI_WIN_ALLOCATE_SHARED
    - You want multiple processes on the same node share a buffer

MPI_WIN_CREATE

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

- Expose a region of memory in an RMA window
  - Only data exposed in a window can be accessed with RMA ops.
- Arguments:
  - base - pointer to local data to expose
  - size - size of local data in bytes (nonnegative integer)
  - disp_unit - local unit size for displacements, in bytes (positive integer)
  - info - info argument (handle)
  - comm - communicator (handle)
  - win – window object (handle)

Example with MPI_WIN_CREATE

```
int main(int argc, char ** argv)
{
    int *a;    MPI_Win win;

    MPI_Init(&argc, &argv);

    /* create private memory */
    MPI_Alloc_mem(1000*sizeof(int), MPI_INFO_NULL, &a);
    /* use private memory like you normally would */
    a[0] = 1;  a[1] = 2;

    /* collectively declare memory as remotely accessible */
    MPI_Win_create(a, 1000*sizeof(int), sizeof(int),
           MPI_INFO_NULL, MPI_COMM_WORLD, &win);

    /* Array ‘a’ is now accessibly by all processes in
     * MPI_COMM_WORLD */

    MPI_Win_free(&win);
    MPI_Free_mem(a);
    MPI_Finalize(); return 0;
}
```

MPI_WIN_ALLOCATE

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

- Create a remotely accessible memory region in an RMA window
  - Only data exposed in a window can be accessed with RMA ops.
- Arguments:
  - size - size of local data in bytes (nonnegative integer)
  - disp_unit- local unit size for displacements, in bytes (positive integer)
  - info - info argument (handle)
  - comm - communicator (handle)
  - baseptr - pointer to exposed local data
  - win – window object (handle)

Example with MPI_WIN_ALLOCATE

```
int main(int argc, char ** argv)
{
    int *a;    MPI_Win win;

    MPI_Init(&argc, &argv);

    /* collectively create remote accessible memory in a window */
    MPI_Win_allocate(1000*sizeof(int), sizeof(int), MPI_INFO_NULL,
                     MPI_COMM_WORLD, &a, &win);

    /* Array ‘a’ is now accessible from all processes in
     * MPI_COMM_WORLD */

    MPI_Win_free(&win);

    MPI_Finalize(); return 0;
}
```

MPI_WIN_CREATE_DYNAMIC

```
int MPI_Win_create_dynamic(MPI_Info info, MPI_Comm comm,
                           MPI_Win *win)
```

- Create an RMA window, to which data can later be attached
  - Only data exposed in a window can be accessed with RMA ops
- Initially "empty"
  - Application can dynamically attach/detach memory to this window by calling MPI_Win_attach/detach
  - Application can access data on this window only after a memory region has been attached
- Window origin is MPI_BOTTOM
  - Displacements are segment addresses relative to MPI_BOTTOM
  - Must tell others the displacement after calling attach

Example with MPI_WIN_CREATE_DYNAMIC

```
int main(int argc, char ** argv)
{
    int *a;    MPI_Win win;

    MPI_Init(&argc, &argv);
    MPI_Win_create_dynamic(MPI_INFO_NULL, MPI_COMM_WORLD, &win);

    /* create private memory */
    a = (int *) malloc(1000 * sizeof(int));
    /* use private memory like you normally would */
    a[0] = 1;  a[1] = 2;

    /* locally declare memory as remotely accessible */
    MPI_Win_attach(win, a, 1000*sizeof(int));

    /* Array ‘a’ is now accessible from all processes */

    /* undeclare remotely accessible memory */
    MPI_Win_detach(win, a);  free(a);
    MPI_Win_free(&win);

    MPI_Finalize(); return 0;
}
```

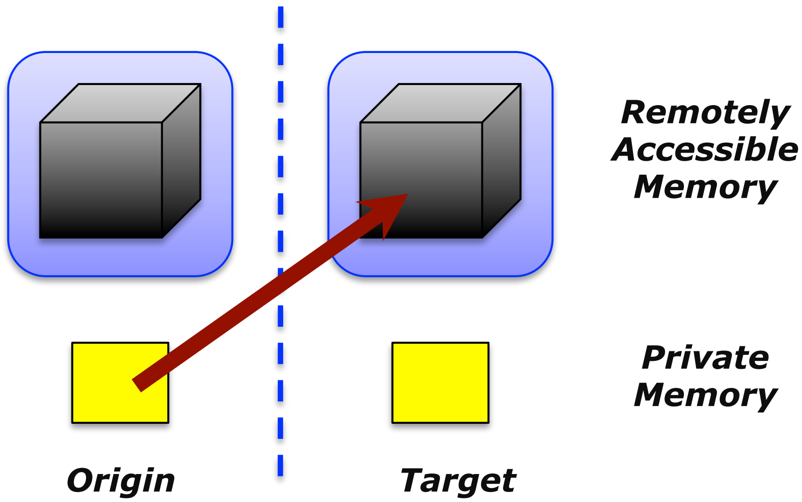
Data movement

- MPI provides ability to read, write and atomically modify data in remotely accessible memory regions
  - MPI_GET
  - MPI_PUT
  - MPI_ACCUMULATE
  - MPI_GET_ACCUMULATE
  - MPI_COMPARE_AND_SWAP
  - MPI_FETCH_AND_OP

Data movement: *Put*

```
MPI_Put(void *origin_addr, int origin_count,
    MPI_Datatype origin_dtype, int target_rank,
    MPI_Aint target_disp, int target_count,
    MPI_Datatype target_dtype, MPI_Win win)
```

- Move data from origin, to target
- Separate data description triples for origin and target



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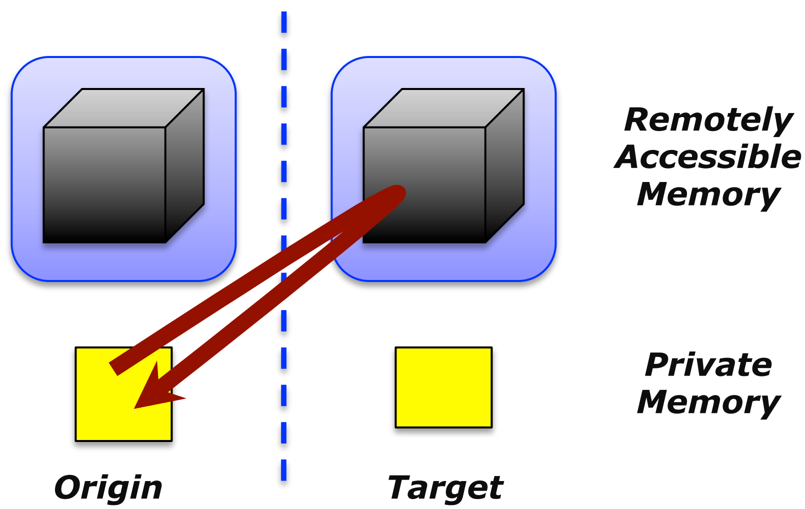
Data movement: *Get*

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

- Move data to origin, from target



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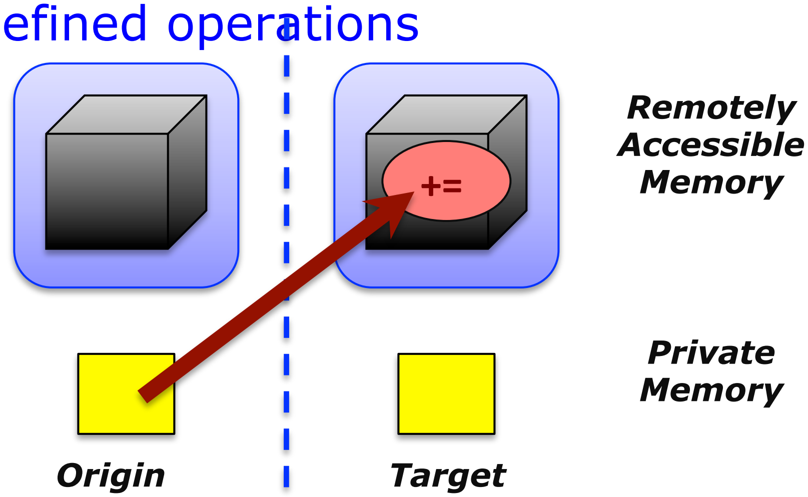
Atomic Data Aggregation: *Accumulate*

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

- Element-wise atomic update operation, similar to a put
  - Reduces origin and target data into target buffer using op argument as combiner
  - Predefined ops only, no user-defined operations
- Different data layouts between target/origin OK
  - Basic type elements must match
- Op = MPI_REPLACE
  - Implements *f(a,b)=b*
  - Element-wise atomic PUT



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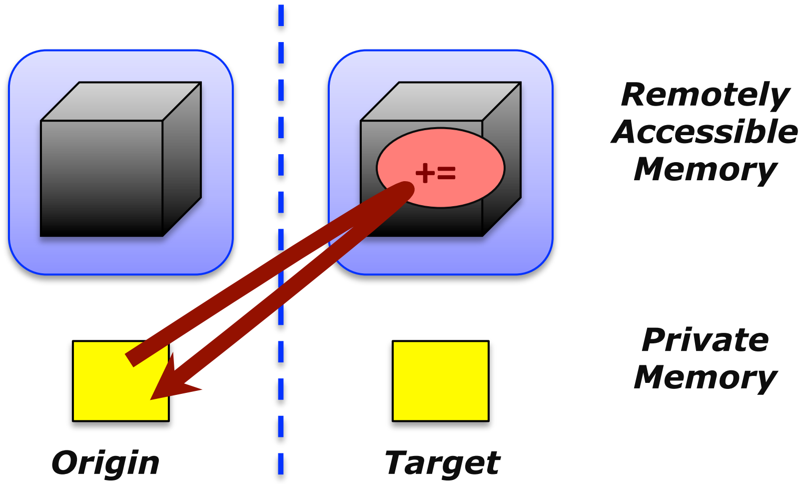
Atomic Data Aggregation: Get Accumulate

```
MPI_Get_accumulate(void *origin_addr, int origin_count,
    MPI_Datatype origin_dtype, void *result_addr,
    int result_count, MPI_Datatype result_dtype,
    int target_rank, MPI_Aint target_disp,
    int target_count, MPI_Datatype target_dype,
    MPI_Op op, MPI_Win win)
```

- Element-wise atomic read-modify-write
  - Op = MPI_SUM, MPI_PROD, MPI_OR, MPI_REPLACE, MPI_NO_OP, …
  - Predefined ops only
- Result stored in target buffer
- Original data stored in result buf
- Different data layouts between target/origin OK
  - Basic type elements must match
- Element-wise atomic get with MPI_NO_OP
- Element-wise atomic swap with MPI_REPLACE



Atomic Data Aggregation: *CAS and FOP*

```
MPI_Fetch_and_op(void *origin_addr, void *result_addr,
    MPI_Datatype dtype, int target_rank,
    MPI_Aint target_disp, MPI_Op op, MPI_Win win)
```

```
MPI_Compare_and_swap(void *origin_addr, void *compare_addr,
    void *result_addr, MPI_Datatype dtype, int target_rank,
    MPI_Aint target_disp, MPI_Win win)
```

- FOP: Simpler version of MPI_Get_accumulate
  - All buffers share a single predefined datatype
  - No count argument (it's always 1)
  - Simpler interface allows hardware optimization
- CAS: Atomic swap if target value is equal to compare value

Ordering of Operations in MPI RMA

- No guaranteed ordering for Put/Get operations
- Result of concurrent Puts to the same location undefined
- Result of Get concurrent Put/Accumulate undefined
  - Can be garbage in both cases
- Result of concurrent accumulate operations to the same location are defined according to the order in which the occurred
  - Atomic put: Accumulate with op = MPI_REPLACE
  - Atomic get: Get_accumulate with op = MPI_NO_OP
- Accumulate operations from a given process are ordered by default
  - User can tell the MPI implementation that ordering is not required as optimization hint
  - You can ask for only the needed orderings, e.g., RAW (read-after-write), WAR, RAR, or WAW

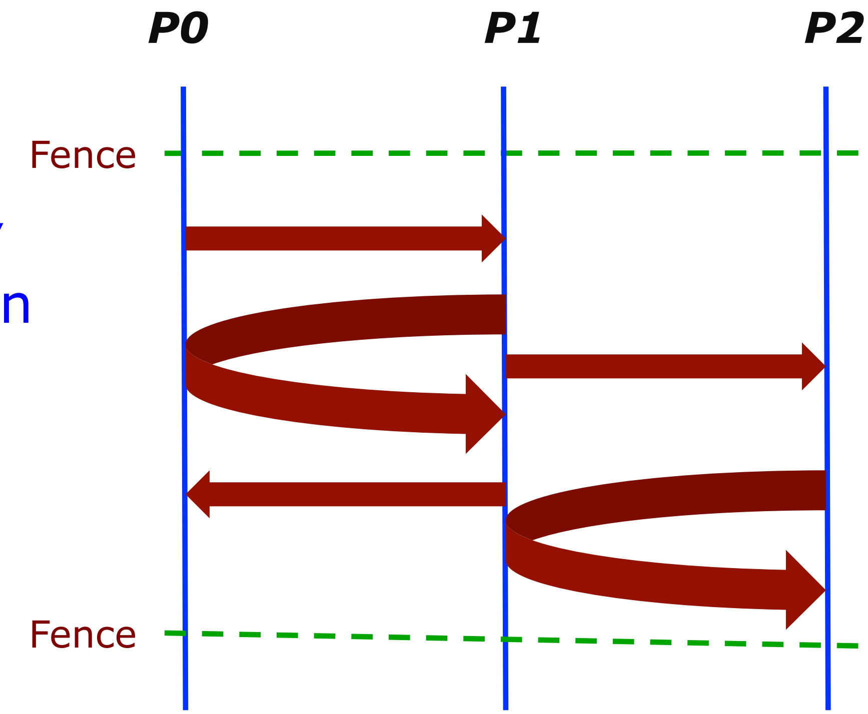
RMA Synchronization Models

- RMA data access model
  - When is a process allowed to read/write remotely accessible memory?
  - When is data written by process X is available for process Y to read?
  - RMA synchronization models define these semantics
- Three synchronization models provided by MPI:
  - Fence (active target)
  - Post-start-complete-wait (generalized active target)
  - Lock/Unlock (passive target)
- Data accesses occur within "epochs"
  - *Access epochs*: contain a set of operations issued by an origin process
  - *Exposure epochs*: enable remote processes to access and/or update a target's window
  - Epochs define ordering and completion semantics
  - Synchronization models provide mechanisms for establishing epochs
    - E.g., starting, ending, and synchronizing epochs

Fence: Active Target Synchronization

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

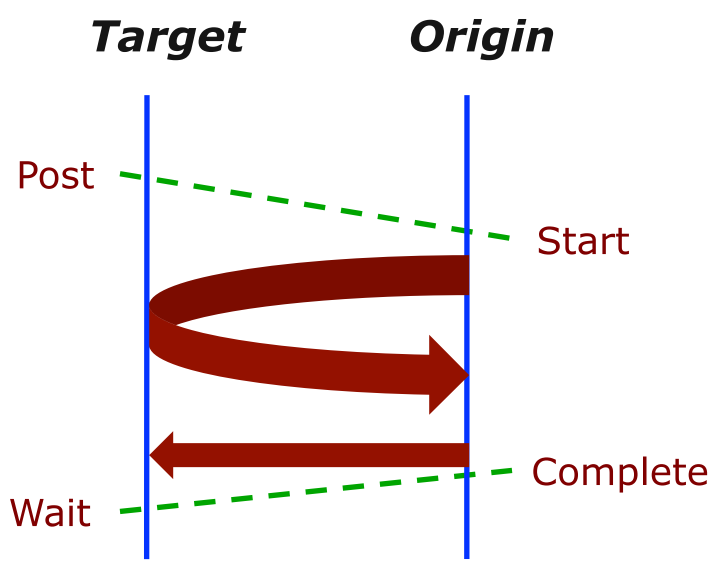
- Collective synchronization model
- Starts *and* ends access and exposure epochs on all processes in the window
- All processes in group of “win” do an MPI_WIN_FENCE to open an epoch
- Everyone can issue PUT/GET operations to read/write data
- Everyone does an MPI_WIN_FENCE to close the epoch
- All operations complete at the second fence synchronization



PSCW: Generalized Active Target Synchronization

```
MPI_Win_post/start(MPI_Group grp, int assert, MPI_Win win)
MPI_Win_complete/wait(MPI_Win win)
```

- Like FENCE, but origin and target specify who they communicate with
- Target: Exposure epoch
  - Opened with MPI_Win_post
  - Closed by MPI_Win_wait
- Origin: Access epoch
  - Opened by MPI_Win_start
  - Closed by MPI_Win_complete
- All synchronization operations may block, to enforce P-S/C-W ordering
  - Processes can be both origins and targets



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Using Active Target Synchronization

- Active target RMA works well for many BSP-style program
  - Halo exchange
  - Dense linear algebra
- How might you write the dense matrix-vector multiply using
  - MPI_Get: Instead of Allgather
  - MPI_Put: Instead of send/receive
- Do you think using Get instead of Allgather is a good choice at scale? Why or why not? How would use use a performance model to argue your choice?