PGAS Programming: The ARMCI Approach

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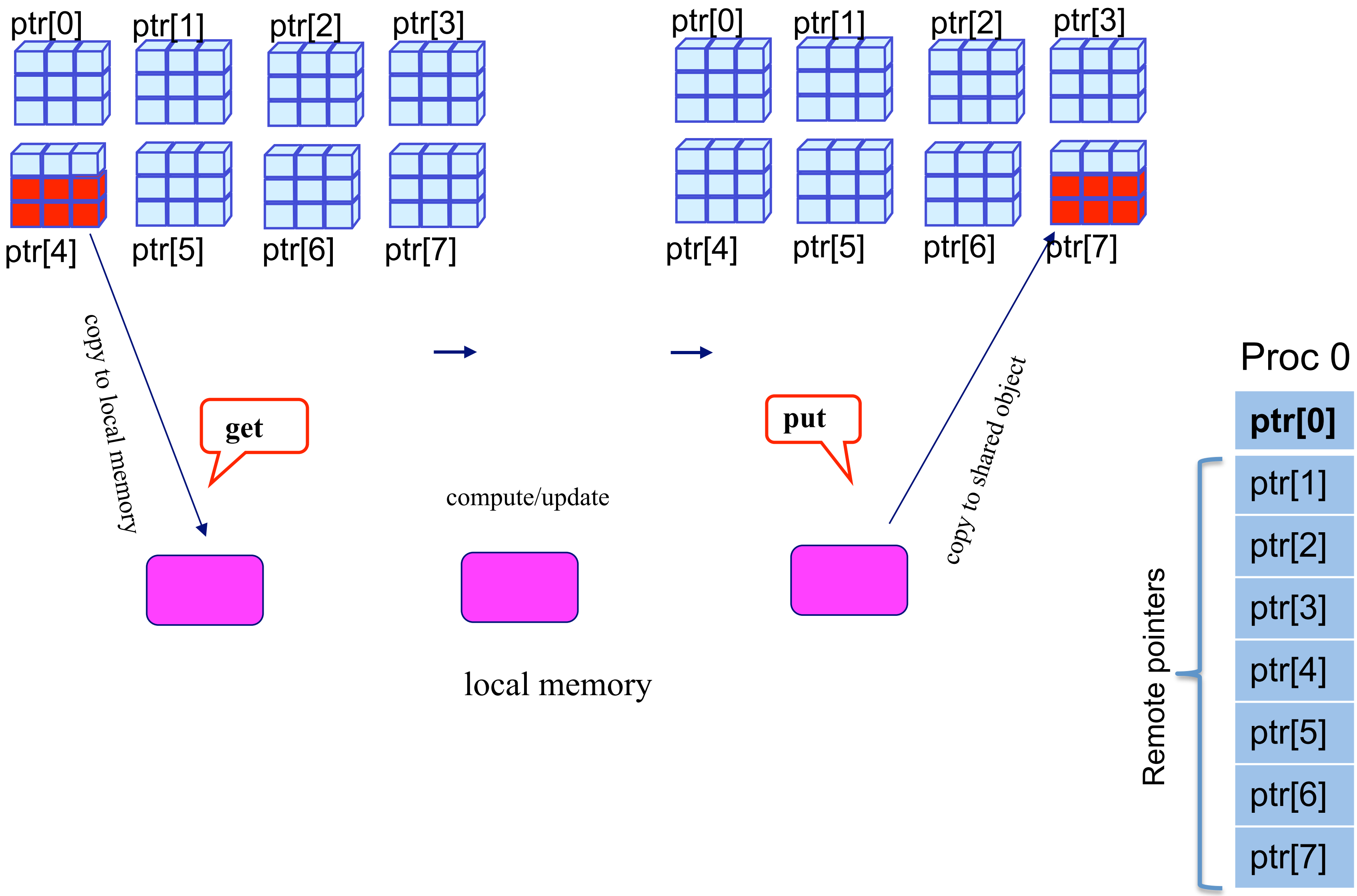
ARMCI Model


ptr[0]
ptr[1]
ptr[2]
ptr[3]
ptr[4]
ptr[5]
ptr[6]
ptr[7]
copy to local memory
get
compute/update
put
copy to shared object
local memory
Proc 0
ptr[0]
ptr[1]
ptr[2]
ptr[3]
ptr[4]
ptr[5]
ptr[6]
ptr[7]
Remote pointers

Outline

- Writing, Building, and Running ARMCI Programs
- Basic Calls
- Intermediate Calls
- Advanced Calls

Writing, Building and Running ARMCI programs

- Installing ARMCI
- Writing ARMCI programs
- Compiling and linking
- Running ARMCI programs
- For detailed information
  - ARMCI Webpage (or search: **ARMCI**)
    - ARMCI software, papers, docs, APIs, etc.
    - http://www.emsl.pnl.gov/docs/parsoft/armci/
  - ARMCI API Documentation
    - http://www.emsl.pnl.gov/docs/parsoft/armci/documentation.htm
  - ARMCI Support/Help Mailing list
    - hpctools@pnl.gov

Installing ARMCI

- configure; make; make install
  - Refer to README/INSTALL for detailed installed instructions
- Specify the underlying network communication protocol
  - By default ARMCI builds over sockets
  - For high-performance interconnects, it is <u>strongly recommended</u> to configure ARMCI as in table below
    - If you are not sure about the network, then use the ARMCI auto-detect feature to build ARMCI with the best available network in your system*

Configure option	Network
configure --with-openib	Infiniband OpenIB
configure --with-dcmf --host=powerpc-bgp-linux --build=powerpc64-bgp-linux	IBM BG/P
configure --with-bgml[=ARG]	IBM BG/L
configure --with-lapi	IBM LAPI
configure --with-portals	Cray XT Seastar (portals)
configure --with-cray-shmem	Cray XT shmem
configure --with-mpi-spawn	MPI-2 dynamic process mgmt
configure --with-sockets	Ethernet (TCP/IP Sockets)
configure --enable-autodetect	* Attempts to locate HPC interconnects besides SOCKETS

Writing ARMCI Programs

- ARMCI Definitions and Data types
  - *#include* "armci.h"
- ARMCI_Init, ARMCI_Finalize --> initializes and terminates ARMCI library

```
#include <stdio.h>
#include "mpi.h"
#include "armci.h"

int main( int argc, char **argv ) {
        MPI_Init( &argc, &argv );
        ARMCI_Init(); /* (or) ARMCI_Init_args(&argc, &argv); */

        printf( "Hello world\n" );

        ARMCI_Finalize();
        MPI_Finalize();
        return 0;
}
```

Writing ARMCI Programs

- ARMCI is compatible with MPI
- ARMCI requires the following functionalities from a message passing library (MPI/TCGMSG)
  - initialization and termination of processes
  - Broadcast, Barrier
- The message-passing library has to be
  - initialized before the ARMCI library
  - terminated after the ARMCI library is terminated

```
#include <stdio.h>
#include "mpi.h"
#include "armci.h"

int main( int argc, char **argv ) {
          MPI_Init( &argc, &argv );
          ARMCI_Init();

          printf( "Hello world\n" );

          ARMCI_Finalize();
          MPI_Finalize();
          return 0;
}
```

Compiling and Linking ARMCI Programs

- For example, compile and link ARMCI test program (armci_test.c) as follows.

```
ARMCI_INCLUDE     = /home/manoj/armci-1.5/include
ARMCI_LIB         = -L/home/manoj/armci-1.5/lib -larmci

mpicc -I$(ARMCI_INCLUDE) -o armci_test armci_test.c $(ARMCI_LIB) -lm
```

Running ARMCI Programs

- Example: Running a test program “armci_test” on 2 processes
  - mpirun -np 2 armci_test
- Running an ARMCI program is same as MPI

Outline

- Writing, Building, and Running ARMCI Programs
- Basic Calls
- Intermediate Calls
- Advanced Calls

ARMCI Basic Operations

- ARMCI programming model is very simple.
- Most of a parallel program can be written with these basic calls
  - `ARMCI_Init, ARMCI_Finalize`
  - `ARMCI_Malloc, ARMCI_Free`
  - `ARMCI_Put, ARMCI_Get`
  - `ARMCI_Barrier`

ARMCI Initialization/Termination

- There are two functions to *initialize* ARMCI:
  - `int ARMCI_Init()`
  - `int ARMCI_Init_args(int *argc, char ***argv)`
- To *terminate* ARMCI program:
  - `void ARMCI_Finalize()`

```
#include <stdio.h>
#include "mpi.h"
#include "armci.h"

int main( int argc, char **argv ) {
          MPI_Init( &argc, &argv );
          ARMCI_Init();

          printf( "Hello world\n" );

          ARMCI_Finalize();
          MPI_Finalize();
          return 0;
}
```

Parallel Environment - Process Information

- **Parallel Environment:**
  - how many processes are working together (*size*)
  - what their IDs are (ranges from 0 to *size*-1)
  - Since ARMCI is compatible with MPI, you can get these from MPI_Comm_rank/MPI_Comm_size

Memory Allocation

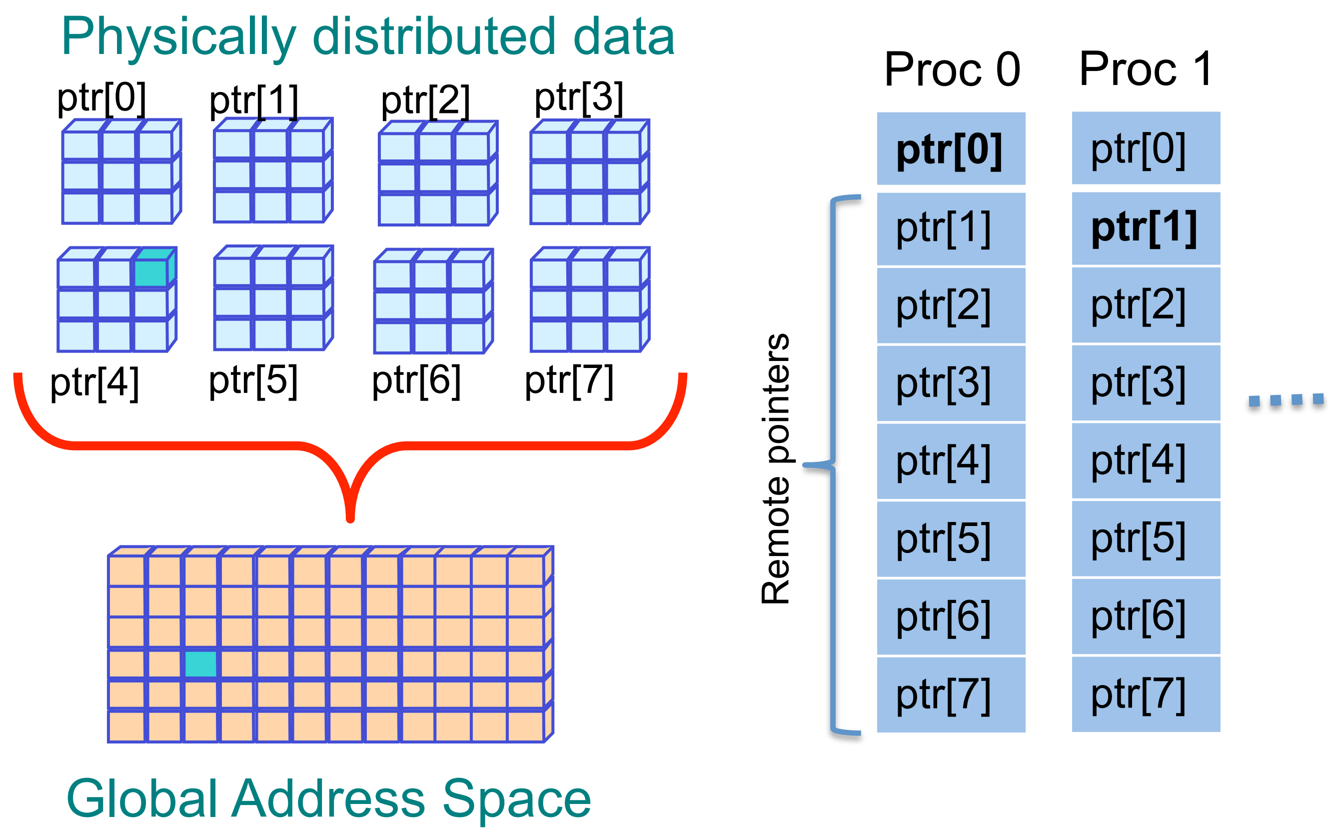
- Collective operation to allocate memory that can be used in the context of ARMCI operations (e.g. put, get, accumulate, rmw, etc)
  - Remote pointers
  - Pinned/registered memory
  - Non-symmetric

```
int ARMCI_Malloc(void* ptr[], armci_size_t bytes)
int ARMCI_Free(void *address)
```

ARGUMENTS:
ptr - Pointer array. Each pointer points to allocated memory of one process.
bytes - The size of allocated memory in bytes.

RETURN VALUE:
zero - Successful; other value - Error code (described in release notes).

Memory Allocation

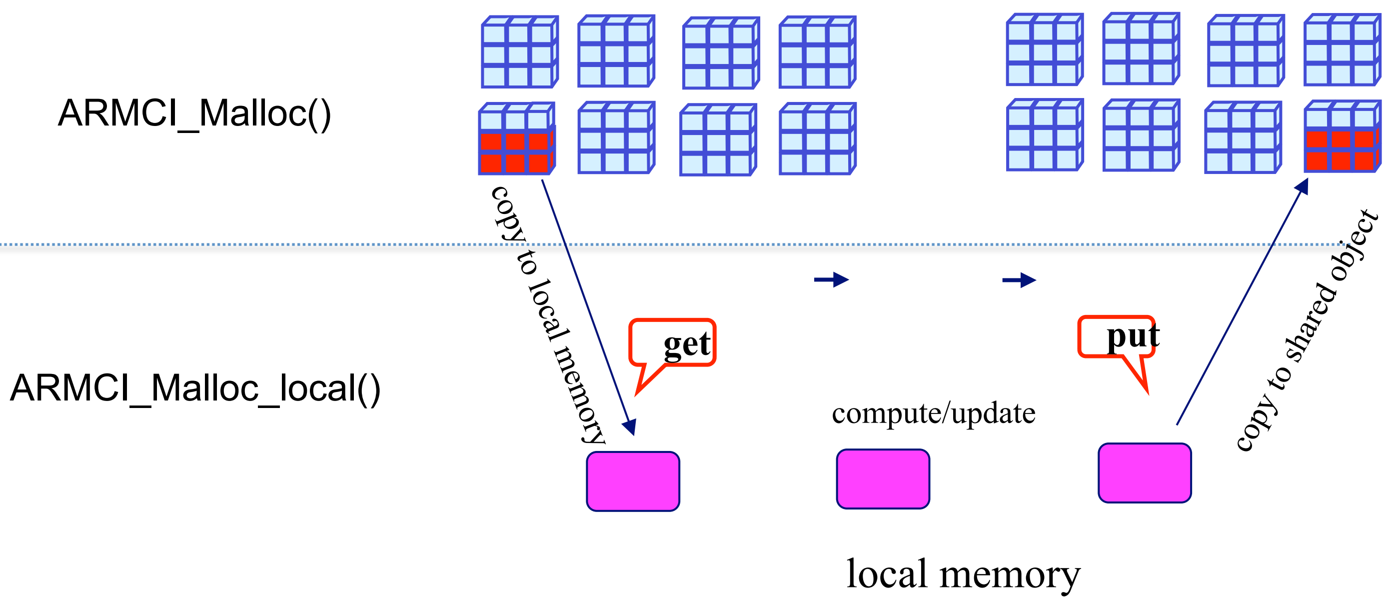



```
int ARMCI_Malloc(void* ptr[], armci_size_t bytes)
```

Memory Allocation (Contd.)

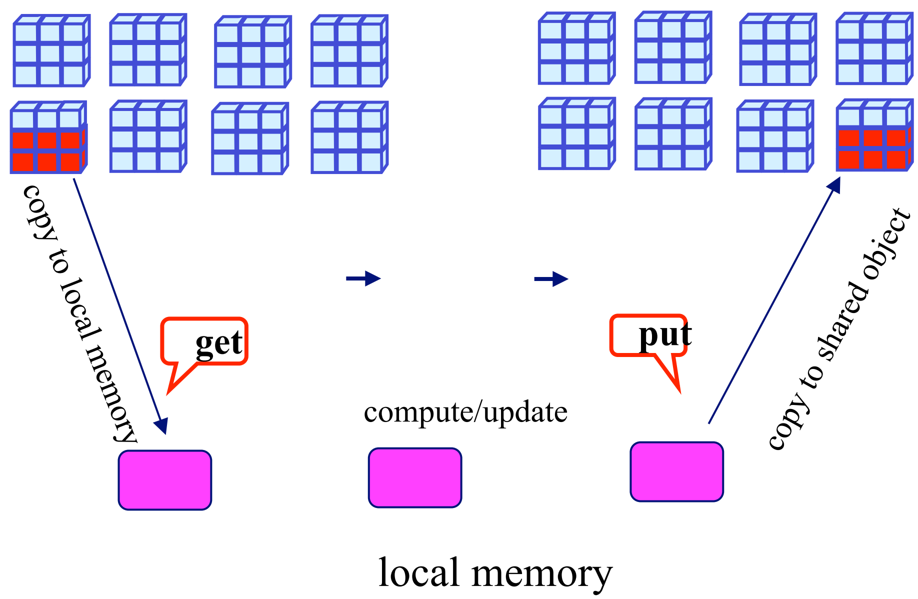
- ARMCI_Malloc_local()
- Non Collective Memory allocation
- Pinned/registered memory
  - Enables zero-copy

```
void* ARMCI_Malloc_local(armci_size_t bytes)
int   ARMCI_Free_local(void *address)
```

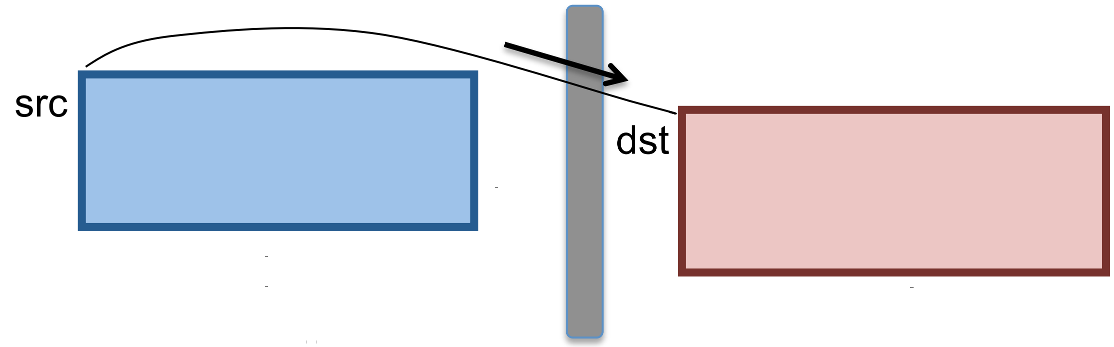


Data Transfer Operations

- Contiguous data transfer (put, get, acc)
- Non-Contiguous data transfer
  - Strided API (puts, gets, accs)
  - Vector API (putv, getv, accv)



Put




```
int ARMCI_Put(void* src, void* dst, int bytes, int proc)
```

PURPOSE: Blocking transfer of contiguous data from the local process memory (source) to remote process memory (destination).

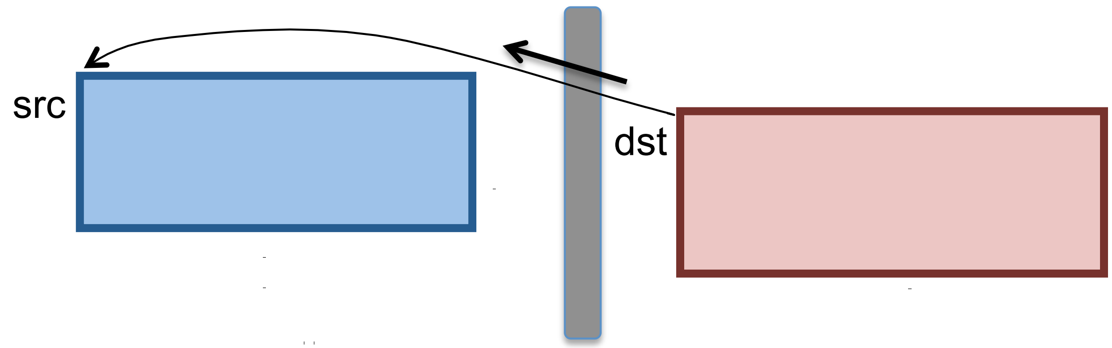
ARGUMENTS:

- src - Source starting address of the data block to put.
- dst - Destination starting address to put data.
- bytes - amount of data to transfer in bytes.
- proc - Remote process ID (destination).

RETURN VALUE:

- zero - Successful.
- other value - Error code (described in the release notes)

Get




```
int ARMCI_Get(void* src, void* dst, int bytes, int proc)
```

PURPOSE: Blocking transfer of contiguous data from the remote process memory (source) to the calling process memory (destination).

ARGUMENTS:

- src - Source starting address of the data block to get.
- dst - Destination starting address to get the data.
- bytes - amount of data to transfer in bytes.
- proc - Remote process ID (destination).

RETURN VALUE:

- zero - Successful.
- other value - Error code (described in the release notes).

Accumulate

```
int ARMCI_Acc(int datatype, void *scale,
              void* src, void* dst,
              int bytes, int proc)
```

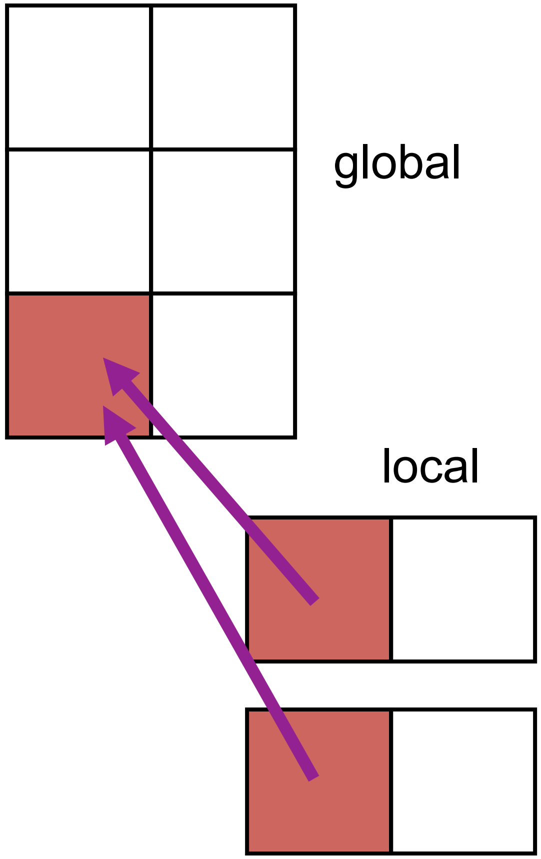
PURPOSE: Blocking operation that <u>atomically</u> updates the memory of a remote process (destination).

ARGUMENTS:

datatype - Supported data types are:

ARMCI_ACC_INT -> int, ARMCI_ACC_LNG -> long,
ARMCI_ACC_FLT -> float, ARMCI_ACC_DBL-> double,
ARMCI_ACC_CPL -> complex,
ARMCI_ACC_DCPL -> double complex

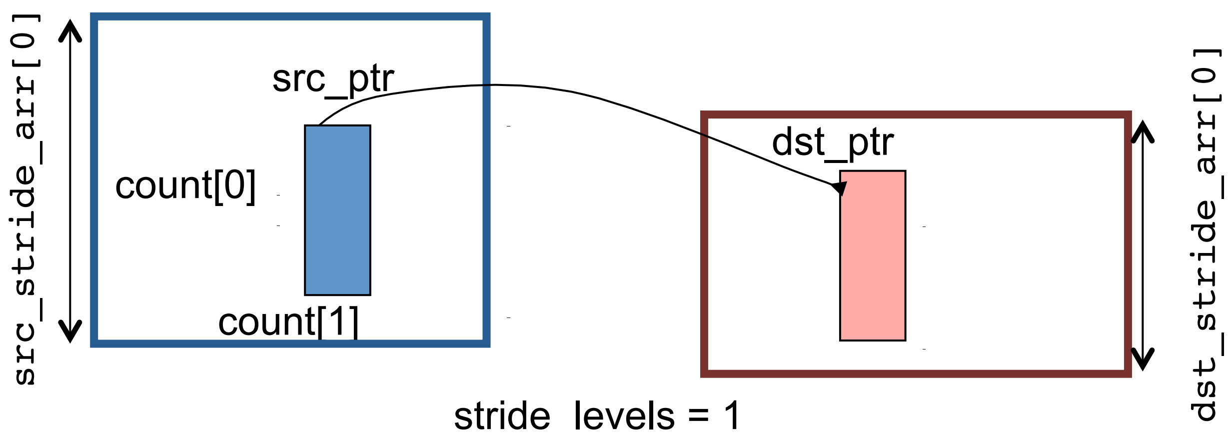
scale - Scale for data (*dest* = *dest* + *scale* * *src*)
src - Source starting address of data to transfer
dst - Destination starting address to add incoming data
bytes - amount of data to transfer in bytes
proc - Remote process ID (destination)



Strided API

- Strided API to handle non-contiguous data transfer
  - ARMCI_PutS, ARMCI_GetS, ARMCI_AccS
- Can handle arbitrary N-dimensional array sections

```
int ARMCI_PutS(src_ptr, src_stride_arr, dst_ptr,
               dst_stride_arr, count, stride_levels, proc)
```



Strided API - Example

Example: Assume two 2-dimensional C arrays residing on different processes.

```
double A[10][20]; /* local process */
double B[20][30]; /* remote process */
```

To put a block of data, 3x6, starting at location (1, 2) in A to B in location (3, 4), the arguments of ARMCI_PutS can be set as following.

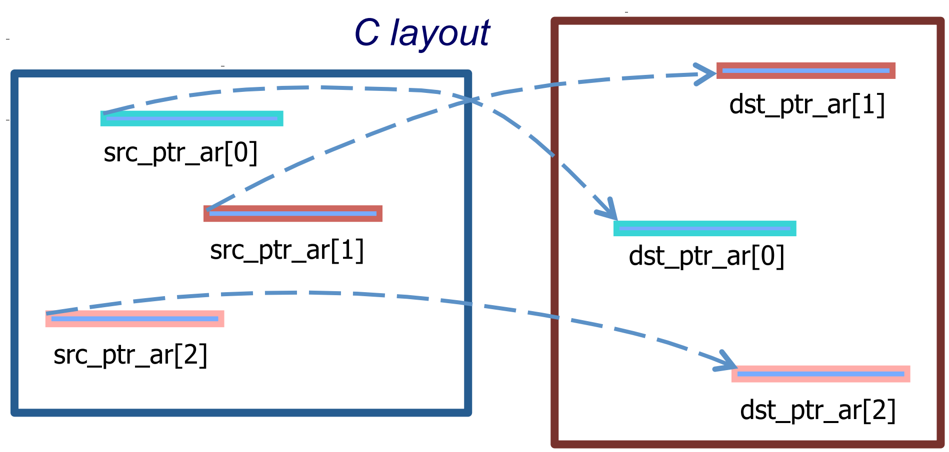
```
src_ptr          = &A[0][0] + (1 * 20 + 2);      /* row-major in C */
src_stride_ar[0] = 20 * sizeof(double); /* number of bytes for the stride*/
dst_ptr          = &B[0][0] + (3 * 30 + 4);
dst_stride_ar[0] = 30 * sizeof(double);
count[0] = 6 * sizeof(double);          /* bytes of contiguous data */
count[1] = 3;       /* number of rows (C layout) of contiguous data */
stride_levels = 1;
proc = ID;          /* remote process ID where array B resides*/
```

Vector API

Most general API for non-contiguous data transfer

- ARMCI_PutV, ARMCI_GetV, ARMCI_AccV
- based on the I/O vector API (Unix *readv/writev*)
- Vector descriptor specifies sets of equally-sized data segments

```
int
ARMCI_PutV(armci_giov_t dscr_arr[],
           int arr_len, int proc)

typedef struct {
      void *src_ptr_ar[];
      void *dst_ptr_ar[];
      int bytes;
      int ptr_ar_len;
} armci_giov_t;
```



Synchronization

- Fence
- Barrier
- Data consistency

Fence

```
void ARMCI_Fence(int proc)
```

PURPOSE: Blocks the calling process until all put or accumulate operations issued to the specified remote process complete at the destination.
ARGUMENTS:
proc - Remote process ID.

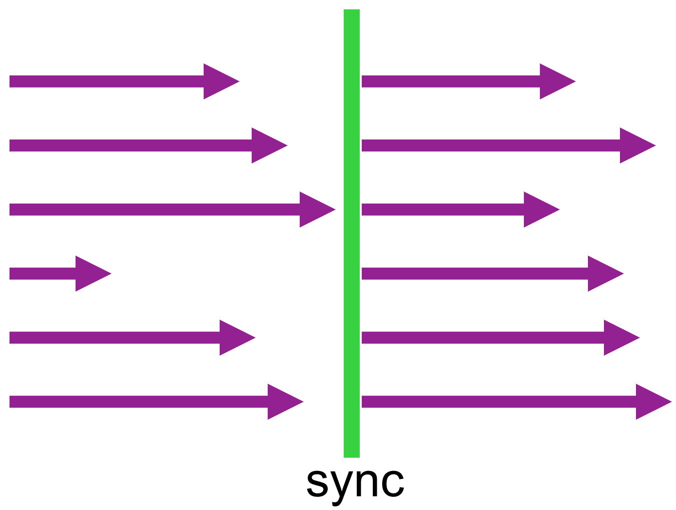
```
void ARMCI_AllFence()
```

PURPOSE: Blocks the calling process until all the outstanding put or accumulate operations complete remotely regardless of the destination processor.

ARMCI Barrier

```
void ARMCI_Barrier()
```

- Synchronize processors and memory. This operation combines functionality of MPI_Barrier and ARMCI_AllFence



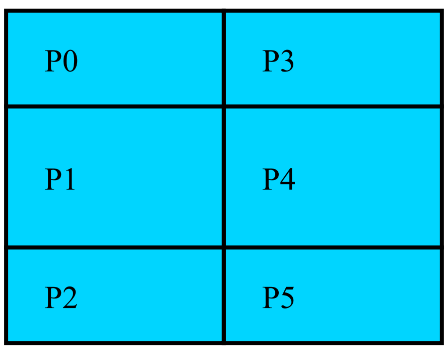
Completion and Ordering

- Put/Accumulate
  - Blocks the calling process until put/accumulate operation is completed locally and the buffer is safe to reuse (<u>local completion</u>)
- Fence
  - Ensures put/accumulate operations, issued to the specified remote process, complete at the destination (<u>remote completion</u>)
- All blocking calls (e.g. ARMCI_Put) are ordered
  - Non-blocking operations (e.g. ARMCI_Nbput) are NOT ordered

Illustration: Creating a 2-D Global Array

**g_a = GA_Create(type,dims[2],
name, chunk[2])**

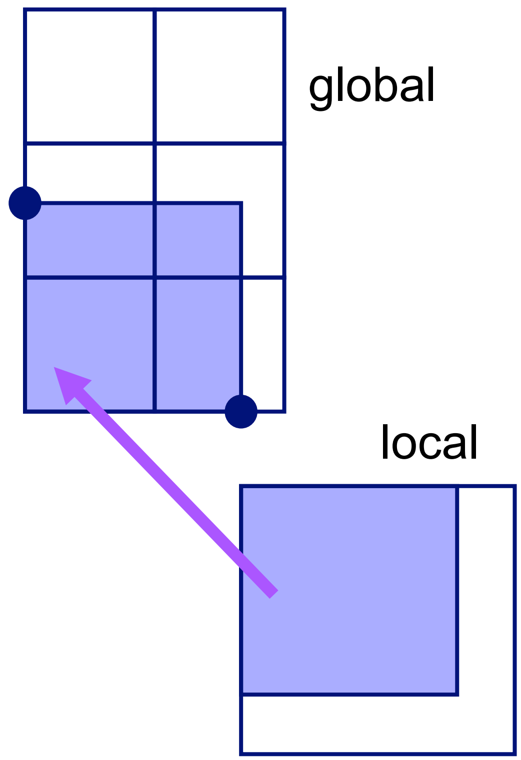
- Blocked distribution
- Locate free index in array of handles
- Store meta-data
- Compute bytes to allocate on this process
- Allocate memory




```
static struct {
   int active;
   int type, dims[2], blocks[2];
   void *ptr_arr[MAXPROC];
} hndl[MAX_HANDLES];


int NGA_Create(type,dims[2],
               name,chunk[2]) {
   int ga, bytes;
   ga = /*ga s.t. hndl[ga]==0*/
   hndl[ga].active=1;

   /*copy type,dims[2] into hndl[ga]*/

   /*compute size of blocking*/
   compute_blocking(chunk,blocks);

   bytes = size(type)*blocks[0]*
           blocks[1];
   ARMCI_Malloc(hndl[ga].ptr_arr,
                bytes);
}
```

GA_Put

```
void NGA_Put(ga, lo[2], hi[2], buf, ld) {
  /*determine list of blocks to obtain and which procs own
   them*/
   foreach block {
     src_ptr= buf + /*offset corresponding to this block*/;
     src_stride_arr = ld;
     dst_ptr = hndl[ga].ptr_arr[proc] + /* offset at
                                           remote end */;
     dst_stride_arr = blocks;
     stride_levels = 2;
     seg_count[0] = sizeof(type)*(hi[0] – lo[0]+1);
     seg_count[1] = hi[1]-lo[1]+1;
     proc = /* (local/remote) process owns this block */

     ARMCI_Put(src_ptr, src_stride_arr, dst_ptr,
               dst_stride_arr, stride_levels,
               seg_count, proc);
   }
}
```



Locks/Mutexes

- Mutual exclusion primitive
- Locks identified by integers
- Creation: Each process specifies the number of locks on itself

```
ARMCI_Create_mutexes(nmutexes)

ARMCI_Lock(lockid, proc)

ARMCI_Unlock(lockid, proc)
```

Non-Blocking Communication

- Allows overlapping of data transfers and computations
  - Technique for latency hiding
- Non-blocking operations initiate a communication call and then return control to the application immediately
- operation completed locally by making a call to the *wait* routine
- Non-blocking for all variants of Put, Get, and Acc

```
ARMCI_Nbget(void* src, void* dst, int bytes, int proc,
            armci_nbhdl_t* nbhandle)

ARMCI_Wait(armci_nbhdl_t* nbhandle)
```

Implicit Handles

- Simplifies non-blocking handle management
- Call non-blocking calls with NULL handle
  - An implicit handle is allocated
- Wait on all implicit handles, or those to a specific process

```
ARMCI_Nbget(src, dst, bytes, proc, NULL)

ARMCI_Waitproc(proc)

ARMCI_Waitall()
```

Aggregate handles

- Group many small communications into a large one
  - Improves bandwidth when non-latency sensitive
- Approach:
  - Set a non-blocking handles as aggregate
  - Perform a number of non-blocking calls with that handle
  - Communication is completed upon wait().

```
ARMCI_SET_AGGREGATE_HANDLE(nbhandle)
ARMCI_Nbget(src, dst, bytes, proc, nbhandle)
…
ARMCI_Wait(nbhandle)
ARMCI_UNSET_AGGREGATE_HANDLE(nbhandle)
```

Rmw

- Combines atomically the specified integer value with the corresponding integer value (int or long) at the remote memory location and returns the original value found at that location
- Atomic operations
  - ARMCI_FETCH_AND_ADD -> int
  - ARMCI_FETCH_AND_ADD_LONG -> long
  - ARMCI_SWAP -> int
  - ARMCI_SWAP_LONG ->long
- Remote pointer allocated with ARMCI_Malloc()

```
int ARMCI_Rmw(int op, void *ploc, void *prem,
              int value, proc)
```

ARMCI Processor Groups

- Collections of processors (e.g. the world group) can be decomposed into processor groups
- Processor groups only affect global (collective) operations
- RDMA operations (Put/Get/Acc variants) are always on world process ids (same as ranks in MPI_COMM_WORLD)

ARMCI Group Operations

- Basic operations
  - `ARMCI_Group_create, ARMCI_Group_destroy`
  - `ARMCI_Malloc_group, ARMCI_Free_group`
  - `ARMCI_Group_rank, ARMCI_Group_size`
  - `ARMCI_Absolute_id`

Group Management

- Create and destroy groups
- Provide list of process ranks (from world group)

```
ARMCI_Group_create(int n, int *rank_list, ARMCI_Group *gout)

ARMCI_Group_free(ARMCI_Group *g)
```

Group Memory Allocation

- Create and destroy RDMA memory in a group
- Similar to calls to (de-)allocate on all processes
  - Additional group argument

```
ARMCI_Malloc_group(void *ptr_arr[], armci_size_t bytes,
                   ARMCI_Group *g)

ARMCI_Free_group(void *ptr, ARMCI_Group *g)
```

Managing Group Ranks

- A processes rank and size in a group
  - `ARMCI_Group_rank(ARMCI_Group *g, int *rank)`
  - `ARMCI_Group_size(ARMCI_Group *g, int *size)`
- Translate group rank of a process into rank in world group (same as MPI ranks)
  - `ARMCI_Absolute_id(ARMCI_Group *g, int rank)`

Summary

- Version 1.5 available
- Supported platforms
  - Linux clusters with Infiniband, GigE, Quadrics, Myrinet networks
  - IBM Bluegene/P, Bluegene/L, SP
  - Cray XT
  - Fujitsu
  - NEC
  - Windows
- Ongoing development
  - IBM Bluewaters
  - Cray Baker (Gemini interconnect)