SINGLE-SIDED PGAS COMMUNICATIONS LIBRARIES

Advanced use of OpenSHMEM

Outline

- Point-to-point synchronisation
- Collectives
- Strided transfers
- Dynamic symmetric memory allocation
- Locks and atomic updates

Point-to-point synchronisation

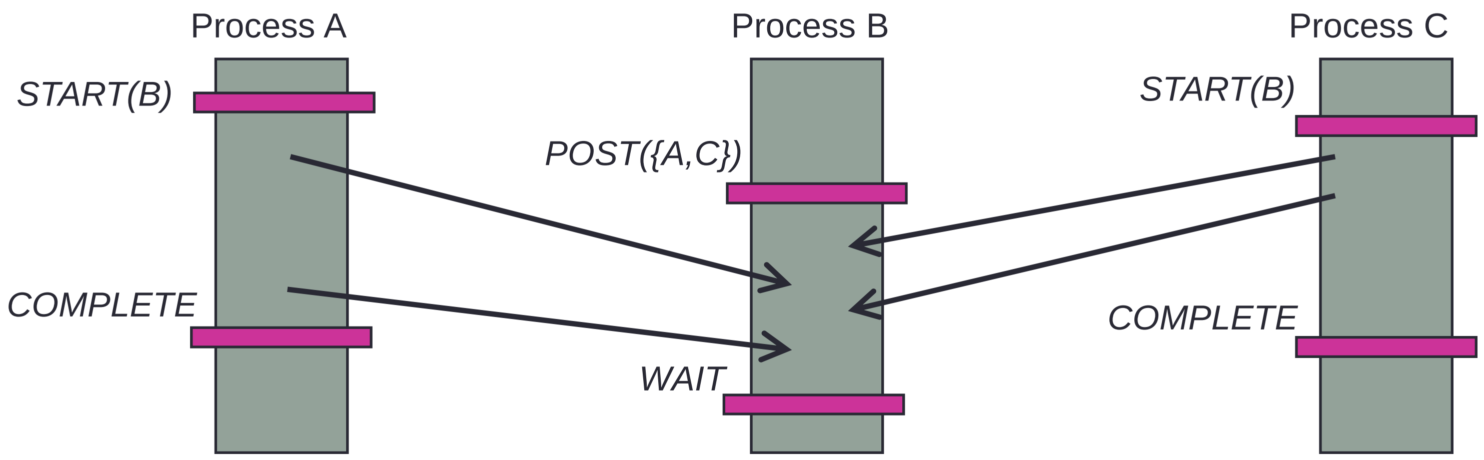
- Barrier synchronisation works in simple cases, but …

- Performance issues
  - will not scale to large numbers of PEs
  - overkill in many situations
  - e.g. in traffic model, only need to synchronise with neighbours

- May not be sensible to use barriers
  - what if communications is only between a few PEs?
  - why should all PEs wait when most are not communicating?

2) Pairwise Model

- Useful when comms pattern is known in advance
- Implemented via library routines and/or flag variables



- More complicated model
  - Closer to message-passing than previous collective approach
  - But can be more efficient and flexible

OpenSHMEM idiom

- Origin PE
  - perform communication
  - write a flag variable to indicate completion
- Remote PE
  - wait until flag variable is written
  - can then access data (put) or modify buffer (get)
- Seems simple but …
  - how do we make sure the flag arrives after the data (for put)?
  - how do we make sure that the flag is reread from memory at the remote PE and not optimised away by the compiler?

Fence and wait

Order of arrival not guaranteed, e.g. dynamic routing on XC30

- Origin PE

```
put(target,source,len,remote_pe)
shmem_fence()
put(flag,flagvalue,len,remote_pe)
```

Ensures ordering of puts to **`remote_pe`** before and after fence

- Remote PE (assume flag is initialised to **`defaultvalue`**)

```
shmem_wait(flag, defaultvalue)
```

Wait until flag differs from **`defaultvalue`**

Simple spin-loop may be optimised away

Notes

- Ensuring initialisation of flag may require synchronisation

- Can also encode information in flag
  - e.g. initialise to -1
  - write the identifier of the origin PE to flag
  - `remote_pe` now knows where the data came from

- Fence works pairwise between PEs
  - can also call `shmem_quiet()`
  - waits until **all** outstanding puts from origin have **completed**
  - not usually needed

- **Not** sufficient to have volatile flag (in C)

Flagging requires separate put

- Origin PE: `int source[N+1];`

```
initialize_data(source, N)
source[N] = 1
put(target,source,N+1,remote_pe)
```

Try to put flag at end of data

Send data and flag together

- Remote PE: `int target[N+1];`

```
// assume previous initialisation target[N] = -1
shmem_wait(target[N], -1)
```

Assume arrival of flag means arrival of data

- **Incorrect!**
  - no guarantee of order of data arrival
  - even *within* a single put call

Collectives

- Many collective patterns recur in parallel codes
  - broadcast
  - global sum
  - …
- OpenSHMEM provides higher-level routines
  - analogous to MPI collectives …
  - … but harder to use!
- Issues
  - user must provide (and maybe initialise) various workspace buffers
  - only certain subsets can be specified
  - synchronisation issues between calls

Example: global sum of double

```
void shmem_double_sum_to_all(double *target, double *source,
int nreduce, int PE_start, int logPE_stride, int PE_size,
double *pWrk, long *pSync);
```

- Parameters
    - **`target`**: output buffer (symmetric storage)
    - **`source`**: input buffer (symmetric storage)
    - **`nreduce`**: number of doubles to reduce (i.e. size of source and target)
    - **`PE_start`**, **`logPE_stride`**, **`PE_size`**: *active set* of PEs taking part
    - **`pWrk`**: symmetric work array whose size depends on **`nreduce`**
    - **`pSync`**: fixed-size symmetric array for synchronisation flags etc.

Notes

- Active sets
  - all PEs in the active set must call the collective routine
  - start, start+2^{stride}, start + $2*2^{stride}$, start+$3*2^{stride}$, …, start+(size-1)*2^{stride}
  - the triplet **`(0,0,shmem_n_pes())`** specifies all the PEs
  - the triplet **`(1,1,shmem_n_pes()/2)`** specifies all the odd PEs
  - more restrictive than MPI communicators

- Work arrays
  - **`pWrk`** of size **`max(nreduce/2+1,_SHMEM_REDUCE_MIN_WRKDATA_SIZE)`**
    - in Fortran: **`max(nreduce/2+1, SHMEM_REDUCE_MIN_WRKDATA_SIZE)`**
  - **`pSync`** of size **`_SHMEM_REDUCE_SYNC_SIZE`**
    - in Fortran: **`SHMEM_REDUCE_SYNC_SIZE`**

Collective synchronisation issues

- **`pSync`** must be initialised prior to ***first*** call
  - **`SHMEM_SYNC_VALUE (Fortran)`**
  - **`_SHMEM_SYNC_VALUE (C)`**
  - may require synchronisation between initialisation and first call
    - values are reset after the call completes
  - or use static initialisation
- Cannot use the same work or sync arrays if two calls can overlap
  - separate by barrier
  - toggle between **`pWrk1`** and **`pWrk2`** etc.

Example

```
shmem_double_sum_to_all(xsum, x, 1, 0, 0, shmem_n_pes(),
                        pWrk, pSync);
// Ensure reduction is over before reusing workspace
shmem_barrier_all();

shmem_double_sum_to_all(ysum, y, 1, 0, 0, shmem_n_pes(),
                        pWrk, pSync);

…


shmem_double_sum_to_all(xsum, x, 1, 0, 0, shmem_n_pes(),
                        pWrk1, pSync1);
// Use different workspace for next reduction

shmem_double_sum_to_all(ysum, y, 1, 0, 0, shmem_n_pes(),
                        pWrk2, pSync2);
```

Strided transfers

- Simple strided patterns can be sent in a single put
  - more restrictive than even **`MPI_Type_vector()`**

```
double precision, save :: x(0:N+1, 0:N+1)
// send halo up in the 2nd dimension
CALL SHMEM_DOUBLE_IPUT(x(0,1), x(N+1,1), N+2, N+2, N, pe_up)
```

- Sends *N* data elements separated by *N+2*
  - here it picks out x(N+1,1), x(N+1, 2), …, x(N+1, N) at source
  - writes to x(0,1), x(0, 2), …, x(0, N) at target on pe_up
- Can specify different strides at target and source

Dynamic memory allocation (C)

- Static allocation in symmetric memory is very restrictive

- In C, use an alternative to malloc
  - `void *shmalloc(size_t size);`

```
// allocate reduction workspace
double *pWrk;
pWrksize = max(nreduce/2+1,_SHMEM_REDUCE_MIN_WRKDATA_SIZE);
pWrk = (double *) shmalloc(pWrksize*sizeof(double));
```

- Must be called by all PEs (a collective routine)
  - Usual issues with C multidimensional arrays, e.g. see **dosharpen.c**
  - also have **shfree();**

Dynamic memory allocation (Fortran)

- Malloc-like routine provided in Fortran
  - **`CALL SHPALLOC(addr, length, errcode, abort)`**
  - **`addr`** is a "Cray pointer" to an array; **`length`** counted in ***32-bit words***
  - last two arguments relate to behaviour on error (see manual)
- Relatively simple for 1D arrays

array contains 64-bit doubles

```
double precision :: pWrk(1)  ! Dummy declaration
pointer (addr, pWrk)         ! Get pointer to array
call shpalloc(addr, 2*pWrksize, errcode, 0)
pWrk(3) = 99
```

Multidimensional Fortran arrays

- Compiler needs to know leading array dimensions
  - cannot just declare dimensions as 1

```
double precision :: matrix(N,N)  ! Dummy declaration
pointer (maddr, matrix)          ! Get pointer
…
! before shpalloc, no storage associated with matrix
call shpalloc(maddr, 2*N*N, errcode, 0)
matrix(7,4) = 34.0
```

  - see **`dosharpen.f90`** for real examples

- Also have **`shpdeallc()`**

Locks

- Can lock integer variables
  - this is a global lock (e.g. stored on PE 0) which could be used for critical sections etc.

```
shmem_set_lock(lock);
shmem_clear_lock(lock);
islocked = shmem_test_lock(lock);
```

  - all locks must be initialised to zero

- Can be used to protect access to data
  - requires all code to respect association of lock with data

Atomic Memory Operations

- Locks can be very heavyweight for simple operations
  - e.g. adding one to a remote variable:

```
get pointer for lock on remote pe
obtain the lock
get value from remote pe
add one to value
put value back
release lock
```

- OpenSHMEM has atomic memory operations
  - e.g., **`CALL SHMEM_INT4_ADD(target, value, remote_pe)`**
  - atomically adds **`value`** to **`target`** on **`remote_pe`**
  - also have increment, swap, fetch-and-add,…

Summary

- OpenSHMEM contains all the routines you would expect of a PGAS library
  - see www.openshmem.org
- A bit confusing in places, often due to history of non-standard implementations
- May be more portable than languages such as UPC and coarrays
  - does not require compiler support
- Very efficient on Cray platforms