MPI Shared Memory Model

MPI processes behaving as threads

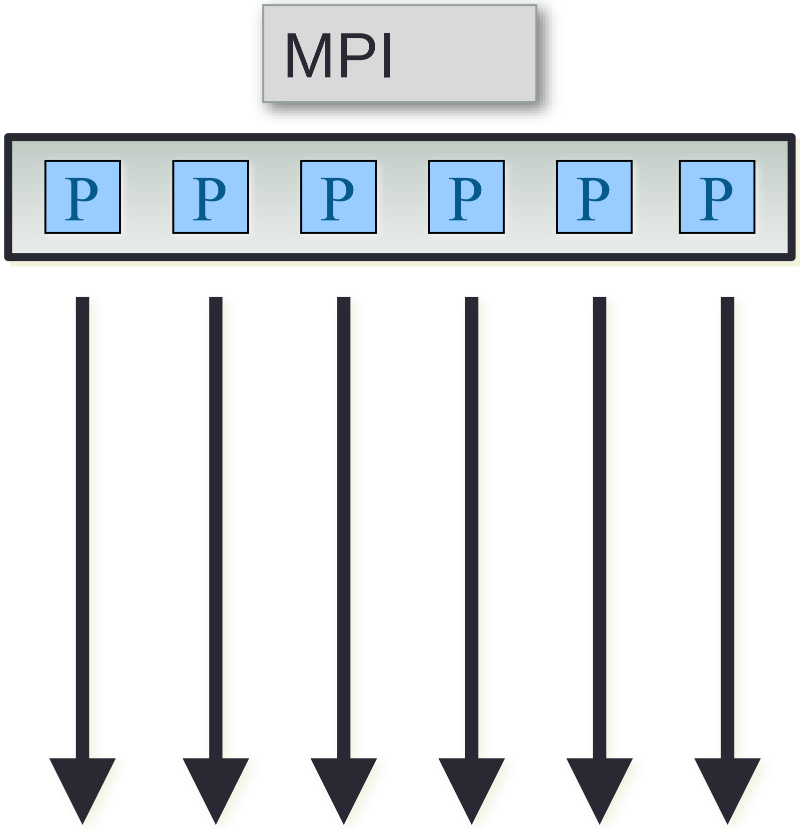
Reusing this material

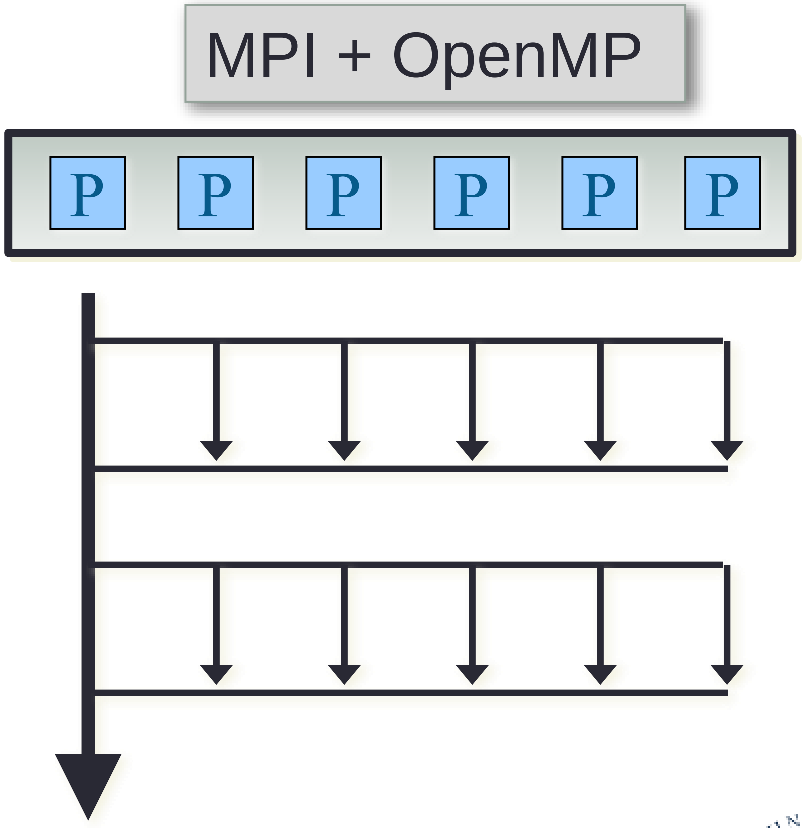
Overview

- Motivation
- Node-local communicators
- Shared window allocation
- Synchronisation

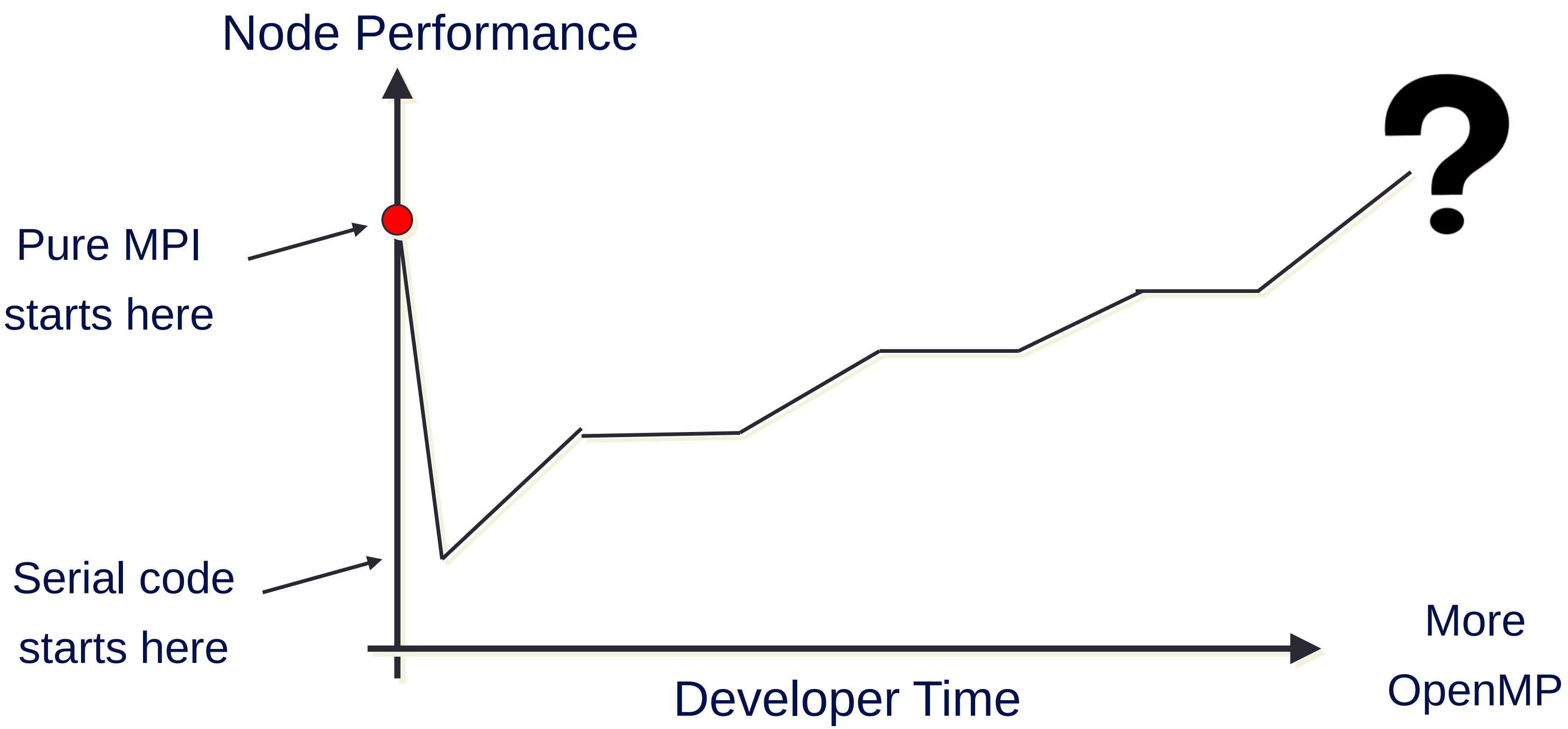
MPI + OpenMP

- In OMP parallel regions, all threads access shared arrays
  - why can’t we do this with MPI processes?





Consequences of MPI + OpenMP



- Some successes reported - often due to “threshold” effects
  - not enough memory to use all cores with MPI
  - fixed scalability limit of MPI parallelisation (e.g. slab-based FFTs)

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Other use cases

- Saving memory
  - some programs have large, static lookup tables
  - in MPI, need one copy per process
    - on ARCHER2, this means 128 copies on each node!
  - much more efficient to have one copy per node
- NUMA-friendly memory allocation
  - sometimes, rank 0 on a node allocates lots of memory at startup
  - possible to use all the memory on the local NUMA region
    - ARCHER2 has 8 NUMA regions each with 32 MiB
  - subsequent allocations on ranks 0-15 now in different NUMA region
    - can be a disaster for performance
  - MPI shared memory allocation can be collective

Exploiting Shared Memory

- With standard RMA
  - publish local memory in a collective shared window
  - can do read and write with MPI_Get / MPI_Put
  - plus appropriate synchronisation, e.g. MPI_Win_fence()
- Seems wasteful on a node
  - why can't all processes just read and write directly as in OpenMP?

- Requirement
  - technically requires the Unified model
    - where there is no distinction between RMA and local memory
  - can check this callng `MPI_Win_get_attr` with `MPI_WIN_MODEL`
    - model should be MPI_WIN_UNIFIED
  - this is not a restriction in practice for standard CPU architectures

Procedure

- Processes join separate communicators for each node
- Shared array allocation across all processes on a node
  - each process receives a local array
  - OS can arrange for local arrays to be part of a single global array
- Remote access by indexing outside limits of local array
  - e.g. `localarray[-1]` will be last entry on the previous process
- Need appropriate synchronisation for remote accesses
- Still need MPI calls for inter-node communication
  - e.g. standard send and receive

Splitting the communicator

```
int MPI_Comm_split_type(MPI_Comm comm, int split_type,
  int key, MPI_Info  info, MPI_Comm *newcomm)
```

```
MPI_COMM_SPLIT_TYPE(COMM, SPLIT_TYPE, KEY, INFO,
                    NEWCOMM, IERROR)
INTEGER COMM, SPLIT_TYPE, KEY, INFO, NEWCOMM, IERROR
```

- comm: parent communicator, e.g. MPI_COMM_WORLD
- split_type: MPI_COMM_TYPE_SHARED
- key: controls rank ordering within sub-communicator
- info: can just use default: MPI_INFO_NULL

Example

```
MPI_Comm_split_type(MPI_COMM_WORLD, MPI_COMM_TYPE_SHARED,
                    rank, MPI_INFO_NULL, &nodecomm);
```

COMM_WORLD

size = 12

rank

0 1 2 3 4 5 6 7 8 9 10 11

0 1 2 3 4 5 0 1 2 3 4 5

rank	rank
size = 6	size = 6
nodecomm	**nodecomm**

Allocating the array

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

MPI_WIN_ALLOCATE_SHARED(SIZE, DISP_UNIT, INFO, COMM, BASEPTR,
                        WIN, IERROR)
  INTEGER(KIND=MPI_ADDRESS_KIND) SIZE, BASEPTR
  INTEGER DISP_UNIT, INFO, COMM, WIN, IERROR
```

- size: window size in bytes
- disp_unit: basic counting unit in bytes, e.g. sizeof(int)
- info: can just use default: MPI_INFO_NULL
- comm: parent comm (must be within a single node)
- baseptr: allocated storage
- win: allocated window

Traffic Model Example

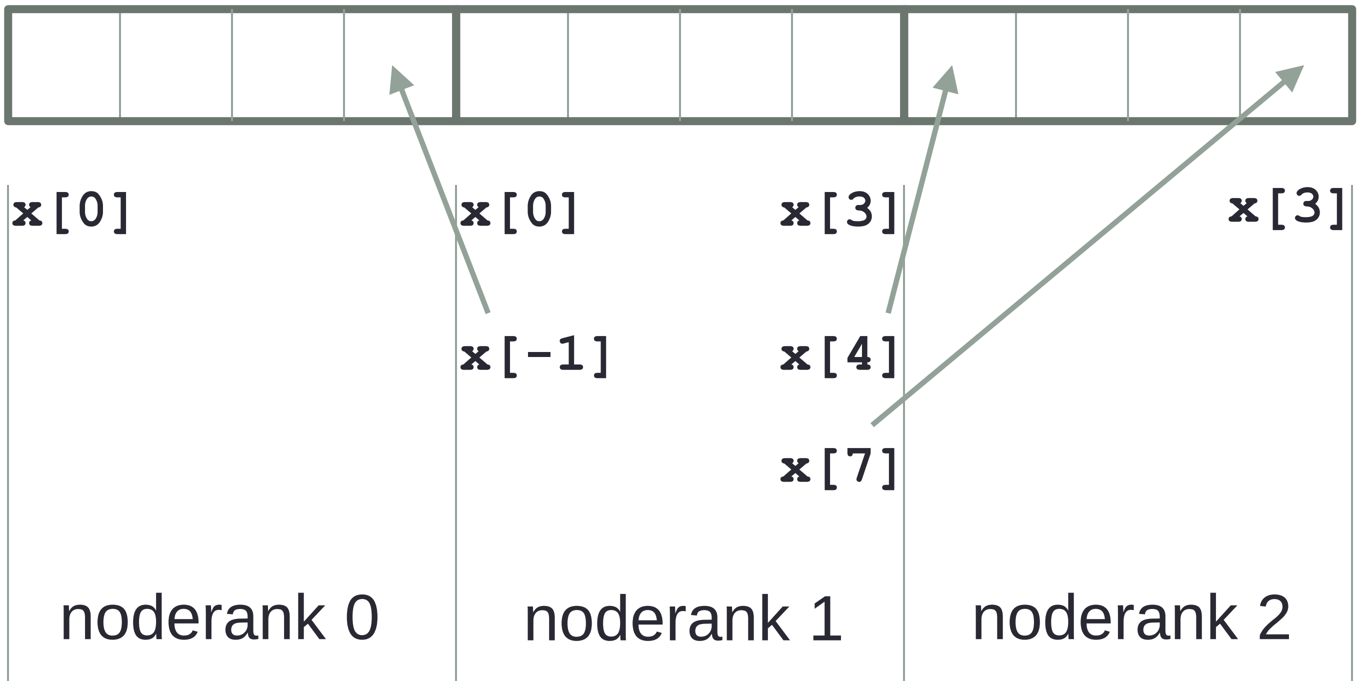
```
MPI_Comm nodecomm;
int *oldroad;
MPI_Win nodewin;
MPI_Aint winsize;
int displ_unit;

winsize = (nlocal+2)*sizeof(int);

// displacements counted in units of integers
disp_unit = sizeof(int);

MPI_Win_allocate_shared(winsize, disp_unit,
            MPI_INFO_NULL, nodecomm, &oldroad, &nodewin);
```

Shared Array with nlocal = 2



- Default is contiguous block of memory across processes
  - use value of info, alloc_shared_noncontig = true, to relax this

Accessing another rank's memory

- In previous diagram
  - rank 1 can access rank 0's x[0] by referencing its own `x[-4]`
- Might be more convenient to reference as `x0[0]`
  - but how do we find out address for x0 ?
  - or perhaps data is only allocated on rank 0 – what is its address?
- Rank 0 could MPI_Send its value of x to rank 1
  - will not work in general!
- Separate processes can have different virtual addresses (i.e. pointer values) for the same physical location
  - OS may do this deliberately to foil buffer overflow hacking attacks
- Must use special call
  - see `MPI_Win_shared_query`()
  - gives us a local pointer which we can use to access remote data

Synchronisation

- Can do halo swapping by direct copies
  - need to ensure data is ready beforehand and available afterwards
  - requires synchronisation, e.g. MPI_Win_fence()
  - takes hints – can just set to default of 0

- Entirely analogous to OpenMP
  - bracket remote accesses with omp_barrier or begin / end parallel

```
MPI_Win_fence(0, nodewin);
oldroad[nlocal+1] = oldroad[nlocal-1]
oldroad[-1]       = oldroad[1];
MPI_Win_fence(0, nodewin);
```

Off-node comms

- Direct read / write only works within node

- Still need MPI calls for inter-node
  - e.g. noderank = 0 and noderank = nodesize-1 call MPI_Send / Recv
  - could actually use *any* rank to do this ...

- This must take place in MPI_COMM_WORLD

Conclusion

- Relatively simple syntax for shared memory in MPI
  - much better than roll-your-own solutions
- Possible use cases
  - on-node communications without needing MPI
  - one copy of static data per node (not per process)

- Advantages
  - an incremental “plug and play” approach unlike MPI + OpenMP
- Disadvantages
  - no automatic support for splitting up parallel loops
  - global array may have halo data sprinkled inside
    - so may not help in some memory-limited cases