Performance of Fortran Coarrays on the Cray XE6

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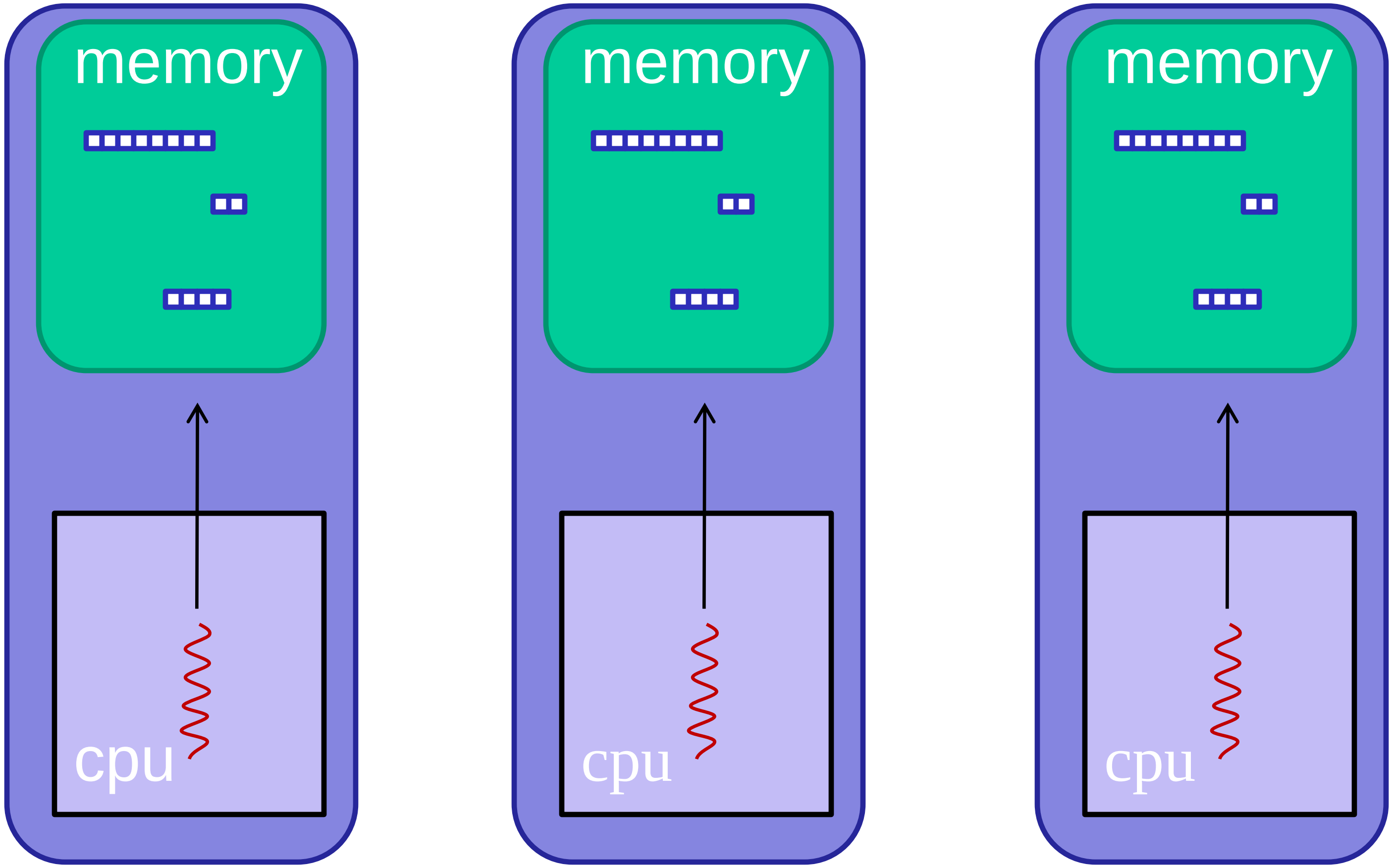
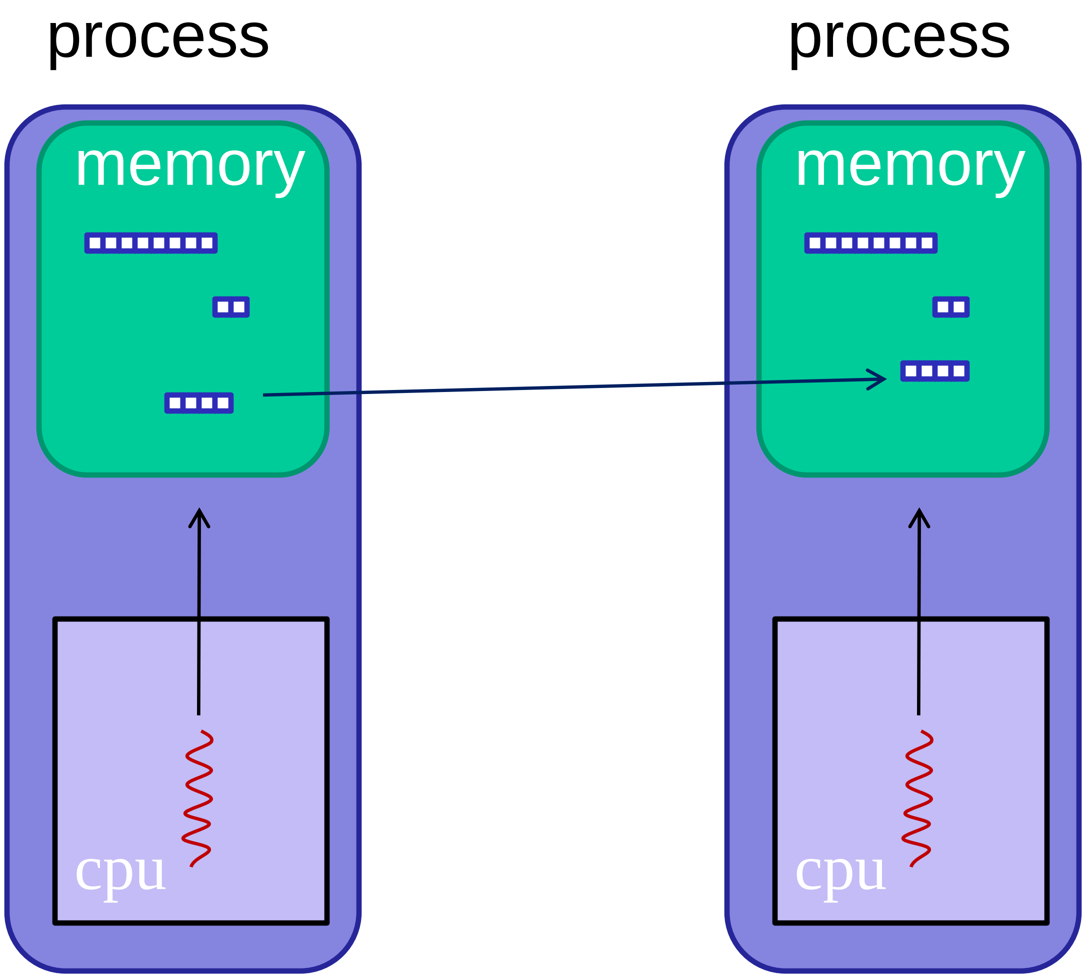
PGAS languages and exascale

- Issues foreseen for MPI at large scale
  - manycore memory footprint
  - excessive synchronisation
  - high latency
  - message matching overheads
  - …
- Partitioned Global Address Space models
  - private and shared data
  - direct read/write from/to remote memory
  - compiler support
  - no explicit buffering
- Two main implementations
  - Fortran Coarrays (part of Fortran 2008 standard)
  - Unified Parallel C

Message-Passing

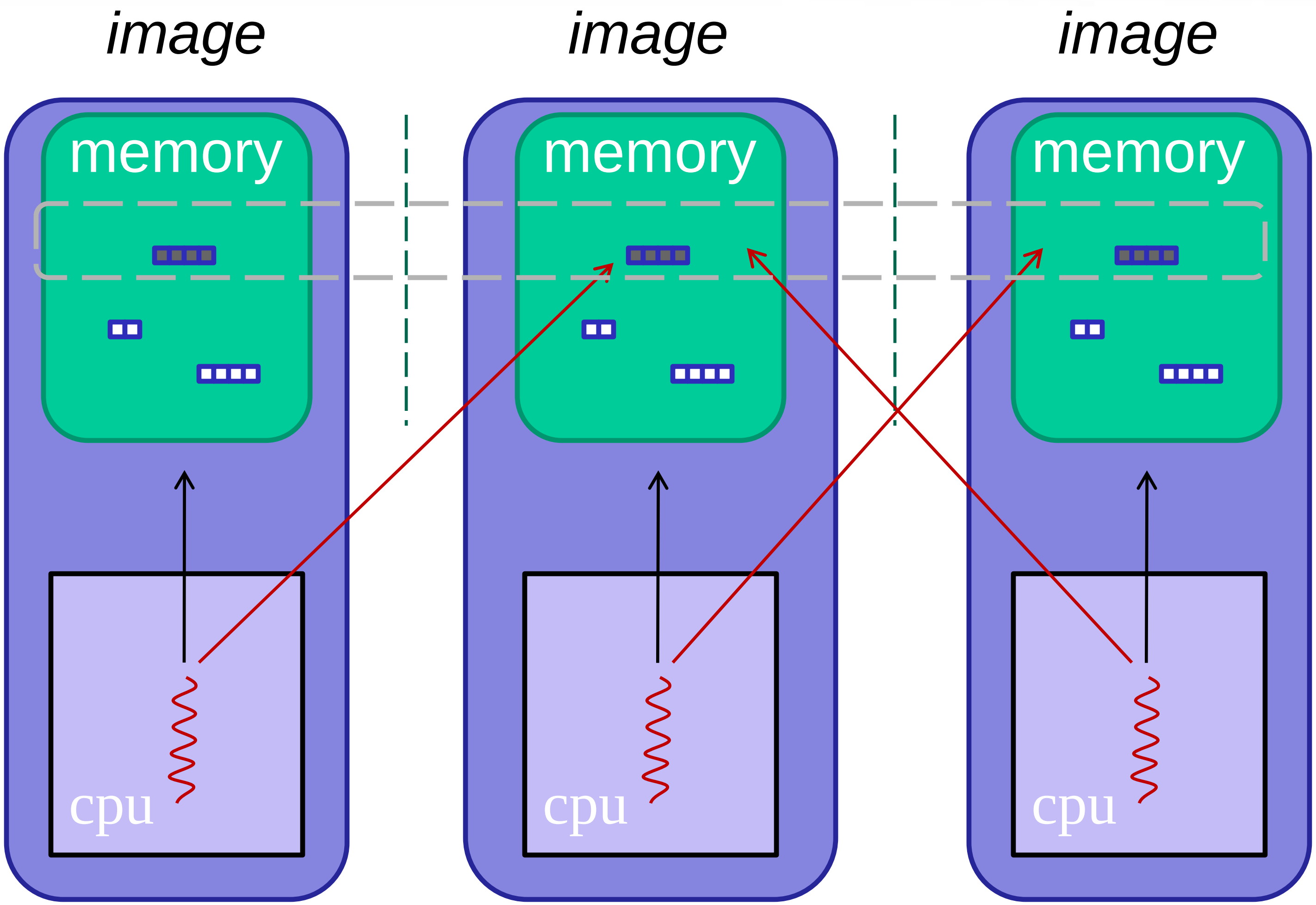


MPI

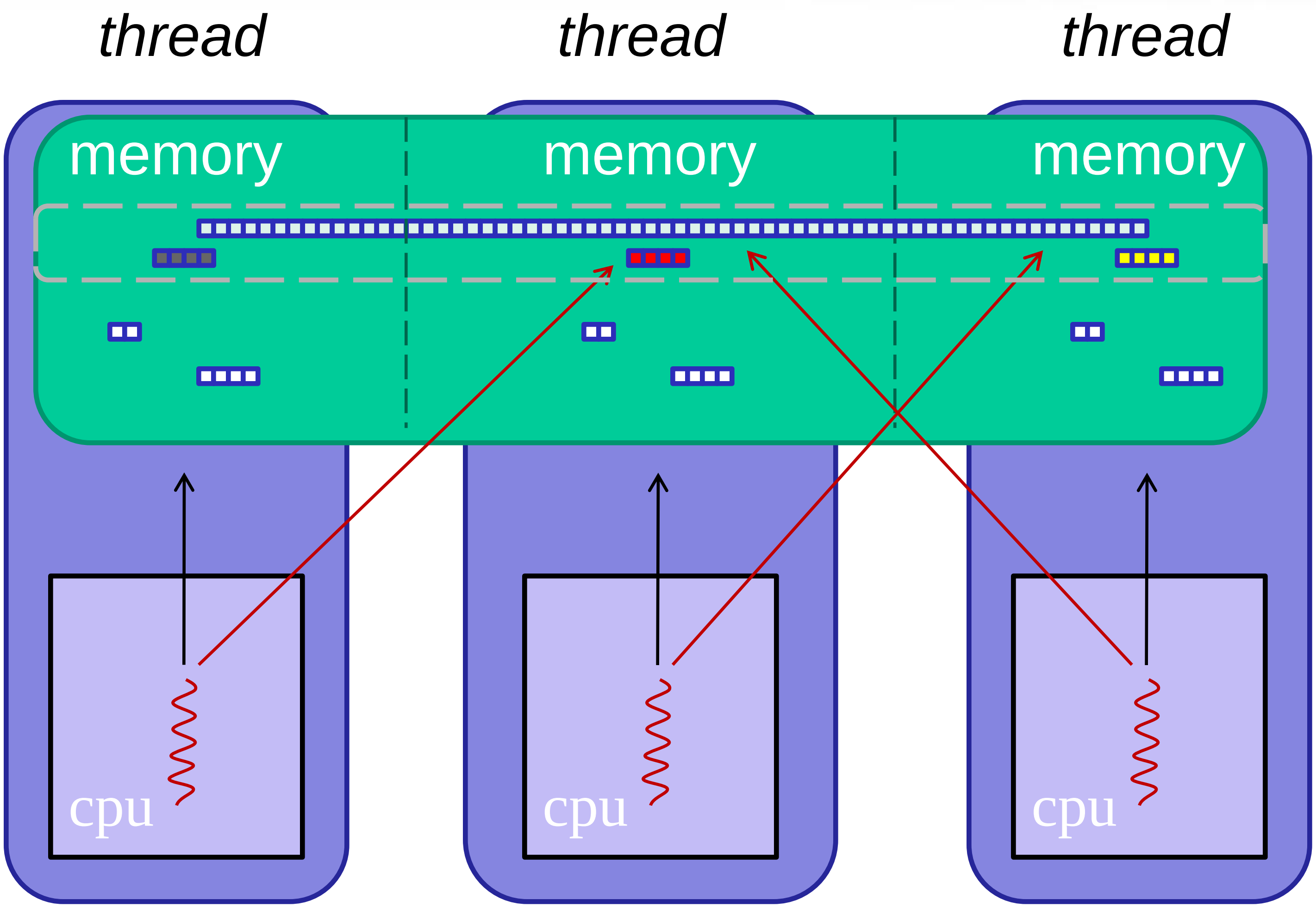


`MPI_Send(a,...,1,…)` **`MPI_Recv(a,...,0,…)`**

Fortran coarrays



UPC



Minimal syntax extension to Fortran

- SPMD execution model on multiple *images*
- Declare data to be remotely accessible

```
real, dimension(10), codimension[*] :: x
real x(10)[*]
```

- Access remote data directly

```
x(2)     = x(3)[7]   ! remote read from image 7
x(6)[4] = x(1)       ! remote write  to image 4
```

- Explicit synchronisation: global and point-to-point

```
sync all; sync images(imagelist)
```

- Supports multiple dimensions and codimensions

What to benchmark?

- Minimal syntax
  - plus a few synchronisation intrinsics
  - no collectives (yet …)
  - different to, e.g., MPI and UPC
- Need to decide on particular data access and communications patterns
- Several ways to describe same pattern
  - array syntax, explicit loops, inline or subroutine, …
  - important to understand compiler capabilities

Initial benchmark

- Single contiguous point-to-point read and write
- Multiple contiguous point-to-point read and write
- Strided point-to-point read and write
- All basic synchronisation operations
- Various representative synchronisation patterns
- Halo-swapping in a multi-dimensional regular domain decomposition

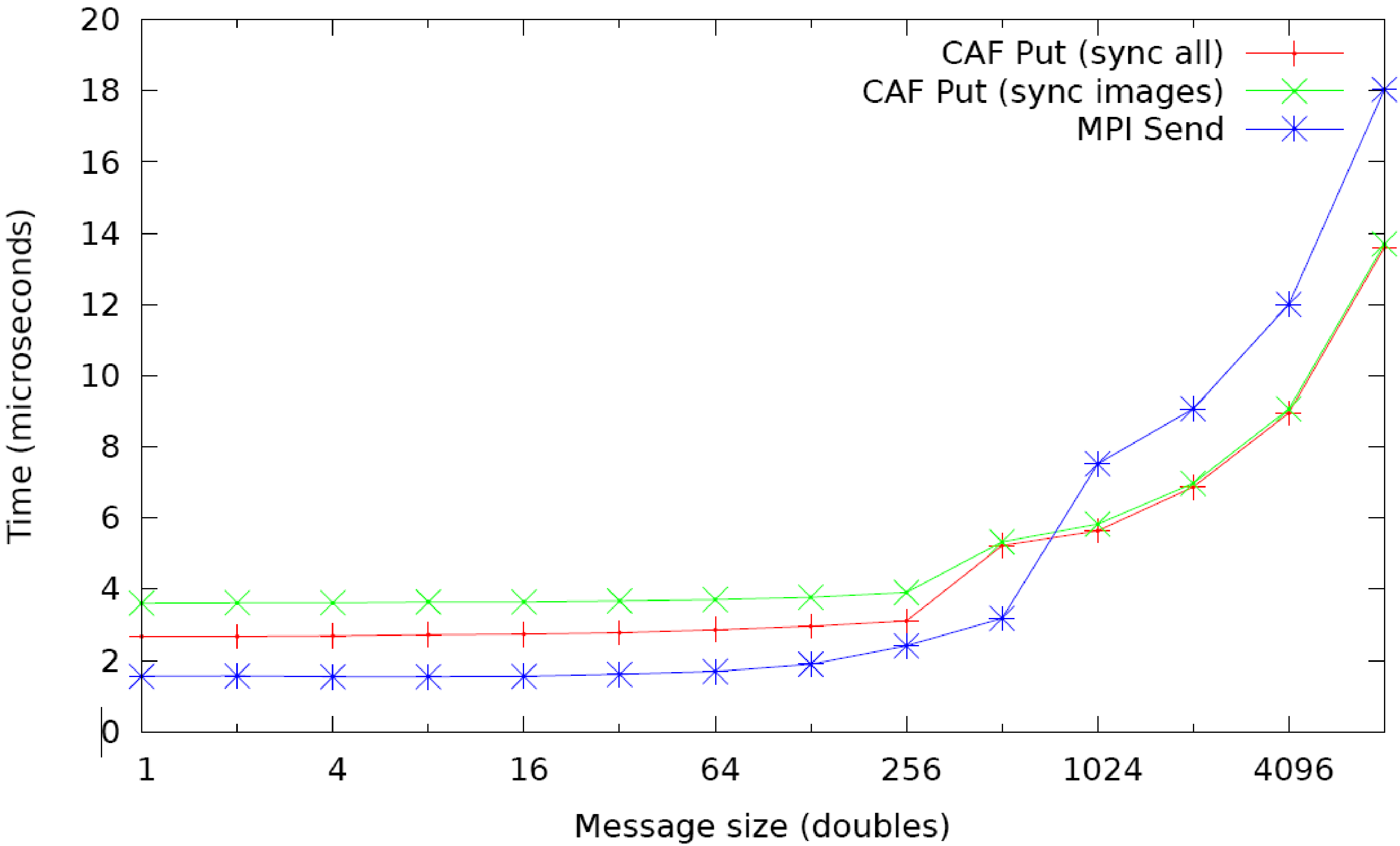
- All communications include synchronisation cost
  - use double precision (8-byte) values as the basic type
  - use Fortran array syntax (mostly)

- Synchronisations overhead measured separately as overhead = (delay + sync) – delay

Platforms

- HECToR
  - UK National Supercomputer
  - 90,000 cores, 2x16-core Interlagos nodes, GEMINI interconnect
  - plus internal Cray XE6 development system

Ping-Pong

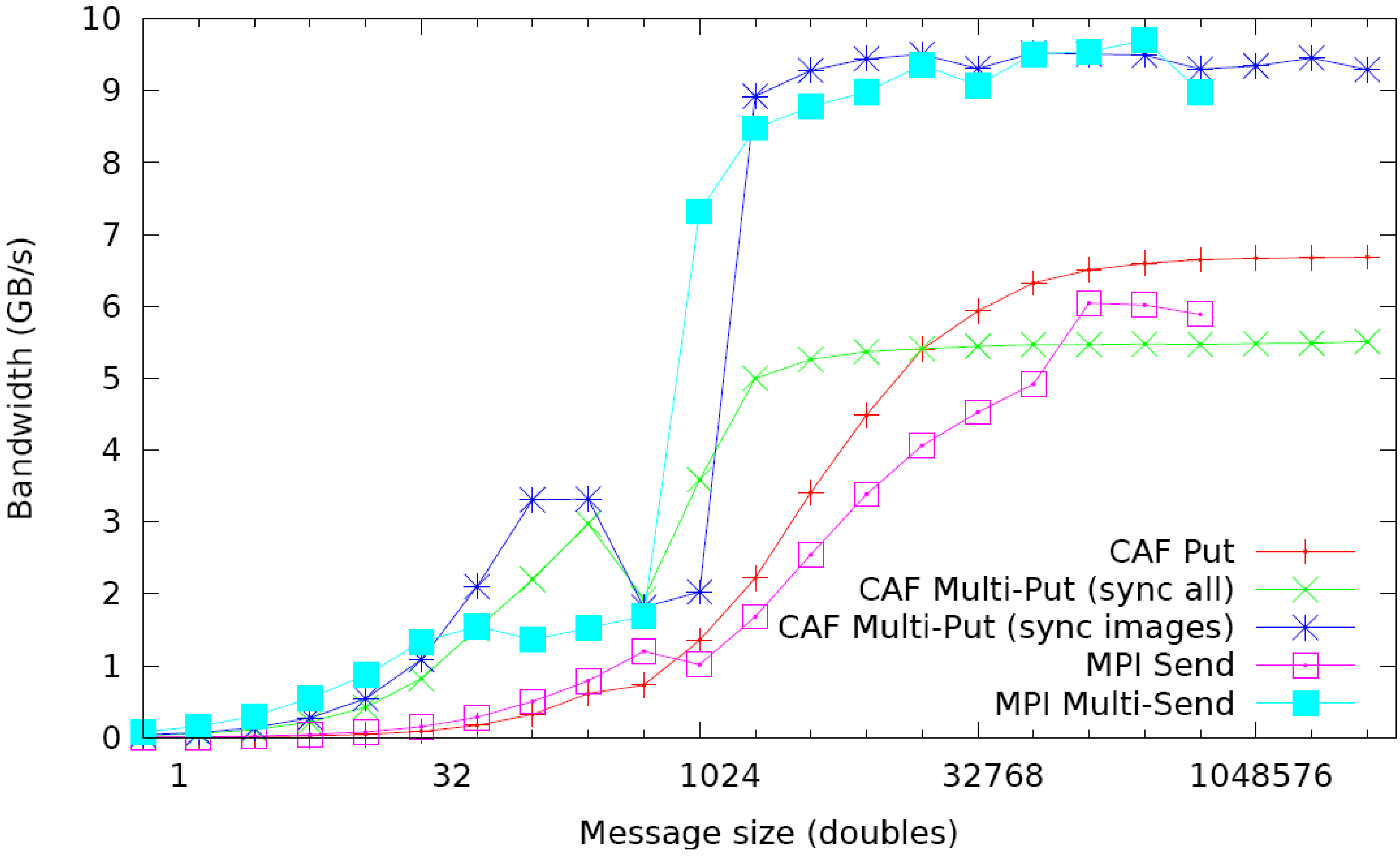


CAF Put (sync all)
CAF Put (sync images)
MPI Send
Time (microseconds)
Message size (doubles)
20
18
16
14
12
10
8
6
4
2
0
1
4
16
64
256
1024
4096

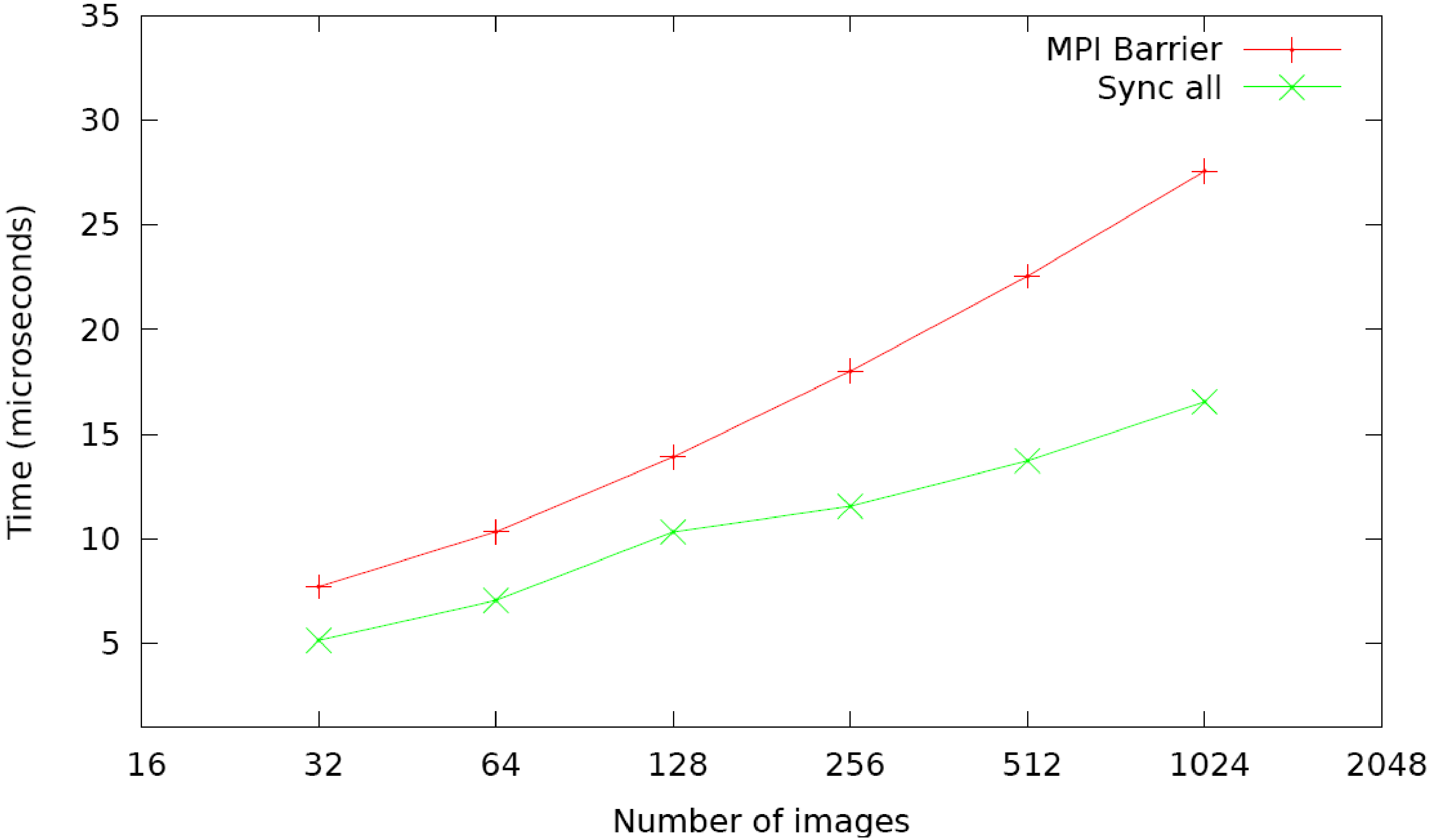
Synchronisation

- All coarray operations require explicit synchronisation calls for correctness
  - typically two!
- Ping-pong benchmark includes synchronisation
  - dominates the transfer time
  - actual transfers take about 1.3 μs per double (see later)
- Measure synchronisation explicitly in benchmark
  - global (sync all): 2.3 μs
  - pt-to-pt (sync images): 3.6 μs
- Not completely consistent, but implies latency worse than MPI
- However…
  - MPI synchronises per message pair
  - coarray synchronisation is between images
- Potential to issue many coarray ops between single sync pair

Multi Ping-Pong



Global Synchronisation



Strided Ping-Pong

Mode	time per double (μs)	total bandwidth (MB/s)
Single ping-pong		
Put (DO loop)	1.3	6.1
Put (array syntax)	0.3	25.3
Get (DO loop)	1.2	6.5
Get (array syntax)	1.2	6.6
Multi ping-pong		
Put (DO loop)	0.06	129
Put (array syntax)	0.02	364
Get (DO loop)	0.06	142
Get (array syntax)	0.06	141

Point-to-point synchronisation patterns

- Should be advantageous when running on many images
  - images must mutually synchronise

```
sync images(imagelist)
```

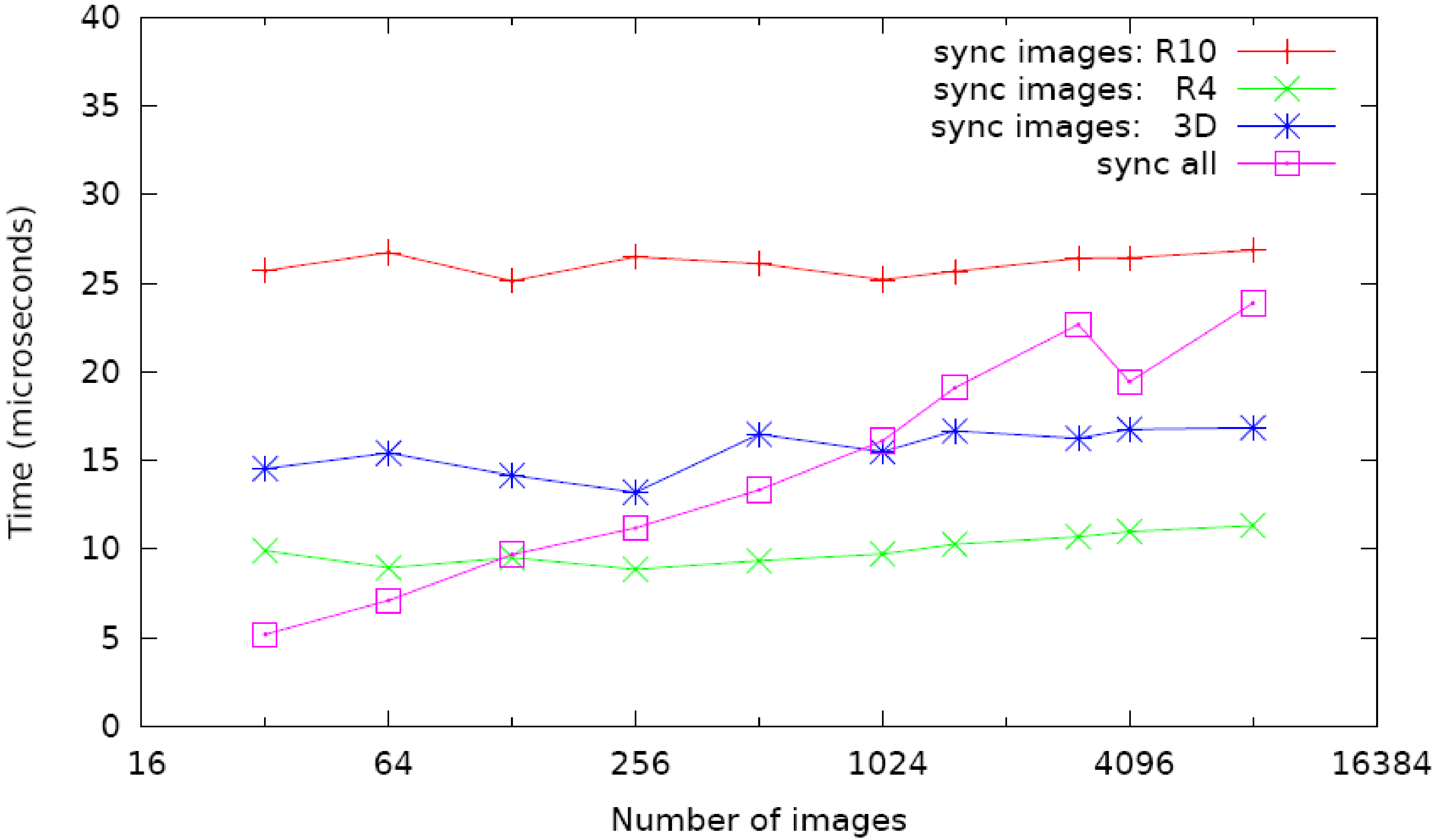
  - user must ensure they all match up

- L*X*
  - each image pairs with *X* images in a (periodic) line
  - e.g. L4 pairs with image-2, image-1, image+1 and image+2

- R*X*
  - same as L*X* but images are randomly permuted
  - ensures many off-node messages

- 3D
  - six neighbours in a 3D cartesian grid

Point-to-point Synchronisation Perfomance



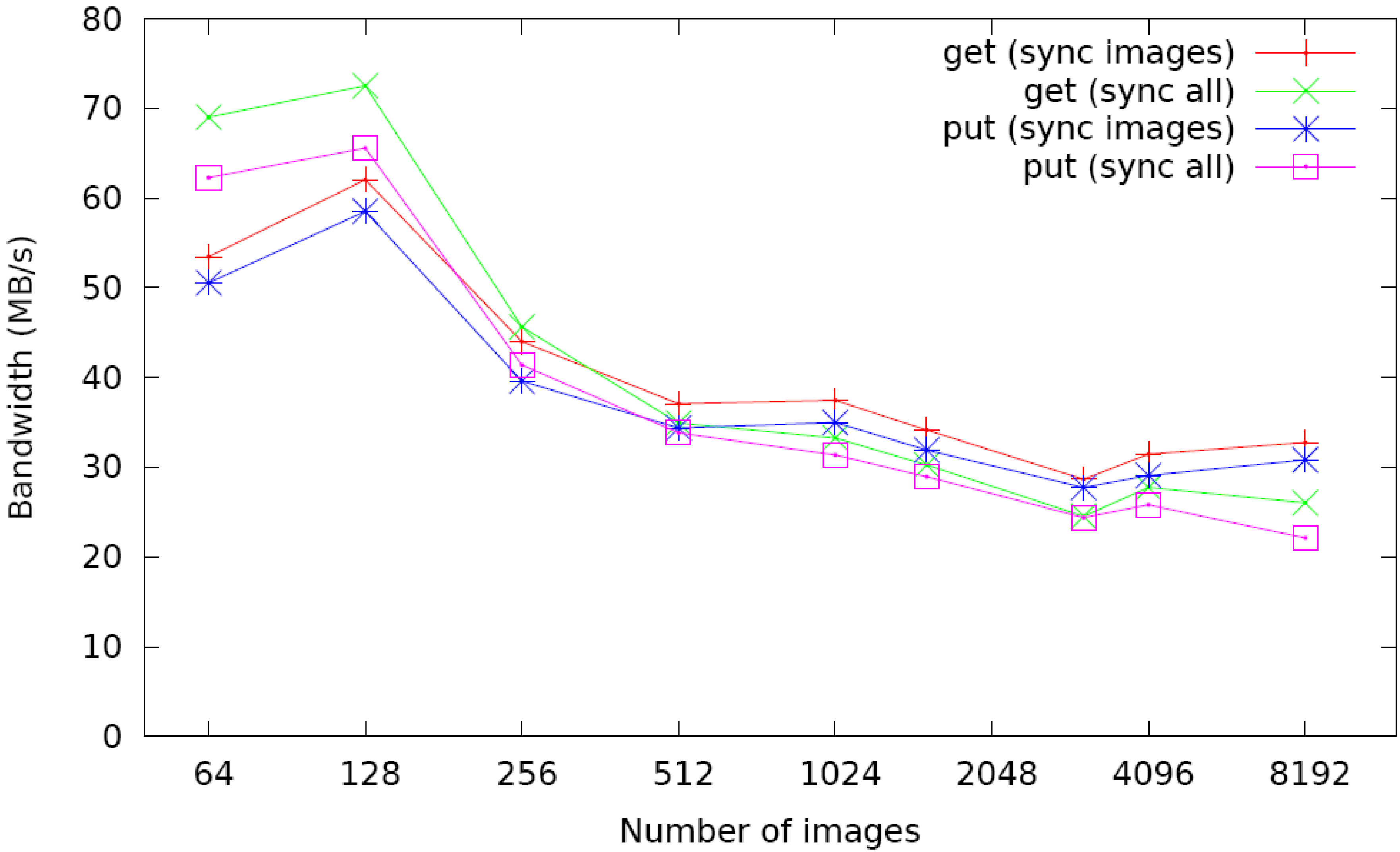
3D halo swap

- Fixed volume, weak scaling

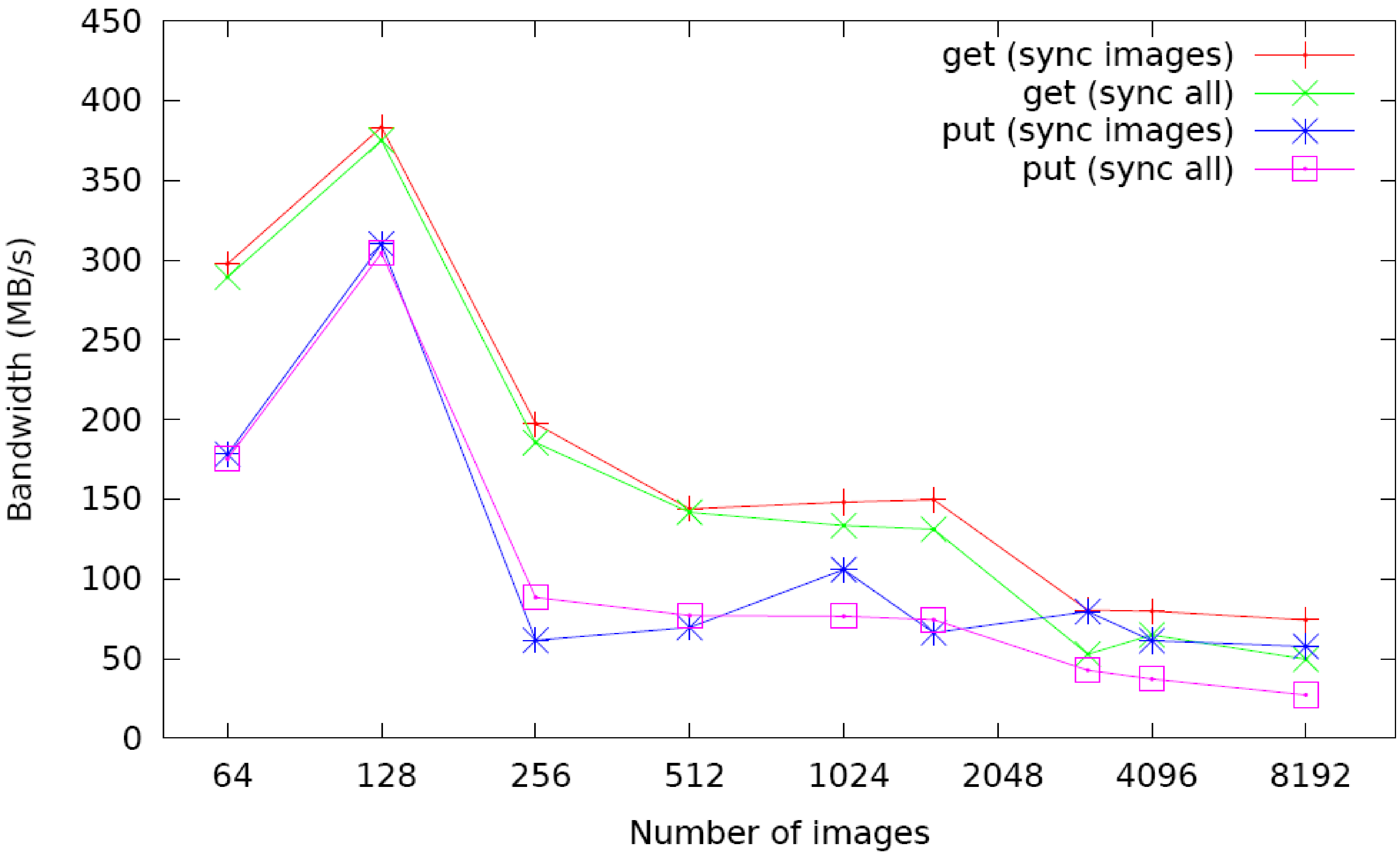
- 3D domain decomposition as suggested by MPI_Cart_dims
  – reversed for Fortran ordering

- Measure time for complete halo swap operation
  – remote read (get) and write (put)
  – sync images and sync all

3D Halo Swaps (10x10x10)



3D Halo Swaps (100x100x100)



Conclusions

- Simple benchmarks give good insight into performance characteristics of Fortran coarrays
- Cray compiler quite mature
  - good ability to pattern match (i.e. “vectorise” remote operations)
  - performance generally good on XE6
  - significant advantages from point-to-point synchronisation
  - but explicit buffering would still be faster than strided access
- Essential to have verification tests
  - benchmark has a “do verify” option which impacts performance
  - previous Cray compilers have sometimes had bugs
  - e.g. wrong data transferred in 3D halo swaps
  - earliest Intel compiler implemented `sync images` as a no-op!
  - Cray bugs fixed quickly but you do need to detect them …

Further work

- Increase scope of benchmark
  - overlap of communications and calculations (via compiler directive)
  - more complicated data transfer patterns (e.g. for locks)
  - include proposed coarray collectives
- Tidy up and make available for general release

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Backup: Lock and Critical