HPI Hasso Plattner Institut
IT Systems Engineering | Universität Potsdam

NUMA with **Open MPI**

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Agenda

1. MPI and Open MPI
2. MPI Concepts
3. NUMA with (Open)MPI
4. Examples

What is MPI?

A message-passing library

interface specification

[**M**essage-**P**assing **I**nterface]

Goals of MPI

develop a widely used standard for writing message-passing programs

portability and ease of use

efficient communication | can be used in a **heterogeneous environment**

a reliable communication interface | **Thread safety**

C and Fortran bindings for the interface

Evolution of MPI

MPI-1.0 (1994)

- **MPI-1.1** (1995)
- **MPI-1.2** (1997)
- **MPI-1.3** (2008)

MPI-2.0 (1997)

- **MPI-2.1** (2008)
- **MPI-2.2** (2009)

MPI-3.0 (2012)

- *MPI-3.1* (2015)

MPI-4.0 *(20??)*

Open MPI

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… is an open source* MPI implementation

FT-MPI [University of Tennessee]

LA-MPI [Los Alamos National Laboratory]

LAM/MPI [Indiana University]

with contributions from the PACX-MPI team [University of Stuttgart]

[* Open source license based on the BSD license]

Open MPI

... supports / implements:

Full MPI-3 standard conformance

Thread safety and concurrency | Dynamic process spawning

Support network heterogeneity | **Network and process fault tolerance**

High performance on all platforms | Portable and maintainable

Component-based design, documented APIs

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Concepts

autonomous processes

executing their own code (MIMD style)

processes communicate via

calls to **MPI communication primitives**

each process executed in its **own address space**

(shared-memory implementations of MPI are possible)

Concepts: group, context, communicator

group

ordered set of process identifiers

process associated with **rank [0, n-1]**

context

communicationg space

communicator

provides **independent process addressing**

MPI_COMM_WORLD and MPI_COMM_SELF

Concepts: point-to-point communication

sending and receiving of messages by processes

blocking and non-blocking versions

communiation modes: **S**tandard, **B**uffered, **S**ynchronous and **R**eady

```
int MPI_Send(
  void *buffer, int count, MPI_Datatype type,
  int destRank,
  int messageTag,
  MPI_Comm communicator)
```

Concepts: point-to-point communication

```
int MPI_Send(
void *buf, int count, MPI_Datatype type, int dest,   int tag, MPI_Comm comm)

int MPI_Recv(
void *buf, int count, MPI_Datatype type, int source, int tag, MPI_Comm comm, MPI_Status *st)
```

non-blocking versions:

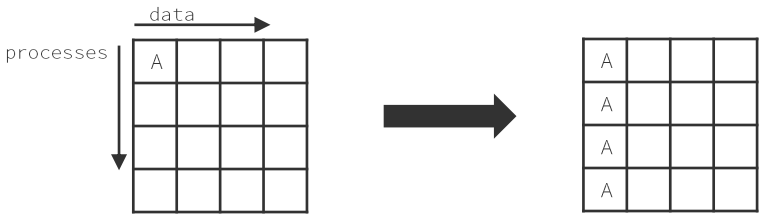
```
int MPI_Isend( … , MPI_Request *req)
int MPI_Irecv( … , MPI_Request *req)
→ MPI_Wait and MPI_Test
```

Concepts: collective operations

communication that involves a **group of processes**

data movement and **collective computation**

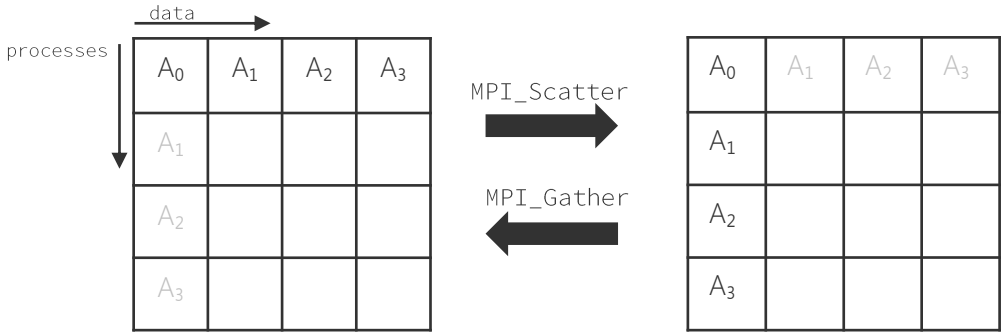
```
int MPI_Bcast(void *buffer, int count, MPI_Datatype type,
              int root, MPI_Comm comm)
```



Concepts: collective operations

`MPI_Gather / MPI_Scatter`

gather data from all members of a group to one member /
scatter data from one member to all members of a group



`MPI_Allgather`

a variation on Gather where all members of a group receive the result

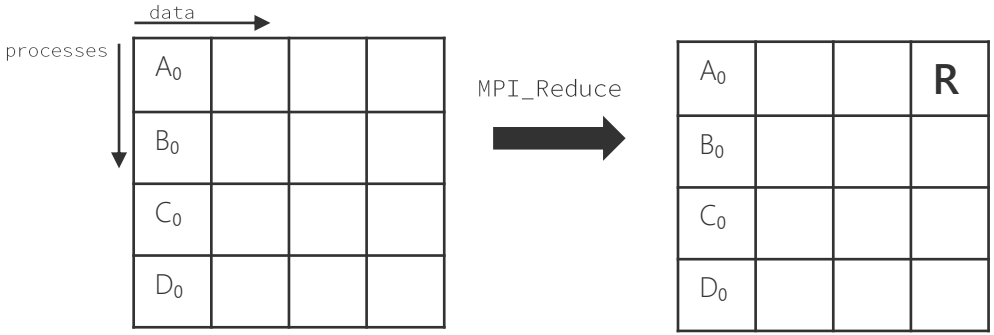
`MPI_Alltoall`

scatter / gather data from all members to all members of a group (complete exchange)

Concepts: collective operations

`MPI_Reduce`

Reduces values on all processes within a group



`MPI_Op:`

`MAX & MIN | SUM & PROD`

`LAND & BAND`

`LOR & BOR | LXOR & BXOR`

`MAXLOC & MINLOC`

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`MPI_Allreduce`

result is returned to all members of a group

`MPI_Reduce_scatter`

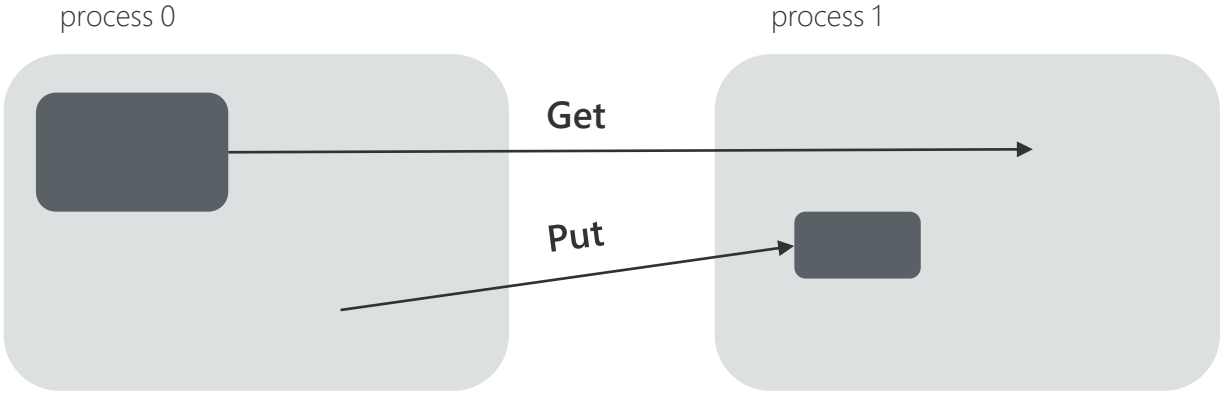
a combined reduction and scatter operation

Concepts: collective operations

```
int MPI_Gather/MPI_Scatter(
const void *sendbuf, int sendcount, MPI_Datatype sendtype, void *recvbuf,
int recvcount, MPI_Datatype recvtype, int root, MPI_Comm comm)
```

```
int Reduce(
const void *sendbuf, void *recvbuf, int count, MPI_Datatype datatype,
MPI_Op op, int root, MPI_Comm comm)
```

Concepts: one-sided communication




```
MPI_Win_create

→ MPI_Get/MPI_Put & MPI_Win_fence
```

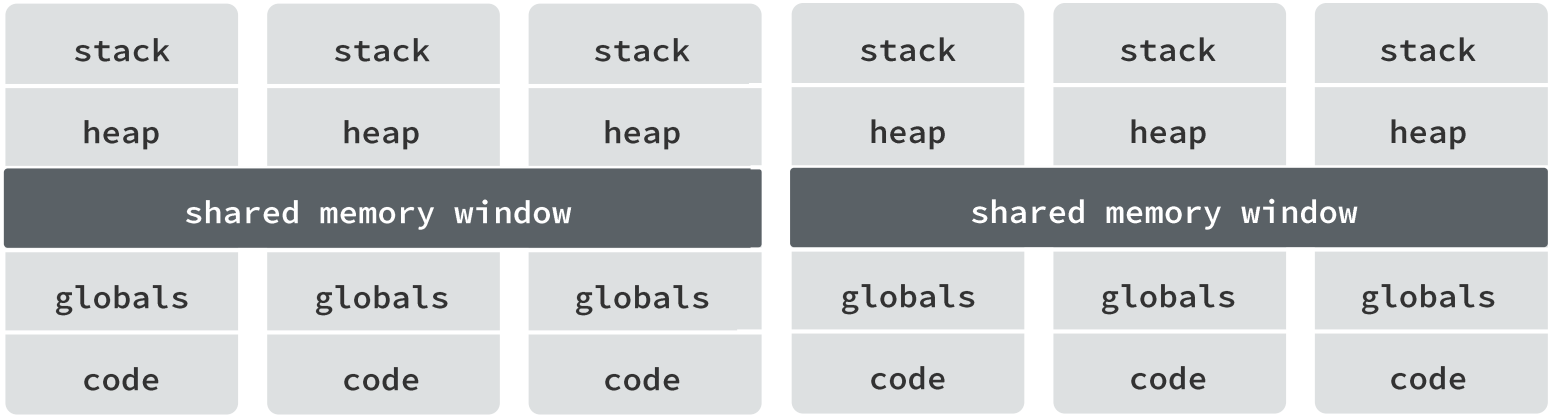
Concepts: one-sided communication

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

MPI_Get/MPI_Put(
void *orig_addr, int orig_count, MPI_Datatype orig_type, int targ_rank,
MPI_Aint targ_disp, int targ_count, MPI_Datatype targ_type, MPI_Win win)

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

Concepts: shared memory



disciplined sharing

`MPI_Win_allocate_shared`

`MPI_Win_shared_query`

`MPI_Comm_split_type`

Concepts: shared memory

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

int MPI_Win_shared_query(
MPI_Win win, int rank, MPI_Aint *size, int *disp_unit, void *baseptr)

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

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Run an Open MPI program

compile

mpicc mpiProgram.c

run program

mpirun <options> program

-c, -n, -np <#>	run <#> copies of program on given nodes
-H, -host <h1,...,hN>	list of hosts on which to invoke processes
-hostfile <hostfile>	

Mapping, ranking and binding with Open MPI

mapping

assigns a default location to each process

ranking

assigns an MPI_COMM_WORLD rank value to each process

binding

constrains each process to run on specific processors

Mapping, ranking and binding with Open MPI

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mapping

-map-by <foo>	map to the specified object (combine with modifiers) [slot, hwthread, core, l1cache, l2cache, l3cache, socket, numa, board, none, ...]
-rf <rankfile>	define mapping per rank [MPI_COMM_WORLD]

--map-by ppr:n:node

on each node, launch n processes

--map-by ppr:n:socket

on each node, launch n processes * #sockets

ranking

--rank-by <foo>	rank in round-robin fashion [slot, hwthread, core, l1cache, l2cache, l3cache, socket, numa, board, none]

binding

--bind-to <foo>	bind processes to the specified object [slot, hwthread, core, l1cache, l2cache, l3cache, socket, numa, board, none]
-report-bindings	report any bindings for launched processes

Shared memory

MPI implementations use shared memory for

process communication

collective operations

…

Open MPI

sm btl (shared-memory Byte Transfer Layer)

Shared memory

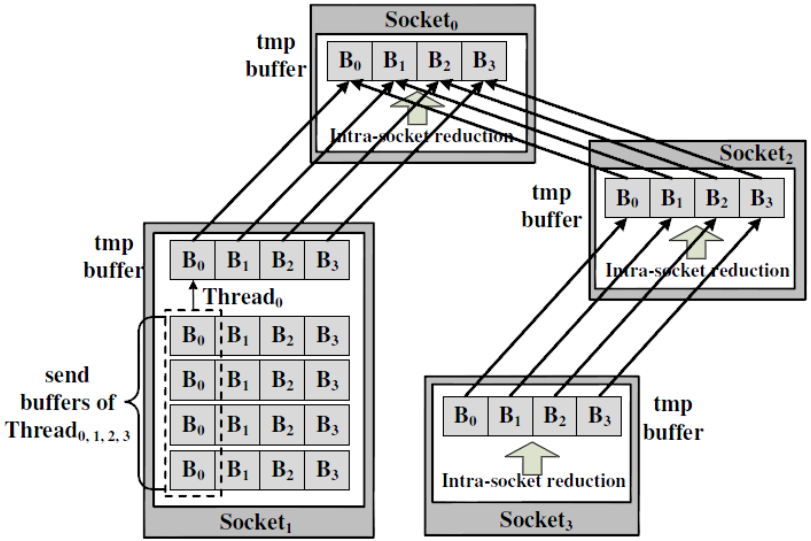

Figure 7: Hierarchical parallel-reduce, for 1 node with 4 sockets; each socket includes 4 cores.

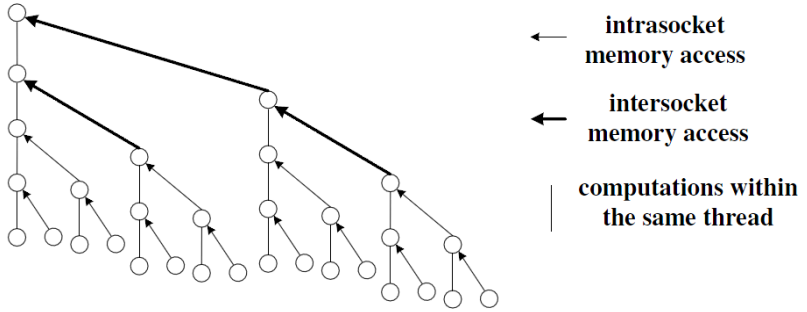

Figure 3: Binary reduction tree, for 1 node with 4 sockets; each socket includes 4 cores.

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[NUMA-aware shared-memory collective communication for MPI]

Hybrid Programming

combining MPI with different programming models

MPI was designed to encourage hybrid programming!

most common: **MPI + threads**

e.g. PGAS / Pthreads / **OpenMP**

→ **MPI + OpenMP**

Hybrid Programming

```
int MPI_Init_thread(
int *argc, char ***argv,    int required, int *provided)
```

```
MPI_THREAD_SINGLE
   Only one thread will execute.

MPI_THREAD_FUNNELED
   If the process is multithreaded, only the thread that called
   MPI_Init_thread will make MPI calls.

MPI_THREAD_SERIALIZED
   If the process is multithreaded, only one thread will make MPI library
   calls at one time.

MPI_THREAD_MULTIPLE
   If the process is multithreaded, multiple threads may call MPI at once
   with no restrictions.
```

MPI and Hardware

at least 25 % of TOP100 use MPI

→ hardware MPI implementations of MPI /

hardware acceleration for collective operations

… developed **M**PI **O**ffload **E**ngine

SGI UV 2000

[top500.org/lists/2014/11/]

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Hello World

Hybrid MPI with OpenMP

… first listen to Matthias' presentation

NUMA with Open MPI

MPI is a widely used standard

hardware implementations of MPI /
hardware accelaration for MPI operations

Open MPI uses autodetected topology
for optimizations

Sources

William Gropp, Ewing Lusk, and Anthony Skjellum. 2014. Using Mpi: Portable Parallel Programming with the Message-Passing Interface. MIT Press, Cambridge, MA, USA.

William Gropp, Torsten Hoefler, and Rajeev Thakur. 2014. Using Advanced Mpi: Modern Features of the Message-Passing Interface. MIT Press, Cambridge, MA, USA.

MPI-3.0 standard: Message Passing Interface Forum. 2012. MPI: A Message-Passing Interface Standard Version 3.0.

LI, Shigang; HOEFLER, Torsten; SNIR, Marc. NUMA-aware shared-memory collective communication for MPI. In: Proceedings of the 22nd international symposium on High-performance parallel and distributed computing. ACM, 2013. S. 85-96

Open MPI website: https://www.open-mpi.org