NUMA Control for Hybrid Applications

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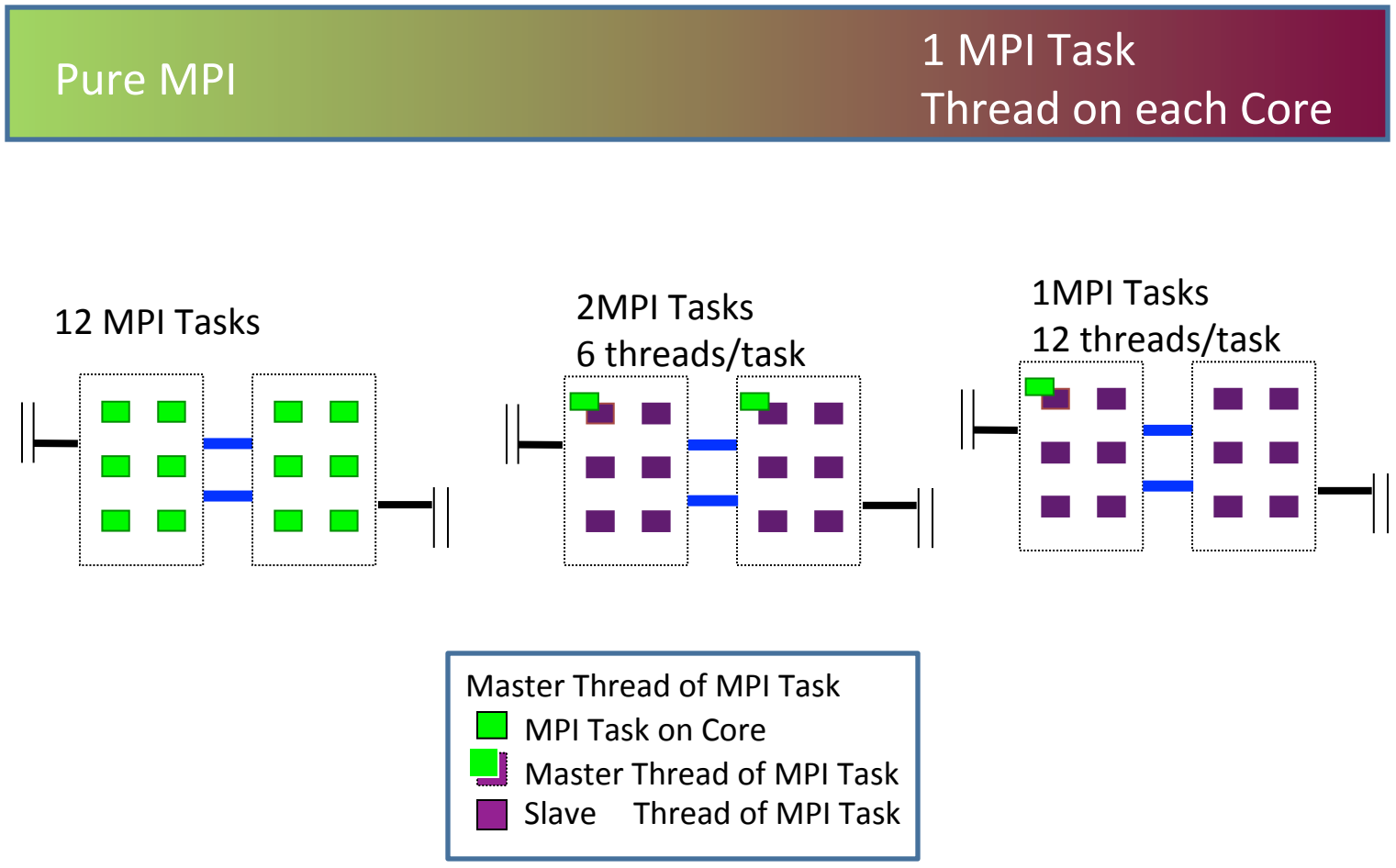
Hybrid Applications

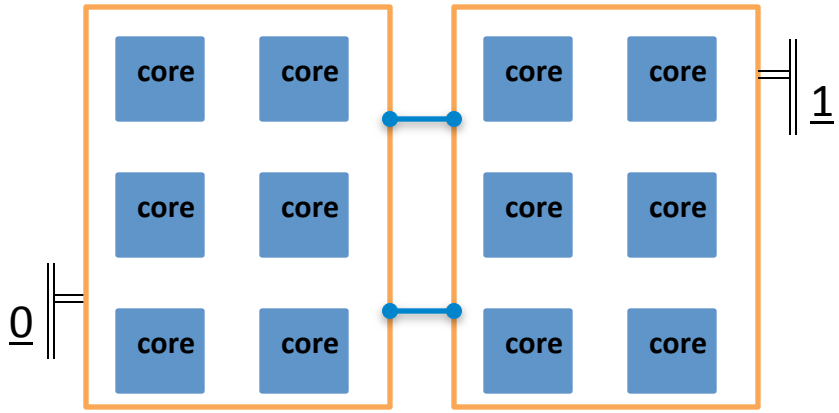
- Typical definition of hybrid application
  - Uses both message passing (MPI) and a form of shared memory algorithm (OMP)
  - Runs on multicore systems
- Hybrid execution does not guarantee optimal performance
  - Multicore systems have multilayered, complex memory architecture
  - Actual performance is heavily application dependent
- **N**on-**U**niform **M**emory **A**ccess -NUMA
  - Shared memory with underlying multiple levels
  - Different access latencies for different levels
  - Complicated by asymmetries in multisocket, multicore systems
  - More responsibility on the programmer to make application efficient

Modes of Hybrid Operation



Needs for NUMA Control

- Asymmetric multi-core configuration on node requires better control on core affinity and memory policy.
  - Load balancing issues on node
- Slowest CPU/core on node may limit overall performance
  - use only balanced nodes, or
  - employ special in-code load balancing measures
- Applications performance can be enhanced by specific arrangement of
  - tasks (process affinity)
  - memory allocation (memory policy)



NUMA Operations

- Each process/thread is executed by a core and has access to a certain memory space
  - Core assigned by process affinity
  - Memory allocation assigned by memory policy

- The control of process affinity and memory policy using NUMA operations
  - NUMA Control is managed by the kernel (default).
  - Default NUMA Control settings can be overridden with **numaclt**.

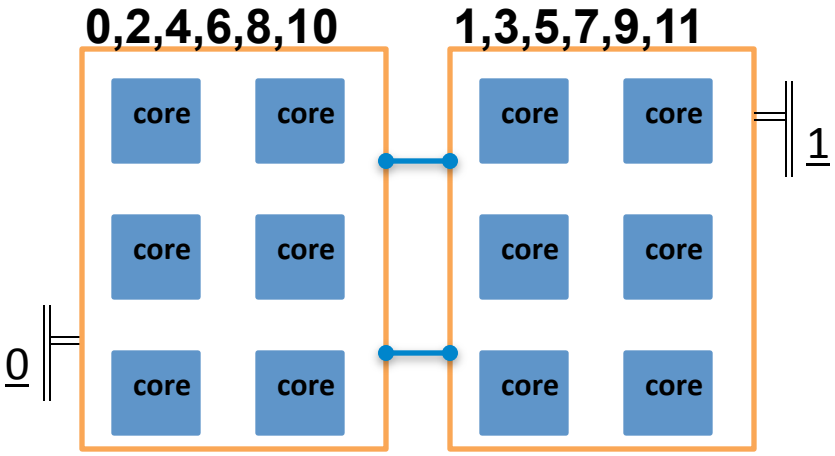
NUMA Operations

- Ways Process Affinity and Memory Policy can be managed:
  - Dynamically on a running process (knowing process id)
  - At process execution (with wrapper command)
  - Within program through F90/C API
- Users can alter Kernel Policies by manually setting Process Affinity and Memory Policy
  - Users can assign their own processes onto specific cores.
  - Avoid overlapping of multiple processes

numactl Syntax

- Affinity and Policy can be changed externally through **numactl** at the socket and core level.

Command: **numactl <options> ./a.out**



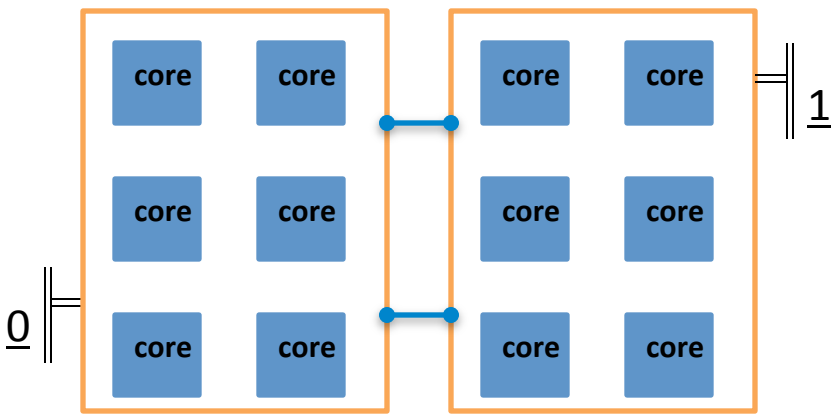
Process affinity: socket references and core references

Memory policy: socket references

numactl Options on Lonestar

	cmd	option	arguments	description
Socket Affinity	numactl	**-N**	{0,1}	Only execute process on cores of this (these) socket (s).
Memory Policy	numactl	**-l**	{no argument}	Allocate on current socket.
Memory Policy	numactl	**-i**	{0,1}	Allocate round robin (interleave) on these sockets.
Memory Policy	numactl	**--preferred=**	{0,1} select only one	Allocate on this socket; fallback to any other if full .
Memory Policy	numactl	**-m**	{0,1}	Only allocate on this (these) socket (s).
Core Affinity	numactl	**--physcpubind**	{0,1,2,3, 4,5,6,7, 8,9,10,11}	Only execute process on this (these) Core(s).

General Tips for Process Affinity and Memory Policies



Process affinity:

- MPI tasks shall be evenly populated on multi sockets
- Threads per task shall be evenly loaded on multi cores

Memory policy:

- MPI – local is best
- SMP – Interleave may be the best for large, completely shared arrays
- SMP – local may be the best for private arrays
- Once allocated, memory structure is fixed

Hybrid Runs with NUMA Control

- A single MPI task (process) is launched and becomes the “master thread”.
- It uses any **numactl** options specified on the launch command.
- When a parallel region forks the slave threads, the slaves inherit the affinity and memory policy of the master thread (launch process).

Hybrid Batch Script 12 threads

- Make sure 1 MPI task is created on each node
- Set number of OMP threads for each node
- Can control only memory allocation
- No simple/standard way to control thread-core affinity

job script (Bourne shell)

```
...
#! -pe  1way  96
...
export OMP_NUM_THREADS=12
ibrun numactl –i all ./a.out
```

Hybrid Batch Script 2 tasks, 6 threads/task

job script (Bourne shell)

```
...
#! -pe  2way  96
...
export OMP_NUM_THREADS=6
ibrun numa.sh
```

```
#!/bin/bash
# Unset any MPI Affinities
export MV2_USE_AFFINITY=0
export MV2_ENABLE_AFFINITY=0
export VIADEV_USE_AFFINITY=0
export VIADEV_ENABLE_AFFINITY=0

# Get rank from appropriate MPI API variable
[ "x$MPIRUN_RANK" != "x" ] && myrank=
$MPIRUN_RANK
[ "x$PMI_ID" != "x" ] && myrank=$PMI_ID
[ "x$OMPI_COMM_WORLD_RANK" != "x" ] &&
myrank=$OMPI_COMM_WORLD_RANK
[ "x$OMPI_MCA_ns_nds_vpid" != "x" ] && myrank=
$OMPI_MCA_ns_nds_vpid

localrank=$(( $myrank % 2 ))

socket=localrank

exec numactl --cpunodebind $socket -m $socket ./a.out
```

Hybrid Batch Script with tacc_affinity

- Simple setup for ensuring evenly distributed core setup for your hybrid runs.
- tacc_affinity is not the single magic solution for every application out there - you can modify the script and replace tacc_affinity with yours for your code.

job script **(Bourne shell)**

```
...
#! -pe  4way  192
...
export OMP_NUM_THREADS=3
ibrun tacc_affinity ./a.out
```

tacc_affinity

```
#!/bin/bash
# -*- shell-script -*-

# First determine "wayness" of PE
myway=`builtin echo $PE | /bin/sed s/way//`

export MV2_USE_AFFINITY=0
export MV2_ENABLE_AFFINITY=0
export VIADEV_USE_AFFINITY=0
export VIADEV_ENABLE_AFFINITY=0

my_rank=$(( ${PMI_RANK-0} + ${PMI_ID-0} + ${MPIRUN_RANK-0} + $
   {OMPI_COMM_WORLD_RANK-0} + ${OMPI_MCA_ns_nds_vpid-0} ))
```

tacc_affinity (cont'd)

```
local_rank=$(( $my_rank % $myway ))

if [ $myway -eq 1 ]; then
      numnode="0,1"
 elif [ $myway -eq 2 ]; then
      numnode=$local_rank
 elif [ $myway -le 4 ]; then
      numnode=$(( local_rank / 2 ))
 elif [ $myway -le 6 ]; then
      numnode=$(( local_rank / 3 ))
 elif [ $myway -le 8 ]; then
      numnode=$(( local_rank / 4 ))
 elif [ $myway -le 10 ]; then
      numnode=$(( local_rank / 5 ))
 elif [ $myway -le 12 ]; then
      numnode=$(( local_rank / 6 ))
fi

exec numactl --cpunodebind=$numnode --membind=$numnode $*
```

Summary

- NUMA control ensures hybrid jobs to run with optimal core affinity and memory policy.
- Users have global, socket, core-level control for process and threads arrangement.
- Possible to get great return with small investment by avoiding non-optimal core/ memory policy.