NUMA Control for Hybrid Applications

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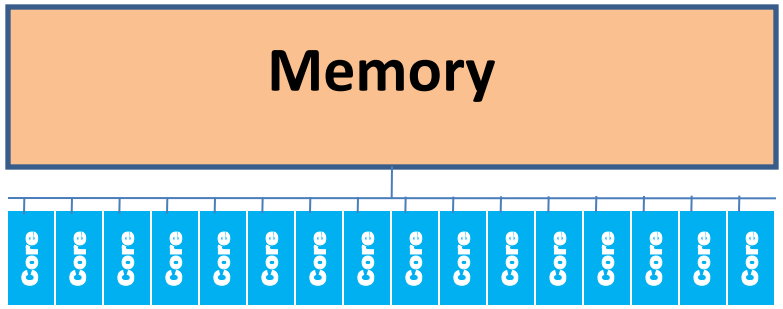
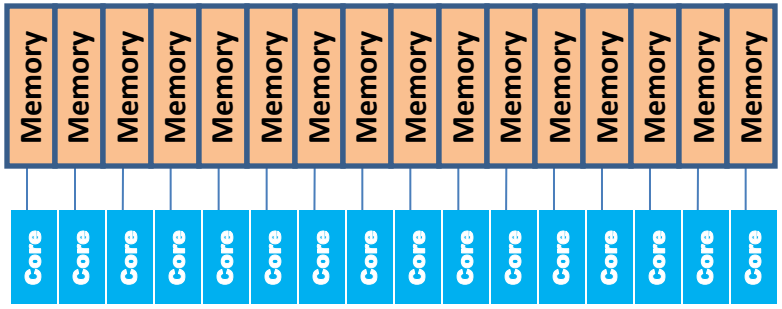
Parallel Paradigms

OpenMP



Run a bunch of threads in shared memory(spawned by a single a.out).

MPI



Run a bunch of a.out's as distributed memory paradigm

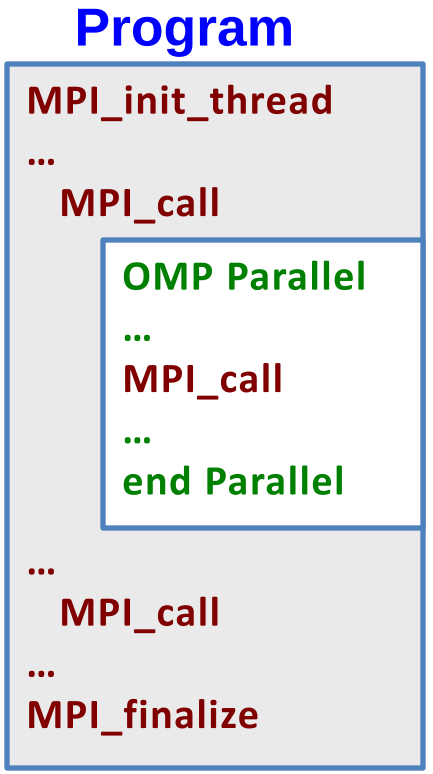
- **Distributed and Shared Memory Parallel Paradigms in HPC**

  MPI: addresses data movement in distributed memory (between processes-- executables)

  OpenMP: addresses data access in shared memory (among threads in an executable)

Hybrid Program Model

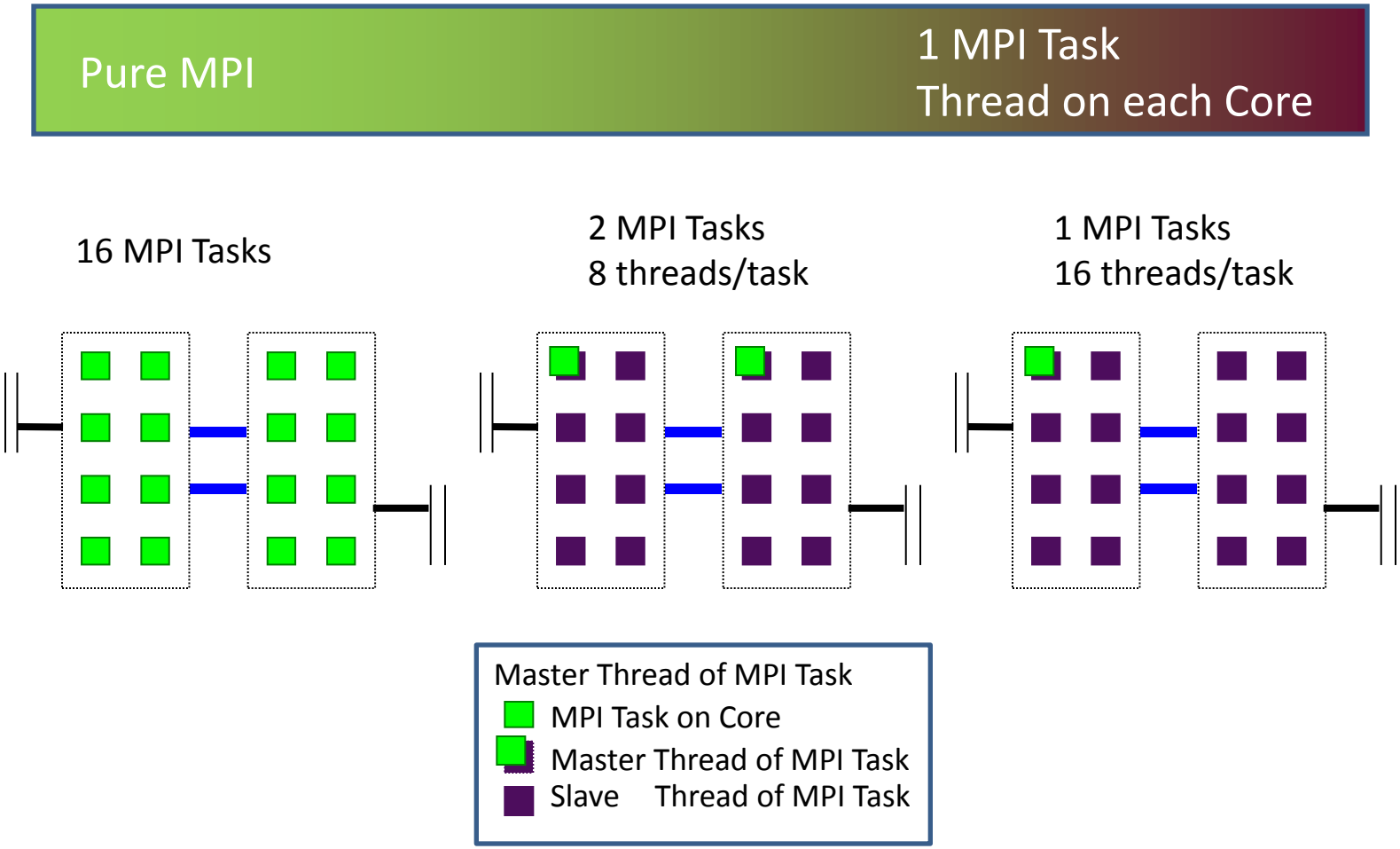
- Start with special MPI initialization
- Create OMP parallel regions within MPI task (process).
  - Serial regions are the master thread or MPI task.
  - MPI rank is known to all threads
- Call MPI library in serial or parallel regions.
- Finalize MPI



Hybrid Applications

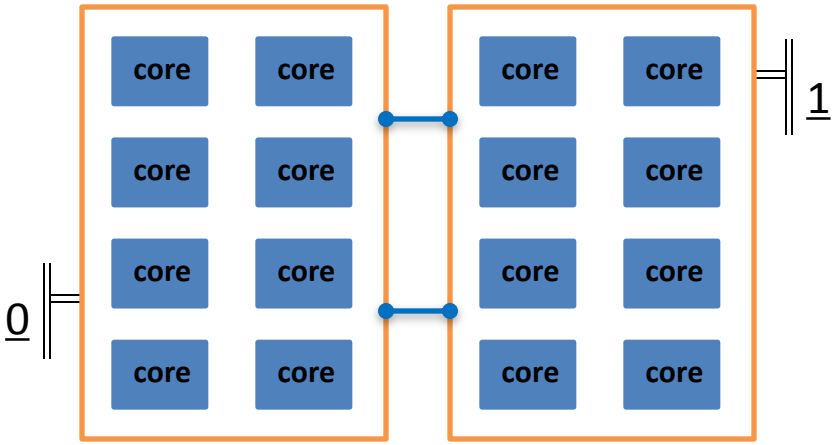
- Typical definition of hybrid application
  - Uses both message passing (MPI) and a form of shared memory algorithm (OpenMP), e.g., uses MPI task as a container for OpenMP threads
  - Runs on multicore systems
- Hybrid execution does not guarantee optimal performance
  - Multicore systems have multilayered, 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

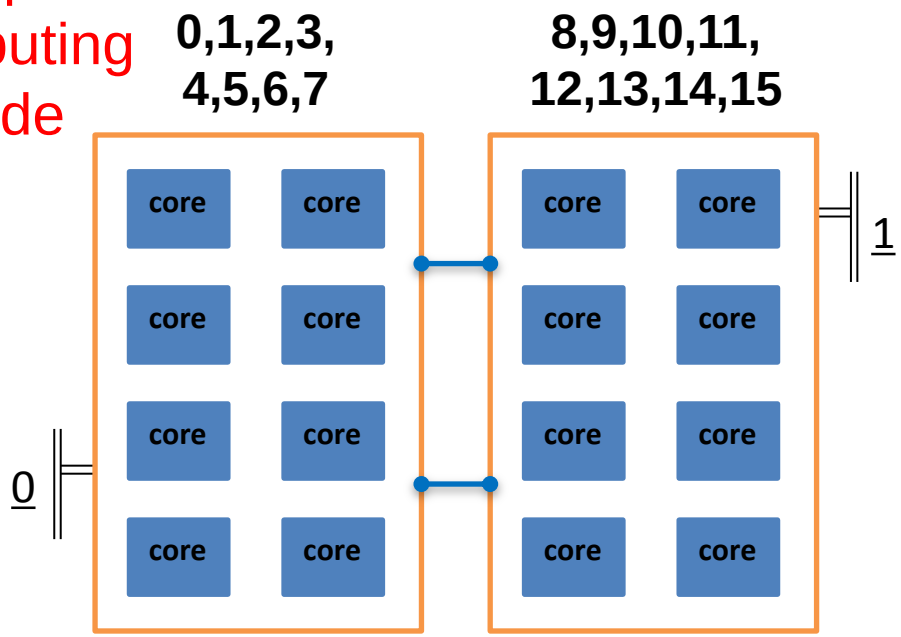
- Ways Process Affinity and Memory Policy can be managed:
  - Dynamically on a running process (knowing process id)
  - At process execution (with wrapper command)
  - Within program through F90/C API
- Users can alter Kernel Policies by manually setting Process Affinity and Memory Policy
  - Users can 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

Stampede computing node



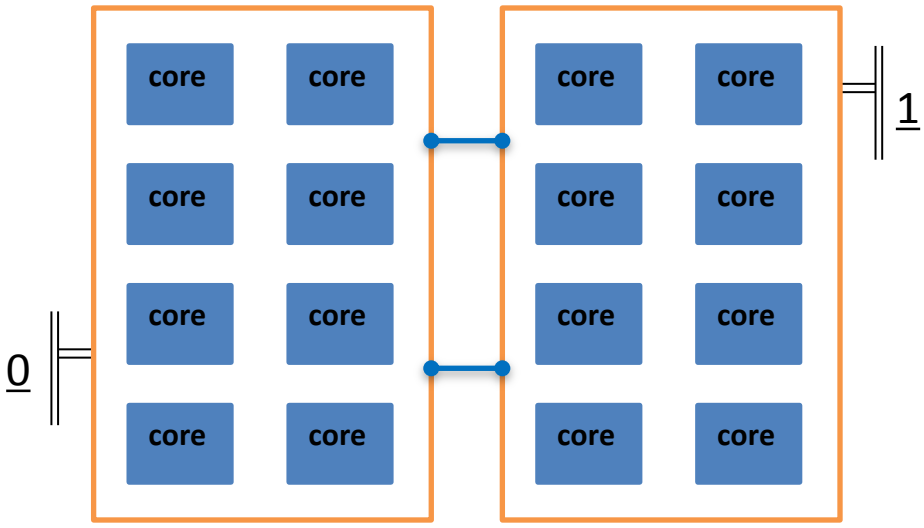
Process affinity: socket references and core references

Memory policy: socket references

numactl Options on Stampede

	cmd	option	arguments	description
Socket Affinity	numactl	**-N --cpunodebind=**	{0,1}	Only execute process on cores of this (these) socket(s).
Memory Policy	numactl	**-l --localalloc**	{no argument}	Allocate on current socket.
Memory Policy	numactl	**-i --interleave=**	{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 --membind=**	{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, 12,13,14,15}	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 16 threads

- Make sure 1 MPI task is created on each node
- Set number of OMP threads for each MPI task
- Can control only memory allocation

Number of MPI task on each node: **n/N**

job script (**Bourne shell**)

```
...

#SBATCH –N 6
#SBATCH –n 6

...

export OMP_NUM_THREADS=16

# Unset any MPI Affinities
export MV2_USE_AFFINITY=0
export MV2_ENABLE_AFFINITY=0
export VIADEV_USE_AFFINITY=0
export VIADEV_ENABLE_AFFINITY=0

ibrun numactl –i all ./a.out
```

Hybrid Batch Script 2 tasks, 8 threads/task

job script (Bourne shell)

```
...
#SBATCH –N 6
#SBATCH –n 12

...
export OMP_NUM_THREADS=8
ibrun numa.sh ./a.out
```

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

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)**

```
...
#SBATCH –N 6
#SBATCH –n 24
...
export OMP_NUM_THREADS=4
ibrun tacc_affinity ./a.out
```

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.

tacc_affinity

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

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} ))

# If running under "ibrun", TACC_pe_ppn will already be set
# else get info from SLURM_TASKS_PER_NODE
if [ -z "$TACC_pe_ppn" ]
then
        myway=`echo $SLURM_TASKS_PER_NODE | awk -F '(' '{print $1}'`
else
        myway=$TACC_pe_ppn
fi
```

tacc_affinity (cont'd)

```
local_rank=$(( $my_rank % $myway ))
EvenRanks=$(( $myway % 2 ))

if [ "$SYSHOST" = stampede ]; then

  # if 1 task/node, allow memory on both sockets
  if [ $myway -eq 1 ]; then
      numnode="0,1"
  # if 2 tasks/node, set 1st task on 0, 2nd on 1
  elif [ $myway -eq 2 ]; then
      numnode="$local_rank"
  # if even number of tasks per node, place memory on alternate chips
  elif [ $EvenRanks -eq 0 ]; then
      numnode=$(( $local_rank % 2 ))
  # if odd number of tasks per node, do nothing -- i.e., allow memory on both
    sockets
  else
      numnode="0,1"
  fi

Fi

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