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EXCELENCIA SEVERO OCHOA

DLB: Dynamic Load Balancing Library

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January 2018

Tutorial

What is Load Imbalance

- Irregular distribution of load among resources.
  - Resources can be: computational, network, processing units…
- Our target: MPI load Imbalance
  - MPI is the standard de facto in HPC applications
  - MPI processes do not share data
    - Moving data around is expensive

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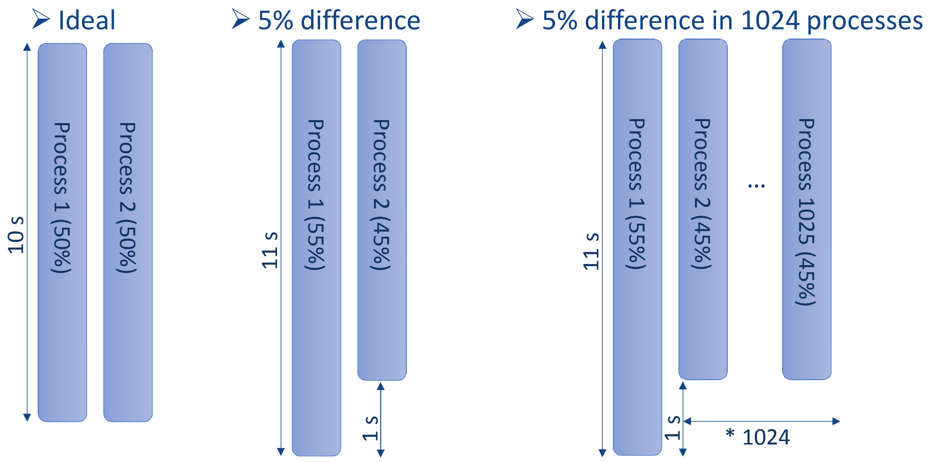
Load Imbalance: Magnitude of the tragedy



1s * 1024 CPUS = 1024 s = 17 minutes of CPU
17m * 10.000 time steps = **2.844 CPU hours**

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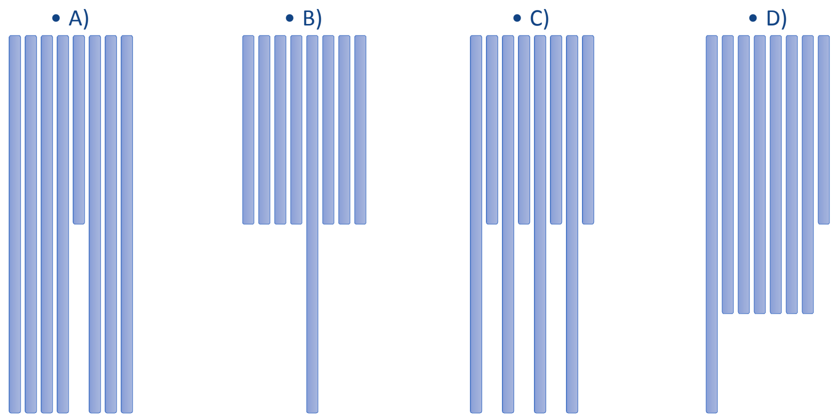
Load Imbalance: Measuring it

➢ Which application is more imbalanced? 🤔



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Load Imbalance: Measuring it

➢ Our focus is to make the most efficient use of computational resources

$$Load\ Balance = \frac{Useful\ CPU\ time}{Total\ used\ CPU\ time} =$$

$$= \frac{\sum_{n=1}^{numProcs}(t_n)}{Max_{n=1}^{numProcs}(t_n) * numProcs} = \frac{Average_{n=1}^{numProcs}(t_n)}{Max_{n=1}^{numProcs}(t_n)}$$

- $numProcs$ = number of MPI processes
- t_n = execution time of process n
- $0 < LB < 1$
- $LB = 1$ → Perfect Load Balance)

$$LB = \frac{Useful = 3 + 1{,}5 = \mathbf{4,5}}{UsedCPU = 3 * 2 = \mathbf{6}} = 0{,}75$$

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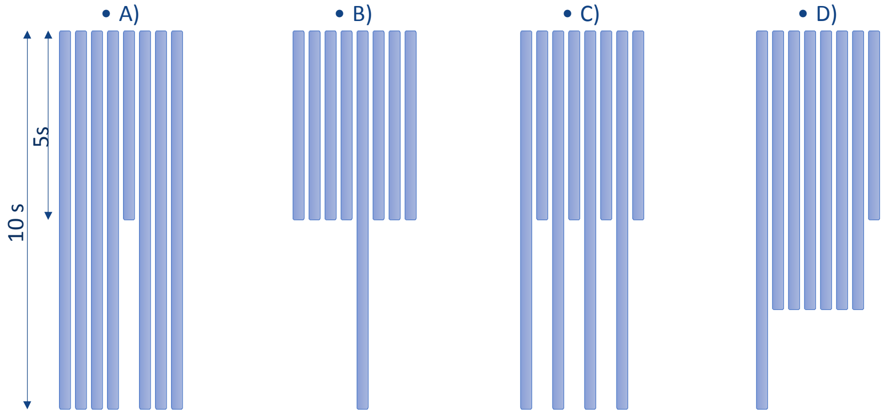
Load Imbalance: Measuring it

$$LB = \frac{useful\ CPU}{used\ CPU}$$

➢ Which application is more imbalanced?

- A)
- B)
- C)
- D)



$$\frac{(7 * 10) + 5}{10 * 8} = 0{,}9375$$

$$\frac{(7 * 5) + 10}{10 * 8} = 0{,}5625$$

$$\frac{(4 * 10) + (4 * 5)}{10 * 8} = 0{,}75$$

$$\frac{10 + 5 + (6 * 7{,}5)}{10 * 8} = 0{,}75$$

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Load Imbalance: Solution from developers?

- Expensive in terms of:
  - Computational resources
  - Personal resources
- What happens if we change the input?
- And the hardware?
- Is it a real solution?

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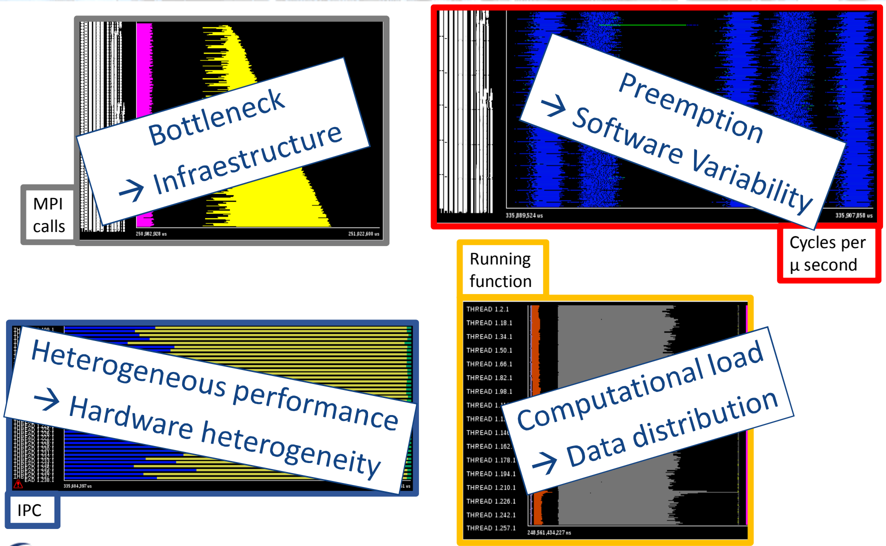
Load Imbalance: Where?



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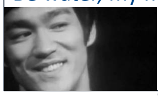
Load Imbalance: Still searching for a solution…

- Different sources… different solutions
  - Data distribution
    - Redistribute → New Input, redistribute again?
  - Hardware heterogeneity
    - Tune specifically for architecture → New machine, tune again?
  - Infrastructure
    - Adapt code to infrastructure → New software or hardware, adapt again?
  - Software/Hardware variability
    - ???

- Our Solution: React when imbalance is happening
  - We can not fight it, lets adapt!
  - One solution to ~~rule~~ solve them all

Be water, my friend !!!



Bruce Lee

The DLB Library

Dynamic Load Balancing - DLB

- Our objectives:
  - Address all sources of imbalance
    - Fine Grain, dynamic…
    - How?
      - Detect imbalance at runtime
      - React immediately
  - Real product for HPC
    - Use common programming model/environment
      - MPI + OpenMP
  - Transparent to the application
    - Runtime library

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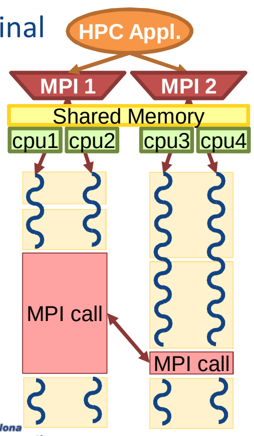
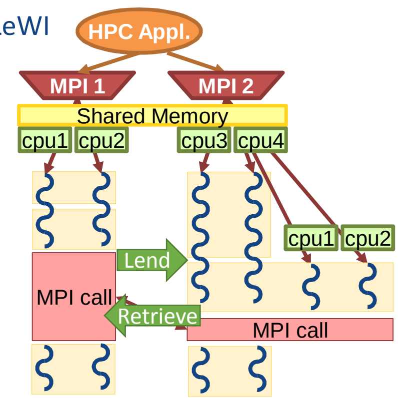
The idea: Lend When Idle (LeWI)

- Load balance MPI processes within a computational node
  - Use computational resources of a process when not using them to speed up another process in the same node

- Original



- LeWI



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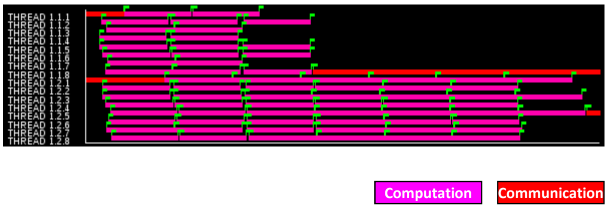
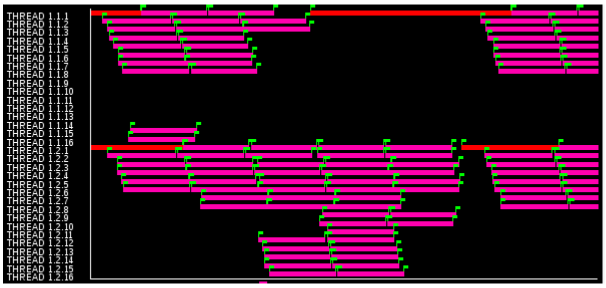
LeWI: A ~~image~~ trace is worth a thousand words

- Original:
  - 2x8





- With LeWI:
  - 2x8

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DLB: Main concepts

- **CPU (core)**: Minimum computing unit acknowledged by DLB, where one thread (and only one at the same time) can run.
- **Idle CPU**: A CPU that is not being used to do useful computation.
- **Owner**: Process that owns a CPU. A process owns the resources where it is started. A CPU can only be owned by one process at the same time.
- **Lend**: When the owner of a CPU is not using it, the CPU can be lent to the system. When a CPU is lent, a process that it is not its owner can use it.
- **Claim**: When the owner of a CPU wants to use it after lending it, the owner can claim the CPU.
- **Ask for Resources**: A process of the system can ask DLB for idle CPUs to speed up its execution.

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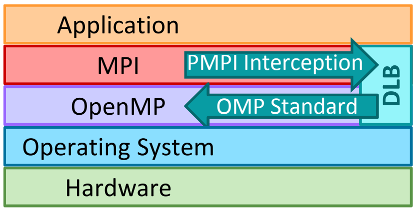
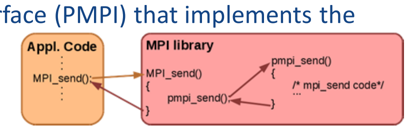
DLB: How?

- Runtime library: DLB
  - Transversal to different layers of the software stack
  - Using standard mechanisms whenever possible
    - Facilitate the adoption without modifying existing codes
  - MPI:
    - Intercept MPI calls using PMPI standard interface
  - OpenMP:
    - Use standard OpenMP API
    - omp_set_num_threads(x)

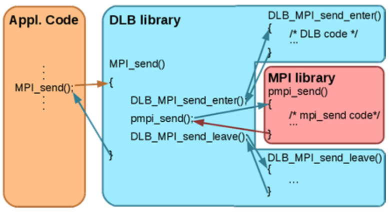


PMPI Interception

- PMPI: Profiling interface for MPI
  - MPI libraries implement an internal interface (PMPI) that implements the MPI call code

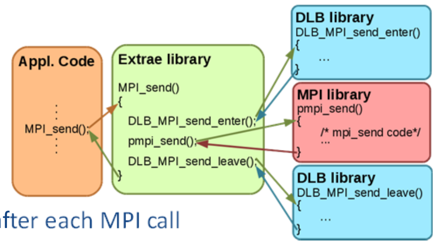


  - MPI calls can be redefined in a dynamic library
  - The intercepting library is loaded when starting the application
    - `export LD_PRELOAD = libdlb_mpi.so`
    - The dynamically loaded library has preference
  - Within the intercepted call the corresponding PMPI function must be called



PMPI Interception

- Using DLB and Extrae
  - Both use PMPI interface



- Integration:
  - Extrae intercepts MPI calls with PMPI
  - DLB API called from Extrae before and after each MPI call
  - DLB does not intercept MPI calls
    - `export LD_PRELOAD = libdlb_mpi_instr.so`

- And other profiling tools using PMPI?
  - We are studding using PnMPI
    - Allows n tools intercepting MPI
    - An order between them must be selected
    - All the tools must support PnMPI
    - So far no conflicts have been found… Future Work

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MPI blocking mode

- MPI is greedy in the use of CPU
  - By default it will busy wait for messages/synchronizations to arrive
  - If the CPU is used by the MPI process waiting for the message we can not use it for doing useful computation by another thread.

- Different behavior for different MPI libraries 😱

- We have two options:
  - Leave all the CPUs assigned to a process but one
    - `export DLB_ARGS += "--lewi-mpi=no"`
  - Tell MPI not to busy wait
    - `export I_MPI_WAIT_MODE=1`
    - `export DLB_ARGS += "--lewi-mpi"`

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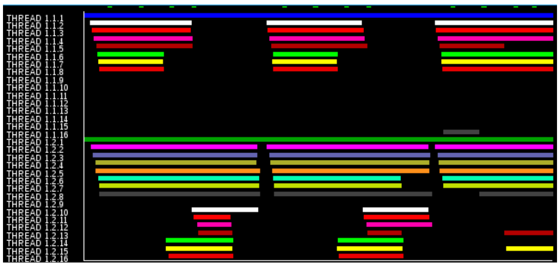
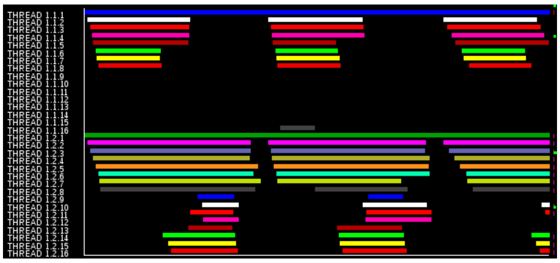
MPI blocking mode

- --lewi-mpi =no



- --lewi-mpi



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OpenMP: Malleability

- OpenMP is malleable, we can change number of threads
  - `omp_set_num_threads(int x)`
  - But only outside a parallel region

- But some programming practices can avoid malleability:
  - Program in function of the thread Id
    - `omp_get_thread_num(int x)`
    - Fear if you see this call!
  - Do reductions "by hand"
    - Allocate memory in function of the number of threads and each one will reduce in its piece of data.
  - Avoid these practices please!

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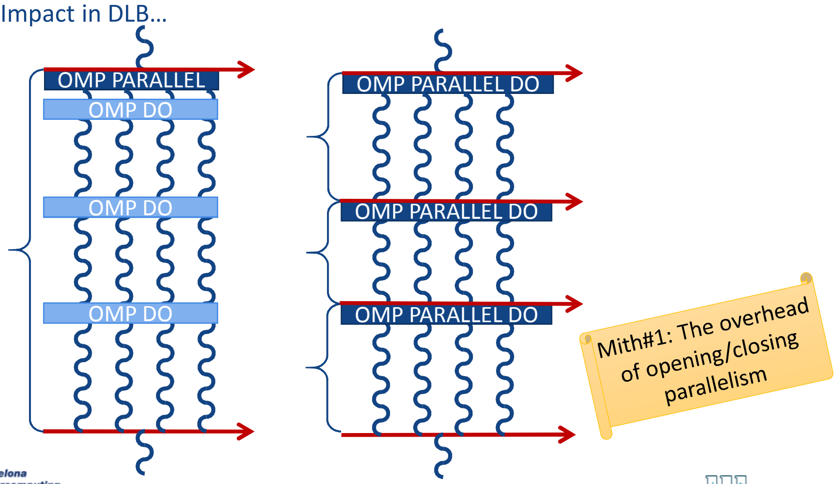
OpenMP: Malleability

- Use omp_set_num_threads(x)
  - It can only be called outside a parallel region (says the OpenMP standard)
  - Impact in DLB…



OpenMP in DLB

- Add a call to `int DLB_Borrow(void)` before each `parallel`
- `int DLB_Borrow(void)` will check the system for idle CPUs and update the number of threads in case necessary

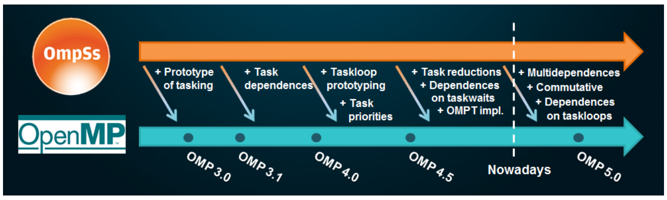
```
DLB_Borrow();
#pragma omp parallel do
for (i=0; i<n; i++){
    compute…
    …
}
```

```
int DLB_Borrow(void){
    check_idle_cpus(x);
    set_omp_num_threads(x);
}
```

- This can be done by an automatic replacement in the code
- Latest news!
  - Working in using OMPT (tracing tool for OpenMP to appear in 5.0)
- Meanwhile…

Integration with Nanos++

- Nanos++: Parallel Runtime developed at BSC
  - Implements OpenMP 4.5 and OmpSs
  - Forerunner for OpenMP
- Mercurium: Source to source compiler developed at BSC
  - Generates code for Nanos++



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Integration with Nanos++

- There is no need to modify the application at all
  - The runtime will call the DLB API where necessary to ask for resources or return them
- Compile with Mercurium
- Run enabling DLB
  - Mandatory: NX_ARGS+= `“--enable-dlb --enable-block”`
  - Recommended: NX_ARGS+= `“--force-tie-master”`
  - In some cases: NX_ARGS+= `“--warmup-threads”`
- Win! 💪

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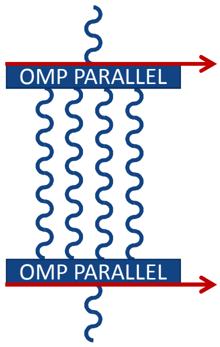
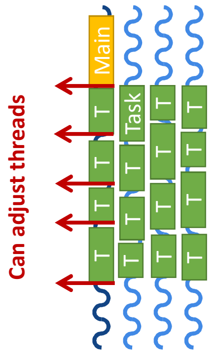
More malleability with OmpSs

- OpenMP (Fork-join model)

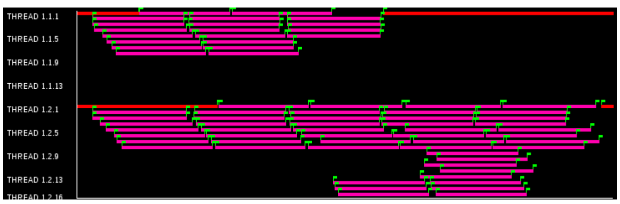


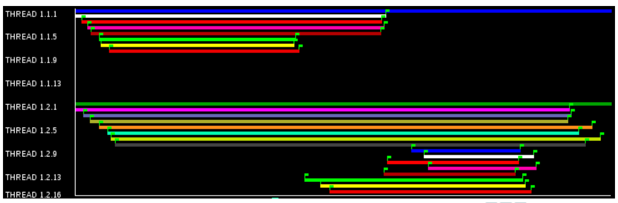
- OmpSs(Task based)



Integration with Nanos++

- Taking advantage of the integration and increased OmpSs malleability
  - Threads are autonomous
    - Fast response
    - The master thread is not a bottleneck
    - Benefit from imbalances at OmpSs level too





Summing up to use DLB…

- `export LD_PRELOAD = libdlb_mpi.so`
- `export DLB_ARGS = "--lewi"`

- If we want to use the CPU executing the MPI calls
  - `export I_MPI_WAIT_MODE=1`
  - `export DLB_ARGS += "–lewi-mpi"`

- If we use Nanos++
  - `NX_ARGS+= "--enable-dlb --enable-block"`
  - `NX_ARGS+= "--force-tie-master --warmup-threads"`
- else
  - Add `DLB_Borrow()` before each `#pragma omp parallel`

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Multiple Applications

- We can share CPUs between different applications running in the same node

- Do not need MPI

- Transparent to the user, works out of the box

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DROM
Dynamic Resource Ownership Management

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DROM: Dynamic Resource Ownership Management

- API for superior entity
  - Job Scheduler
  - Resource manager
  - User
- Allow to change the assigned resources (CPUs) to a process
- Some possible use cases:
  - A) User wants to give more priority to one of the processes in the node
  - B) Job scheduler wants to start a high priority app. using the resources allocated for an other application
  - C) Application is not using the resources in a node efficiently (i.e the bottleneck is on another node) can free them to avoid accounting.

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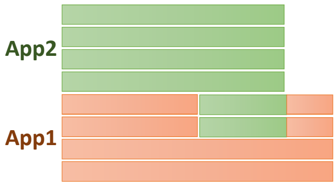
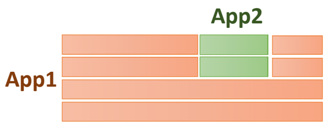
DROM: Use cases

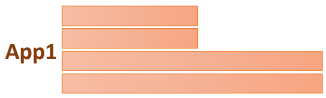
- A) User:
  Increase priority to App2



- B) Job Scheduler:
  Run High priority App2 in resources assigned to App1



- C) App1: Release 2 CPUs because not using efficiently



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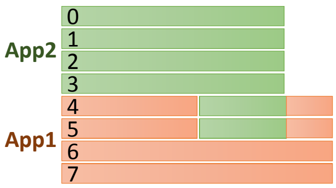
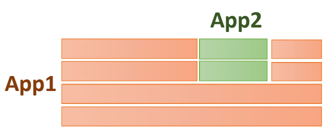
DROM: How to



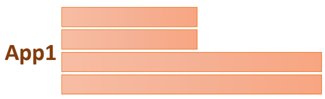
- A)

```
$> dlb_taskset -p pid_app2 –c 0-5
```



- B)

```
$> dlb_taskset -c 0,1 ./App2
```



- C)

```
DLB_DROM_SetProcessMask(my_pid, [0,0,1,1]);
```

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About DLB

- Current stable version 2.0 (January 2018)
  - LeWI
    - Full support of MPI.
    - Full support with Nanos5 runtime.
    - Support for OpenMP through API.
  - DROM
    - With OMPT support
  - Mode of communication with runtimes:
    - Asynchronous
    - Polling
    - Callback system: Ease of integration
  - New DLB API
    - Refactored
    - More exhaustive
    - More clear
- Free Download under LGPL-v3 license:

https://pm.bsc.es/dlb-downloads

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Work in Progress

- DROM
  - Implemented, evaluate performance
- OMPT
  - Enable use for any OpenMP runtime supporting OMPT (OpenMP 5.0)
  - Not "legal" according to the standard
- Study performance in many-core
  - i.e. Intel Xeon Phi KNL 256 threads
- Runtime Monitoring Tool
  - Monitor different levels and collect metrics
  - Offer an API to consult metrics during execution
- Load Balancing across containers
  - Studding feasibility, performance, issues and opportunities
  - Docker, Singularity…

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Challenges

- Transversal to different layers, make the cooperate!!
  - MPI libraries are not willing to expose the non busy wait mode
    - They want all CPU cycles for them, but they are wasting them…
  - OS could help handling the cores? Giving priorities?
- Change mentality from "heroism programming" to trusting the runtime
  - Applications should stop doing things "by hand"
  - Let's help them:
    - By addressing their needs and offering non intrusive solutions
    - By offering transversal solutions
- Malleability, malleability everywhere!!!
  - Application, Programming model, job scheduler…

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FAQ

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FAQ

- ➢ Why not “learn” and use previous redistribution?
- ➢ What about data locality?
- ➢ My application does not perform well with OpenMP
- ➢ What about load balance between nodes?
- ➢ Why not overload CPUS, it’s the same you do!
- ➢ How do you decide to which process CPUS go?
- ➢ I already have a load balancing algorithm within my application
- ➢ How do I know the different options in DLB?

Why not “learn” and use previous redistribution?

- ➢ There is a policy in DLB that does a “static” distribution of CPUs based in the load of each process
  - `--policy=WEIGHT`
    - Detects iterations, based in the MPI calls pattern
    - Computes an optimum distribution of CPUs
    - Applies it
  - Performance was much worse than LeWI → LeWI is more flexible
  - Code is deprecated

- ➢ Another policy that merge the functionality of WEIGHT and LeWI was implemented (Redistribute and Lend)
  - `--policy=RaL`
  - Performance was equal to the one obtained by LeWI

- ➢ We can recover these if we find the need

How do you decide to which process CPUS go?

- We do not decide it, it is first come, first served
- So far, our experience is: If there is a free CPU and some one willing to use it, do it.
- But… we might implement some accounting in the future if more actors come in… different apps, different users, different programming models…
- We DO decide which CPU to take first…

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What about data locality?

- In some kernels spawning threads to another socket can have a penalty
- We can choose with flag **`--lewi-affinity`** in DLB_ARGS environment variable which CPU a process will acquire **first** when asking for resources,,,
  - `any` : Take the first free CPU, does not take into account topology
  - `nearby-first` : Take first CPUs that are "affine" to me, and then the others
  - `spread-ifempty` : Take first CPUs that are affine to me, take CPUs from another socket only if all the CPUs in that socket are free (meaning no body is running there)
  - `nearby-only` : Take only CPUs that are affine to me

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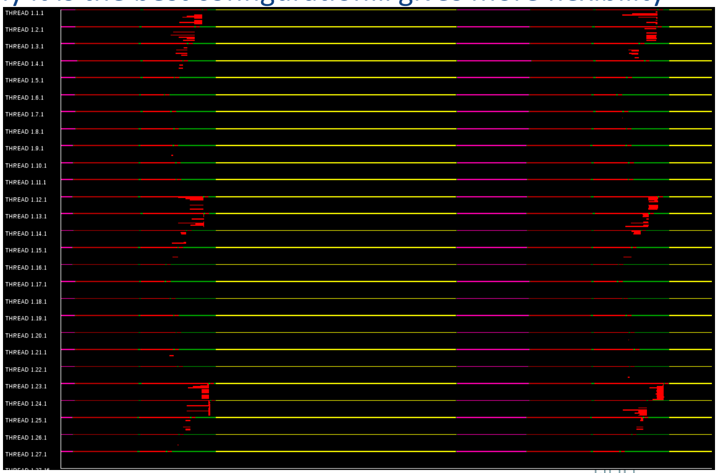
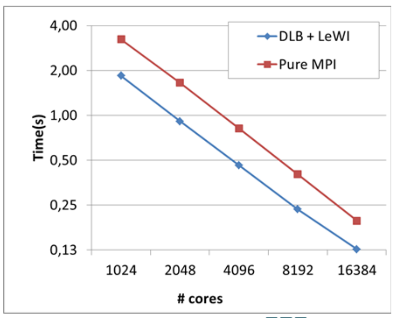
My application does not perform well/it is not parallelized with OpenMP

- Don't worry!
- In fact usually it is the best configuration… gives more flexibility to DLB



What about load balance between nodes?

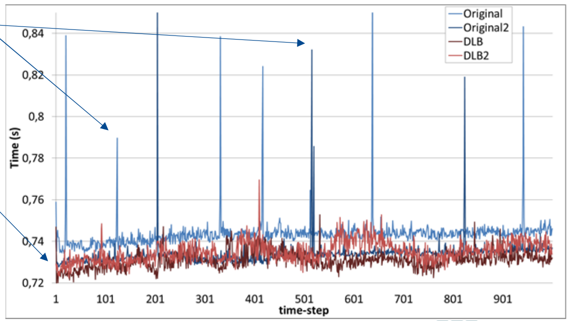
- We do not have any solution for this yet
- It is a quite different problem
  - Big difference in granularity, moving data between nodes is expensive
- But… good news is…
  - We are achieving very good results by balancing inside the node even when running up to 1024 nodes



I already have a load balancing algorithm within my application

- Does it solve this?
- Fine grain + system noise
- Blue lines original application (2 different runs)
- Red lines same run with DLB (2 different runs)

Clearly visible spikes without DLB are absorbed by DLB



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How do I know the different options in DLB?

- `[DLB_HOME]/bin/dlb –help`

```
The library configuration can be set using arguments
added to the DLB_ARGS environment variable.
Possible options are listed below:
--lewi:                 no              (bool)
--drom:                 no              (bool)
--mode:                 polling         [polling, async]
--verbose:          {api:microlb:shmem:mpi_api:mpi_intercept:stats:drom:async:ompt}
--verbose-format:       node:pid:thread {node:pid:mpinode:mpirank:thread}
--instrument:           yes             (bool)
--instrument-counters:  no              (bool)
--lewi-mpi:             no              (bool)
--lewi-mpi-calls:       all             [all, barrier, collectives]
--lewi-affinity:        nearby-first    [any, nearby-first, nearby-only, spread-
ifempty]
--lewi-greedy:          no              (bool)
--lewi-warmup:          no              (bool)
```

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EXCELENCIA SEVERO OCHOA

Thank you

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