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Programming with OmpSs-2

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Quick Overview

OmpSs-2 is a programming model composed of a set of directives and library routines that can be used in conjunction with a high-level programming language (such as C, C++ or Fortran) in order to develop concurrent applications. Its name originally comes from two other programming models: **OpenMP** and **StarSs**. The design principles of these two programming models constitute the fundamental ideas used to conceive the OmpSs philosophy.

OmpSs-2 **thread-pool** execution model differs from the **fork-join** parallelism implemented in OpenMP.

A **task** is the minimum execution entity that can be managed independently by the runtime scheduler. **Task dependences** let the user annotate the data flow of the program and are used to determine, at runtime, if the parallel execution of two tasks may cause data races.

The reference implementation of OmpSs-2 is based on the **Mercurium** source-to-source compiler and the **Nanos6** runtime library:

- Mercurium source-to-source compiler provides the necessary support for transforming the high-level directives into a parallelized version of the application.
- Nanos6 runtime library provides services to manage all the parallelism in the user-application, including task creation, synchronization and data movement, as well as support for resource heterogeneity.

Additional information about the OmpSs-2 programming model can be found at:

- OmpSs-2 official website. [?https://pm.bsc.es/ompss-2](https://pm.bsc.es/ompss-2)
- OmpSs-2 specification. [?https://pm.bsc.es/ftp/ompss-2/doc/spec](https://pm.bsc.es/ftp/ompss-2/doc/spec)
- OmpSs-2 user guide. [?https://pm.bsc.es/ftp/ompss-2/doc/user-guide](https://pm.bsc.es/ftp/ompss-2/doc/user-guide)
- OmpSs-2 examples repository. [?https://pm.bsc.es/gitlab/ompss-2/examples](https://pm.bsc.es/gitlab/ompss-2/examples)
- OmpSs-2 manual with examples and exercises. [?https://pm.bsc.es/ftp/ompss-2/doc/examples/index.html](https://pm.bsc.es/ftp/ompss-2/doc/examples/index.html)
- Mercurium official website. [?Link 1](#), [?Link 2](#)
- Nanos official website. [?Link 1](#), [?Link 2](#)

Quick Setup on DEEP System for a Shared-Memory Parallel Application

We highly recommend to interactively log in a **cluster module (CM) node** to begin using OmpSs-2. To request an entire CM node for an interactive session, please execute the following command to use all the 48 available threads:

```
srun -p dp-cn -N 1 -n 1 -c 48 --pty /bin/bash -i
```

Note that the command above is consistent with the actual hardware configuration of the cluster module with **hyper-threading enabled**.

OmpSs-2 has already been installed on DEEP and can be used by simply executing the following commands:

```
module load Intel/2019.5.281-GCC-8.3.0 ParaStationMPI/5.4.6-1-mt
```

```
module load OmpSs-2
```

Remember that OmpSs-2 uses a **thread-pool** execution model which means that it **permanently uses all the threads** present on the system. Users are strongly encouraged to always check the **system affinity** by running the **NUMA command** `srun numactl --show`:

```
$ srun numactl --show
policy: default
preferred node: current
physcpubind: 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39
cpubind: 0 1
nodebind: 0 1
membind: 0 1
```

as well as the **Nanos6 command** `srun nanos6-info --runtime-details | grep List`:

```
$ srun nanos6-info --runtime-details | grep List
Initial CPU List 0-47
NUMA Node 0 CPU List 0-35
NUMA Node 1 CPU List 12-47
```

System affinity can be used to specify, for example, the ratio of MPI and OmpSs-2 processes for a hybrid application and can be modified by user request in different ways:

- Via the command `srun` or `salloc`. However, if the affinity given by SLURM does not correspond to the resources requested, it should be reported to the system administrators.
- Via the command `numactl`.
- Via the command `taskset`.

Using the Repositories

All the examples shown here are publicly available at [?https://pm.bsc.es/gitlab/omps-2/examples](https://pm.bsc.es/gitlab/omps-2/examples). Users must clone/download each example's repository and then transfer it to a DEEP working directory.

System Configuration

Please refer to section [Quick Setup on DEEP System](#) to get a functional version of OmpSs-2 on DEEP. It is also recommended to run OmpSs-2 via an interactive session on a cluster module (CM) node.

Building and Running the Examples

All the examples come with a Makefile already configured to build (e.g. `make`) and run (e.g. `make run`) them. You can clean the directory with the command `make clean`.

Controlling the Available Threads

In order to limit or constraint the available threads for an application, the Unix **taskset** tool can be used to launch applications with a given thread affinity. In order to use `taskset`, simply precede the application's binary with `taskset` followed by a list of CPU IDs specifying the desired affinity:

```
taskset -c 0,2-4 ./application
```

The example above will run **application** with 4 cores: 0, 2, 3, 4.

Creating Dependency Graphs

Nanos6 allows for a graphical representation of data dependencies to be extracted. In order to generate said graph, run the application with the **NANOS6** environment variable set to **graph**:

```
NANOS6=graph ./application
```

By default graph nodes will include the full path of the source code. To remove it, set the following environment variable:

```
NANOS6_GRAPH_SHORTEN_FILENAMES=1
```

The result will be a PDF file with several pages, each representing the graph at a certain point in time. For best results, we suggest to display the PDF with **single page** view, showing a full page and to advance page by page.

Obtaining Statistics

Another equally interesting feature of Nanos6 is obtaining statistics. To do so, simply run the application as:

```
NANOS6=stats ./application OR also NANOS6=stats-papi ./application
```

The first collects timing statistics while the second also records hardware counters (compilation with PAPI is needed for the second). By default, the statistics are emitted standard error when the program ends.

Tracing with Extrae

A **trace.sh** file can be used to include all the environment variables needed to get an instrumentation trace of the execution. The content of this file is as follows:

```
#!/bin/bash
export EXTRAE_CONFIG_FILE=extrae.xml
export NANOS6="extrae"
$*
```

Additionally, you will need to change your running script in order to invoke the program through this trace.sh script so that it looks like:

```
./trace.sh ./application
```

Although you can also edit your running script adding all the environment variables related with the instrumentation, it is preferable to use this extra script to easily change between instrumented and non-instrumented executions. When in need to instrument your execution, simply include trace.sh before the program invocation. Note that the **extrae.xml** file, which is used to configure the Extrae library to get a Paraver trace, is also needed.

A Step-By-Step Detailed Guide to Execute the Multisaxpy Benchmark

Users must clone/download this example's repository from [?https://pm.bsc.es/gitlab/ompss-2/examples/multisaxpy](https://pm.bsc.es/gitlab/ompss-2/examples/multisaxpy) and transfer it to a DEEP working directory.

Description

This benchmark runs several SAXPY operations. SAXPY is a combination of scalar multiplication and vector addition (a common operation in computations with vector processors) and constitutes a level 1 operation in the Basic Linear Algebra Subprograms (BLAS) package.

There are **7 implementations** of this benchmark.

Execution Instructions

```
./multisaxpy SIZE BLOCK_SIZE ITERATIONS
```

where:

- `SIZE` is the number of elements of the vectors used on the SAXPY operation.
- The SAXPY operation will be applied to the vector in blocks that contains `BLOCK_SIZE` elements.
- `ITERATIONS` is the number of times the SAXPY operation is executed.

Downloading, Building and Executing this Benchmark

Clone the repository to your local machine:

```
git clone https://pm.bsc.es/gitlab/ompss-2/examples/multisaxpy
```

and upload it to the `/work/cdeep/USERNAME/` directory (which might not exist yet) of the DEEP cluster:

```
scp -r multisaxpy/ USERNAME@deep.fz-juelich.de:~/work/cdeep/USERNAME/
```

Now connect to the DEEP login node:

```
ssh -X USERNAME@deep.fz-juelich.de
```

and from there open the `multisaxpy` folder:

```
cd /work/cdeep/USERNAME/multisaxpy
```

and request an interactive cluster module (CM) node in order to use all the available 48 threads to run a pure OmpSs-2 application:

```
srun -p dp-cn -N 1 -n 1 -c 48 --pty /bin/bash -i
```

Load the OmpSs-2 module via the following commands:

```
module load Intel/2019.5.281-GCC-8.3.0 ParaStationMPI/5.4.6-1-mt
```

```
module load OmpSs-2
```

and check the affinity via the command `srun numactly --show` which should report the following:

```
$ srun numactly --show
policy: default
preferred node: current
physcpubind: 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39
cpubind: 0 1
nodebind: 0 1
membind: 0 1
```

Now you should be able to clean, build and execute this benchmark via the command `make`:

```
$ make clean
rm -f 01.multisaxpy_seq 02.multisaxpy_task_loop 03.multisaxpy_task 04.multisaxpy_task+dep 05.multisaxpy_task+weakdep 06.mu

$ make
mcxx --ompss-2 01.multisaxpy_seq.cpp main.cpp -o 01.multisaxpy_seq -lrt
mcxx --ompss-2 02.multisaxpy_task_loop.cpp main.cpp -o 02.multisaxpy_task_loop -lrt
mcxx --ompss-2 03.multisaxpy_task.cpp main.cpp -o 03.multisaxpy_task -lrt
03.multisaxpy_task.cpp:3:13: info: adding task function 'axy_task' for device 'smp'
03.multisaxpy_task.cpp:12:3: info: call to task function '::axy_task'
03.multisaxpy_task.cpp:3:13: info: task function declared here
mcxx --ompss-2 04.multisaxpy_task+dep.cpp main.cpp -o 04.multisaxpy_task+dep -lrt
04.multisaxpy_task+dep.cpp:3:13: info: adding task function 'axy_task' for device 'smp'
04.multisaxpy_task+dep.cpp:12:3: info: call to task function '::axy_task'
04.multisaxpy_task+dep.cpp:3:13: info: task function declared here
mcxx --ompss-2 05.multisaxpy_task+weakdep.cpp main.cpp -o 05.multisaxpy_task+weakdep -lrt
05.multisaxpy_task+weakdep.cpp:3:13: info: adding task function 'axy_task' for device 'smp'
05.multisaxpy_task+weakdep.cpp:12:3: info: call to task function '::axy_task'
05.multisaxpy_task+weakdep.cpp:3:13: info: task function declared here
mcxx --ompss-2 06.multisaxpy_task_loop+weakdep.cpp main.cpp -o 06.multisaxpy_task_loop+weakdep -lrt
mcxx --ompss-2 07.multisaxpy_task+reduction.cpp main.cpp -o 07.multisaxpy_task+reduction -lrt
07.multisaxpy_task+reduction.cpp:14:13: info: reduction of variable 'yy' of type 'double [elements]' solved to 'operator +
<openmp-builtin-reductions>:1:1: info: reduction declared here
07.multisaxpy_task+reduction.cpp:21:13: info: reduction of variable 'y' of type 'double [N]' solved to 'operator +
<openmp-builtin-reductions>:1:1: info: reduction declared here

$ make run
./01.multisaxpy_seq 16777216 8192 100
```

```

size: 16777216, bs: 8192, iterations: 100, time: 3.30132, performance: 0.508197
NANOS6_SCHEDULER=fifo ./02.multisaxpy_task_loop 16777216 8192 100
size: 16777216, bs: 8192, iterations: 100, time: 0.411888, performance: 4.07325
./03.multisaxpy_task 16777216 8192 100
size: 16777216, bs: 8192, iterations: 100, time: 0.648536, performance: 2.58694
./04.multisaxpy_task+dep 16777216 8192 100
size: 16777216, bs: 8192, iterations: 100, time: 1.04207, performance: 1.60998
./05.multisaxpy_task+weakdep 16777216 8192 100
size: 16777216, bs: 8192, iterations: 100, time: 1.09049, performance: 1.5385
NANOS6_SCHEDULER=fifo ./06.multisaxpy_task_loop+weakdep 16777216 8192 100
size: 16777216, bs: 8192, iterations: 100, time: 8.91, performance: 0.188296
./07.multisaxpy_task+reduction 16777216 8192 100
size: 16777216, bs: 8192, iterations: 100, time: 7.03558, performance: 0.238462

```

Override the Number of Threads Used

Let's have a closer look at the third implementation, i.e. *03.multisaxpy_task*, which took 0.648536 seconds to finish using 48 threads. Remember that a full CM node features 48 threads (0-47) divided in two sockets: 0-11,24-35 for the first socket and 12-23,36-47 for the second socket. **Notice that they are indeed not consecutive!**

We can change the threads used by OmpSs-2 with the Linux command `taskset`. For example, the command to run this binary with 24 threads interleaved between the two sockets would be:

```
taskset -c 0-23 ./03.multisaxpy_task 16777216 8192 100
```

Similarly, to run this benchmark using all the 24 threads of the second socket use the following command:

```
taskset -c 12-23,36-47 ./03.multisaxpy_task 16777216 8192 100
```

You can also try to run this example with only 12 threads of the first socket:

```
taskset -c 0-11 ./03.multisaxpy_task 16777216 8192 100
```

or 12 threads interleaved between the two sockets:

```
taskset -c 0-5,12-17 ./03.multisaxpy_task 16777216 8192 100
```

Changing the number of threads assigned to OmpSs-2 affects the performance of the application and not necessarily in a negative way, e.g. see below:

```

$ ./03.multisaxpy_task 16777216 8192 100
size: 16777216, bs: 8192, iterations: 100, time: 0.653537, performance: 2.56714
$ taskset -c 0-23 ./03.multisaxpy_task 16777216 8192 100
size: 16777216, bs: 8192, iterations: 100, time: 0.686265, performance: 2.44471
$ taskset -c 12-23,36-47 ./03.multisaxpy_task 16777216 8192 100
size: 16777216, bs: 8192, iterations: 100, time: 0.650363, performance: 2.57967
$ taskset -c 0-11 ./03.multisaxpy_task 16777216 8192 100
size: 16777216, bs: 8192, iterations: 100, time: 0.55417, performance: 3.02745
$ taskset -c 0-5,12-17 ./03.multisaxpy_task 16777216 8192 100
size: 16777216, bs: 8192, iterations: 100, time: 0.705859, performance: 2.37685

```

Creating a Dependency Graph

Let's continue with the same example used above and create a dependency graph using only 12 threads of one socket (e.g. the second), which demonstrated to be the affinity giving the best results. Furthermore, we are not longer interested in running 100 iterations (nor using a large number of elements) for graph purposes and hence only one iteration will suffice to generate a complete graph of this application. Run the following command:

```
NANOS6=graph taskset -c 12-23 ./03.multisaxpy_task 196608 8192 1
```

Once it has finished it should have created a script with the name `graph-XXXXX-YYYYYYYYY-script.sh` and a directory `graph-XXXXX-YYYYYYYYY-components`. Execute said script by typing the following (note that it requires the tool `dot`):

```
bash graph-XXXXX-YYYYYYYYY-script.sh
```

to merge the intermediate results into a single PDF file which should look like this:

which illustrates 24 tasks executed in parallel using 12 threads.

Obtaining statistics

The visual execution of tasks can be further complemented with statistics. Executing the following command:

```
NANOS6=stats taskset -c 12-23 ./03.multisaxpy_task 196608 8192 1
```

will give you the information below:

```
$ NANOS6=stats taskset -c 12-23 ./03.multisaxpy_task 196608 8192 1
size: 196608, bs: 8192, iterations: 1, time: 0.000241, performance: 0.815801
STATS      Total CPUs          12
STATS      Total time            2.42573e+07      ns
STATS      Total threads         12
STATS      Mean threads per CPU   1
STATS      Mean tasks per thread  2.08333

STATS      Mean thread lifetime   3.65355e+09      %
STATS      Mean thread running time 100      %
STATS      Mean effective parallelism 0.123268

STATS      All Tasks instances    25
STATS      All Tasks mean instantiation time 1445      ns      0.885064      %
STATS      All Tasks mean pending time 0      ns      0      %
STATS      All Tasks mean ready time 32446      ns      19.8732      %
STATS      All Tasks mean execution time 119605      ns      73.2582      %
STATS      All Tasks mean blocked time 3702      ns      2.26748      %
STATS      All Tasks mean zombie time 6067      ns      3.71604      %
STATS      All Tasks mean lifetime 163265      ns

STATS      03.multisaxpy_task.cpp:3:13 instances 24
STATS      03.multisaxpy_task.cpp:3:13 mean instantiation time 1251      ns      1.75051      %
STATS      03.multisaxpy_task.cpp:3:13 mean pending time 0      ns      0      %
STATS      03.multisaxpy_task.cpp:3:13 mean ready time 32944      ns      46.0981      %
STATS      03.multisaxpy_task.cpp:3:13 mean execution time 31079      ns      43.4884      %
STATS      03.multisaxpy_task.cpp:3:13 mean blocked time 0      ns      0      %
STATS      03.multisaxpy_task.cpp:3:13 mean zombie time 6191      ns      8.66298      %
STATS      03.multisaxpy_task.cpp:3:13 mean lifetime 71465      ns

STATS      main instances 1
STATS      main mean instantiation time 6089      ns      0.2573      %
STATS      main mean pending time 0      ns      0      %
STATS      main mean ready time 20505      ns      0.866471      %
STATS      main mean execution time 2244241      ns      94.8339      %
STATS      main mean blocked time 92553      ns      3.91097      %
STATS      main mean zombie time 3108      ns      0.131333      %
STATS      main mean lifetime 2366496      ns

STATS      Phase 1 03.multisaxpy_task.cpp:3:13 instances 24
STATS      Phase 1 03.multisaxpy_task.cpp:3:13 mean instantiation time 1251      ns      1.75051      %
STATS      Phase 1 03.multisaxpy_task.cpp:3:13 mean pending time 0      ns      0      %
STATS      Phase 1 03.multisaxpy_task.cpp:3:13 mean ready time 32944      ns      46.0981      %
STATS      Phase 1 03.multisaxpy_task.cpp:3:13 mean execution time 31079      ns      43.4884      %
STATS      Phase 1 03.multisaxpy_task.cpp:3:13 mean blocked time 0      ns      0      %
STATS      Phase 1 03.multisaxpy_task.cpp:3:13 mean zombie time 6191      ns      8.66298      %
STATS      Phase 1 03.multisaxpy_task.cpp:3:13 mean lifetime 71465      ns

STATS      Phase 1 instances 24
```



```

STATS      Phase 1 mean instantiation time      1251      ns      1.75051      %
STATS      Phase 1 mean pending time           0          ns      0            %
STATS      Phase 1 mean ready time            32944      ns      46.0981      %
STATS      Phase 1 mean execution time        31079      ns      43.4884      %
STATS      Phase 1 mean blocked time          0          ns      0            %
STATS      Phase 1 mean zombie time           6191      ns      8.66298      %
STATS      Phase 1 mean lifetime              71465      ns
STATS      Phase 1 effective parallelism      0.165278

```

Additionally, you can get information related to hardware counters via PAPI. For this, firstly load the PAPI module:

```
module load PAPI/5.7.0
```

and then execute:

```
NANOS6=stats-papi taskset -c 12-23 ./03.multisaxpy_task 196608 8192 1
```

to get statistics:

```

$ NANOS6=stats-papi taskset -c 12-23 ./03.multisaxpy_task 196608 8192 1
size: 196608, bs: 8192, iterations: 1, time: 0.000236, performance: 0.833085
STATS      Total CPUs                12
STATS      Total time                3.06985e+07      ns
STATS      Total threads                12
STATS      Mean threads per CPU          1
STATS      Mean tasks per thread        2.08333

STATS      Mean thread lifetime        2.88807e+09      %
STATS      Mean thread running time     100            %
STATS      Mean effective parallelism    0.13271

STATS      All Tasks instances            25
STATS      All Tasks mean instantiation time 2708          ns      1.52238      %
STATS      All Tasks mean pending time     0            ns      0            %
STATS      All Tasks mean ready time       9032         ns      5.07761      %
STATS      All Tasks mean execution time   162959       ns      91.6123      %
STATS      All Tasks mean blocked time     1105         ns      0.621209     %
STATS      All Tasks mean zombie time     2075         ns      1.16652      %
STATS      All Tasks mean lifetime        177879       ns
STATS      All Tasks Real frequency        0.658047     GHz
STATS      All Tasks Virtual frequency    0.782649     GHz
STATS      All Tasks IPC                1.66625
STATS      All Tasks L2 data cache miss ratio 3.203
STATS      All Tasks Real nsecs          3804026      nsecs
STATS      All Tasks Virtual nsecs        3198406      nsecs
STATS      All Tasks Instructions          4171011      instructions
STATS      All Tasks Total cycles          2503229
STATS      All Tasks Instr completed      4171011
STATS      All Tasks L2D cache accesses   16754
STATS      All Tasks L2D cache misses    53663
STATS      All Tasks Reference cycles    2054784

STATS      03.multisaxpy_task.cpp:3:13 instances      24
STATS      03.multisaxpy_task.cpp:3:13 mean instantiation time      2498      ns      4.60435      %
STATS      03.multisaxpy_task.cpp:3:13 mean pending time           0          ns      0            %
STATS      03.multisaxpy_task.cpp:3:13 mean ready time            8237      ns      15.1826      %
STATS      03.multisaxpy_task.cpp:3:13 mean execution time        41452      ns      76.405      %
STATS      03.multisaxpy_task.cpp:3:13 mean blocked time          0          ns      0            %
STATS      03.multisaxpy_task.cpp:3:13 mean zombie time           2066      ns      3.80808      %
STATS      03.multisaxpy_task.cpp:3:13 mean lifetime              54253      ns
STATS      03.multisaxpy_task.cpp:3:13 Real frequency            3.16748     GHz

```

```

STATS      03.multisaxpy_task.cpp:3:13 Virtual frequency      3.18873      GHz
STATS      03.multisaxpy_task.cpp:3:13 IPC                  1.72954
STATS      03.multisaxpy_task.cpp:3:13 L2 data cache miss ratio      3.96831
STATS      03.multisaxpy_task.cpp:3:13 Real nsecs          755566      nsecs
STATS      03.multisaxpy_task.cpp:3:13 Virtual nsecs        750532      nsecs
STATS      03.multisaxpy_task.cpp:3:13 Instructions          4139211     instructions
STATS      03.multisaxpy_task.cpp:3:13 Total cycles          2393243
STATS      03.multisaxpy_task.cpp:3:13 Instr completed       4139211
STATS      03.multisaxpy_task.cpp:3:13 L2D cache accesses    13316
STATS      03.multisaxpy_task.cpp:3:13 L2D cache misses      52842
STATS      03.multisaxpy_task.cpp:3:13 Reference cycles      1964416

STATS      main instances          1
STATS      main mean instantiation time      7755      ns      0.246588      %
STATS      main mean pending time           0      ns      0      %
STATS      main mean ready time            28131     ns      0.894488      %
STATS      main mean execution time         3079121   ns      97.9076      %
STATS      main mean blocked time          27636     ns      0.878749      %
STATS      main mean zombie time           2284      ns      0.0726249     %
STATS      main mean lifetime              3144927   ns
STATS      main Real frequency              0.0360792  GHz
STATS      main Virtual frequency          0.0449312  GHz
STATS      main IPC                      0.289128
STATS      main L2 data cache miss ratio    0.238802
STATS      main Real nsecs                 3048460    nsecs
STATS      main Virtual nsecs              2447874    nsecs
STATS      main Instructions                31800      instructions
STATS      main Total cycles               109986
STATS      main Instr completed            31800
STATS      main L2D cache accesses          3438
STATS      main L2D cache misses            821
STATS      main Reference cycles           90368

STATS      Phase 1 03.multisaxpy_task.cpp:3:13 instances      24
STATS      Phase 1 03.multisaxpy_task.cpp:3:13 mean instantiation time      2498      ns      4.60435      %
STATS      Phase 1 03.multisaxpy_task.cpp:3:13 mean pending time           0      ns      0      %
STATS      Phase 1 03.multisaxpy_task.cpp:3:13 mean ready time            8237     ns      15.1826      %
STATS      Phase 1 03.multisaxpy_task.cpp:3:13 mean execution time         41452     ns      76.405      %
STATS      Phase 1 03.multisaxpy_task.cpp:3:13 mean blocked time          0      ns      0      %
STATS      Phase 1 03.multisaxpy_task.cpp:3:13 mean zombie time           2066     ns      3.80808      %
STATS      Phase 1 03.multisaxpy_task.cpp:3:13 mean lifetime              54253     ns
STATS      Phase 1 03.multisaxpy_task.cpp:3:13 Real frequency          3.16748    GHz
STATS      Phase 1 03.multisaxpy_task.cpp:3:13 Virtual frequency          3.18873    GHz
STATS      Phase 1 03.multisaxpy_task.cpp:3:13 IPC                  1.72954
STATS      Phase 1 03.multisaxpy_task.cpp:3:13 L2 data cache miss ratio      3.96831
STATS      Phase 1 03.multisaxpy_task.cpp:3:13 Real nsecs          755566      nsecs
STATS      Phase 1 03.multisaxpy_task.cpp:3:13 Virtual nsecs        750532      nsecs
STATS      Phase 1 03.multisaxpy_task.cpp:3:13 Instructions          4139211     instructions
STATS      Phase 1 03.multisaxpy_task.cpp:3:13 Total cycles          2393243
STATS      Phase 1 03.multisaxpy_task.cpp:3:13 Instr completed       4139211
STATS      Phase 1 03.multisaxpy_task.cpp:3:13 L2D cache accesses    13316
STATS      Phase 1 03.multisaxpy_task.cpp:3:13 L2D cache misses      52842
STATS      Phase 1 03.multisaxpy_task.cpp:3:13 Reference cycles      1964416

STATS      Phase 1 instances          24
STATS      Phase 1 mean instantiation time      2498      ns      4.60435      %
STATS      Phase 1 mean pending time           0      ns      0      %
STATS      Phase 1 mean ready time            8237     ns      15.1826      %
STATS      Phase 1 mean execution time         41452     ns      76.405      %
STATS      Phase 1 mean blocked time          0      ns      0      %
STATS      Phase 1 mean zombie time           2066     ns      3.80808      %

```

STATS	Phase 1 mean lifetime	54253	ns
STATS	Phase 1 Real frequency	3.16748	GHz
STATS	Phase 1 Virtual frequency	3.18873	GHz
STATS	Phase 1 IPC	1.72954	
STATS	Phase 1 L2 data cache miss ratio		3.96831
STATS	Phase 1 Real nsecs	755566	nsecs
STATS	Phase 1 Virtual nsecs	750532	nsecs
STATS	Phase 1 Instructions	4139211	instructions
STATS	Phase 1 Total cycles	2393243	
STATS	Phase 1 Instr completed	4139211	
STATS	Phase 1 L2D cache accesses	13316	
STATS	Phase 1 L2D cache misses	52842	
STATS	Phase 1 Reference cycles	1964416	
STATS	Phase 1 effective parallelism	0.217033	

Tracing with Extrae

THIS SECTION IS WORK IN PROGRESS, PLEASE IGNORE IT

To get traces of this benchmark using Extrae firstly load the corresponding module:

```
module load Extrae/3.7.1
```

and charge the Extrae environment in your active session:

```
source /usr/local/software/skylake/Stages/2019a/software/Extrae/3.7.1-ipsmpi-2019a-mt/etc/extrae.sh
```

Then copy a preconfigured *extrae.xml* file to instrument OmpSs-2 to your current working directory *multisaxpy*:

```
cp /usr/local/software/skylake/Stages/2019a/software/Extrae/3.7.1-ipsmpi-2019a-mt/share/example/OMPSS/extrae.xml
.
```

The next step is to create a new file *trace.sh*:

```
touch trace.sh
```

with the necessary permission to be executed:

```
chmod +x trace.sh
```

and fill it with the following text:

```
#!/bin/bash
export EXTRAE_CONFIG_FILE=extrae.xml
export NANOS6="extrae"
$*
```

Now execute the benchmark keeping its original size but only 20 iterations with the following command:

```
taskset -c 12-23 ./trace.sh ./03.multisaxpy_task 16777216 8192 20
```

References

- [?https://pm.bsc.es/gitlab/omps-2/examples/multisaxpy](https://pm.bsc.es/gitlab/omps-2/examples/multisaxpy)
- [?https://pm.bsc.es/ftp/omps-2/doc/examples/local/sphinx/03-fundamentals.html](https://pm.bsc.es/ftp/omps-2/doc/examples/local/sphinx/03-fundamentals.html)
- [?https://en.wikipedia.org/wiki/AXPY](https://en.wikipedia.org/wiki/AXPY)

Dot-product Benchmark

Users must clone/download this example's repository from <https://pm.bsc.es/gitlab/ompss-2/examples/dot-product> and transfer it to a DEEP working directory.

Description

This benchmark runs a dot-product operation. The dot-product (also known as scalar product) is an algebraic operation that takes two equal-length sequences of numbers and returns a single number.

There are **3 implementations** of this benchmark.

Execution Instructions

```
./dot_product SIZE CHUNK_SIZE
```

where:

- `SIZE` is the number of elements of the vectors used on the dot-product operation.
- The dot-product operation will be applied to the vector in blocks that contains `CHUNK_SIZE` elements.

References

- <https://pm.bsc.es/gitlab/ompss-2/examples/dot-product>
 - https://en.wikipedia.org/wiki/Dot_product
-

Mergesort Benchmark

Users must clone/download this example's repository from <https://pm.bsc.es/gitlab/ompss-2/examples/mergesort> and transfer it to a DEEP working directory.

Description

This benchmark is a recursive sorting algorithm based on comparisons.

There are **6 implementations** of this benchmark.

Execution Instructions

```
./mergesort N BLOCK_SIZE
```

where:

- `N` is the number of elements to be sorted. Mandatory for all versions of this benchmark.
- `BLOCK_SIZE` is used to determine the threshold when the task becomes *final*. If the array size is less or equal than `BLOCK_SIZE`, the task will become final, so no more tasks will be created inside it. Mandatory for all versions of this benchmark.

References

- <https://pm.bsc.es/gitlab/ompss-2/examples/mergesort>
 - https://en.wikipedia.org/wiki/Merge_sort
-

Nqueens Benchmark

Users must clone/download this example's repository from <https://pm.bsc.es/gitlab/ompss-2/examples/nqueens> and transfer it to a DEEP working directory.

Description

This benchmark computes, for a $N \times N$ chessboard, the number of configurations of placing N chess queens in the chessboard such that none of them is able to attack any other. It is implemented using a branch-and-bound algorithm.

There are **7 implementations** of this benchmark.

Execution Instructions

```
./n-queens N [threshold]
```

where:

- N is the chessboard's size. Mandatory for all versions of this benchmark.
- `threshold` is the number of rows of the chessboard that will generate tasks.

The remaining rows ($N - \text{threshold}$) will not generate tasks and will be executed in serial mode. Mandatory from all versions of this benchmark except from 01 (sequential version) and 02 (fully parallel version).

References

- [?https://pm.bsc.es/gitlab/ompss-2/examples/nqueens](https://pm.bsc.es/gitlab/ompss-2/examples/nqueens)
- [?https://en.wikipedia.org/wiki/Eight_queens_puzzle](https://en.wikipedia.org/wiki/Eight_queens_puzzle)

Matmul Benchmark

Users must clone/download this example's repository from [?https://pm.bsc.es/gitlab/ompss-2/examples/matmul](https://pm.bsc.es/gitlab/ompss-2/examples/matmul) and transfer it to a DEEP working directory.

Description

This benchmark runs a matrix multiplication operation $C = A \cdot B$, where A has size $N \times M$, B has size $M \times P$, and the resulting matrix C has size $N \times P$.

There are **3 implementations** of this benchmark.

Execution Instructions

```
./matmul N M P BLOCK_SIZE
```

where:

- N is the number of rows of the matrix A .
- M is the number of columns of the matrix A and the number of rows of the matrix B .
- P is the number of columns of the matrix B .
- The matrix multiplication operation will be applied in blocks that contains $\text{BLOCK_SIZE} \times \text{BLOCK_SIZE}$ elements.

References

- [?https://pm.bsc.es/gitlab/ompss-2/examples/matmul](https://pm.bsc.es/gitlab/ompss-2/examples/matmul)
- [?https://pm.bsc.es/ftp/ompss-2/doc/examples/local/sphinx/02-examples.html](https://pm.bsc.es/ftp/ompss-2/doc/examples/local/sphinx/02-examples.html)
- [?https://en.wikipedia.org/wiki/Matrix_multiplication_algorithm](https://en.wikipedia.org/wiki/Matrix_multiplication_algorithm)

Cholesky Benchmark (OmpSs-2+MKL)

Users must clone/download this example's repository from [?https://pm.bsc.es/gitlab/ompss-2/examples/cholesky](https://pm.bsc.es/gitlab/ompss-2/examples/cholesky) and transfer it to a DEEP working directory.

Description

This benchmark is a decomposition of a Hermitian, positive-definite matrix into the product of a lower triangular matrix and its conjugate transpose. This Cholesky decomposition is carried out with OmpSs-2 using tasks with priorities.

There are **3 implementations** of this benchmark.

The code uses the CBLAS and LAPACKE interfaces to both BLAS and LAPACK. By default we try to find MKL, ATLAS and LAPACKE from the MKLROOT, LIBRARY_PATH and C_INCLUDE_PATH environment variables. If you are using an implementation with other linking requirements, please edit the LIBS entry in the makefile accordingly.

The Makefile has three additional rules:

- **run**: runs each version one after the other.
- **run-graph**: runs the OmpSs-2 versions with the graph instrumentation.
- **run-extrae**: runs the OmpSs-2 versions with the extrae instrumentation.

For the graph instrumentation, it is recommended to view the resulting PDF in single page mode and to advance through the pages. This will show the actual instantiation and execution of the code. For the extrae instrumentation, extrae must be loaded and available at least through the LD_LIBRARY_PATH environment variable.

Execution Instructions

```
./cholesky SIZE BLOCK_SIZE
```

where:

- `SIZE` is the number of elements per side of the matrix.
- The decomposition is made by blocks of `BLOCK_SIZE` by `BLOCK_SIZE` elements.

References

- [?https://pm.bsc.es/gitlab/omps-2/examples/cholesky](https://pm.bsc.es/gitlab/omps-2/examples/cholesky)
- [?https://pm.bsc.es/ftp/omps-2/doc/examples/02-examples/cholesky-mkl/README.html](https://pm.bsc.es/ftp/omps-2/doc/examples/02-examples/cholesky-mkl/README.html)
- [?https://en.wikipedia.org/wiki/Eight_queens_puzzle](https://en.wikipedia.org/wiki/Eight_queens_puzzle)