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Barcelona Supercomputing Center
Centro Nacional de Supercomputación

OmpSs Hands-on

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PACT2018 tutorial
Limassol, Nov 4th, 2018

Software requirements

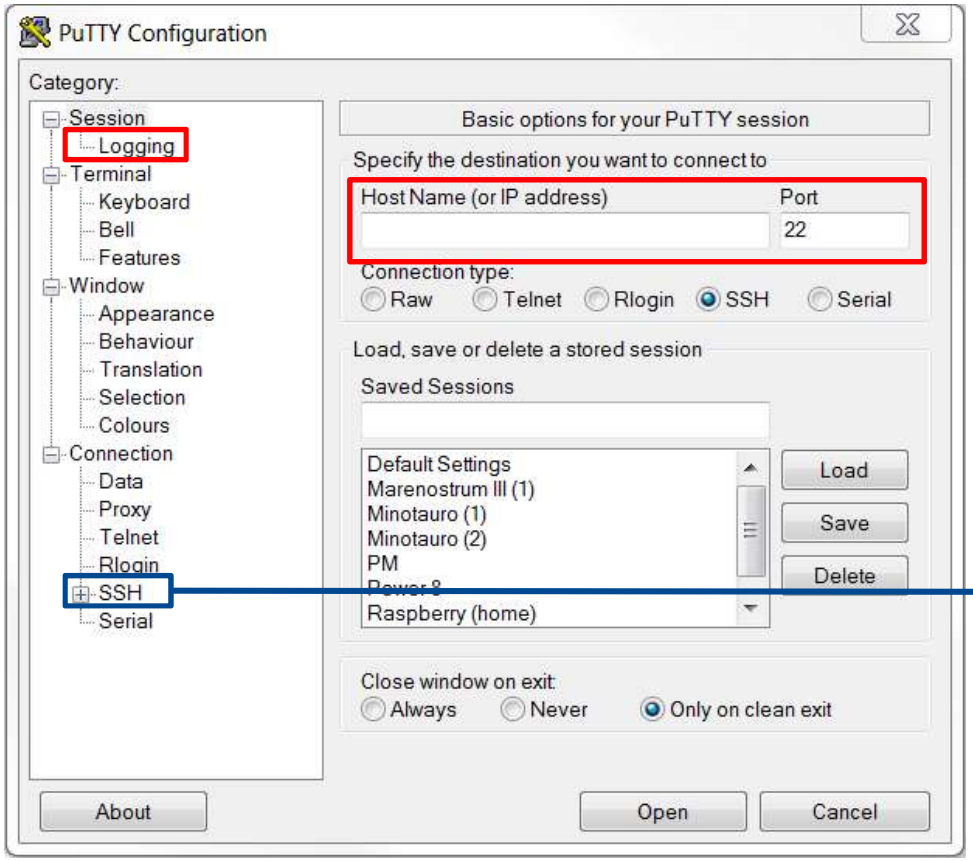
SSH: Secure shell (to connect the HPC system)

- Linux: has native support of secure shell “ssh user@host”
- Windows: need to install a ssh program
  - » PuTTY http://www.chiark.greenend.org.uk/~sgtatham/putty/download.html
  - » MobaXterm http://mobaxterm.mobatek.net/download.html

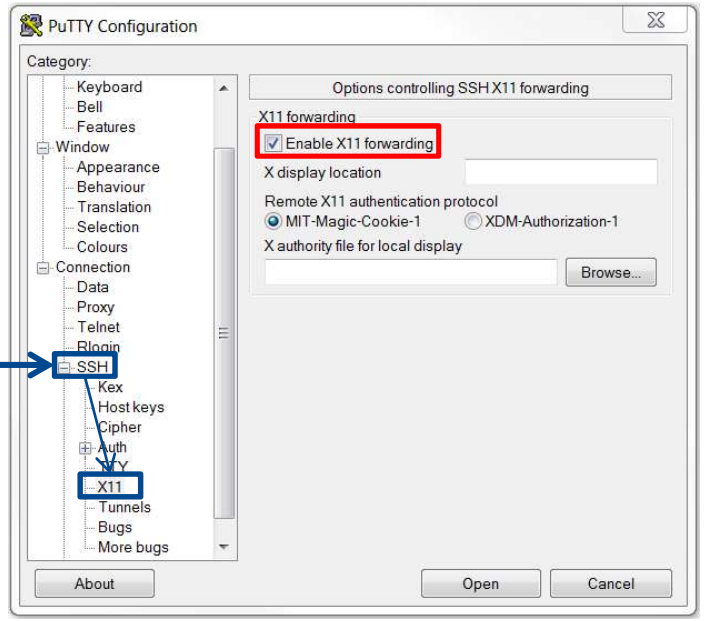
X Server / X forwarding (for wxparaver or .pdf readers)

- Linux: has native support (remember to connect with “ssh -X user@host”
- Windows: need to install a X server program
  - » Xming https://sourceforge.net/projects/xming/
  - » MobaXterm already includes a X server within the package

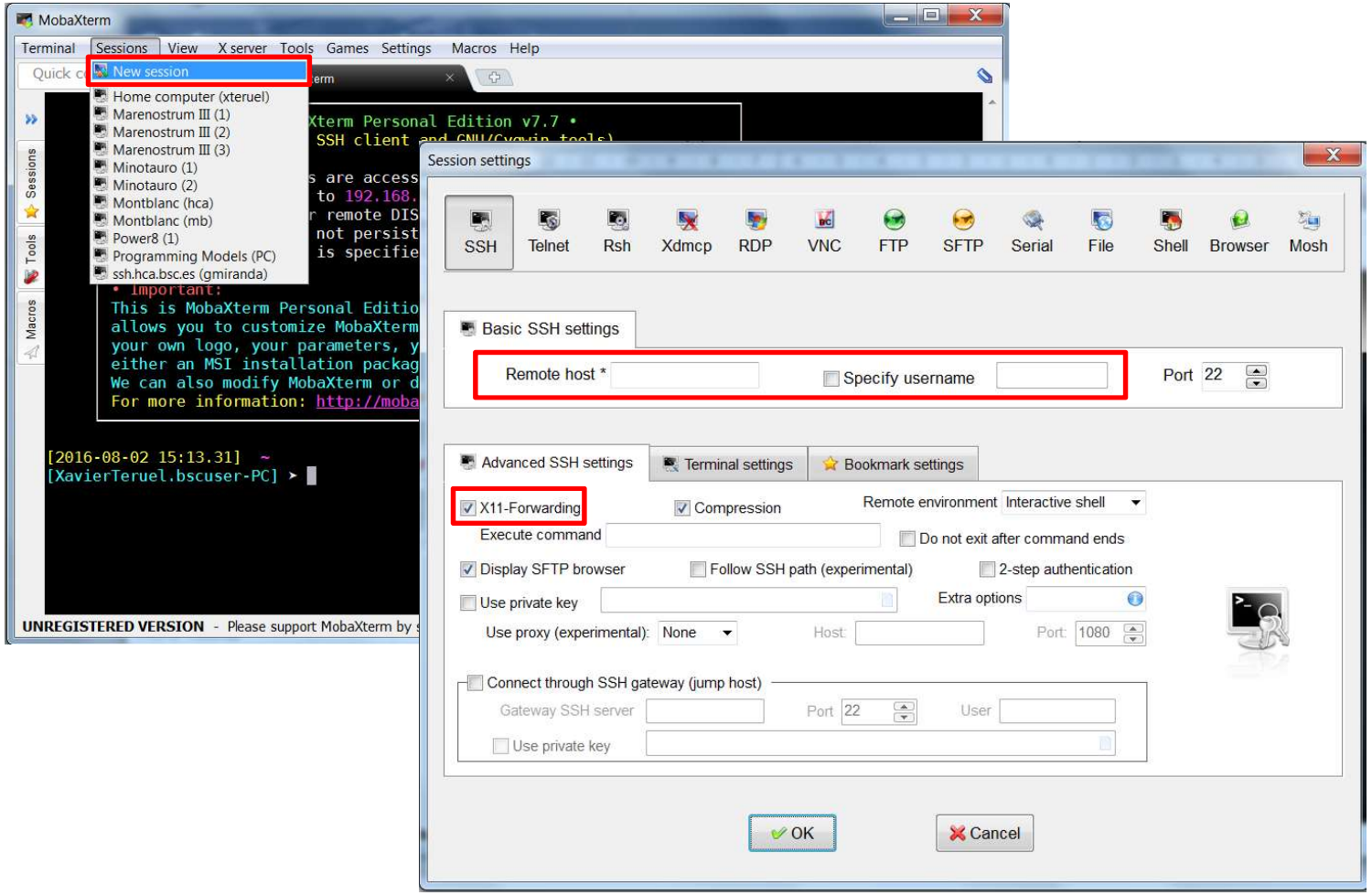
PuTTY: ssh configuration



Before open session make sure…



MobaXterm: ssh configuration



System overview (Grendel)

Provided by the GAZ (Computer Architecture Group), from the University of Zaragoza. Thanks!!

Single node machine

- 4 cores Intel(R) Core(TM) i7-7700 CPU @ 3.6GHz (2-way hyperthreaded)
- 32 Gbytes RAM
- 2TBytes disk

- NVIDIA Corporation GK104 [GeForce GTX 760 OEM] (rev a1)

- Intel/Altera Corporation Device ab00 (rev 01)...
  - » $ aoc --list-boards
  - » Board list:
  - » de5net_a7

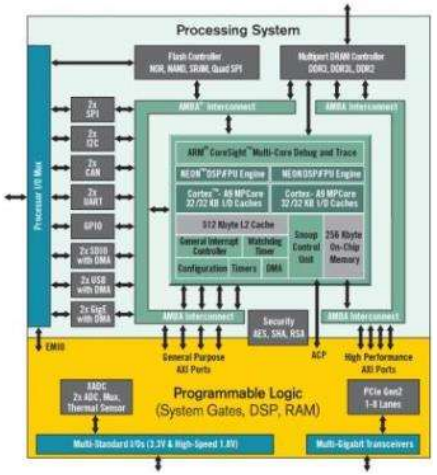
grendel.cps.unizar.es

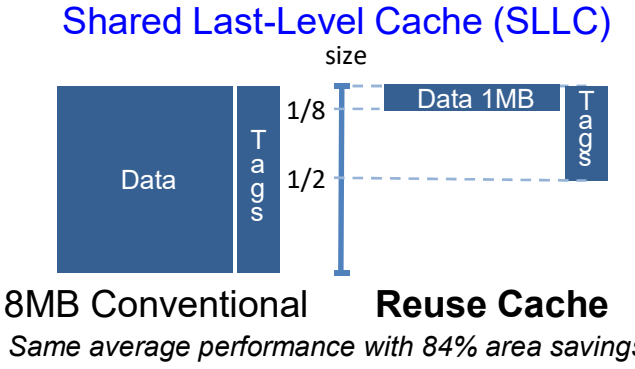
gaZ: Computer Architecture Group

- The University of Zaragoza was founded in 1542
- More than 30000 students and 5000 faculty and staff
- 17 faculty members form the gaZ (Computer Architecture group at Univ. Zaragoza)
  - Víctor Vinyals (leader)
  - Rubén Gran
  - Darío Suárez

gaZ: Computer Architecture Group

- Memory Hierarchy
- Caches for predictable WCET
- Scheduling in Real Time Systems
- FPGAs, HW/SW codesign
  - Heterogeneous execution with CPU, GPU, FPGAs, and accelerators
  - Load balancing/scheduling/…
- **Searching for collaborations!!**





Same average performance with 84% area savings

Account and login information [Grendel]

Get your identifier

- Identifiers are single digit numbers [0-5]

Username and password

- `Username: ompss<your_id_here>`
- `Password: ompsspact`

Example: for identifier 3, account information would be:

- `Username: ompss3`
- `Password: ompsspact`

System overview (Minotauro)

- 39 nodes
  - » 2 Intel E5649 6C at 2.53 GHz
  - » 2 M2090 NVIDIA GPU Cards (Fermi)
  - » 24 GB of Main memory
  - » Peak Performance: 88.60 Tflop/s
    - *M2090: 81.20 Tflop/s*
    - *E5649: 7.40 Tflop/s*
  - » 250 GB SSD as local storage
  - » 2 Infiniband QDR (40 Gbit each)

- 61 nodes
  - » 2 Intel Xeon E5-2630 v3 (Haswell) 8 core 2.4GHz
  - » 2 K80 NVIDIA GPU Cards
  - » 128 GB of Main memory
  - » Peak Performance: 250.94 Tflops
    - *K80: 226.98 Tflop/s*
    - *E5-2630: 23.96 Tflop/s*
  - » 120 GB SSD as local storage
  - » 1 PCIe 3.0 8GT/s Mellanox ConnectX 3FDR 56 Gbit
  - » 4 Gigabit Ethernet ports

mt1.bsc.es
mt2.bsc.es

Account and login information [Minotauro]

Get your identifier

- Identifiers are two digit numbers [26-37]

Username and password

- `Username: nct010<your_id_here>`
- `Password: InParallelOct18.0<your_id_here>`

Example: for identifier 31, account information would be:

- `Username: nct01031`
- `Password: InParallelOct18.031`

`Reservation Name: Parallel18`

Getting the examples package

Exercises available in http:/pm.bsc.es

Home

The main objective of the Programming Models group is to investigate programming paradigms towards productive programming and their implementation through intelligent runtime systems that effectively exploit performance out of the target architecture (from multicore and SMT processors to shared- and distributed-memory systems, small and large-scale cluster systems, including both homogenous and heterogenous systems that use accelerators like GPUs).

Download latest OmpSs version

We currently organize our work around the design of **OmpSs**, a set of extensions to provide support to asynchronous tasks and heterogeneity. They are integrated into OpenMP as a base language and interoperate with MPI and CUDA (OpenCL and OpenACC interoperability is in progress). This programming model relies on top of:

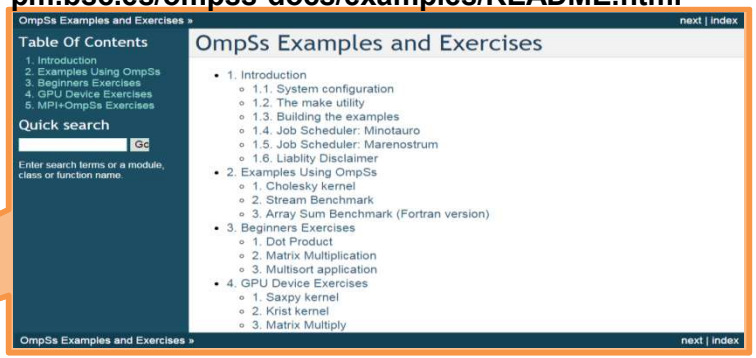
- Our **Mercurium** source-to-source compiler provides the necessary support for transforming the high-level directives into a parallelized version of the application.
- Our **Nanos++** runtime library provides the parallel services to manage all the parallelism in the user-application, including task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

Documentation

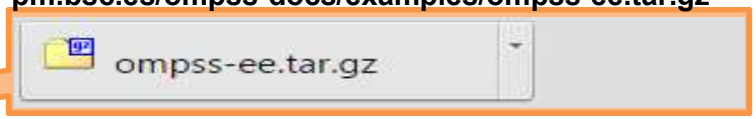
- *OmpSs Specification* (**html**) (**pdf**)
- *OmpSs User Guide* (**html**) (**pdf**)
- *OmpSs Examples and Exercises* (**html**) (**pdf**) (**tar.gz**)
- *OmpSs Developer Manuals*
  - *Mercurium Compiler Developer Manual* (**trac**)
  - *Nanos++ RTL Developer Manual* (**trac**)

- Exercise scripts in *.html* and *.pdf* formats
- A single package including all source files
- Simple to configure, compile and execute

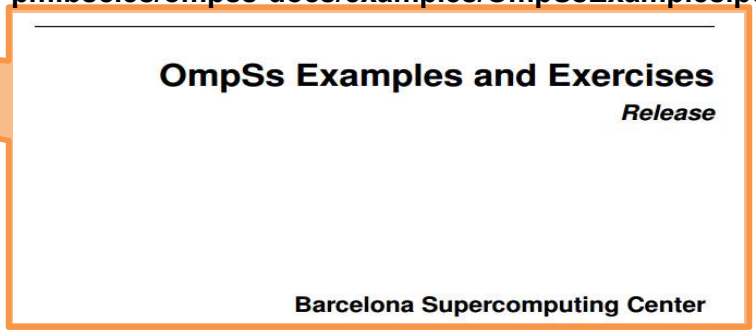
pm.bsc.es/ompss-docs/examples/README.html



pm.bsc.es/ompss-docs/examples/ompss-ee.tar.gz



pm.bsc.es/ompss-docs/examples/OmpSsExamples.pdf



Extract and configure example package

(1) Extracting the sources

```
$ tar –xvf ompss-ee.tar.gz
<list of extracted files>
```

(2) Main directory

```
$ cd ompss-ee
$ ls
00-introduction
01-examples
02-beginners
03-gpu-devices
04-mpi+ompss
05-ompss+dlb
common-files
configure.sh
paraver-cfgs
README.rst
```

(3) Configure

```
$ source configure.sh
Basic configuration...
  Mercurium compiler at /apps/ompss/bin
  Extrae library at /apps/extrae/bin
  Paraver utility at /apps/wxparaver/bin
  ...
Aditional libraries...
MPI library at /opt/mpi/bullxmpi/.../lib
MKL library at /opt/.../mkl/lib/intel64/
ATLAS library at /opt/.../ATLAS/3.9.51/lib
```

Building the example package

(1) nn-session / exercise

```
$ cd 01-examples/cholesky
$
```

(2) Directory contents

```
$ ls
cholesky.c
cholesky.h
Makefile
README.rst
```

(3) README.rst file (script)

```
$ vi README.rst
$
```

(4) Run “make” will create…

```
$ make
Building: program-d, program-i and program-p
Creating: mutirun.sh, run-once.sh, trace.sh and
extrae.xml
```

» different executable versions (suffixed -d, -i and -p)
» different scripts to run your programs
» a extrae.xml file (as default to get your paraver traces)

```
$ ls
cholesky.c      cholesky-d
cholesky.h      cholesky-i
cholesky-p      extrae.xml
Makefile        multirun.sh
README.rst      run-once.sh
trace.sh
```

Running the example package (Minotauro)

Checking script configuration

```
$ vi run-once.sh
$
```

run-once.sh

```
#!/bin/bash
# @ job_name = ompss-ee
# @ partition = debug
## @ reservation =
. . .
PROGRAM=cholesky-p
export NX_THREADS=4
. . .
./$PROGRAM 4096 5
```

```
## @ partition = debug
# @ reservation = ?????
```

Submitting the script

```
$ mnsubmit run-once.sh
Submitted batch job 1234567
```

Exercise directory

```
$ ls
cholesky.c      cholesky-d
cholesky.h      cholesky-i
cholesky-p      extrae.xml
Makefile        multirun.sh
README.rst      run-once.sh
trace.sh
```

Directory after execution

```
$ ls
cholesky.c          cholesky-d
cholesky.h          cholesky-i
cholesky-p          extrae.xml
Makefile            multirun.sh
ompss-ee_nnnnn.err  ompss-ee_nnnnn.out
README.rst          run-once.sh
trace.sh
```

Instrumenting the example package

Checking configuration scripts

```
$ vi run-once.sh trace.sh
$
```

run-once.sh

```
#!/bin/bash
. . .
PROGRAM=cholesky-i
export NX_SMP_WORKERS=4
. . .
./trace.sh ./$PROGRAM 4096 512 1
```

trace.sh

```
#!/bin/bash
. . .
export EXTRAE_CONFIG_FILE=extrae.xml
export NX_INSTRUMENTATION=extrae

$*
```

Exercise directory

```
$ ls
cholesky.c      cholesky-d
cholesky.h      cholesky-i
cholesky-p      extrae.xml
Makefile        multirun.sh
README.rst      run-once.sh
trace.sh
```

Submitting the script

```
$ submit run-once.sh
Creating: cholesky.prv, cholesky.pcf cholesky.raw
```

Visualizing paraver traces [1/5]

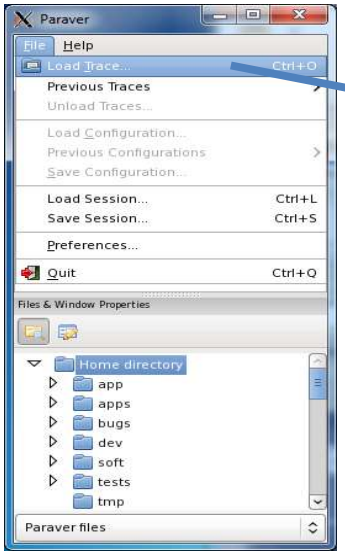
Running paraver tool

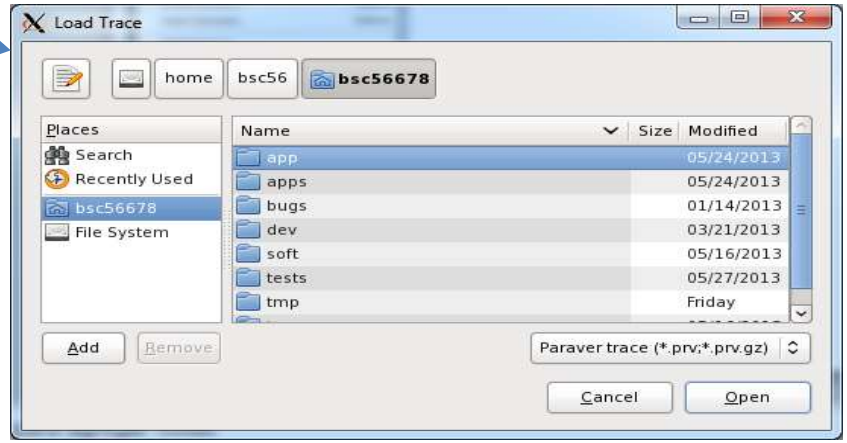
```
$ paraver
$
```

— Load a Paraver trace

Suite exercise directory

```
$ ls
cholesky.c        cholesky-d
cholesky.h        cholesky-i
cholesky-i.pcf    cholesky-i.prv
cholesky-i.raw    cholesky-p
extrae.xml        Makefile
multirun.sh       README.rst
run-once.sh       trace.sh
```





Visualizing paraver traces [2/5]

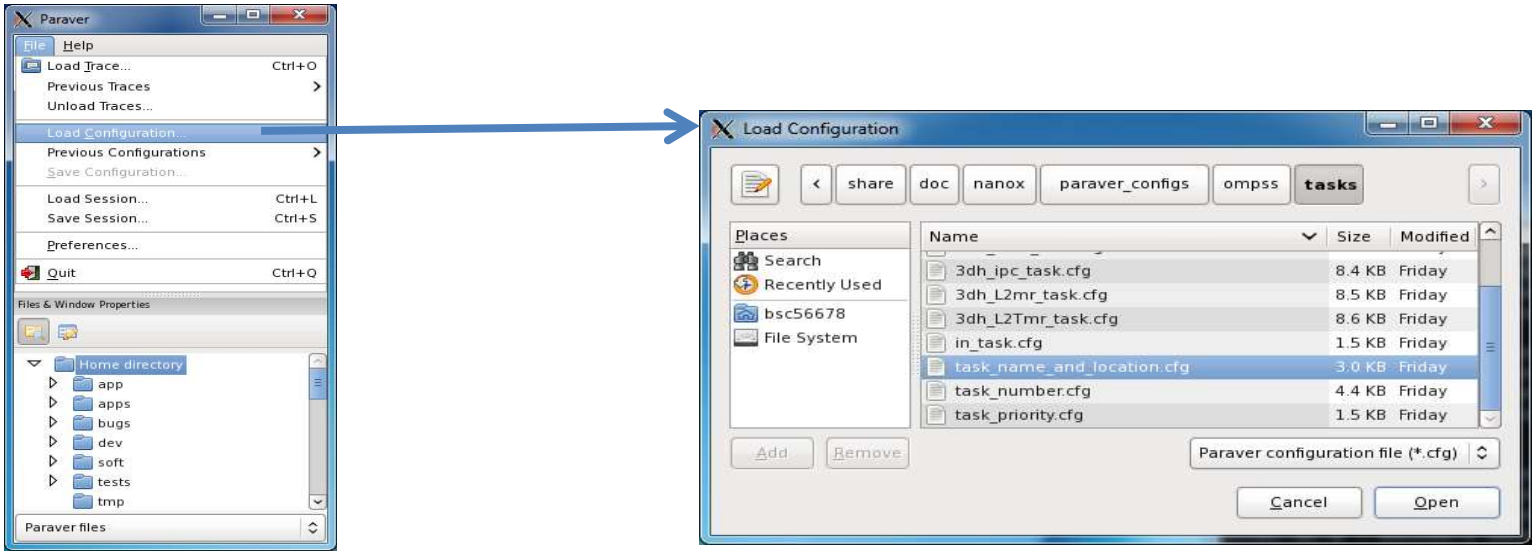
Running paraver tool

```
$ paraver
$
```

— Load a Paraver trace
— Load a configuration file

Suite root directory

```
$ ls
01-examples              02-beginners
03-gpu-devices           04-mpi+ompss
common-files             configure.sh
paraver-cfgs             README.rst
```

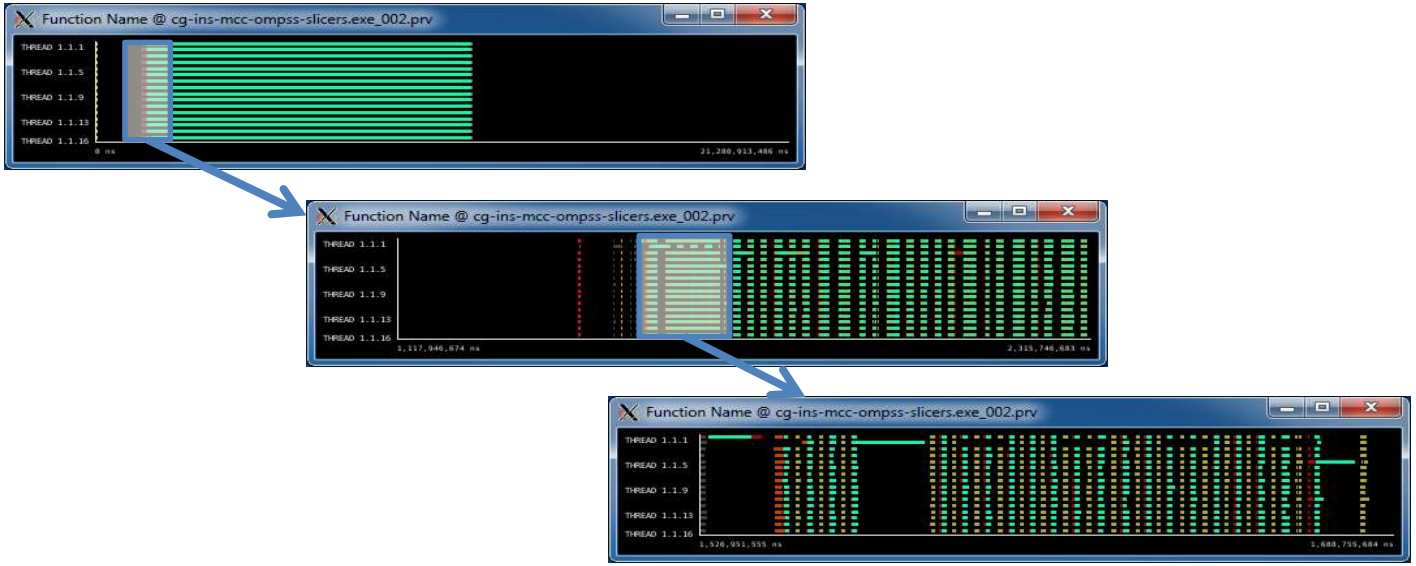


Visualizing paraver traces [3/5]

Running paraver tool

```
$ paraver
$
```

- Load a Paraver trace
- Load a configuration file
- Trace analysis (zoom in, details)



Suite root directory

```
$ ls
01-examples             02-beginners
03-gpu-devices          04-mpi+ompss
common-files            configure.sh
paraver-cfgs            README.rst
```

Visualizing paraver traces [4/5]

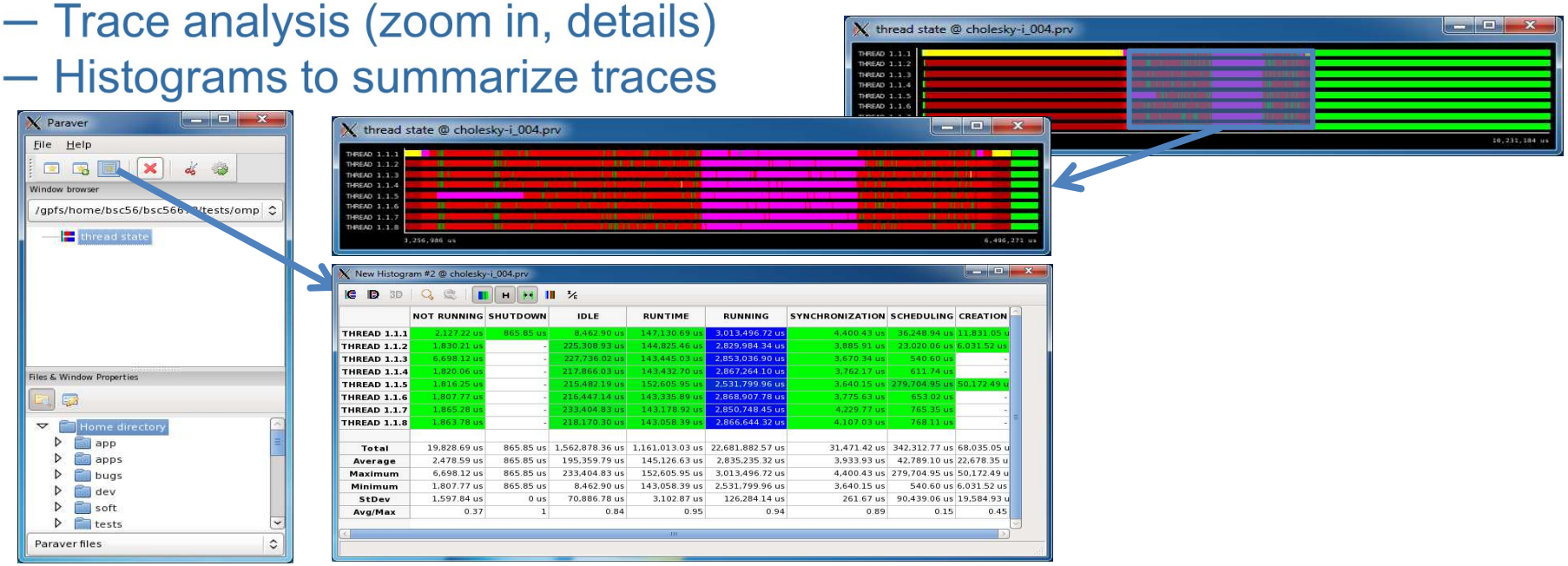
Running paraver tool

```
$ paraver
$
```

- Load a Paraver trace
- Load a configuration file
- Trace analysis (zoom in, details)
- Histograms to summarize traces

Suite root directory

```
$ ls
01-examples              02-beginners
03-gpu-devices           04-mpi+ompss
common-files             configure.sh
paraver-cfgs             README.rst
```



	NOT RUNNING	SHUTDOWN	IDLE	RUNTIME	RUNNING	SYNCHRONIZATION	SCHEDULING	CREATION
THREAD 1.1.1	2,127.22 us	865.85 us	8,462.90 us	147,130.69 us	3,013,496.72 us	4,400.43 us	36,248.94 us	11,831.05 u
THREAD 1.1.2	1,830.21 us	-	225,308.93 us	144,825.46 us	2,829,984.34 us	3,885.91 us	23,020.06 us	6,031.52 us
THREAD 1.1.3	6,698.12 us	-	227,736.02 us	143,445.03 us	2,853,036.90 us	3,670.34 us	540.60 us	-
THREAD 1.1.4	1,820.06 us	-	217,866.03 us	143,432.70 us	2,867,264.10 us	3,762.17 us	611.74 us	-
THREAD 1.1.5	1,816.25 us	-	215,482.19 us	152,605.95 us	2,531,799.96 us	3,640.15 us	279,704.95 us	50,172.49 u
THREAD 1.1.6	1,807.77 us	-	216,447.14 us	143,335.89 us	2,868,907.78 us	3,775.63 us	653.02 us	-
THREAD 1.1.7	1,865.28 us	-	233,404.83 us	143,178.92 us	2,850,748.45 us	4,229.77 us	765.35 us	-
THREAD 1.1.8	1,863.78 us	-	218,170.30 us	143,058.39 us	2,866,644.32 us	4,107.03 us	768.11 us	-
Total	19,828.69 us	865.85 us	1,562,878.36 us	1,161,013.03 us	22,681,882.57 us	31,471.42 us	342,312.77 us	68,035.05 u
Average	2,478.59 us	865.85 us	195,359.79 us	145,126.63 us	2,835,235.32 us	3,933.93 us	42,789.10 us	22,678.35 u
Maximum	6,698.12 us	865.85 us	233,404.83 us	152,605.95 us	3,013,496.72 us	4,400.43 us	279,704.95 us	50,172.49 u
Minimum	1,807.77 us	865.85 us	8,462.90 us	143,058.39 us	2,531,799.96 us	3,640.15 us	540.60 us	6,031.52 us
StDev	1,597.84 us	0 us	70,886.78 us	3,102.87 us	126,284.14 us	261.67 us	90,439.06 us	19,584.93 u
Avg/Max	0.37	1	0.84	0.95	0.94	0.89	0.15	0.45

Visualizing paraver traces [5/5]

Running paraver tool

```
$ paraver
$
```

- Load a Paraver trace
- Load a configuration file
- Trace analysis (zoom in, details)
- Histograms to summarize traces
- Other configuration files
  - » ompss / runtime / thread_state.cfg
  - » ompss / runtime / nanos_API.cfg
  - » ompss / tasks / task_name_and_location.cfg
  - » ompss / cuda / …
  - » hwc / papi / performance / …

Suite root directory

```
$ ls
01-examples             02-beginners
03-gpu-devices          04-mpi+ompss
common-files            configure.sh
paraver-cfgs            README.rst
```

- more info about paraver instrumentation tool

http://pm.bsc.es/ompss-docs/user-guide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Compile and Execute

Compile and execute

Exercise's location: 01-examples

```
~ompss-ee:$ ls
01-examples                02-beginners
03-gpu-devices             04-mpi+ompss
...
```

Compile and execute (guidelines)

- Code is completely annotated, you DON'T need to modify it. Review source code, check different directives and their clauses
- Run *corresponding* executable version
  - » program-p → performance's version
  - » program-i → instrumentation's version
  - » program-d → debug's version
- Check scalability → compute speed-up
- Runtime options (schedulers, …)
- Get task dependency graph / paraver traces

Hands-on session's contents

Exercise 3.2: Cholesky kernel
Exercise 3.3: Stream (barr | deps) bmarks
Exercise 3.4: Array sum kernel

Remember to configure your system

```
$ source configure.sh
Basic configuration...
```

Check running script (before submit)

```
$ vi run-once.sh
$
```

- Scripts run-once.sh, multi-run.sh or trace.sh
- Executable program's version (-p, -i or -d)
- Job scheduler configuration (queue)
- Other runtime's options used in the script

Documents at http:/pm.bsc.es

Exercise 3.2: Cholesky kernel

Location: 01-examples / cholesky

Source code description

- cholesky.c → main code
- cholesky.h→ headers

Compile and execute the program

```
#pragma omp task inout([ts][ts]A)
void omp_potrf(double * const A, int ts, int ld)
{ ... }
```

Things to do:

- Code is completely annotated, you DON'T need to modify it
- Review source code, check different directives and their clauses
- Check different versions (performance, instrumented & debug)
- Check other runtime options (schedulers, …)
- Check (scalability), execute for different number of thread → compute speed-up
- Get a task dependency graph to analyse dependences
- Get different paraver traces and visualize them: thread state, task name,…

Exercise 3.4: Array sum kernel

Location: 01-examples / array-sum-fortran

Source code description

- array_sum.f90 → main code (single file)

Compile and execute the program

```
!$OMP TASK OUT(VEC1(I:I+BS-1), VEC2(I:I+BS-1), RESULTS(I:I+BS-1))&
!$OMP PRIVATE(J) FIRSTPRIVATE(I, BS) LABEL(INIT_TASK)
   DO J = I, I+BS-1 ...
```

Things to do:

- Code is completely annotated, you DON'T need to modify it
- Review source code, check different directives and their clauses
- Check different versions (performance, instrumented & debug)
- Check other runtime options (schedulers, …)
- Check (scalability), execute for different number of thread → compute speed-up
- Get a task dependency graph to analyse dependences
- Get different paraver traces and visualize them: thread state, task name,…

Exercise 3.3: Stream benchmark

Location: 01-examples / stream-xxxx (where xxxx = barr | deps)

Source code description

- stream-xxxx.c → main code (single file)

Compile and execute the programs

```
for (j=0; j<N; j+=BSIZE)
#pragma omp task
...
#pragma omp taskwait
for (j=0; j<N; j+=BSIZE)
```

```
for (j=0; j<N; j+=BSIZE)
#pragma omp task in([bs]a) out([bs]c)
...
for (j=0; j<N; j+=BSIZE)
#pragma omp task in([bs]a) out([bs]c)
```

Things to do:

- Code is completely annotated, you DON'T need to modify it. Review source code, check different directives and their clauses. Compare the two parallelization approaches (one based in the taskwait, the other in dependences)
- Check different versions (performance, instrumented & debug) and other runtimes options
- Check (scalability), execute for different number of thread → compute speed-up
- Get a task dependency graph to analyse dependences
- Get different paraver traces and visualize them: thread state, task name,…


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OmpSs Fundamentals

OmpSs Fundamentals

Exercise's location: 02-beginners

```
~ompss-ee:$ ls
01-examples                02-beginners
03-gpu-devices             04-mpi+ompss
...
```

OmpSs Fundamentals (guidelines)

- Complete the source code annotation using OmpSs directives (creating tasks)
- Include OmpSs synchronization directives when needed (synchronize tasks)
- Run *corresponding* executable version
  - » program-p → performance's version
  - » program-i → instrumentation's version
  - » program-d → debug's version
- Check scalability → compute speed-up
- Runtime options (schedulers, …)
- Get task dependency graph / paraver traces

Hands-on session's contents

Continue previous session's exercises
Exercise 4.1: Matrix multiply kernel
Exercise 4.2: Dot product kernel
Exercise 4.3: Multisort kernel (rec.)

Remember to configure your system

```
$ source configure.sh
Basic configuration...
```

Check running script (before submit)

```
$ vi run-once.sh
$
```

- Scripts run-once.sh, multi-run.sh or trace.sh
- Executable program's version (-p, -i or -d)
- Job scheduler configuration (queue)
- Other runtime's options used in the script

Documents at http:/pm.bsc.es

Exercise 4.1: Matrix multiplication kernel

Location: 02-beginners / matmul

Source code description

- matmul.c → main code (single file)

Creating tasks

```
for (i = 0; i < DIM; i++)
  for (j = 0; j < DIM; j++)
    for (k = 0; k < DIM; k++)
      matmul ((double *)A[i][k], (double *)B[k][j], (double *)C[i][j], NB);
```

Things to do:

- Look for candidate to become a task
- Don't forget to wait for all task before completion
- Check scalability (for different versions), use runtime options (schedulers, …)
- Get a task dependency graph and/or paraver traces

Exercise 4.2: Dot product kernel

Location: 02-beginners / dot-product

Source code description

- dot-product.c → main code (single file)

Creating tasks

```
for (long i=0; i<N; i+=CHUNK_SIZE) {
  actual_size = (N-CHUNK_SIZE>=CHUNK_SIZE)?CHUNK_SIZE:(N-CHUNK_SIZE);
  C[j]=0;
  for (long ii=0; ii<actual_size; ii++) {
     C[j]+= A[i+ii] * B[i+ii];
  }
  acc += C[j];
  j++;
}
```

Things to do:

- Complete the annotation of tasks. Think how they must be synchronized
- Check different parallelization approaches: concurrent, atomics, commutatives…
- Check scalability (for different versions), use runtime options (schedulers, …)
- Get a task dependency graph and/or paraver traces

Exercise 4.3: Multisort kernel

Location: 02-beginners / multisort

Source code description

- multisort.c → main code (single file)

Creating (nested) tasks

```
multisort(n/4L, &data[0], &tmp[0]);
multisort(n/4L, &data[n/4L], &tmp[n/4L]);
...
merge(n/4L, &data[0], &data[n/4L], &tmp[0], 0, n/2L);
merge(n/4L, &data[n/2L], &data[3L*n/4L], &tmp[n/2L], 0, n/2L);

merge(n/2L, &tmp[0], &tmp[n/2L], &data[0], 0, n);
```

Things to do:

- Think how the tasks must be synchronized
- Check different parallelization approaches: taskwait/dependences
- Check scalability (for different versions), use runtime options (schedulers, …)
- Get a task dependency graph (different domains) and/or paraver traces


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OmpSs + CUDA

OmpSs + CUDA

Exercise's location: 03-gpu-devices

```
~ompss-ee:$ ls
01-examples                02-beginners
03-gpu-devices             04-mpi+ompss
...
```

OmpSs + CUDA (guidelines)

- Complete existent OmpSs annotation as required (devices, ndrange, copies, dependences,…)
- Complete the source code annotation using OmpSs directives (target directive)
- Include OmpSs synchronization directives when needed (synchronize tasks)
- Run *corresponding* executable version
  - » program-p → performance's version
  - » program-i → instrumentation's version
  - » program-d → debug's version

Hands-on session's contents

Continue previous session's exercises
Exercise 5.2: SAXPY kernel
Exercise 5.3: Krist kernel
Exercise 5.4: Matrix multiply

Remember to configure your system

```
$ source configure.sh
Basic configuration...
```

+ CUDA 8.0 & gcc 4.9.x

Check running script (before submit)

```
$ vi run-once.sh
$
```

- Scripts run-once.sh, multi-run.sh or trace.sh
- Executable program's version (-p, -i or -d)
- Job scheduler configuration (queue)
- Other runtime's options used in the script

Documents at http:/pm.bsc.es

Exercise 4.1: SAXPY kernel

Location: 03-gpu-devices / saxpy-cuda

Source code description

- File kernel.cu → saxpy CUDA version (definition)
- File saxpy.c → main code, kernel invokation
- File kernel.h → kernel header (partially annotated)

The NDRange clause

```
#pragma target device(cuda) copy_deps ndrange( /*????*/ )
#pragma omp task in([n]x) inout([n]y)
__global__ void saxpy(int n, float a,float* x, float* y);
```

Things to do:

- Complete the OmpSs annotation (NDRange clause)
- Check execution and behaviour for different thread hierarchy configurations
- Check different runtime options (devices, max mem, prefetch, overlap…)

Exercise 4.2: Krist kernel

Location: 03-gpu-devices / krist-cuda

Source code description

- File kernel.cu → cstructface CUDA version
- File krist.c → main code, kernel invokation
- File kernel.h → kernel header (partially annotated)
- File clocks.c → get time support to measure performance (support)

Target and task directives (device support)

```
#pragma omp target device(cuda) ...
#pragma omp task ...
__global__ void cstructfac(int na, int number_of_elements, int nc, float f2, int NA,
                TYPE_A* a, int NH, TYPE_H* h, int NE, TYPE_E* output_array);
```

Things to do:

- Complete the target directive (copies, thread hierarchy,…)
- Complete the task directive (dependences,…)
- Try different complile- (ndrange,…) and run- time options (devices, prefetch,…)

Exercise 4.3: Matrix Multiply

Location: 03-gpu-devices / matmul-cuda

Source code description

- File matmul.c → main code, kernel invokation
- File kernel.cu → Muld CUDA version
- File kernel.h → kernel header (lack of declaration)
- Support files → cclocks, check, driver, gendat and prtspeed

Declare a CUDA task

```
// Kernel declaration as a task should be here
// Remember, we want to multiply two matrices (A*B=C)
// Matrix sizes are NB*NB
```

Things to do:

- Write the target directive (device, copies, thread hierarchy,…)
- Write the task directive (dependences,…)
- Check program execution verification
- Try different complile- (ndrange,…) and run- time options (devices, prefetch,…)

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Thank you!

For further information please contact

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