



TECHNISCHE
UNIVERSITÄT
DRESDEN

Center for Information Services and High Performance Computing (ZIH)

Introduction to HPC at ZIH

November 2022

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HPC wiki has the answer

Please check our HPC wiki at <https://doc.zih.tu-dresden.de>



ZIH HPC Compendium

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Access to ZIH Systems

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HPC Support

● Operation Status
hpcsupport@zih.tu-dresden.de

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- first version 1991, Linus Torvalds
- hardware-independent operating system
- 'Linux' is the name of the kernel as well as of the whole operating system
- since 1993 under GNU public license (GNU/Linux)
- various distributions for all purposes (OpenSuSE, SLES, Ubuntu, Debian, Fedora, RedHat,...)
<http://www.distrowatch.com>



Tools for SSH access

Tools to access HPC systems at ZIH from Windows systems
(see https://doc.../access/ssh_login)

- command line login: PuTTY, Secure Shell
- file transfer: WinSCP, Secure Shell
- GUI transfer (Xming, Xming-Mesa, X-Win32)

- integrated solution: MobaXterm

MobaXterm step-by-step instructions

see our Wiki at https://doc.../access/ssh_mobaxterm

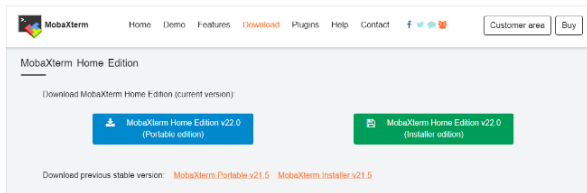


MobaXterm is an enhanced terminal for Windows with an X11 server, a tabbed SSH client, network tools and more.

Visit its homepage for more information (<https://mobaxterm.mobatek.net>).

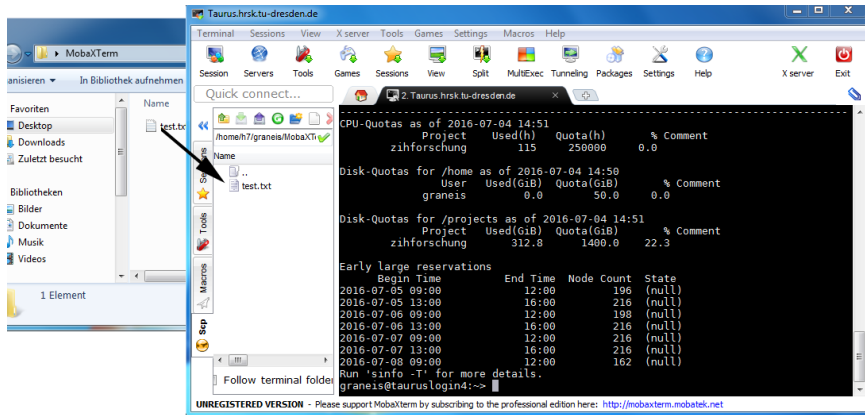
Download and install

To download go to [MobaXterm homepage](#) and download a free home edition.



MobaXterm

- console to HPC systems (including X11 forwarding)
- transfer files to and from the HPC systems
- browse through the HPC file systems



In tedious field work **1520** jellyfish specimen were collected. Now the workflow in the lab is as follows:

- A scanner checks each sample for 300 different proteins
Result: a file per specimen, one line per protein.
- For each protein, some software calculates statistics.
- Scientist writes up results for a paper.

Timeline – Publish within a month?

- Protein scanner: 2 weeks hard work in the lab
- Manually (GUI) select 1520 files in a file open dialog for analysis is boring and thus error-prone. (30s per "open" = 12h + processing time)

An adequate automation process for batch analysis would help.

Command shell - bash

*"Today, many end users rarely, if ever, use command-line interfaces and instead rely upon graphical user interfaces and menu-driven interactions. However, many software developers, system administrators and **advanced users** still rely heavily on command-line interfaces to perform tasks more efficiently..." (Wikipedia)*

The shell...

- tries to locate a program from an absolute (`/usr/bin/vi`) or relative (`./myprog`, or `bin/myprog`) path
- expands file names like `ls error*.txt`
- provides set of environment variables (`printenv [NAME]`) like...

<code>PATH</code>	search path for binaries
<code>LD_LIBRARY_PATH</code>	search path for dynamic libraries
<code>HOME</code>	path to user's home directory

Program execution is controlled by command line options.

Basic commands

<code>pwd</code>	print work directory
<code>ls</code>	list directory (<code>ls -ltrs bin</code>)
<code>cd</code>	change directory (<code>cd = cd \$HOME</code>)
<code>mkdir</code>	create directory (<code>mkdir -p child/grandchild</code>)
<code>rm</code>	remove file/directory Caution: No trash bin! (<code>rm -rf tmp/*.err</code>)
<code>rmdir</code>	remove directory
<code>cp</code>	copy file/directory (<code>cp -r results ~/projectXY/</code>)
<code>mv</code>	move/rename file/directory (<code>mv results ~/projectXY/</code>)
<code>chmod</code>	change access properties (<code>chmod a+r readme.txt</code>)
<code>find</code>	find a file (<code>find . -name "*.c"</code>) or <code>find . -name "core*" -exec rm {} \;</code>

Basic commands (cont'd)

<code>echo</code>	display text to stdout <code>echo \$PATH</code>
<code>cat</code>	display contents of a file <code>cat > newfile.txt</code>
<code>less, more</code>	pagewise display (<code>less README</code>)
<code>grep</code>	search for words/text (<code>grep result out.res</code>)
<code>file</code>	determine type of a file
<code>ps</code>	display running processes (<code>ps -axuf</code>)
<code>kill</code>	kill a process (<code>kill -9 12813</code>)
<code>top</code>	display table of processes (interactive per default)
<code>ssh</code>	secure shell to a remote machine (<code>ssh -X mark@taurus.hrsk.tu-dresden.de</code>)

Basic commands (cont'd)

<code>echo</code>	display text to stdout <code>echo \$PATH</code>
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<code>ssh</code>	secure shell to a remote machine (<code>ssh -X mark@taurus.hrsk.tu-dresden.de</code>)

Editors:

- `vi` - a cryptic, non-intuitive, powerful, universal editor. The web has several “cheat sheets” of `vi`.
- `emacs` - a cryptic, non-intuitive, powerful, universal editor. But it comes with an X11 GUI.
- `nedit` - an intuitive editor with an X11 GUI.
(`module load modenv/classic nedit`)

Help at the command line

Every Linux command comes with detailed manual pages. The command `man <program>` is the first aid kit for Linux questions.

CHMOD(1)

User Commands

CHMOD(1)

NAME

`chmod` - change file mode bits

SYNOPSIS

```
chmod [OPTION]... MODE[,MODE]... FILE...  
chmod [OPTION]... OCTAL-MODE FILE...  
chmod [OPTION]... --reference=REFILE FILE...
```

DESCRIPTION

This manual page documents the GNU version of `chmod`. `chmod` changes the file mode bits of each given file according to mode, which can be either a symbolic representation of changes to make, or an octal number representing the bit pattern for the new mode bits.

The format of a symbolic mode is [ugoa...][[+]=][perms...]...., where perms is either zero or more letters from the set `rwxkst`, or a single letter from the set `ugo`. Multiple symbolic modes can be given, separated by commas.

A combination of the letters `ugo`a controls which users' access to the file will be changed: the user who owns it (u), other users in the file's group (g), other users not in the file's group (o), or all users (a). If none of these are given, the effect is as if a were given, but bits that are set in

Manual page `chmod(1)` line 1

Linux file systems

- mounted remote file systems can be accessed like local resources.
- names are **case sensitive**
- system programs in `/bin`, `/usr/bin`
- third party applications, libraries and tools, special software trees e.g.
 - normally in `/opt`
 - ZIH's HPC systems in `/sw`
- every user has her own home directory
 - `/home/<login>`
 - e.g. `/home/mark`

Special directories:

- `~` = home directory (`cd ~` or `cd $HOME`)
- `.` = current directory
- `..` = parent directory

Nelle's Pipeline II

Hypothetical look at the protein scans...

```
~ > ls  
scan_results
```

Nelle's Pipeline II

Hypothetical look at the protein scans...

```
~ > ls  
scan_results
```

```
~ > mkdir Jellyfish2020  
~ > mv scan_results Jellyfish2020  
~ > cd Jellyfish2020
```

```
~/Jellyfish2020 > ls scan_results  
spec_0001.out spec_0002.out spec_0003.out spec_0004.out
```


Nelle's Pipeline II

Hypothetical look at the protein scans...

```
~ > ls  
scan_results
```

```
~ > mkdir Jellyfish2020  
~ > mv scan_results Jellyfish2020  
~ > cd Jellyfish2020
```

```
~/Jellyfish2020 > ls scan_results  
spec_0001.out spec_0002.out spec_0003.out spec_0004.out
```

```
~/Jellyfish2020 > for f in scan_results/* ; do \  
    calc_statistics $f ; done
```

Remark: Large computations not on the login nodes.

File properties

Every file or directory has its access properties:

- 3 levels of access: **u**ser, **g**roup, **o**ther
- 3 properties per level: **r**ead, **w**rite, **x**ecute (for directories: execute = enter)
- list directory `ls -l .`

-wx	-wx	-x	1 mark zih	9828	Apr 22 13:19	omp
-w	-	-	1 mark staff	521	Apr 22 13:19	omp.c
-w	-	-	1 mark zih	310288384	May 7 19:01	p1s055.30880.core
-w	-	-	1 mark root	116007687	Apr 12 12:56	pluk.tgz
dwx	-x	-x	4 mark staff	4096	Mar 18 16:44	projekte

dir/link user group other

Default: User has all access rights in her `$HOME`-directory.

Which access rights shall be added/removed (easy way)

- set a file readable for all: `chmod a+r readme.txt`
- remove all rights for the group: `chmod g-rwx readme.txt`

Redirection of I/O

Linux is a text-oriented operating system. Input and output is 'streamable'.

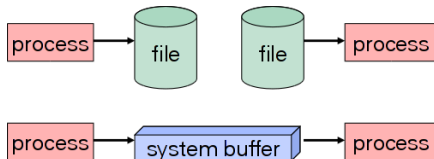
- standard streams are: stdin, stdout, stderr
- streams can be redirected from/to files
e.g. `myprog <in.txt >out.txt`
- error messages (warnings) are separated from normal program output
e.g. `myprog 2>error.txt >out.txt`
- merge error messages and output: `myprog 2>&1 out_err.txt`

Attention:

The '>' operator will always empty an existing output file. For appending a stream output to a file use the '>>' operator. e.g. `myprog >>all_outs.txt`.

Command pipelines

Inputs and outputs can also be other programs.



```
ls -la | sort | more
```

```
echo 'Have fun!' | sed -s 's/fun/a break/g'
```

Versatility of Linux (and Linux like operating systems) comes from

- command line controlled program execution
- combining multiple programs in a pipelined execution
- mighty scripting, parsing, and little helper tools (shell, awk, sed, perl, grep, sort)

Hands-on training

Recommended online material:

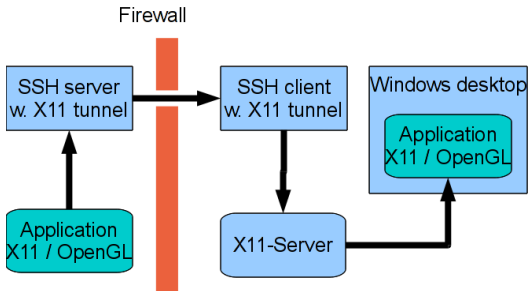
<http://swcarpentry.github.io/shell-novice>

Introducing the Shell	What is a command shell and why would I use one?
Navigating Files and Directories	How can I move around on my computer? How can I see what files and directories I have? How can I specify the location of a file or directory on my computer?
Working With Files and Directories	How can I create, copy, and delete files and directories? How can I edit files?
Pipes and Filters	How can I combine existing commands to do new things?
Loops	How can I perform the same actions on many different files?
Shell Scripts	How can I save and re-use commands?
Finding Things	How can I find files? How can I find things in files?

X11 tunnel

Why do we need it?

- redirect graphic contents (GUI or images) to personal desktop system
- only SSH connections are allowed with HPC systems
- at desktop: X11 server to handle graphic input (mouse, keyboard) and output (window contents)



X11 forwarding

- Linux: `ssh -X ...`
- Mac OS X: <https://support.apple.com/downloads/x11>
- Windows:
 - Public Domain tool Xming/Xming-mesa:
<http://www.straightrunning.com/XmingNotes> or similar product.
 - enable X11 forwarding in the SSH tool
 - integrated solution in MobaXterm
- OpenGL might be an issue

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Questionnaire

Are you already an HPC user...?

- ☐ A yes
- ☐ B no

Questionnaire

Which item describes your HPC-related research best...?

- Ⓐ chemistry and materials science
- Ⓑ life sciences
- Ⓒ physics
- Ⓓ mechanical engineering
- Ⓔ earth sciences
- Ⓕ computer science, mathematics

If none of the above matches: abstain.

Questionnaire

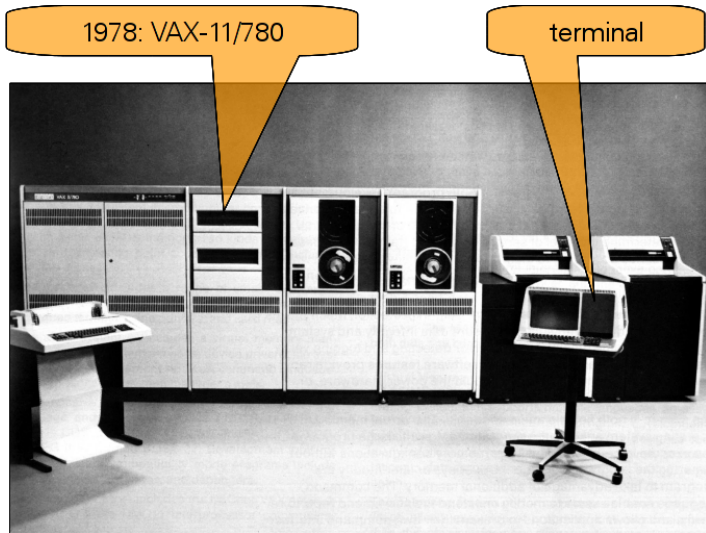
What kind of code do you use mostly (highest CPUh consumption)?

- Ⓐ commercial software
- Ⓑ community software
- Ⓒ “self” developed codes

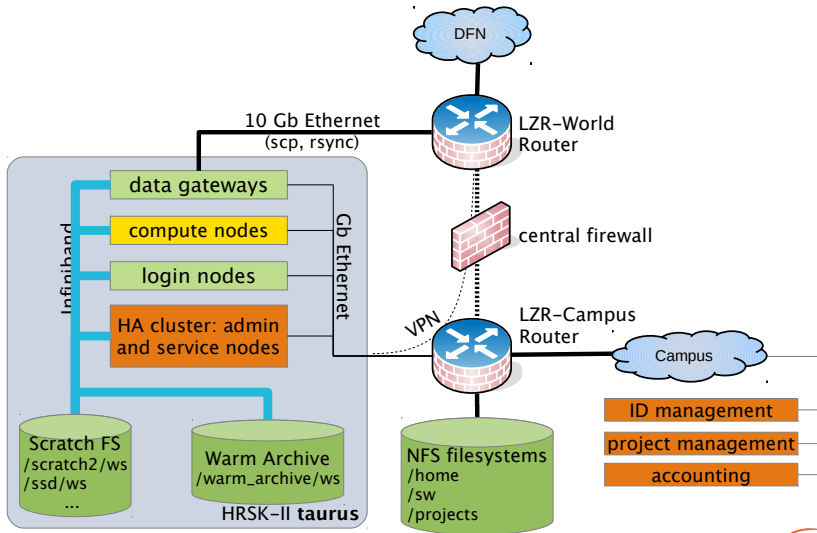
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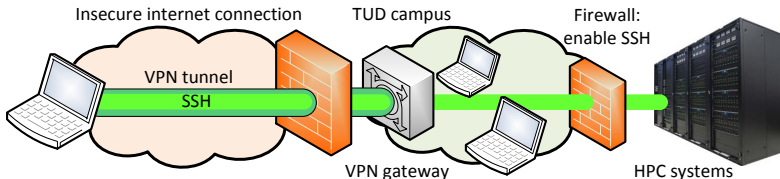
Computer and terminal



Access to the HPC systems



Firewall around HPC systems



The only access to ZIH's HPC systems is

- from within the TU Dresden campus
- via secure shell (ssh).

From other IP ranges: **V**irtual **P**rivate **N**etwork

Data transfer (!) from acknowledged IP ranges, eg:

TU Freiberg	139.20.0.0/16
TU Chemnitz	134.109.0.0/16
Uni Leipzig	139.18.2.0/24

VPN for external users

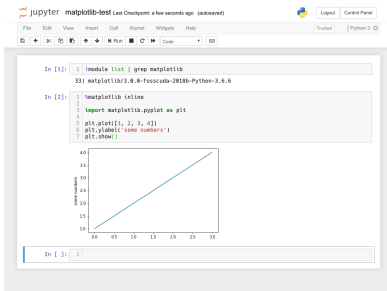
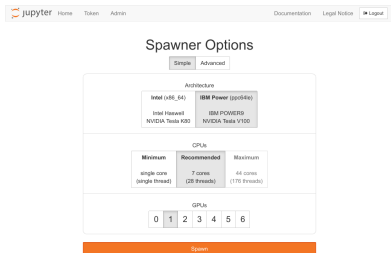
How-To for Linux, Windows, Mac can be found here:

https://tu-dresden.de/zih/dienste/service-katalog/arbeitsumgebung/zugang_datennetz/vpn

- install VPN tool at your local machine
 - OpenConnect (<http://www.infradead.org/openconnect>)
 - Cisco Anyconnect
- configuration
 - gateway vpn2.zih.tu-dresden.de
 - group TUD-vpn-all
 - username <ZIH-LOGIN>@tu-dresden.de
 - password <ZIH-PASSWORD>

Access to HPC

Use X11 forwarding with `ssh -X taurus.hrsk.tu-dresden.de`.
Or use a GUI from your Web browser → JupyterHub.



Detailed documentation can be found at
<https://doc.../access/jupyterhub>.

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HPC at ZIH

- state's computing center for HPC in Saxony
- HPC systems are funded by BMBF and SMWK
- services free of charge to
 - all universities in Saxony,
 - all listed research institutes (e.g. Leibniz, Max Planck, Fraunhofer institutes)
- active projects outside TUD: MPI-CBG, HZDR, IFW, Uni Leipzig, TUBAF)

HPC Infrastructure for Data Analytics

National competence center for data analytics “ScaDS” (with Universität Leipzig)

- hardware extensions
 - NVMe nodes (block storage over Infiniband),
 - nodes for machine learning,
 - “warm archive” for research data, VM images...
 - compute (sub-) cluster
 - large SMP system
 - GPU (sub-) cluster
- new methods to access systems complementary to “classical” HPC mode

Overview

- General purpose cluster from Bull/Atos for highly parallel HPC applications (2013/2015)
- extended with hardware from NEC, IBM, HPE
- running with RHEL/Centos 7
- 1,029.9 TFlop/s total peak performance (rank 66 in top500, 06/2015) - now: 2.6 PFlop/s
- GPU partition with 128 dual GPUs
- all nodes have local SSD



Heterogenous compute resources

- Normal compute nodes
 - Island 4 to 6: 1456 nodes Intel Haswell, (2 x 12 cores), 64,128,256 GB/node
 - Extension of Island 4: 32 nodes Intel Broadwell, (2 x 14 cores), 64 GB/node
 - Island 7: 192 nodes AMD Rome (2 x 64 cores, 512 GB/node)
- Large SMP nodes
 - 5 nodes with 2 TB RAM, Intel Haswell (4 x 14 cores)
 - 1 node with 48 TB RAM, Intel Cascade Lake (896 cores)
- Accelerator nodes
 - Island 2 Phase 2: 64 nodes with 2 x NVidia K80, Intel Haswell (2 x 12 cores)
 - Alpha Centauri: 32 nodes with 6 x NVidia V100-SXM2, IBM Power9 (2 x 22 cores)

Storage for data analytics

- warm archive powered by Quobyte (10 PiB net capacity)
- intermediate archive (disks and tape drives)
- long-term archive (tape drives)

Sub-cluster for data analytics

- 192 nodes, 512 GB RAM, 2x64 cores AMD Rome EPYC 7702
- CentOS 7
- batch partition `romeo`
- for Intel compiler use `intel/2020a` toolchain with `-mavx2 -fma`
- use Intel MKL with environment `export MKL_DEBUG_CPU_TYPE=5`

More information on https://doc.../jobs_and_resources/rome_nodes

Alpha Centauri

Sub-cluster for AI-related computations

- 34 nodes
- 8 × NVIDIA A 100-SXM4, 40GB RAM
- 2 × AMD EPYC CPU 7352, 1 TB RAM
- 3.5 TB local NVMe

More information on https://doc.../jobs_and_resources/alpha-centauri

HPE Superdome Flex

Large shared-memory system (HPE Superdome Flex) for memory-intensive computing (2020)

- 48 TB shared memory
- 10.6 TFlop/s peak performance
- 896 cores Intel 8276M CPU (Cascade Lake) 2.20GHz
- 370 TB local NVMe storage mounted at `/nvme`
- RHEL 7
- batch partition `julia`

Attention: Software based on OpenMPI should not run here.

More information on https://doc.../jobs_and_resources/sd_flex

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Overview

Hierarchy of file systems: **speed** vs. **size** vs. **duration**:

- local SSD `/tmp`
- BeeGFS for data analytics `/beegfs`
- HPC global `/ssd`
- HPC global `/scratch`
- HPC global `/projects`, `/home`
- warm archive `/warm_archive`
- TUD global intermediate archive
- TUD long term storage for research data - `OPARA`

The **number of files** (billions) is critical for all file systems.

Local disk

Recommended at Taurus:

- SSD: best option for lots of small I/O operations, limited size (~ 100GB),
- volatile: data will be deleted automatically after finishing the job,
- Each node has its own local disk.

Attention Multiple processes on the same node share their local disk.

Mounted at `/tmp`

High-IOPS file system

Fastest parallel file systems (IOPS) at each HPC machine:

- large parallel file system for high number of I/O operations,
- management via workspaces,
- All HPC nodes share this file system.

Attention Data might get lost.

Mounted at `/ssd`

BeeGFS file system(s)

Parallel file systems for partition

- large parallel file system for high number of I/O operations,
- based on NVMe,
- management via workspaces,
- “ml” and haswell nodes within “island 6” (accessible with additions Slurm option `--constraint=DA`)

Attention: Data might get lost.

Mounted at `/beegfs`

Scratch file system

Fastest parallel file systems (streaming) at each HPC machine:

- large parallel file system for high bandwidth,
- data may be deleted after 100 days,
- management via workspaces,
- All HPC nodes share this file system.

Attention: Data might get lost. Probably not.

Mounted at `/scratch`

Permanent file systems

Common file system for all ZIH's HPC machines:

- Very slow and small, but with multiple backups.
- Deleted files are accessible via the logical `.snapshot` directory. This directory contains weekly, daily, and hourly snapshots. Copy your file to where you need it.
- Paths to permanent storage are
 - `/home/<login>` (20 GB !) and
 - `/projects/<projectname>` - mounted read-only on compute nodes!with different access rights (cf. Terms of Use).
- All HPC systems of ZIH share these file systems.

Warm archive

Large storage at each HPC machine:

- large parallel file system for moderately high bandwidth,
- management via workspaces,
- all HPC nodes share this file system,
- **mounted read-only on compute nodes**

Mounted at `/warm_archive`

Intermediate and long-term archive

Common tape based file system:

- really slow and large,
- expected storage time of data: about 3 years,
- access under user's control.

Best practice:

- "Low" file count is important.
- Tar and zip your files. (Use datamover nodes.)
- LTO-6 tapes have a capacity of 2.5 TB. Please ask before you plan to archive files larger than 200 GB.

Automated workflows

vs. ...manual control

...

- A set of rules specifies how and when data is moved between storage systems.
- Who defines these rules? User or administrator?
- When are actions triggered?

- User moves her own data.
- User knows when data can be stored away or have to be retrieved for next processing steps.

In general, users are responsible for their data.

Admins care for usability and data integrity.

See https://doc.../data_lifecycle/overview

Tool for users to manage their storage demands

https://doc.../data_lifecycle/workspaces

- In HPC, projects (and data) have limited lifetime.
- User creates a workspace with defined expiration date.
- User can get an email (or calendar entry) before expiration.
- Data is deleted automatically (cf. comment).
- Life-span can be extended twice.

Maximum initial lifetime depends on file system:

Storage system	Duration	Remarks
beegfs	30 days	High-IOPS file system, NVMe.
ssd	30 days	High-IOPS file system, SSDs.
scratch	100 days	High streaming bandwidth, disks.
warm_archive	1 year	Capacity file system, disks.

Workspace - examples

```
nelle@tauruslogin3:~> ws_find -l
available filesystems:
warm_archive
scratch
ssd
beegfs_global0
```

Allocation

```
nelle@tauruslogin3:~> ws_allocate -F ssd SPECint
Info: creating workspace.
/lustre/ssd/ws/nelle-SPECint
remaining extensions : 2
remaining time in days: 5
```

Notification:

```
nelle@tauruslogin3:~> ws_send_ical -m nelle@tu-dresden.de \
-F ssd SPECint
Sent reminder for workspace SPECint to nelle@tu-dresden.de
please do not forget to accept invitation
```

→Calendar invitation: "Workspace SPECint will be deleted on host Taurus"

Workspace - examples

List all allocated workspaces

```
nelle@tauruslogin3:~> ws_list
id: SPECint
workspace directory   : /lustre/ssd/ws/nelle-SPECint
remaining time        : 4 days 23 hours
creation time         : Wed Sep 18 09:41:08 2019
expiration date       : Mon Sep 23 09:41:08 2019
filesystem name       : ssd
available extensions  : 2
```

Extend the life time of a workspace

```
nelle@tauruslogin3:~> ws_extend -F ssd SPECint 10
Info: extending workspace.
/lustre/ssd/ws/mark-SPECint
remaining extensions   : 1
remaining time in days: 10
```

Attention: Extension starts **now**, not at the end of the life time

```
nelle@tauruslogin3:~> ws_list -F ssd
id: SPECint
workspace directory   : /lustre/ssd/ws/nelle-SPECint
remaining time        : 9 days 23 hours
creation time         : Wed Sep 18 09:43:01 2019
expiration date       : Sat Sep 28 09:43:01 2019
filesystem name       : ssd
available extensions  : 1
```

Workspace - examples

Workspace within a job

```
#!/bin/bash
#SBATCH --partition=haswell
...
COMPUTE_DIR=gaussian_${SLURM_JOB_ID}
ws_allocate -F ssd $COMPUTE_DIR 7
export GAUSS_SCRDIR=/ssd/ws/$USER-$COMPUTE_DIR
srun g16 inputfile.gjf logfile.log

#Tell the "ws expirer" to delete without grace period
ws_release -F ssd $COMPUTE_DIR
```

Expiration of workspaces

- expired workspaces are moved automatically to another location
- after a certain time span (30...60d) they are marked for deletion
- during this time workspaces can be restored by the user using `ws_restore`
- Deletion is final - pay attention to expiration date!

Data transfer

Special data transfer nodes are running in batch mode to comfortably transfer large data between different file systems:

- Commands for data transfer are available on all HPC systems with prefix **dt**: dtcp, dtls, dtmv, dtrm, dtrsync, dttar.
- The transfer job is then created, queued, and processed automatically.
- User gets an email after completion of the job.
- Additional commands: dtinfo, dtqueue.

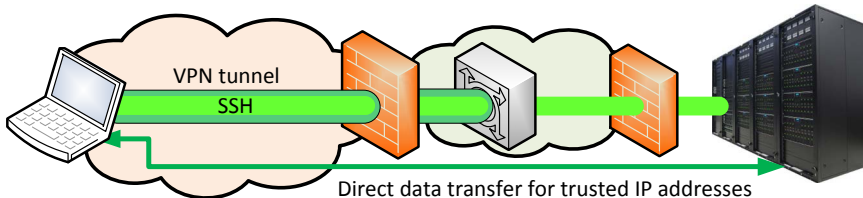
Very simple usage like

```
dttar -czf /warm_archive/ws/jellyfish-2020/results_20190820.tgz \  
/scratch/ws/jellyfish-2020/results
```

See <https://doc.../data-transfer/overview>

External data transfer

The nodes `taurusexport.hrsk.tu-dresden.de` allow access with high bandwidth bypassing firewalls



Restrictions

- trusted IP addresses only
- protocols: sftp, rsync

Agenda

- 1 Linux from the command line
- 2 HPC Environment at ZIH
 - Access to HPC systems at ZIH
 - Compute hardware
 - HPC file systems
 - Software environment at ZIH
- 3 Batch System
- 4 Software Development at ZIH's HPC systems
- 5 HPC Support

Modules

Installed software is organized in modules.

A module is a user interface, that:

- allows you to easily switch between different versions of software
- dynamically sets up user's environment (`PATH`, `LD_LIBRARY_PATH`, ...) and loads dependencies.

Private modules files are possible (e.g. group-wide installed software).

<https://doc.../software/modules>

Installed Software

At the moment 969 Packages!

abacus, abinit, abs1-py, ace, acct, adoic, advisor, afni, alabaster, alembic, algorithm, alias, amber, amdlibm, amdprop, anaconda3, ansys, ansyssem, ant, antlr, ants, anyevent, appipkg, app, appconfig, appdirs, apr, apr-util, archive, archspec, argparse, arpack-ng, array, arrow, asciidoc, ase, asm, asn1crypto, astunparse, async-generator, at-spi2-atk, at-spi2-core, atk, atomicwrites, atompaw, attr, attr, authen, auto_mll, autoconf, autoloader, automake, autotools, avs-express, b, babel, backcall, backports-functools-lru-cache, basemap, batchspawner, bazel, bcrypt, bigdataframeworkconfigure, binutils, bison, bitstring, bleach, blist, blitz++, bokeh, boolean, boost, boost.python, bottleneck, bulxmpi, business, bz2ip2, cachecontrol, cachetools, cachi, cairo, canary, capture, carp, casita, cdo, cepk, cereal, certifi, cffi, cfitsio, cftime, cg, cgall, cgn, chardet, check, chrpath, clang, class, cleo, cliff, clhep, click, clickit, clone, cloudpickle, clustalw2, cmake, collect, colorama, common, comsol, onfig, configparser, configurable-http-proxy, conn, constant, contextlib2, cp2k, cpanplus, cpufrequtils, crashtest, crypt, cryptography, ctags, ctool, cube, cubegui, cubelib, cubew, cubewriter, cuda, cudacore, cudnn, curl, cusp, cwd, cyclo, cython, dalton, damask, darshan, dash, dask, dask-jobqueue, dask-mpi, data, dataheap, date, datetime, db, dbd, dbi, dbx, dbus, ddt, deap, decorator, defusedxml, delft3d, devel, devel-nyprof, dftb+, dftd3-lib, digest, dill, dist, distlib, distributed, dmtcp, doctest, docutils, dolfin, double-conversion, doxygen, dtcmp, dune, dyninst, easybuild, eccodes, ecda, eigen, eiros, elpa, elsi, emacs, email, eman2, emboss, encode, insight, endpoints, enum34, erlangotp, error, espresso, etsf.io, eval, exception, execnet, expat, expect, exporter, extrae, extutils, fennec, ffi, ffmpeg, fftw, fiat, file, filelock, firestarter, flair, flair-geoviewer, flann, flatbuffers, flatbuffers-python, flex, flink, flit, flit-core, fltk, fme, font, fontconfig, foss, fosscuda, fox, fplo, freecad, freeglut, freesurfer, freetype, fridibi, fsl, fsspec, funcsig, funcutils32, future, futures, ga, games, gams, gast, gaussian, gaussview, gautomatch, gc, gcc, gcccore, gcccuda, gcl, gcovr, gctf, gdal, gdb, gdk, gdk-pixbuf, gdrCOPY, geant4, geany, geos, getopt, gettext, gflags, ghc, ghostscript, giflib, git, git-cola, git-lfs, gitpython, g2ps, glew, glib, glibmm, glm, glob2, globalarrays, glog, glpk, gmap, gmock, gmp, gmsh, gnuplot, go, gobject-introspection, golf, gomkl, gompic, google-auth, google-auth-oauthlib, google-pasta, gpaw, guile-setup, gperftools, gpi2, gpi2-mpi, gspdevkit, graph, graphicsmagick, grib-api, grid, groff, gromacs, grpcio, gsl, gsmpi, gsof, gtk+, guile, gulp, gurobi, gviz-api, gzip, h5py, h5utils, hadoop, harfbuzz, hash, haskell-platform, hdeem, hdf, hdf5, hdfview, heaptict, help2man, hip, hoond-blue, horovod, hpc-x, hpx, html, HTML5lib, http, http, hwloc, hyperxex, hypothesis, hypre, icc, iccfort, icu, idna, if, ifort, iimpi, ima, imagemagick, imagesize, imkl, impi, importlib-metadata, importlib-metadata, importlib-resources, iniconfig, inline, inspector, intel, intelpi, intervaltree, inttool, intreehooks, io, iomkl, iompi, iotop, iotrack, ipaddress, ipc, ipopt, ipykernel, ipython, ipython.genutils, ipywidgets, isl, isodate, itac, jasper, java, jedi, jeepney, jinja2, joblib, json, json5, jsoncpp, jsonschema, julia, junit, jupyter-telemetry, jupyter-client, jupyter-contrib-core, jupyter-core, jupyter-nbextensions-configurator, jupyterhub, jupyterhub-jwt-authenticator-v2, jupyterhub-ldapauthenticator, jupyterhub-nativeauthenticator, jupyterhub-simplespawner, jupyterhub-systemdspawner, jupyterlab, jupyterlab_server, keras, keras-preprocessing, keyring, keyrings.alt, kim-api, kiwisolver, knime, lame, lammmps, lbfsgs, ldp3, liac-arff, libarchive, libcerf, libctb, libcircle, libdap, libdrm, libelf, libepoxy, libevent, libfabric, libffi, libgd, libgeotiff, libglu, libglvnd, libgridxc, libharu, libiconv, libint, libjpeg-turbo, libmatheval, libnbc, libpciaccess, libpng, libpsml, libreadline, libsigc++, libsndfile, libsqlite, libssh2, libsvm, libtiff, libtirpc, libtool, libunistring, libunwind, libuiid, libvdxw, libxc, libxml++, libxml2, libxslt, libxsmm, libyaml, liggghts, likwid, lingua, list, littlecms, llvm, lmdb, lo2s, locale, lockfile, log, log4cxx, logger, lpsolve, ls-dyna, ls-dyna-usermat, ls-opt, ls-prepost, lumical, lwgrp, lwp, lz4, m4, m4ri, magma, mail, make, make, make, makeinfo, mako, map, markdown, markupsafe, math, mathematics, matio, matlab, matplotlib, maven, maxima, mce, mdanalysis, med, meep, mercurial, mesa, meson, mesquite, meta, metis, mime, miniconda2, miniconda3, mistune, mixin, mkl, mkl-dnn, mock, modenv, module, molmod, mongod, moo, moose, moosex,



Module environments

Different module environments:

- scs5 - for software built from “recipes” with EasyBuild (default), x86 nodes
- ml - software for machine learning nodes, IBM Power
- hiera - hierarchical module environment (redundant environment)

```
~ > module load modenv/scs5
The following have been reloaded with a version change:
  1) modenv/classic => modenv/scs5

~ > module load modenv/ml
The following have been reloaded with a version change:
  1) modenv/scs5 => modenv/ml
```

Module usage

Use `module spider` to identify your desired module and version (case-sensitive):

```
~> module spider CP2K
-----
CP2K:
-----
Description:
  CP2K is [...]
Versions:
  CP2K/5.1-intel-2018a
  CP2K/6.1-foss-2019a-spglib
  CP2K/6.1-foss-2019a
  CP2K/6.1-intel-2018a-spglib
  CP2K/6.1-intel-2018a
Other possible modules matches:
  cp2k
-----
To find other possible module matches execute:
  $ module -r spider '.*CP2K.*'
-----
For detailed information about a specific "CP2K" package (including h
Note that names that have a trailing (E) are extensions provided by c
For example:

$ module spider CP2K/6.1-intel-2018a
```

Module usage

Information from `module spider`

```
~> module spider SciPy-bundle/2020.03-Python-3.8.2
-----
SciPy-bundle: SciPy-bundle/2020.03-Python-3.8.2
-----

Description:
  Bundle of Python packages for scientific software
You will need to load all module(s) on any one of the lines below to
  modenv/hiera  GCC/9.3.0  OpenMPI/4.0.3
  modenv/hiera  iccifort/2020.1.217  impi/2019.7.217

Help:
  Description
  =====
  Bundle of Python packages for scientific software

  More information
  =====
  - Homepage: https://python.org/

  Included extensions
  =====
  deap-1.3.1, mpi4py-3.0.3, mpmath-1.1.0, numpy-1.18.3, pandas-1.0.
```


Modules for different architectures

Not all software modules are available on all hardware platforms.

Information from [ml_arch_avail](#)

```
~> ml_arch_avail CP2K
CP2K/6.1-foss-2019a: haswell, rome
CP2K/5.1-intel-2018a: sandy, haswell
CP2K/6.1-foss-2019a-spglib: haswell, rome
CP2K/6.1-intel-2018a: sandy, haswell
CP2K/6.1-intel-2018a-spglib: haswell
```

```
~> ml_arch_avail tensorflow|sort
TensorFlow/1.10.0-fosscuda-2018b-Python-3.6.6: sandy, haswell, rome
TensorFlow/1.14.0-PythonAnaconda-3.6: ml
TensorFlow/1.15.0-fosscuda-2019b-Python-3.7.4: haswell, rome, ml
TensorFlow/1.15.0-fosscuda-2019b-Python-3.7.4: haswell, rome, ml
TensorFlow/1.8.0-foss-2018a-Python-3.6.4-CUDA-9.2.88: sandy, haswell, rome
TensorFlow/2.0.0-foss-2019a-Python-3.7.2: sandy, haswell, rome
TensorFlow/2.0.0-fosscuda-2019b-Python-3.7.4: haswell, rome, ml
TensorFlow/2.0.0-fosscuda-2019b-Python-3.7.4: haswell, rome, ml
TensorFlow/2.0.0-PythonAnaconda-3.7: ml
TensorFlow/2.1.0-fosscuda-2019b-Python-3.7.4: haswell, rome, ml
TensorFlow/2.1.0-fosscuda-2019b-Python-3.7.4: haswell, rome, ml
TensorFlow/2.2.0-fosscuda-2019b-Python-3.7.4: ml
```

Module commands

`module avail` - lists all available modules (in the current module environment)

`module spider` - lists all available modules (across all module environments)

`module list` - lists all currently loaded modules

`module show <modname>` - display informations about <modname>

`module load <modname>` - loads module `modname`

`module save` - saves the current modules, to be reloaded at the next login

`module rm <modname>` - unloads module `modname`

`module purge` - unloads all modules

Modules for HPC applications

Loading compiler, MPI, and numeric library (MKL)

```
~> module load intel
Module intel/2020a and 9 dependencies loaded.

~> module list
Currently Loaded Modules:
  1) modenv/scs5                      (S)   5) iccifort/2020.1.217
  2) GCCcore/9.3.0                   6) numactl/2.0.13-GCCcore-9.3.0
  3) zlib/1.2.11-GCCcore-9.3.0       7) UCX/1.8.0-GCCcore-9.3.0
  4) binutils/2.34-GCCcore-9.3.0     8) impi/2019.7.217-iccifort-2020

~> mpicc -show
icc -I/sw/installed/impi/2019.7.217-iccifort-2020.1.217/intel64/include

~> mpicc hello.c

~> srun -n 4 -t 1 -N 1 --mem-per-cpu=500 ./a.out
```

Commercial codes requiring licenses (Matlab, Ansys)

- basic principle: do not use these extensively, we have only a limited number of licenses!
- Matlab: use the Matlab compiler
<https://doc.../software/mathematics/#matlab>

Containers

- Singularity as container environment on Taurus
- Docker containers can easily be converted
- more information at <https://doc.../software/containers>

Agenda

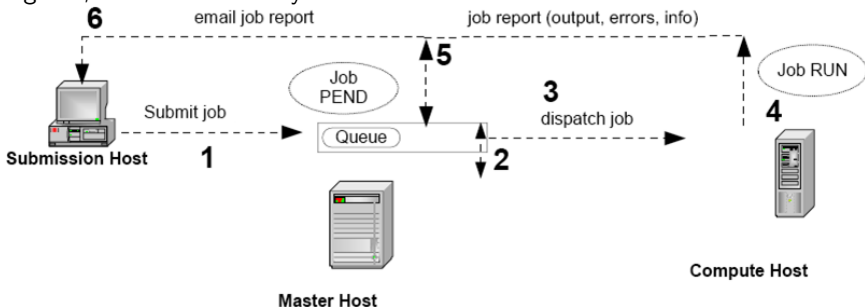
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Why do we need a batchsystem?

- Find an adequate compute system (partition/island) for our needs.
- All resources in use? - The batch system organizes the queueing and messaging for us.
- Allocate the resource for us.
- Connect to the resource, transfer run-time environment, start the job.

Workflow of a batch system

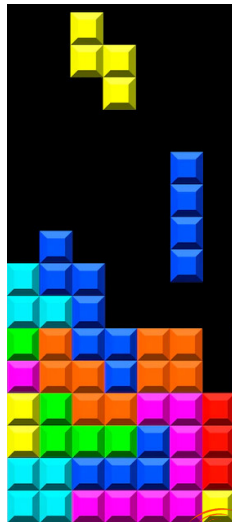
Agreed, we need a batchsystem.



Multi-dimensional optimizations

Optimization goals:

- **Users want short waiting time.**
- Queueing priorities according to:
 - waiting time of the job (+),
 - used CPU time in the last 2 weeks (-),
 - remaining CPU time for the HPC project (+),
 - duration of the job (-)
- Limited resources require efficient job placement:
 - number of compute cores / compute nodes,
 - required memory per core for the job,
 - maximum wall clock time for the job



Useful functions of a batchsystem

Basic user functions:

- submit a job,
- monitor the status of my job (notifications),
- cancel my job

Additional functions:

- check the status of the job queue,
- handle job dependencies,
- handle job arrays

Job submission: required information

In order to allow the scheduler an efficient job placement it needs these specifications:

- requirements: cores, memory per core, (nodes), additional resources (GPU)
- maximum run-time,
- HPC project (normally use primary group which gives `id`),
- who gets an email on which occasion,

... to run the job:

- executable with path and command-line,
- environment is normally taken from the submit shell.

Queueing order

Factors that determine the position in the queue:

- **Total share of the project:**
remaining CPU quota, new project starts with 100% (updated daily)
- **Share within the project:**
balance equal chances between users of one project
- **Age:**
the longer a job waits the higher becomes its priority
- **Recent usage:**
the more CPU time a user has consumed recently the lower becomes her priority,
- **Quality of Service:**
additional control factors, e.g. to restrict the number of long running large jobs

Pre-factors are subject to adaptations by the batch system administrators.

Overview Slurm

submit a job script	<code>sbatch</code>
run interactive job	<code>srun --pty ...</code>
monitor a job status	<code>squeue</code> - Not permanently!
kill a job	<code>scancel</code>
cluster status	<code>sinfo</code> - Not permanently!
host status	<code>sinfo -N</code>
max job time	<code>-t <[hh:]mm:ss></code>
number of processes	<code>-n <N></code>
number of nodes	<code>-N <N></code>
MB per core	<code>--mem-per-cpu</code>
output file	<code>--output=result_%j.txt</code>
error file	<code>--error=error_%j.txt</code>
notification (TUD)	<code>--mail-user <email></code>
notification reason	<code>--mail-type ALL</code>

Overview Slurm

job array	<code>--array 3-8</code>
job ID	<code>\$SLURM_ARRAY_JOB_ID</code>
array idx	<code>\$SLURM_ARRAY_TASK_ID</code>
redirect stdin and stdout (interactive jobs)	<code>--pty</code>
X11 forwarding	<code>--x11=first</code>

Examples for parameters for our batch systems can be found at https://doc.../jobs_and_resources/slurm .

- job arrays,
- job dependencies,
- multi-threaded jobs

Slurm partitions

- **haswell** – largest compute partition, Intel x86_64 based, most software runs here. Differenz sizes of RAM managed by job submit plugin.
- **broadwell** – 32 nodes comparable to **haswell**. Intel x86_64 based. Most software runs here.
- **romeo** – powerful compute partition, AMD x86_64 based, most software should run here.
- **julia** – largest SMP node, Intel x86_64 based. For memory-consuming software. Don't use OpenMPI.
- **gpu2** – GPU partition, Intel x86_64 based. Most GPU software runs here.
- **ml** – powerful GPU partition for Machine Learning. IBM Power based. Only special software runs here.
- **hpd1f** – GPU partition for deep learning project, Intel x86_64 based. Most GPU software runs here.
- **alpha** – powerful GPU partition for ScaDS.AI. (Only short jobs (<24h).)
- **interactive** – **haswell** nodes for interactive jobs
- **gpu2-interactive** – **gpu2** nodes for interactive jobs
- **haswell64ht** – **haswell** nodes with activated HyperThreads

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Slurm examples

Slurm interactive example:

```
srun --ntasks=1 --cpus-per-task=1 --time=1:00:00 \  
--mem-per-cpu=1000 --pty -p interactive bash
```

Slurm X11 example:

```
module load matlab  
srun --ntasks=1 --cpus-per-task=8 --time=1:00:00 \  
--mem-per-cpu=1000 --pty --x11=first -p interactive matlab
```

Remarks:

- default partition Taurus: `-p haswell,broadwell` – maybe also `romeo`?
- normally: shared usage of resources
- if a job asks for more memory it will be canceled by Slurm automatically
- a job is confined to its requested CPUs

Slurm examples

Normal MPI parallel job `sbatch <myjobfile>`

```
#SBATCH --partition=haswell,romeo
#SBATCH --time=8:00:00
#SBATCH --ntasks=64
#SBATCH --mem-per-cpu=780
#SBATCH --mail-type=end
#SBATCH --mail-user=ulf.markwardt@tu-dresden.de
#SBATCH -o output_%j.txt
#SBATCH -e stderr_%j.txt
srun ./path/to/binary
```

Remark: The batch system is responsible to minimize number of nodes.

Slurm examples

Requesting multiple GPU cards

```
#SBATCH --partition=gpu
#SBATCH --time=4:00:00
#SBATCH --job-name=MyGPUJob
#SBATCH --nodes=16
#SBATCH --ntasks-per-node=2
#SBATCH --cpus-per-task=8
#SBATCH --gres=gpu:2
#SBATCH --mem-per-cpu=3014
#SBATCH --mail-type=END
#SBATCH --mail-user=ulf.markwardt@tu-dresden.de

#SBATCH -o stdout
#SBATCH -e stderr
echo 'Running program...'
```

Slurm: Job monitoring

Basic question: Why does my job not start? Try: `whypending <jobid>`

```
> whypending 4719686
Reason Priority means that the job can run as soon as resources free up
Position in queue: 5873
Estimated start time: Fri Sep 18 05:16:29 2020
=====
Resource Availability Information:
=====
Your job is requesting:
  Time Limit: 6-20:00:00
  Nodes: 1
  Cores: 24
  Memory per core: 1500M
  Total Memory: 36000M
  QOS: long
  Features:
  Partitions: haswell64,broadwell

The following nodes are available in partition(s) haswell64,broadwell:
Total: 28
Fully Idle: 0
Partially Idle: 28 (misleading... see note below)
  1 cores free: 5
  2 cores free: 5
  3 cores free: 4
  4 cores free: 7
```

Slurm: Fair share monitoring

Is my fair share really so low???

```
> sshare -u mark -A swtest
```

```
Accounts requested:      : swtest
```

Account	User	Raw Shares	Norm Shares	Raw Usage	Effectv Usage	FairShare
-----	----	-----	-----	-----	-----	-----
swtest		0	0.000000	680889	0.000033	0.000000
swtest	mark	parent	0.000000	16789	0.000001	0.000000

Project information

Look at the login screen. Or [showquota](#)

```
CPU-Quotas as of 2020-09-14 10:54
      Project      Used(h)    Quota(h)          % Comment
      swtest       648440      300000      216.1 Limit reached (SOFT)
* Job priority is minimal for this project

Disk-Quotas for /projects as of 2020-09-14 10:51
      Project      Used(GiB)    Quota(GiB)          % Comment
      swtest       157.5         300.0         52.5
```

As soon as a project reaches its CPU limit the share drops to 0.

As soon as a project reaches its DISK limit submission is blocked.

→ Clean up first!

What is fair...?

Fair share of a project is based on

- leftover CPU quota of the current month: *RawShare* → *NormShares*
- used resources “during the last few days” *RawUsage* → *EffektivUsage*
CPUs usage is summed up with an exponential decay
(half-value period 1 day)

Account	RawShares	NormShares	RawUsage	EffectvUsage	FairShare
p_abc	369	0.001355	123069773	0.034009	0.030841
p_def	342	0.001256	1962604	0.000546	0.941520

$$FairShare = 2^{\frac{-EffektivUsage}{d \cdot NormShares}} \quad (\text{dampening factor } d = 5).$$

See: https://slurm.schedmd.com/priority_multifactor.html

System information

Look at the login screen. Or `nodestat`

```
> nodestat
```

```
-----
nodes available:    1758/1967    nodes unavailable: 209/1967
gpus  available:    464/579     gpus  unavailable: 115/579
-----+-----
```

```
jobs running:      849         |    cores in use:      54764
jobs pending:      3397        |    |    cores unavailable: 5884
jobs suspend:       0          |    gpus  in use:      258
jobs damaged:       1          |
-----
```

CORES / GPUS

	free		resv		down		total	
-----+-----+-----+-----								
Haswell 64GB:	405		10536		672		31248	(mem-per-cpu <= 2583)
Haswell 128GB:	369		0		0		2016	(mem-per-cpu <= 5250)
Haswell 256GB:	612		0		0		1056	(mem-per-cpu <= 1058)
-----+-----+-----+-----								
Broadwell 64GB:	45		0		0		896	(mem-per-cpu <= 2214)
-----+-----+-----+-----								
Rome 512GB:	4818		4480		768		24576	(mem-per-cpu <= 1972)
-----+-----+-----+-----								
SMP 1TB:	0		0		64		64	(mem-per-cpu <= 3187)
SMP 2TB:	224		0		0		280	(mem-per-cpu <= 3650)
-----+-----+-----+-----								
GPUs K20X:	0		0		64		64	(partition = gpu1)
GPUs K60:	19		208		12		248	(partition = gpu2)

Simple job monitoring

Job information

```
~ > sjob 4843539
JobId=4843539 UserId=mark(19423) Account=hpcsupport JobName=bash
TimeLimit=1-00:00:00 NumNodes=171 NumCPUs=4096
TRES=cpu=4096,mem=1200G,node=1,billing=4096 Partition=haswell64,rome
JobState=PENDING Reason=Resources Dependency=(null)
Priority=49533 QOS=normal
StartTime=Unknown SubmitTime=2020-09-18T14:16:06
```


Detailed job monitoring

Detailed job information

```
~ > scontrol show job 4843539
JobId=4843539 JobName=bash
UserId=mark(19423) GroupId=hpcsupport(50245) MCS_label=N/A
Priority=49533 Nice=0 Account=hpcsupport QOS=normal
JobState=PENDING Reason=Resources Dependency=(null)
Requeue=1 Restarts=0 BatchFlag=0 Reboot=0 ExitCode=0:0
RunTime=00:00:00 TimeLimit=1-00:00:00 TimeMin=N/A
SubmitTime=2020-09-18T14:16:06 EligibleTime=2020-09-18T14:16:06
AccrueTime=2020-09-18T14:16:06
StartTime=Unknown EndTime=Unknown Deadline=N/A
SuspendTime=None SecsPreSuspend=0 LastSchedEval=2020-09-18T14:16:26
Partition=haswell64,romeo AllocNode:Sid=tauruslogin3:5741
ReqNodeList=(null) ExcNodeList=(null)
NodeList=(null)
NumNodes=171 NumCPUs=4096 NumTasks=4096 CPUs/Task=1 ReqB:S:C:T=0:0:*
TRES=cpu=4096,mem=1200G,node=1,billing=4096
Socks/Node=* NtasksPerN:B:S:C=0:0:*:1 CoreSpec=*
MinCPUsNode=1 MinMemoryCPU=300M MinTmpDiskNode=0
Features=(null) DelayBoot=00:00:00
OverSubscribe=OK Contiguous=0 Licenses=(null) Network=(null)
Command=bash
WorkDir=/home/h3/mark
Comment=<<
```

Slurm tools

`scontrol show ...`

- `job <number>` – job information
- `reservation [ID]` – information on current and future reservations
- `node <name>` – status of a node

More tools

- `scancel` – cancel job
- `squeue` – show current queue jobs
- `sprio` – show priorities of current queue jobs
- efficiently distribute/collect data files to/from compute nodes: `sbcaster`, `sgather`
- `sinfo` – cluster information (`-T` : reservations)

See man pages or documentation at <http://slurm.schedmd.com>

Still... not starting

The system looks empty, but no job starts. Especially not mine!

- Maybe a reservation prevents my job from starting (`sinfo -T`)
- Maybe an older large job is scheduled and waits for resources:

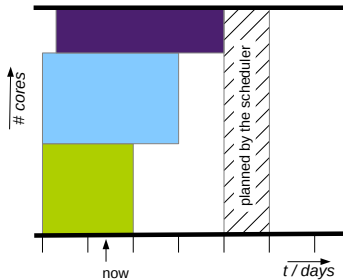
```
~ > sprio -S "-y" | head -n 20
```

JOBID	PARTITION	PRIORITY	SITE	AGE	FAIRSHARE	JOBSIZE	QOS
4832990	haswell64	72001	0	11	26987	4	0
4832990	broadwell	72001	0	11	26987	4	0
4842303	haswell64	65993	0	3	26987	4	0
4842303	broadwell	65993	0	3	26987	4	0

Here is job 4832990 with a very high priority, scheduled for a certain time (see `scontrol show job`) . If my job would finish before that one it could be backfilled.

- Maybe fragmentation would be too high.

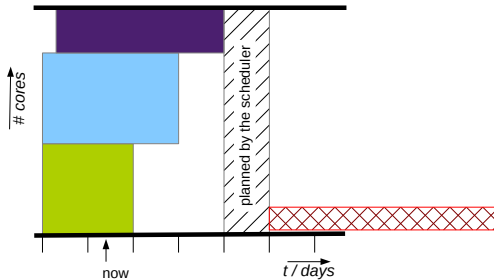
Backfilling



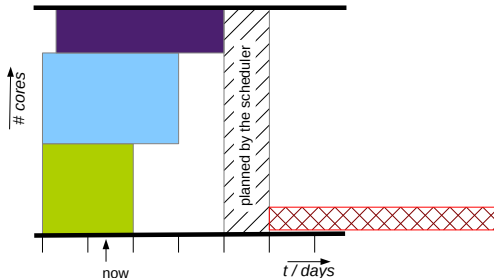
My job to be placed:



Backfilling



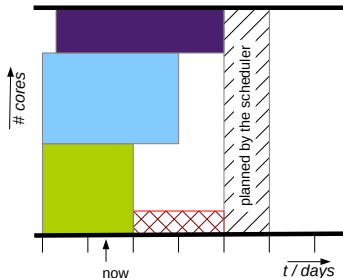
Backfilling



I know my job better:

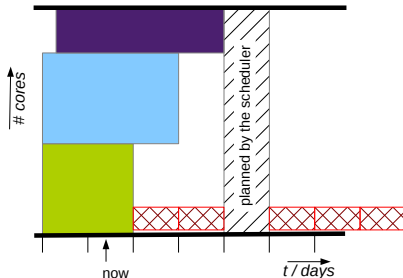


Backfilling



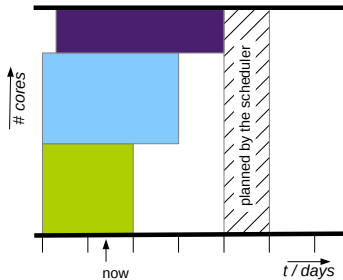
Estimate the maximum run-time of your job!

Backfilling



Try to use shorter jobs!

Backfilling



Allow checkpointing:



Checkpoint / restart

Self-developed code:

- identify best moment to dump “all” data to the file system
- implement data export and import
- implement restart

Commercial or community software

- Check if you can use built-in CR-capabilities of your application:
(e.g. Abaqus, Amber, Gaussian, GROMACS, LAMMPS, NAMD, NWChem, Quantum Espresso, STAR-CCM+, VASP)
- If application does not support checkpointing:
 - ① `module load dmtcp`
 - ② modify your batch script like this:
`srun dmtcp_launch --ib --rm ./my-mpi-application`
 - ③ run the modified script like `dmtcp_sbatch -i 28000,800 mybatch.sh`
This creates chain jobs of length 28000 s, planning 800 s for I/O
- more details at
https://doc.../jobs_and_resources/checkpoint_restart

Make use of heterogeneity of the system

- number of cores per node differ (24, 32, 56, ...)
- memory per core available to the application is less then installed memory (OS needs RAM, too). Stay below the limits to increase the number of potential compute nodes for your job!
- Current numbers for Taurus (as of 2019):
 - 85% of the nodes have 2 GiB RAM per core. Slurm: 1875
 - 10% of the nodes have 4 GiB RAM per core. Slurm: 3995
 - 5% of the nodes have 8 GiB RAM per core. Slurm: 7942
 - 5 large SMP nodes have 56 cores, 2 TiB. Slurm: 36500
 - GPU nodes: 3/2.6 GiB. Slurm: 3000/2538
- AMD Rome nodes (128 cores, 512 GB): 3945
- HPE SDFlex (896 cores, 48 TB): 54006

Let Taurus work!

The batch system (Slurm) manages resources (heterogeneity) and job requirements (cores, RAM, runtime) to optimally use the system.

Normal jobs

- run without interaction (everything prepared in input data and scripts)
- start whenever resources for the particular jobs are available (+ priority)
- can run over hundreds of cores in parallel
- can run as a job array with thousands of independent single core jobs

Run-time considerations

- the larger a system the higher the chance of hitting a problem
- maximum run time: 7 days (today)
- use checkpoint / restart and chain jobs for longer computations
 - controlled by the application
 - controlled by Slurm + additional helper scripts

Nelle's Pipeline III

Let the batch system work... (analyze 1520 files)

```
~/Jellyfish2020 > ls scan_results  
spec_0001.out spec_0002.out spec_0003.out spec_0004.out ...
```

Nelle's Pipeline III

Let the batch system work... (analyze 1520 files)

```
~/Jellyfish2020 > ls scan_results  
spec_0001.out spec_0002.out spec_0003.out spec_0004.out ...
```

```
#!/bin/bash  
#SBATCH -J Jellyfish  
#SBATCH --array 1-1520  
#SBATCH -o jellyfish-%A_%a.out  
#SBATCH -e jellyfish-%A_%a.err  
#SBATCH -n 1  
#SBATCH -c 1  
#SBATCH -p romeo  
#SBATCH --mail-type=end  
#SBATCH --mail-user=your.name@tu-dresden.de  
#SBATCH --time=08:00:00  
calc_statistics scan_results/spec_%4a.out
```

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#SBATCH --time=08:00:00  
calc_statistics scan_results/spec_%4a.out
```

```
~/Jellyfish2020 > sbatch jellyfish2020.slurm
```

Working on Taurus

Interactive jobs

- for pre- or post- processing, compiling and testing / development
- can use terminal or GUI via X11
- several partitions (e.g. `interactive`) are reserved for these jobs.

For rendering applications with GPU support: Nice Desktop Cloud Virtualization (DCV)

- licensed product installed on Taurus
- e.g. rendering with ParaView using GPUs

Remember JupyterHub (<https://doc.../access/jupyterhub>).

High utilization - good for “us” - bad for the users?

- short jobs lead to higher fluctuation (limits 1/2/7 days)
- interactive partition is nearly always empty
 - restricted to one job per user
 - default time 30 min, maximum time 8h
- plan resources in advance (publication deadline) - reserve nodes

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Software development

At https://doc.../software/software_development_overview the following topics are addressed:

- compilers
- mathematical libraries
- debugging
- performance tuning

Available compilers

Which compilers are installed?

- Starting point: <https://doc.../software/compiler>
- Up-to-date information: `module spider ...`

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Which one is “the best”?

- Newer versions are better adapted to modern hardware.
- Newer versions implement more features (e.g. OpenMP 4.0, C++11, Fortran 2010).
- GNU compilers are most portable.
- Listen to hardware vendors. (But not always.)

Available compilers

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- GNU compilers are most portable.
- Listen to hardware vendors. (But not always.)

→ There is no such thing as “best compiler for all codes”.

Expensive operations

Time consuming operations in scientific computing:

- division, power, trigonometric and exponential functions,
- un-cached memory operations (bandwidth, latency)

Expensive operations

Time consuming operations in scientific computing:

- division, power, trigonometric and exponential functions,
- un-cached memory operations (bandwidth, latency)

How to find performance bottlenecks?

- Tools available at ZIH systems (PIKA, perf, hpctoolkit, Vampir, PAPI counters),
- see https://doc.../software/software_development_overview
- additional courses in performance optimization
- Ask ZIH staff about your performance issues!

Low hanging fruits

What is the needed floating point precision?

32 bit vs. 64 bit impacts on

- memory footprint,
- computing speed.

Low hanging fruits

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What is the needed floating point accuracy?

- very strict (replicable),
- slightly relaxed (numerical stability),
- very relaxed (aggressive optimizations)

Low hanging fruits

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- slightly relaxed (numerical stability),
- very relaxed (aggressive optimizations)

→ see man pages!

Options for Intel compiler: “-axavx” for Haswell and “-mavx2 -fma” for AMD ROME.

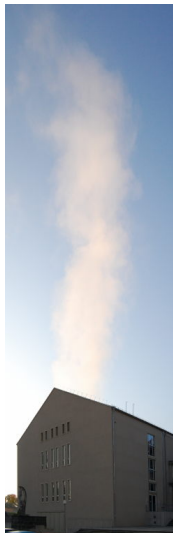
Or compile on the target system in an interactive job (SD Flex/AMD Rome/IBM Power)

Agenda

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On HPC systems: Efficient code is essential!

- the same code is running for several 1000 CPUh
- use of multiple CPUs sometimes does not help (wrong parallelization or job placement)
- parallel scalability



Profiling

... is a form of *dynamic program analysis*.

Profiling allows you to learn

- ... where your (?) program has spent its time ...
- ... which functions have called which other functions ...
- ... how often each function is called ...

while it was executing.

→ Identify slow code – redesign it!

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while it was executing.

→ Identify slow code – redesign it!

Profiling has an impact on performance, but relative performance should be consistent.

Using GNU's gprof

part of GCC available on most unix systems

- compiling and linking (`-pg`):
`g++ -pg my_prog.cpp -o my_prog`
- execute to produce profiling information:
`./my_prog`
- get human readable information:
`gprof my_prog gmon.out > analysis.txt`
- analysis: `vi analysis.txt`

Flat profile:

Each sample counts as 0.01 seconds.

% time	cumulative seconds	self seconds	calls	self s/call	total s/call	name
34.70	16.42	16.42	1	16.42	16.42	func3
33.52	32.29	15.86	1	15.86	15.86	func2
26.97	45.05	12.76	1	12.76	29.19	func1
0.13	45.11	0.06				main

PIKA - Analyzing Job Performance

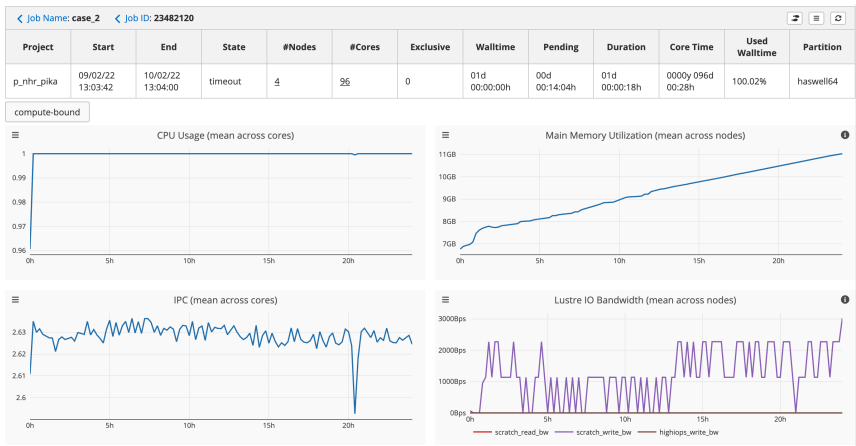
PIKA - a hardware performance monitoring stack to identify inefficient HPC jobs

- statistics are collected with every job run (available for 14 days)
- a web portal allows easy access to own performance data
- graphs can be discussed with ZIH performance experts

A small guide can be found at <https://doc.../software/pika>

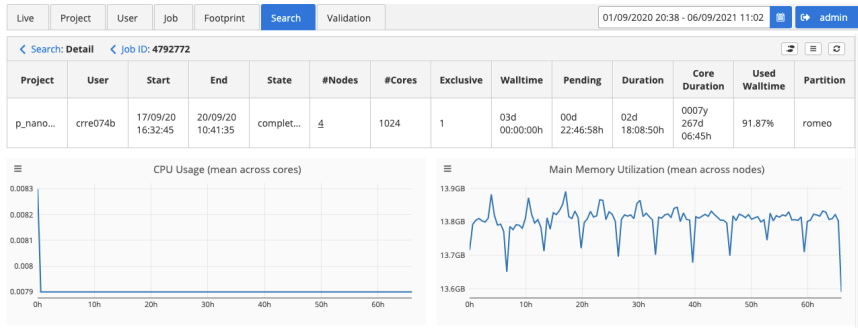
PIKA - Analyzing Job Performance

Potential memory leak



PIKA - Analyzing Job Performance

Low CPU usage

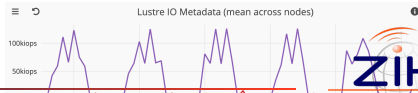
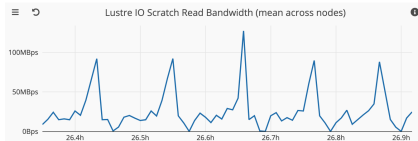
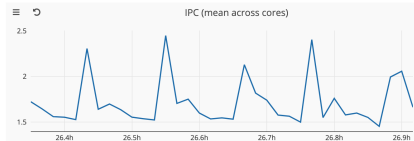
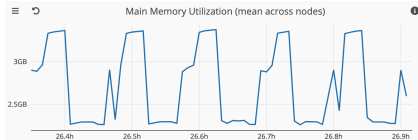
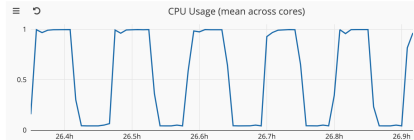


PIKA - Analyzing Job Performance

Alternating I/O and compute

< Job Name: case_3 < Job ID: 21087795

Project	Start	End	State	#Nodes	#Cores	Exclusive	Walltime	Pending	Duration	Core Time	Used Walltime	Partition
p_nhr_pika	01/12/21 22:33:21	04/12/21 22:33:52	timeout	1	24	0	03d 00:00:00h	06d 06:52:05h	03d 00:00:31h	0000y 072d 00:12h	100.01%	haswell64...



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- ➊ Linux from the command line
- ➋ HPC Environment at ZIH
- ➌ Batch System
- ➍ Software Development at ZIH's HPC systems
- ➎ HPC Support
 - Management of HPC projects
 - Channels of communication
 - Kinds of support
 - Beyond support

Start a new project

Two steps for project application:

- 1 online application form
 - with or without existing ZIH login (select institute)
 - head of the project (universities: chair)
 - needed resources (CPUh per month, permanent disk storage...)
 - abstract

After a technical review the project will be enabled for testing and benchmarking with up to 3500 CPUh/month.

Start a new project

Two steps for project application:

- ❶ online application form
 - with or without existing ZIH login (select institute)
 - head of the project (universities: chair)
 - needed resources (CPUh per month, permanent disk storage...)
 - abstract
- ❷ full application (3-4 pages pdf):
 - scientific description of the project
 - preliminary work, state of the art...
 - objectives, used methods
 - software, estimation of needed resources and scalability

Management of HPC projects

Who...

- project leader (normally chair of institute) → accountable
- project administrator (needs HPC login) → responsible

What...

- manage members of the project (add + remove)
(remark: external users need login..)
- check storage consumption within the project,
- retrieve data of retiring members
- contact for ZIH

Online project management

Web access: <https://hpcprojekte.zih.tu-dresden.de/managers>

The front-end to the HPC project database enables the project leader and the project administrator to

- add and remove users from the project,
- define a technical administrator,
- view statistics (resource consumption),
- file a new HPC proposal,
- file results of the HPC project.

Detallansicht

Mitarbeiter

Statistik

Allgemein

Titel

unix-group

f.mendel@tu-dresden.de

Projektdauer

01. August 2009 - 31. August 2014

Förderung

Antragsart

Erstantrag

Hardware

Maschine

CPU-Zeit (Stunden)

CPU-Anzahl pro Job

Speicher (GByte)

Megware-Cluster (atlas)

700.000

128

100

Online project management

Detallansicht

Mitarbeiter

Statistik

Name	Mail	Login
		 Als Administrator festlegen deaktivieren
		 Als Administrator festlegen deaktivieren
		 Als Administrator festlegen deaktivieren
		 Als Administrator festlegen

Legende

-  Der Nutzer darf rechnen.
-  Der Nutzer wurde gesperrt.

Nutzer hinzufügen und aktivieren

Damit ein Nutzer in ein Projekte hinzugefügt werden kann, benötigt dieser ein gültiges ZIH-Login.
[Login-Antrag](#)

Mit einem gültigen ZIH-Login, kann sich der Nutzer dann über folgenden Link für das Projekt aktivieren und reaktivieren.

<https://hpcprojekte.zih.tu-dresden.de/managers/Members/addToProject>

Der Link ist noch bis 16.07.2014 gültig und wird dann automatisch erneuert.

Online project management

Detailsicht

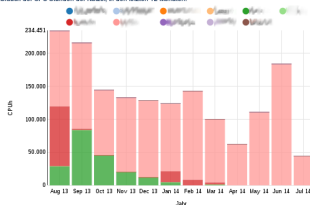
Mitarbeiter

Statistik

CPU-Stunden

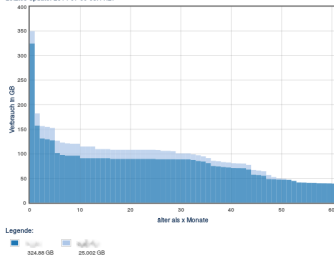
CPUh - Nutzer - Monat

Verbrauch der CPU-Stunden der Nutzer, in den letzten 12 Monaten.



HRSK-Projekt Nutzer

Letztes Update: 2014-07-09 00:11:27



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Channels of communication

ZIH → users:

- training course “Introduction to HPC at ZIH”
- HPC wiki: <https://doc.zih.tu-dresden.de>
 - link to the operation status,
 - knowledge base for all our systems, howtos, tutorials, examples...
- mass notifications per signed email from the sender “[ZIH] HPC Support” to your address ...mailbox.tu-dresden.de or ...tu-dresden.de for:
 - problems with the HPC systems,
 - new features interesting for all HPC users,
 - training courses
- email, phone - in case of requests or emergencies (e.g. user stops the file system).

User → ZIH

- If the machine feels "completely unavailable" please check the operation status first. (Support is notified automatically in case a machine/file system/batch system goes down.)
- Trouble ticket system:
 - advantages
 - reach group of supporters (independent of personal availability),
 - issues are handled according to our internal processes,
 - entry points
 - email: servicedesk@tu-dresden.de or hpcsupport@zih.tu-dresden.de
please: use your ...@tu-dresden address as sender and voluntarily include: name of HPC system, job ID...
 - phone: service desk (0351) 463 40000
 - planned: self service portal
- personal contact
 - phone call, email, talk at the Mensa
 - socializing is fine... but: risk of forgetting

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Kinds of support

HPC management topics:

- HPC project proposal,
- login,
- quota, accounting etc.

HPC usage requests:

- Why does my job not start? - and other questions concerning the batch system
- Why does my job crash?
- How can I ...

Kinds of support

HPC Software questions:

- help with the compiling of a new software
- installation of new applications, libraries, tools
- update to a newer / different version

→ restrictions of this support:

- only if several user groups need this
- no support for a particular software
- allow for some time

Kinds of support

Performance issues

- joint analysis of a piece of SW
- discussion of performance problems
- detailed inspection of self-developed code
- in the long run: help users to help themselves

Storage and workflow issues

- joint analysis of storage capacity needs
- joint development of a storage strategy
- joint design of workflows

Kinds of support

Scalable Data Services and Solutions – Dresden-Leipzig

ScaDS support for data analytics:

- data analysis tools (parallel R/Python, RStudio, Jupyter, etc.)
- Big Data Frameworks (Apache Hadoop, Spark, Flink, etc.)
- software for Deep Learning (TensorFlow, Keras, etc.)
- survey of performance optimization of the mentioned software

<https://www.scads.de/services> or services@scads.de

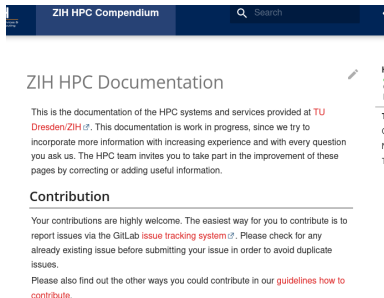
HPC support group

- Anja Gerbes, Claudia Schmidt (project management)
- Matthias Kräublein (accounting and project infrastructure)
- Lars Jitschin, Etienne Keller, Guilherme Calandrini (technical support)
- Danny Rotscher (Slurm, technical support)
- Ulf Markwardt (Slurm, technical support... head of the group)

Contribute to HPC Compendium

Help us out. Simply file issues for HPC compendium:

- Point out mistakes or unclear phrasing.
- Contribute with your expert software knowledge to help researchers of your field in the future.



The screenshot shows the ZIH HPC Compendium website. The header has a dark blue bar with the text "ZIH HPC Compendium" and a search icon. Below the header, the main content area is titled "ZIH HPC Documentation". The text below the title reads: "This is the documentation of the HPC systems and services provided at [TU Dresden/ZIH](#). This documentation is work in progress, since we try to incorporate more information with increasing experience and with every question you ask us. The HPC team invites you to take part in the improvement of these pages by correcting or adding useful information."

Contribution

Your contributions are highly welcome. The easiest way for you to contribute is to report issues via the [GitLab issue tracking system](#). Please check for any already existing issue before submitting your issue in order to avoid duplicate issues.

Please also find out the other ways you could contribute in our [guidelines how to contribute](#).

On the right side of the screenshot, there is a vertical sidebar with navigation links: H, C, h, Tr, C, N, Tr.

Or open a ticket via hpcsupport@zih.tu-dresden.de.

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Beyond support

ZIH is state computing centre for HPC

- hardware funded by DFG and SMWK
- collaboration between (non-IT) scientists and computer scientists
- special focus on data-intensive computing

Joint research projects

- funded by BMBF or BMWi
- ScaDS Dresden Leipzig
- Nvidia CCoE (GPU), IPCC (Xeon Phi)

Scalable software tools to support the optimization of applications for HPC systems

- Data intensive computing and data life cycle
- Performance and energy efficiency analysis for innovative computer architectures
- Distributed computing and cloud computing
- Data analysis, methods and modeling in life sciences
- Parallel programming, algorithms and methods

You can help

If you plan to publish a paper with results based on the used CPU hours of our machines please acknowledge ZIH like...

The authors gratefully acknowledge the GWK support for funding this project by providing computing time through the Center for Information Services and HPC (ZIH) at TU Dresden.

The authors are grateful to the Center for Information Services and High Performance Computing [Zentrum für Informationsdienste und Hochleistungsrechnen (ZIH)] at TU Dresden for providing its facilities for high throughput calculations.

Recapitulation

Most important topics:

- Use the correct file system.
- Hand over the requirements of your application to the batch system.
- Plan your needed resources in advance.
- You are responsible for your application and your data.
We can help you.
- Please acknowledge ZIH and send us the publication.

Thank you!

This presentation - and much more - can be found at

<https://doc.zih.tu-dresden.de>