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aiXcelerate 2021: Part I – File I/O

HPC.NRW Competence Network

DAS KOMPETENZNETZWERK FÜR HOCHLEISTUNGSRECHNEN in NRW.

I/O Analysis with Darshan

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aiXcelerate 2021: Part I – File I/O

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Agenda

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- I/O in HPC Application Overview
- Challenges in I/O measurement
- I/O measurement methods
- Darshan Overview
- Darshan in CLAIX

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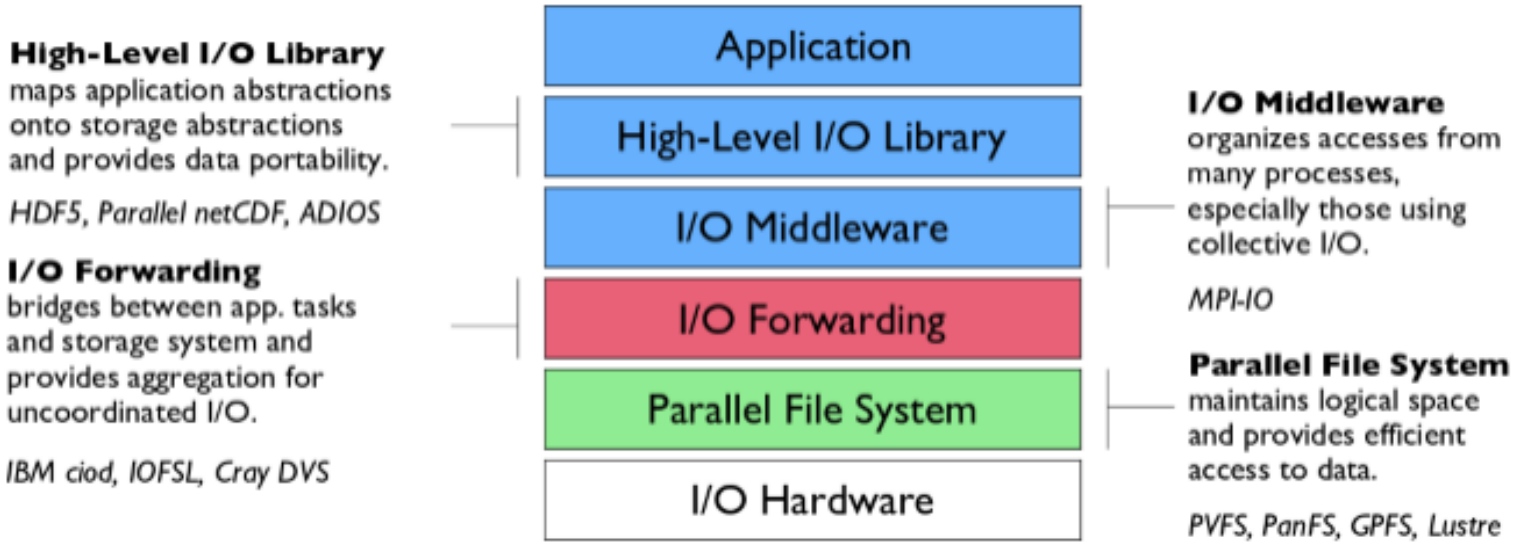
I/O in HPC Application Overview



Additional I/O software provides improved performance and usability over accessing the parallel file system directly. Reduces or (ideally) eliminates need for optimization in application codes.

** This slides are adapted from IISWC 2014, Darshan – I/O Workload Characterization in MPI Applications https://www.mcs.anl.gov/research/projects/darshan/tutorials/iiswc2014/*

Challenges in I/O Measurement

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- There are many programming model and patterns that can be used by application to do I/O. It may have many components accessing different files at different time
- I/O performance is affected by the computation and network performance. It's difficult to isolate just I/O
- I/O performance is sensitive to changes in access method, libraries, file systems, and hardware
- I/O performance might be perturbed by the tools used to instrument it

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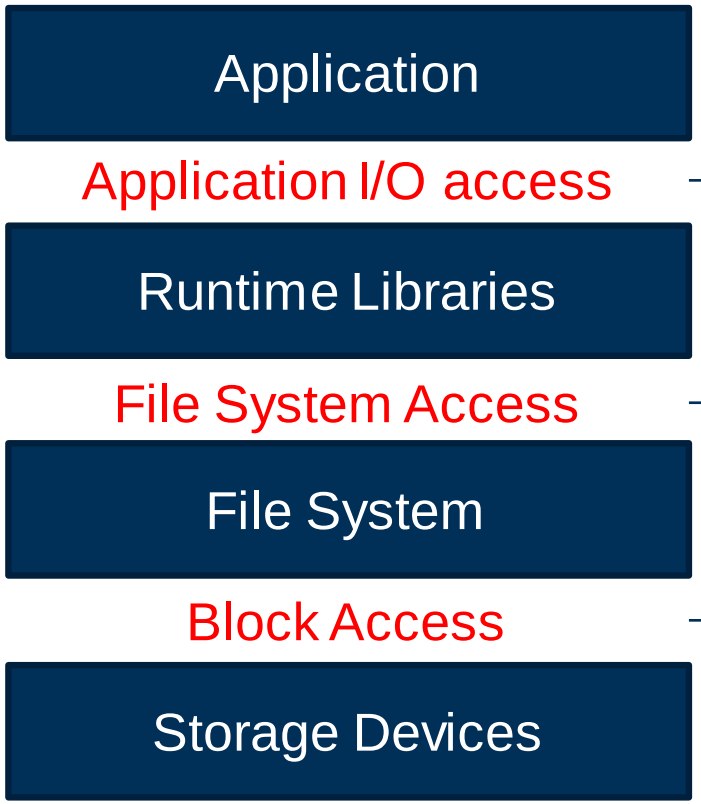
I/O Measurement Strategy



Application I/O Tracing & profiling tools

- I/O Access expressed by the application
- Tools: Darshan, Extrae, Score-P, Tau

File System or POSIX Instrumentation

- I/O access patterns after they have been translated by I/O libraries such as MPI-IO or HDF5
- Tools: Lustre & GPFS Diagnostic, most tracing and profiling tools like Extrae, Tau, Score-P

Block Device Instrumentation

- Raw access to the disks
- Tools: Vendor specific tools, Linux block tracing

Darshan Overview

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- **Open source runtime library**
  - Darshan instrumentation inserted at build time (for static executables) and at run time (for dynamic executables)
  - Captures POSIX I/O, MPI-IO, and limited HDF5 and PNetCDF functions
- **Minimal impact on the application**
  - Low memory consumption
  - Log data collected and compressed at MPI_Finalize() time
  - Instrumentation enabled via software modules, environment variables, or compiler scripts
  - Doesn't need to change source code or makefile
  - No filesystem dependencies

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Using Darshan Runtime

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- Compile C, C++, Fortran program that uses MPI.
  - *If it's not an MPI program, put MPI_Init() in the beginning of the code and MPI_finalize() at the end to enable Darshan generating log file*
  - *The latest version of Darshan doesn't need to use this trick ☺*
- Run the application
- Look for the Darshan log file
  - This will be in a particular directory (depending on your system's configuration)
  - The log file has .darshan extension
- Use Darshan command line tools to analyze the log file
- **Darshan does not capture a trace of all I/O operations**: instead, it reports key statistics, counters, and timing information for each file accessed by the application

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Using Darshan Analysis Tools

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- Key tools:
  - **darshan-job-summary.pl** : creates pdf files with graph for initial analysis
  - **darshan-summary-per-file.sh** : similar with above but creates separate pdf file for each file created by Darshan application
  - **darshan-parser**: dumps all information into ascii (text) format
- Python based analysis:
  - Experimental work for Darshan eXtended Tracing : https://jeanbez.gitlab.io/pdsw-2021/
- Documentation: https://www.mcs.anl.gov/research/projects/darshan/docs/darshan-util.html

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Darshan in CLAIX – Generating Darshan Log File

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- Login to Claix
  - `$ module load DEV-TOOLS darshan`
  - Below information will show up. This sample is with intelmpi:

```
Use 'export DARSHAN_LOGPATH=<path>' to define experiment directory
Set LD_PRELOAD=/rwthfs/rz/SW/UTIL/perf-
tools/darshan/3.1.8/intelmpi2018.4.274/lib/libdarshan.so to enable measurement
```

- Use above information to generate Darshan measurement in your job script
  - `export DARSHAN_LOGPATH=<path>`
  - `export LD_PRELOAD=/rwthfs/rz/SW/UTIL/perf-tools/darshan/3.1.8/intelmpi2018.4.274/lib/libdarshan.so`
  - Run the application, e.g: `$MPIEXEC some.binary`

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Darshan in CLAIX – Generating Darshan PDF Report

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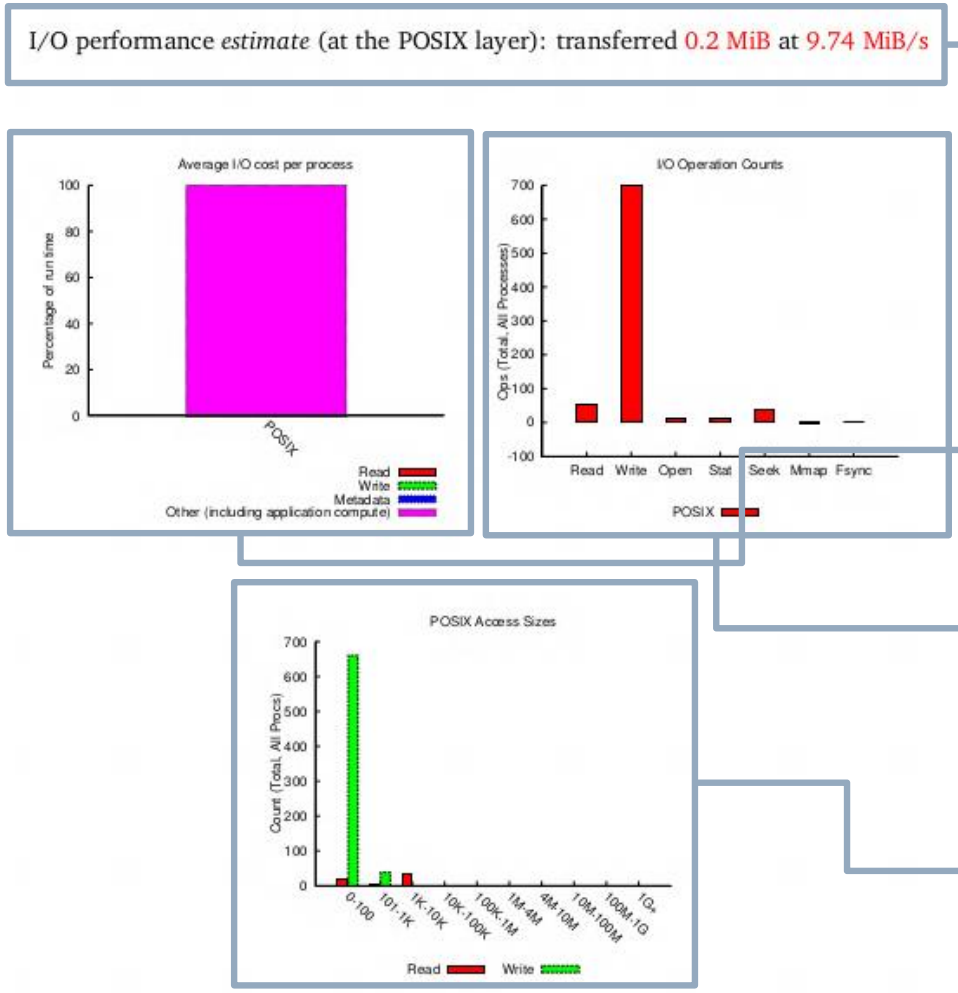
- In your designated `DARSHAN_LOGPATH` directory you will find new file with .darshan extension. Run:
  - `$ darshan-job-summary.pl *.darshan`
- In your current directory you will find new pdf file with the same name as the darshan log file
  - If the generation stucks, exit from the program (ctrl + c). Most of the time, it is because of several LaTeX components are not available in your environment and you need to load texlive module
  - `$ module load MISC texlive`
  - Repeat the process
- Open the pdf file

Darshan in CLAIX - Interpreting Darshan Report (1)



Shows the amount of data transferred and what the bandwidth was. The bandwidth data could be used to determine the I/O scalability of the application at different MPI process counts to determine if I/O is scaling linearly

Percentage of I/O in the runtime

I/O operation counts. Ideally, the operation counts should be small as possible as a large number could indicate a performance issue

Read/Write access size chart. Ideally, the number of I/O operations should be low with large access sizes

Darshan in CLAIX - Interpreting Darshan Report (2)

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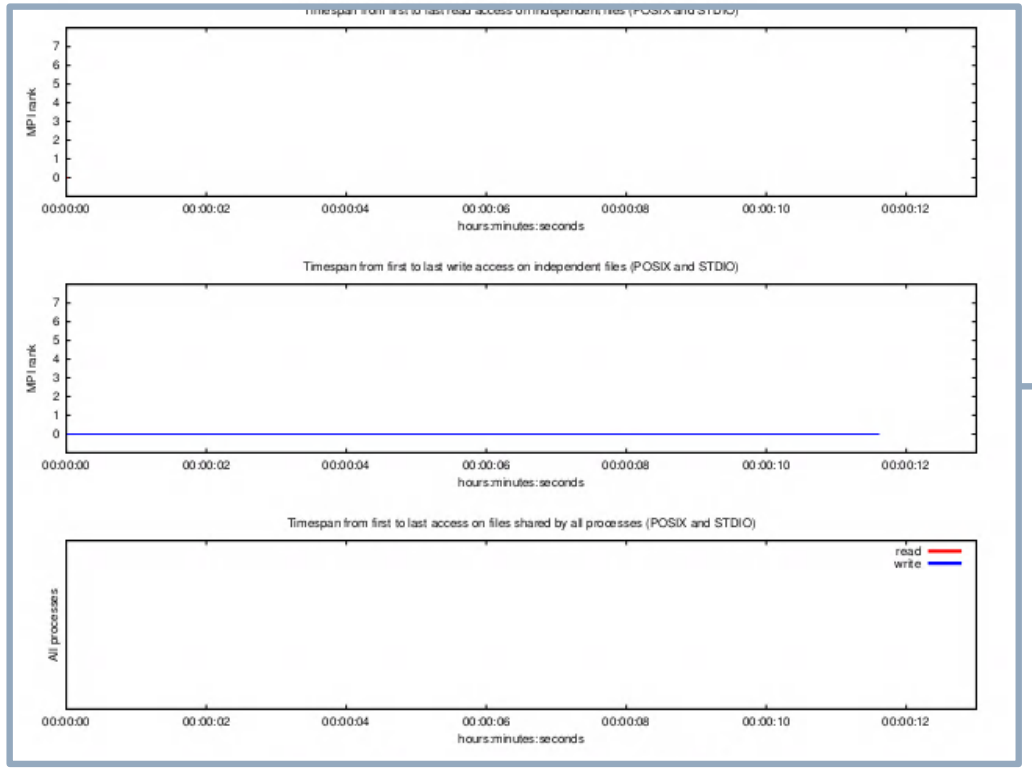
Most Common Access Sizes (POSIX or MPI-IO)

	access size	count
POSIX	48	174
	32	88
	37	88
	51	87

File Count Summary (estimated by POSIX I/O access offsets)

type	number of files	avg. size	max size
total opened	3	13K	27K
read-only files	1	551	551
write-only files	1	27K	27K
read/write files	1	9.3K	9.3K
created files	2	19K	27K



The tables give a breakdown of the access sizes, and the table on the right shows the file count summary.
Ideally, the file operation counts should be low, particularly the write-only files.

I/O timeline. Can see only write or only read timeline as well as aggregated timeline. In this case, nothing to see because the size is too small

Darshan in CLAIX - Interpreting Darshan Report (3)

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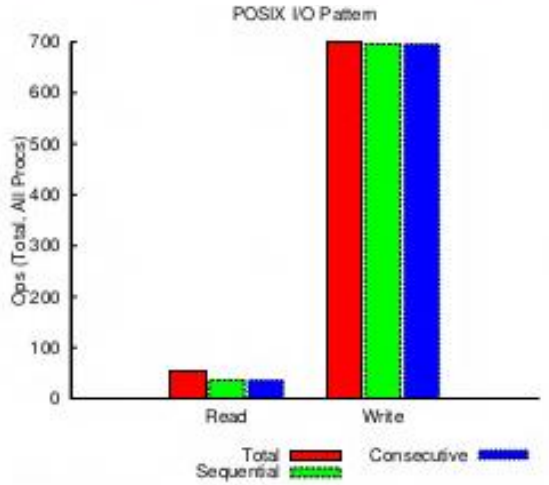
Average I/O per process (POSIX and STDIO)

	Cumulative time spent in I/O functions (seconds)	Amount of I/O (MB)
Independent reads	1.025e-05	0.000131368637084961
Independent writes	0.00204075	0.00327908992767334
Independent metadata	0.00011225	N/A
Shared reads	0.000100125	0.0181560516357422
Shared writes	2.9625e-05	0.00113475322723389
Shared metadata	0.000577875	N/A

Data Transfer Per Filesystem (POSIX and STDIO)

File System	Write		Read	
	MiB	Ratio	MiB	Ratio
/rwthfs/rz/cluster/hpcwork/qi190786	0.03531	1.00000	0.14630	1.00000



sequential: An I/O op issued at an offset greater than where the previous I/O op ended.
consecutive: An I/O op issued at the offset immediately following the end of the previous I/O op.

The table shows detailed I/O process and the filesystem data transfer speed. Both are useful to determine whether the application is running the correct file system

I/O pattern breaks down the consecutive & contiguous I/O components

Darshan in CLAIX - Interpreting Darshan Report (4)

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Variance in Shared Files (POSIX and STDIO)

File Suffix	Processes	Fastest			Slowest			σ	
		Rank	Time	Bytes	Rank	Time	Bytes	Time	Bytes
...f/tea.in.tmp	8	1	0.000548	19K	0	0.001340	28K	0	3.15e+03

The last table shows the variance of POSIX I/O data across the MPI processes. Can be used to determine if there are any load imbalances across the MPI processes

Darshan in CLAIX – Profiling Dynamic Executable

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- The easiest way to profile an application with Darshan is to build a dynamic executable (executable that is dynamically linked with the MPI library). To determine if your executable is dynamic or not, type:

```
$ ldd <executeable>
```

- If the output shows the MPI library, then it is dynamically linked.
- Set the Darshan log path variable and put LD_PRELOAD in front of the MPI execution command with the Darshan library :

```
$ export DARSHAN_LOGPATH=.
$ LD_PRELOAD=<follow notes in loaded module> <mpiexec command>
<executable>
```

- A trace file will be created in the current working directory. The trace file name should start with the user name and has .darshan extension

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Darshan in CLAIX – Profiling Static Executable

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- For static executable, new compile script needs to be generated to include darshan.
- Some examples for MPICH based MPI library:

```
$ darshan-gen-cc.pl `which mpicc` --output mpicc.darshan
$ darshan-gen-cxx.pl `which mpicxx` --output mpicxx.darshan
$ darshan-gen-fortran.pl `which mpif77` --output mpif77.darshan
$ darshan-gen-fortran.pl `which mpif90` --output mpif90.darshan
```

- For other types of libraries, can refer to the darshan-get-* files or contact the Darshan support mailing list

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Darshan in CLAIX – Runtime Variables (1)

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- `DARSHAN_DISABLE`: disables Darshan instrumentation
- `DARSHAN_INTERNAL_TIMING`: enables internal instrumentation that will print the time required to startup and shutdown Darshan to stderr at run time.
- `DARSHAN_LOGHINTS`: specifies the MPI-IO hints to use when storing the Darshan output file. The format is a semicolon-delimited list of `key=value pairs`, for example: `hint1=value1;hint2=value2`
- `DARSHAN_MEMALIGN`: specifies a value for system memory alignment
- `DARSHAN_DISABLE_SHARED_REDUCTION`: disables the step in Darshan aggregation in which files that were accessed by all ranks are collapsed into a single cumulative file record at rank 0. This option retains more per-process information at the expense of creating larger log files. Note that it is up to individual instrumentation module implementations whether this environment variable is actually honored.
- `DARSHAN_LOGPATH`: specifies the path to write Darshan log files to. Note that this directory needs to be formatted using the darshan-mk-log-dirs script.
- `DARSHAN_ENABLE_NONMPI`: setting this environment variable is required to generate Darshan logs for non-MPI applications

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Darshan in CLAIX – Runtime Variables (2)

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- `DARSHAN_LOGFILE`: specifies the path (directory + Darshan log file name) to write the output Darshan log to. This overrides the default Darshan behavior of automatically generating a log file name and adding it to a log file directory formatted using darshan-mk-log-dirs script.
- `DARSHAN_MODMEM`: specifies the maximum amount of memory (in MiB) Darshan instrumentation modules can collectively consume at runtime (if not specified, Darshan uses a default quota of 2 MiB).
- `DARSHAN_EXCLUDE_DIRS`: specifies a list of comma-separated paths that Darshan will not instrument at runtime (in addition to Darshan's default blacklist)
- `DXT_ENABLE_IO_TRACE`: setting this environment variable enables the DXT (Darshan eXtended Tracing) modules at runtime for all files instrumented by Darshan. Currently, DXT is hard-coded to use a maximum of 4 MiB of trace memory per process (in addition to memory used by other modules).
- `DXT_DISABLE_IO_TRACE`: setting this environment variable disables the DXT module at runtime for all files instrumented by Darshan.

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Darshan in CLAIX – Additional Notes

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- Beware of the compiler combination when using Darshan, some compiler combinations are not supported in the CLAIX modules
- HDF5 Support
  - Current Darshan module doesn't support HDF5 profiling, create a new installation `--enable-hdf5-mod=/path/to/hdf5/`
  - The default report generator tools doesn't show the HDF5 output
- Machine learning application usually produces a lot of files. Consider filtering the files using: `DARSHAN_EXCLUDE_DIRS` variable
  - There's a limit of 1024 files per process in Darshan that can't be changed. If the application hits the limit, the rest of the files will not be recorded.

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