Hewlett Packard Enterprise

Bit-reproducibility in UK Met Office Weather and Climate Applications

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Overview

- What is bit-reproducibility and why does it matter?
- Study 1: binary portability and reproducibility of results
- Dynamically linked libraries
- Study 2: binary portability and reproducibility of results (take 2)
- Study 3: AMD Milan vs. AMD Genoa
- Summary

What is bit-reproducibility and why does it matter?

Lorenz and the “butterfly effect”

- Many systems of scientific interest can be modelled by differential equations which describe the rate of change of one quantity (e.g. position) with respect to another quantity (e.g. time)
- For a time-dependent problem it is necessary to specify initial values (e.g. position at time $t = 0$)
- Lorenz (1963) presented numerical solutions to a system of ordinary non-linear differential equations representing convection
- He observed that:

> *“… nonperiodic solutions are ordinarily unstable with respect to small modifications, so that slightly differing initial states can evolve into considerably different states.”*

- This is often referred to as “the butterfly effect”
- This is inherent to the mathematics and can’t be avoided
- Lorenz, E. N., 1963: Deterministic Nonperiodic Flow. J. Atmos. Sci., 20, 130–141, https://doi.org/10.1175/1520-0469(1963)020<0130:DNF>2.0.CO;2.
- See also earlier work e.g. Poincaré

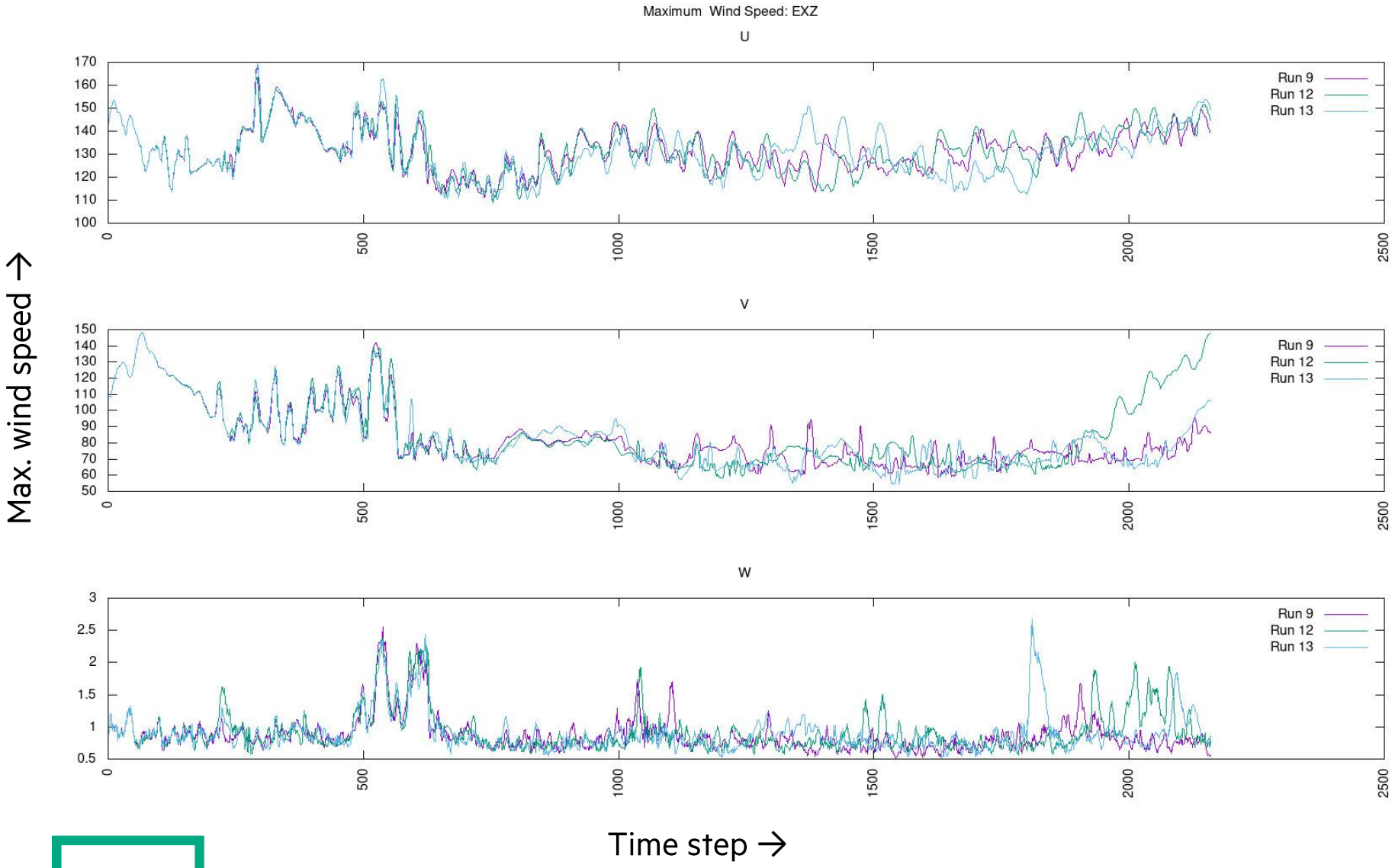
Floating point arithmetic

- Floating point arithmetic is not the same as arithmetic with real numbers
- For example, not necessarily associative: $(a + b) + c \neq a + (b + c)$
- Order of operations matters (e.g. re-ordering instructions for optimisation, summation)
- Impact of round-off on summation of sea-surface height:
  - He, Y., and Ding, C.H.Q. (2000). https://doi.org/10.1145/335231.335253
  - He, Y., and Ding, C.H.Q. (2001). https://doi.org/10.1023/A:1008153532043
- Software (e.g. compilers, libraries) and hardware (e.g. processor architecture) can both affect results
- This is not *necessarily* about right and wrong answers:
  - Floating point arithmetic is an approximation to arithmetic with real numbers
  - Different approximations can give different round-off errors
- More information in: David Goldberg. 1991. What every computer scientist should know about floating-point arithmetic. ACM Comput. Surv. 23, 1 (March 1991), 5–48. https://doi.org/10.1145/103162.103163

Impact on weather and climate modelling

- The governing equations of fluid dynamics are partial differential equations (PDEs) which describe the rate of change of quantities (e.g. density, velocity, energy) with respect to more than one variable (e.g. position, time)
- Solutions to PDEs can be very sensitive to small perturbations
- Although the “butterfly effect” is often described in terms of initial conditions (imperfect knowledge of the state of the atmosphere), the solution is sensitive to perturbations at any time
- Even the tiny changes caused by different floating-point approximations can grow as the solution moves forward in time
- This can cause different outcomes for scientifically important variables

Impact on weather and climate modelling



Maximum wind speed from a climate model run on the same system with:

- CCE 13.0.0, SLES15SP2
- CCE 13.0.0, SLES15SP3
- CCE 15.0.0, SLES15SP3

More on this later …

Motivation

- Is bit-reproducibility important if we are interested in long-term energy balance and mean climate? Is this relevant if we are running ensembles?
- Reproducibility does matter:
  - Re-run a short section of a long climate simulation in order to generate new diagnostics
  - The response to a perturbation is non-linear. It is not obvious if a change in results is caused by a different round-off or a subtle bug. Need scientific validation to ensure forecast skill or representation of climate is not adversely affected
  - Being able to reproduce results is an important part of the scientific method
- The studies presented in this talk are motivated by the following questions:
  - What are the effects of software updates:
    - Updating to a newer programming environment?
    - Applying operating system updates?
  - The UK Met Office systems comprise two phases based on AMD Milan and AMD Genoa processors. Do results bit-reproduce between the two processor types?

Study 1: binary portability and reproducibility of results

Study 1: experiment set up

- Application:
  - UK Met Office Unified Model (UM) in a global climate configuration (um-global-climate)
  - 30 model days of a climate simulation (2160 time steps)
  - This configuration gives bit-reproducible results with different MPI/OpenMP parallelisations
- Systems:
  - UK Met Office development system (EXZ)
  - HPE in-house system (Loki)
  - Both systems had AMD Milan processors
  - Both systems ran the COS operating system
- Executables were compiled on EXZ with CCE 12.0.3 and CCE 13.0.0
- Executables were copied to Loki (no recompilation)

Study 1: results

- Ran um-global-climate on EXZ and Loki:
  - Different MPI decompositions
  - Different network providers (OFI vs. UCX). At the time EXZ was Slingshot-10 and Loki was Slingshot-11.
  - Different Programming Environments with different compiler (CCE) versions

Run	System	CCE	Fabric provider	Decomposition	Time
Run 1	EXZ	12.0.3	OFI	16x20	2117s
Run 2	EXZ	12.0.3	UCX	16x20	2309s
Run 3	EXZ	12.0.3	OFI	20x16	2126s
Run 4	EXZ	12.0.3	UCX	20x16	2454s
Run 5	EXZ	13.0.0	OFI	16x20	2107s
Run 6	Loki	13.0.0	OFI	16x20	2192s
Run 7	Loki	12.0.3	OFI	16x20	2147s

Study 1: results

- All EXZ runs give identical results
- Both Loki runs give identical results
- EXZ and Loki results differ
- MPI decomposition, fabric provider and PE version did not affect results
- One or more differences between EXZ and Loki affected the results – what was different?

Run	System	CCE	Fabric provider	Decomposition	Time
Run 1	EXZ	12.0.3	OFI	16x20	2117s
Run 2	EXZ	12.0.3	UCX	16x20	2309s
Run 3	EXZ	12.0.3	OFI	20x16	2126s
Run 4	EXZ	12.0.3	UCX	20x16	2454s
Run 5	EXZ	13.0.0	OFI	16x20	2107s
Run 6	Loki	13.0.0	OFI	16x20	2192s
Run 7	Loki	12.0.3	OFI	16x20	2147s

Identical

Identical

Dynamically linked libraries

Dynamically linked libraries

- Dynamically linked libraries are resolved at run time
- Executables in ELF format contain a run time search path (`RPATH`) which specifies directories to search for dynamically linked libraries
- Paths specified by `RPATH` are searched before the paths specified by `LD_LIBRARY_PATH`
- Default `RPATH` for CCE executable comprises:
  - `/opt/cray/pe/cce/13.0.0/cce/x86_64/lib`
  - `/opt/cray/pe/gcc-libs`

```
> readelf -d um-atmos-climate.exe | grep RPATH
 0x000000000000000f (RPATH)
Library rpath: [/opt/cray/pe/cce/13.0.0/cce/x86_64/lib:/opt/cray/pe/gcc-libs]
```

Dynamically linked libraries: RPATH note #1

- There are some symbolic links in `/opt/cray/pe/cce/13.0.0/cce/x86_64/lib` but they all resolve to files in that same directory
- The libraries in `/opt/cray/pe/gcc-libs` are symbolic links to specific GCC versions
- These can vary depending on the default PE

```
                > ls -l /opt/cray/pe/gcc-libs
total 0
lrwxrwxrwx 1 root root 46 Feb 16 16:51 libasan.so.5
           -> /opt/cray/pe/gcc/8.1.0/snos/lib64/libasan.so.5
lrwxrwxrwx 1 root root 47 Feb 16 16:51 libasan.so.6
           -> /opt/cray/pe/gcc/11.2.0/snos/lib64/libasan.so.6
lrwxrwxrwx 1 root root 49 Feb 16 16:51 libatomic.so.1
           -> /opt/cray/pe/gcc/11.2.0/snos/lib64/libatomic.so.1
lrwxrwxrwx 1 root root 46 Feb 16 16:51 libcc1.so.0
           -> /opt/cray/pe/gcc/11.2.0/snos/lib64/libcc1.so.0
```

Dynamically linked libraries: RPATH note #2

- If the programming environment referenced by `RPATH` is not installed, then the corresponding libraries will be picked up from `/opt/cray/pe/lib64` (see `/etc/ld.so.conf.d/cray-pe.conf`)
- Loki had CCE 13.0.0 installed so the directory referenced by `RPATH` was present for the CCE 13.0.0 executable
- Loki did not have CCE 12.0.3 installed and PE libraries were found in `/opt/cray/pe/lib64`
- If the programming environment referenced by `RPATH` is not installed, then the executable will still run but will not use the version of the PE libraries specified by `RPATH`

```
libcraymath.so.1 => /opt/cray/pe/lib64/cce/libcraymath.so.1
```

and

```
/opt/cray/pe/lib64/cce/libcraymath.so.1: symbolic link to \
/opt/cray/pe/cce/13.0.2/cce/x86_64/lib/libcraymath.so.1
```

RPATH: improved consistency with `CRAY_ADD_RPATH`

- Setting the environment variable `CRAY_ADD_RPATH=yes` at build time adds extra `RPATH` entries for more consistent resolution of dynamic dependencies

```
> readelf -d um-atmos-climate.exe | grep RPATH
 0x000000000000000f (RPATH)
Library rpath: [/opt/cray/pe/cce/13.0.0/cce/x86_64/lib:/opt/cray/pe/gcc-libs:
/opt/cray/pe/mpich/8.1.12/ofi/cray/10.0/lib:
/opt/cray/pe/dsmml/0.2.2/dsmml//lib:
/opt/cray/pe/hdf5/1.12.0.7/crayclang/10.0/lib:
/opt/cray/pe/netcdf/4.7.4.7/crayclang/10.0/lib:
/opt/cray/pe/libsci/21.08.1.2/CRAY/9.0/x86_64/lib:
/opt/cray/pe/pmi/6.0.16/lib:
/opt/cray/pe/cce/13.0.0/cce/x86_64/lib/pkgconfig/../:
/opt/cray/xpmem/2.2.40-2.1_3.9__g3cf3325.shasta/lib64]
```

RPATH: Comparing EXZ and Loki

- Compared libraries from `/opt/cray` reported by `ldd` with symbolic links resolved
- Compared with and without `CRAY_ADD_RPATH=yes`

Differences without `CRAY_ADD_RPATH`

```
libfabric.so.1
libhdf5_crayclang.so.200
libhdf5_hl_crayclang.so.200
libmpi_cray.so.12
libmpifort_cray.so.12
libnetcdf_crayclang.so.18
libnetcdff_crayclang.so.7
libpals.so.0
libpmi.so.0
libpmi2.so.0
libxpmem.so.0
```

Differences with `CRAY_ADD_RPATH`

```
libfabric.so.1
libpals.so.0
libsma.so.0
libxpmem.so.0
```

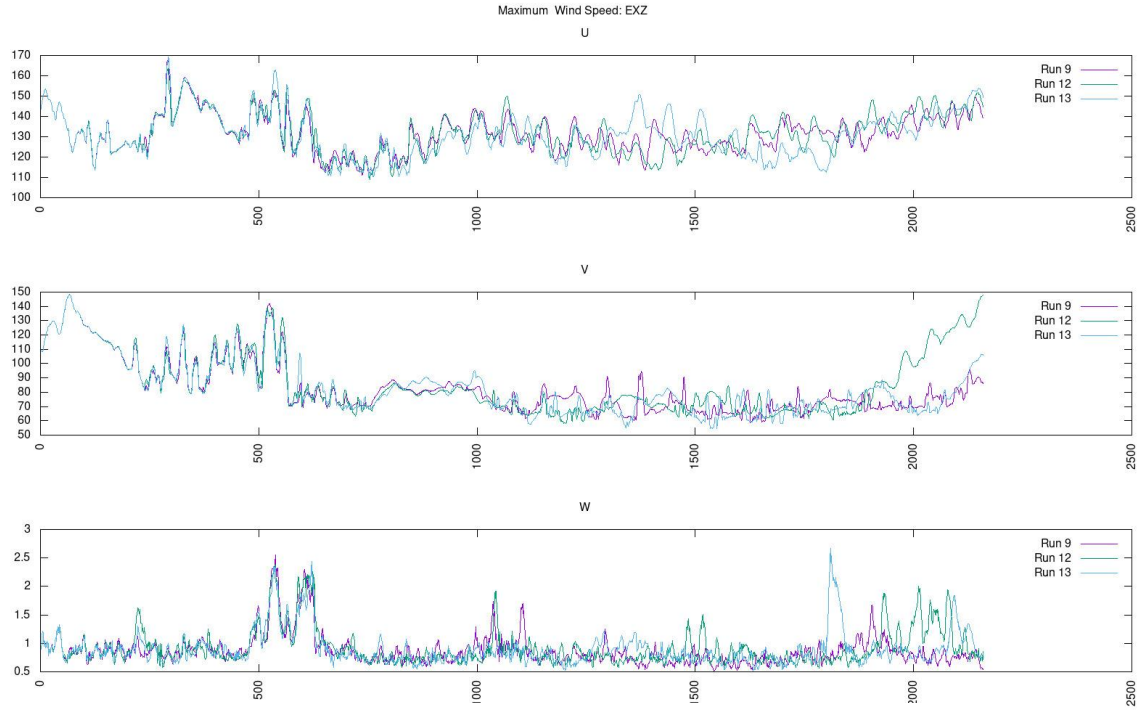
Version specified in `RPATH` not on Loki

`CRAY_ADD_RPATH` has eliminated most differences in libraries from the programming environment but also have different libraries from `/usr/lib64` and `/lib64`
This includes `libc` and `libm`.

Study 2: binary portability and reproducibility of results (take 2)

Study 2: EXZ results

- Follow-up to study 1 at a later time
- Both systems were Slingshot-11 (EXZ upgraded)
- Results from EXZ show:
  - Updating from SLES15 SP2 to SLES15 SP3 changes results
  - Updating from CCE 13.0.0 TO CCE 15.0.0 changes results



Run ID	System	CCE	RPATH?	OS version	Result
Run 9	EXZ	13.0.0	Yes	SLES 15 SP2	No match
Run 12	EXZ	13.0.0	Yes	SLES 15 SP3	Matches 15, 16 & 17
Run 13	EXZ	15.0.0	Yes	SLES 15 SP3	No match
Run 14	Loki	13.0.0	Yes	SLES 15 SP4	Failed
Run 15	Loki	15.0.0	Yes	SLES 15 SP4	Matches 12, 16 & 17
Run 16	Loki	13.0.0	No	SLES 15 SP4	Matches 12, 15 & 17

Study 2: Loki run 14

- Run 14 failed to run (executable built with CCE 13.0.0 and `CRAY_ADD_RPATH=yes`)
- Executable built without `CRAY_ADD_RPATH` **did** run
- `libnetcdf_crayclang.so.18` was not available, only `libnetcdf_crayclang.so.19`
- When `RPATH` is not set this can be handled
- Trade-off between reproducibility and portability

Run ID	System	CCE	RPATH?	OS version	Result
Run 9	EXZ	13.0.0	Yes	SLES 15 SP2	No match
Run 12	EXZ	13.0.0	Yes	SLES 15 SP3	Matches 15, 16 & 17
Run 13	EXZ	15.0.0	Yes	SLES 15 SP3	No match
Run 14	Loki	13.0.0	Yes	SLES 15 SP4	Failed
Run 15	Loki	15.0.0	Yes	SLES 15 SP4	Matches 12, 16 & 17
Run 16	Loki	13.0.0	No	SLES 15 SP4	Matches 12, 15 & 17

Study 2: run 15 vs run 12

- The two successful runs on Loki match run 12 on EXZ
- Run 15 (Loki) matches run 12 (EXZ) despite differences in PE and OS
- Why does run 15 match run 12 (built with CCE 13.0.0) and **not** run 13 (built with CCE 15.0.0)?
- CCE 15 was not available on Loki so the libraries picked up at run time fell back to older versions and matched CCE 13.0.0 results

Run ID	System	CCE	RPATH?	OS version	Result
Run 9	EXZ	13.0.0	Yes	SLES 15 SP2	No match
Run 12	EXZ	13.0.0	Yes	SLES 15 SP3	Matches 15, 16 & 17
Run 13	EXZ	15.0.0	Yes	SLES 15 SP3	No match
Run 14	Loki	13.0.0	Yes	SLES 15 SP4	Failed
Run 15	Loki	15.0.0	Yes	SLES 15 SP4	Matches 12, 16 & 17
Run 16	Loki	13.0.0	No	SLES 15 SP4	Matches 12, 15 & 17

Study 2: run 16 vs run 12

- The two successful runs on Loki match run 12 on EXZ
- Run 16 (Loki) matches run 12 (EXZ) despite not setting `CRAY_ADD_RPATH` and differences in OS
- In this case setting `CRAY_ADD_RPATH` was not required to achieve reproducible results, however this may depend on the application (e.g. if `libsci` is used)

Run ID	System	CCE	RPATH?	OS version	Result
Run 9	EXZ	13.0.0	Yes	SLES 15 SP2	No match
Run 12	EXZ	13.0.0	Yes	SLES 15 SP3	Matches 15, 16 & 17
Run 13	EXZ	15.0.0	Yes	SLES 15 SP3	No match
Run 14	Loki	13.0.0	Yes	SLES 15 SP4	Failed
Run 15	Loki	15.0.0	Yes	SLES 15 SP4	Matches 12, 16 & 17
Run 16	Loki	13.0.0	No	SLES 15 SP4	Matches 12, 15 & 17

Study 3: AMD Milan vs. AMD Genoa

Study 3: AMD Milan vs. AMD Genoa

- Compared results on Met Office development system (EXZ) and production systems
- Production systems have AMD Milan based compute nodes and AMD Genoa based compute nodes
- Need bit-reproducible results between the two different processor types

Run	Compiled on	Run on	Extra env. vars	Matches
Run 26	EXZ	EXZ	None	EXZ
Run 27	EXZ	Prod Milan	None	EXZ
Run 28	Prod	Prod Milan	None	EXZ
Run 29	Prod	Prod Genoa	None	Prod Genoa
Run 30	Prod	Prod Genoa	`LIBSCI_ARCH_OVERRIDE=milan`	Prod Genoa
Run 31	Prod	Prod Genoa	`CRAYLIBS_ARCH_OVERRIDE=x86-milan`	EXZ

Study 3: AMD Milan vs. AMD Genoa

- We can move the executable from EXZ to production system and reproduce results on Milan ✅
- We can recompile on production system and reproduce EXZ results ✅

Run	Compiled on	Run on	Extra env. vars	Matches
Run 26	EXZ	EXZ	None	EXZ
Run 27	EXZ	Prod Milan	None	EXZ
Run 28	Prod	Prod Milan	None	EXZ
Run 29	Prod	Prod Genoa	None	Prod Genoa
Run 30	Prod	Prod Genoa	`LIBSCI_ARCH_OVERRIDE=milan`	Prod Genoa
Run 31	Prod	Prod Genoa	`CRAYLIBS_ARCH_OVERRIDE=x86-milan`	EXZ

Study 3: AMD Milan vs. AMD Genoa

- Running same the executable on Genoa produces different results ❌
- Some code paths are determined at run-time to optimize performance
- Need to ensure Milan code paths are followed to ensure bit-reproducible results:
  - `CRAYLIBS_ARCH_OVERRIDE=x86-milan`
  - `LIBSCI_ARCH_OVERRIDE=milan`
- Achieve bit-reproducible results between Milan and Genoa nodes when using the same executable and `CRAYLIBS_ARCH_OVERRIDE=x86-milan` ✅

Run	Compiled on	Run on	Extra env. vars	Matches
Run 26	EXZ	EXZ	None	EXZ
Run 27	EXZ	Prod Milan	None	EXZ
Run 28	Prod	Prod Milan	None	EXZ
Run 29	Prod	Prod Genoa	None	Prod Genoa
Run 30	Prod	Prod Genoa	`LIBSCI_ARCH_OVERRIDE=milan`	Prod Genoa
Run 31	Prod	Prod Genoa	`CRAYLIBS_ARCH_OVERRIDE=x86-milan`	EXZ

Summary

- Weather and climate models are sensitive to changes in even the least significant bit of model variables (“butterfly effect”)
- Very difficult to achieve consistent round-off with floating-point arithmetic
- Which dynamic libraries are resolved at run-time can change model results significantly, even when the executable is identical
- `CRAY_ADD_RPATH=yes` can eliminate most differences in libraries from the programming environment but care is still required:
  - If the programming environment referenced by `RPATH` is not present at run time the executable can run successfully but will not use the expected versions of the PE libraries
  - Updates to PEs can change symbolic links to libraries (e.g. GCC)
- Updates to PE can change results at the bit-level, but not always
- Updates to OS can change results at the bit-level, but not always
- Bit-reproducible results between Milan and Genoa processors was achieved but needed to disable run-time code path selection

Thank you

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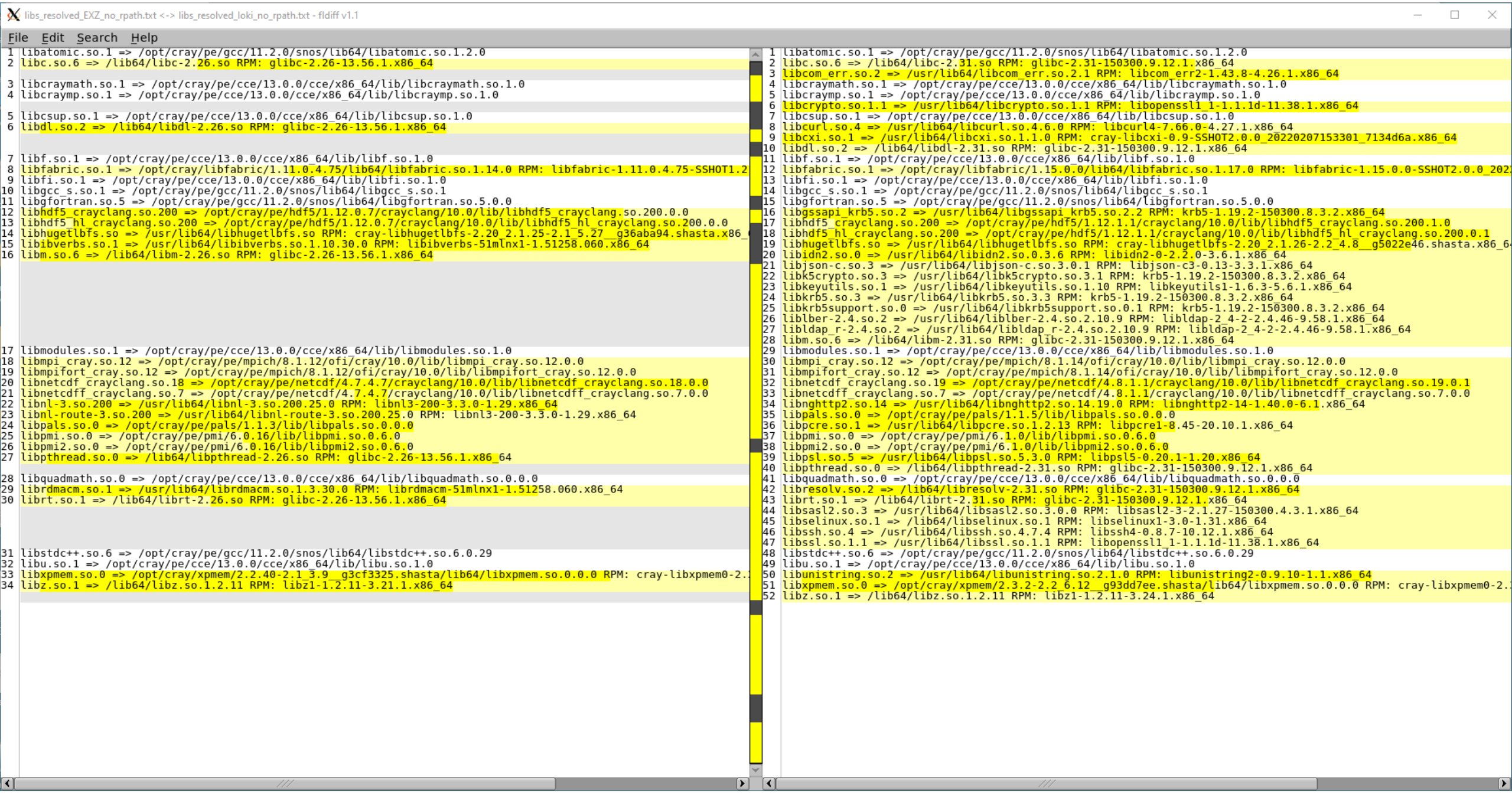
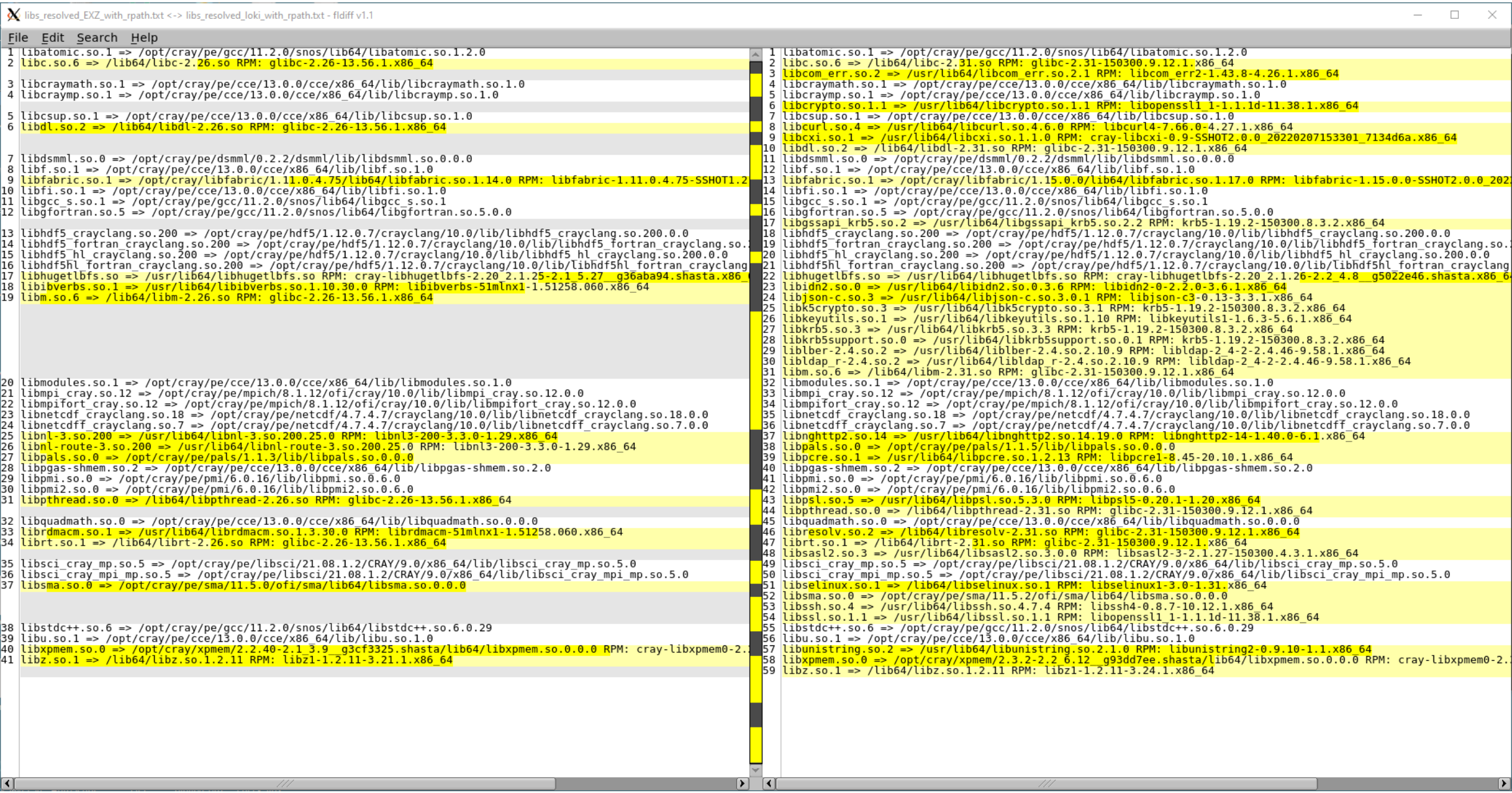

libs_resolved_EXZ_no_rpath.txt <-> libs_resolved_loki_no_rpath.txt - fldiff v1.1
File Edit Search Help
1 libatomic.so.1 => /opt/cray/pe/gcc/11.2.0/snos/lib64/libatomic.so.1.2.0
2 libc.so.6 => /lib64/libc-2.26.so RPM: glibc-2.26-13.56.1.x86_64
3 libcraymath.so.1 => /opt/cray/pe/cce/13.0.0/cce/x86_64/lib/libcraymath.so.1.0
4 libcraymp.so.1 => /opt/cray/pe/cce/13.0.0/cce/x86_64/lib/libcraymp.so.1.0
5 libcsup.so.1 => /opt/cray/pe/cce/13.0.0/cce/x86_64/lib/libcsup.so.1.0
6 libdl.so.2 => /lib64/libdl-2.26.so RPM: glibc-2.26-13.56.1.x86_64
7 libf.so.1 => /opt/cray/pe/cce/13.0.0/cce/x86_64/lib/libf.so.1.0
8 libfabric.so.1 => /opt/cray/libfabric/1.11.0.4.75/lib64/libfabric.so.1.14.0 RPM: libfabric-1.11.0.4.75-SSHOT1.2
9 libfi.so.1 => /opt/cray/pe/cce/13.0.0/cce/x86_64/lib/libfi.so.1.0
10 libgcc_s.so.1 => /opt/cray/pe/gcc/11.2.0/snos/lib64/libgcc_s.so.1
11 libgfortran.so.5 => /opt/cray/pe/gcc/11.2.0/snos/lib64/libgfortran.so.5.0.0
12 libhdf5_crayclang.so.200 => /opt/cray/pe/hdf5/1.12.0.7/crayclang/10.0/lib/libhdf5_crayclang.so.200.0.0
13 libhdf5_hl_crayclang.so.200 => /opt/cray/pe/hdf5/1.12.0.7/crayclang/10.0/lib/libhdf5_hl_crayclang.so.200.0.0
14 libhugetlbfs.so => /usr/lib64/libhugetlbfs.so RPM: cray-libhugetlbfs-2.20_2.1.25-2.1_5.27__g36aba94.shasta.x86_
15 libibverbs.so.1 => /usr/lib64/libibverbs.so.1.10.30.0 RPM: libibverbs-51mlnx1-1.51258.060.x86_64
16 libm.so.6 => /lib64/libm-2.26.so RPM: glibc-2.26-13.56.1.x86_64
17 libmodules.so.1 => /opt/cray/pe/cce/13.0.0/cce/x86_64/lib/libmodules.so.1.0
18 libmpi_cray.so.12 => /opt/cray/pe/mpich/8.1.12/ofi/cray/10.0/lib/libmpi_cray.so.12.0.0
19 libmpifort_cray.so.12 => /opt/cray/pe/mpich/8.1.12/ofi/cray/10.0/lib/libmpifort_cray.so.12.0.0
20 libnetcdf_crayclang.so.18 => /opt/cray/pe/netcdf/4.7.4.7/crayclang/10.0/lib/libnetcdf_crayclang.so.18.0.0
21 libnetcdff_crayclang.so.7 => /opt/cray/pe/netcdf/4.7.4.7/crayclang/10.0/lib/libnetcdff_crayclang.so.7.0.0
22 libnl-3.so.200 => /usr/lib64/libnl-3.so.200.25.0 RPM: libnl3-200-3.3.0-1.29.x86_64
23 libnl-route-3.so.200 => /usr/lib64/libnl-route-3.so.200.25.0 RPM: libnl3-200-3.3.0-1.29.x86_64
24 libpals.so.0 => /opt/cray/pe/pals/1.1.3/lib/libpals.so.0.0.0
25 libpmi.so.0 => /opt/cray/pe/pmi/6.0.16/lib/libpmi.so.0.6.0
26 libpmi2.so.0 => /opt/cray/pe/pmi/6.0.16/lib/libpmi2.so.0.6.0
27 libpthread.so.0 => /lib64/libpthread-2.26.so RPM: glibc-2.26-13.56.1.x86_64
28 libquadmath.so.0 => /opt/cray/pe/cce/13.0.0/cce/x86_64/lib/libquadmath.so.0.0.0
29 librdmacm.so.1 => /usr/lib64/librdmacm.so.1.3.30.0 RPM: librdmacm-51mlnx1-1.51258.060.x86_64
30 librt.so.1 => /lib64/librt-2.26.so RPM: glibc-2.26-13.56.1.x86_64
31 libstdc++.so.6 => /opt/cray/pe/gcc/11.2.0/snos/lib64/libstdc++.so.6.0.29
32 libu.so.1 => /opt/cray/pe/cce/13.0.0/cce/x86_64/lib/libu.so.1.0
33 libxpmem.so.0 => /opt/cray/xpmem/2.2.40-2.1_3.9__g3cf3325.shasta/lib64/libxpmem.so.0.0.0 RPM: cray-libxpmem0-2.
34 libz.so.1 => /lib64/libz.so.1.2.11 RPM: libz1-1.2.11-3.21.1.x86_64
1 libatomic.so.1 => /opt/cray/pe/gcc/11.2.0/snos/lib64/libatomic.so.1.2.0
2 libc.so.6 => /lib64/libc-2.31.so RPM: glibc-2.31-150300.9.12.1.x86_64
3 libcom_err.so.2 => /usr/lib64/libcom_err.so.2.1 RPM: libcom_err2-1.43.8-4.26.1.x86_64
4 libcraymath.so.1 => /opt/cray/pe/cce/13.0.0/cce/x86_64/lib/libcraymath.so.1.0
5 libcraymp.so.1 => /opt/cray/pe/cce/13.0.0/cce/x86_64/lib/libcraymp.so.1.0
6 libcrypto.so.1.1 => /usr/lib64/libcrypto.so.1.1 RPM: libopenssl1_1-1.1.1d-11.38.1.x86_64
7 libcsup.so.1 => /opt/cray/pe/cce/13.0.0/cce/x86_64/lib/libcsup.so.1.0
8 libcurl.so.4 => /usr/lib64/libcurl.so.4.6.0 RPM: libcurl4-7.66.0-4.27.1.x86_64
9 libcxi.so.1 => /usr/lib64/libcxi.so.1.1.0 RPM: cray-libcxi-0.9-SSHOT2.0.0_20220207153301_7134d6a.x86_64
10 libdl.so.2 => /lib64/libdl-2.31.so RPM: glibc-2.31-150300.9.12.1.x86_64
11 libf.so.1 => /opt/cray/pe/cce/13.0.0/cce/x86_64/lib/libf.so.1.0
12 libfabric.so.1 => /opt/cray/libfabric/1.15.0.0/lib64/libfabric.so.1.17.0 RPM: libfabric-1.15.0.0-SSHOT2.0.0_202
13 libfi.so.1 => /opt/cray/pe/cce/13.0.0/cce/x86_64/lib/libfi.so.1.0
14 libgcc_s.so.1 => /opt/cray/pe/gcc/11.2.0/snos/lib64/libgcc_s.so.1
15 libgfortran.so.5 => /opt/cray/pe/gcc/11.2.0/snos/lib64/libgfortran.so.5.0.0
16 libgssapi_krb5.so.2 => /usr/lib64/libgssapi_krb5.so.2.2 RPM: krb5-1.19.2-150300.8.3.2.x86_64
17 libhdf5_crayclang.so.200 => /opt/cray/pe/hdf5/1.12.1.1/crayclang/10.0/lib/libhdf5_crayclang.so.200.1.0
18 libhdf5_hl_crayclang.so.200 => /opt/cray/pe/hdf5/1.12.1.1/crayclang/10.0/lib/libhdf5_hl_crayclang.so.200.0.1
19 libhugetlbfs.so => /usr/lib64/libhugetlbfs.so RPM: cray-libhugetlbfs-2.20_2.1.26-2.2_4.8__g5022e46.shasta.x86_6
20 libidn2.so.0 => /usr/lib64/libidn2.so.0.3.6 RPM: libidn2-0-2.2.0-3.6.1.x86_64
21 libjson-c.so.3 => /usr/lib64/libjson-c.so.3.0.1 RPM: libjson-c3-0.13-3.3.1.x86_64
22 libk5crypto.so.3 => /usr/lib64/libk5crypto.so.3.1 RPM: krb5-1.19.2-150300.8.3.2.x86_64
23 libkeyutils.so.1 => /usr/lib64/libkeyutils.so.1.10 RPM: libkeyutils1-1.6.3-5.6.1.x86_64
24 libkrb5.so.3 => /usr/lib64/libkrb5.so.3.3 RPM: krb5-1.19.2-150300.8.3.2.x86_64
25 libkrb5support.so.0 => /usr/lib64/libkrb5support.so.0.1 RPM: krb5-1.19.2-150300.8.3.2.x86_64
26 liblber-2.4.so.2 => /usr/lib64/liblber-2.4.so.2.10.9 RPM: libldap-2_4-2-2.4.46-9.58.1.x86_64
27 libldap_r-2.4.so.2 => /usr/lib64/libldap_r-2.4.so.2.10.9 RPM: libldap-2_4-2-2.4.46-9.58.1.x86_64
28 libm.so.6 => /lib64/libm-2.31.so RPM: glibc-2.31-150300.9.12.1.x86_64
29 libmodules.so.1 => /opt/cray/pe/cce/13.0.0/cce/x86_64/lib/libmodules.so.1.0
30 libmpi_cray.so.12 => /opt/cray/pe/mpich/8.1.14/ofi/cray/10.0/lib/libmpi_cray.so.12.0.0
31 libmpifort_cray.so.12 => /opt/cray/pe/mpich/8.1.14/ofi/cray/10.0/lib/libmpifort_cray.so.12.0.0
32 libnetcdf_crayclang.so.19 => /opt/cray/pe/netcdf/4.8.1.1/crayclang/10.0/lib/libnetcdf_crayclang.so.19.0.1
33 libnetcdff_crayclang.so.7 => /opt/cray/pe/netcdf/4.8.1.1/crayclang/10.0/lib/libnetcdff_crayclang.so.7.0.0
34 libnghttp2.so.14 => /usr/lib64/libnghttp2.so.14.19.0 RPM: libnghttp2-14-1.40.0-6.1.x86_64
35 libpals.so.0 => /opt/cray/pe/pals/1.1.5/lib/libpals.so.0.0.0
36 libpcre.so.1 => /usr/lib64/libpcre.so.1.2.13 RPM: libpcre1-8.45-20.10.1.x86_64
37 libpmi.so.0 => /opt/cray/pe/pmi/6.1.0/lib/libpmi.so.0.6.0
38 libpmi2.so.0 => /opt/cray/pe/pmi/6.1.0/lib/libpmi2.so.0.6.0
39 libpsl.so.5 => /usr/lib64/libpsl.so.5.3.0 RPM: libpsl5-0.20.1-1.20.x86_64
40 libpthread.so.0 => /lib64/libpthread-2.31.so RPM: glibc-2.31-150300.9.12.1.x86_64
41 libquadmath.so.0 => /opt/cray/pe/cce/13.0.0/cce/x86_64/lib/libquadmath.so.0.0.0
42 libresolv.so.2 => /lib64/libresolv-2.31.so RPM: glibc-2.31-150300.9.12.1.x86_64
43 librt.so.1 => /lib64/librt-2.31.so RPM: glibc-2.31-150300.9.12.1.x86_64
44 libsasl2.so.3 => /usr/lib64/libsasl2.so.3.0.0 RPM: libsasl2-3-2.1.27-150300.4.3.1.x86_64
45 libselinux.so.1 => /lib64/libselinux.so.1 RPM: libselinux1-3.0-1.31.x86_64
46 libssh.so.4 => /usr/lib64/libssh.so.4.7.4 RPM: libssh4-0.8.7-10.12.1.x86_64
47 libssl.so.1.1 => /usr/lib64/libssl.so.1.1 RPM: libopenssl1_1-1.1.1d-11.38.1.x86_64
48 libstdc++.so.6 => /opt/cray/pe/gcc/11.2.0/snos/lib64/libstdc++.so.6.0.29
49 libu.so.1 => /opt/cray/pe/cce/13.0.0/cce/x86_64/lib/libu.so.1.0
50 libunistring.so.2 => /usr/lib64/libunistring.so.2.1.0 RPM: libunistring2-0.9.10-1.1.x86_64
51 libxpmem.so.0 => /opt/cray/xpmem/2.3.2-2.2_6.12__g93dd7ee.shasta/lib64/libxpmem.so.0.0.0 RPM: cray-libxpmem0-2.
52 libz.so.1 => /lib64/libz.so.1.2.11 RPM: libz1-1.2.11-3.24.1.x86_64


libs_resolved_EXZ_with_rpath.txt <-> libs_resolved_loki_with_rpath.txt - fldiff v1.1
File Edit Search Help
libatomic.so.1 => /opt/cray/pe/gcc/11.2.0/snos/lib64/libatomic.so.1.2.0
libc.so.6 => /lib64/libc-2.26.so RPM: glibc-2.26-13.56.1.x86_64
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libhdf5hl_fortran_crayclang.so.200 => /opt/cray/pe/hdf5/1.12.0.7/crayclang/10.0/lib/libhdf5hl_fortran_crayclang
libhugetlbfs.so => /usr/lib64/libhugetlbfs.so RPM: cray-libhugetlbfs-2.20_2.1.25-2.1_5.27__g36aba94.shasta.x86_
libibverbs.so.1 => /usr/lib64/libibverbs.so.1.10.30.0 RPM: libibverbs-51mlnx1-1.51258.060.x86_64
libm.so.6 => /lib64/libm-2.26.so RPM: glibc-2.26-13.56.1.x86_64
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libxpmem.so.0 => /opt/cray/xpmem/2.2.40-2.1_3.9__g3cf3325.shasta/lib64/libxpmem.so.0.0.0 RPM: cray-libxpmem0-2.
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libc.so.6 => /lib64/libc-2.31.so RPM: glibc-2.31-150300.9.12.1.x86_64
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libcrypto.so.1.1 => /usr/lib64/libcrypto.so.1.1 RPM: libopenssl1_1-1.1.1d-11.38.1.x86_64
libcsup.so.1 => /opt/cray/pe/cce/13.0.0/cce/x86_64/lib/libcsup.so.1.0
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libfabric.so.1 => /opt/cray/libfabric/1.15.0.0/lib64/libfabric.so.1.17.0 RPM: libfabric-1.15.0.0-SSHOT2.0.0_202
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liblber-2.4.so.2 => /usr/lib64/liblber-2.4.so.2.10.9 RPM: libldap-2_4-2-2.4.46-9.58.1.x86_64
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librt.so.1 => /lib64/librt-2.31.so RPM: glibc-2.31-150300.9.12.1.x86_64
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libunistring.so.2 => /usr/lib64/libunistring.so.2.1.0 RPM: libunistring2-0.9.10-1.1.x86_64
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libz.so.1 => /lib64/libz.so.1.2.11 RPM: libz1-1.2.11-3.24.1.x86_64