UCLouvain

Plateforme technologique de Calcul Intensif et Stockage de Masse

EURO BELGIUM

Checkpointing

Olivier Mattelaer

What is checkpointing

```
$ ./count
```

```
$ ./count
1
```

```
$ ./count
1
2
```

```
$ ./count
1
2
3
```

```
$ ./count
1
2
3^C
$
```

```
$ ./count
1
2
3^C
$ ./count
```

```
$ ./count
1
2
3^C
$ ./count
1
```

Without checkpointing:

```
$ ./count
1
2
3^C
$ ./count
1
```

Without checkpointing:

```
$ ./count
1
2
3^C
$ ./count
1
```

With checkpointing:

```
$ ./count
1
2
3^C
$ ./count
4
```

Without checkpointing:

```
$ ./count
1
2
3^C
$ ./count
1
2
```

With checkpointing:

```
$ ./count
1
2
3^C
$ ./count
4
5
```

Without checkpointing:

```
$ ./count
1
2
3^C
$ ./count
1
2
3
```

With checkpointing:

```
$ ./count
1
2
3^C
$ ./count
4
5
6
```

Without checkpointing:

```
$ ./count
1
2
^C
$ ./count
1
2
3
```

With checkpointing:

```
$ ./count
1
2
^C
$ ./count
4
5
6
```

Checkpointing:

'saving' a computation so that it can be resumed later

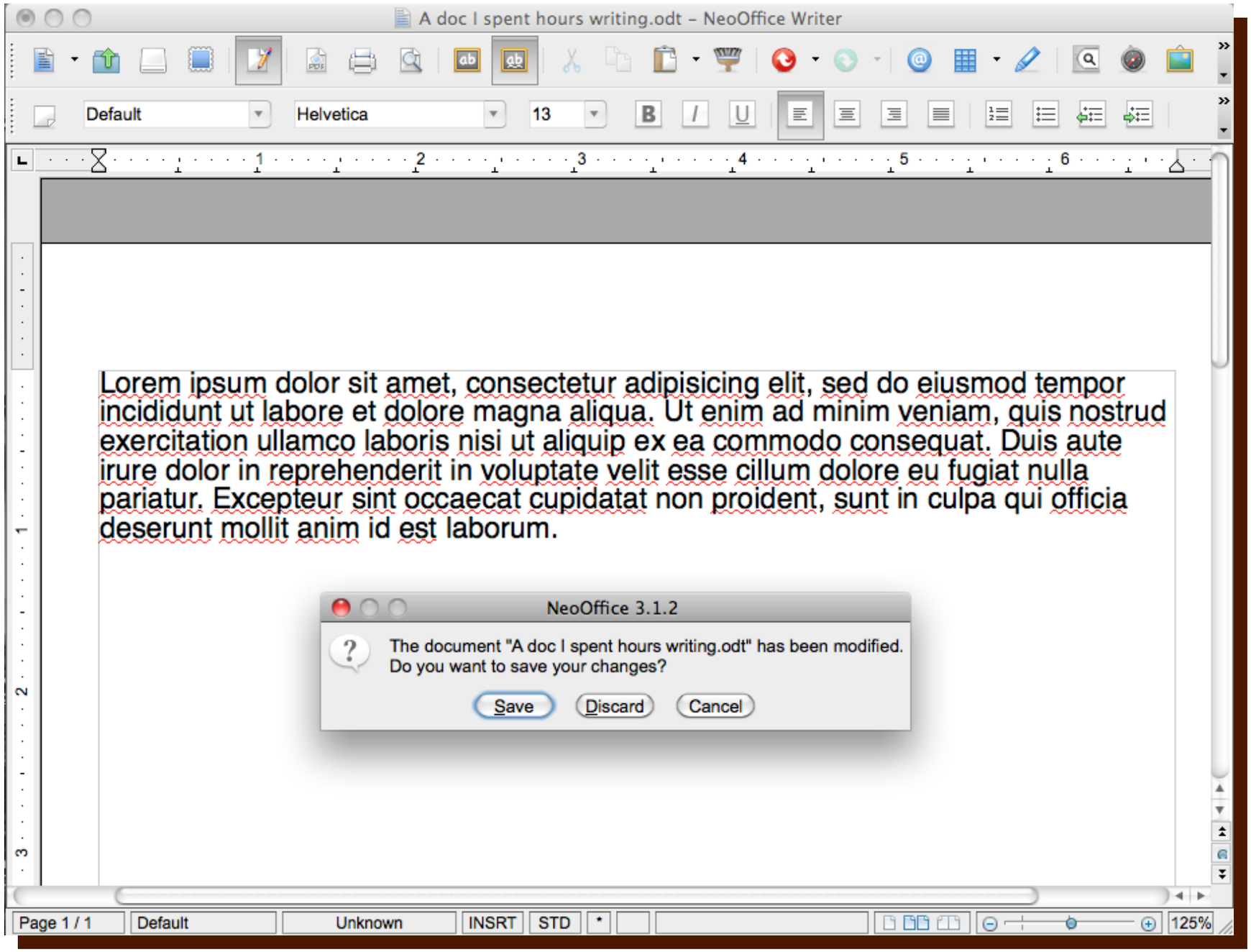
(rather than started again)

Today's agenda:

1. General concepts and scientific soft.
2. Working with Signals
3. Slurm recipes
4. DMTCP

Why do we need checkpointing

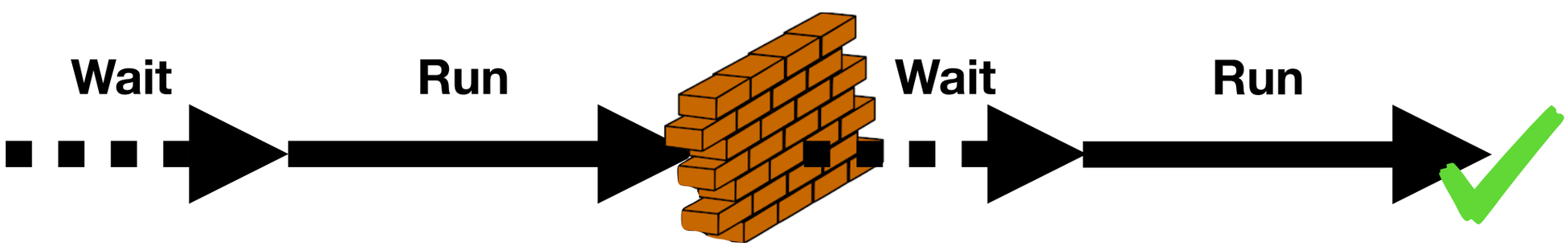
Imagine a text editor without 'checkpointing' ...



Goals of checkpointing in HPC:

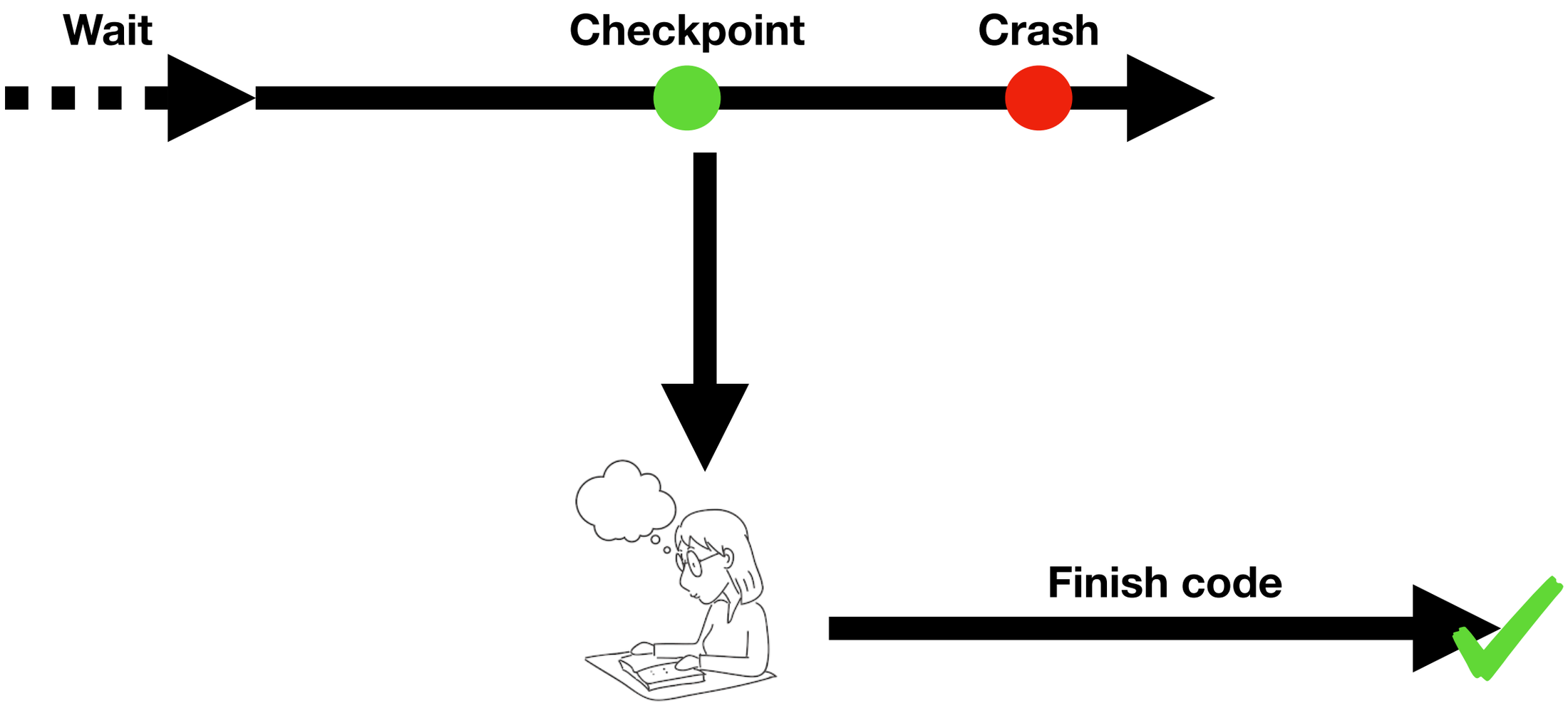
1. Fit in time constraints
2. Debugging, monitoring
3. Cope with hardware failures
4. Job preemption

Wall-Time

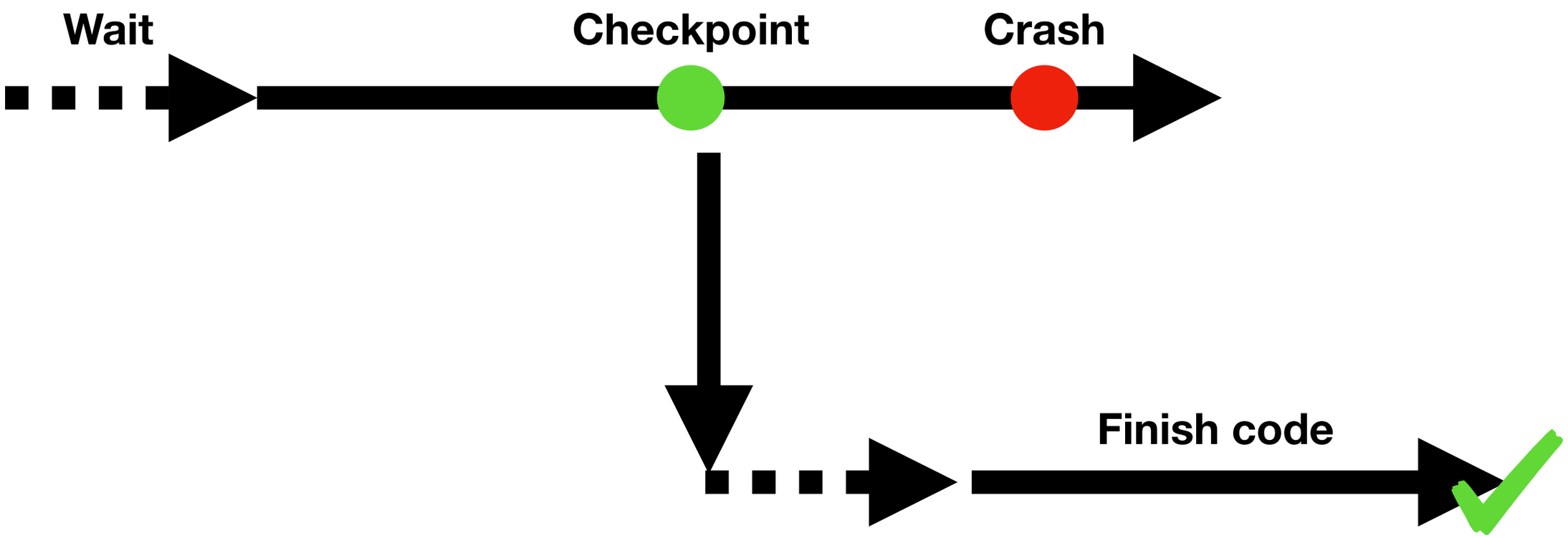


Killed

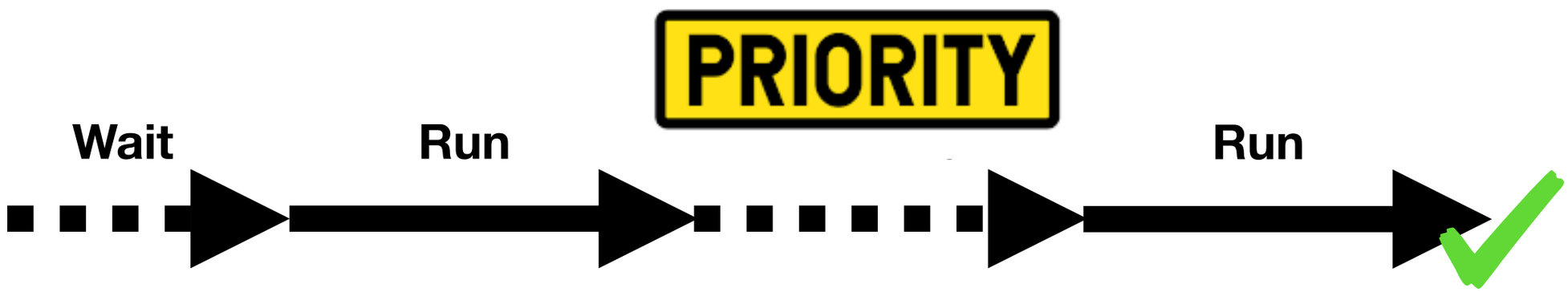
Debug



Hardware crash



Pre-emption



suspended wait

1 Checkpointing with scientific software
Do they support checkpointing?

Working with checkpoint-restart-able software

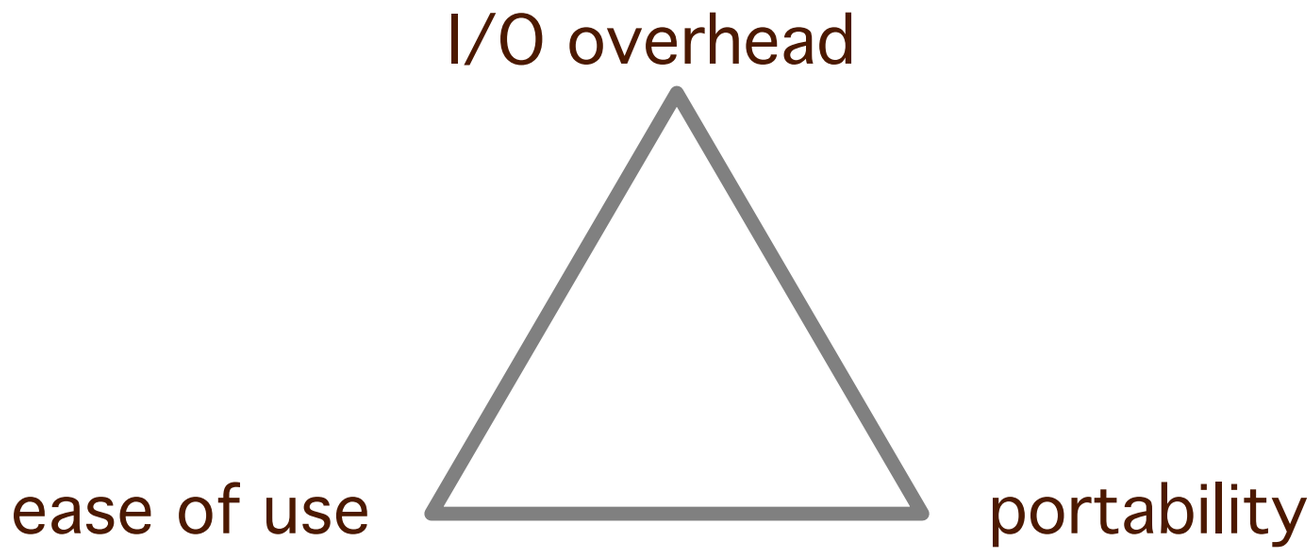
Many scientific software have built-in checkpointing capabilities

(although it might not be called that way)

Check the documentation

Need to implement it yourself?

Evaluate the options : tradeoff between



Transparency for developer	Portability to other systems	Size of state to save	Checkpointing overhead
Do I need to write a lot of additional code ?	Can I stop on one system and restart on another ?	How many GB of disk does it require ?	How many FLOPs lost to ensure checkpointing ?

Demo #1

count.py
Save state at each iteration

2

Using UNIX signals to reduce overhead : do not save the state at each iteration -- wait for the signal.

UNIX processes can receive 'signals' from the user, the OS, or another process

SIGHUP	1	Exit	Hangup
SIGINT	2	Exit	Interrupt
SIGQUIT	3	Core	Quit
SIGILL	4	Core	Illegal Instruction
SIGTRAP	5	Core	Trace/Breakpoint Trap
SIGABRT	6	Core	Abort
SIGEMT	7	Core	Emulation Trap
SIGFPE	8	Core	Arithmetic Exception
SIGKILL	9	Exit	Killed
SIGBUS	10	Core	Bus Error
SIGSEGV	11	Core	Segmentation Fault
SIGSYS	12	Core	Bad System Call
SIGPIPE	13	Exit	Broken Pipe
SIGALRM	14	Exit	Alarm Clock
SIGTERM	15	Exit	Terminated
SIGUSR1	16	Exit	User Signal 1
SIGUSR2	17	Exit	User Signal 2
SIGCHLD	18	Ignore	Child Status
SIGPWR	19	Ignore	Power Fail/Restart
SIGWINCH	20	Ignore	Window Size Change
SIGURG	21	Ignore	Urgent Socket Condition
SIGPOLL	22	Ignore	Socket I/O Possible
SIGSTOP	23	Stop	Stopped (signal)
SIGTSTP	24	Stop	Stopped (user)
SIGCONT	25	Ignore	Continued
SIGTTIN	26	Stop	Stopped (tty input)
SIGTTOU	27	Stop	Stopped (tty output)
SIGVTALRM	28	Exit	Virtual Timer Expired
SIGPROF	29	Exit	Profiling Timer Expired
SIGXCPU	30	Core	CPU time limit exceeded
SIGXFSZ	31	Core	File size limit exceeded
SIGWAITING	32	Ignore	All LWPs blocked
SIGLWP	33	Ignore	Virtual Interprocessor Interrupt for Threads Library
SIGAIO	34	Ignore	Asynchronous I/O

UNIX processes can receive 'signals' from the user, the OS, or another process

^C

^D

SIGHUP	1	Exit	Hangup
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SIGQUIT	3	Core	Quit
SIGILL	4	Core	Illegal Instruction
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SIGAIO	34	Ignore	Asynchronous I/O

kill -9

kill

^Z

fg, bg

UNIX processes can receive 'signals' from the user, the OS, or another process

e.g.

SIGHUP	1	Exit	Hangup
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SIGABRT	6	Core	Abort
SIGEMT	7	Core	Emulation Trap
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UNIX processes can receive 'signals' with an associated default action

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SIGILL	4	Core	Illegal Instruction
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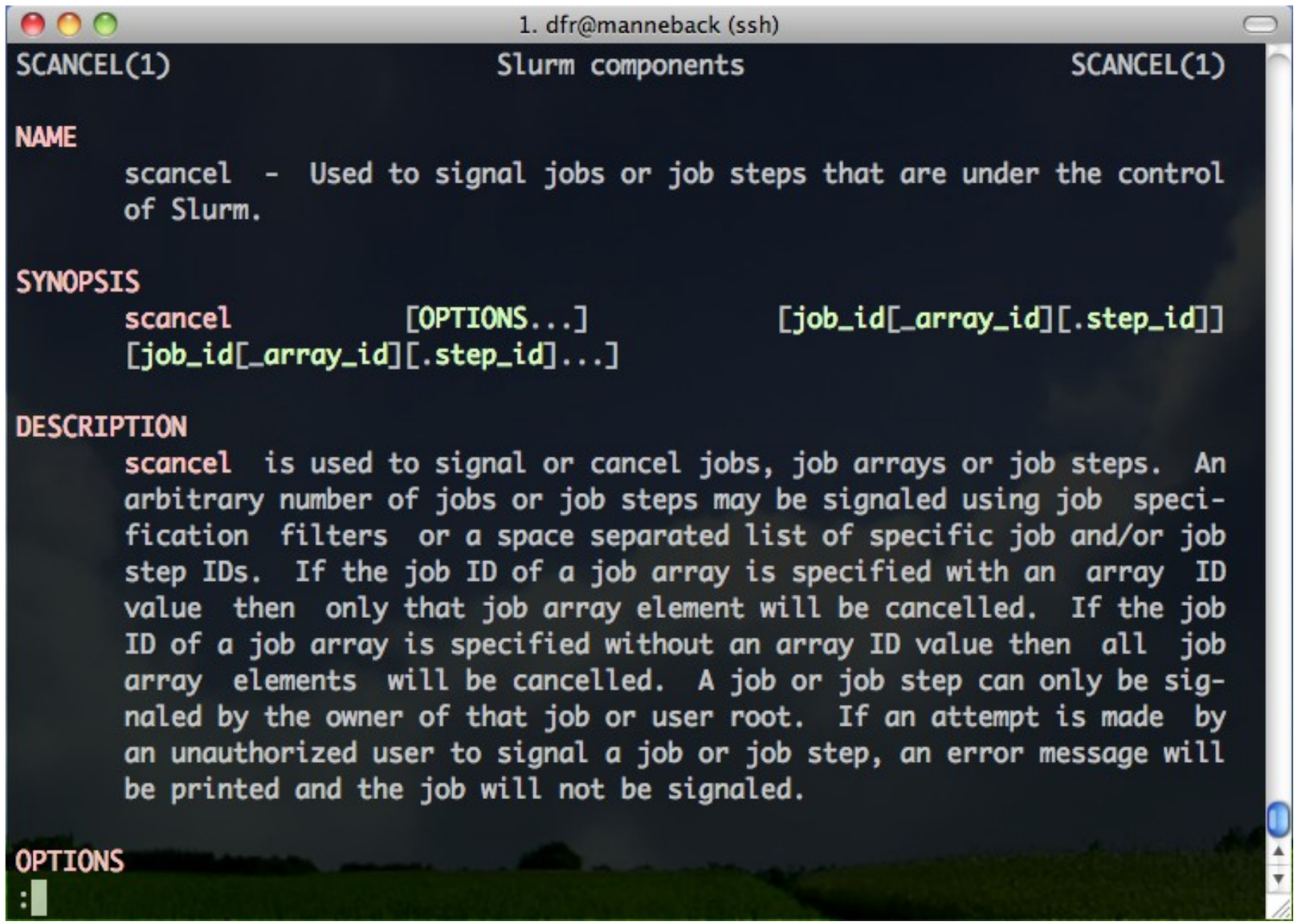
Demo #2

count-signal.py
Catch control-C to save state

3

Use Slurm signaling abilities to manage checkpoint-able software in Slurm scripts on the clusters.

scancel is used to send signals to jobs



scancel -s SIGINT JOBID

--signal to have Slurm send signals automatically before the end of the allocation

root@lm3-m001:~ (ssh)

```
       AllowSpecResourcesUsage  is enabled, the job will be allowed to override CoreSpecCount
       and use the specialized resources on nodes it is allocated.  This option  can  not  be
       used with the --thread-spec option.

   --signal=[B:]<sig_num>[@<sig_time>]
       When  a  job  is  within sig_time seconds of its end time, send it the signal sig_num.
       Due to the resolution of event handling by Slurm, the signal may be sent up to 60 sec-
       onds earlier than specified.  sig_num may either be a signal number or name (e.g. "10"
       or "USR1").  sig_time must have an integer value between 0 and 65535.  By default,  no
       signal  is  sent  before  the  job's  end time.  If a sig_num is specified without any
       sig_time, the default time will be 60 seconds.  Use the "B:" option to signal only the
       batch  shell,  none  of the other processes will be signaled. By default all job steps
       will be signaled, but not the batch shell itself.

   --sockets-per-node=<sockets>
       Restrict node selection to nodes with at least the specified number of  sockets.   See
       additional information under -B option above when task/affinity plugin is enabled.

   --spread-job
       Spread  the  job  allocation over as many nodes as possible and attempt to evenly dis-
       tribute tasks across the allocated nodes.   This  option  disables  the  topology/tree
       plugin.
```

--signal=B:SIGINT send signal to the bash script
--signal=SIGINT send signal to the srun command

Note the --open-mode=append

root@lm3-m001:~ (ssh)

```
File Edit Options Buffers Tools Sh-Script Help
#!/bin/bash

#SBATCH --job-name=test
#SBATCH --output=test.signal
#SBATCH --open-mode=append
#SBATCH --time=0-00:03:00
#SBATCH --signal=SIGINT@60
#SBATCH --ntasks=1
#SBATCH --partition=debug

date
echo "restarted ${SLURM_RESTART_COUNT-0}"
module load Python/2.7.14-foss-2017b
python --version
srun --overcommit -n1 python ./count-signal.py
```

Note that we need the srun here

Demo #3

submit-signal.sh
python: Catch control-C to save state
Slurm send control-C between 1 and 2 minutes

submit-signal2.sh
python: Catch control-C to save state
Slurm send control-C between 1 and 2 minutes
Automatic re-queuing

Adding requeuing automatically

root@lm3-m001:~ (ssh)

```
File Edit Options Buffers Tools Sh-Script Help
#!/bin/bash

#SBATCH --job-name=test
#SBATCH --output=test.signal.watch
#SBATCH --open-mode=append
#SBATCH --time=0-00:05:00
#SBATCH --signal=B:USR1@60
#SBATCH --ntasks=1
#SBATCH --partition=debug

timeout()
{
    echo "TRAPPED"
    scancel -s SIGINT $SLURM_JOB_ID
     scontrol requeue $SLURM_JOB_ID
}

# call your_cleanup_function once we receive USR1 signal
trap 'timeout' USR1

date
echo "restarted ${SLURM_RESTART_COUNT-0}"
module load Python/2.7.14-foss-2017b
srun --overcommit -n1 python /home/ucl/cp3/omatt/checkpointing/count.py &
wait
```

Send signal to bash with USR1

Catch the signal (USR1)
-> send ^C to python script (save state)
-> re-queue the job

Important here!

Demo #4

slurm-signal-3.sh

Slurm send USR1 between 1 and 2 minutes
Bash catch the message send Ctrl-c to python
python: Catch control-C to save state
Automatic resubmission

4 Making non restartable software restartable with DMTCP

DMTCP: Distributed MultiThreaded CheckPointing

About DMTCP:

DMTCP (Distributed MultiThreaded Checkpointing) transparently checkpoints a single-host or distributed computation in user-space -- with no modifications to user code or to the O/S. It works on most Linux applications, including Python, Matlab, R, GUI desktops, MPI, etc. It is robust and widely used (on Sourceforge since 2007).

Among the applications supported by DMTCP are MPI (various implementations), OpenMP, MATLAB, Python, Perl, R, and many programming languages and shell scripting languages. With the use of TightVNC, it can also checkpoint and restart X Window applications. The OpenGL library for 3D graphics is supported through a special plugin. It also has strong support for HPC (High Performance Computing) environments, including MPI, SLURM, InfiniBand, and other components. See QUICK-START.md for further details.

DMTCP supports the commonly used OFED API for InfiniBand, as well as its integration with various implementations of MPI, and resource managers (e.g., SLURM). See contrib/infiniband/README for more details.

News | See Also | Authors | Acknowledgment

Announcement!

We are currently looking for well qualified applicants who are interested in joining a Ph.D. program in order to do research on checkpointing with applications to HPC, supercomputing, cloud computing, security, and other areas. Interested applicants should write to Gene Cooperman (gene@ccs.neu.edu) at Northeastern University.

News

[2019-08-14]: Upcoming releases:

1. A totally revised DMTCP module for support of MPI is planned (based on MANA; MPI-Agnostic, Network-Agnostic; see DMTCP Publications).
2. Longer-term, a DMTCP version 3.0 is being prepared with new and better features (e.g., user-programmable barriers within a plugin). If you would like to try it now, see Downloads.

[2019-08-14]: DMTCP 2.6.0 released!

Advertised Features

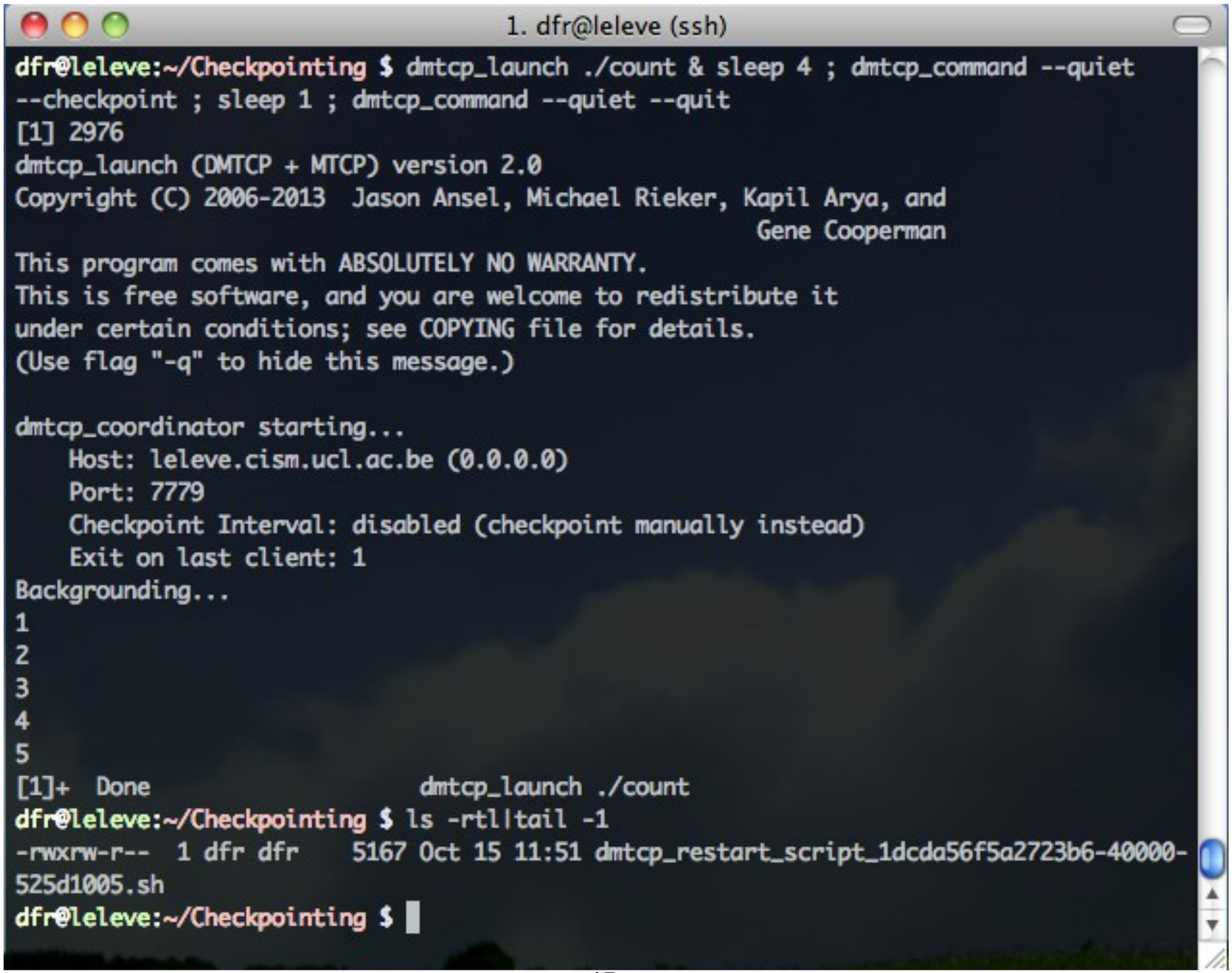
- Distributed Multi-Threaded CheckPointing
- Works with Linux Kernel 2.6.9 and later
- Supports sequential and multi-threaded computations across single/multiple hosts
- Entirely in user space (no kernel modules or root privilege)
- Transparent (no recompiling, no re-linking)
- Written at Northeastern U. and MIT and under active development for 5+ years
- LGPL'd and freely available
- No remote I/O
- Supports threads, mutexes/semaphoes, forks, shared memory, exec, and many more

From their FAQ:

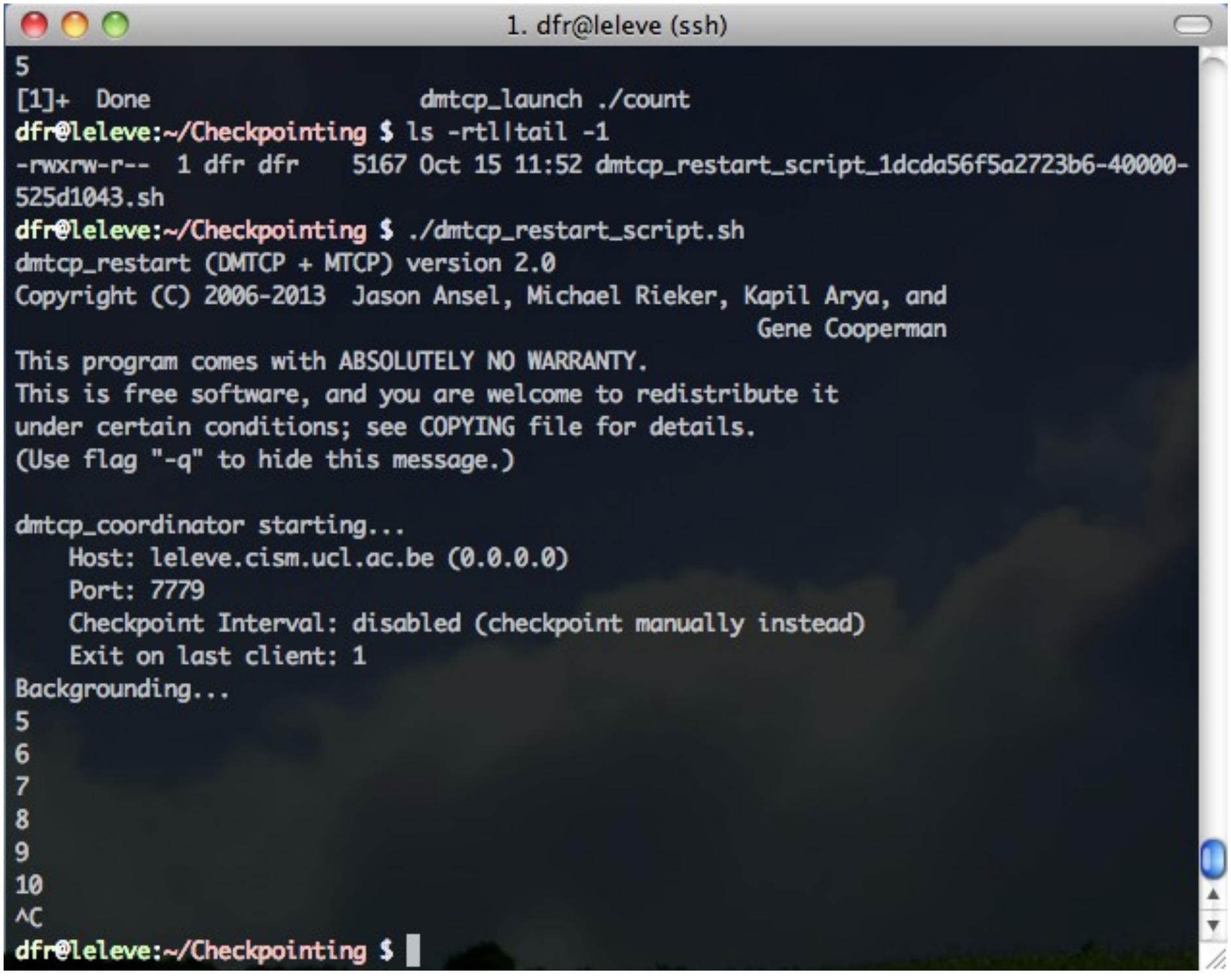
“**What types of programs can DMTCP checkpoint?**
It checkpoints most binary programs on most Linux distributions. Some examples on which users have verified that DMTCP works are: Matlab, R, Java, Python, Perl, Ruby, PHP, Ocaml, GCL (GNU Common Lisp), emacs, vi/cscope, Open MPI, MPICH-2, OpenMP, and Cilk. See Supported Applications for further details. Our goal is to support DMTCP for all vanilla programs. If DMTCP does not work correctly on your program, **then this is a bug in DMTCP.** We would be appreciative if you can then file a bug report with DMTCP.”

Imagine a non-checkpointable program

Run with dmtcp_launch (runs monitoring daemon if necessary)



Restart with dmtcp_restart_script.sh



Apply it for Slurm

```
#################################################################################
# 1. Start DMTCP coordinator
#################################################################################

start_coordinator -i 10 # -i 120 ... <put dmtcp coordinator options here>


#################################################################################
# 2. Launch application
# 2.1. If you use mpiexec/mpirun to launch an application, use the following
#      command line:
#        $ dmtcp_launch --rm mpiexec <mpi-options> ./<app-binary> <app-options>
# 2.2. If you use PMI1 to launch an application, use the following command line:
#        $ srun dmtcp_launch --rm ./<app-binary> <app-options>
# Note: PMI2 is not supported yet.
# 2.3. If you use the Stampede supercomputer at Texas Advanced Computing Center
#      (TACC), use ibrun command to launch the application (--rm is not required):
#        $ ibrun dmtcp_launch ./<app-binary> <app-options>
#################################################################################

srun dmtcp_launch --allow-file-overwrite --rm python -u count-orig.py 10<&- 11>&-
```

start coordinator

Normal job with decorator

Slurm aware

Lemaitre3 specific!

Resubmit

```
#------------------------------------ Launch application ---------------------#

################################################################################
# 1. Start DMTCP coordinator
################################################################################

start_coordinator -i 10 # -i 120 ... <put dmtcp coordinator options here>

################################################################################
# 2. Restart application
################################################################################

/bin/bash ./dmtcp_restart_script.sh -h $DMTCP_COORD_HOST -p $DMTCP_COORD_PORT

################################################################################
# If you use the Stampede supercomputer at Texas Advanced Computing Center
# (TACC), add the --hostfile option:
# /bin/bash ./dmtcp_restart_script.sh -h $DMTCP_COORD_HOST -p $DMTCP_COORD_PORT\
#                                     --hostfile $HOSTFILE
################################################################################
```

start coordinator

Script created by previous run

Let’s combine everything

Use DMTCP with periodic check
add an additional checkpoint before wall time
Auto resubmit

Solution

```
#!/bin/bash
# Put your SLURM options here
#SBATCH --partition=debug         # change to proper partition name or remove
#SBATCH --time=00:00:30           # put proper time of reservation here
#SBATCH --nodes=1                 # number of nodes
#SBATCH --ntasks-per-node=1       # processes per node
#SBATCH --job-name="dmtcp_job"    # change to your job name
#SBATCH --output=slurm.dmtcp      # change to proper file name or remove for defaults
#SBATCH --signal=B:USR1@60
#SBATCH --open-mode=append
```

```
################################################################################
# 1. Start DMTCP coordinator
################################################################################

start_coordinator -i 10 # -i 120 ... <put dmtcp coordinator options here>


################################################################################
# 2. Launch application
################################################################################
echo "requeue #${SLURM_RESTART_COUNT}"

if [[ -e dmtcp_restart_script.sh && "${SLURM_RESTART_COUNT}" != "" ]]; then
    /bin/bash ./dmtcp_restart_script.sh -h $DMTCP_COORD_HOST -p $DMTCP_COORD_PORT &
else
      srun dmtcp_launch --allow-file-overwrite --rm python -u count-orig.py 10<&- 11>&- &
fi


################################################################################
# 3. setup requeue for the wall time
# Note the #SBATCH --signal=B:USR1@60 which is needed
################################################################################
timeout(){
echo "doing checkpoint"
dmtcp_command  --checkpoint
sleep 2
echo "doing checkpoint; done"
dmtcp_command --quit
sleep 2
scontrol requeue $SLURM_JOB_ID
}

trap 'timeout' USR1
wait
```

Solution

Periodic checkpoint

```
#!/bin/bash
# Put your SLURM options here
#SBATCH --partition=debug          # change to proper partition name or remove
#SBATCH --time=00:00:30            # put proper time of reservation here
#SBATCH --nodes=1                  # number of nodes
#SBATCH --ntasks-per-node=1        # processes per node
#SBATCH --job-name="dmtcp_job"     # change to your job name
#SBATCH --output=slurm.dmtcp       # change to proper file name or remove for defaults
#SBATCH --signal=B:USR1@60
#SBATCH --open-mode=append
```

```
################################################################################
# 1. Start DMTCP coordinator
################################################################################

start_coordinator -i 10 # -i 120 ... <put dmtcp coordinator options here>

################################################################################
# 2. Launch application
################################################################################
echo "requeue #${SLURM_RESTART_COUNT}"

if [[ -e dmtcp_restart_script.sh && "${SLURM_RESTART_COUNT}" != "" ]]; then
    /bin/bash ./dmtcp_restart_script.sh -h $DMTCP_COORD_HOST -p $DMTCP_COORD_PORT &
else
      srun dmtcp_launch --allow-file-overwrite --rm python -u count-orig.py 10<&- 11>&- &
fi


################################################################################
# 3. setup requeue for the wall time
# Note the #SBATCH --signal=B:USR1@60 which is needed
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timeout(){
echo "doing checkpoint"
dmtcp_command  --checkpoint
sleep 2
echo "doing checkpoint; done"
dmtcp_command --quit
sleep 2
scontrol requeue $SLURM_JOB_ID
}

trap 'timeout' USR1
wait
```

Solution

Periodic checkpoint

Checkpoint at walltime

```
#!/bin/bash
# Put your SLURM options here
#SBATCH --partition=debug          # change to proper partition name or remove
#SBATCH --time=00:00:30            # put proper time of reservation here
#SBATCH --nodes=1                  # number of nodes
#SBATCH --ntasks-per-node=1        # processes per node
#SBATCH --job-name="dmtcp_job"     # change to your job name
#SBATCH --output=slurm_dmtcp       # change to proper file name or remove for defaults
#SBATCH --signal=B:USR1@60
#SBATCH --open-mode=append
```

```
################################################################################
# 1. Start DMTCP coordinator
################################################################################

start_coordinator -i 10 # -i 120 ... <put dmtcp coordinator options here>


################################################################################
# 2. Launch application
################################################################################
echo "requeue #${SLURM_RESTART_COUNT}"

if [[ -e dmtcp_restart_script.sh && "${SLURM_RESTART_COUNT}" != "" ]]; then
    /bin/bash ./dmtcp_restart_script.sh -h $DMTCP_COORD_HOST -p $DMTCP_COORD_PORT &
else
      srun dmtcp_launch --allow-file-overwrite --rm python -u count-orig.py 10<&- 11>&- &
fi


################################################################################
# 3. setup requeue for the wall time
# Note the #SBATCH --signal=B:USR1@60 which is needed
################################################################################
timeout(){
echo "doing checkpoint"
dmtcp_command  --checkpoint
sleep 2
echo "doing checkpoint; done"
dmtcp_command --quit
sleep 2
scontrol requeue $SLURM_JOB_ID
}

trap 'timeout' USR1
wait
```

Solution

Periodic checkpoint

Checkpoint at walltime

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Solution

Periodic checkpoint

Checkpoint at walltime

Auto-resubmit

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Solution

Periodic checkpoint

Checkpoint at walltime

Auto-resubmit

Additional

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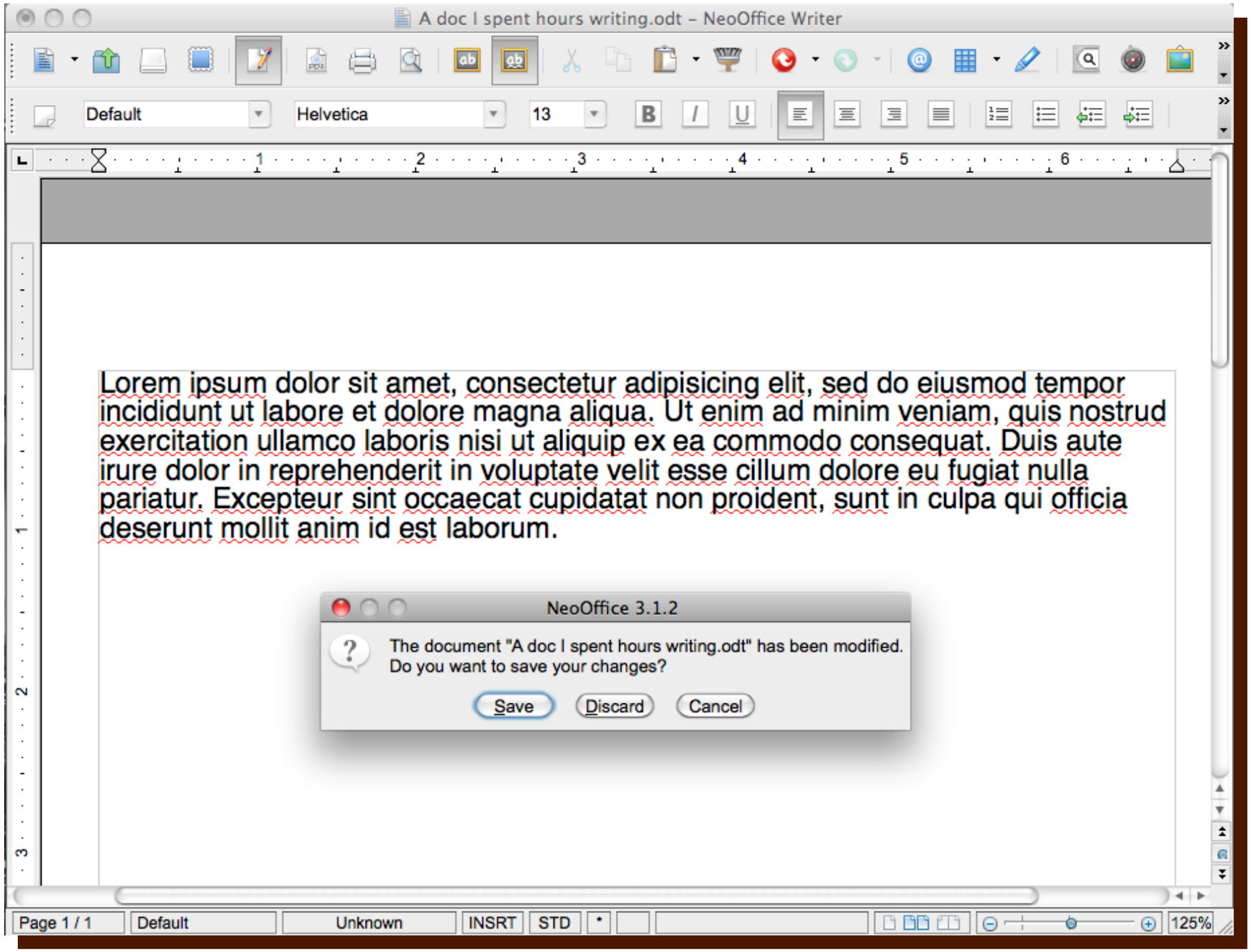
Summary, Wrap-up and Conclusions.

Never click 'Discard' again...



The submission script(s)

- Either one big one or two small ones
- Checkpoint periodically or --signal
- Requeue automatically
- Open-mode=append