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An introduction to checkpointing for scientific applications

November 2013
CISM/CÉCI training session

What is checkpointing

?

Without checkpointing:

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

With checkpointing:

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

Without checkpointing:

With checkpointing:

Checkpointing:

'saving' a computation

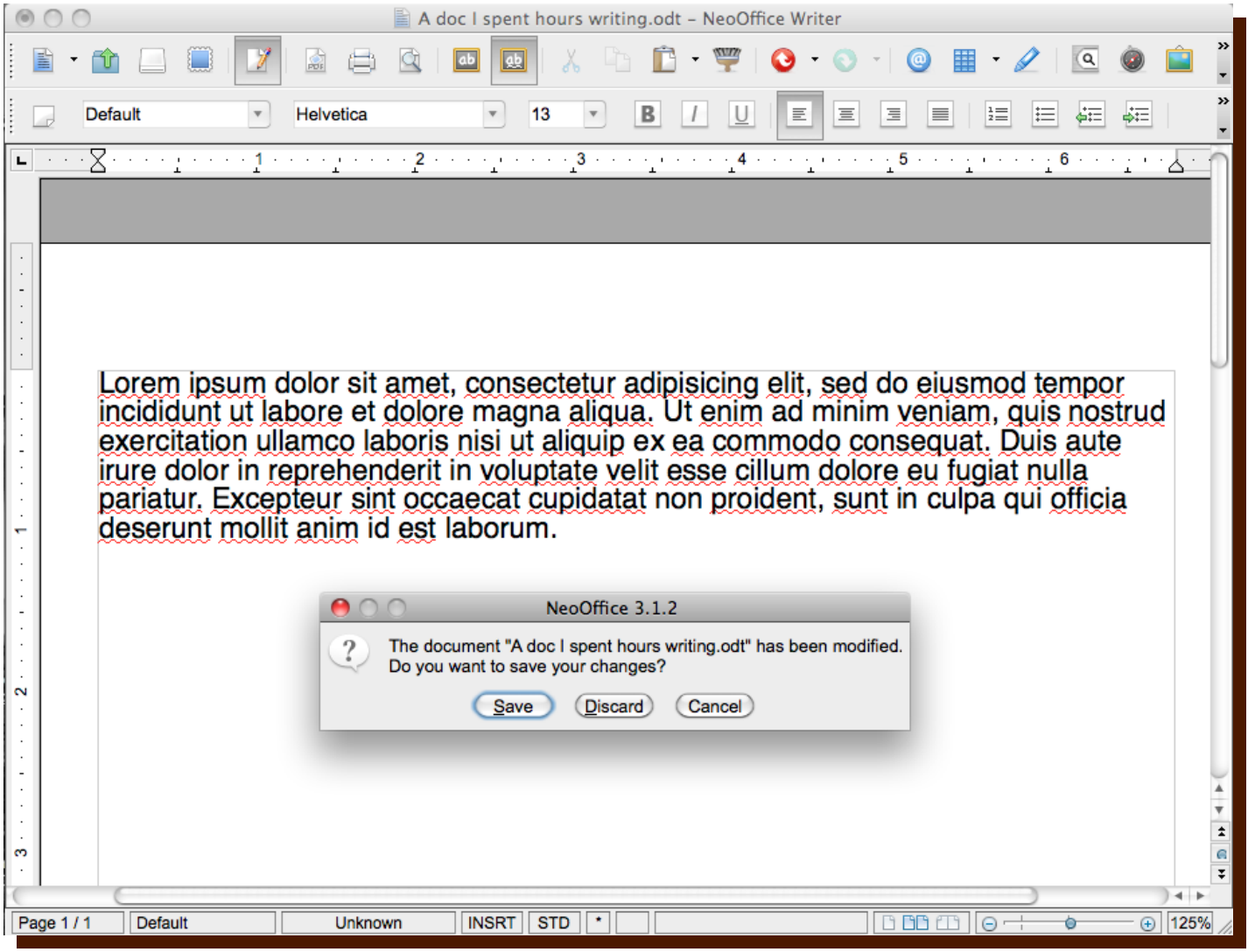
so that it can be resumed later

(rather than started again)

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 NODE_FAILs
4. Gang scheduling and preemption

The idea:

Values in variables
Open files
...

Position in the code
Signal or event
...

Save the program state

every time a checkpoint is encountered

and restart from there upon (un)planned stop

rather than bootstrap again from scratch

starting loops at iteration 0
creating tmp files
...

The key questions ...

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 ?

Who's in charge of all that ?

	Transparency for developer	Portability to other systems	Size of state to save	Checkpointing overhead
the application itself	--	+++	--	-
a library	-	++	--	-
the compiler	+	++	-	+
a run-time	+	+	++	+
the OS	++	-	++	++
the hardware	+++	--	+++	+++

Today's agenda:

1. How to make your program checkpoint-able
   - -> concepts and examples
   - -> recipes (design patterns)

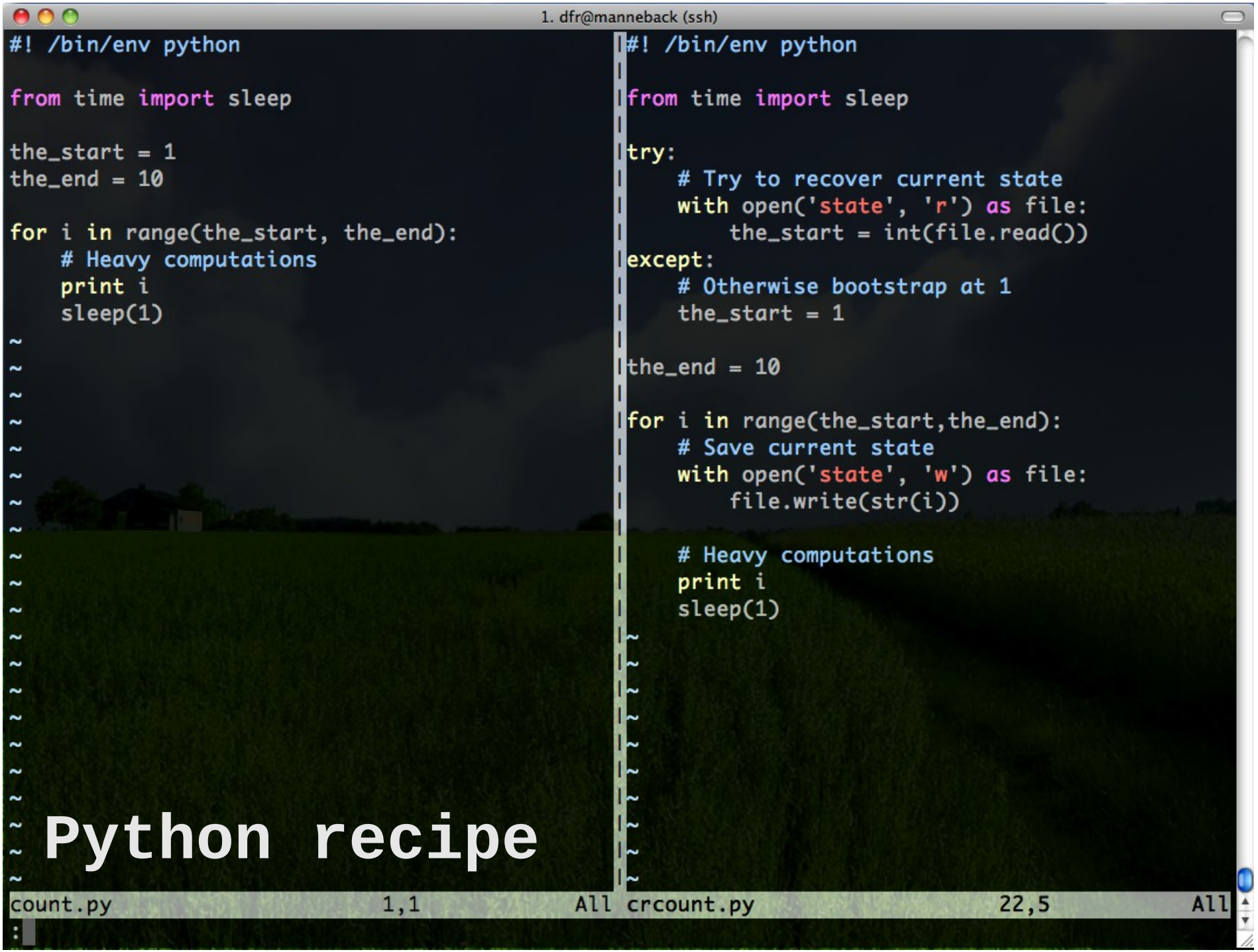
   Slurm integration
2. How to make someone else's program checkpoint-able
   - -> BLCR
   - -> DMTCP

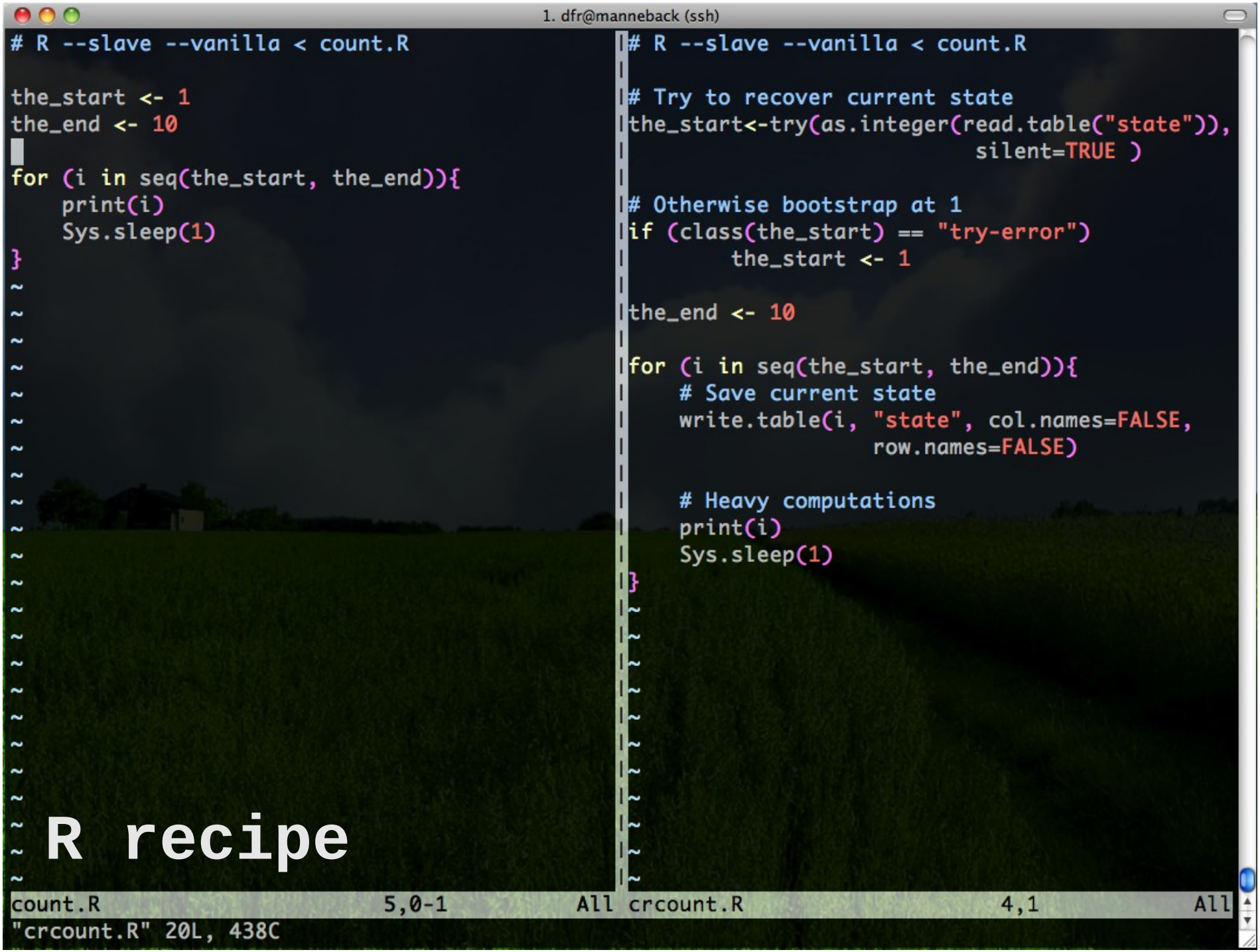
Part One: Checkpointing when you have the code

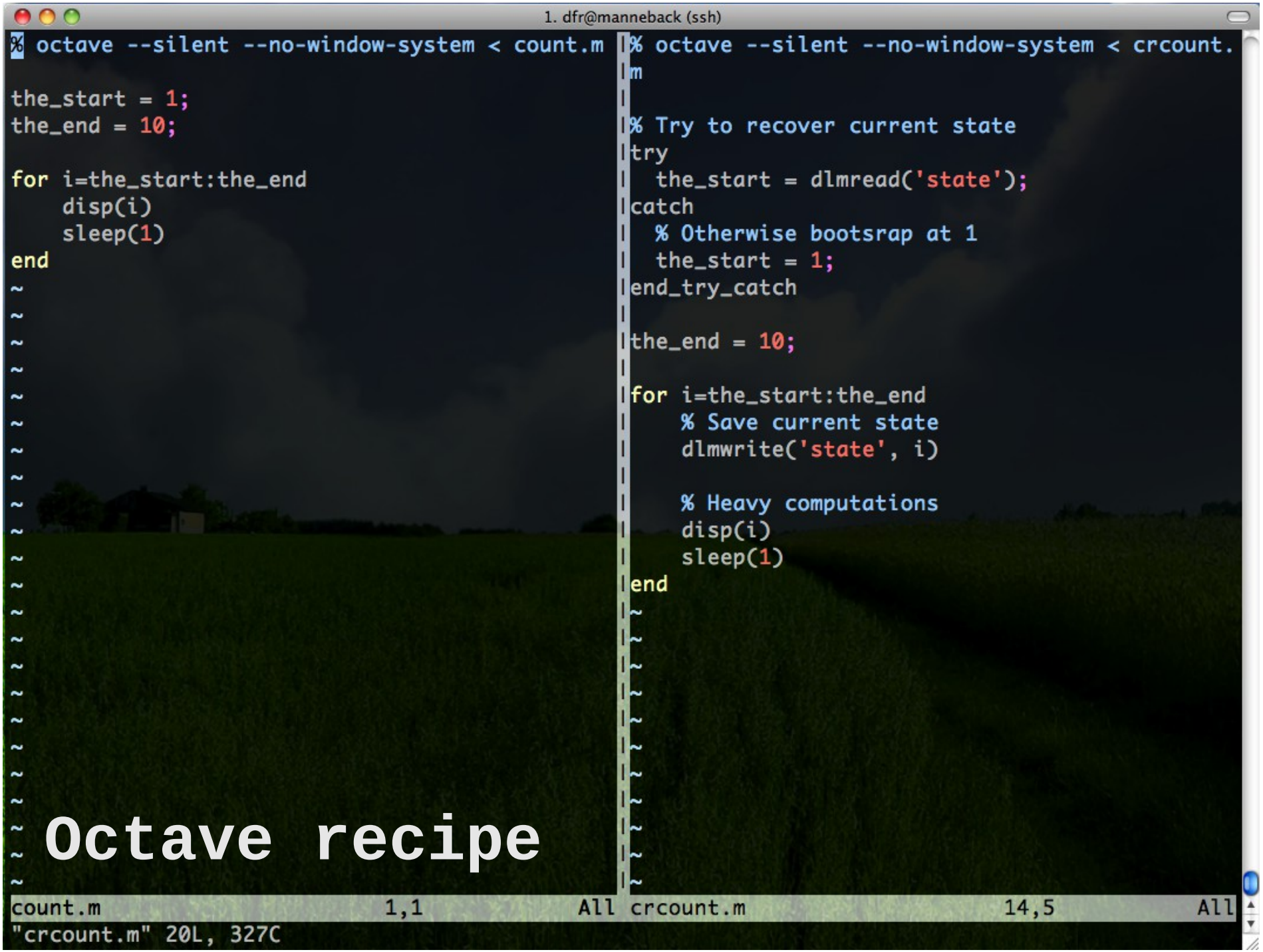
So you can play

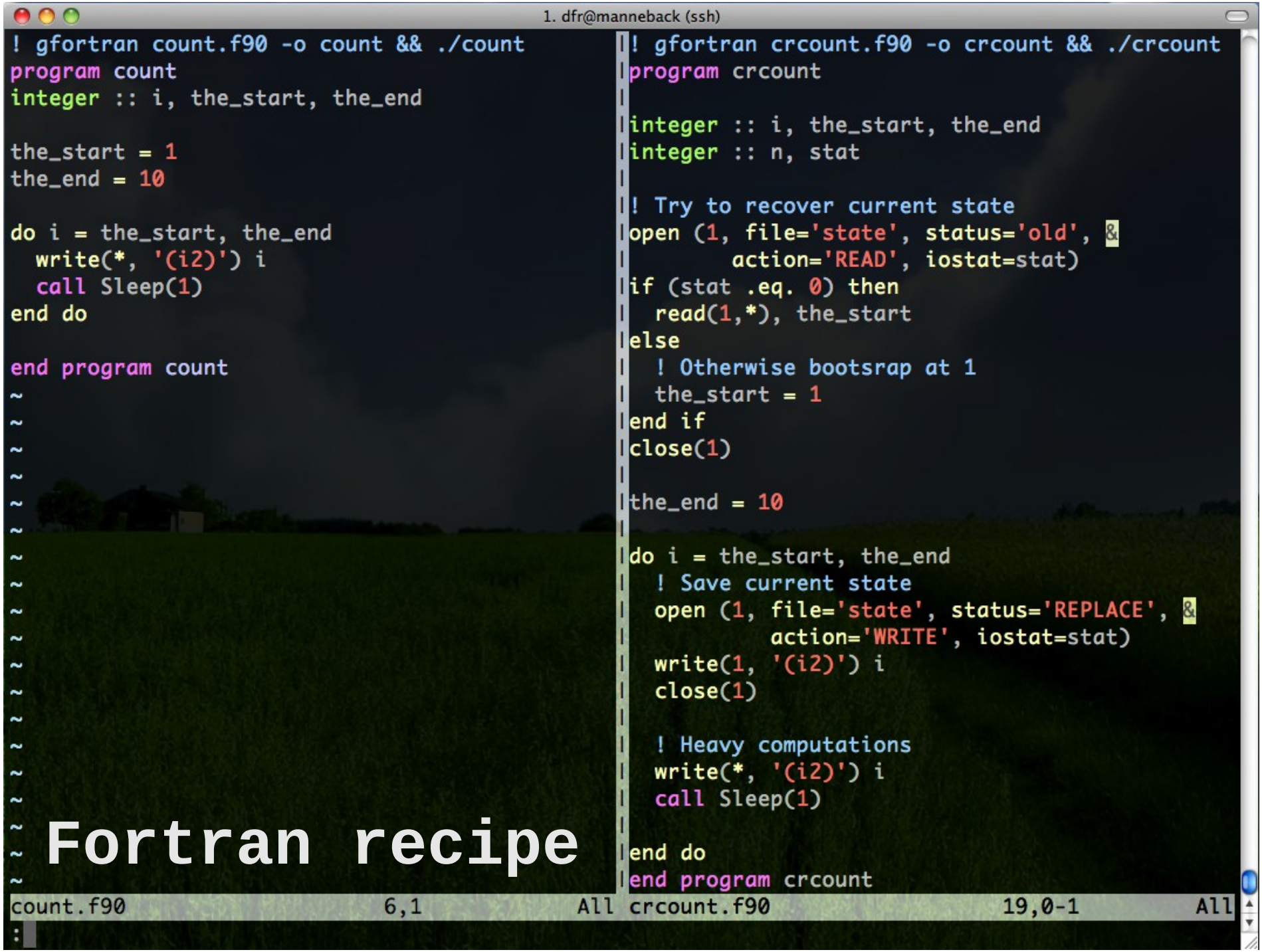
On hmem: ~dfr/checkpoint.tgz

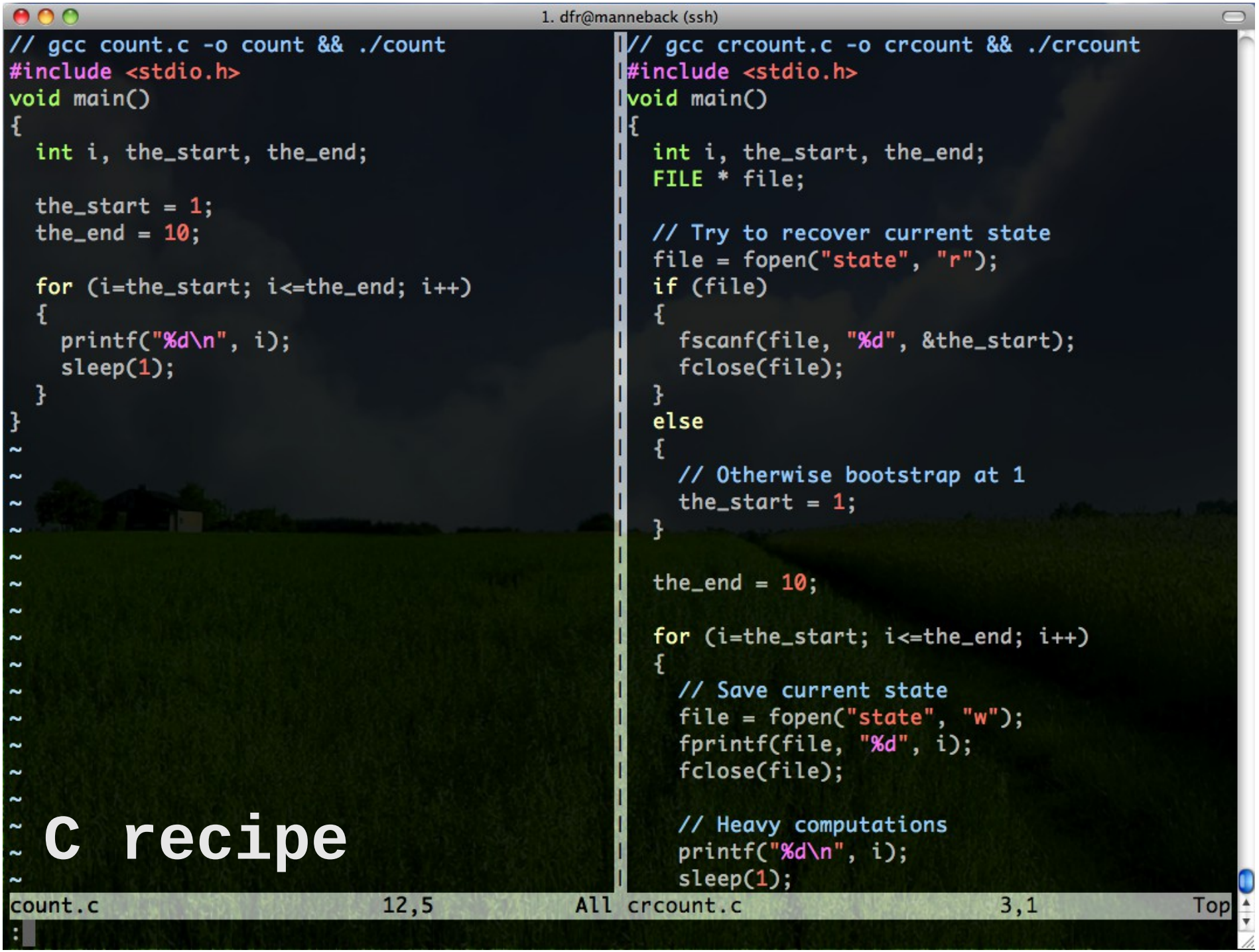
1 Making a program checkpoint-able by saving its state every iteration and looking for a state file on startup.


1. dfr@manneback (ssh)
#! /bin/env python
from time import sleep
the_start = 1
the_end = 10
for i in range(the_start, the_end):
# Heavy computations
print i
sleep(1)
#! /bin/env python
from time import sleep
try:
# Try to recover current state
with open('state', 'r') as file:
the_start = int(file.read())
except:
# Otherwise bootstrap at 1
the_start = 1
the_end = 10
for i in range(the_start,the_end):
# Save current state
with open('state', 'w') as file:
file.write(str(i))
# Heavy computations
print i
sleep(1)
Python recipe
count.py 1,1 All
crcount.py 22,5 All
:


1. dfr@manneback (ssh)
# R --slave --vanilla < count.R
the_start <- 1
the_end <- 10
for (i in seq(the_start, the_end)){
print(i)
Sys.sleep(1)
}
# R --slave --vanilla < count.R
# Try to recover current state
the_start<-try(as.integer(read.table("state")),
silent=TRUE)
# Otherwise bootstrap at 1
if (class(the_start) == "try-error")
the_start <- 1
the_end <- 10
for (i in seq(the_start, the_end)){
# Save current state
write.table(i, "state", col.names=FALSE,
row.names=FALSE)
# Heavy computations
print(i)
Sys.sleep(1)
}
R recipe
count.R 5,0-1 All
crcount.R 4,1 All
"crcount.R" 20L, 438C


1. dfr@manneback (ssh)
% octave --silent --no-window-system < count.m
the_start = 1;
the_end = 10;
for i=the_start:the_end
disp(i)
sleep(1)
end
% octave --silent --no-window-system < crcount.m
% Try to recover current state
try
the_start = dlmread('state');
catch
% Otherwise bootsrap at 1
the_start = 1;
end_try_catch
the_end = 10;
for i=the_start:the_end
% Save current state
dlmwrite('state', i)
% Heavy computations
disp(i)
sleep(1)
end
Octave recipe
count.m 1,1 All
crcount.m 14,5 All
"crcount.m" 20L, 327C


1. dfr@manneback (ssh)
! gfortran count.f90 -o count && ./count
program count
integer :: i, the_start, the_end
the_start = 1
the_end = 10
do i = the_start, the_end
write(*, '(i2)') i
call Sleep(1)
end do
end program count
count.f90 6,1 All
! gfortran crcount.f90 -o crcount && ./crcount
program crcount
integer :: i, the_start, the_end
integer :: n, stat
! Try to recover current state
open (1, file='state', status='old', &
action='READ', iostat=stat)
if (stat .eq. 0) then
read(1,*), the_start
else
! Otherwise bootsrap at 1
the_start = 1
end if
close(1)
the_end = 10
do i = the_start, the_end
! Save current state
open (1, file='state', status='REPLACE', &
action='WRITE', iostat=stat)
write(1, '(i2)') i
close(1)
! Heavy computations
write(*, '(i2)') i
call Sleep(1)
end do
end program crcount
crcount.f90 19,0-1 All
Fortran recipe


1. dfr@manneback (ssh)
// gcc count.c -o count && ./count
#include <stdio.h>
void main()
{
int i, the_start, the_end;
the_start = 1;
the_end = 10;
for (i=the_start; i<=the_end; i++)
{
printf("%d\n", i);
sleep(1);
}
}
// gcc crcount.c -o crcount && ./crcount
#include <stdio.h>
void main()
{
int i, the_start, the_end;
FILE * file;
// Try to recover current state
file = fopen("state", "r");
if (file)
{
fscanf(file, "%d", &the_start);
fclose(file);
}
else
{
// Otherwise bootstrap at 1
the_start = 1;
}
the_end = 10;
for (i=the_start; i<=the_end; i++)
{
// Save current state
file = fopen("state", "w");
fprintf(file, "%d", i);
fclose(file);
// Heavy computations
printf("%d\n", i);
sleep(1);
C recipe
count.c 12,5 All
crcount.c 3,1 Top
:

The general recipe

1. Look for a state file
   (name can be hardcoded, or,
   better, passed as parameter)
2. If found, then restore state
   (initialize all variables with content
   of the file state)

   Else, bootstrap (create initial state)
3. Periodically save the state

In the previous example : The state is just an integer
Periodically means 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
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SIGTRAP	5	Core	Trace/Breakpoint Trap
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`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
SIGINT	2	Exit	Interrupt
SIGQUIT	3	Core	Quit
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SIGABRT	6	Core	Abort
SIGEMT	7	Core	Emulation Trap
SIGFPE	8	Core	Arithmetic Exception
SIGKILL	9	Exit	Killed
SIGBUS	10	Core	Bus Error
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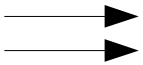
UNIX processes can receive 'signals' from the user, the OS, or another process

e.g.



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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
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SIGBUS	10	Core	Bus Error
SIGSEGV	11	Core	Segmentation Fault
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SIGPIPE	13	Exit	Broken Pipe
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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)
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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' with an associated default action

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
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SIGCHLD	18	Ignore	Child Status
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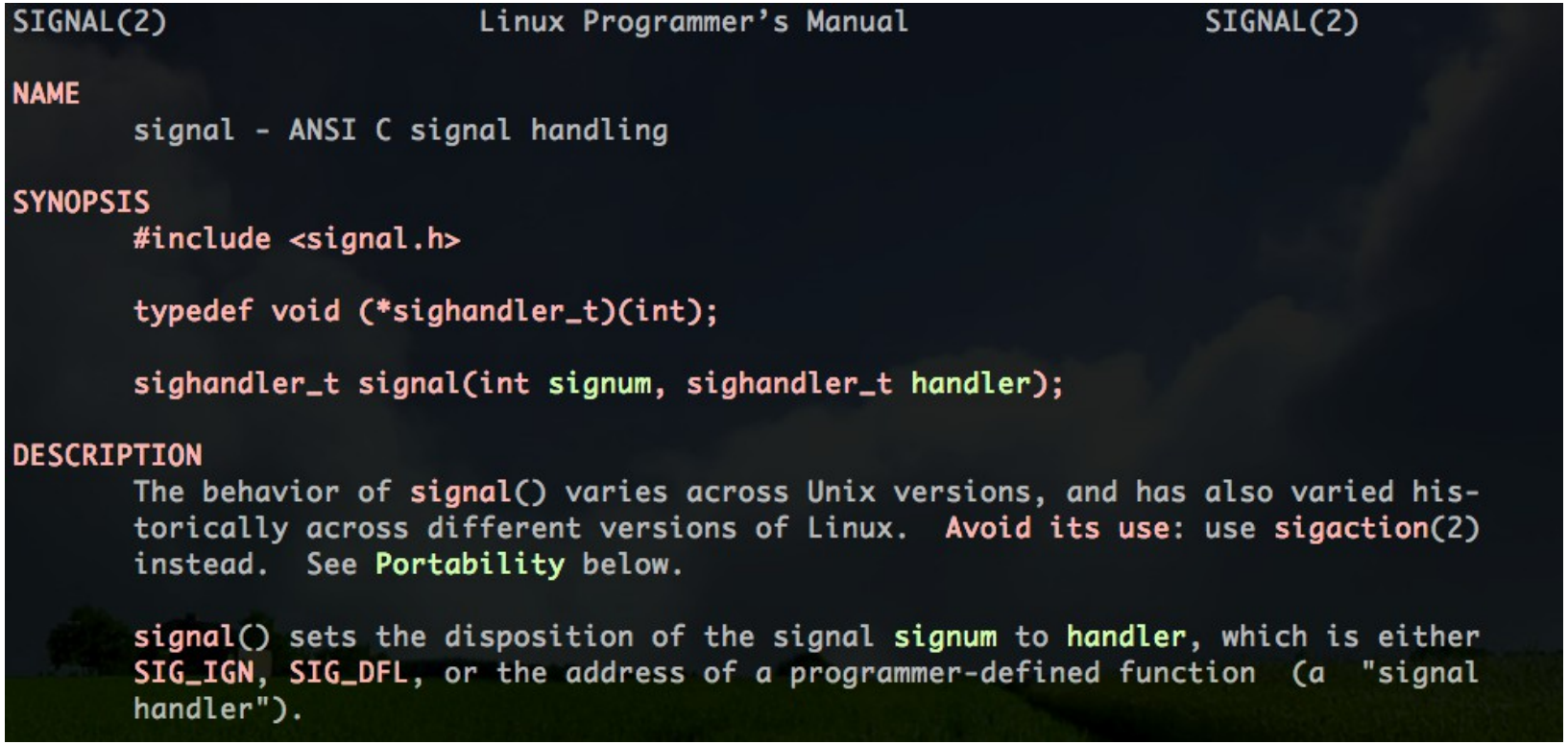
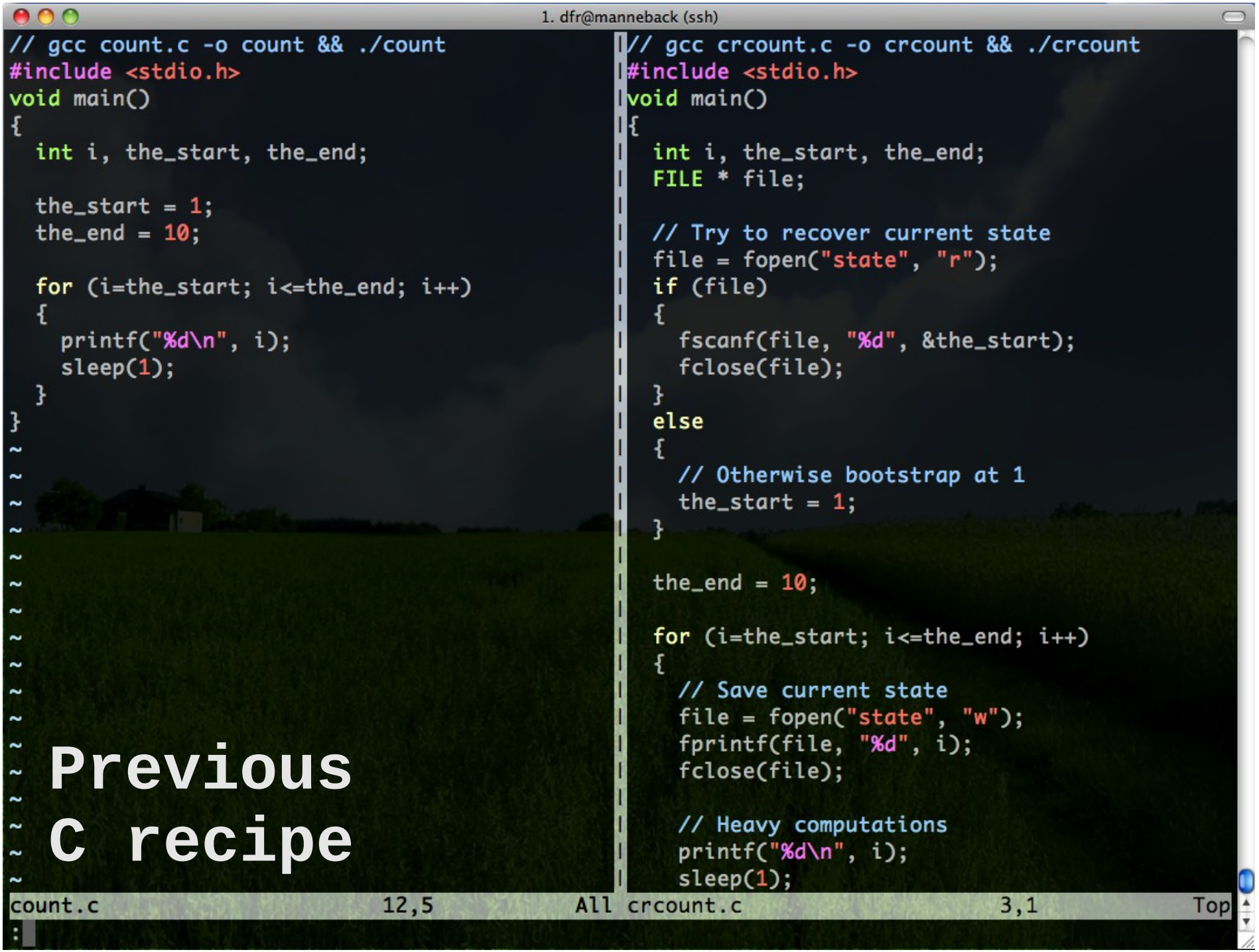
SIGWINCH	20	Ignore	Window Size Change
SIGURG	21	Ignore	Urgent Socket Condition
SIGPOLL	22	Ignore	Socket I/O Possible
SIGSTOP	23	Stop	Stopped (signal)
SIGTSTP	24	Stop	Stopped (user)
SIGCONT	25	Ignore	Continued
SIGTTIN	26	Stop	Stopped (tty input)
SIGTTOU	27	Stop	Stopped (tty output)
SIGVTALRM	28	Exit	Virtual 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' and handle ('trap') them



```
SIGNAL(2)                  Linux Programmer's Manual                 SIGNAL(2)

NAME
       signal - ANSI C signal handling

SYNOPSIS
       #include <signal.h>

       typedef void (*sighandler_t)(int);

       sighandler_t signal(int signum, sighandler_t handler);

DESCRIPTION
       The behavior of signal() varies across Unix versions, and has also varied his-
       torically across different versions of Linux.  Avoid its use: use sigaction(2)
       instead.  See Portability below.

       signal() sets the disposition of the signal signum to handler, which is either
       SIG_IGN, SIG_DFL, or the address of a programmer-defined function  (a  "signal
       handler").
```

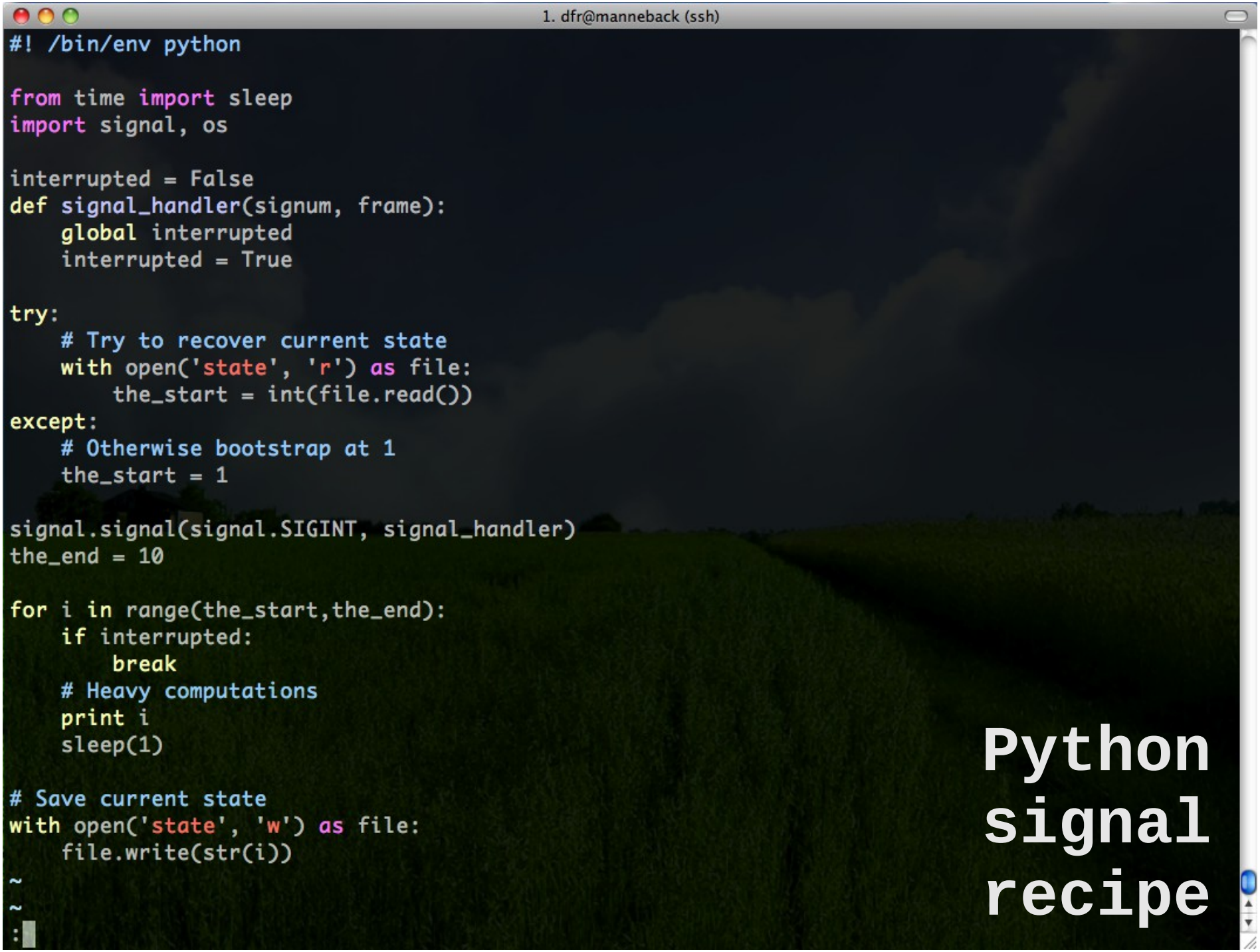

1. dfr@manneback (ssh)
// gcc count.c -o count && ./count
#include <stdio.h>
void main()
{
int i, the_start, the_end;
the_start = 1;
the_end = 10;
for (i=the_start; i<=the_end; i++)
{
printf("%d\n", i);
sleep(1);
}
}
// gcc crcount.c -o crcount && ./crcount
#include <stdio.h>
void main()
{
int i, the_start, the_end;
FILE * file;
// Try to recover current state
file = fopen("state", "r");
if (file)
{
fscanf(file, "%d", &the_start);
fclose(file);
}
else
{
// Otherwise bootstrap at 1
the_start = 1;
}
the_end = 10;
for (i=the_start; i<=the_end; i++)
{
// Save current state
file = fopen("state", "w");
fprintf(file, "%d", i);
fclose(file);
// Heavy computations
printf("%d\n", i);
sleep(1);
Previous
C recipe
count.c 12,5 All
crcount.c 3,1 Top

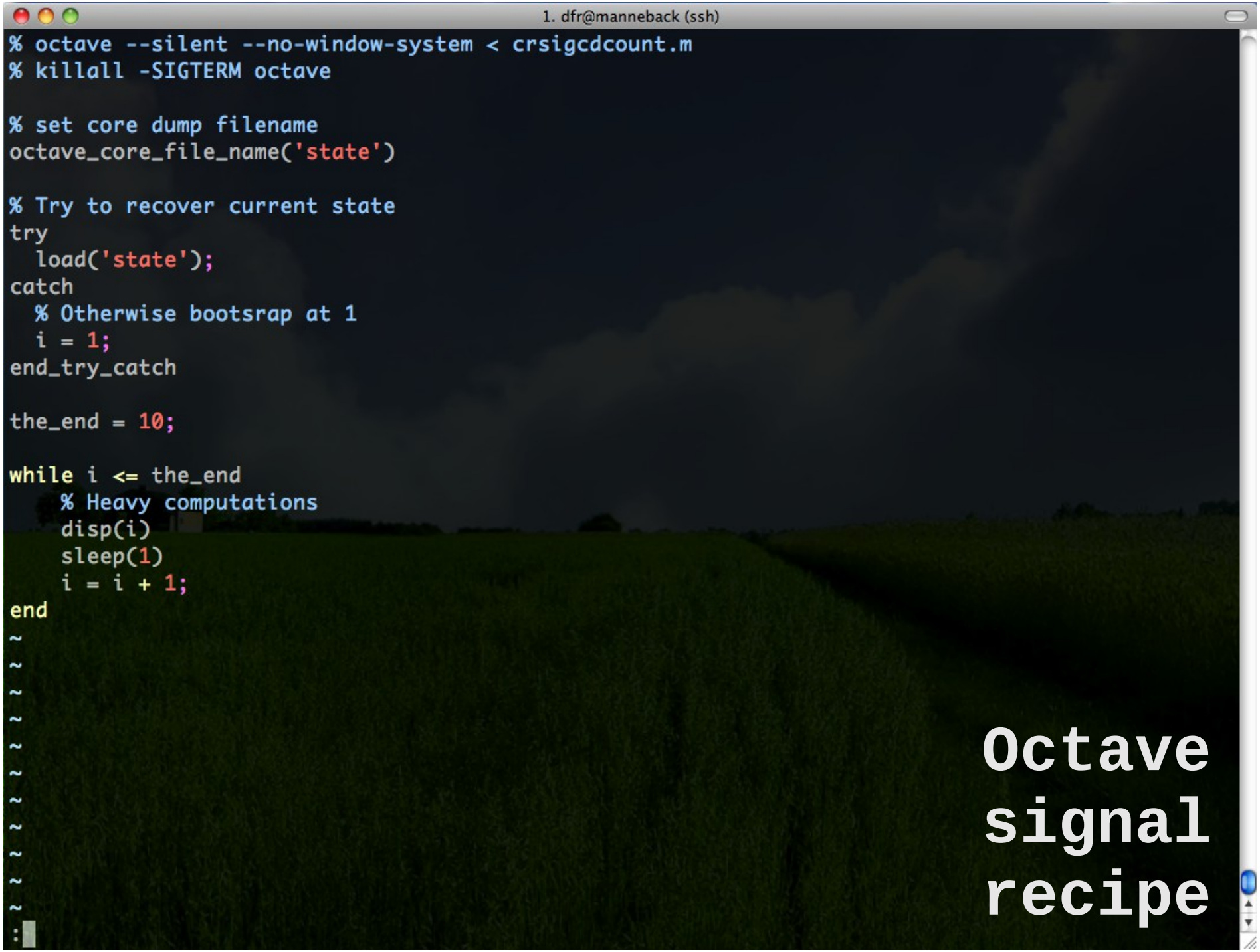

1. dfr@manneback (ssh)
// gcc crsigxcount.c -o crsigexcount && ./crsig
excount
#include <stdlib.h>
#include <signal.h>
#include <stdio.h>
volatile sig_atomic_t i = 1;
FILE * file;
void catch_signal(int sig)
{
// Save current state
file = fopen("state", "w");
fprintf(file, "%d", i);
fclose(file);
// Exit
exit(0);
}
void main()
{
int the_start, the_end;
// Register signal handler
signal(SIGINT, catch_signal);
// Try to recover current state
file = fopen("state", "r");
if (file)
{
fscanf(file, "%d", &the_start);
fclose(file);
}
else
{
// Otherwise bootstrap at 1
the_start = 1;
}
the_end = 10;
for (i=the_start; i<=the_end; i++)
{
// Heavy computations that might
// be interrupted
printf("%d\n", i);
sleep(1);
}
}
C signal recipe
crsigexcount.c 5,1 Top
crsigexcount.c 50,8 Bot
:

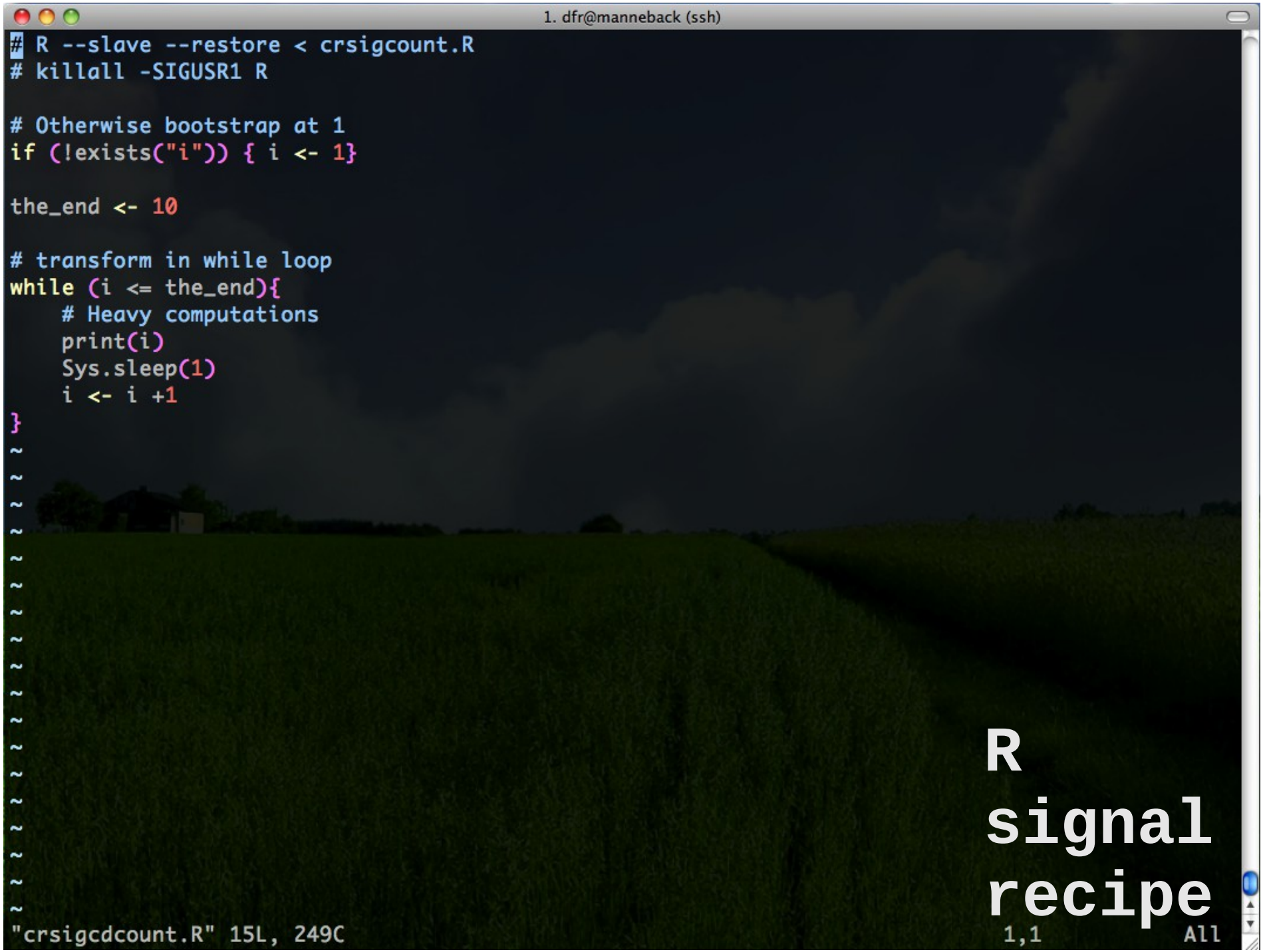

1. dfr@manneback (ssh)
// gcc crsigvacount.c -o crsigvacount && ./crsi
gvacount
#include <stdlib.h>
#include <signal.h>
#include <stdio.h>
volatile sig_atomic_t interrupted = 0;
void catch_signal(int sig)
{
interrupted = 1;
}
void main()
{
int i, the_start, the_end;
FILE * file;
// Register signal handler
signal(SIGINT, catch_signal);
// Try to recover current state
file = fopen("state", "r");
if (file)
{
fscanf(file, "%d", &the_start);
fclose(file);
}
else
else
{
// Otherwise bootstrap at 1
the_start = 1;
}
the_end = 10;
for (i=the_start; i<=the_end && !interrupted;
i++)
{
// Heavy computations that
// might be interrupted
printf("%d\n", i);
sleep(1);
}
// Iterations are over or
// have been interrupted
// Anyway save the state.
file = fopen("state", "w");
fprintf(file, "%d", i);
fclose(file);
}
C signal recipe
crsigvacount.c 15,0-1 Top
crsigvacount.c 61,0-1 Bot
"crsigvacount.c" 61L, 890C written


1. dfr@manneback (ssh)
! gfortran crsigvacount.f90 -o crsigvacount&& ./crsigvacount
subroutine catch_signal
logical :: interrupted
common interrupted
interrupted = .true.
end subroutine catch_signal
program crcount
integer :: i, the_start, the_end
integer :: stat
logical :: interrupted
common interrupted
external catch_signal
integer, parameter :: SIGINT = 2
call signal(SIGINT, catch_signal)
! Try to recover current state
open (1, file='state', status='old', &
action='READ', iostat=stat)
if (stat .eq. 0) then
read(1,*), the_start
else
! Otherwise bootsrap at 1
the_start = 1
end if
close(1)
the_end = 10
interrupted = .false.
do i = the_start, the_end
if (interrupted) exit
! Heavy computations
write(*, '(i2)') i
call Sleep(1)
end do
! Save current state
open (1, file='state', status='REPLACE', &
action='WRITE', iostat=stat)
write(1, '(i2)') i
close(1)
end program crcount
Fortan signal recipe
crsigvacount.f90 28,0-1 Top
crsigvacount.f90 62,0-1 Bot
"crsigvacount.f90" 62L, 917C written


1. dfr@manneback (ssh)
! wget https://bitbucket.org/nxg/libsigwatch/downloads/libsigwatch-1.0.tar.gz
! tar xf libsigwatch-1.0.tar.gz
! (cd libsigwatch-1.0 && ./configure && make)
! gfortran libsigwatch-1.0/.libs/sigwatch.o crsigvalibcount.f90 -o crsigvalibcount && ./crsigvalibcount
program crcount
integer :: i, the_start, the_end
integer :: stat, sig
integer, parameter :: SIGINT = 2
integer :: watchsignalname, getlastsignal
! Try to recover current state
open (1, file='state', status='old', action='READ', iostat=stat)
if (stat .eq. 0) then
read(1,*), the_start
else
! Otherwise bootsrap at 1
the_start = 1
end if
close(1)
stat = watchsignalname("INT", 99)
crsigvalibcount.f90 26,0-1 Top
the_end = 10
do i = the_start, the_end
sig = getlastsignal()
if (sig.eq.99) exit
! Heavy computations
write(*, '(i2)') i
call Sleep(1)
end do
! Save current state
open (1, file='state', status='REPLACE', action='WRITE', iostat=stat)
write(1, '(i2)') i
close(1)
end program crcount
crsigvalibcount.f90 41,1 Bot
"crsigvalibcount.f90" 55L, 962C written
Fortan signal recipe


1. dfr@manneback (ssh)
#! /bin/env python
from time import sleep
import signal, os
interrupted = False
def signal_handler(signum, frame):
global interrupted
interrupted = True
try:
# Try to recover current state
with open('state', 'r') as file:
the_start = int(file.read())
except:
# Otherwise bootstrap at 1
the_start = 1
signal.signal(signal.SIGINT, signal_handler)
the_end = 10
for i in range(the_start,the_end):
if interrupted:
break
Heavy computations
print i
sleep(1)
# Save current state
with open('state', 'w') as file:
file.write(str(i))
~
~
:
Python signal recipe


1. dfr@manneback (ssh)
% octave --silent --no-window-system < crsigcdcount.m
% killall -SIGTERM octave
% set core dump filename
octave_core_file_name('state')
% Try to recover current state
try
load('state');
catch
% Otherwise bootsrap at 1
i = 1;
end_try_catch
the_end = 10;
while i <= the_end
% Heavy computations
disp(i)
sleep(1)
i = i + 1;
end
Octave signal recipe


1. dfr@manneback (ssh)
# R --slave --restore < crsigcount.R
# killall -SIGUSR1 R
# Otherwise bootstrap at 1
if (!exists("i")) { i <- 1}
the_end <- 10
# transform in while loop
while (i <= the_end){
# Heavy computations
print(i)
Sys.sleep(1)
i <- i +1
}
"crsigcdcount.R" 15L, 249C
1,1 All
R signal recipe

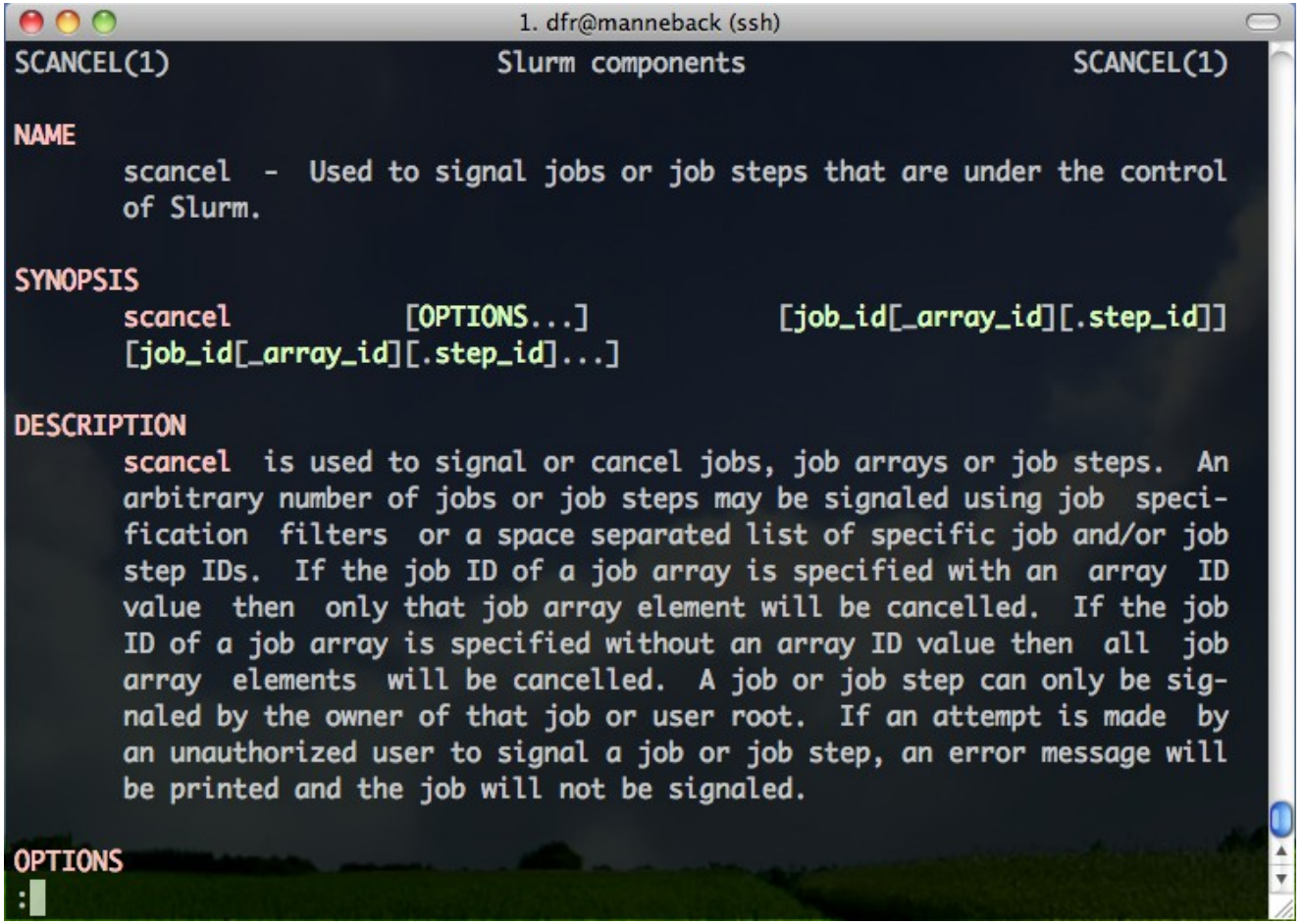
The general recipe

1. Register a signal handler
   (a function that will modify a global variable when recieving a signal)
2. Test the value of the global variable periodically
   (At a moment when the state is consistent an easy to recreate)
3. If the value indicates so, save state to disk
   (and optionally gracefully stop)

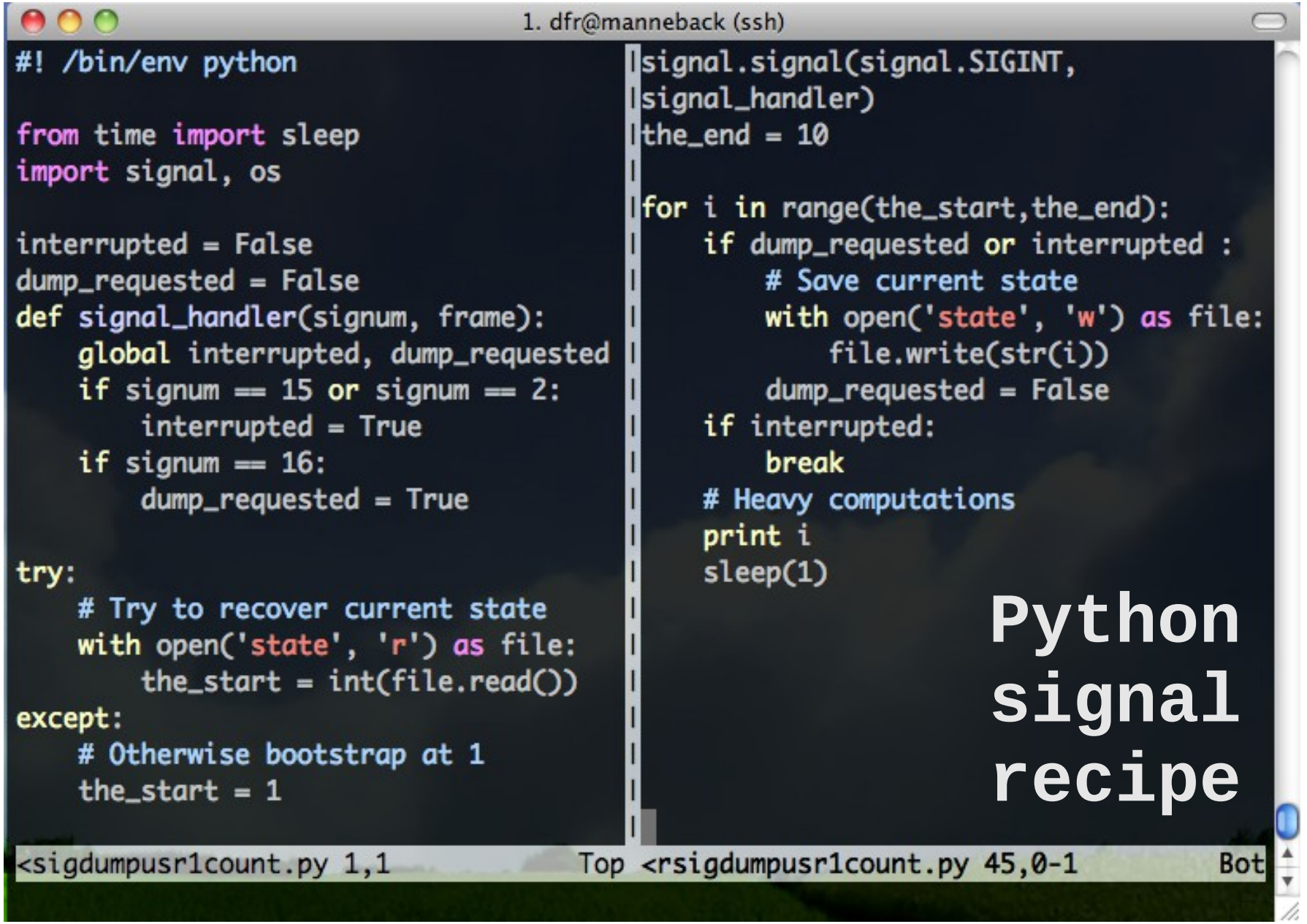
In the previous example : The state is just an integer
Periodically means at each iteration

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

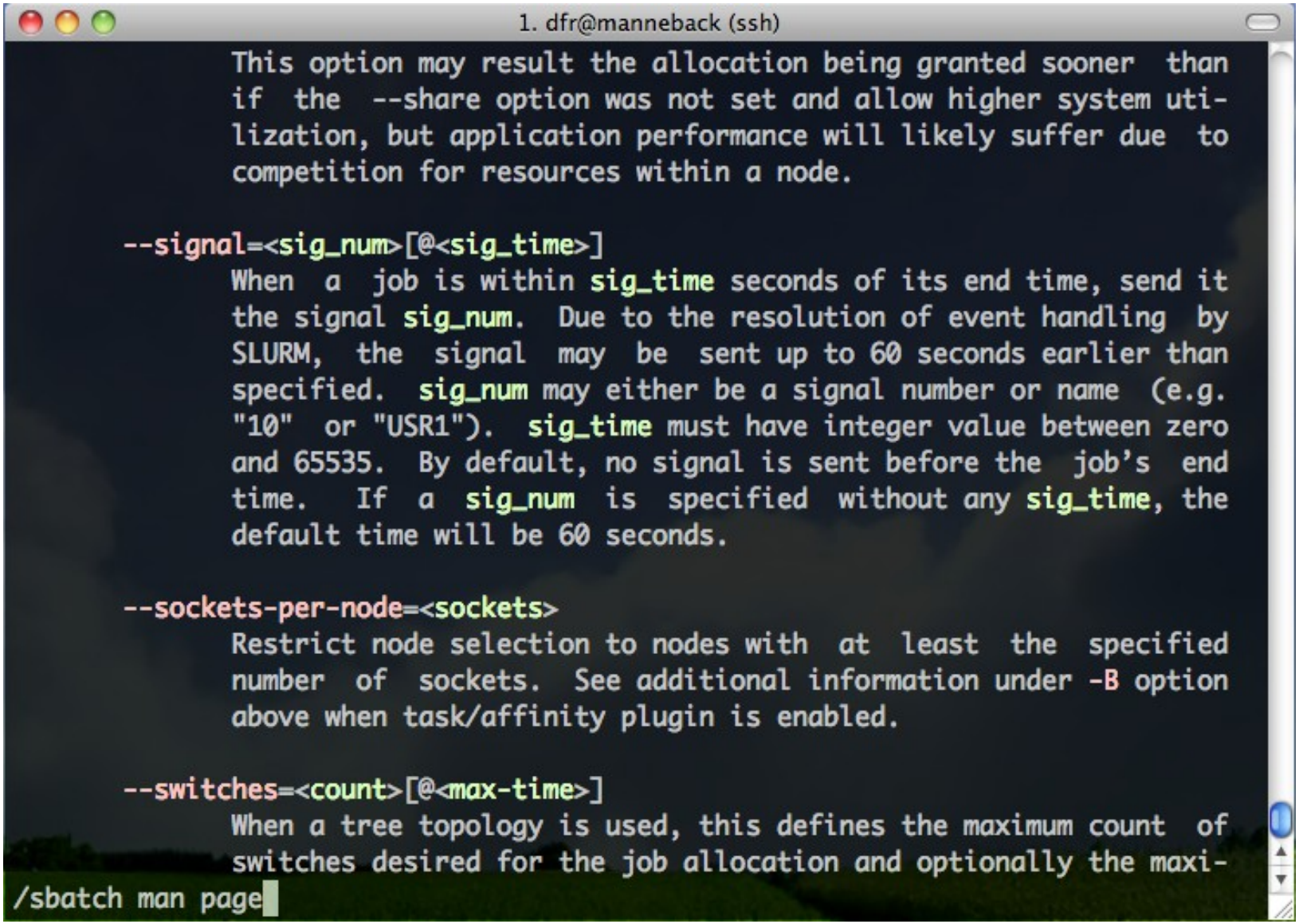
scancel is used to send signals to jobs



Example: use scancel --signal USR1 $SLURM_JOB_ID to force state dump for reviewing/debugging



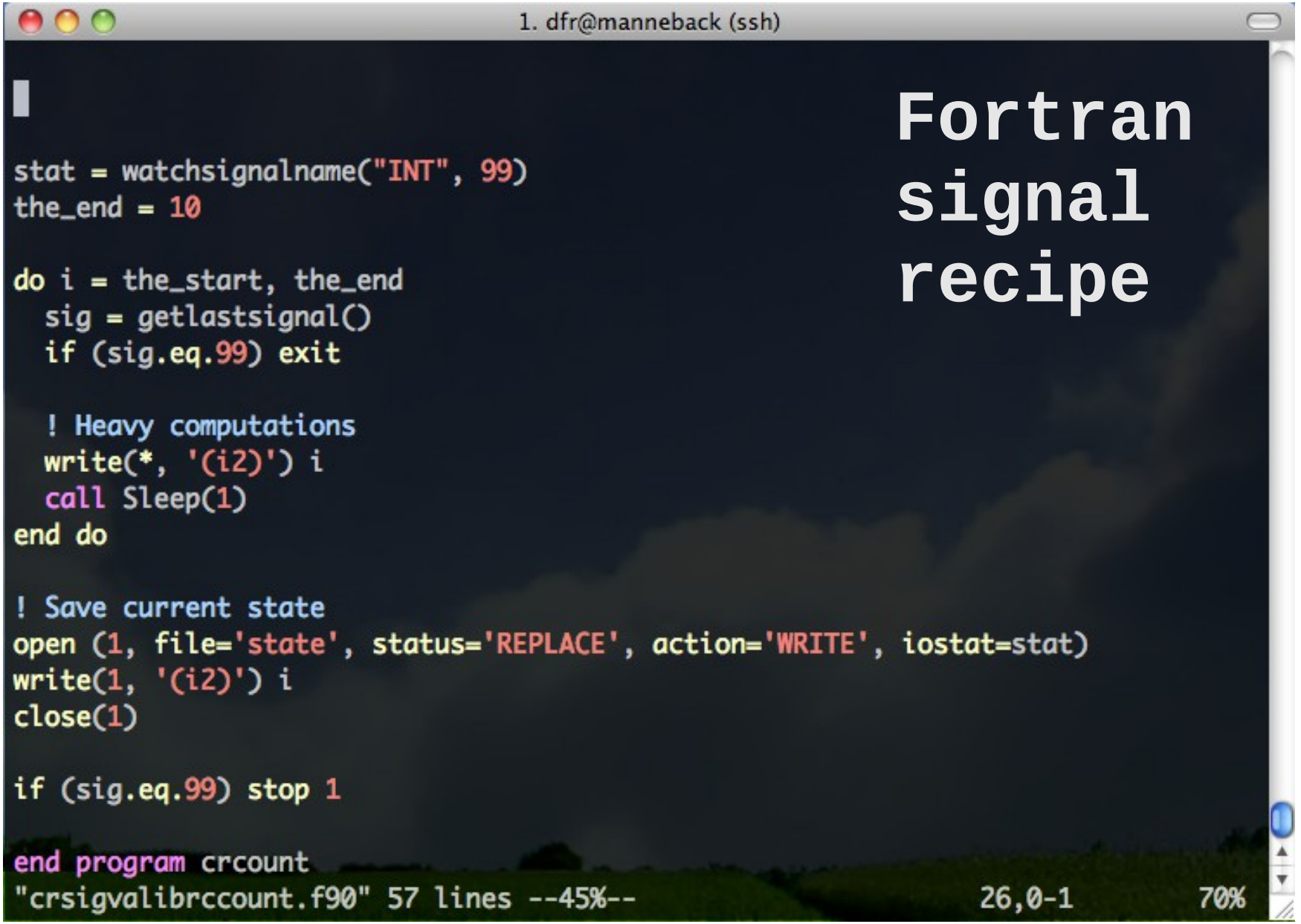
--signal to have Slurm send signals automatically before the end of the allocation



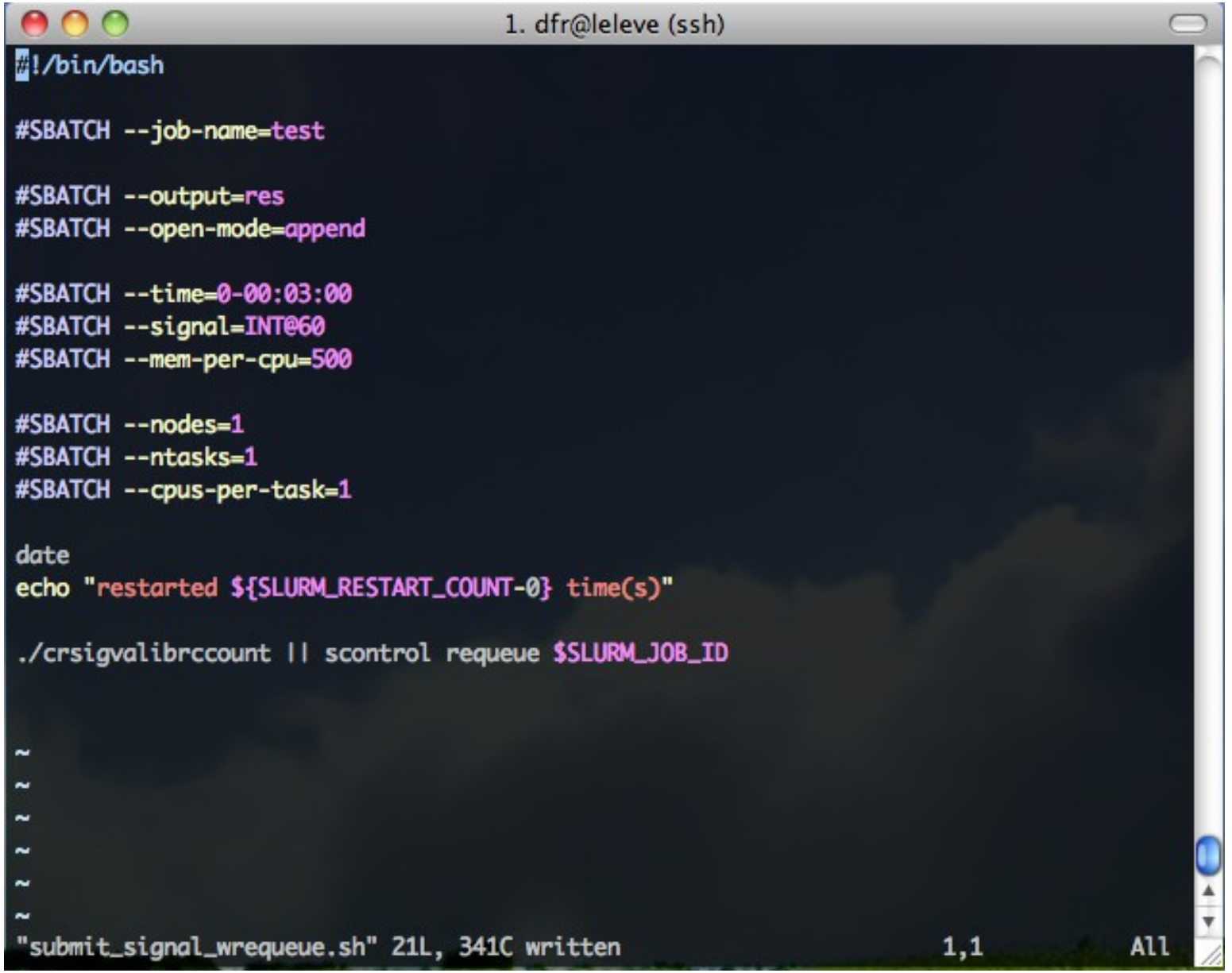
Example: send SIGINT 60 seconds before job is killed (so, here, after 2 minutes)

```
#!/bin/bash

#SBATCH --job-name=test

#SBATCH --output=res

#SBATCH --time=0-00:03:00
#SBATCH --signal=INT@60
#SBATCH --mem-per-cpu=500

#SBATCH --nodes=1
#SBATCH --ntasks=1
#SBATCH --cpus-per-task=1
```

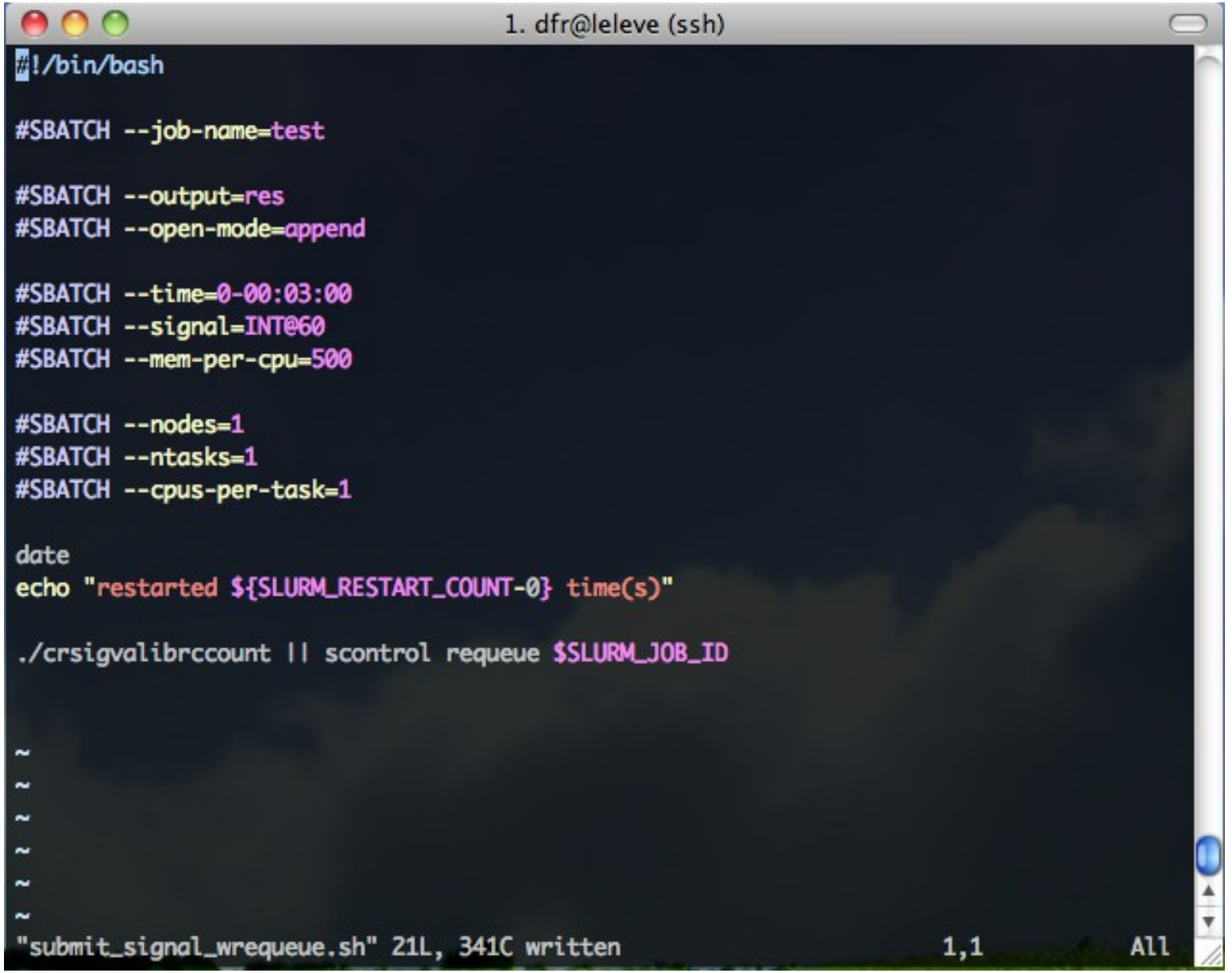
Set non-zero return code when stopping because of a received signal



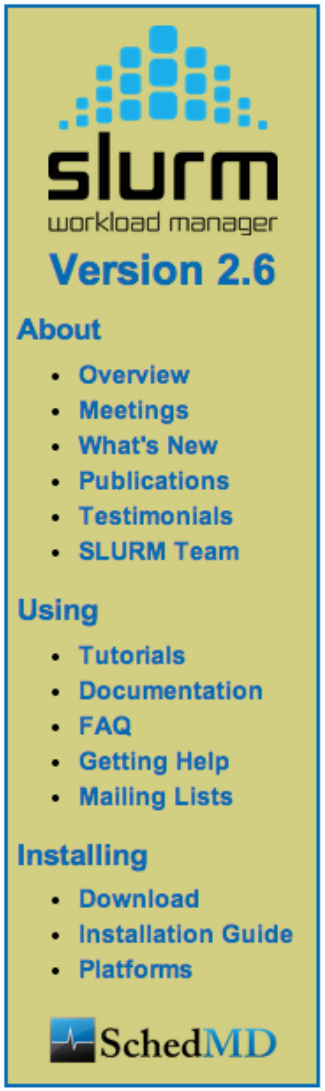
Then you can have your job re-queued automatically



Note the --open-mode=append



Or chain the jobs...



-d, --dependency=<*dependency_list*>
Defer the start of this job until the specified dependencies have been satisfied completed. <*dependency_list*> is of the form <*type:job_id[:job_id][,type:job_id[:job_id]]*>. Many jobs can share the same dependency and these jobs may even belong to different users. The value may be changed after job submission using the scontrol command.

after:job_id[:jobid...]
This job can begin execution after the specified jobs have begun execution.

afterany:job_id[:jobid...]
This job can begin execution after the specified jobs have terminated.

afternotok:job_id[:jobid...]
This job can begin execution after the specified jobs have terminated in some failed state (non-zero exit code, node failure, timed out, etc).

afterok:job_id[:jobid...]
This job can begin execution after the specified jobs have successfully executed (ran to completion with an exit code of zero).

expand:job_id
Resources allocated to this job should be used to expand the specified job. The job to expand must share the same QOS (Quality of Service) and partition. Gang scheduling of resources in the partition is also not supported.

singleton
This job can begin execution after any previously launched jobs sharing the same job name and user have terminated.

-D, --workdir=<*directory*>
Set the working directory of the batch script to *directory* before it is executed.

Set a non-zero exit code

C: exit(1)

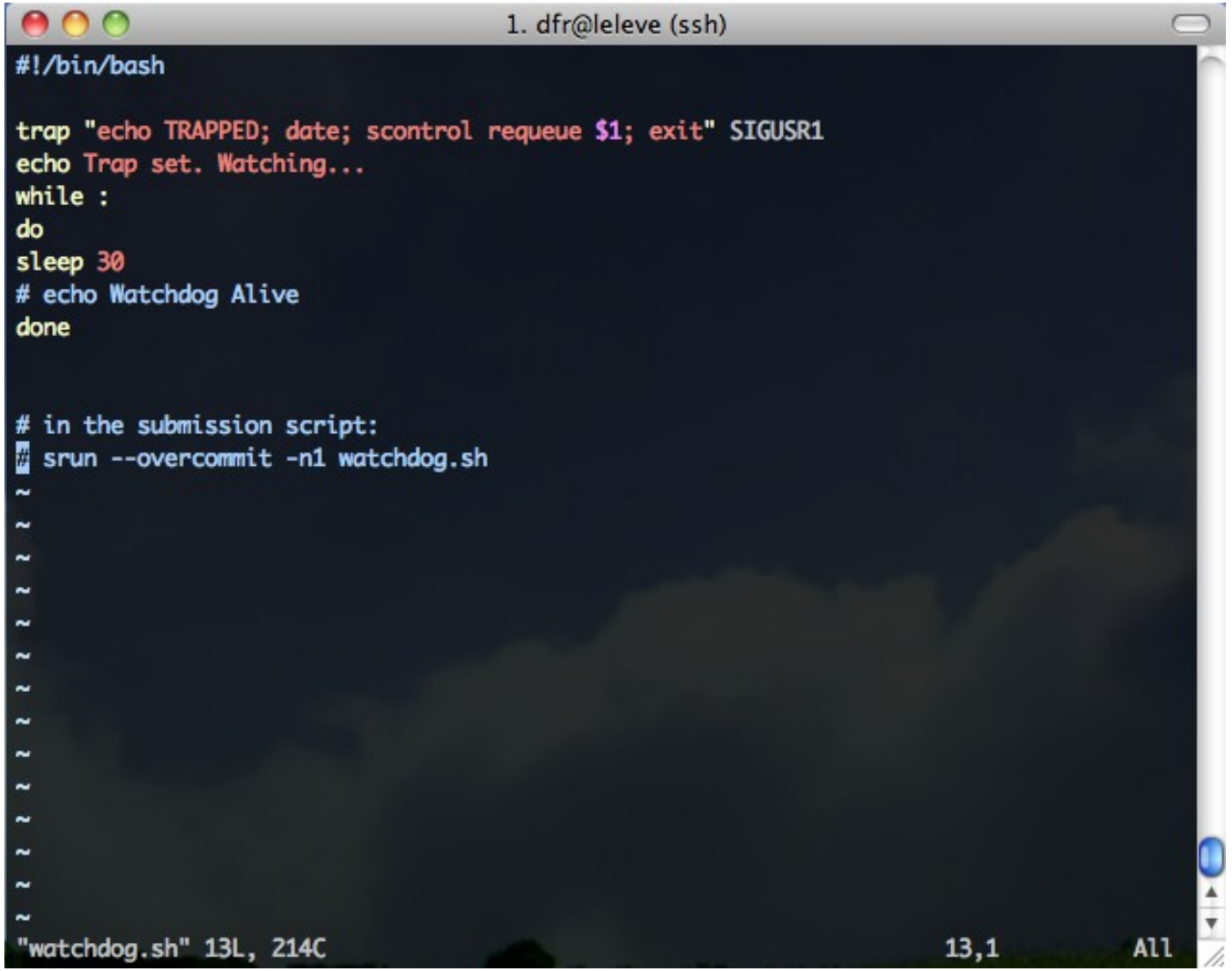
Fortran: stop 1

Octave: exit(1)

R: quit(status=1)

Python: sys.exit(1)

Using a signal-based watchdog to re-queue the job just before it is killed



4 Use serialization tools and libraries for efficient and persistent data storage on disk

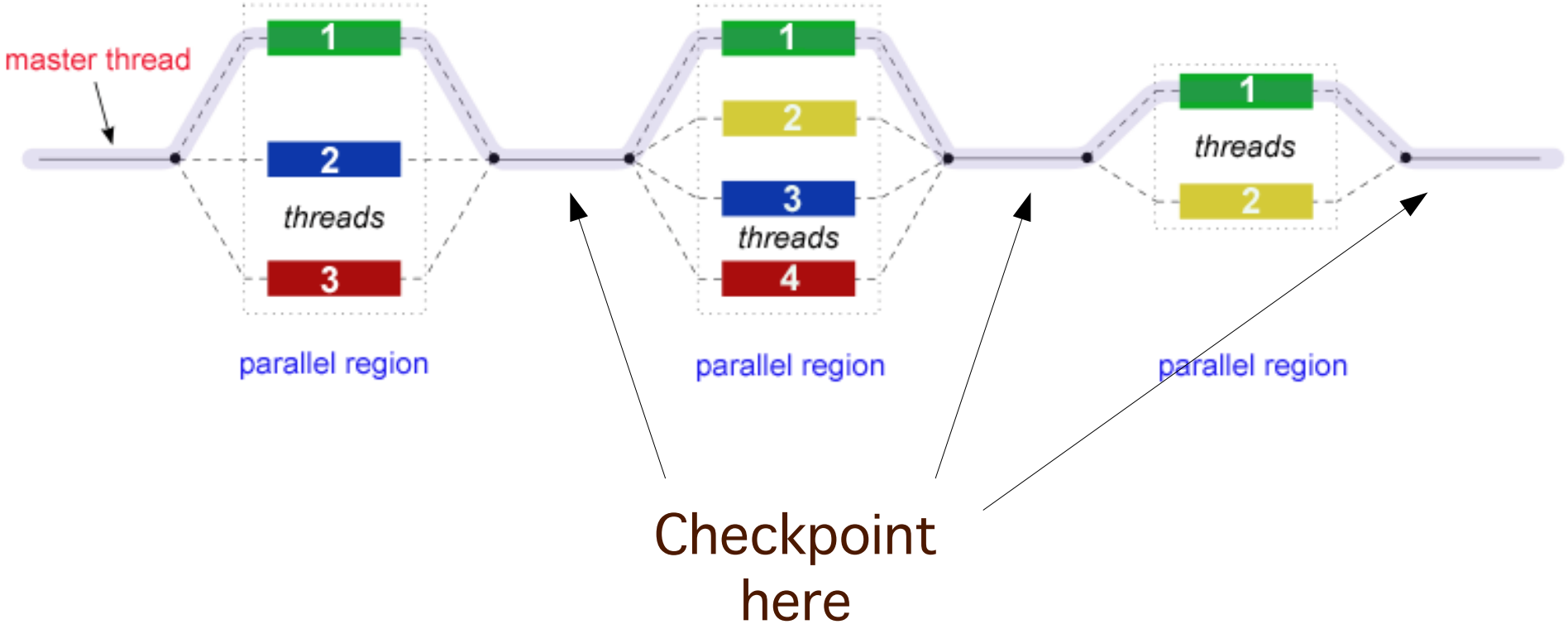
Standard data file format allow browsing, postprocessing and transmitting intermediate data

Data size	Storage type
~10MB	CSV
~10GB	Zipped CSV or Binary
~100GB	HDF5, sqlite
~ 10TB	MongoDB, Postgres

5

Parallel programs are better checkpointed after a global synchronization.

In the fork-join model, checkpoint after a join and before a fork



Easily ensure state consistency

Allows restarting with a different number of threads

Sādhanā, Vol. 25, Part 5, October 2000, pp. 489–510. © Printed in India

A survey of checkpointing algorithms for parallel and distributed computers

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MS received 27 August 1998; revised 8 June 2000

Abstract. *Checkpoint* is defined as a designated place in a program at which normal processing is interrupted specifically to preserve the status information necessary to allow resumption of processing at a later time. *Checkpointing* is the process of saving the status information. This paper surveys the algorithms which have been reported in the literature for checkpointing parallel/distributed systems. It has been observed that most of the algorithms published for checkpointing in message passing systems are based on the seminal article by Chandy and Lamport. A large number of articles have been published in this area by relaxing the assumptions made in this paper and by extending it to minimise the overheads of coordination and context saving. Checkpointing for shared memory systems primarily extend cache coherence protocols to maintain a consistent memory. All of them assume that the main memory is safe for storing the context. Recently algorithms have been published for distributed shared memory systems, which extend the cache coherence protocols used in shared memory systems. They however also include methods for storing the status of distributed memory in stable storage. Most of the algorithms assume that there is no knowledge about the programs being executed. It is however felt that in development of parallel programs the user has to do a fair amount of work in distributing tasks and this information can be effectively used to simplify checkpointing and rollback recovery.

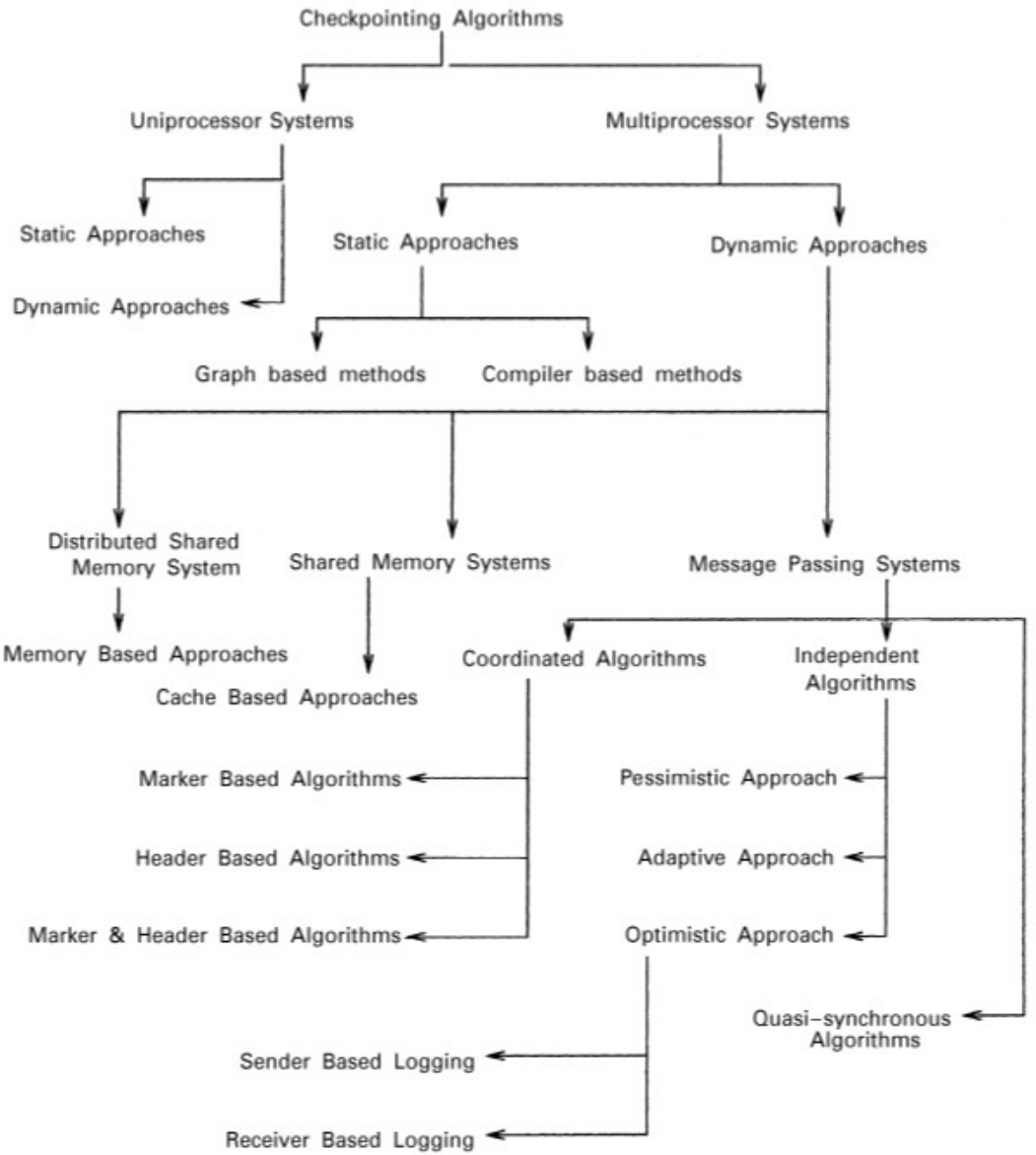


Figure 2. Classification of checkpointing algorithms.

FAQ:
Fault tolerance for parallel MPI jobs

3. Does Open MPI support checkpoint and restart of parallel jobs (similar to LAM/MPI)?

Yes. The v1.3 series was the first release series of Open MPI to include support for the transparent, coordinated checkpointing and restarting of MPI processes (similar to LAM/MPI).

Open MPI supports both the the BLCR checkpoint/restart system and a "self" checkpointer that allows applications to perform their own checkpoint/restart functionality while taking advantage of the Open MPI checkpoint/restart infrastructure. For both of these, Open MPI provides a coordinated checkpoint/restart protocol and integration with a variety of network interconnects including shared memory, Ethernet, InfiniBand, and Myrinet.

The implementation introduces a series of new frameworks and components designed to support a variety of checkpoint and restart techniques. This allows us to support the methods described above (application-directed, BLCR, etc.) as well as other kinds of checkpoint/restart systems (e.g., Condor, libckpt) and protocols (e.g., uncoordinated, message induced).

Note: The checkpoint/restart support was last released as part of the v1.6 series. The v1.7 series and the Open MPI trunk do not support this functionality (most of the code is present in the repository, but it is known to be non-functional in most cases). This feature is looking for a maintainer. Interested parties should inquire on the developers mailing list.

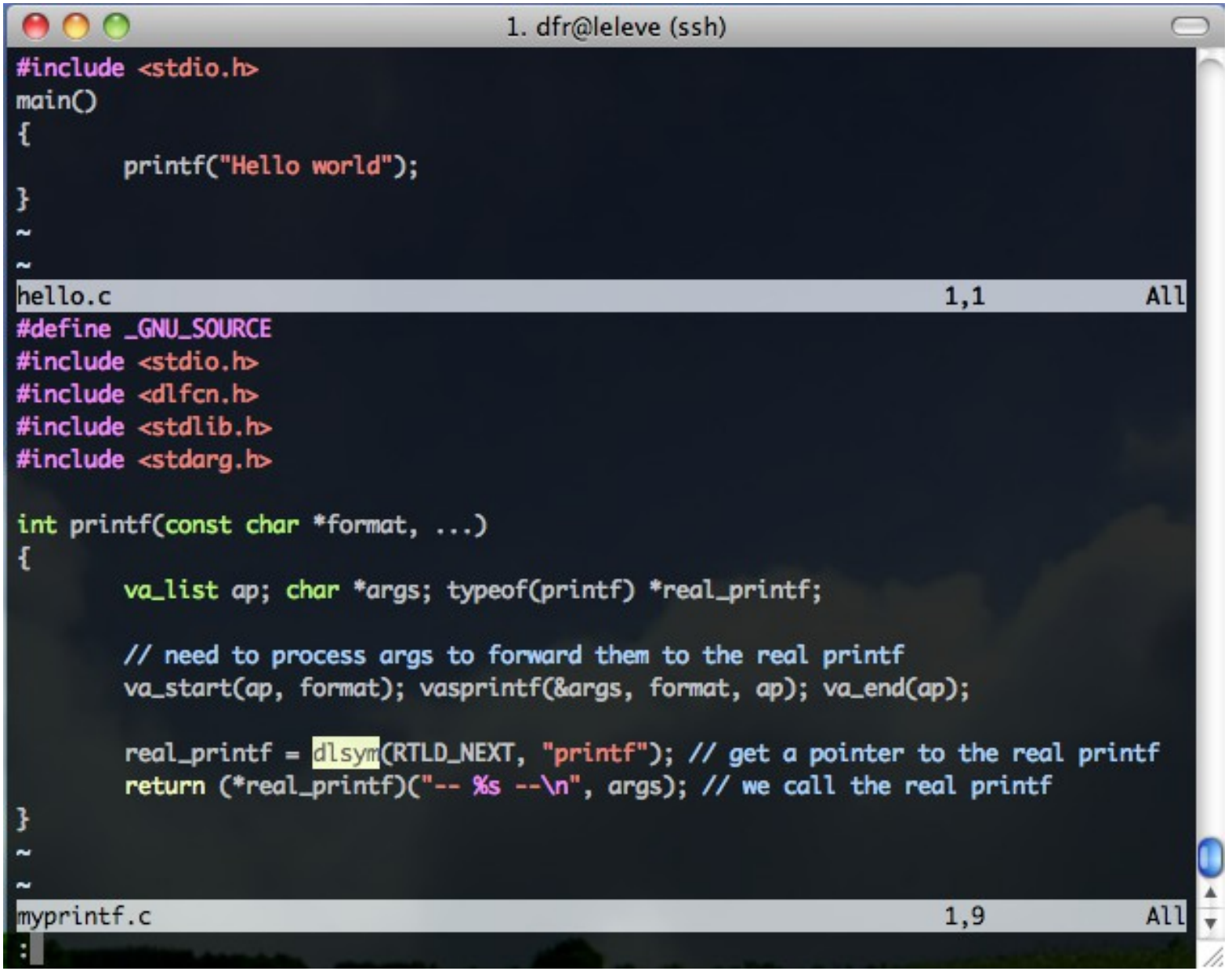
Part Two: Checkpointing when you do **not** have the code

6 Use programs and libraries that enable other programs with checkpoint/restart capabilities.

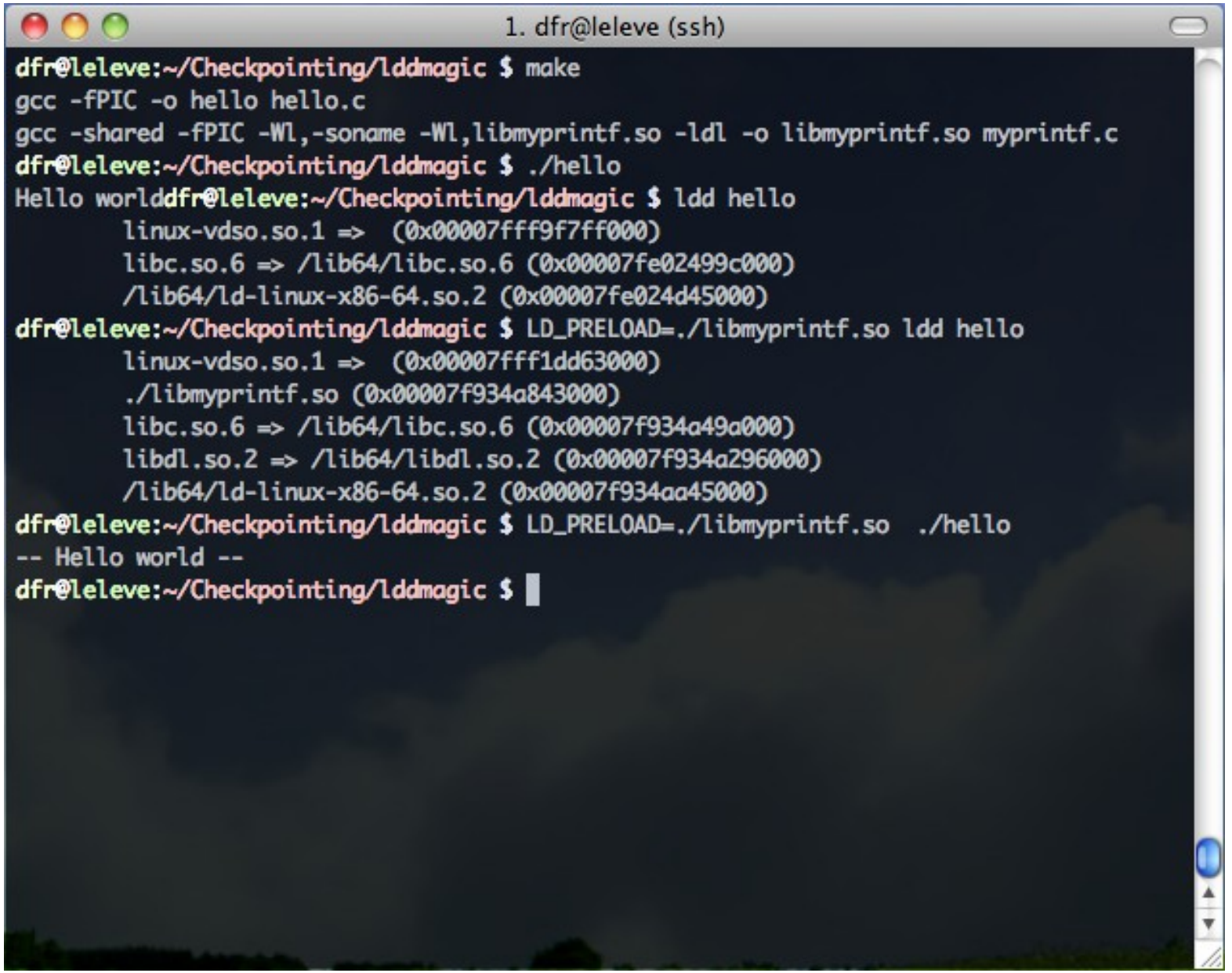
Such program needs to:

1. Access the process' memory
   (the c/r program forks itself as the process, or uses a kernel module)
2. Access the processor state at any moment
   (it uses signals to interrupt the process and provoke storage of the registers on the stack)
3. Track the state changing actions (fork, exec, system, etc.)
   (wrap standard library functions with LD_PRELOAD'ed custom functions)
4. Inject checkpointing code in the program
   (LD_PRELOAD a library with signal handlers)

LD_PRELOAD magic



LD_PRELOAD magic



7 BLCR : the Berkely Labs Checkpoint/ Restart for Linux works with a kernel module and a shared library

GROUPS & DEPTS

- Advanced Computing for Science Dept.
- Applied Numerical Algorithms Group
- Biological Data Management & Technology Center
- CCSE
- Computational Cosmology Center
- Future Technologies Group
  - Research
    - Current Projects
      - Other Projects
      - CoDEx
      - GASNet
      - FastOS
      - Green Flash
      - TOP500
      - BeBOP
      - Berkeley UPC
      - CAL
      - ASIM

Berkeley Lab Checkpoint/Restart (BLCR) for LINUX

Future Technologies Group researchers are developing a hybrid kernel/user implementation of checkpoint/restart. Their goal is to provide a robust, production quality implementation that checkpoints a wide range of applications, without requiring changes to be made to application code. This work focuses on checkpointing parallel applications that communicate through MPI, and on compatibility with the software suite produced by the SciDAC Scalable Systems Software ISIC. This work is broken down into 4 main areas:

- Checkpoint/Restart for Linux (CR)
- Checkpointable MPI Libraries
- Resource Management Interface to Checkpoint/Restart
- Development of Process Management Interfaces

News

January 29, 2013

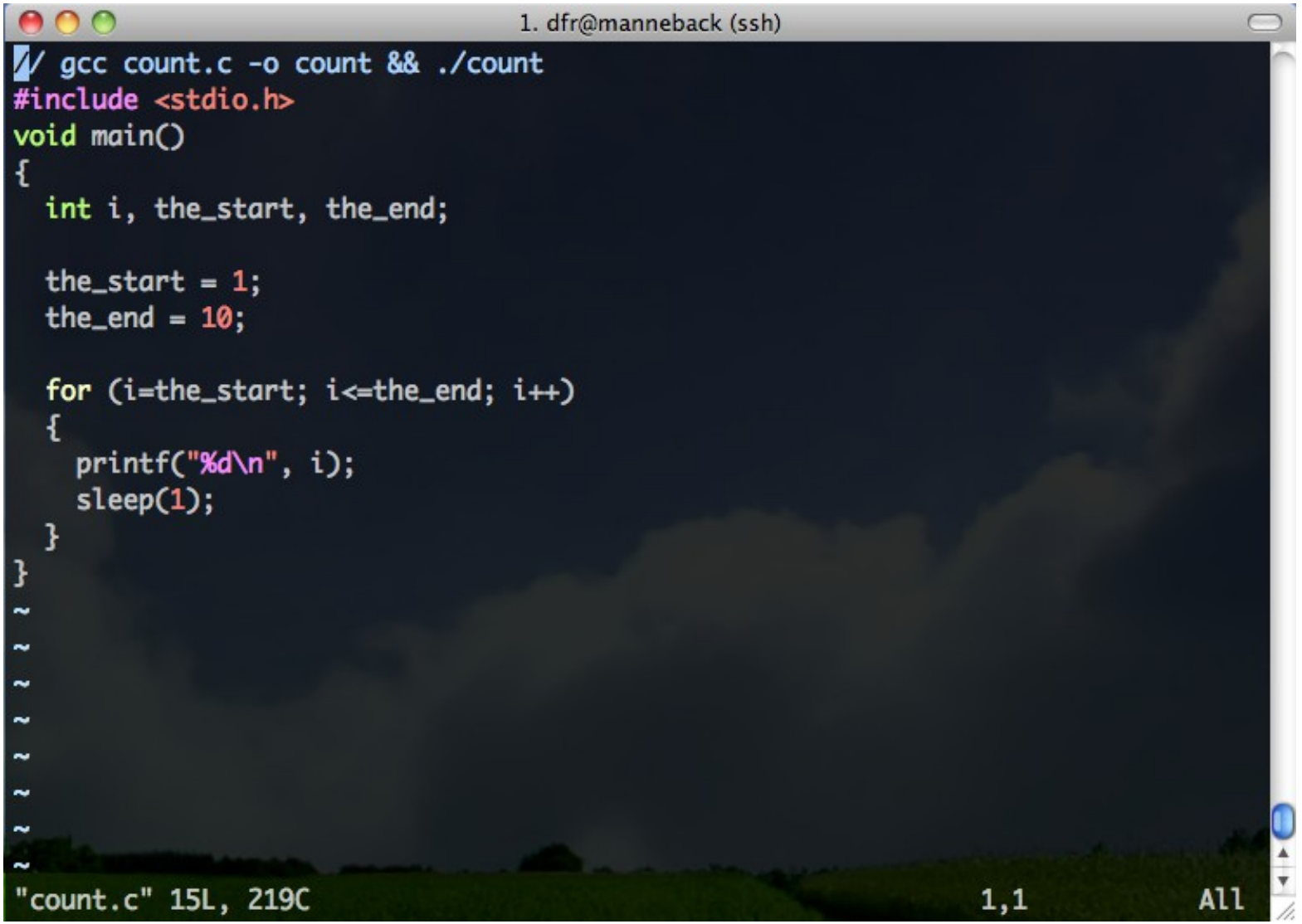
Version 0.8.5 is now available from the **Checkpoint Downloads** page.
This version fixes several bugs, and extends support to kernels through 3.7.1.

January 14, 2013

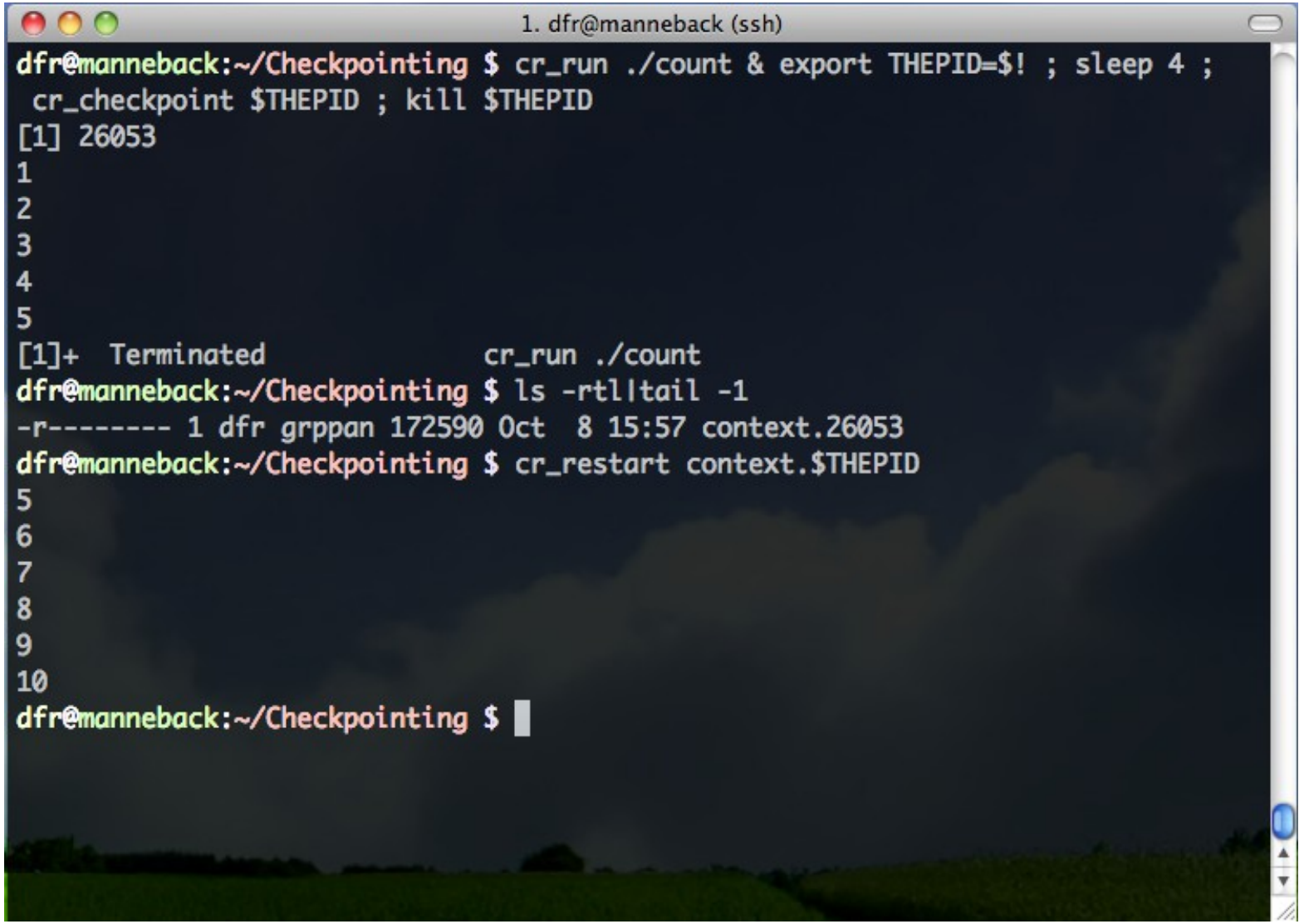
Advertised Features

- Fully SMP safe
- Rebuilds the virtual address space and restores registers
- Supports the NPTL implementation of POSIX threads (LinuxThreads is no longer supported)
- Restores file descriptors, and state associated with an open file
- Restores signal handlers, signal mask, and pending signals.
- Restores the process ID (PID), thread group ID (TGID), parent process ID (PPID), and process tree to old state.
- Support save and restore of groups of related processes and the pipes that connect them.
- Should work with nearly any x86 or x86_64 Linux system that uses a 2.6 kernel (see FAQ for most recent info). Verified to work on SuSE Linux 9.x and up; Red Hat 8 and 9; Red Hat Enterprise Linux version 3, 4and 5; Fedora Core 5 through 10; and many vanilla Linux kernels (from kernel.org) from 2.6.0 on up (and many more).
- Experimental support is present for PPC, PPC64 and ARM architectures. We consider this support experimental mainly because of our limited ability to test it.
- Xen dom0 an domU are both supported with Xen 3.1.2 or newer.
- Tested with the GNU C library (glibc) versions 2.1 through 2.6

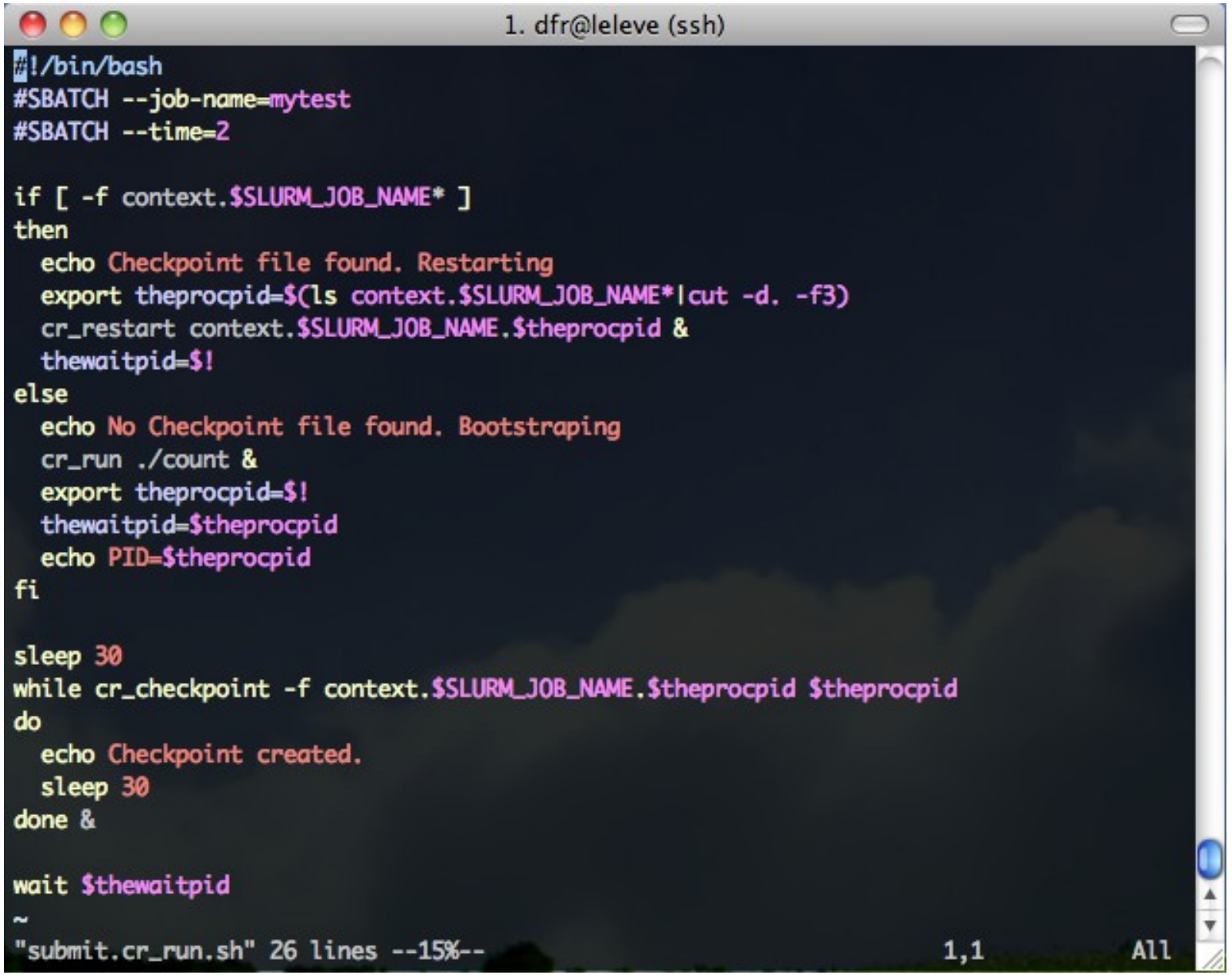
Recall the non-checkpointable program



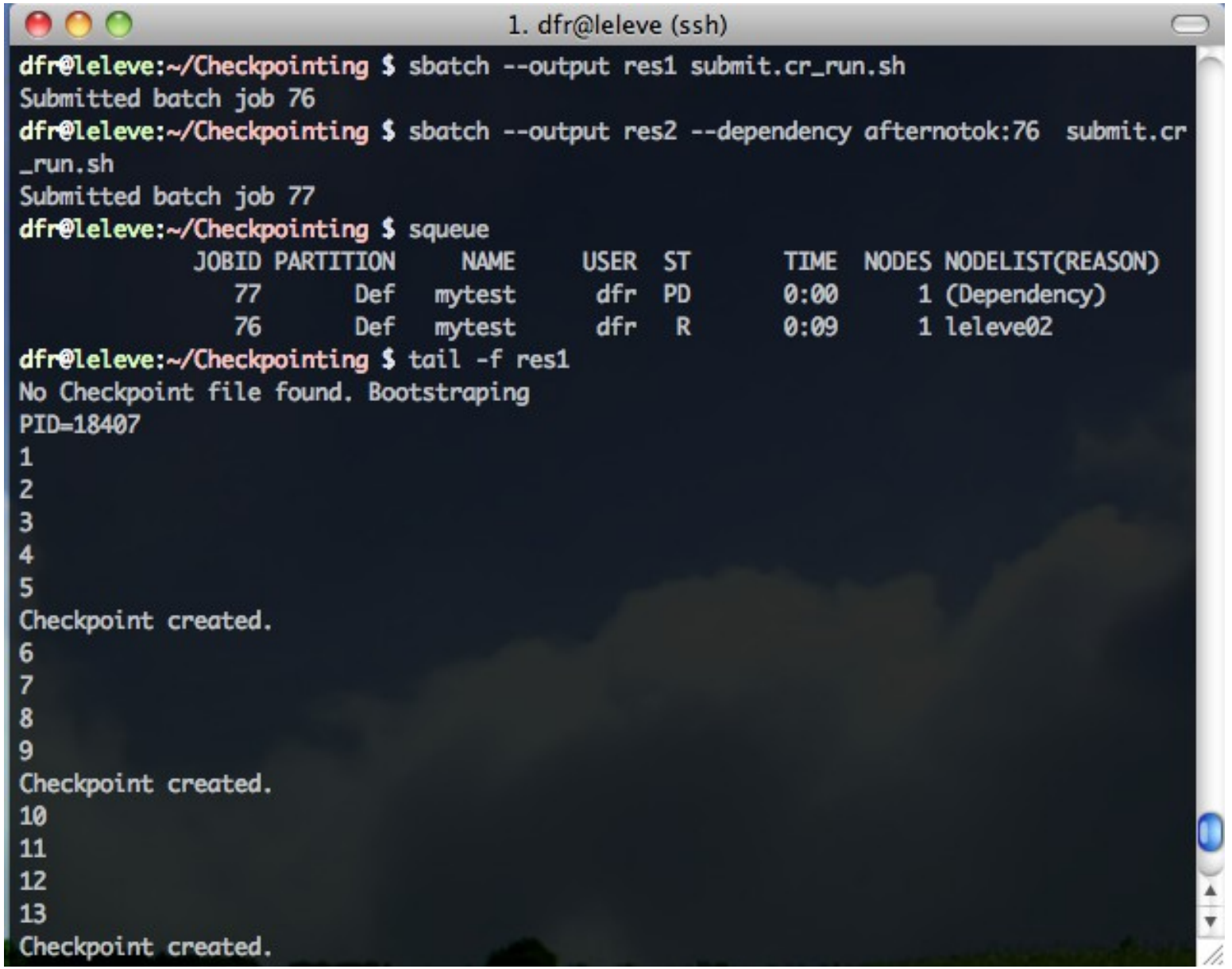
Run with cr_run ; restart with cr_restart



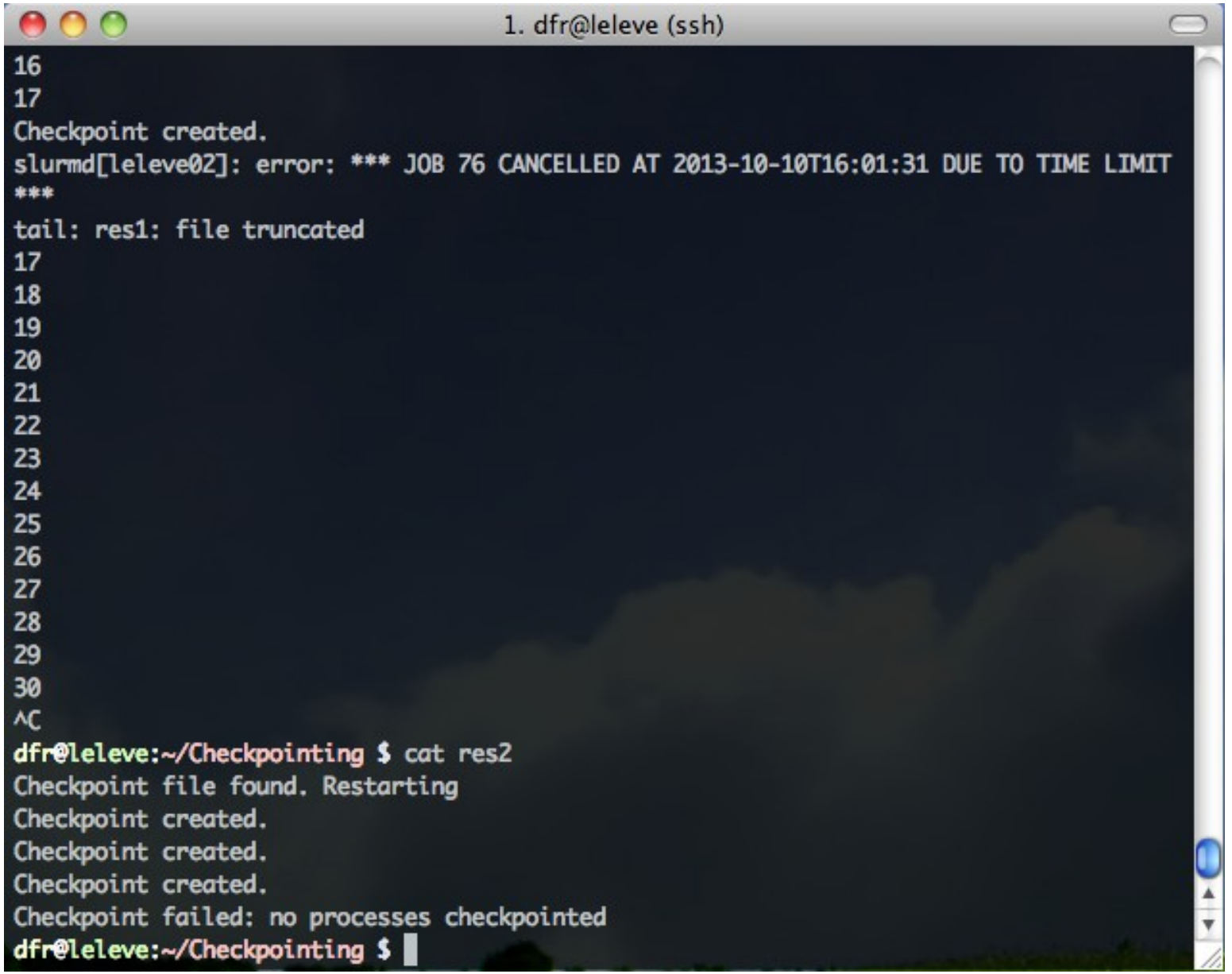
The submission script looks for checkpoint and cr_runs or cr_restarts accordingly



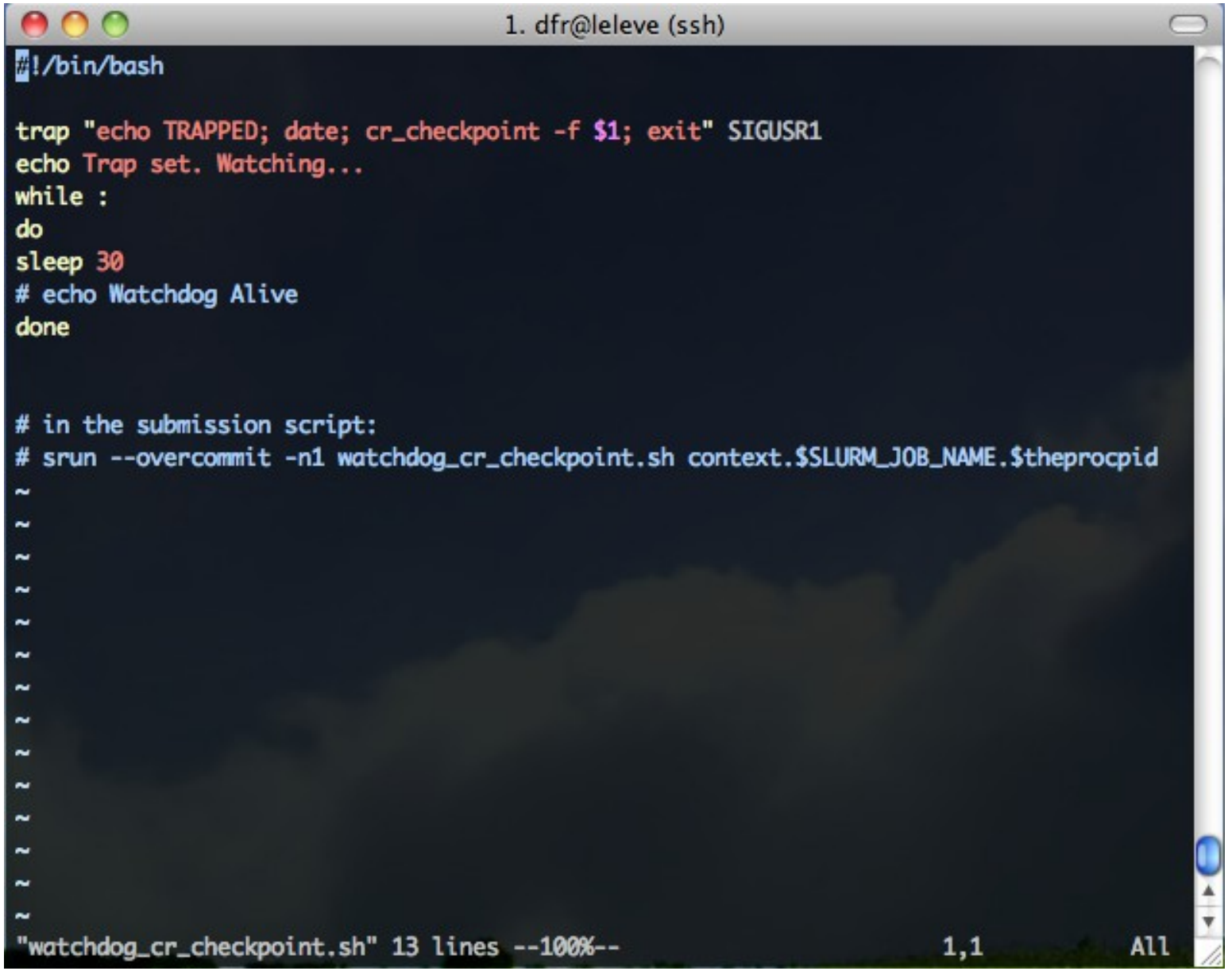
Two jobs are submitted
A checkpoint is created periodically



At restart, note ./count still write to res1 while the submission script writes to res2



Alternatively, use a signal watchdog



SLURM Checkpoint/Restart with BLCR

Overview

SLURM version 2.0 has been integrated with Berkeley Lab Checkpoint/Restart (BLCR) in order to provide automatic job checkpoint/restart support. Functionality provided includes:

1. Checkpoint of whole batch jobs in addition to job steps
2. Periodic checkpoint of batch jobs and job steps
3. Restart execution of batch jobs and job steps from checkpoint files
4. Automatically requeue and restart the execution of batch jobs upon node failure

The general mode of operation is to

1. Start the job step using the **srun_cr** command as described below.
2. Create a checkpoint of **srun_cr** using BLCR's **cr_checkpoint** command and cancel the job. **srun_cr** will automatically checkpoint your job.
3. Restart **srun_cr** using BLCR's **cr_restart** command. The job will be restarted using a newly allocated jobid.

NOTE: checkpoint/blcr cannot restart interactive jobs. It can create checkpoints for both interactive and batch steps, but **only batch jobs can be restarted.**

NOTE: BLCR operation has been verified with MVAPICH2. Some other MPI implementations should also work.

User Commands

The following documents SLURM changes specific to BLCR support. Basic familiarity with SLURM commands is assumed.

srun

Several options have been added to support checkpoint restart:

- **--checkpoint**: Specifies the interval between creating checkpoints of the job step. By default, the job step will have no checkpoints created. Acceptable time formats include

8 DMTCP : Distributed MultiThreading CheckPointing works with an independent monitoring process and a shared library

DMTCP: Distributed MultiThreaded CheckPointing

Home

Downloads

SF project page

Browse Source

Demo

Supported Apps

Condor Integration

Manual/Documentation

API

FAQ

Publications

Contact Us

About DMTCP:

DMTCP (Distributed MultiThreaded Checkpointing) is a tool to transparently checkpoint the state of multiple simultaneous applications, including multi-threaded and distributed applications. It operates directly on the user binary executable, without any Linux kernel modules or other kernel modifications.

Among the applications supported by DMTCP are Open MPI, MATLAB, Python, Perl, and many programming languages and shell scripting languages. Starting with release 1.2.0, DMTCP also supports GNU screen sessions, including vim/cscope and emacs. With the use of TightVNC, it can also checkpoint and restart X Window applications, as long as they do not use extensions (e.g.: no OpenGL, no video). See the QUICK-START file for further details.

DMTCP supports InfiniBand internally as of Aug., 2013, and will soon be released.

DMTCP is also the basis for URDB, the Universal Reversible Debugger. URDB was an experimental project for reversibility for four debuggers: gdb, MATLAB, python (pdb), and perl (perl -d). It is now obsolete, and work is continuing on a newer internal project, which will be released as open source in the future.

News | See Also | Authors | Acknowledgement

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 and reversible debugging. Interested applicants should write to Gene Cooperman (gene@ccs.neu.edu) at Northeastern University.

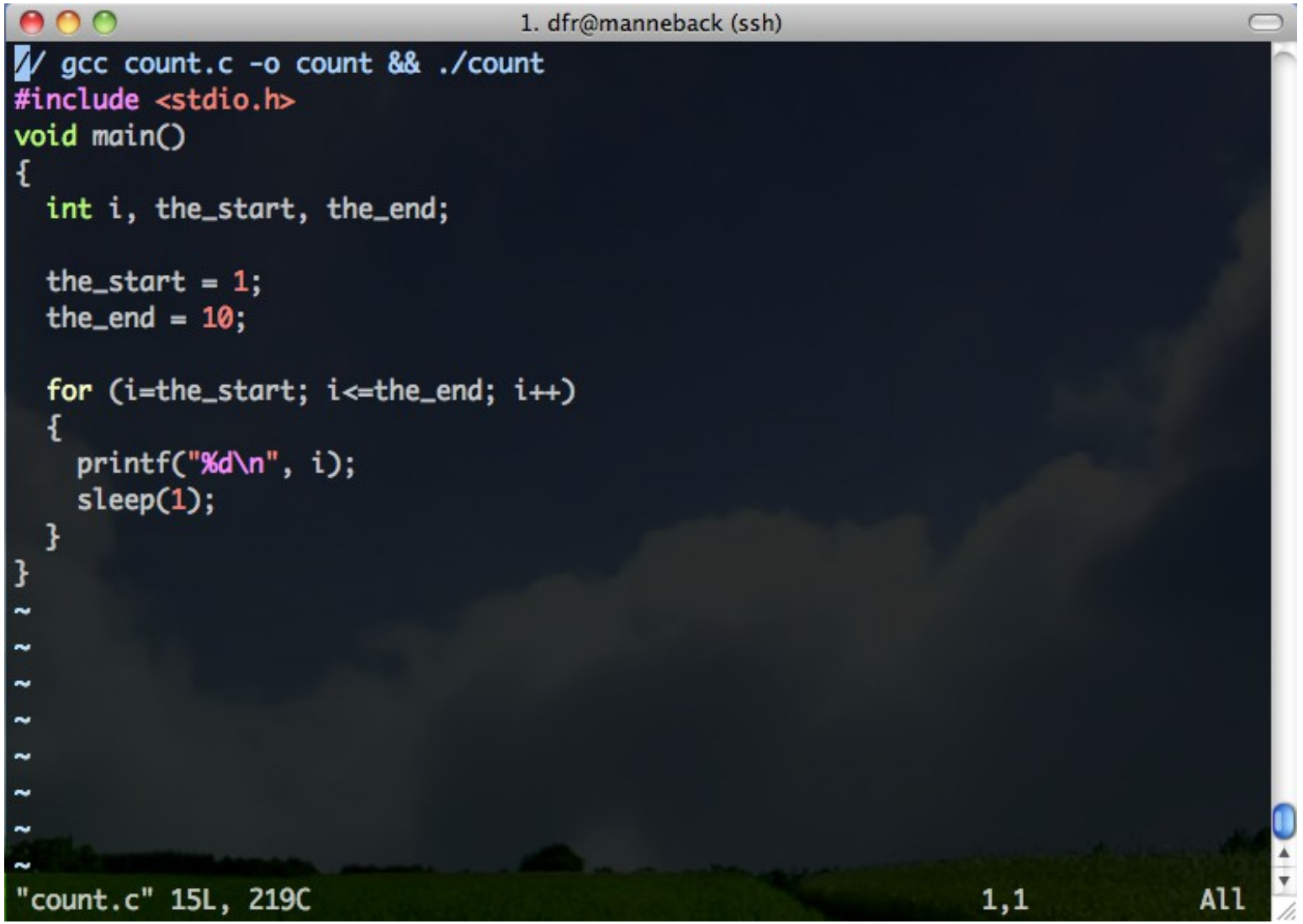
Advertised Features

- 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 4+ years
- LGPL'd and freely available
- No remote I/O
- Supports threads, mutexes/semaphoes, forks, shared memory, exec, and many more

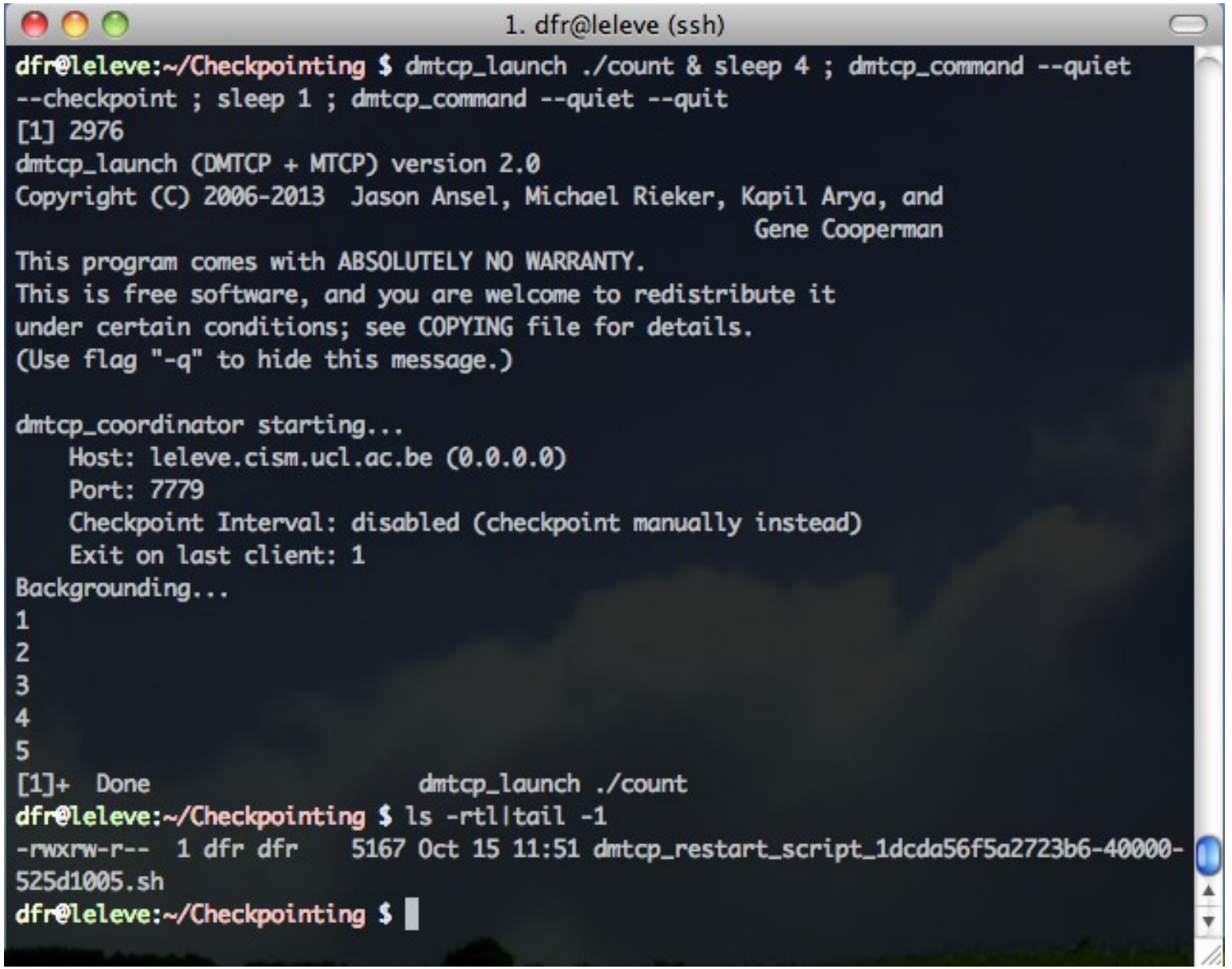
From their FAQ:

“**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.”

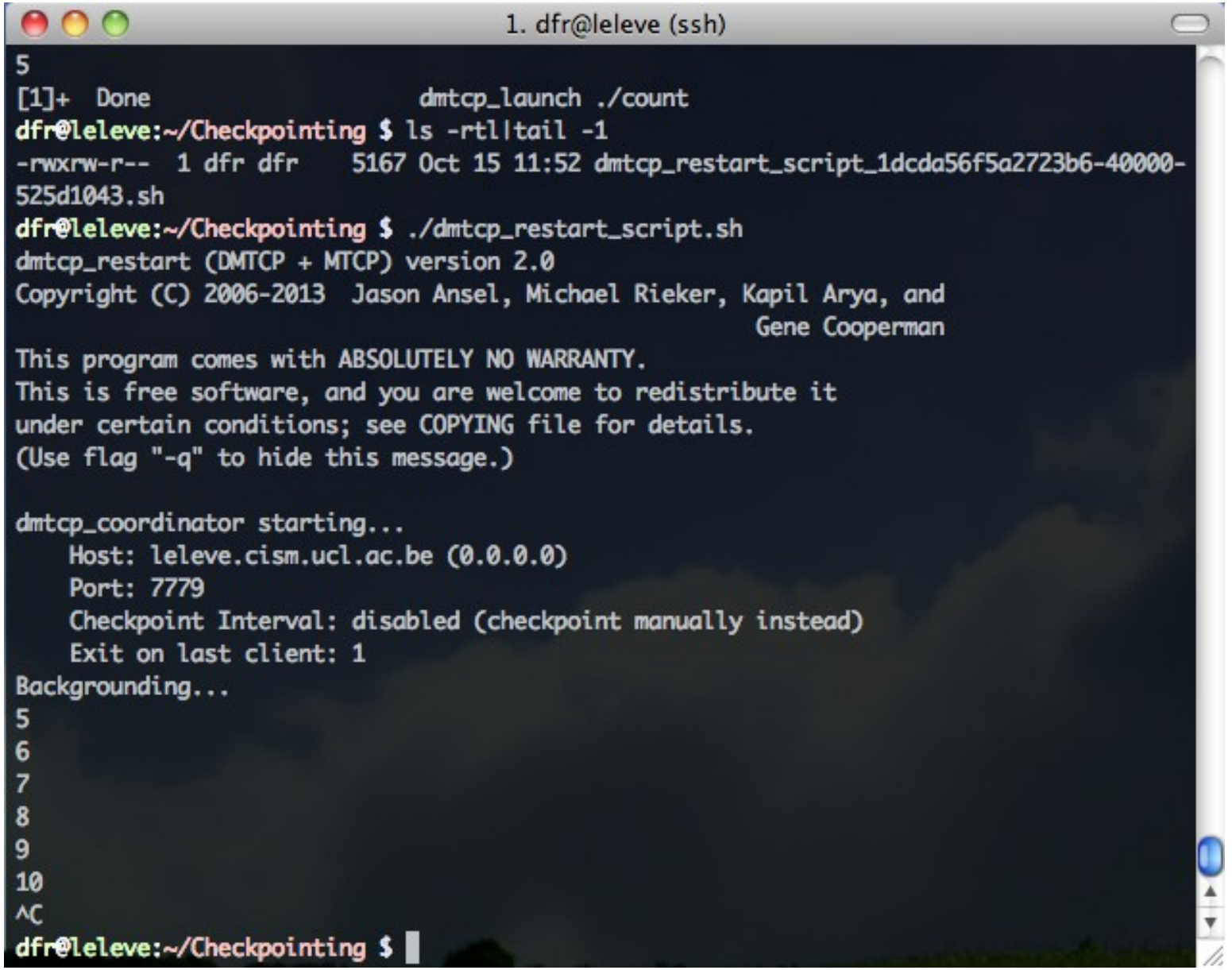
Recall the non-checkpointable program



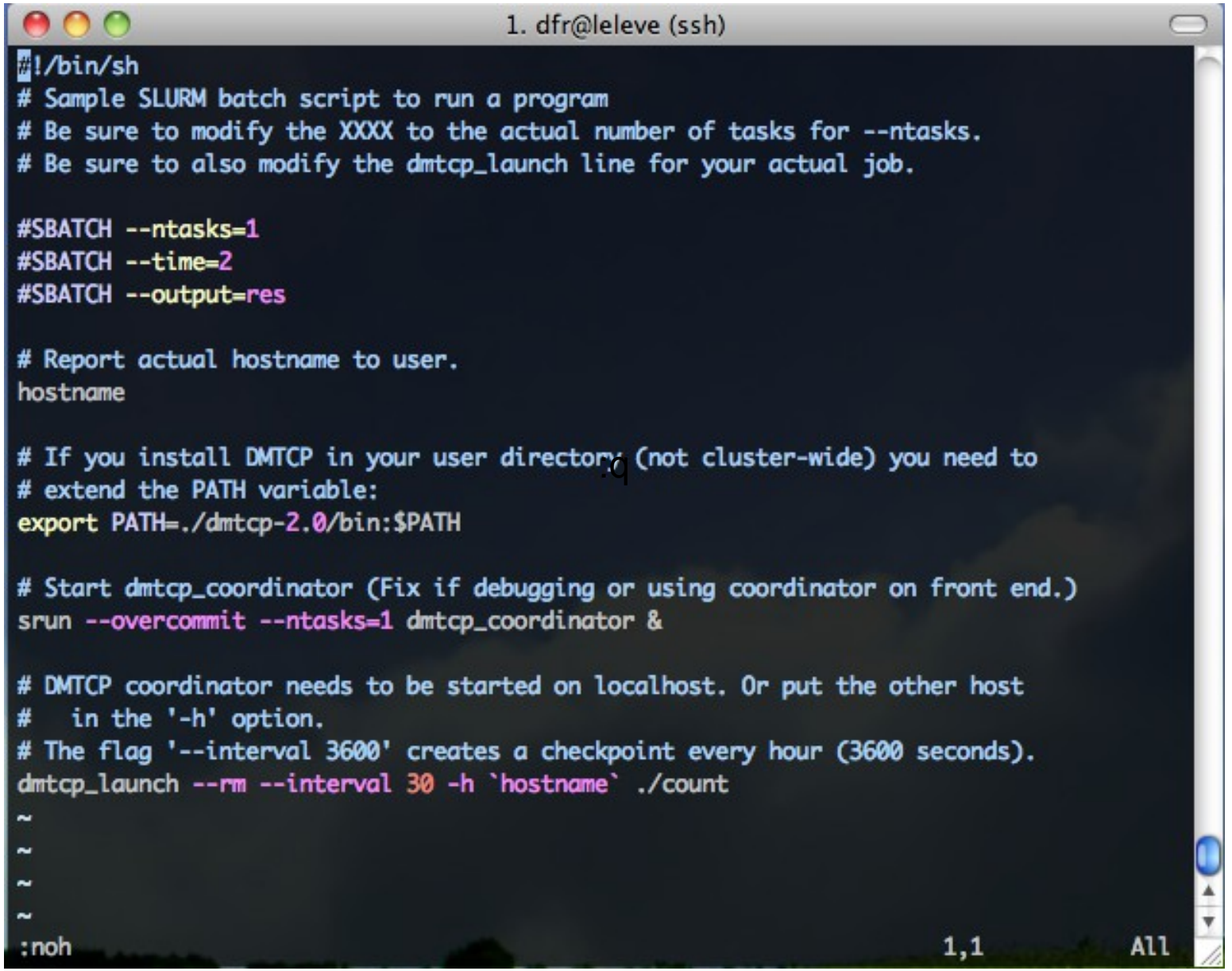
Run with dmtcp_launch (runs monitoring daemon if necessary)



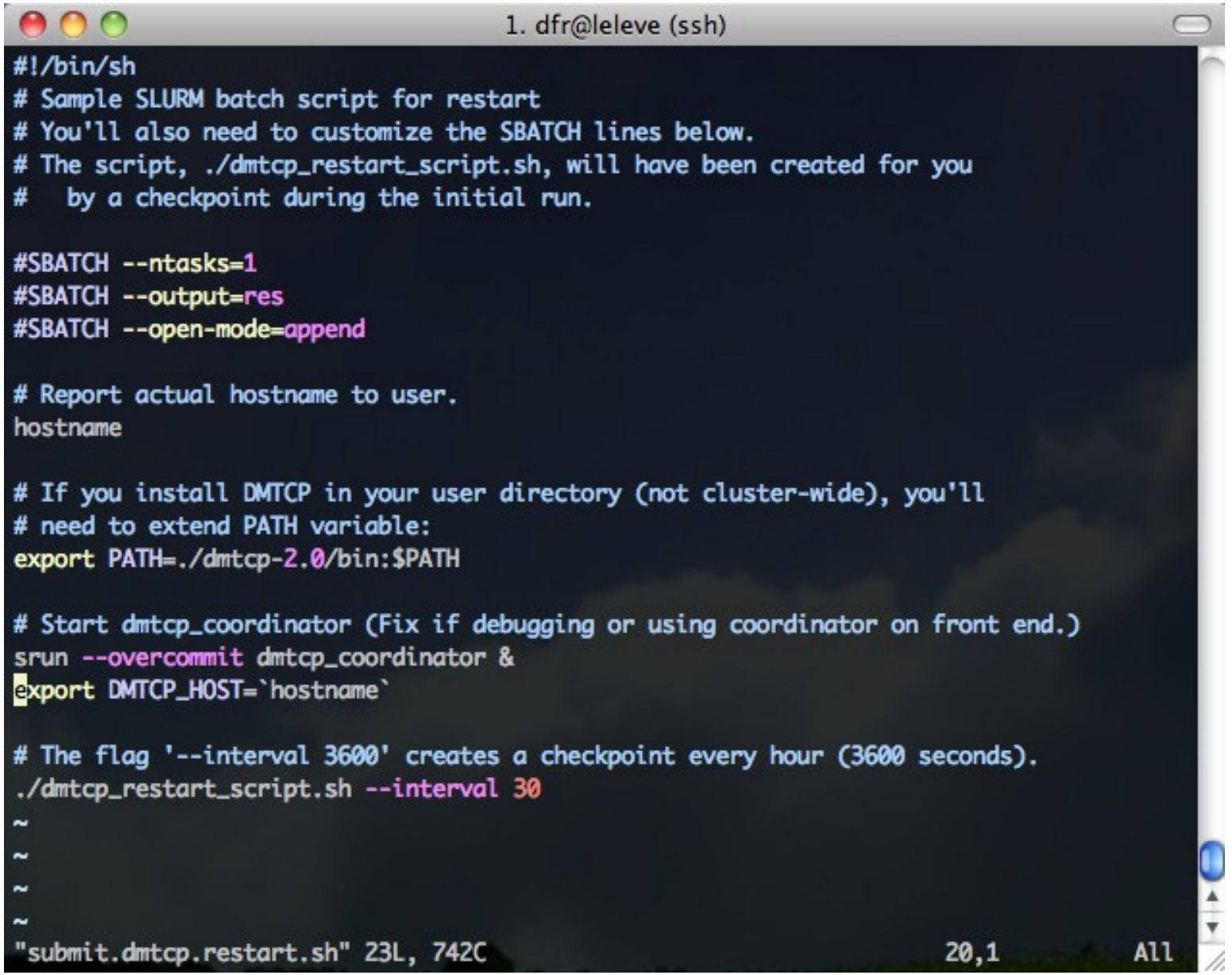
Restart with dmtcp_restart_script.sh

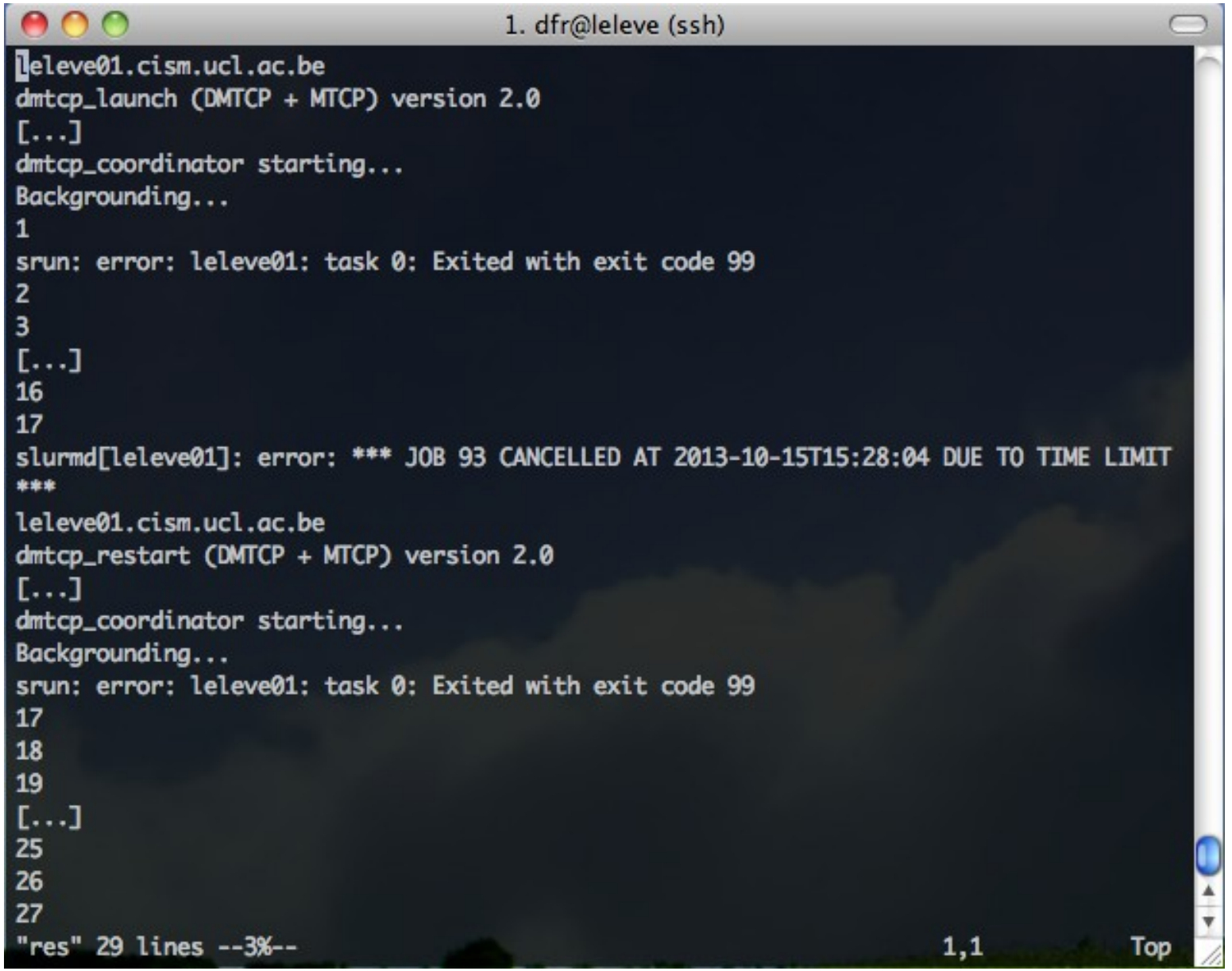


Launch the coordinator and the program with automatic checkpointing every 30 seconds

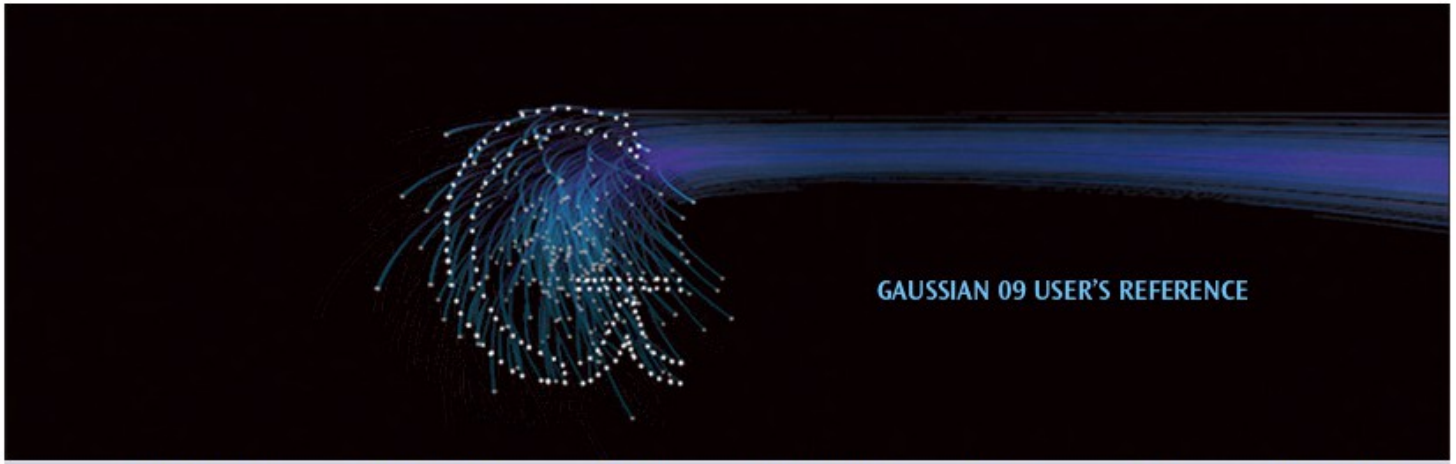


Launch coordinator and restart program




1. dfr@leleve (ssh)
leleve01.cism.ucl.ac.be
dmtcp_launch (DMTCP + MTCP) version 2.0
[...]
dmtcp_coordinator starting...
Backgrounding...
1
srun: error: leleve01: task 0: Exited with exit code 99
2
3
[...]
16
17
slurmd[leleve01]: error: *** JOB 93 CANCELLED AT 2013-10-15T15:28:04 DUE TO TIME LIMIT
***
leleve01.cism.ucl.ac.be
dmtcp_restart (DMTCP + MTCP) version 2.0
[...]
dmtcp_coordinator starting...
Backgrounding...
srun: error: leleve01: task 0: Exited with exit code 99
17
18
19
[...]
25
26
27
"res" 29 lines --3%--
1,1
Top

9 Check whether your scientific software is checkpointable. Many of them are...



Structure of the Formatted Checkpoint File

This file is designed to be machine independent with a structure that makes it easy for post-processors to extract required data and ignore the remainder. The latter fact is important for extensibility as future additions will not interfere with applications designed for previous revisions. Typically a job is run specifying a .chk file, which is the binary file containing results from a calculation which are potentially useful in later calculations or for post-processing, and then after Gaussian 09 has completed, the **formchk** utility is run to generate the text .fchk file from the binary .chk file. There is also a utility, **unfchk**, to reverse the process. For backwards compatibility, running **formchk** without any options produces a subset of the full information. This document describes the results of running **formchk -3** *chkfile fchkfile*, which produces a version 3 formatted checkpoint file (the current and most full-featured version).

Here is a description of the data in Fortran formatted form, although there is no particular reason to use Fortran as opposed to other languages to read the data.

Using Gaussian Checkpoint Files

Since the queues on the scientific servers have time limits, the Gaussian calculations may be terminated prematurely due to running out of time. To restart such a prematurely terminated calculation, one can use the checkpointing facilitated via the Gaussian supported checkpointing file. However, note here that the primary use of a checkpoint file is to use the results of one calculation as the starting point for a second calculation.

When a Gaussian calculation is restarted using information from a checkpoint file, the new calculation results (or the continuation from the uncompleted run) will be placed in the exact same checkpoint file, overwriting the original checkpoint file. THUS IT IS ALWAYS SAFER TO MAKE A BACKUP COPY OF THE CHECKPOINT FILE. Note that it is possible for a checkpoint file to become corrupted (i.e. if a calculation dies while writing to the checkpoint file).

Gaussian will use a checkpoint file if the command:

```
%Chk=file_name
```

appears before the route card in the input file. If the specified file does not exist, it will be created. If the specified file does exist, information to be used in the present calculation can be read from it.

Commands for reading from the checkpoint file

A calculation can be started using information from the checkpoint file by including one of the following commands in the route card.

`ChkBasis`	Read the basis set from the checkpoint file.
`SCF=Restart`	Restart an SCF calculation from the checkpoint file. This is normally used when an SCF calculation failed finish for some reason.
`IRC=Restart`	Restarts an IRC calculation that did not complete, or restarts an IRC calculation for which additional points along the reaction path are desired.
`Scan=Restart`	Restarts a potential energy surface scan which did not complete.
`Freq=Restart`	Restarts a numerical frequency calculation which did not complete. Analytic frequency calculations cannot be restarted.
`Polar=Restart`	Restarts a numerical polarizability calculation which did not complete.
`CIS=Restart`	Restarts a CIS (Configuration Interaction – Single excitation) calculation which did not complete.
`Opt=Restart`	Restarts an geometry optimization which did not complete.
`Geom=Checkpoint`	Reads the molecular geometry from the checkpoint file.
`Geom=AllCheckpoint`	Reads the molecular geometry, charge, multiplicity and title from the checkpoint file. This is often used to start a second calculation at a different level of theory.
`Guess=Read`	Reads the initial guess from the checkpoint file. If the basis set specified is different from the basis set used in the job which generated the checkpoint file, then the wave function will be projected from one basis to the other. This is an efficient way to switch from one basis to another.
`Density=Checkpoint`	Reads the density from the checkpoint file. This inplies Guess=Only so that no integrals or SCF are computed. This is used to compute the population analysis or create cube files from a wave function without rerunning the job.
`Field=Checkpoint`	Reads the 34 multipole components of a finite field from the checkpoint file.
`Field=EChk`	Reads the 3 electric dipole field components from the checkpoint file.
`Charge=Check`	Reads point charges from the checkpoint file.
`ReArchive`	This option is used to generate an archive entry from the information in the checkpoint file. No calculation is run.

Abaqus 6.11

Abaqus/CAE User's Manual

SIMULIA

Parallelization

Use the **Parallelization** tabbed page to configure the parallel execution of the Abaqus analysis jobs during the optimization process, such as the number of processors to use and the parallelization method. For more information, see "Controlling job parallel execution," Section 19.8.8.

Precision

Use the **Precision** tabbed page to choose the precision of nodal output that is written to the output database during the Abaqus analysis. For more information, see "Controlling job precision," Section 19.8.9.

19.6 Restarting an analysis

If your model contains multiple steps, you do not have to analyze all of the steps in a single analysis job. Indeed, it is often desirable to run a complex analysis in stages. This allows you to examine the results and confirm that the analysis is performing as expected before continuing with the next stage. The restart files generated by an Abaqus analysis allow you to continue the analysis from a specified step. For more information, see "Restarting an analysis," Section 9.1.1 of the Abaqus Analysis User's Manual.

This section describes the restart capability in Abaqus/CAE. The following topics provide some background information:

- "Controlling a restart analysis," Section 19.6.1
- "Files required to restart an analysis," Section 19.6.2
- "Rules governing a restart analysis," Section 19.6.3
- "The relationship between the model and the restart analysis," Section 19.6.4

The following topics describe examples of the most common uses for restart analysis:

- "Restarting after adding more analysis steps to the model," Section 19.6.5
- "Restarting after modifying existing analysis steps," Section 19.6.6
- "Restarting from the middle of a step," Section 19.6.7
- "Visualizing results from restart analyses," Section 19.6.8
- "Recovering an Abaqus/Standard analysis," Section 19.6.9
- "Remote submission of restart jobs," Section 19.6.10

19.6.1 Controlling a restart analysis

By default, no restart information is written for an Abaqus/Standard or an Abaqus/CFD analysis and restart information is written only at the beginning and end of each step for an Abaqus/Explicit analysis.

MOLPRO

Users Manual
Version 2012.1

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SHA1 0034bbaeb6d4f13a081e892956fbbd55b2271035

6.2 Ending a job (---)

The end of the input is signaled by either an end of file, or a

```
---
```

card. All input following the --- card is ignored.

Alternatively, a job can be stopped at at some place by inserting an EXIT card. This could also be in the middle of a DO loop or an IF block. If in such a case the --- card would be used, an error would result, since the ENDDO or ENDIF cards would not be found.

6.3 Restarting a job (RESTART)

In contrast to MOLPRO92 and older versions, the current version of MOLPRO attempts to recover all information from all permanent files by default. If a restart is unwanted, the NEW option can be used on the FILE directive. The RESTART directive as described below can still be used as in MOLPRO92, but is usually not needed.

RESTART,$r_1, r_2, r_3, r_4, \ldots$;

The r_i specify which files are restarted. These files must have been allocated before using FILE cards. There are two possible formats for the r_i:

a) $0 < r_i < 10$: Restart file r_i and restore all information.

b) $r_i = name.nr$: Restart file nr but truncate before record *name*.

If all $r_i = 0$, then all permanent files are restarted. However, if at least one r_i is not equal to zero, only the specified files are restarted.

Examples:

`RESTART;`	will restart all permanent files allocated with FILE cards (default)
`RESTART,1;`	will restart file 1 only
`RESTART,2;`	will restart file 2 only
`RESTART,1,2,3;`	will restart files 1-3
`RESTART,2000.1;`	will restart file 1 and truncate before record 2000.

6.4 Including secondary input files (INCLUDE)

INCLUDE,*file*[,ECHO];

Insert the contents of the specified *file* in the input stream. In most implementations the file name given is used directly in a Fortran open statement. If *file* begins with the character '/', then it will be interpreted as an absolute file name. Otherwise, it will be assumed to be a path relative to the directory from which the Molpro has been launched. If, however, the file is not found, an attempt will be made instead to read it relative to the system lib/include directory, where any standard procedures may be found.

If the ECHO option is specified, the included file is echoed to the output in the normal way, but by default its contents are not printed. The included file may itself contain INCLUDE commands up to a maximum nesting depth of 10.

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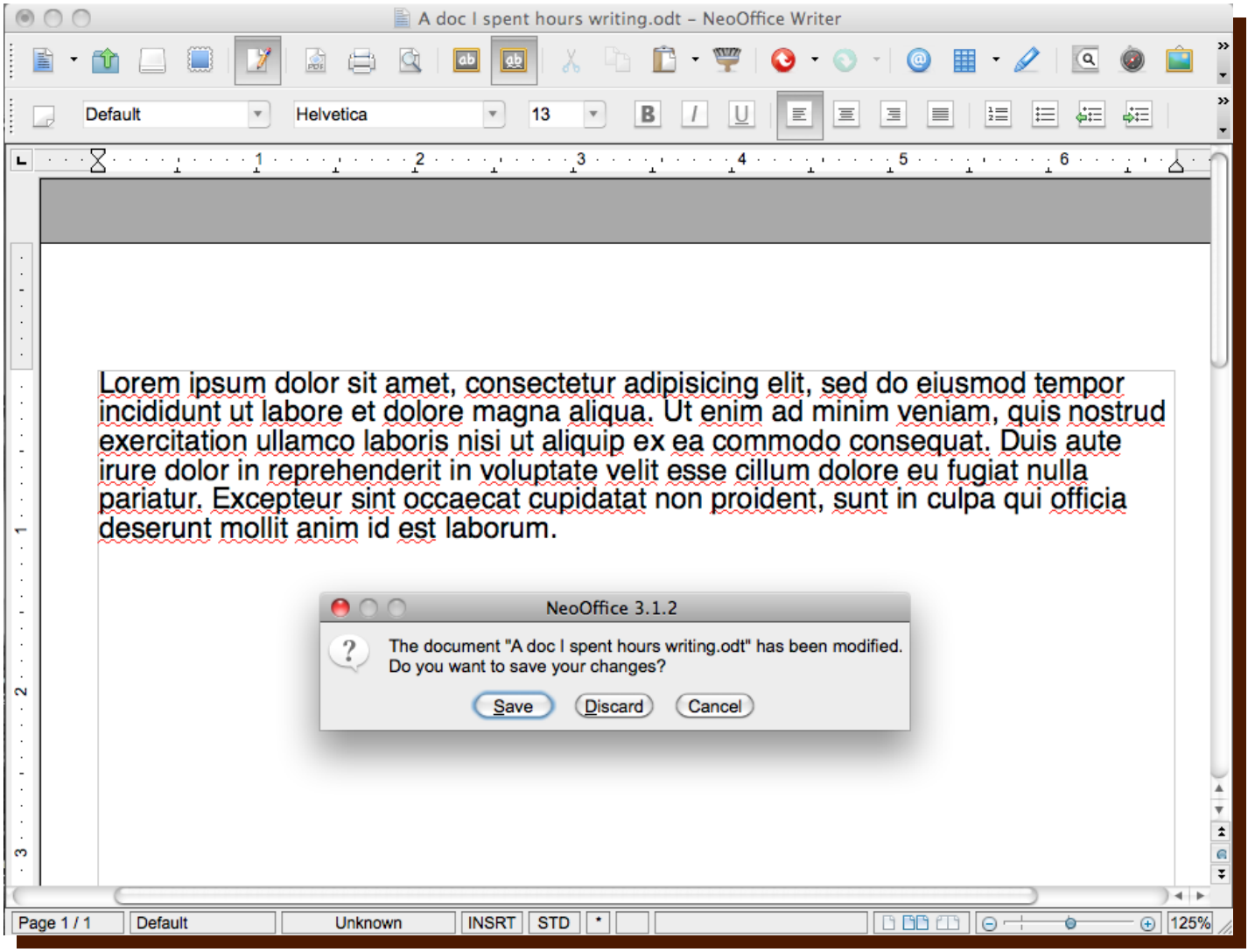
UCL/CISM - FNRS/CÉCI

Summary, Wrap-up and Conclusions.

November 2013
CISM/CÉCI training session

Never click 'Discard' again...



- Application-based checkpointing
  - Efficient: save only needed data
  - Coarse temporal granularity: Good for fault tolerance, bad for preemption
  - Requires effort by programmer
- Library-based (DMTCP)
  - Portable across platforms
  - Transparent to application
  - Can't restore all resources
- Kernel-based checkpointing (BLCR)
  - Not portable
  - Transparent to application
  - Needs root access to install
  - Can save/restore all resources

- If you're the developer:
  - Make initializations conditional
  - Save minimal reconstructable state periodically
  - Save full workspace upon signal
  - Checkpoint after a synchronization

The submission script(s)

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

BLCR, DMTCP, own recipe...