Debugging and Performance Analysis Tools at NERSC

2013 BOUT++ Workshop

Woo-Sun Yang
NERSC User Services Group

September 4, 2013
Overview

• Survey of selected debugging and profiling tools at NERSC
  – To provide a quick start

• Some examples presented are using ‘elm-pb’
  – Build scripts (and batch scripts for some cases, too) available in a NERSC training directory
    % module load training
    % ls $EXAMPLES (/project/projectdirs/training/2013/BOUT++/examples)
  – Note: Example results in the presentation were obtained with BOUT-1.0, but the scripts are updated for BOUT-2.0
Debugging Tools
Let us control the pace of running your code by

- Advancing a line or lines of your program at a time (‘next’, ‘step’, ‘continue’, ...)
- Stopping execution at certain locations in your program
  - Set a “breakpoint” where you want execution to stop
  - Set a “watchpoint” for a variable or an expression to make the program stop when its value changes

Let us examine execution flow or check variables to see if it is running as expected
Debuggers on NERSC machines

• **Parallel debuggers with a graphical user interface**
  – DDT (Distributed Debugging Tool)
    • Can run for up to 8192 tasks
  – TotalView
    • Can run for up to 512 tasks

• **Cray Debugger Support Tools**
  – STAT (Stack Trace Analysis Tool)
  – ATP (Abnormal Termination Processing)
    • A system that monitors user applications and replaces the core dump with a more comprehensive stack backtrace and analysis
  – lgdb
    • A modified gdb for parallel programs that interfaces with aprun
For information

- **DDT**
  - `$ALLINEA_TOOLS_DOCDIR/userguide.pdf` (after loading `allineatools` module)

- **TotalView**

- [NERSC](http://www.nersc.gov)
Running DDT

To compile with -g to have debugging symbols

Let’s try this example

Start an interactive batch session

Use DDT

Set the number of MPI tasks to 128
Running DDT (cont’d)

- Navigate using the buttons
- Parallel stack frame view is helpful in quickly finding out where each process is executing
- To check the value of a variable, right-click on a variable or check the pane on the right
- Sparklines to quickly show variation over tasks
Running TotalView

```bash
% qsub -IV -lmppwidth=144
% cd $PBS_O_WORKDIR
% module load totalview
% totalview aprun -a -n 128 ./elm_pb
```

Then,

- Click OK in the ‘Startup Parameters - aprun’ window
- Click ‘Go’ button in the main window
- Click ‘Yes’ to the question ‘Process aprun is a parallel job. Do you want to stop the job now?’
Running TotalView (cont’d)

To see the value of a variable, right-click on a variable to “dive” on it or just hover mouse over it.

Navigate using the buttons

To see the value of a variable, right-click on a variable to “dive” on it or just hover mouse over it.

<table>
<thead>
<tr>
<th>ID/</th>
<th>Rank</th>
<th>Host</th>
<th>Status</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>&lt;local&gt;</td>
<td>T</td>
<td>aprun (1 active threads)</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>nid01793</td>
<td>T</td>
<td>aprun&lt;elm_pb&gt;.0 (2 active threads)</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>nid01793</td>
<td>T</td>
<td>aprun&lt;elm_pb&gt;.1 (1 active thread)</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>nid01793</td>
<td>T</td>
<td>aprun&lt;elm_pb&gt;.2 (1 active thread)</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>nid01793</td>
<td>T</td>
<td>aprun&lt;elm_pb&gt;.3 (1 active thread)</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>nid01793</td>
<td>T</td>
<td>aprun&lt;elm_pb&gt;.4 (1 active thread)</td>
</tr>
<tr>
<td>7</td>
<td>5</td>
<td>nid01793</td>
<td>T</td>
<td>aprun&lt;elm_pb&gt;.5 (1 active thread)</td>
</tr>
<tr>
<td>8</td>
<td>6</td>
<td>nid01793</td>
<td>T</td>
<td>aprun&lt;elm_pb&gt;.6 (1 active thread)</td>
</tr>
<tr>
<td>9</td>
<td>7</td>
<td>nid01793</td>
<td>T</td>
<td>aprun&lt;elm_pb&gt;.7 (1 active thread)</td>
</tr>
</tbody>
</table>
• **STAT (Stack Trace Analysis Tool)**

  • Gathers stack backtraces (the function calling sequences) from all processes of a running application and merges them into a single file (*.dot)
    – The output shows the location in the code that each process is executing
    – Can be used for debugging a hung application

  • **STAT commands (after loading the ‘stat’ module)**
    – stat (STAT or stat-cl): invokes STAT to gather stack traces
    – statview (STATview or stat-view): a GUI to view STAT results
    – statgui (STATGUI or stat-gui): a GUI to run STAT or view results

• **For more info:**
  – ‘intro_stat’, ‘STAT’, ‘statview’ and ‘statgui’ man pages
Gathering backtraces for a hung application using STAT

% qstat -f 6397413
... login_node_id = nid05621
%
% ssh -XY nid05621
% ps -aux | grep your_login_name
... wyang 9246 0.0 0.0 27320 2100 ? S 18:41 /usr/bin/aprun -n 48 alf+hopper
%
% module load stat
% stat 9246
... Attaching to application...
Attached!
Application already paused... ignoring request to pause
Sampling traces...
Traces sampled!
... Resuming the application...
Resumed!
Merging traces...
Traces merged!
Detaching from application...
Detached!

Find the MOM node that launched the app.
Log into the MOM node
Find pid

Results written to /scratch/scratchdirs/wyang/stat_results/alf+hopper.0000
% ls -l stat_results/alf+hopper.0000/*.
dot
-rw------- 1 wyang wyang 665 2013-08-27 18:45 stat_results/alf+hopper.0000/alf+hopper.0000.3D.dot
% statview stat_results/alf+hopper.0000/alf+hopper.0000.3D.dot
Attaching to an application using STAT

% qstat -f 6398933
... login_node_id = nid05620
% ssh -XY nid05620
...% ps -aux | grep your_login_name
... wyang 4007 0.0 0.0 26920 2100 ? S 09:00 /usr/bin/aprun -n 48 a1f+hopper
% module load stat
% statgui 4007

Find the MOM node that launched the app.
Log into the MOM node
Find pid
Attach to the app.
ATP (Abnormal Termination Processing)

• When enabled, ATP gathers stack backtraces from all processes of a failing application
  – Output saved in atpMergedBT.dot and atpMergedBT_line.dot (which shows source code line numbers)
  – They are viewed with statview

• By default, the atp module is loaded on Hopper and Edison, but ATP is not enabled

• Can make core dumps (core.atp.apid.rank), too, by setting coredumpsize unlimited, but the location of failure can be inaccurate
  – unlimit coredumpsize  # for csh/tcsh
  – ulimit -c unlimited    # for sh/bash/ksh

• For more info
  – ‘intro_atp’ man page
Running an application with ATP

```bash
% cp $ATP_HOME/demos/testMPIApp.c .
% cc -o testMPIApp testMPIApp.c
% cat runit
#!/bin/csh
#PBS -l mppwidth=24
#PBS -l walltime=5:00
#PBS -q debug
#PBS -j oe

cd $PBS_O_WORKDIR
setenv ATP_ENABLED 1  # Enable ATP
#unlimit coredumpsize  # For core dumps
aprun -n 8 ./testMPIApp 1 4
% qsub runit
6399762.hopque01

% cat runit.o6399762
...
Application 20111543 is crashing. ATP analysis proceeding...
...
Process died with signal 4: 'Illegal instruction'
View application merged backtrace tree with: statview atpMergedBT.dot
...
% module load stat
% statview atpMergedBT.dot  # or statview atpMergedBT_line.dot
```
Hung application with ATP

- Force to generate a BT from a hung application
- For the following to work, the batch job should have ATP enabled in the batch script

```
% apstat                                    Find apid
...                                      ...
  Apid ResId   User   PEs Nodes   Age State    Command
...                                    ...
  20112743    3768   wyang   48     2   0h02m    run        a1f+hopper
...                                    ...
% apkill 20112743                        Kill the hung application
% cat runit.o6399999
...
Application 20112743 is crashing. ATP analysis proceeding...
...
Process died with signal 15: 'Terminated'
View application merged backtrace tree with: statview atpMergedBT.dot
...
% module load stat
% statview atpMergedBT.dot    # or statview atpMergedBT_line.dot
```
**lgdb**

- **Line (not GUI) mode parallel debugger by Cray**
  - Just like GDB but for MPI applications; threading not supported
  - Many GDB commands inherited
- **Use for**
  - Launching an application
  - Attaching to a running application
    - Useful for debugging a hung application
  - Comparative debugging
- **Some entities used by lgdb**
  - Process Set
    - Set of MPI processes used
    - Denote it by a scalar or, in case of MPI applications, array variable
    - Use this variable to refer to a group of the processes
  - Decomposition descriptor for distributed arrays
  - Assertion scripts: commands used for comparing variable values during comparative debugging
Launching an application with lgdb

% cc -g -o hello_mpi_c hello_mpi.c
% qsub -IV -lmppwidth=24 -q debug
...
% cd $PBS_O_WORKDIR
% module rm altd
% module load cray-lgdb
% lgdb
...
launch $pset{8} hello_mpi_c
break hello_mpi.c:21
continue

print $pset::myRank
pset[0]: 0
...
pset[7]: 7
print $pset{3}::myRank
pset[3]: 3

Launching ‘hello_mpi_c’ with 8 MPI tasks; I am going to call this process set ‘$pset’
Setting a breakpoint at line 21 of hello_mpi.c
Check the value of ‘myRank’ for all the processes in $pset
Print the value of ‘myRank’ for process $pset[3] only

See the usage example in the man page which uses the example code in $CRAY_LGDB_DIR/demos/mpi_example
Attaching lgdb to an application

% qstat -f 6398933
... login_node_id = nid05620

% apstat
... Apid ResId User PEs Nodes Age State Command
... 200108035 1516 wyang 8 1 0h02m run a.out

% ssh nid05620
...
% module load cray-lgdb
% lgdb
...
dbg all> attach $pset 200108035
Attaching to alps applications, please wait...
... Attach complete
dbg all> backtrace
...
dbg all> print $pset::myRank
pset[0]: 0
...

Find the MOM node that launched the app.

Find apid

Log into the MOM node

Attach to the app.; I am going to call the process set `$pset`; $pset$ is an array variable whose size is determined automatically

Check the backtraces

Check the value of `myRank` for all the processes in `$pset`
Comparative debugging with lgdb

• To find a bug introduced in a version by running the new and old versions side by side and comparing the results

• Preliminary but can be still useful
  – Comparative debugging will be formally introduced with the future release of CCDB (Cray Comparative Debugger)

• A detailed walk-through in ‘Using the lgdb Comparative Debugging Feature’ ([http://docs.cray.com/books/S-0042-20/S-0042-20.pdf](http://docs.cray.com/books/S-0042-20/S-0042-20.pdf)) using the example codes in $CRAY_LGDB_DIR/demos/hpcc_demo
Performance analysis tools

• **Measure code performance in order to identify performance bottlenecks and improve them**

• **Two types of measurement**
  – Sampling
    • Sample where the program is executing (i.e., ‘program counter’) at regular time intervals (or certain events)
    • Low overhead
  – Tracing
    • Count some event such as the number of times certain library functions or user functions are executed
    • Need to specify a list of the functions to be traced

• **Some tools available at NERSC**
  – CrayPat: for sampling or tracing
  – IPM: for sampling
  – MAP: for sampling
CrayPat (Cray Performance Measurement and Analysis Tools)

• Steps
  1. ‘module load perftools’ before starting to build your code
  2. Instrument your program using ‘pat_build’
     • Build your code; *.o must be kept as well as *.a, if any
     • `pat_build [options] a.out` # to create an instrumented binary, a.out+pat
  3. Execute your instrumented program
     • `aprun ... ./a.out+pat`
     • Performance data saved in `a.out+pat+#####-####e.xf` (e: s for sampling or t for tracing)
  4. Analyze the resulting data
     • `pat_report a.out+pat+#####-####e.xf`

• Instrumentation types (and their `pat_build` options)
  – For sampling
  – For tracing – Specify a list of the functions to be traced
    • User functions: using `pat_build`’s -T,-t, -u (-u for all; can increase run time significantly)
    • Preset trace groups for popular functions: using `pat_build`’s -g
      – mpi, heap, io, omp, blas, lapack, ...
Sampling with CrayPat

% module rm darshan
% module load perftools
% ./configure
% make
% cd examples/elm-pb
% make
% pat_build -f elm_pb
% cat runit

... aprun -n 128 ./elm_pb+pat
% qsub runit
6416027.hopque01
% pat_report elm_pb+pat+20194488_4680s.xf > my.rpt
% more my.rpt
% app2 elm_pb+pat+20194488_4680s.ap2
% rm elm_pb+pat+20194488+4680s.xf

Unload darshan as it will interfere with perftools

Build an instr. binary; -f to overwrite if there is one already

Use the instr. binary

ASCII text report captured in my.rpt
See the report
Visualization of the results using a GUI tool, app2
Not needed as you now have a .ap2 file;
*.ap2 is self-contained and portable while .xf is not;
text report can be generated from .ap2, too
Tracing with CrayPat (one way - using Automatic Program Analysis)

% module rm darshan
% module load perftools
% ./configure
% make
% cd examples/elm-pb
% make
% pat_build -f -O apa elm_pb
% cat runit

... aprun -n 128 ./elm_pb+pat
% qsub runit
6415765.hopque01
% pat_report elm_pb+pat+20192069_1225s.xf > mys.rpt
% more elm_pb+pat+20192069_1255s.apa

% pat_build -f -O elm_pb+pat+20192069_1225s.apa
% cat runit

... aprun -n 128 ./elm_pb+apa
% qsub runit
6415831.hopque01
% pat_report elm_pb+apa+20193028-1791t.xf > myt.rpt
% more myt.rpt
% app2 elm_pb+apa+20193028-1791t.ap2
% rm *.xf

Unload darshan as it will interfere with perftools

Special option for building an instr. binary for sampling

Sampling run

See what functions/groups are suggested for tracing, and edit if you want

Build a new instr. binary for tracing, guided by the sampling results

Use the new instr. binary for tracing

ASCII text report in myt.rpt

If you want...

Not needed as you now have .ap2 files
CrayPat-lite

- A simplified version of CrayPat
  - No need for you to manually build an instrumented binary
  - *.ap2, *.rpt (text report) files are generated for you

```bash
% module rm darshan
% module load perftools-lite
% ./configure
% make
% cd examples/elm-pb
% make
% cat runit
...
#setenv CRAY_LITE sample_profile
setenv CRAY_ROOTFS DSL
aprun -n 128 ./elm_pb
% qsub runit
6416899.hopque01
% more runit.o6416899
% more elm_pb+20199902-445s.rpt
% app2 elm_pb+20199902_445s.ap2
% rm elm_pb+20199902_445s.xf
```

Unload darshan as it will interfere with perftools

‘sample_profile’ for sampling; ‘event_profile’ for tracing

You need this line (because of pat_report)

Performance summary included in stdout file

Same text report saved in elm_pb+*.rpt

If you want...

Not needed as you have a .ap2 file
%% more myt.rpt
...

Table 1: Profile by Function Group and Function

<table>
<thead>
<tr>
<th>Time%</th>
<th>Time</th>
<th>Imb. Time</th>
<th>Imb. Time%</th>
<th>Calls</th>
<th>Group Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>100.0%</td>
<td>925.231187</td>
<td>--</td>
<td>--</td>
<td>3316802.0</td>
<td>Total</td>
</tr>
<tr>
<td>85.8%</td>
<td>793.976022</td>
<td>--</td>
<td>--</td>
<td>2.0</td>
<td>USER</td>
</tr>
<tr>
<td>85.8%</td>
<td>793.976006</td>
<td>46.283832</td>
<td>5.6%</td>
<td>1.0</td>
<td>main</td>
</tr>
<tr>
<td>8.7%</td>
<td>80.708496</td>
<td>28.767508</td>
<td>35.6%</td>
<td>88812.0</td>
<td>MPI_SYNC</td>
</tr>
<tr>
<td>8.7%</td>
<td>80.708496</td>
<td>28.767508</td>
<td>35.6%</td>
<td>88812.0</td>
<td>MPI_Allreduce(sync)</td>
</tr>
<tr>
<td>5.5%</td>
<td>50.546518</td>
<td>--</td>
<td>--</td>
<td>3227787.0</td>
<td>MPI</td>
</tr>
<tr>
<td>3.2%</td>
<td>29.195955</td>
<td>23.581497</td>
<td>45.0%</td>
<td>498535.0</td>
<td>MPI_Send</td>
</tr>
<tr>
<td>1.0%</td>
<td>8.821983</td>
<td>21.931692</td>
<td>71.9%</td>
<td>381225.0</td>
<td>MPI_Waitany</td>
</tr>
</tbody>
</table>

...
CrayPat results displayed with app2
More things to do with CrayPat…

• **Automatic Rank Order Analysis**
  – Suggests a better MPI rank placement

• **CrayPat API**
  – Instrument and get tracing results only for selected regions of your code

• **Monitor a selected group of hardware counters (floating point operations, cache usage, etc.) or network performance counters**

• **Reveal**
  – A new tool that combines run-time performance stats and program source code visualization with compile-time optimization feedback for optimization

• **For info:**
  – Pat_help online help systems
    % pat_help
  – ‘Using Cray Performance Measurement and Analysis Tools’ (S-2376-610, [http://docs.cray.com/books/S-2376-610/S-2376-610.pdf](http://docs.cray.com/books/S-2376-610/S-2376-610.pdf))
IPM (Integrated Performance Monitoring)

- Profiling tool with a low overhead that reports
  - Floating point operations
  - Memory usage
  - MPI function timings
  - Hardware counters data
  - Load imbalance
  - …

- For info:
Profiling using IPM

% module rm darshan
% module load ipm
% ./configure EXTRA_LIBS="${IPM_GNU}"
% make
% cd examples/elm-pb
% make
% cat runit
...

#setenv IPM_REPORT terse
setenv IPM_REPORT full
setenv IPM_HPM PAPI_FP_OPS,PAPI_TOT_INS,PAPI_L1_DCM,PAPI_L1_DCA
aprun -n 128 ./elm_pb
% qsub runit
6418950.hopque01
% more runit.06418950
% ipm_parse -html wyang.1378041829.ipm.xml
...
% tar -cvf ipmrpt.tar elm_pb_128_wyang.1378041829.ipm.xml_ipm_6418950.hopque01

Unload darshan as it will interfere
Add the IPM link flags to EXTRA_LIBS
Choose either type; ‘terse’ is default
Set hardware counters if you want; only PAPI_FP_OPS is set by def.
See the text report at the end of the stdout file
Create html files out of xml

Do the following on your local desktop where a web browser exists; get the file, untar it and open index.html in the created directory using a web browser

localmachine % scp myloginid@hopper.nersc.gov:/my/directory/ipmrpt.tar .
localmachine % tar -xvf ipmrpt.tar
IPM results (1)

% more runit.o6418950
...
##IPM2v0.xx####################################################
#
# command   : ./elm_pb
# start     : Sun Sep 01 13:23:49 2013   host      : nid00779
# stop      : Sun Sep 01 13:38:47 2013   wallclock : 897.22
# mpi_tasks : 128 on 6 nodes            %comm    : 11.93
# mem [GB]  : 3.38                      gflop/sec : 29.24
#
#           :   [total]   <avg>     min      max
# wallclock :  114836.90   897.16    897.11   897.22
# MPI       :  13698.07    107.02     77.43    145.18
# %wall     :                     11.93    8.63     16.18
# #calls    :
#   MPI     : 212841728   1662826   1183837   1731253
# mem [GB]  :          3.38         0.03         0.02         0.03
#
#                             [time]   [count]   <%wall>
# MPI_Allreduce       9126.85   11367936     7.95
# MPI_Send            3093.66   63812480     2.69
# MPI_Waitany         804.80    48796800     0.70
# MPI_Wait            644.26    25025280     0.56
IPM results (2)

Command: /elm_pb

codename: unknown
username: wyang

Host: nid00779 (x86_64_Linux)
Start: 09/01/13/06:23:49
Wallclock: 8.97548e+02 sec
Stop: 09/01/13/06:38:47
%comm: 11.9231699516349
Total Memory: 3.4472039999999 gbytes
Total Gflop/sec: 0.0347140253223225
Switch(send): 0 gbytes
Switch(recv): 0 gbytes

**Computation**

<table>
<thead>
<tr>
<th>Event</th>
<th>Count</th>
<th>Pop</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAPI_FP_OPS</td>
<td>2623087788085</td>
<td>*</td>
</tr>
<tr>
<td>PAPI_L1_DCA</td>
<td>12786850543094</td>
<td>*</td>
</tr>
<tr>
<td>PAPI_L1_DCM</td>
<td>186381889684</td>
<td>*</td>
</tr>
<tr>
<td>PAPI_TOT_INS</td>
<td>242606121165071</td>
<td>*</td>
</tr>
</tbody>
</table>

**Communication**

% of MPI Time

**HPM Counter Statistics**

<table>
<thead>
<tr>
<th>Event</th>
<th>Ntasks</th>
<th>Avg</th>
<th>Min(rank)</th>
<th>Max(rank)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAPI_FP_OPS</td>
<td>*</td>
<td>204928733438.16</td>
<td>183408469176 (67)</td>
<td>218388257083 (112)</td>
</tr>
<tr>
<td>PAPI_L1_DCA</td>
<td>*</td>
<td>998972698696.05</td>
<td>930195300088 (117)</td>
<td>1059000558265 (75)</td>
</tr>
<tr>
<td>PAPI_L1_DCM</td>
<td>*</td>
<td>1456108513.16</td>
<td>1147365493 (121)</td>
<td>2912526906 (19)</td>
</tr>
<tr>
<td>PAPI_TOT_INS</td>
<td>*</td>
<td>1895360321602.12</td>
<td>1770354532482 (117)</td>
<td>2016061278284 (75)</td>
</tr>
</tbody>
</table>

Communication Event Statistics (0.00% detail, 1.3698e+04 error)

<table>
<thead>
<tr>
<th>Buffer Size</th>
<th>Ncalls</th>
<th>Total Time</th>
<th>Min Time</th>
<th>Max Time</th>
<th>%MPI</th>
<th>% Wall</th>
</tr>
</thead>
</table>

Load balance by task: HPM counters
• New parallel profiling tool with GUI by Allinea Software
• Can run MAP for up to 512 tasks
  – Shared by other users
• Need to build two small libraries for sampling, MAP sampler and MPI wrapper libraries
  – make-map-static-libraries: for static linking
  – make-map-cray-libraries: for dynamic linking
• Need to follow a certain linking order - see the user manual
• For info:
  – $ALLINEATOOLS_DOCDIR/userguide.pdf (after loading the allineatools module)
  – https://www.nersc.gov/users/software/debugging-and-profiling/MAP/
Using MAP

% module load allineatools
% ./configure CXXFLAGS="-g" LDFLAGS="-v"
% sed -i 's/@$(LD)/$(LD)/' make.config
% make
% make-map-static-cray-libraries lib
% cd examples(elm-pb)
% set cmd=`make |& grep "collect2" | \ 
  sed -e 's/collect2/collect2 --eh-frame-hdr/\ 
  -e 's/\(-lmpichcxx_gnu_46\)/\-L..\//..\//\lib -lmap-sampler-pmpi \ 
  -undefined=allinea_init_sampler_now -lmap-sampler \1/` 
% eval "$cmd"
% ls -lrt
...
-rwx------ 1 wyang wyang 28842273 2013-09-01 22:30 elm_pb

% qsub -IV -lmppwidth=144 ...
% cd $PBS_O_WORKDIR
% map ./elm_pb
% ls -lrt
...
-rw------- 1 wyang wyang 7889009 2013-09-01 22:59 elm_pb_128p_2013-09-01_22-43.map

Add ‘-g’ to CXXFLAGS to get debugging symbols; add ‘-v’ (verbose) to LDFLAGS to get the detailed link line printed to terminal
Change make.config to echo the link command
Build the libs in ‘lib’ directory that MAP needs
Build and capture the link line; modify it to include the libs that MAP needs
Run the modified link command
Run with MAP; select 128 tasks in the Run window
Profiling results saved in a file
MAP results

```c
for(int i=0;i<OUT;i++) {
    
    /// Run the solver for one output timestep
    simtime = run(simtime + TIMESTEP);
    iteration++;

    /// Check if the run succeeded
    if(simtime < 0.0) { [...] }

    /// Write the restart file
```

---

U.S. DEPARTMENT OF
Energy

Office of
Science