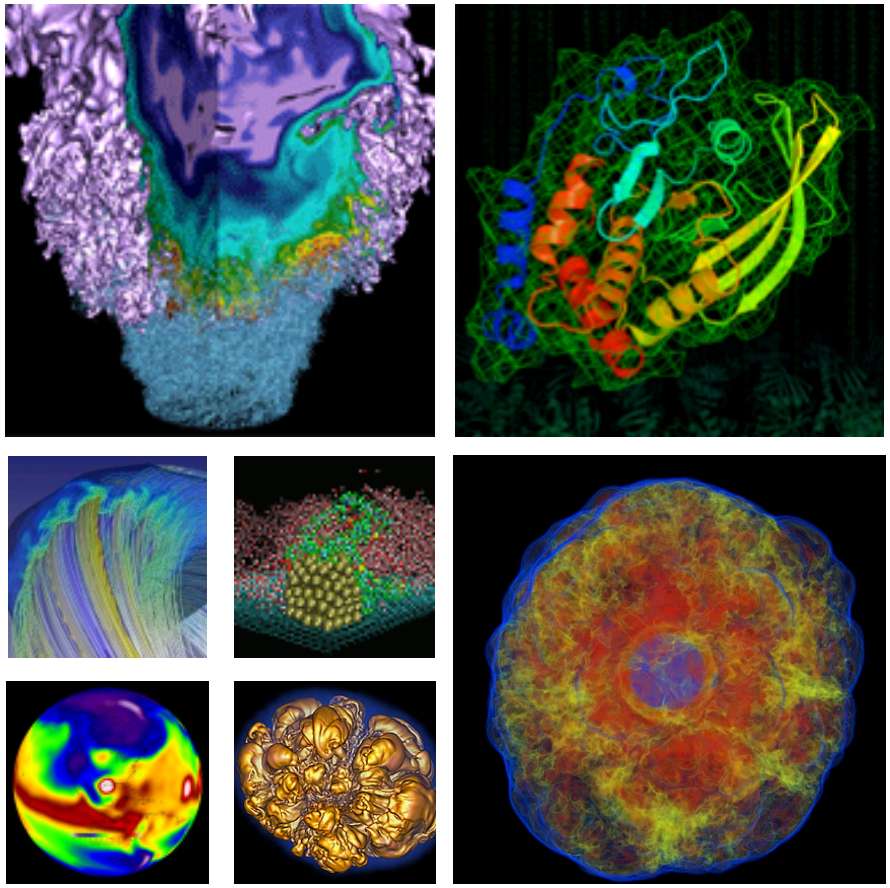
Debugging Tools



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NERSC 40 YEARS at the FOREFRONT 1974-2014

U.S. DEPARTMENT OF ENERGY | Office of Science

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Debuggers on NERSC machines

- **Parallel debuggers with a graphical user interface**
  - DDT (Distributed Debugging Tool)
  - TotalView
- **Specialized debuggers on Hopper and Edison**
  - STAT (Stack Trace Analysis Tool)
    - Collect stack backtraces from all (MPI) tasks
  - ATP (Abnormal Termination Processing)
    - Collect stack backtraces from all (MPI) tasks when an application fails
  - CCDB (Cray Comparative Debugger)
    - Comparative debugging
- **Valgrind**
  - Suite of debugging and profiler tools

DDT and TotalView

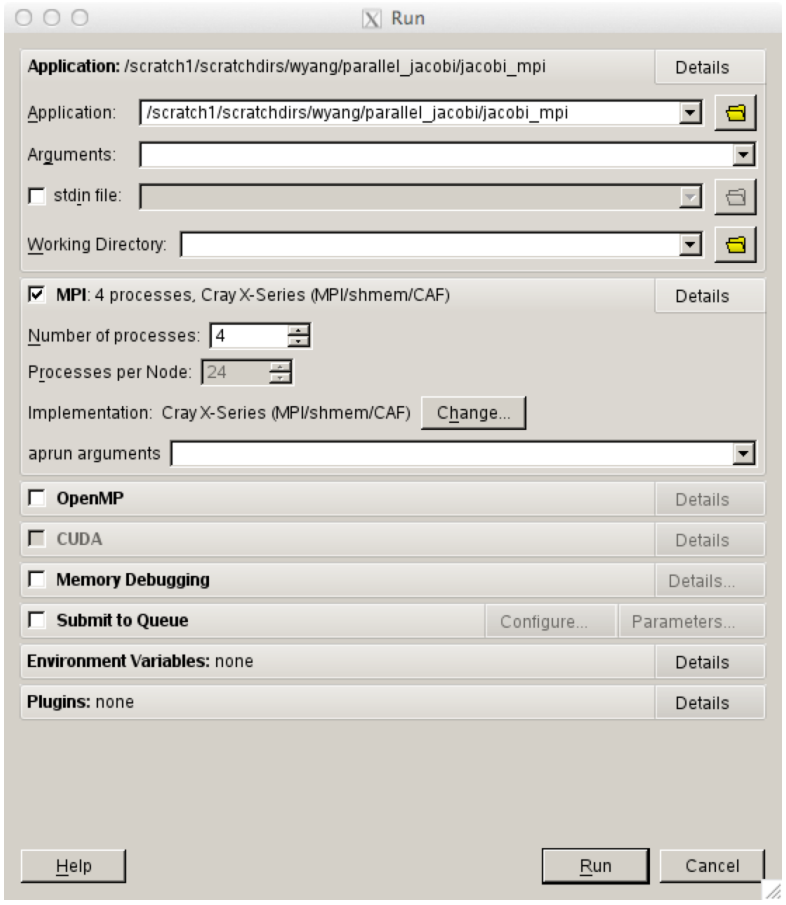
- **GUI-based traditional parallel debuggers**
  - Control program's execution pace by it advance to a desired location
  - Set breakpoints, watchpoints and tracepoints
  - Display the values of variables and expressions, and visualize arrays
    - To check whether the program is executing as expected
  - Memory debugging
  - And more…
- **Works for C, C++, Fortran programs with MPI, OpenMP, pthreads**
  - DDT supports CAF (Coarray Fortran) and UPC (Unified Parallel C), too
- **Maximum application size to use the debuggers at NERSC**
  - DDT: up to 8192 MPI tasks
  - TotalView: up to 512 MPI tasks
  - Licenses shared among users
- **For info**
  - $ALLINEA_TOOLS_DOCDIR/userguide.pdf (after loading the 'allineatools' module)
  - http://www.nersc.gov/users/software/debugging-and-profiling/ddt/
  - http://www.roguewave.com/products/totalview
  - http://www.nersc.gov/users/software/debugging-and-profiling/totalview/

DDT

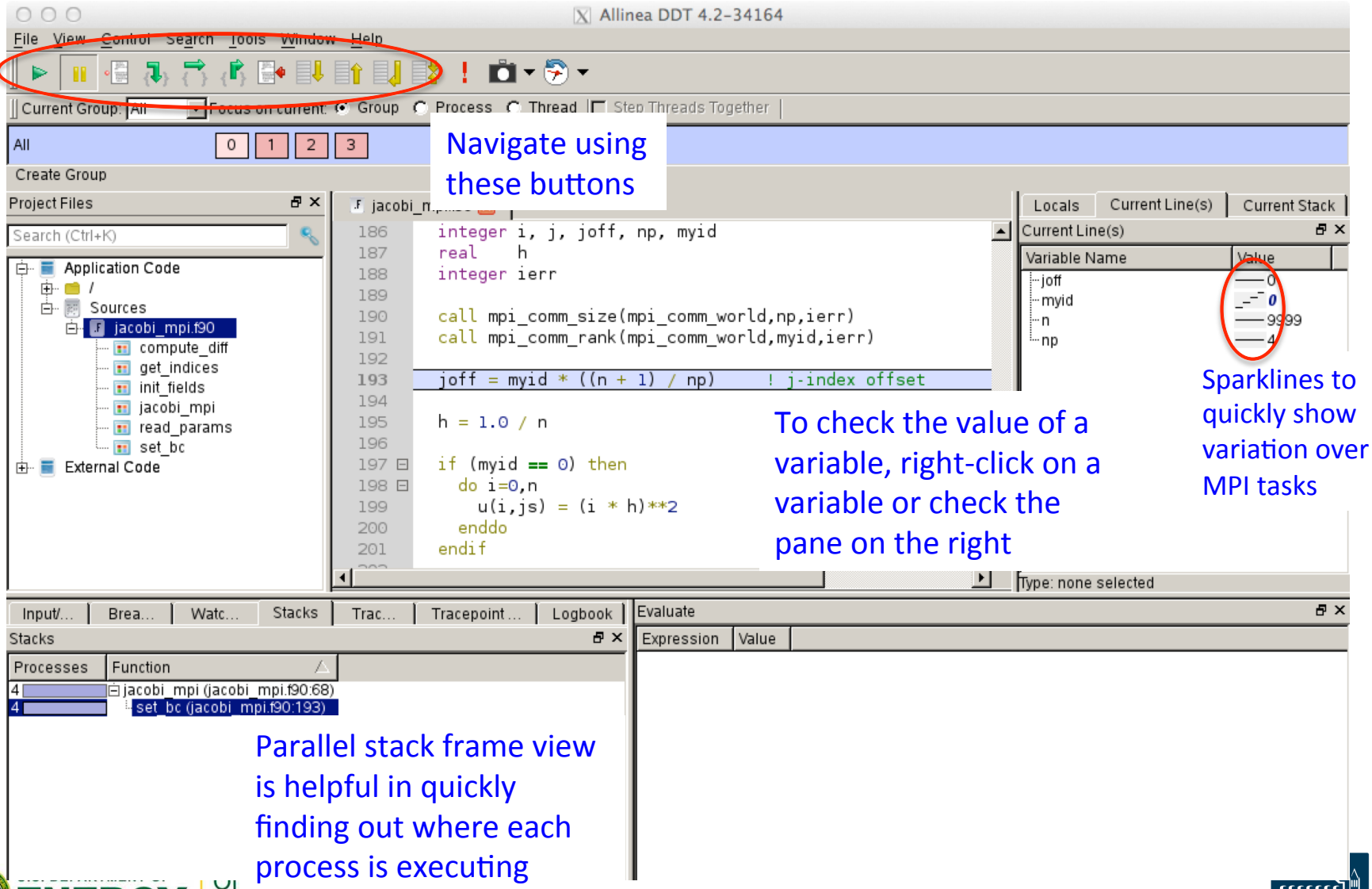
```
% ftn -g -O0 -o jacobi_mpi jacobi_mpi.f90
```
Compile with -g to have debugging symbols
Include -O0 for the Intel compiler

```
% qsub -IV -lmppwidth=24,walltime=30:00 -q debug
```
Start an interactive batch session

```
% cd $PBS_O_WORKDIR
% module load allineatools
% ddt ./jacobi_mpi
```
Load the allineatools module to use DDT
Start DDT

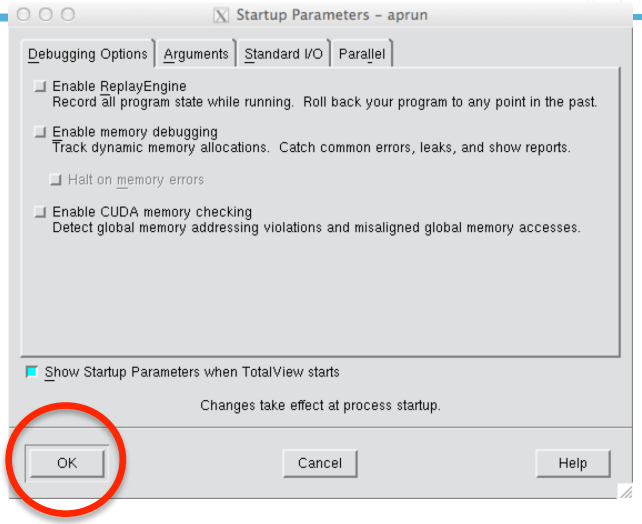


DDT (cont'd)


Allinea DDT 4.2-34164
File View Control Search Tools Window Help
Current Group: All
Focus on current: Group Process Thread Step Threads Together
All 0 1 2 3
Create Group
Project Files
Search (Ctrl+K)
Application Code
/
Sources
jacobi_mpi.f90
compute_diff
get_indices
init_fields
jacobi_mpi
read_params
set_bc
External Code
Navigate using these buttons
186 integer i, j, joff, np, myid
187 real h
188 integer ierr
189
190 call mpi_comm_size(mpi_comm_world,np,ierr)
191 call mpi_comm_rank(mpi_comm_world,myid,ierr)
192
193 joff = myid * ((n + 1) / np) ! j-index offset
194
195 h = 1.0 / n
196
197 if (myid == 0) then
198 do i=0,n
199 u(i,js) = (i * h)**2
200 enddo
201 endif
Locals Current Line(s) Current Stack
Current Line(s)
Variable Name Value
joff 0
myid 0
n 9999
np 4
Sparklines to quickly show variation over MPI tasks
To check the value of a variable, right-click on a variable or check the pane on the right
Type: none selected
Input/... Brea... Watc... Stacks Trac... Tracepoint ... Logbook
Stacks
Processes Function
4 jacobi_mpi (jacobi_mpi.f90:68)
4 set_bc (jacobi_mpi.f90:193)
Parallel stack frame view is helpful in quickly finding out where each process is executing
Evaluate
Expression Value

TotalView

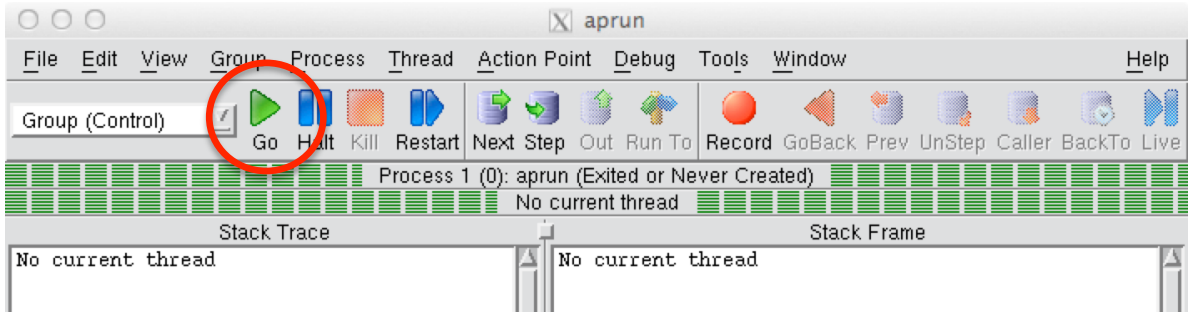
```
% qsub -IV -lmppwidth=24,walltime=30:00 -q debug
% cd $PBS_O_WORKDIR
% module load totalview
% totalview aprun -a -n 4 ./jacobi_mpi
```



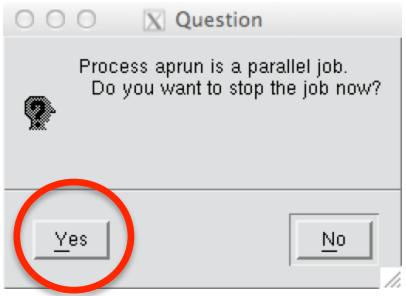
Then,

- Click OK in the 'Startup Parameters - aprun' window

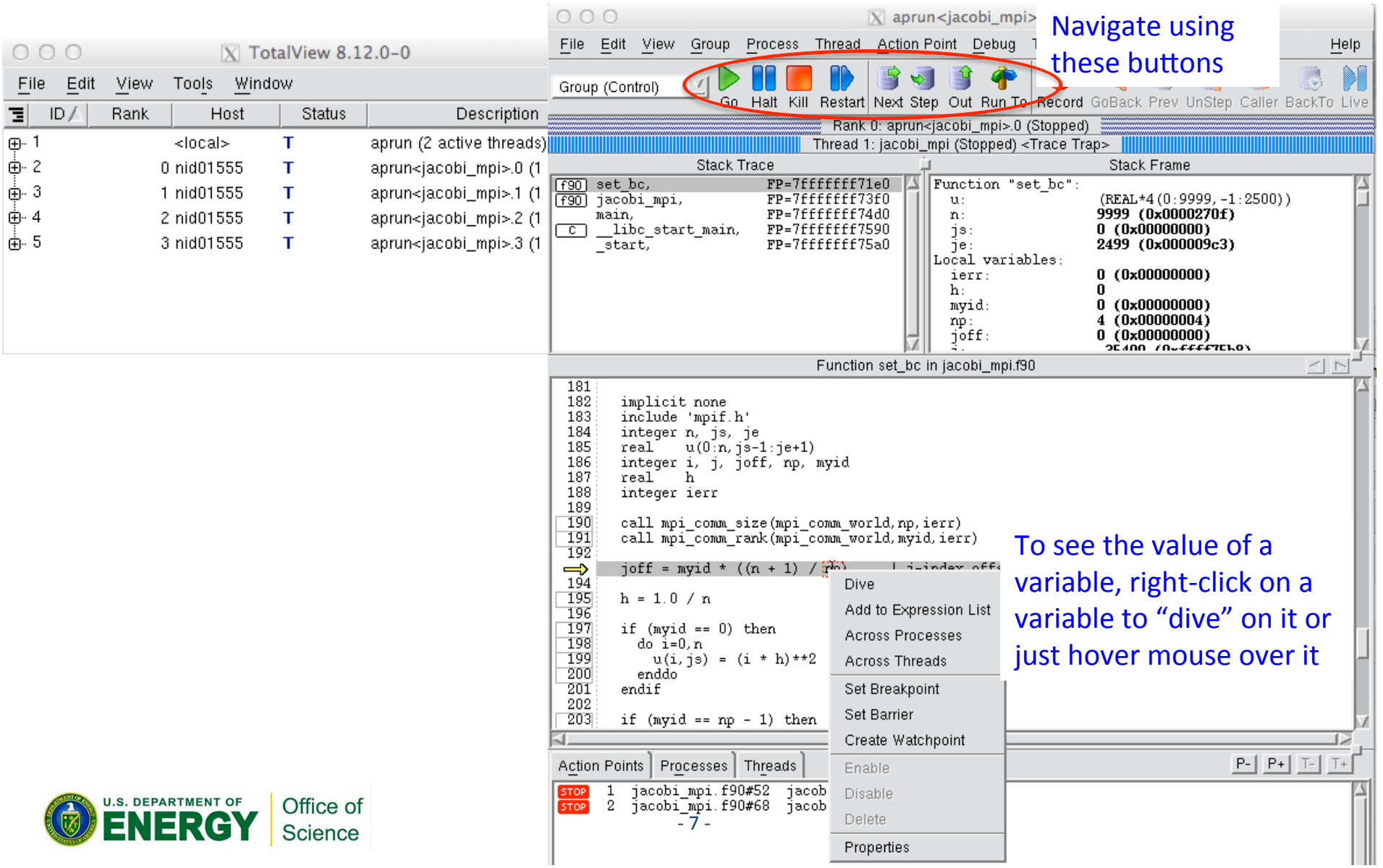
- Click 'Go' button in the main window



- Click 'Yes' to the question 'Process aprun is a parallel job. Do you want to stop the job now?'



TotalView (cont'd)



STAT (Stack Trace Analysis Tool)

- **Gathers stack backtraces (showing the function calling sequences leading up to the ones in the current stack frames) from all (MPI) processes and merges them into a single file (*.dot)**
  - Results displayed graphically as a call tree showing the location in the code that each process is executing and how it got there
  - Can be useful for debugging a hung application
  - With the info learned from STAT, can investigate further with DDT or TotalView
- **Works for MPI, CAF and UPC, but not OpenMP**
- **STAT commands (after loading the 'stat' module)**
  - stat (STAT or stat-cl): invokes STAT to gather stack backtraces
  - statview (STATview or stat-view): a GUI to view the 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
  - https://computing.llnl.gov/code/STAT/stat_userguide.pdf
  - http://www.nersc.gov/users/software/debugging-and-profiling/stat-2/

Hung application with STAT

```
% qstat -f 722272
...
 login_node_id = nid02051
```

Find the MOM node that launched the app.

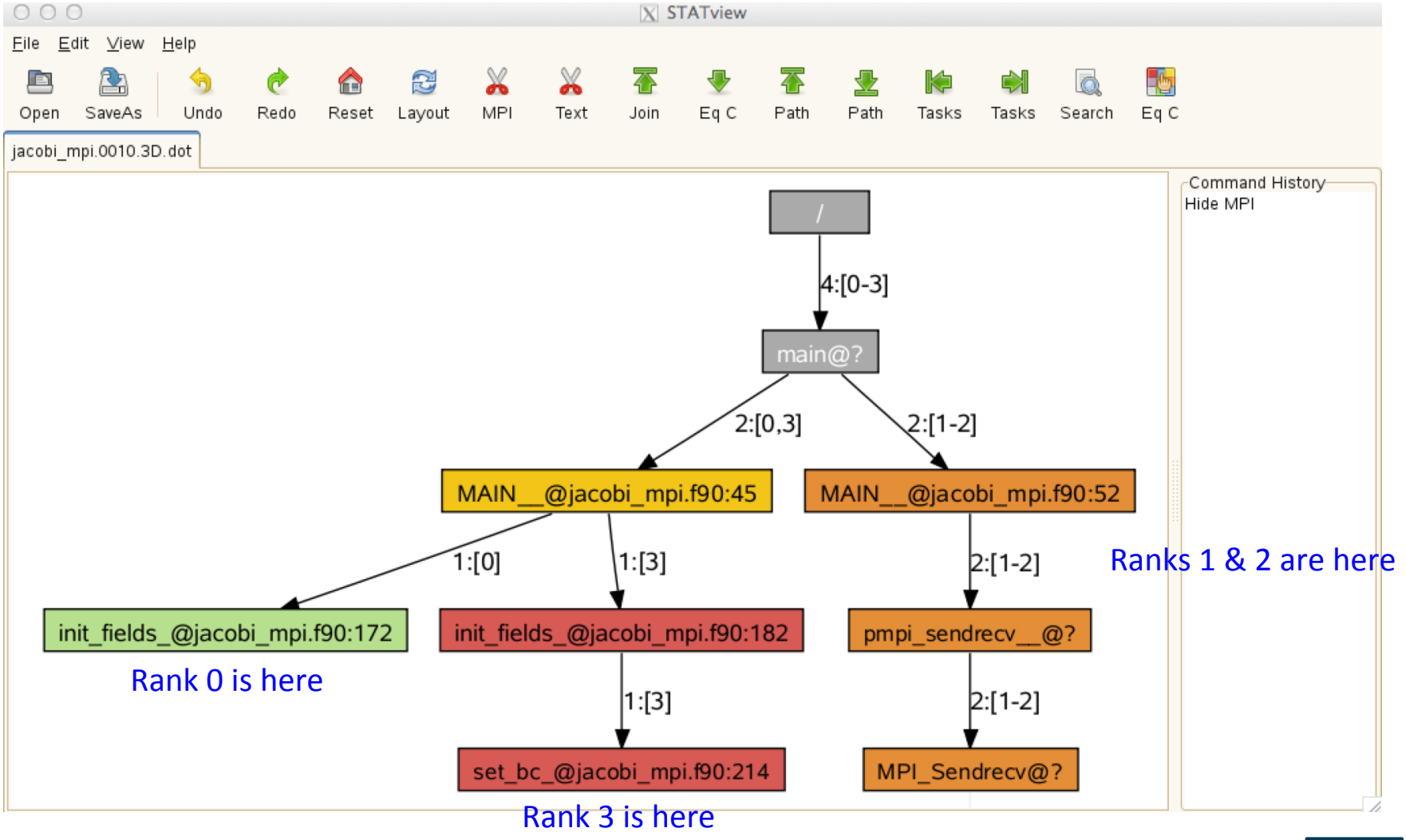
```
% ssh -XY nid02051
% ps -f
```

Log into the MOM node
Find pid

```
UID        PID  PPID  C STIME TTY          TIME CMD
wyang    23953 16045  0 Feb01 pts/0    00:00:00 aprun -n 4 ./jacobi_mpi
wyang    23961 23953  0 Feb01 pts/0    00:00:00 aprun -n 4 ./jacobi_mpi
…
% module load stat
% stat -i 23953
…
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!

Results written to /scratch1/scratchdirs/wyang/parallel_jacobi/stat_results/jacobi_mpi.0010
% ls -l stat_results/jacobi_mpi.0010/*.dot
-rw-r----- 1 wyang wyang 2227 Feb  2 00:09 stat_results/jacobi_mpi.0010/jacobi_mpi.0010.3D.dot
% statview stat_results/jacobi_mpi.0010/jacobi_mpi.0010.3D.dot
```

Run ‘stat’ for the process 10921; -i to get source line numbers
STAT samples stack backtraces a few times

Hung application with STAT (Cont'd)



ATP (Abnormal Termination Processing)

- **ATP gathers stack backtraces from all processes of a failing application**
  - Invokes STAT underneath
  - Output in atpMergedBT.dot and atpMergedBT_line.dot (which shows source code line numbers), which are to be viewed with statview
- **By default, the atp module is loaded on Hopper and Edison, but ATP is *not* enabled; to enable:**
  - setenv ATP_ENABLED 1 # csh/tcsh
  - export ATP_ENABLED=1 # sh/bash/ksh

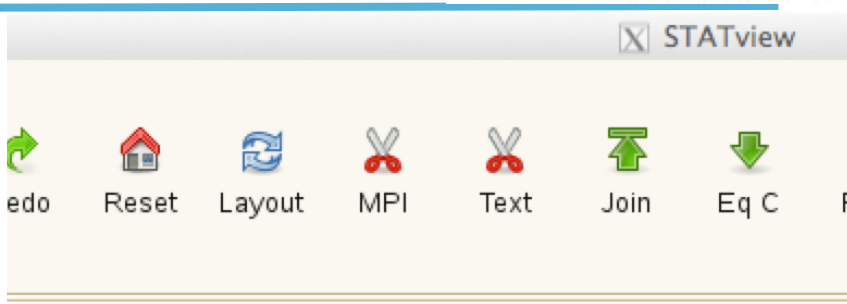
  Include this in your dot file (e.g., .tcshrc.ext) to enable ATP by default
- **Can make core dumps (core.atp.*apid*.*rank*), too, by setting coredumpsize unlimited:**
  - unlimit coredumpsize # for csh/tcsh
  - ulimit -c unlimited # for sh/bash/ksh

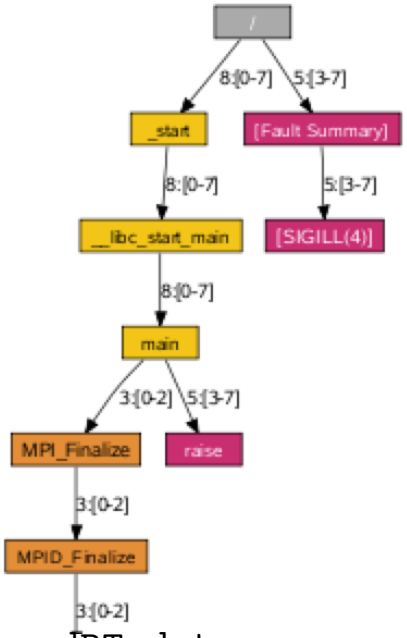
  but they do not represent the exact same moment in time (therefore the location of a failure can be inaccurate)
- **For more info**
  - 'intro_atp' man page
  - http://www.nersc.gov/users/software/debugging-and-profiling/gdb-and-atp/

Running an application with ATP

```
% 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
 aprun -n 8 ./testMPIApp 1 4

% qsub runit
714152.edique02

% cat runit.o714152
…
Application 2885291 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
```

Enable ATP

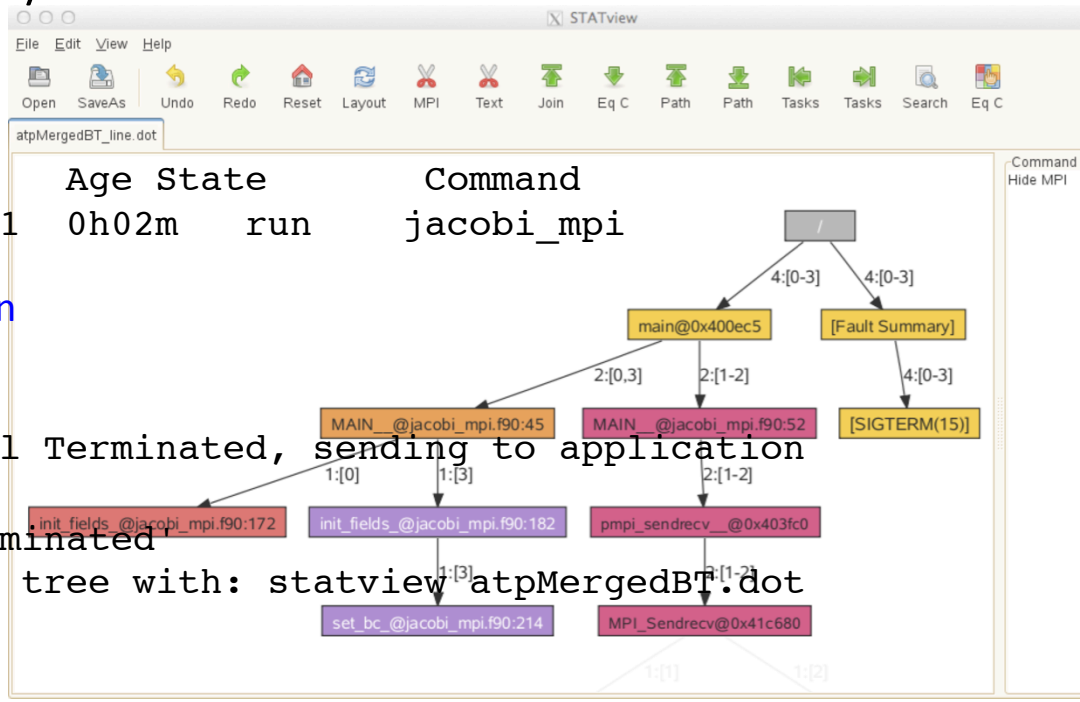




Hung application with ATP

- **Force to generate backtraces from a hung application**
- **For the following to work, must have used**
  - 'setenv ATP_ENABLED 1' in batch script
  - 'setenv FOR_IGNORE_EXCEPTION true' in batch script for Intel Fortran
  - '-f no-backtrace' at compile/link time for GNU Fortran

```
% apstat                    Find apid
…
 Apid   ResId      User   PEs Nodes     Age State         Command
2885161 140092     wyang    4     1   0h02m   run      jacobi_mpi
…
% apkill 2885161           Kill the application
% cat runit.o714080
…
aprun: Apid 2885161: Caught signal Terminated, sending to application
…
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
```



CCDB (Cray Comparative Debugger)

- **Find a bug introduced in a version, by running two versions side by side and comparing data between them**
- **GUI**
- **It runs the command line mode version, lgdb (Cray Line Mode Parallel Debugger), underneath**
- **Supports MPI; doesn't support threading**
- **For info:**
  - ccdb man page and help pages
  - lgdb man page and help pages
  - '*Using the lgdb Comparative Debugging Feature*', http://docs.cray.com/books/S-0042-22/S-0042-22.pdf
  - http://www.nersc.gov/users/software/debugging-and-profiling/ccdb-lgdb/ (work in progress)

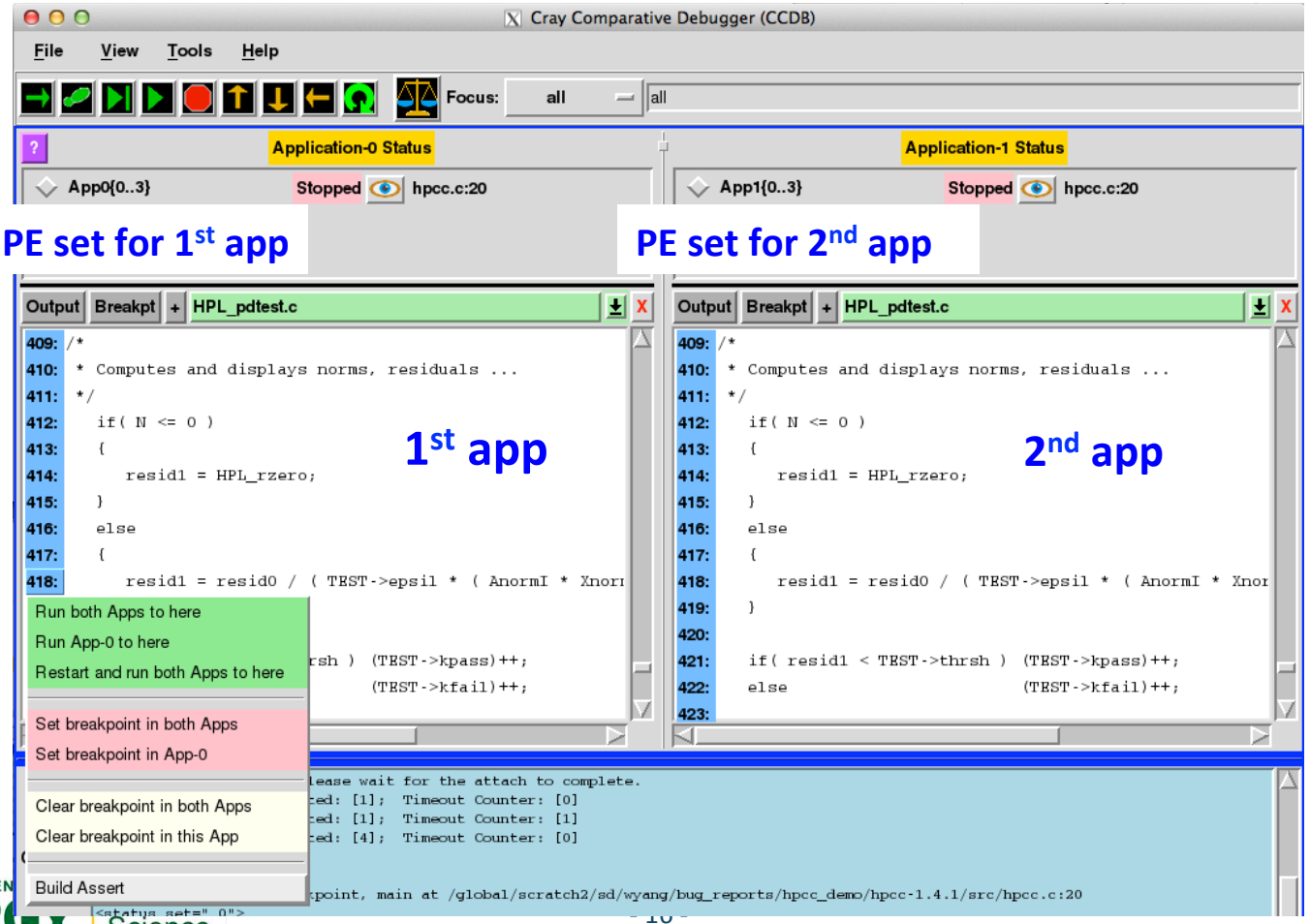
CCDB (Cont'd)

- **To compare something between two applications, need to specify**
  - Variable name
  - Location in a source file
  - How the global data for the variable is distributed over MPI processes
  - Set of MPI processes ("PE set") for the distribution
- **3 entities used in CCDB (and lgdb)**
  - PE set: A set of MPI processes
  - Decomposition: How an array is distributed over PEs
  - Assertion script: A collection of mathematical relationships (e.g., equality) to be tested

Running CCDB

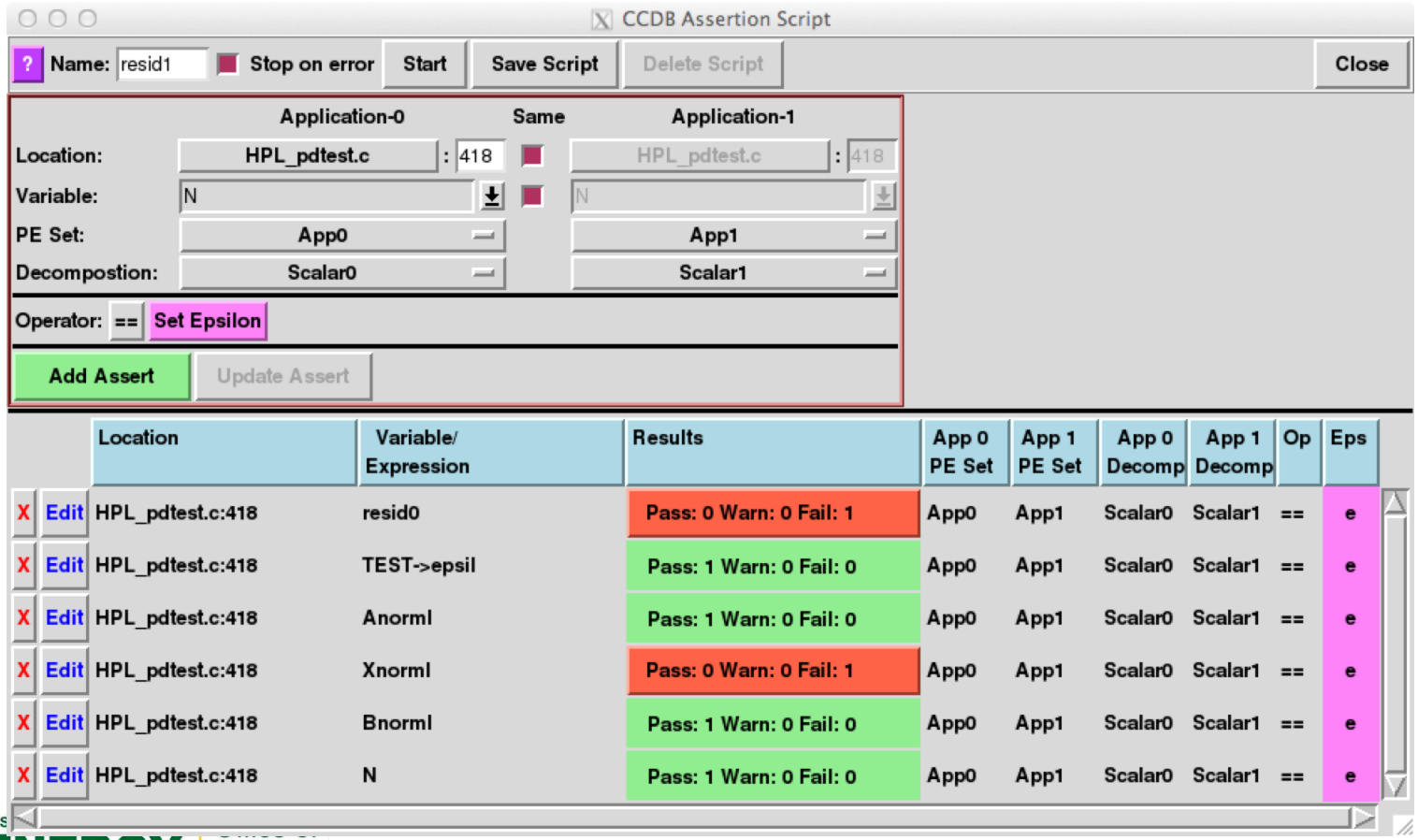
```
% qsub -IV -lmppwidth=48,walltime=30:00 -q debug
% cd $PBS_O_WORKDIR
% module load cray-ccdb
% ccdb
```

Request enough nodes to run two apps. simultaneously



CCDB assertion script

- **This script tests whether the 6 variables have the same values between the applications, at line 418 of HPL_pdtest.c; resid0 and Xnorml don't**



	Location	Variable/ Expression	Results	App 0 PE Set	App 1 PE Set	App 0 Decomp	App 1 Decomp	Op	Eps
X Edit	HPL_pdtest.c:418	resid0	Pass: 0 Warn: 0 Fail: 1	App0	App1	Scalar0	Scalar1	==	e
X Edit	HPL_pdtest.c:418	TEST->epsil	Pass: 1 Warn: 0 Fail: 0	App0	App1	Scalar0	Scalar1	==	e
X Edit	HPL_pdtest.c:418	Anorml	Pass: 1 Warn: 0 Fail: 0	App0	App1	Scalar0	Scalar1	==	e
X Edit	HPL_pdtest.c:418	Xnorml	Pass: 0 Warn: 0 Fail: 1	App0	App1	Scalar0	Scalar1	==	e
X Edit	HPL_pdtest.c:418	Bnorml	Pass: 1 Warn: 0 Fail: 0	App0	App1	Scalar0	Scalar1	==	e
X Edit	HPL_pdtest.c:418	N	Pass: 1 Warn: 0 Fail: 0	App0	App1	Scalar0	Scalar1	==	e

Valgrind

- **Suite of debugging and profiler tools**
- **Tools include**
  - **memcheck**: memory error and memory leaks detection
  - **cachegrind**: a cache and branch-prediction profiler
  - **callgrind**: a call-graph generating cache and branch prediction profiler
  - **massif**, **dhat (exp-dhat)**: heap profilers
  - **helgrind**, **drd**: pthreads error detectors
- **For info:**
  - http://valgrind.org/docs/manual/manual.html

Valgrind's memcheck

```
% qsub -IV -lmppwidth=24,walltime=30:00 -q debug
% cd $PBS_O_WORKDIR
% module load valgrind
% ftn -dynamic -g -O0 memory_leaks.f $VALGRIND_MPI_LINK
% aprun -n 2 valgrind --leak-check=full ./a.out >& report
% awk '/^==/ {print $1}' report | sort -u
==46886==
==46887==
==46888==
==46889==
```

Could have explicitly added '--tool=memcheck'; save res in 'report'

Found four sub-reports, each starting a line with its PID
(--log-file with %p doesn't seem to work properly with aprun…)

- **Out of 4 sub-reports, two are for the application's 2 MPI tasks; let's look at the one for process ID 46888**

```
% awk '/^==46888/ {print}' report
```

Show the result for PID 46888

```
…
==46888== 8,000,000 bytes in 2 blocks are possibly lost in loss record 33 of 37
==46888==    at 0x4C27F9E: malloc (vg_replace_malloc.c:291)
==46888==    by 0x424A93: for_allocate (in /scratch1/scratchdirs/wyang/valgrind/a.out)
==46888==    by 0x408269: sub_bad_ (memory_leaks.f:37)
==46888==    by 0x407DF5: MAIN__ (memory_leaks.f:14)
==46888==    by 0x407D55: main (in /scratch1/scratchdirs/wyang/valgrind/a.out)
…
```

- **Can suppress spurious error messages by using a suppression file (--suppressions=/path/to/directory/file)**

Valgrind's cachegrind

```
% ftn -g -O2 memory_leaks.f
% aprun -n 2 valgrind --tool=cachegrind ./a.out
% ls -lrt
…
-rw------- 1 wyang wyang  14112 Jan 31 08:55 cachegrind.out.46848
-rw------- 1 wyang wyang  34532 Jan 31 08:55 cachegrind.out.46849
-rw------- 1 wyang wyang  33926 Jan 31 08:55 cachegrind.out.46850
-rw------- 1 wyang wyang  15251 Jan 31 08:55 cachegrind.out.46847
```

Use -g but keep the usual optimization level

- **It generates 4 separate reports just like before, and two are for the application's 2 MPI tasks; let's look at the one for process ID 46849**

```
% cg_annotate cachegrind.out.46849
--------------------------------------------------------------------------------
I1 cache:         32768 B, 64 B, 8-way associative
D1 cache:         32768 B, 64 B, 8-way associative
LL cache:         31457280 B, 64 B, 30-way associative
Command:          ./a.out
Data file:        cachegrind.out.46849
…
--------------------------------------------------------------------------------
         Ir I1mr ILmr          Dr     D1mr    DLmr          Dw     D1mw     DLmw  file:function
--------------------------------------------------------------------------------
220,000,000    4    4 28,000,000       12       2 20,000,000        0        0  ???:for_random_number_single
 25,250,536   43   40    500,069  250,016       2  8,000,073  250,020  187,498  /some/path/
memory_leak.f:MAIN__
…
```

Valgrind's callgrind

```
% ftn -g -O2 memory_leaks.f
% aprun -n 2 valgrind --tool=callgrind ./a.out
% ls -lrt
…
-rw------- 1 wyang wyang  38527 Feb  1 13:16 callgrind.out.43223
-rw------- 1 wyang wyang 117581 Feb  1 13:17 callgrind.out.43225
-rw------- 1 wyang wyang 124967 Feb  1 13:17 callgrind.out.43224
-rw------- 1 wyang wyang  47409 Feb  1 13:17 callgrind.out.43222
```

Use -g but keep the usual optimization level

- It generates 4 separate reports just like before, and two are for the application's 2 MPI tasks; let's look at the one for process ID 43224

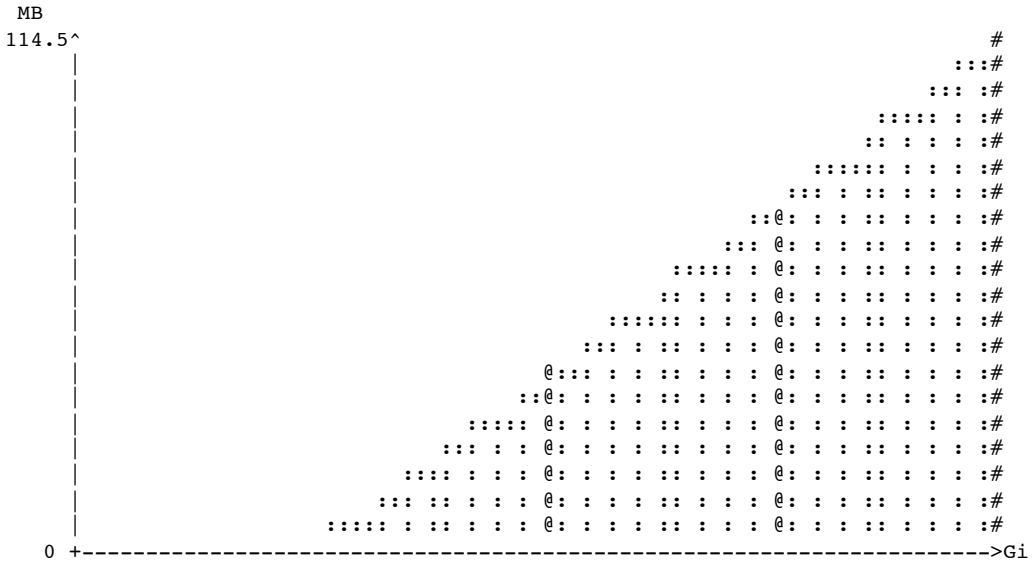
```
% callgrind_annotate callgrind.out.43224 memory_leaks.f
…
--------------------------------------------------------------------------------
-- User-annotated source: memory_leaks.f
--------------------------------------------------------------------------------
…
 .        subroutine sub_ok(val,n)      ! no memory leak
          .        integer n
          .        real val
         40        real, allocatable :: a(:)
        240        allocate (a(n))
      2,425  => ???:for_alloc_allocatable (10x)
        810  => ???:for_check_mult_overflow64 (10x)
50,000,070        call random_number(a)
550,000,000  => ???:for_random_number_single (10000000x)
 3,125,926        val = val + sum(a)
          .  !     deallocate(a)                 ! ok not to deallocate
        180        end
      1,379  => ???:for_dealloc_allocatable (10x)
…
```

Valgrind's heap profilers

- **massif and exp-dhat for profiling heap memory usage**

```
% ifort -g -O2 memory_leaks_serial.f
% valgrind --tool=massif ./a.out
% ls -lrt
…
-rw-------  1 wyang wyang    12008 Feb  1 12:40 massif.out.1384
% ms_print massif.out.1384
```

Doesn't seem to work with compiler wrappers at the moment, so let's try a serial code




```
…
--------------------------------------------------------------------------------
  n        time(i)         total(B)   useful-heap(B) extra-heap(B)    stacks(B)
--------------------------------------------------------------------------------
…
 67  2,414,128,664      120,000,280      120,000,032           248            0
```

@ for detailed snapshot where detailed info is provided

for peak snapshot where the peak heap usage is

This example strongly suggests memory leaks

Thank you.