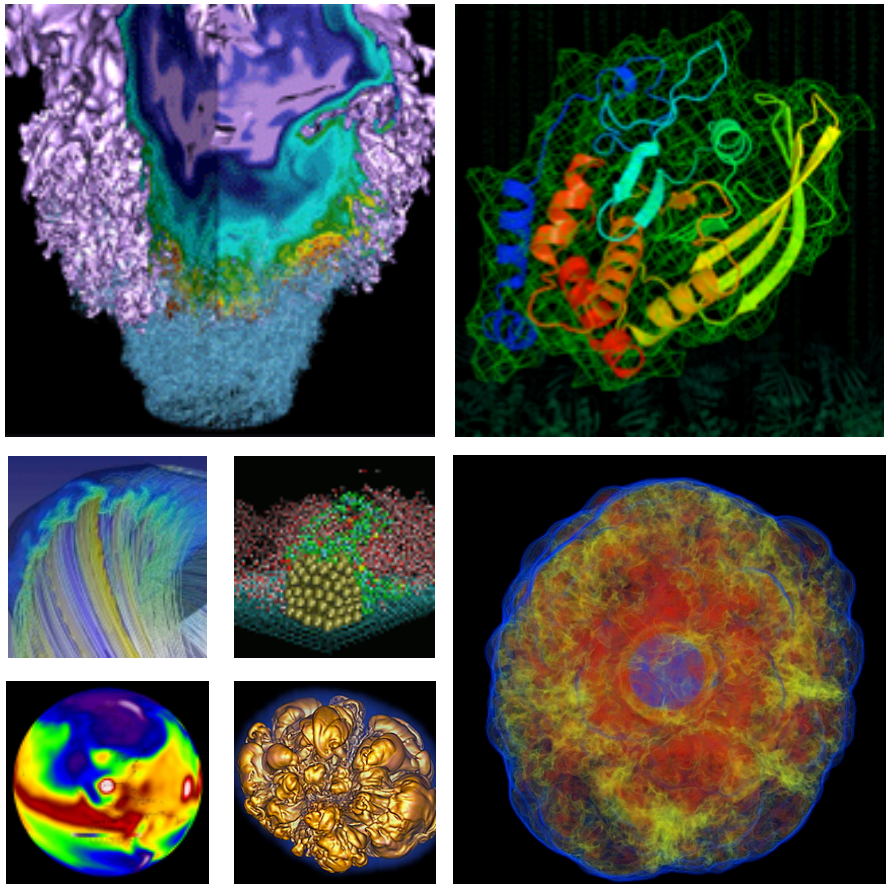
Parallel Debugging Tools

New User Training 2017



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Debugging

- **Why debugging?**
  - Your program crashes for a unknown reason
  - Your program gives wrong results
- **How to find coding errors?**
  - Using print statements
    - Insert print statements in strategic locations
    - Can be difficult to know where the code fails and whether variables have incorrect values
    - Recompile whenever you make a change - tedious and time-consuming
  - Using debuggers
    - You compile only once (generally)
    - Can point to where the code fails
    - They let you control execution pace of your program and examine variables
    - Useful tools can aid your detective work greatly
      - Visualization and statistics
      - Memory debugging
      - MPI message queue

Parallel debuggers on Cori and Edison

- **Parallel debuggers with a graphical user interface**
  - DDT (Distributed Debugging Tool)
  - TotalView
- **Specialized debuggers on Cori 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
- **Valgrind**
  - Suite of debugging and profiling tools

DDT and TotalView

- **GUI-based traditional parallel debuggers**
  - Intuitive and simple to use; many useful tools
  - Allow to control program's execution pace and, sometimes, execution path
    - Set breakpoints, watchpoints and tracepoints
  - Display the values of variables and expressions, and visualize arrays
    - Check whether the program is executing as expected
  - Memory debugging
  - Message queue feature **NOT** working with Cray MPI
- **Works for C, C++, Fortran programs with MPI, OpenMP, pthreads**
  - DDT supports CAF (Coarray Fortran) and UPC (Unified Parallel C), too
- **Maximum application size for the debuggers at NERSC**
  - DDT: up to 4096 MPI tasks on Cori (Haswell and KNL) and Edison
  - TotalView: up to 512 MPI tasks on Cori (Haswell) and Edison
  - Licenses shared among users and machines
- **For info**
  - https://www.allinea.com/products/ddt
  - 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/

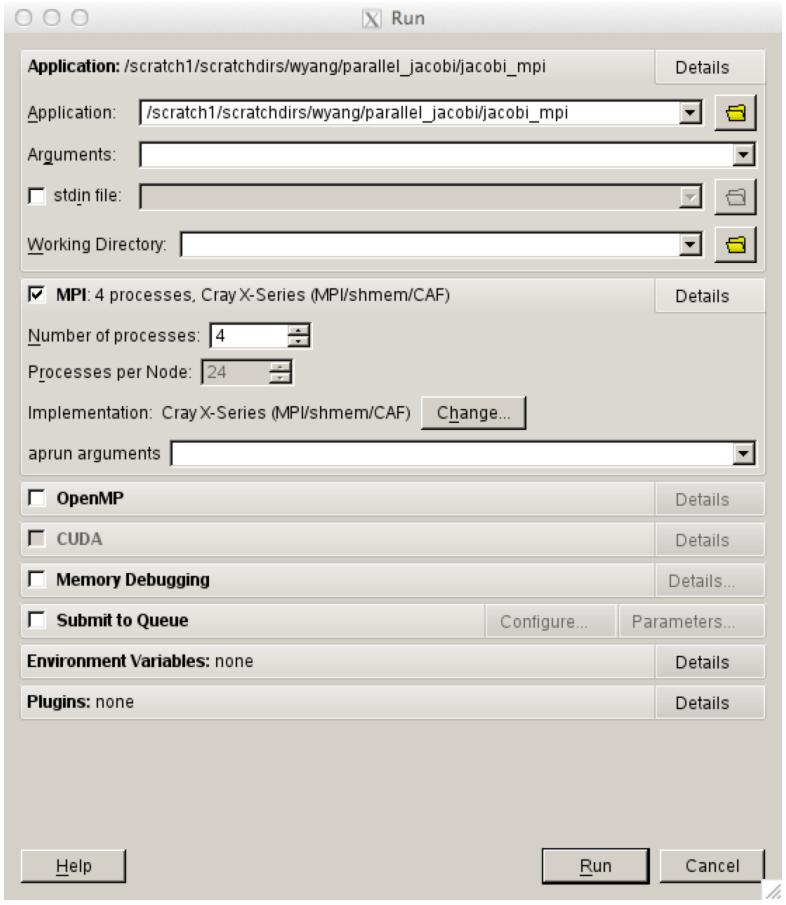
How to build and run with DDT

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

```
$ salloc -N 1 -t 30:00 -p debug -C knl,quad,cache
```
Start an interactive batch session

```
$ module load allineatools
```
Load the allineatools module to use DDT

```
$ ddt ./jacobi_mpi
```
Start DDT



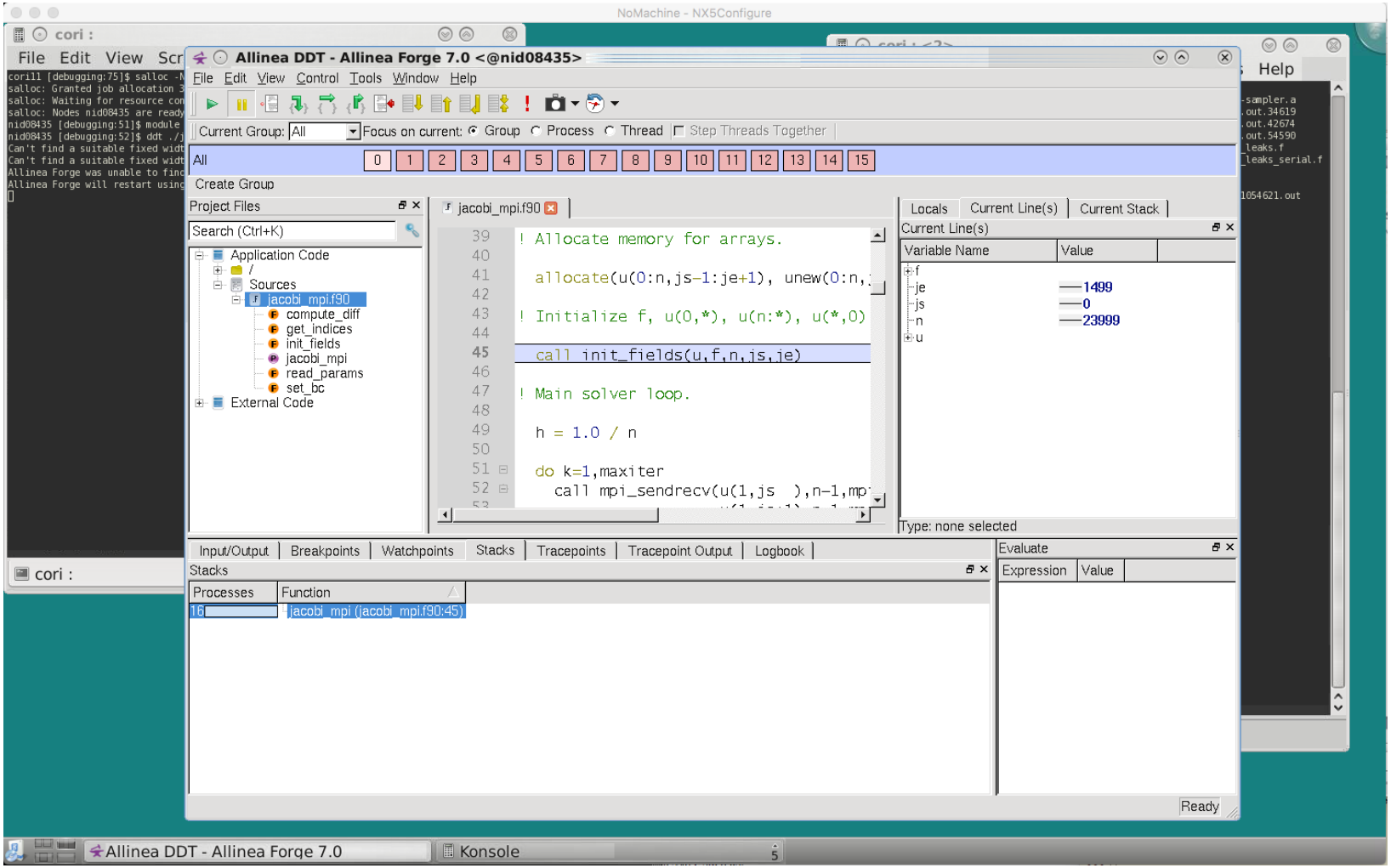
The module name will change to 'forge' for future versions

If you are far away from NERSC

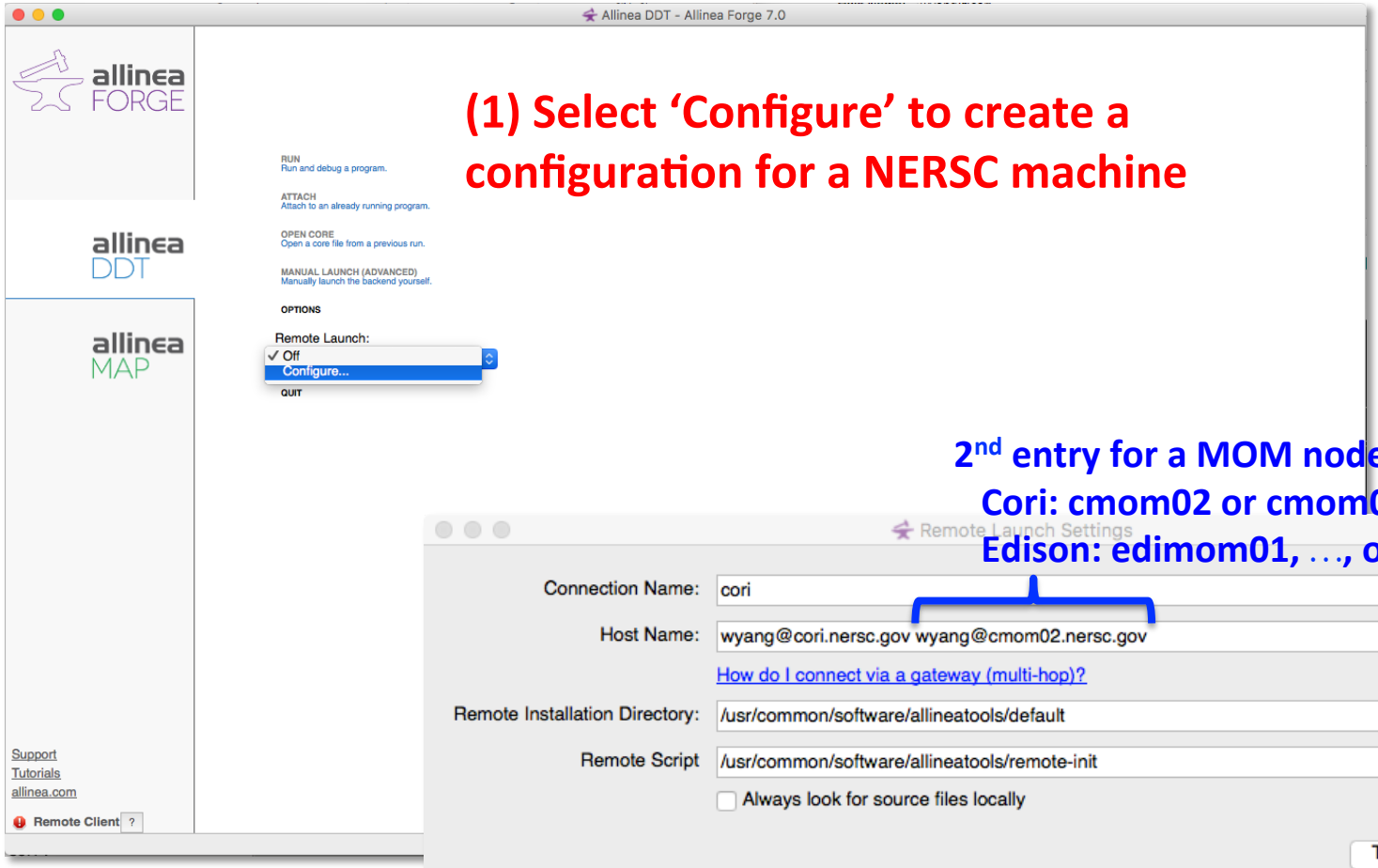
- **Remote X window application (GUI) over network: slow response**

- **Two solutions**
  - Use NX to improve the speed
    - Works with any X window applications
    - https://www.nersc.gov/users/network-connections/using-nx/ (general)
    - http://portal.nersc.gov/project/mpccc/nx/NX_Tutorial/Start_Over.html (installation and quick user guide)
  - Use Allinea Forge remote client
    - Runs on your desktop/laptop
    - Submit a debugging batch job from a NERSC machine and make the client **reverse connect** to the job
    - Displays results in real time
    - No license file required on your local desktop/laptop
    - http://www.allinea.com/products/forge/download (downloading remote clients)

Using NX


NoMachine - NX5Configure
cori :
Allinea DDT - Allinea Forge 7.0 <@nid08435>
File Edit View Control Tools Window Help
Current Group: All
Focus on current: Group Process Thread
Step Threads Together
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
jacobi_mpi.f90
! Allocate memory for arrays.
allocate(u(0:n,js-1:je+1), unew(0:n,
! Initialize f, u(0,*), u(n:*), u(*,0)
call init_fields(u,f,n,js,je)
! Main solver loop.
h = 1.0 / n
do k=1,maxiter
call mpi_sendrecv(u(1,js),n-1,mp
Locals
Current Line(s)
Current Stack
Current Line(s)
Variable Name
Value
f
je
1499
js
0
n
23999
u
Type: none selected
Input/Output
Breakpoints
Watchpoints
Stacks
Tracepoints
Tracepoint Output
Logbook
Stacks
Processes
Function
16
jacobi_mpi (jacobi_mpi.f90:45)
Evaluate
Expression
Value
Ready
Allinea DDT - Allinea Forge 7.0
Konsole

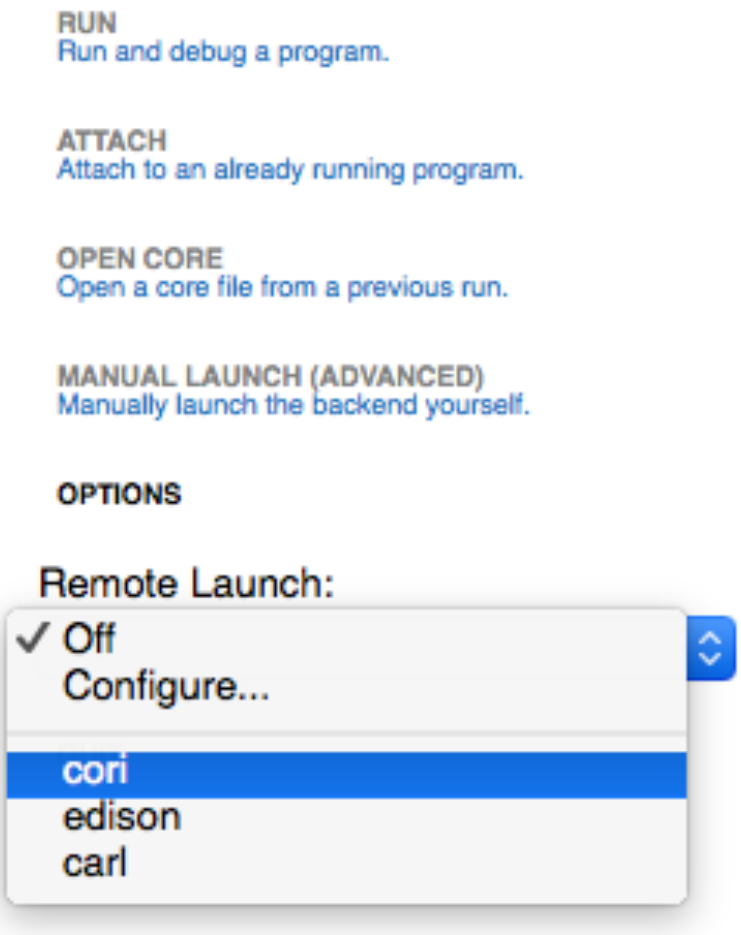
Using Allinea remote client



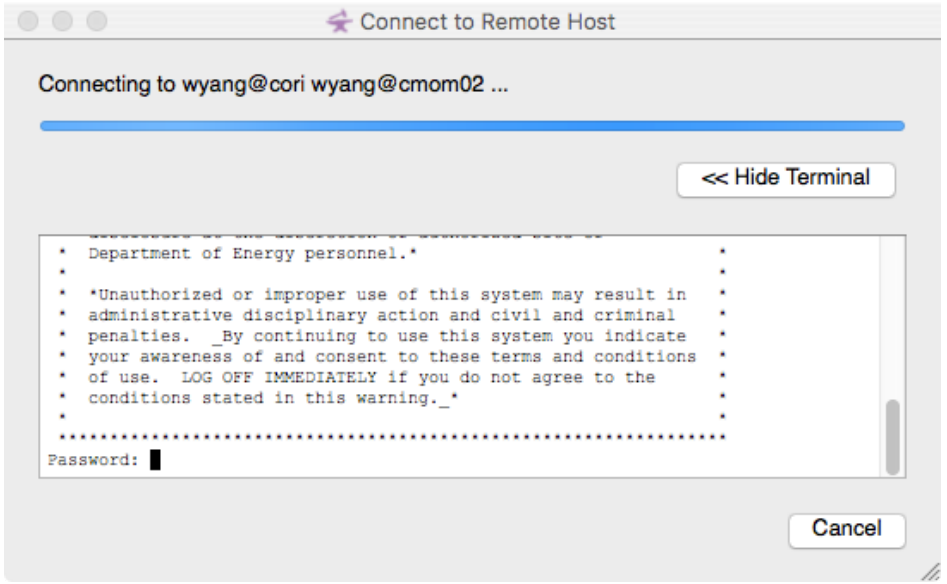
Note that the paths will change for future versions

Using Allinea remote client (Cont'd)

(3) Select a machine



(4) Enter the NIM password

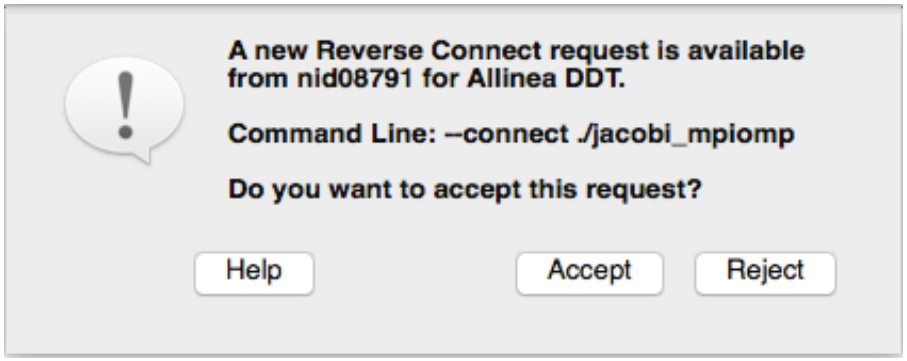


Using Allinea remote client (Cont'd)

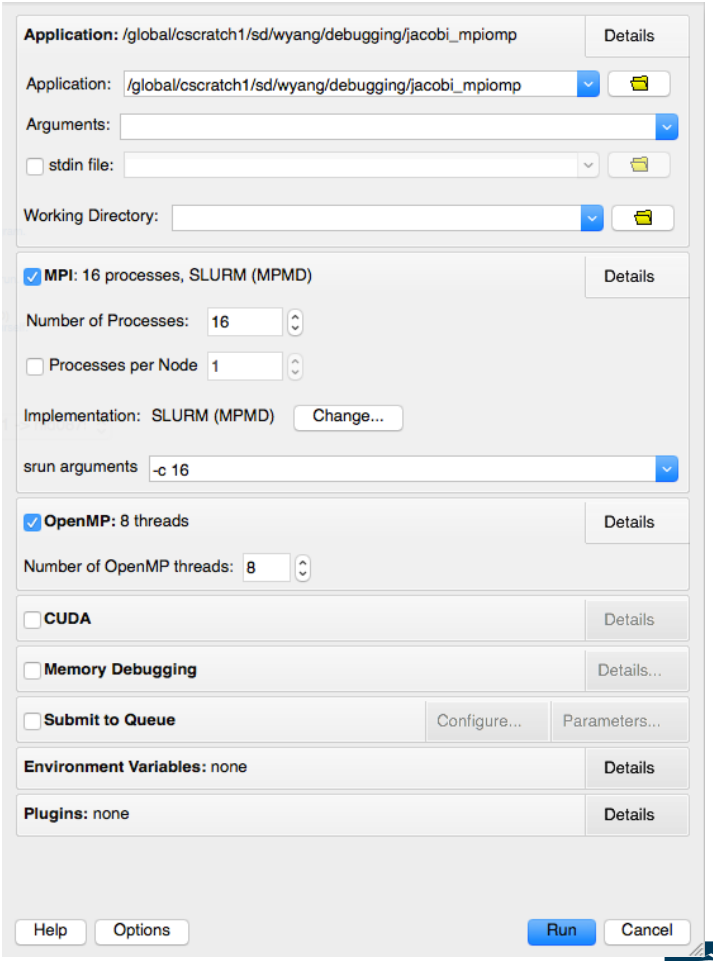
(5) Submit a batch job on a NERSC machine and start DDT

```
$ salloc -N 1 -t 30:00 -p debug -C knl
...
$ module load allineatools
$ ddt --connect ./jacobi_mpiomp
```

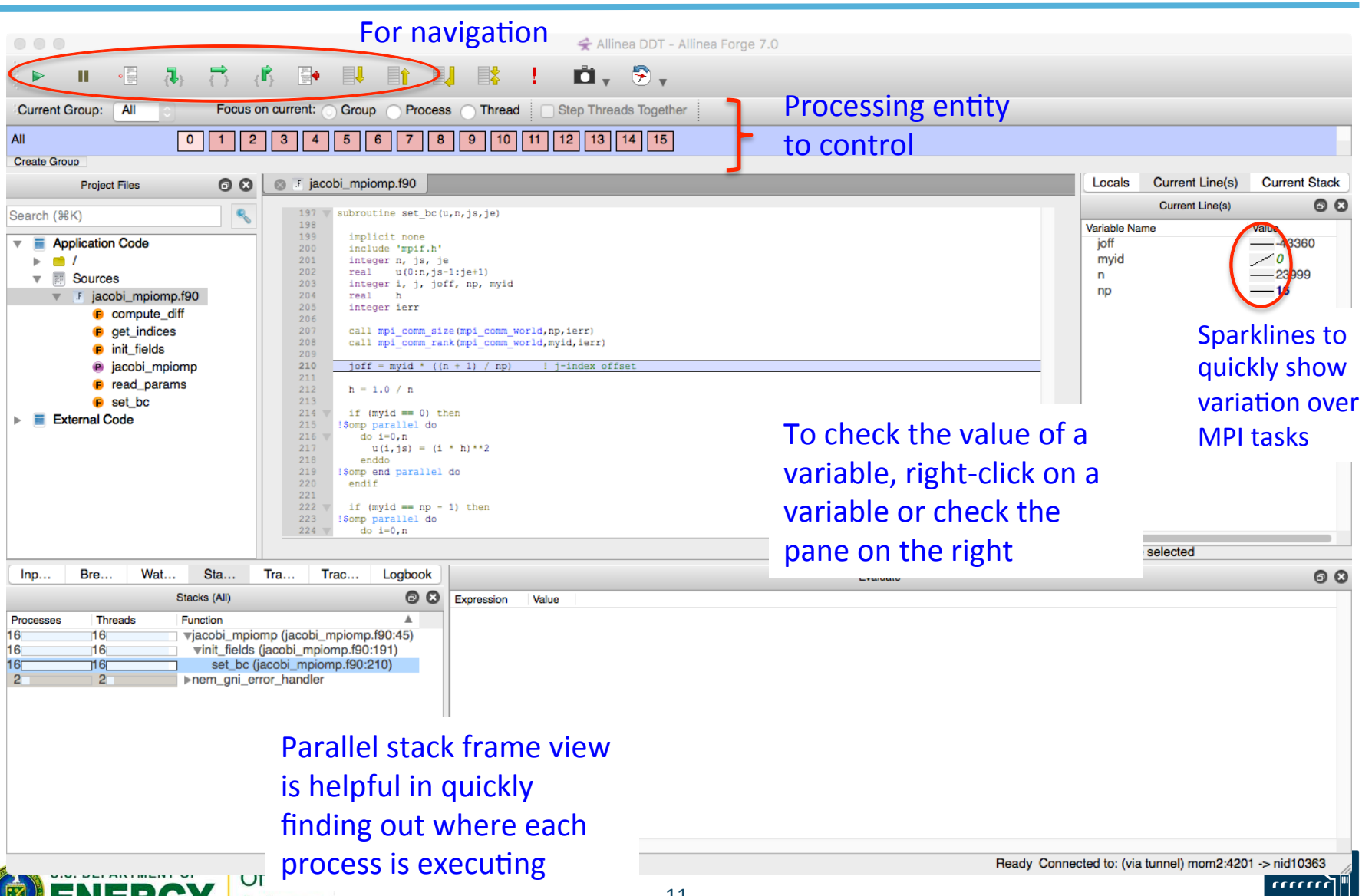
(6) Accept the request



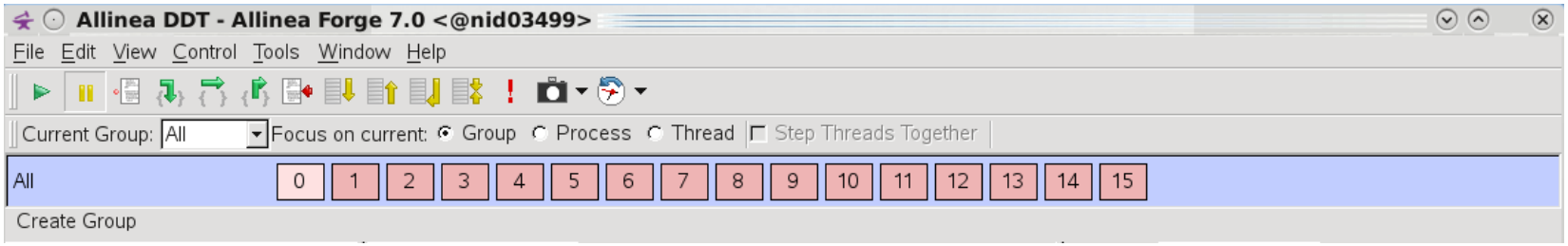
(7) Set parameters and run



DDT window


For navigation
Allinea DDT - Allinea Forge 7.0
Current Group: All
Focus on current: Group Process Thread
Step Threads Together
All
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Create Group
Processing entity to control
Project Files
Search (⌘K)
Application Code
/
Sources
jacobi_mpiomp.f90
compute_diff
get_indices
init_fields
jacobi_mpiomp
read_params
set_bc
External Code
jacobi_mpiomp.f90
subroutine set_bc(u,n,js,je)
implicit none
include 'mpif.h'
integer n, js, je
real u(0:n,js-1:je+1)
integer i, j, joff, np, myid
real h
integer ierr
call mpi_comm_size(mpi_comm_world,np,ierr)
call mpi_comm_rank(mpi_comm_world,myid,ierr)
joff = myid * ((n + 1) / np) ! j-index offset
h = 1.0 / n
if (myid == 0) then
!$omp parallel do
do i=0,n
u(i,js) = (i * h)**2
enddo
!$omp end parallel do
endif
if (myid == np - 1) then
!$omp parallel do
do i=0,n
Locals
Current Line(s)
Current Stack
Current Line(s)
Variable Name
joff
myid
n
np
0
23999
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 MPI tasks
Inp… Bre… Wat… Sta… Tra… Trac… Logbook
Stacks (All)
Processes
Threads
Function
jacobi_mpiomp (jacobi_mpiomp.f90:45)
init_fields (jacobi_mpiomp.f90:191)
set_bc (jacobi_mpiomp.f90:210)
nem_gni_error_handler
Expression
Value
Parallel stack frame view is helpful in quickly finding out where each process is executing
Ready Connected to: (via tunnel) mom2:4201 -> nid10363

Navigation



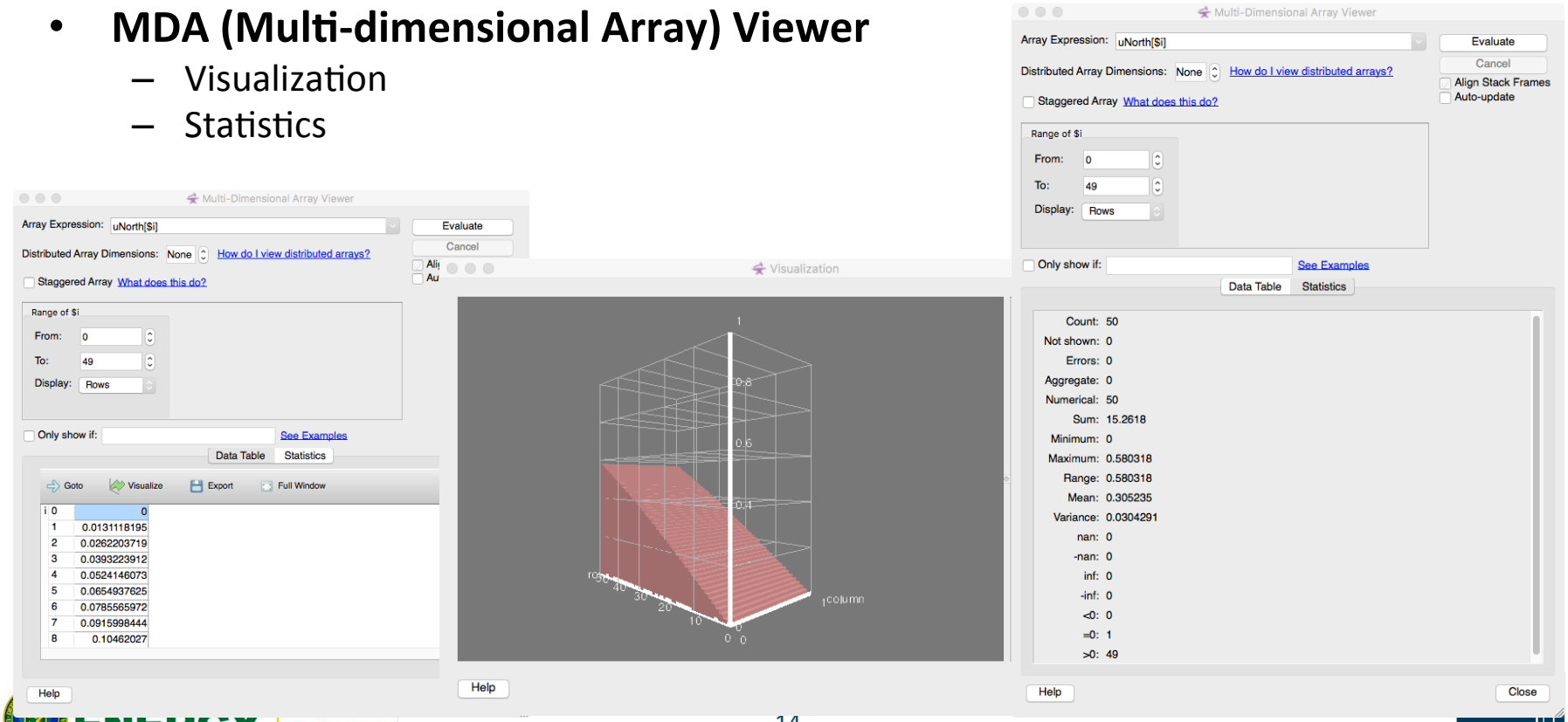
- **Play/Continue**
- **Pause**
- **Add Breakpoint**
- **Step Into**
  - To next line; if it's a function call, enter the function
- **Step Over**
  - To next line in the current stack frame even if it's a function call
- **Step Out**
  - Return to the caller function
- **Run To Line**

Breakpoints, watchpoints and tracepoints

- **Breakpoint**
  - Stops execution when a selected line (breakpoint) is reached
  - Double click on a line to create one; there are other ways, too
- **Watchpoints for variables or expressions**
  - Stops when a variable or an expression changes its value
- **Traceponits**
  - When reached, prints what lines of codes is being executed and the listed variables
- **Can add a condition for an action point**
  - Useful inside a loop
- **Can be active or inactive**

Many ways to check variables

- Right click on a variable for a quick summary
- Variable pane
- Evaluate pane
- Display variable values over processes (Compare across processes) or threads (Compare across threads)
- MDA (Multi-dimensional Array) Viewer
  - Visualization
  - Statistics



Memory debugging

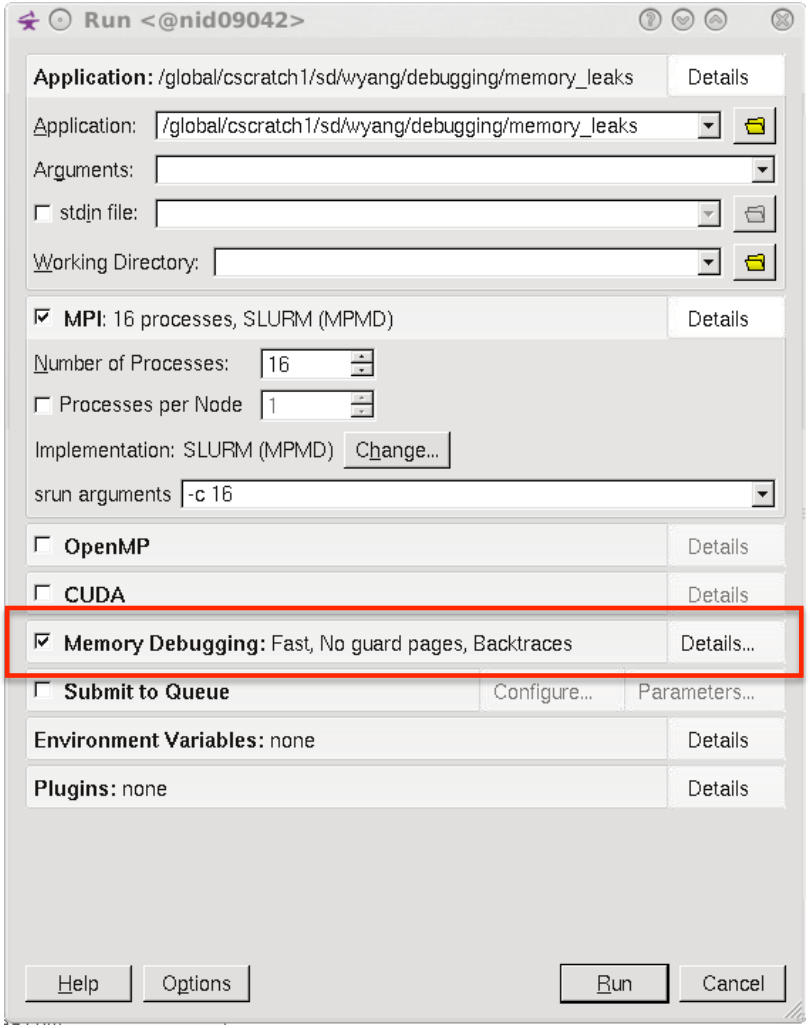
- **Why?**
  - To detect memory leaks
  - To catch out-of-bound array references
  - To catch other memory errors (“double free”, etc.)
  - To see memory usage

- **For a statically-linked executable**
  - For non-threaded code

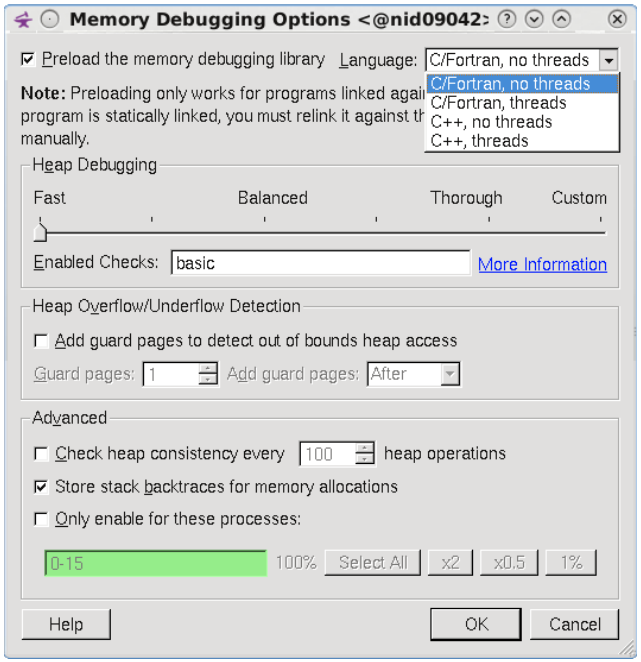
```
$ ftn -c -g -O0 myprog.f
$ static_linking_ddt_md ftn -o myprog myprog.o
#     instead of        ftn -o myprog myprog.o
```

  - **`static_linking_ddt_md_th`** for threaded program
  - Similarly for C and C++ codes
  - static_linking_ddt_md and static_linking_ddt_md_th are utility scripts provided by NERSC
- **For a dynamically-linked executable, build as usual**

Enabling memory debugging



When you click 'Details…'



- **For a dynamically-linked binary only**
  - Check 'Preload the memory debugging library'
  - Select the appropriate one from the 'Language' pull-down menu
- **Adding guard pages (default: 4 KB) before *or* after memory blocks for detecting out-of-bound heap array references**

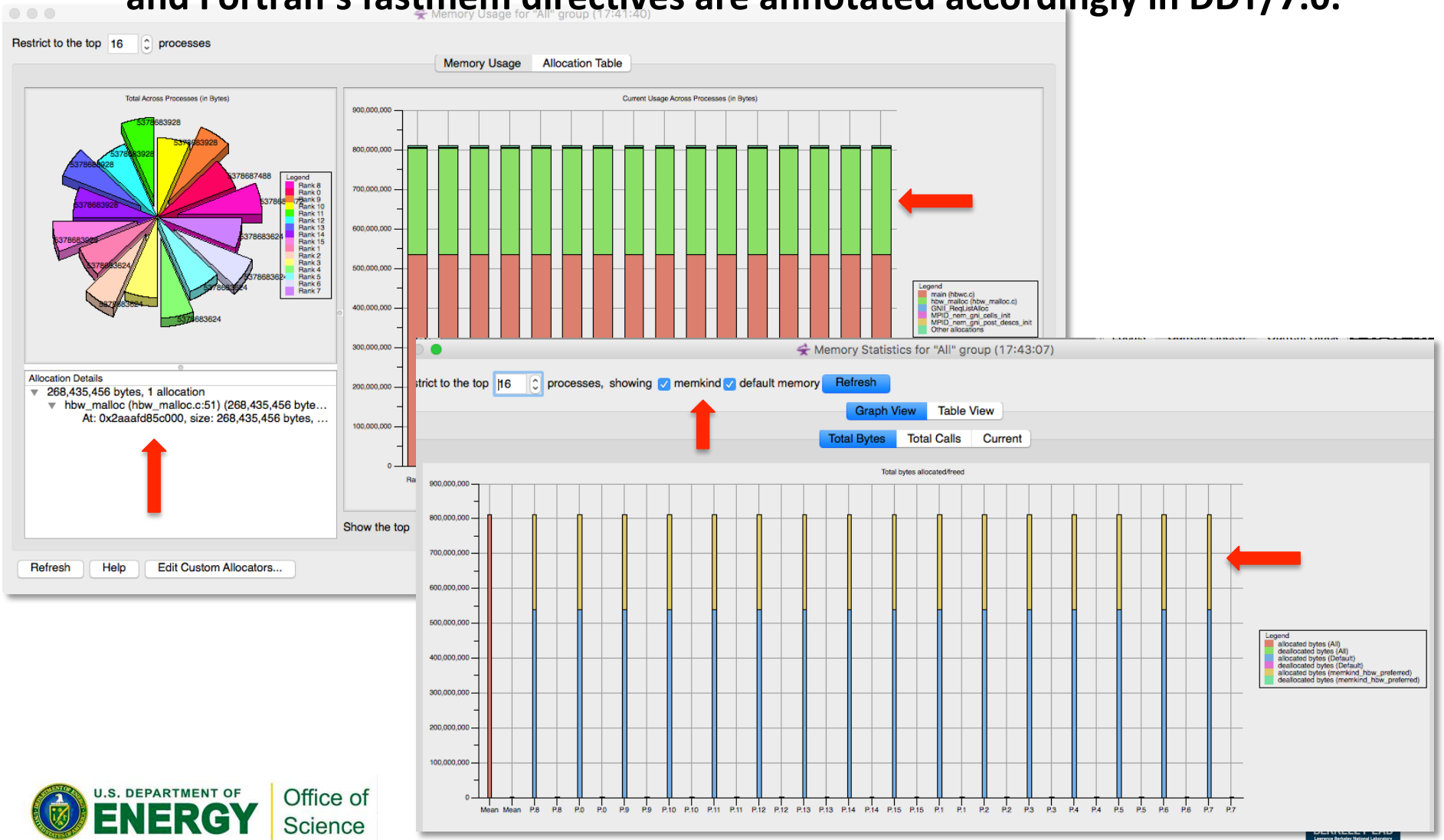
Memory debugging – Overall Memory Stats

Tools > Overall Memory Stats

memory_leaks.f from NERSC DDT web page

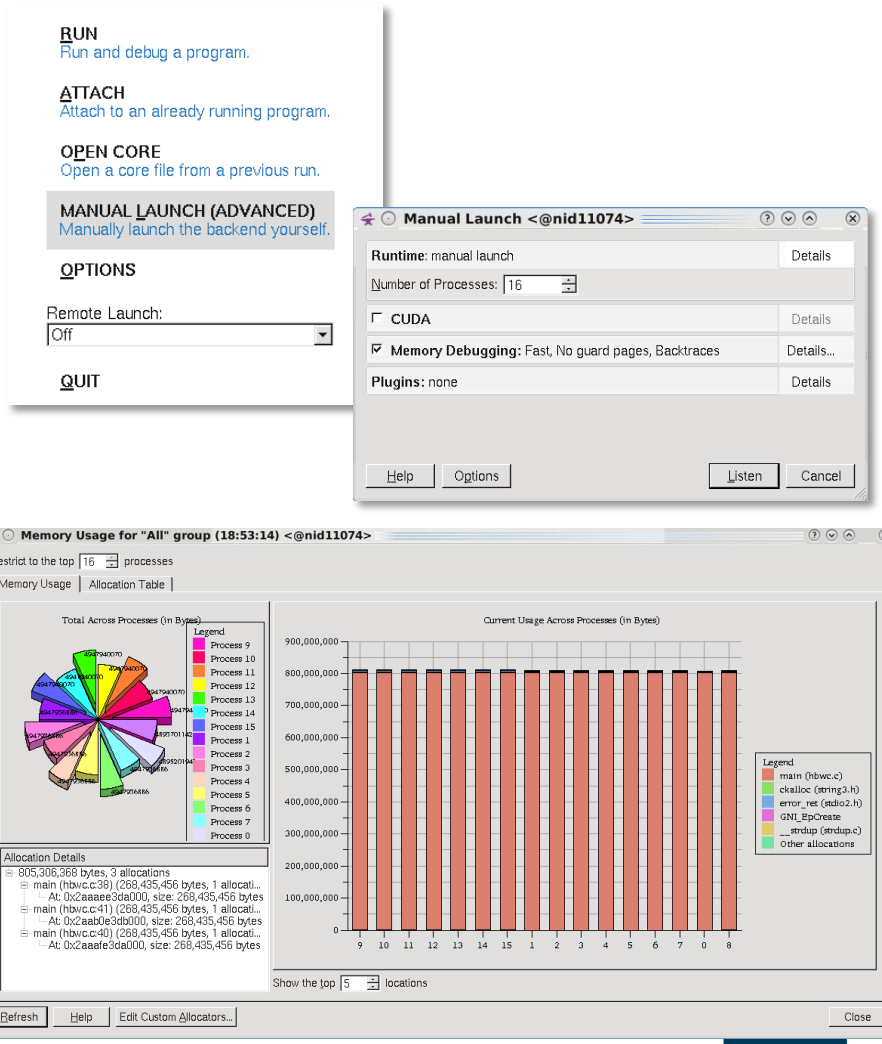
KNL MCDRAM usage on Cori

- **Memory blocks allocated in MCDRAM with memkind's hbw_malloc calls and Fortran's fastmem directives are annotated accordingly in DDT/7.0.**



KNL MCDRAM usage on Cori (Cont'd)

- **With numactl**
  - In an interactive batch job:
    1. Run ddt in background
       ```
       $ ddt &
       ```
    2. Select 'MANUAL LAUNCH (ADVANCED)'
    3. Set run parameters and check 'Memory Debugging'
    4. Click 'Listen'
    5. Run a srun command:
       ```
       $ srun -n … numactl \
         --preferred=1 \
         allinea-client ./a.out
       ```
  - **--mem_bind=**…: simply use srun's --**mem_bind=map_mem:**… instead
  - MCDRAM usage is not properly annotated in version 7.0. Reported to Allinea.

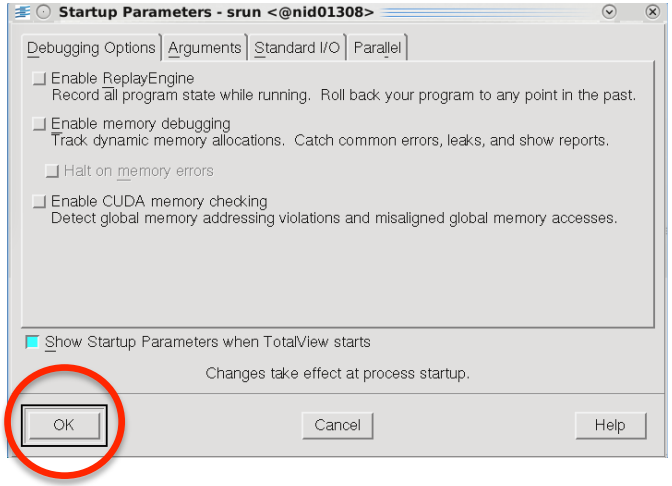


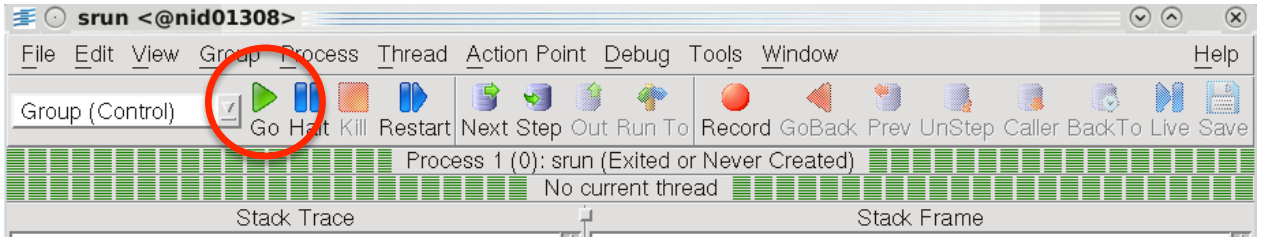
TotalView

```
$ salloc -N 1 -t 30:00 -p debug
$ module load totalview
$ export OMP_NUM_THREADS=6
$ totalview srun -a -n 4 ./jacobi_mpiomp
```

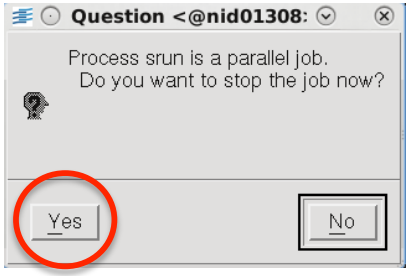
Then,

- Click OK in the 'Startup Parameters - srun' window
- Click 'Go' button in the main window



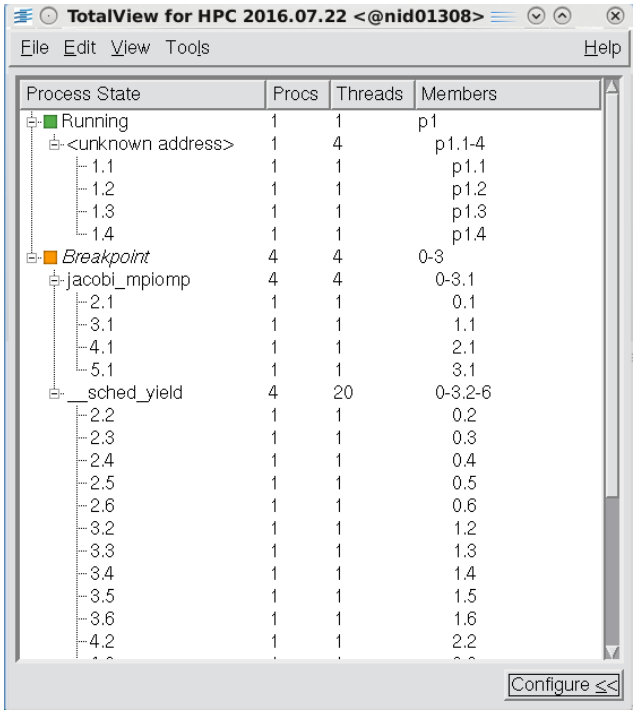


- Click 'Yes' to the question 'Process srun is a parallel job. Do you want to stop the job now?'



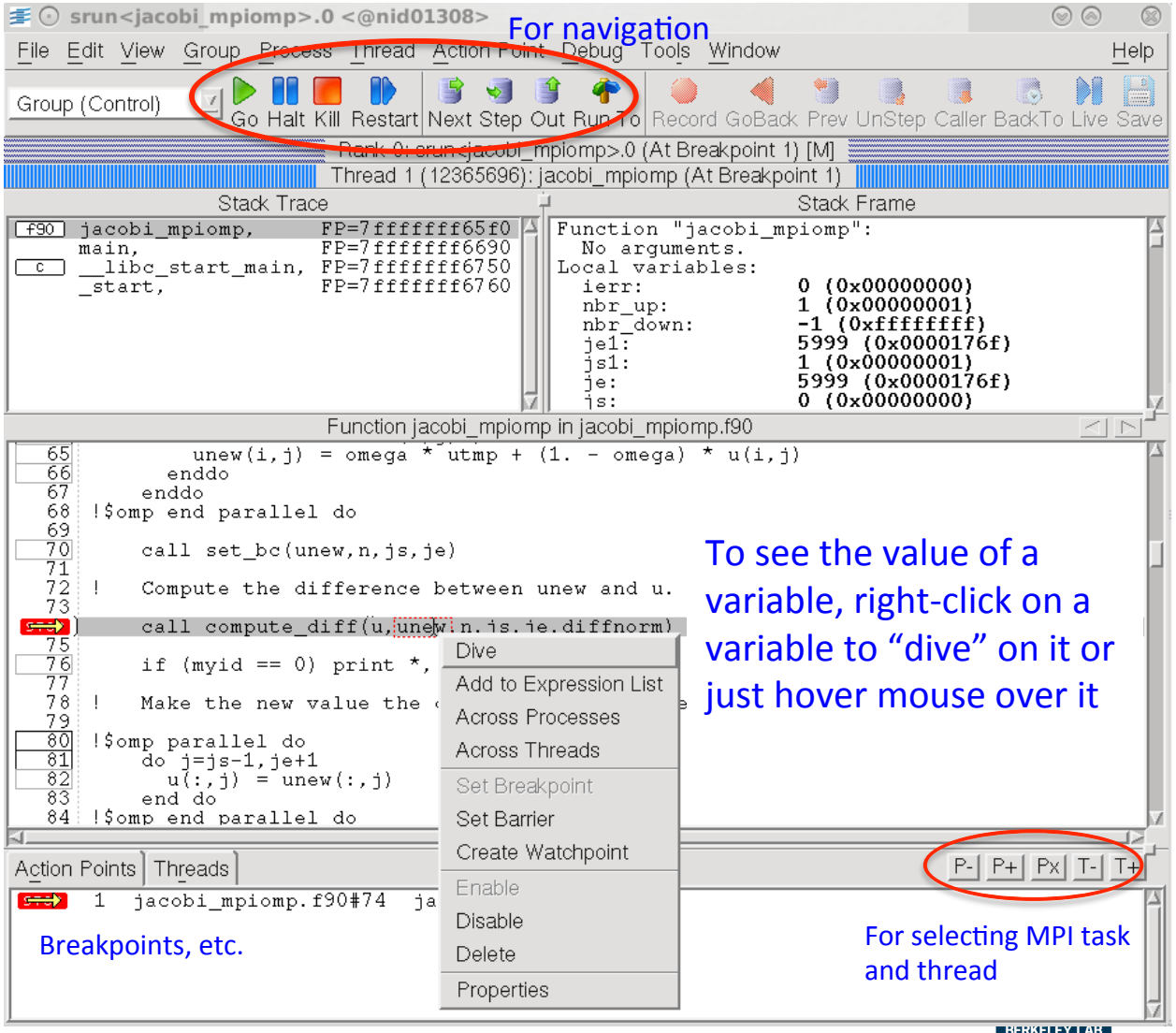
TotalView (cont'd)

Root window



State of MPI tasks and threads; members denoted roughly as '*rank.thread*'

Process window



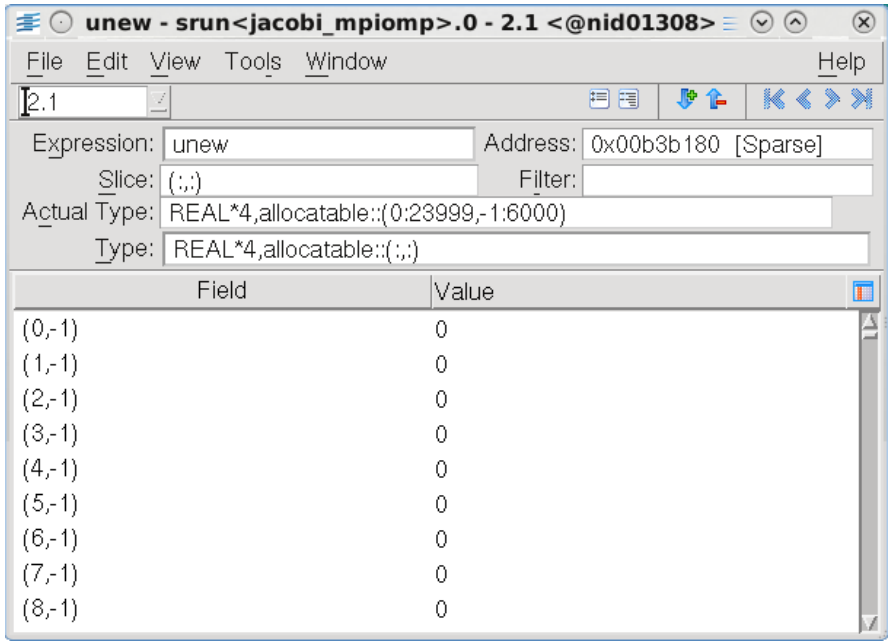
To see the value of a variable, right-click on a variable to "dive" on it or just hover mouse over it

Breakpoints, etc.

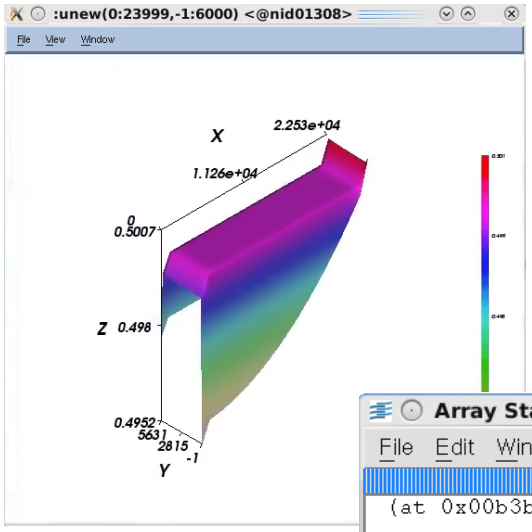
For selecting MPI task and thread

Viewing variables

- **Variable window**

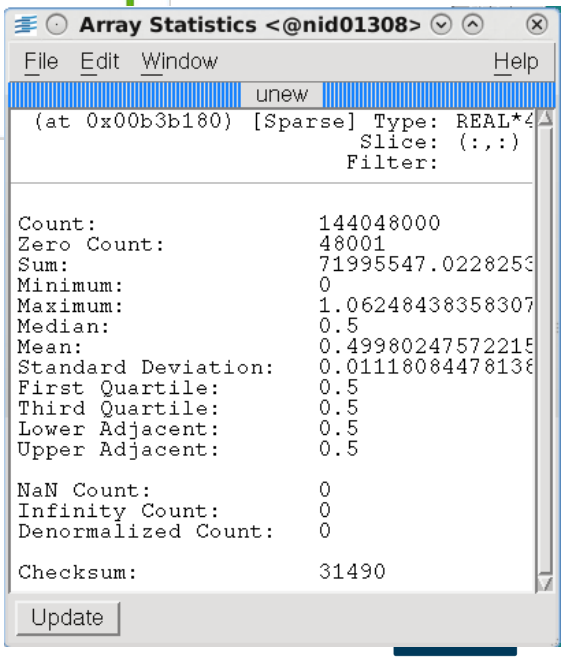


- **Visualization and stats**



Tools > Visualize

Tools > Statistics



Memory debugging with MemoryScape

- **MemoryScape integrated into TotalView for memory debugging**
  - Memory leaks
  - Memory usage
  - Memory corruption
  - …

- **A statically-linked executable**

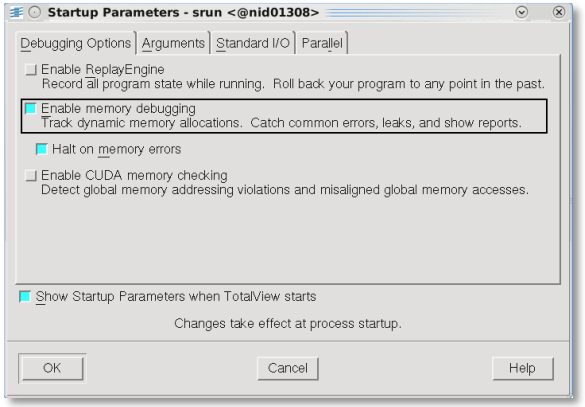
```
$ module load totalview
$ CC -g -O0 -o memry_leaks memory_leaks.o ${TVMEMDEBUG_POST_OPTS}
```

- **A dynamically-linked executable, build as usual**

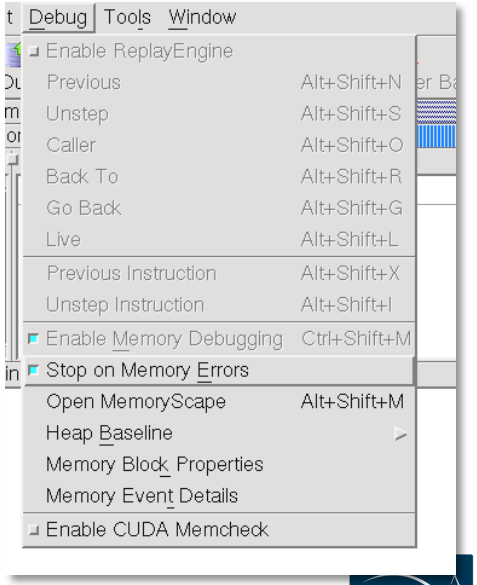
```
$ CC -dynamic -g -O0 -o memry_leaks memory_leaks.o
```

Memory debugging with MemoryScape

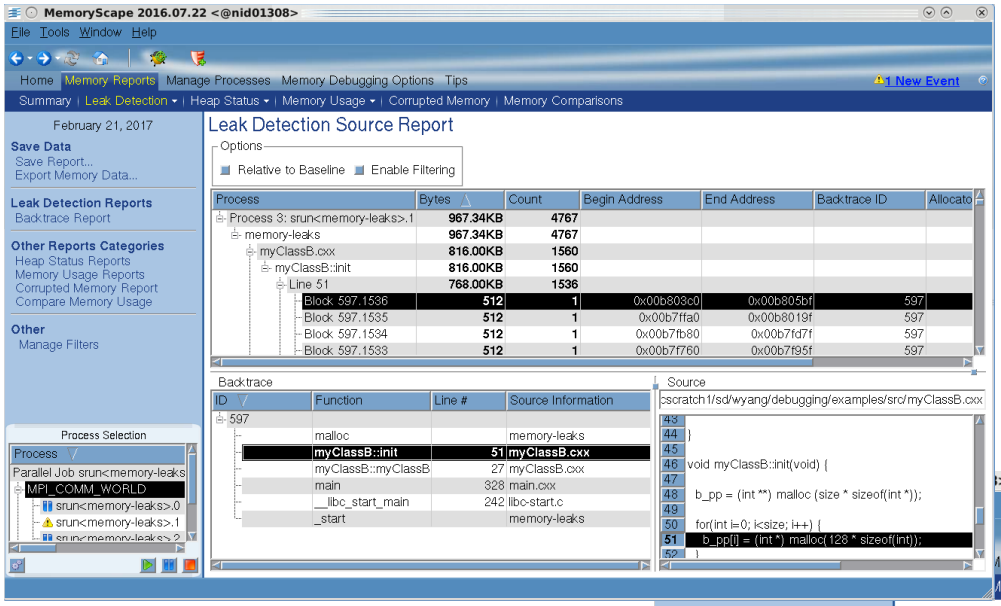
- **Start TotalView and enable memory debugging in the 'Startup Parameters' window**
- **Proceed to use TotalView as usual**

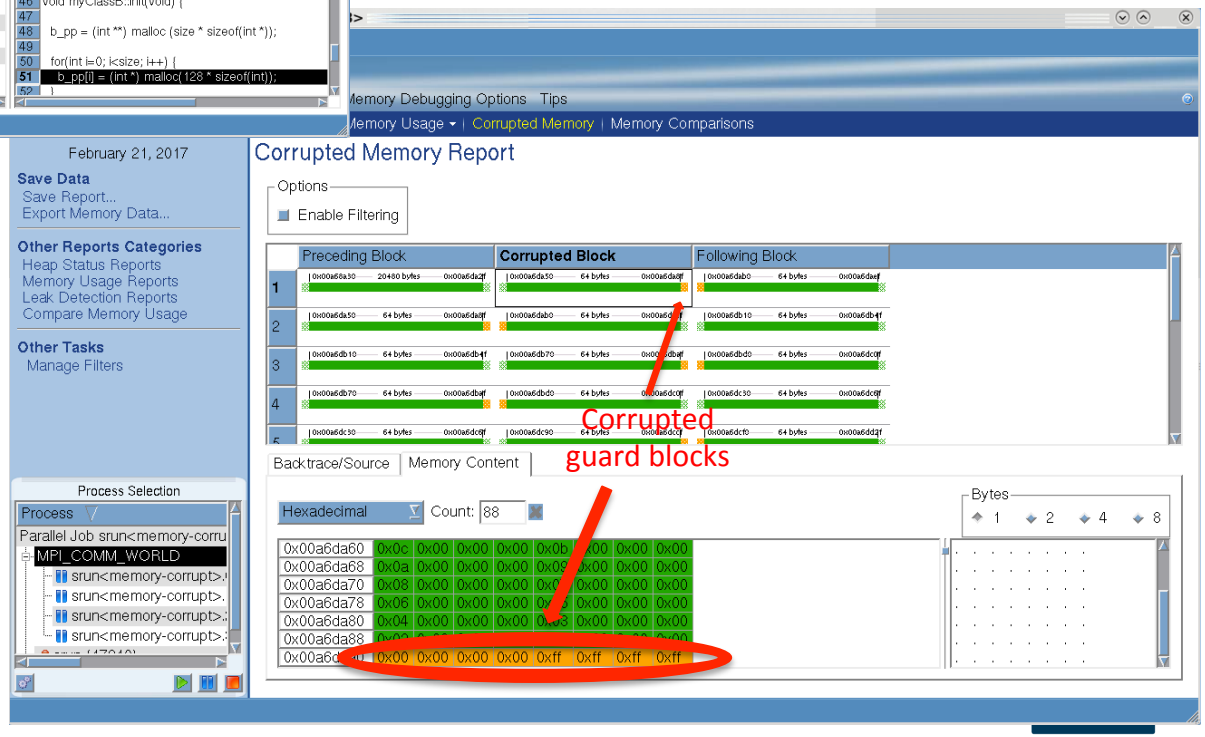


- **For memory-related issues, open MemoryScape from the Debug pull-down menu**



Memory debugging examples





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-cl: invokes STAT to gather stack backtraces
  - stat-view: a GUI to view the results
  - stat-gui: a GUI to run STAT or view results
- **For more info:**
  - 'intro_stat', 'stat-cl', 'stat-view' and 'stat-gui' man pages
  - https://computing.llnl.gov/code/STAT/stat_userguide.pdf
  - http://www.nersc.gov/users/software/debugging-and-profiling/stat-2/

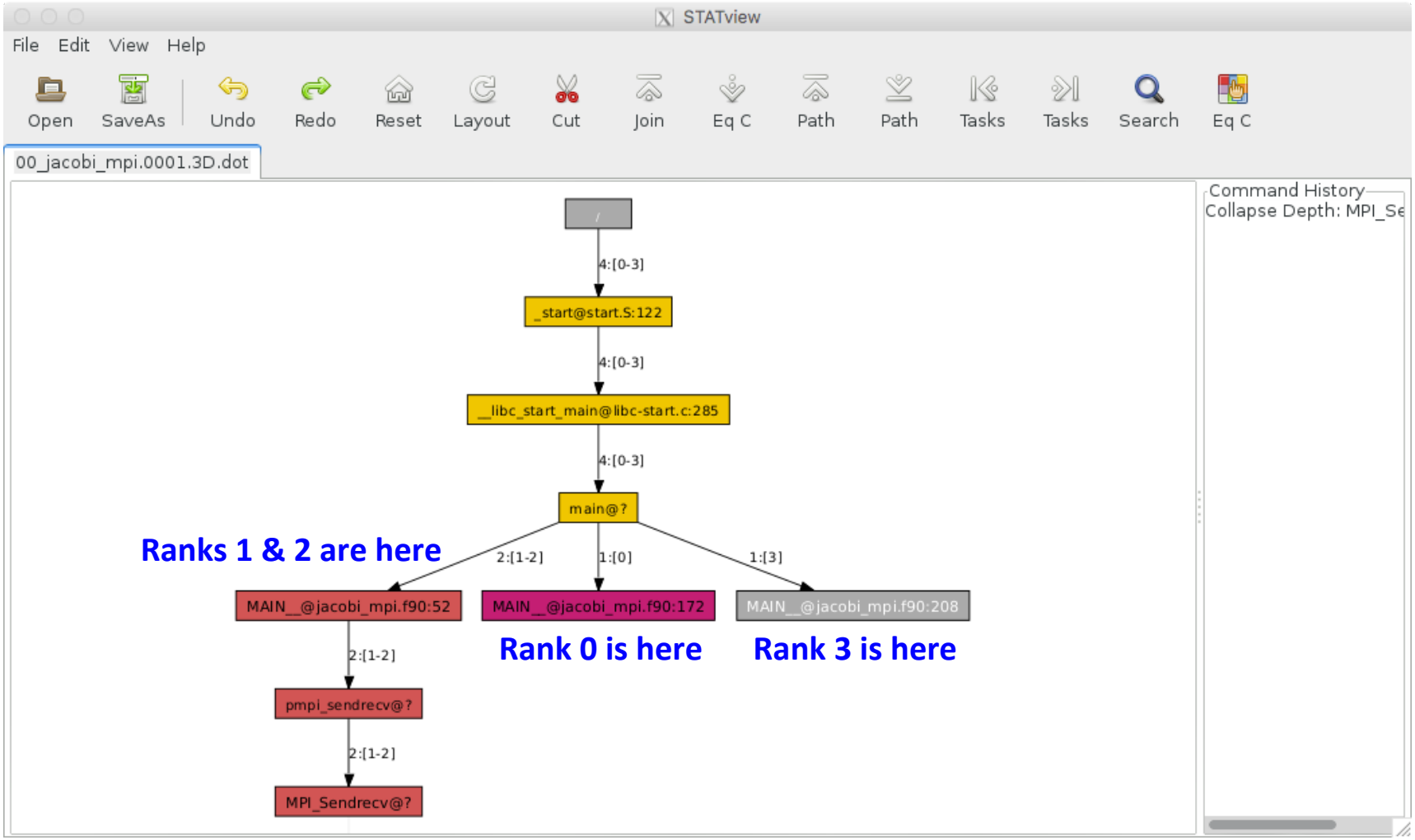
Hung application with STAT

- If your code hangs in a consistent manner, you can use STAT to see if and where some MPI ranks are stuck.
- Currently, one known way to use STAT is as follows.

```
$ ftn -g -o jacobi_mpi jacobi_mpi.f90        with usual optimization flags, if any
$ salloc -N 1 -t 30:00 -p debug -C knl,quad,cache
...
$ srun -n 4 ./jacobi_mpi &
[1] 93834
$ module load stat
$ stat-cl -i 93834                -i to get source line numbers
…                                 STAT samples stack backtraces a few times
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 /global/cscratch1/sd/wyang/debugging/stat_results/jacobi_mpi.0001
$ ls -l stat_results/jacobi_mpi.0001/*.dot
-rw-r----- 1 wyang wyang 2768 Feb 20 21:24 stat_results/jacobi_mpi.0001/00_jacobi_mpi.0001.3D.dot
$ stat-view stat_results/jacobi_mpi.0001/00_jacobi_mpi.0001.3D.dot
```

Hung application with STAT (Cont'd)



ATP (Abnormal Termination Processing)

- **ATP gathers stack backtraces from all processes if an application fails**
  - Invokes STAT underneath
  - Output in atpMergedBT.dot and atpMergedBT_line.dot (which shows source code line numbers), which are to be viewed with stat-view
- **By default, the atp module is loaded on Cori and Edison, but ATP is *not* enabled; to enable:**

```
export ATP_ENABLED=1    # sh/bash/ksh
setenv ATP_ENABLED 1    # csh/tcsh
```

- **Can get core dumps (core.atp.*jobid*.*rank*), too, by setting coredumpsize unlimited:**

```
ulimit -c unlimited     # sh/bash/ksh
unlimit coredumpsize    # csh/tcsh
```

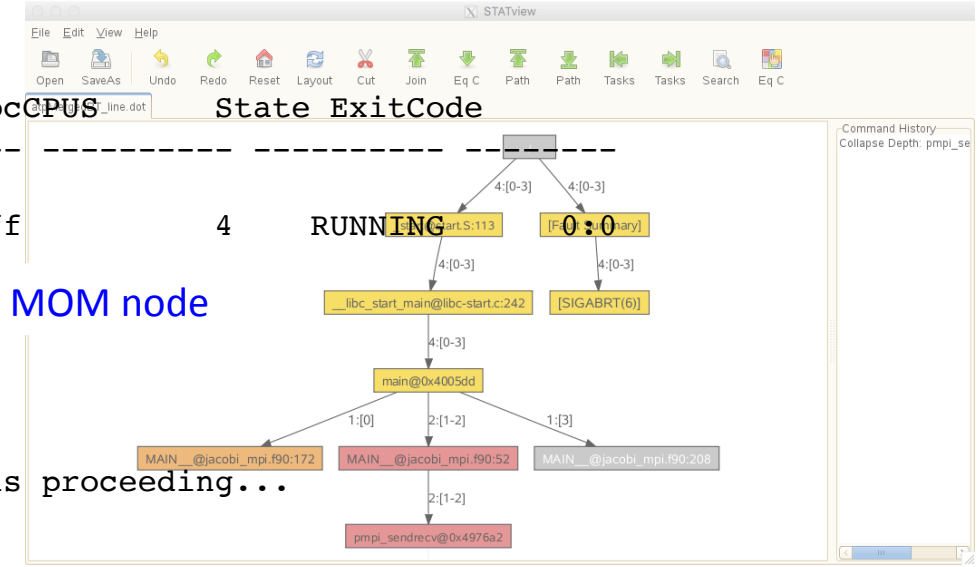
  but they do not represent the exact same moment in time (therefore the location of a failure can be inaccurate)

- **For more info**
  - 'intro_atp' man page
  - http://www.nersc.gov/users/software/debugging-and-profiling/stat-and-atp/

Hung application with ATP

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

```
$ sacct -j 4097861   Find the job step ID
JobID    JobName  Partition    Account  AllocCPUS      State ExitCode
------------ ---------- ---------- ---------- ---------- ---------- --------
...
4097861.0    jacobi_mp+                 nstaff          4    RUNNING      0:0
...
$ ssh edimom02       Kill the application on a MOM node
$ scancel -s ABRT 4097861.0
$ exit
$ cat slurm-4097861.out
Application 4097861 is crashing. ATP analysis proceeding...
...
Process died with signal 6: 'Aborted'
View application merged backtrace tree with: stat-view atpMergedBT.dot
...
$ module load stat
$ stat-view atpMergedBT.dot    # or statview atpMergedBT_line.dot
```



Valgrind

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

Valgrind's memcheck

```
$ module load valgrind
$ ftn -dynamic -g -O0 memory_leaks.f $VALGRIND_MPI_LINK
$ salloc -N 1 -t 30:00 -p debug -C knl
$ srun -n 2 valgrind --leak-check=full --log-file=%p ./a.out
$ ls -l
...
-rw-r--r--  1 wyang wyang    7550 Feb 21 23:36 91835
-rw-r--r--  1 wyang wyang    7550 Feb 21 23:36 91836
```

Could have explicitly added '--tool=memcheck'

- **Let's look at the report for process 91835**

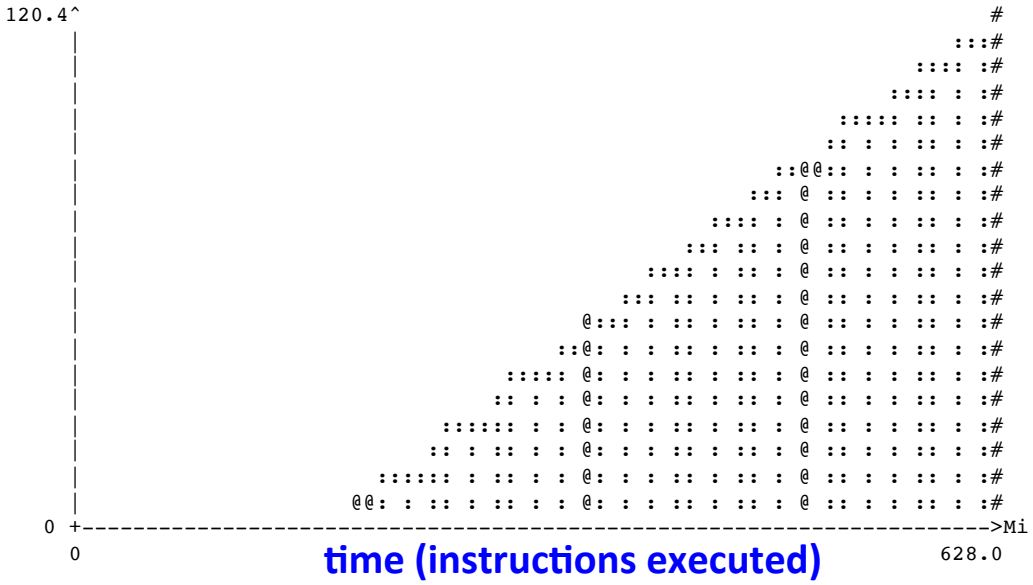
```
$ more 91835
...
==91835== LEAK SUMMARY:
==91835==    definitely lost: 83,886,880 bytes in 20 blocks
==91835==    indirectly lost: 0 bytes in 0 blocks
==91835==      possibly lost: 41,943,440 bytes in 10 blocks
==91835==    still reachable: 103,903 bytes in 74 blocks
==91835==         suppressed: 0 bytes in 0 blocks
...
```

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

Valgrind's massif

- **For profiling heap memory usage**

```
$ ftn -g -O2 memory_leaks.f
$ srun -n 2 -c 128 valgrind --tool=massif ./a.out
$ ls -lrt
…
-rw------- 1 wyang wyang 50233 Feb 21 23:55 massif.out.92841
-rw------- 1 wyang wyang 81113 Feb 21 23:55 massif.out.92842
$ ms_print massif.out.92841
```




```
Number of snapshots: 95
 Detailed snapshots: [14, 29, 44, 48, 50, 51, 61, 71, 81, 91 (peak)]
```

':': normal snapshot; basic info provided

'@': detailed snapshot where detailed info is provided

'#': peak snapshot where the peak heap usage is

This example strongly suggests memory leaks

Valgrind's massif (Cont'd)

```
...
--------------------------------------------------------------------------------
  n        time(i)         total(B)   useful-heap(B) extra-heap(B)    stacks(B)
--------------------------------------------------------------------------------
 82    531,809,757       96,862,856       96,761,707       101,149            0
...
 91    658,233,924      126,259,976      126,130,750       129,226            0
99.90% (126,130,750B) (heap allocation functions) malloc/new/new[], --alloc-fns, etc.
->99.66% (125,830,320B) 0x4E3FF6A: _mm_malloc (in /opt/intel/compilers_and_libraries_2017.1.132/lin
ux/compiler/lib/intel64_lin/libintlc.so.5)
| ->99.66% (125,830,320B) 0x40AF1F: for_allocate (in /global/cscratch1/sd/wyang/debugging/memory_le
aks)
| | ->33.22% (41,943,440B) 0x4033AF: MAIN__ (memory_leaks.f:41)
| | | ->33.22% (41,943,440B) 0x402FDC: main (in /global/cscratch1/sd/wyang/debugging/memory_leaks)
| | |
| | ->33.22% (41,943,440B) 0x403621: MAIN__ (memory_leaks.f:51)
| | | ->33.22% (41,943,440B) 0x402FDC: main (in /global/cscratch1/sd/wyang/debugging/memory_leaks)
| | |
| | ->33.22% (41,943,440B) 0x403898: MAIN__ (memory_leaks.f:54)
| |   ->33.22% (41,943,440B) 0x402FDC: main (in /global/cscratch1/sd/wyang/debugging/memory_leaks)
| |
| ->00.00% (0B) in 1+ places, all below ms_print's threshold (01.00%)
|
->00.24% (300,430B) in 1+ places, all below ms_print's threshold (01.00%)

--------------------------------------------------------------------------------
  n        time(i)         total(B)   useful-heap(B) extra-heap(B)    stacks(B)
--------------------------------------------------------------------------------
...
 94    658,456,870      126,056,640      125,935,407       121,233            0
```

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