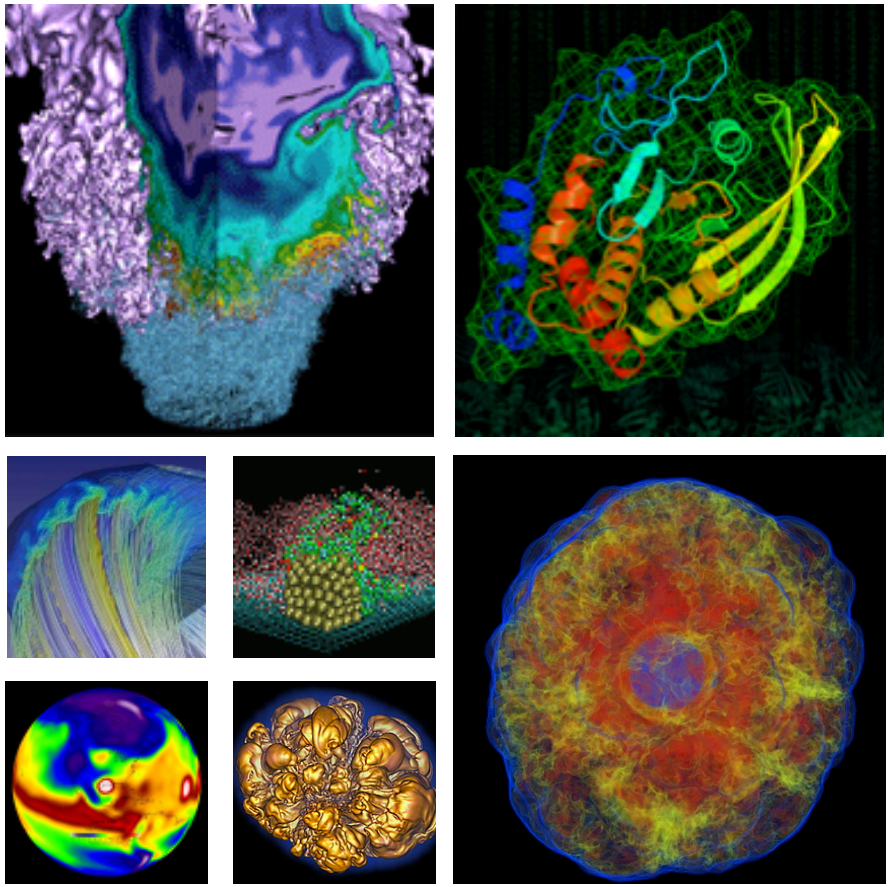
Parallel Debugging Tools

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/

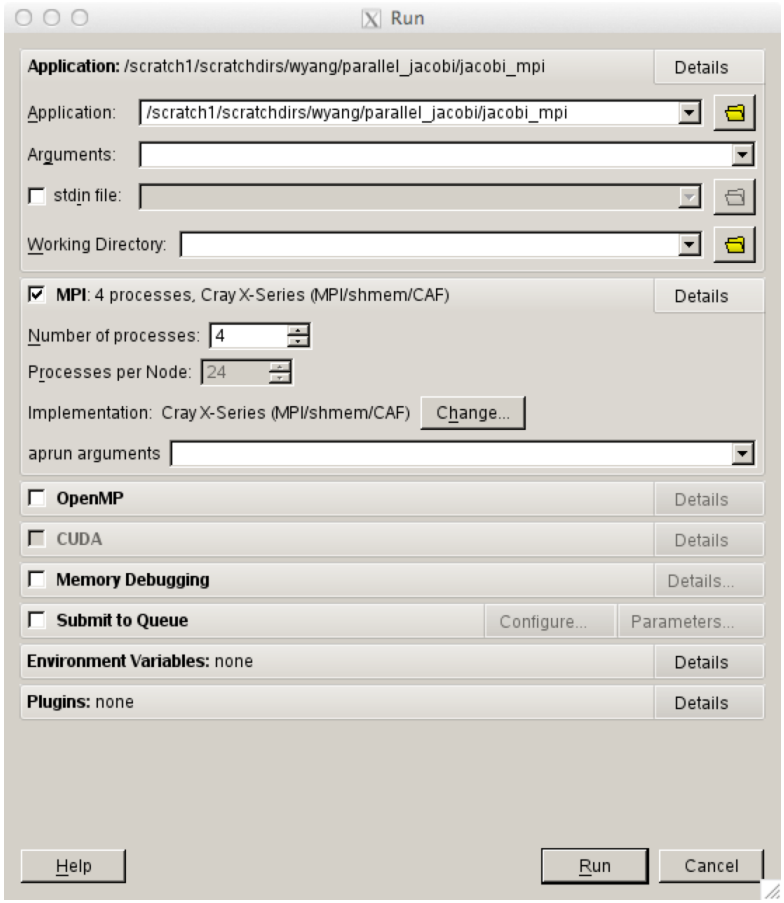
How to build and run with DDT

```
$ 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
$ module load allineatools
$ ddt ./jacobi_mpi
```

Start an interactive batch session
Load the allineatools module to use DDT
Start DDT



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

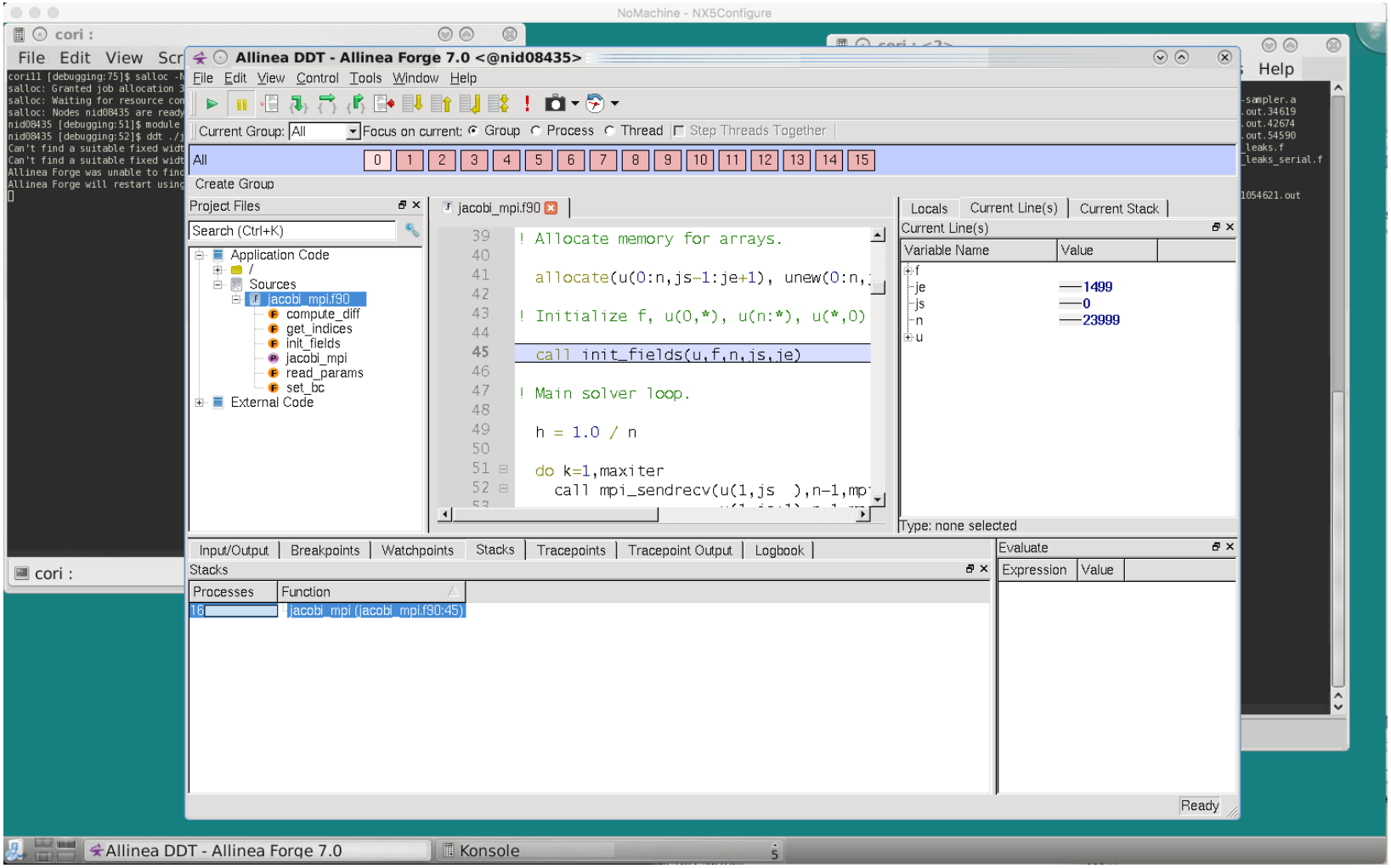
If you are far away from NERSC

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

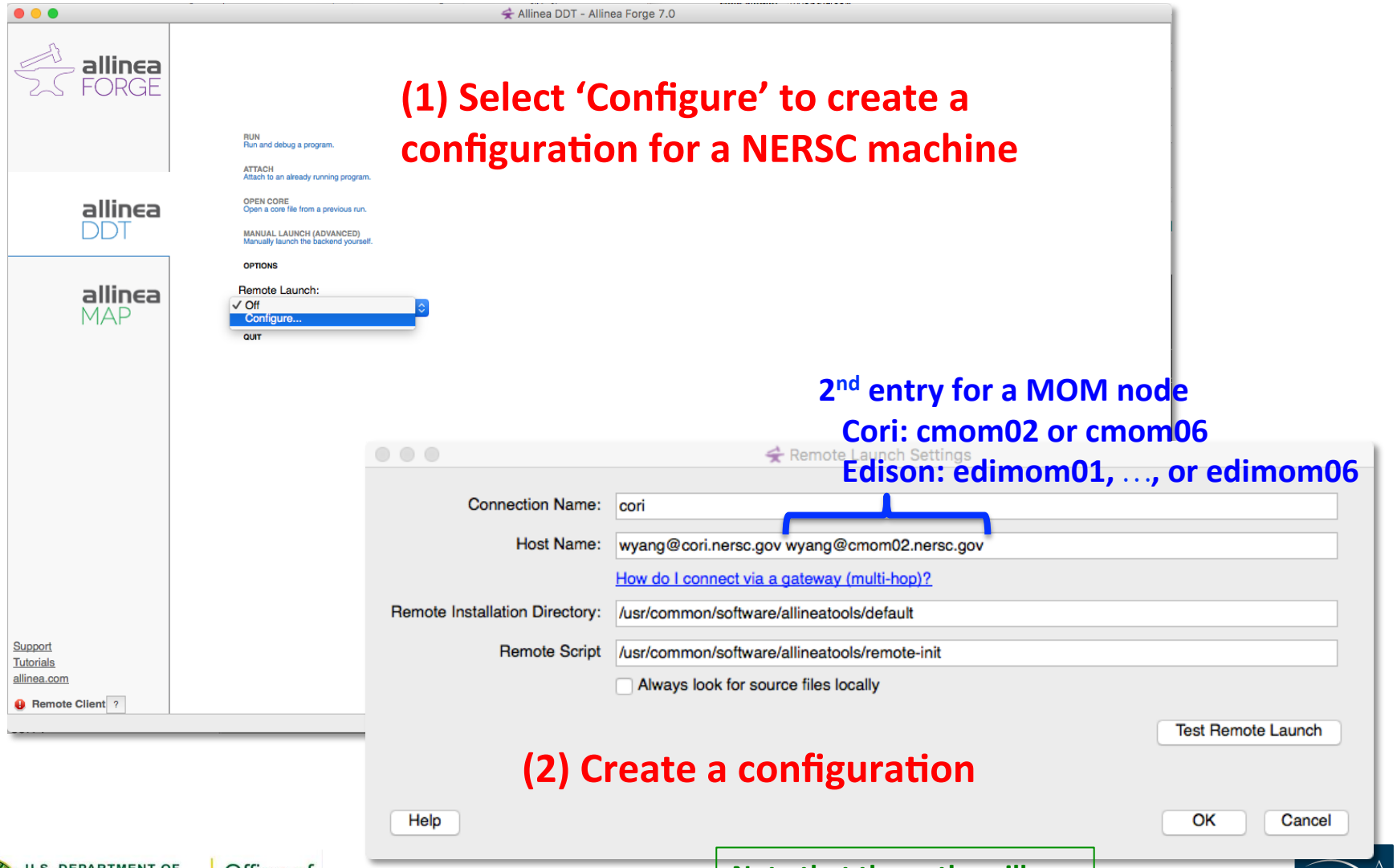
- **Two solutions**
  - Use NX to improve the speed
    - Works with any X window applications
    - https://www.nersc.gov/users/network-connections/using-nx/ (general)
    - http://portal.nersc.gov/project/mpccc/nx/NX_Tutorial/Start_Over.html (installation and quick user guide)

  - 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 :
File Edit View Scr
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
All 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
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
jacobi_mpi (jacobi_mpi.f90:45)
Evaluate
Expression Value
Ready
Allinea DDT - Allinea Forge 7.0
Konsole
Help

Using Allinea remote client



(1) Select 'Configure' to create a configuration for a NERSC machine

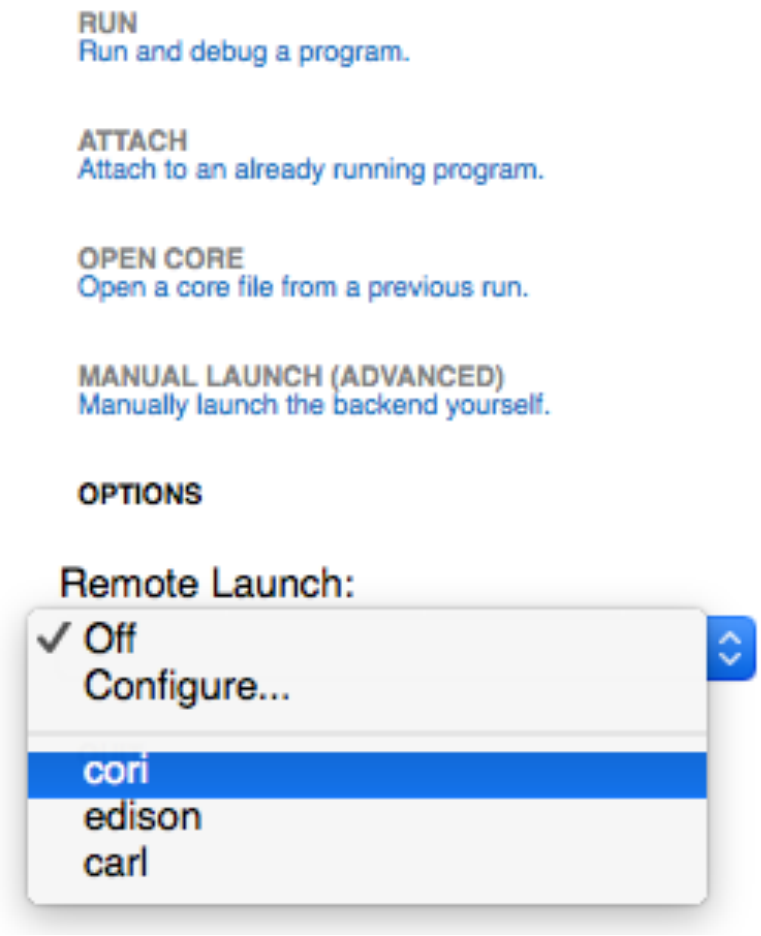
2nd entry for a MOM node
Cori: cmom02 or cmom06
Edison: edimom01, …, or edimom06

(2) Create a configuration

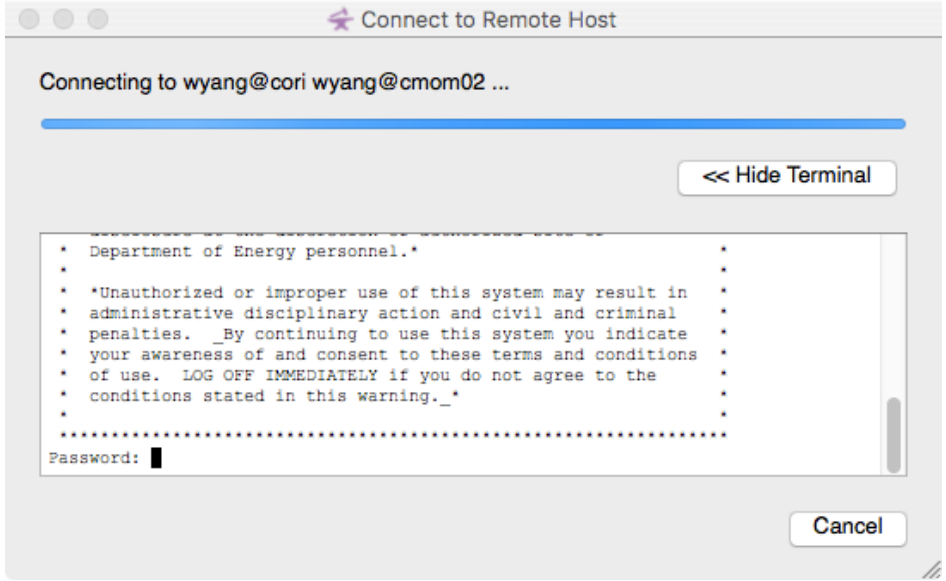
Note that the paths will change for future versions

Using Allinea remote client (Cont'd)

(3) Select a machine



(4) Enter the NIM password

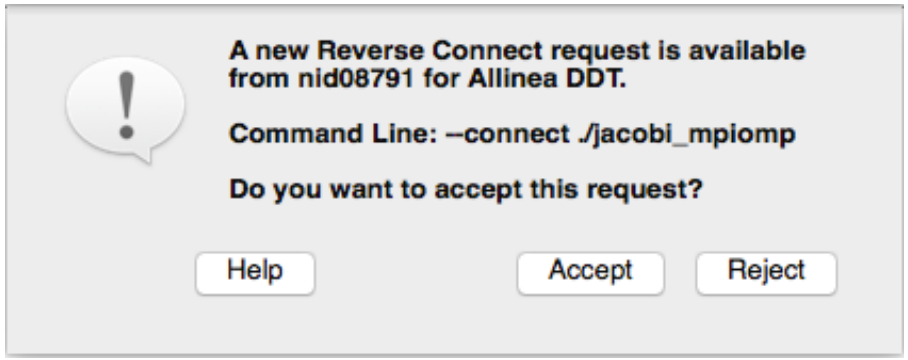


Using Allinea remote client (Cont'd)

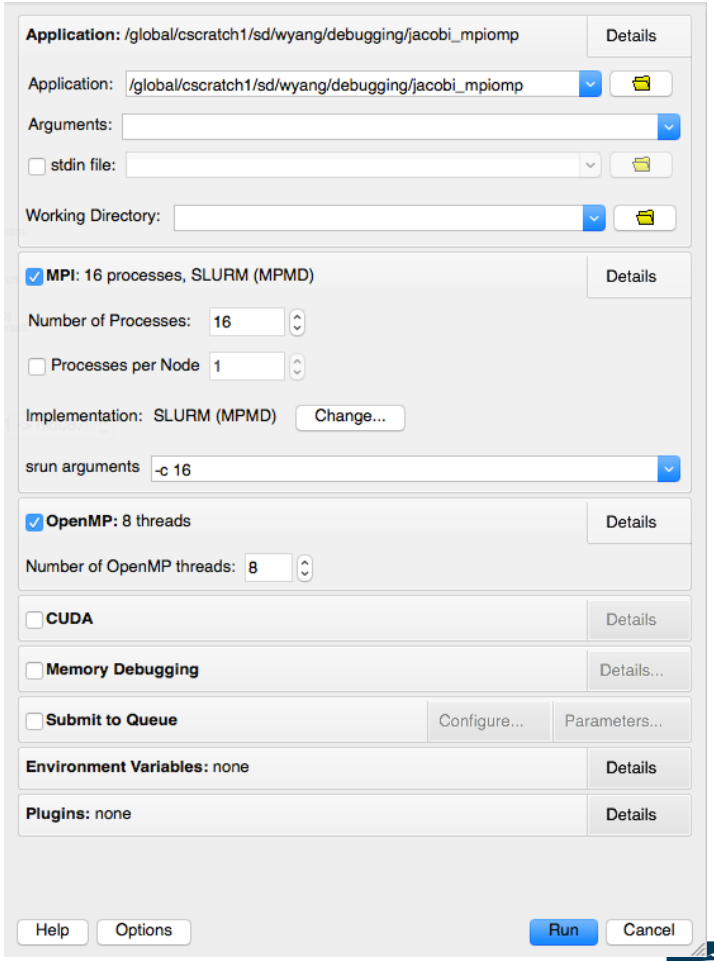
(5) Submit a batch job on a NERSC machine and start DDT

```
$ 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

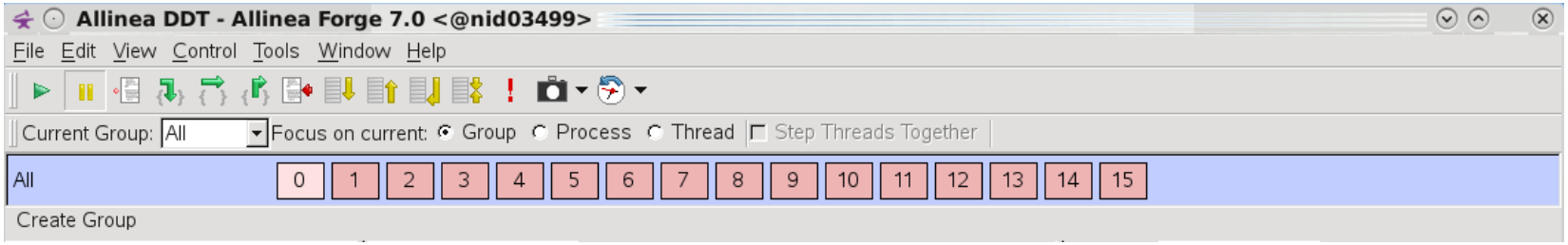
Processing entity to control

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

Parallel stack frame view is helpful in quickly finding out where each process is executing

Navigation



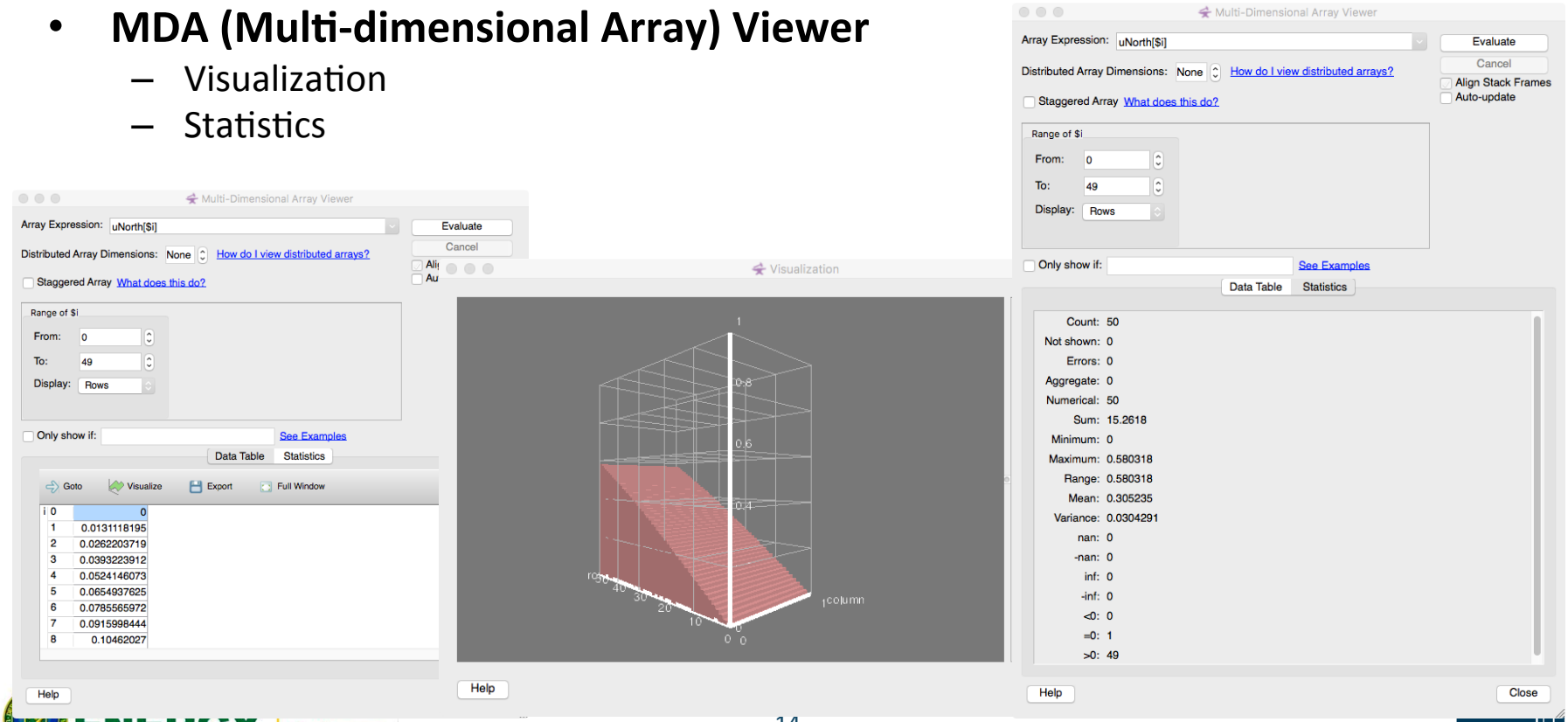
- **Play/Continue**
- **Pause**
- **Add Breakpoint**
- **Step Into**
  - To next line; if it's a function call, enter the function
- **Step Over**
  - To next line in the current stack frame even if it's a function call
- **Step Out**
  - Return to the caller function
- **Run To Line**

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

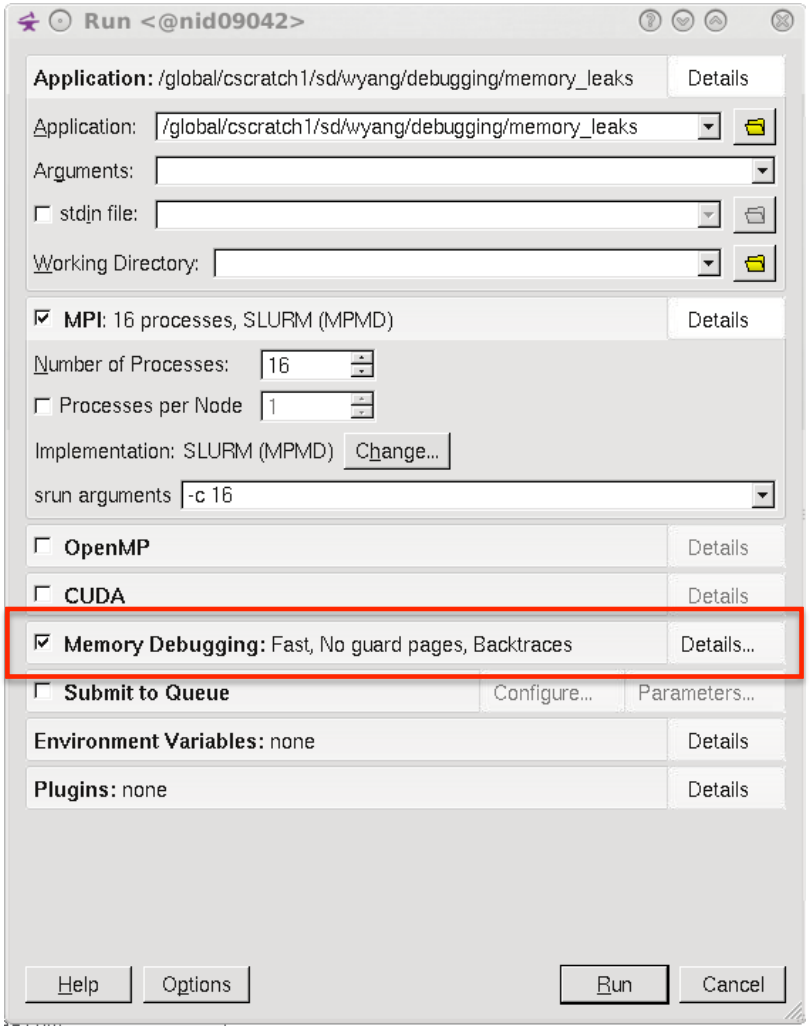
- **Why?**
  - To detect memory leaks
  - To catch out-of-bound array references
  - To catch other memory errors ("double free", etc.)
  - To see memory usage

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

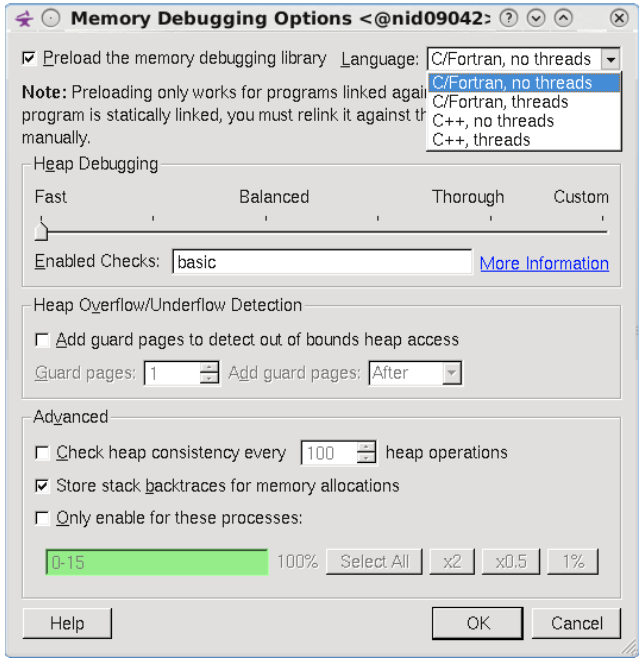
```
$ ftn -c -g -O0 myprog.f
$ static_linking_ddt_md ftn -o myprog myprog.o
#     instead of        ftn -o myprog myprog.o
```

  - **`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…'

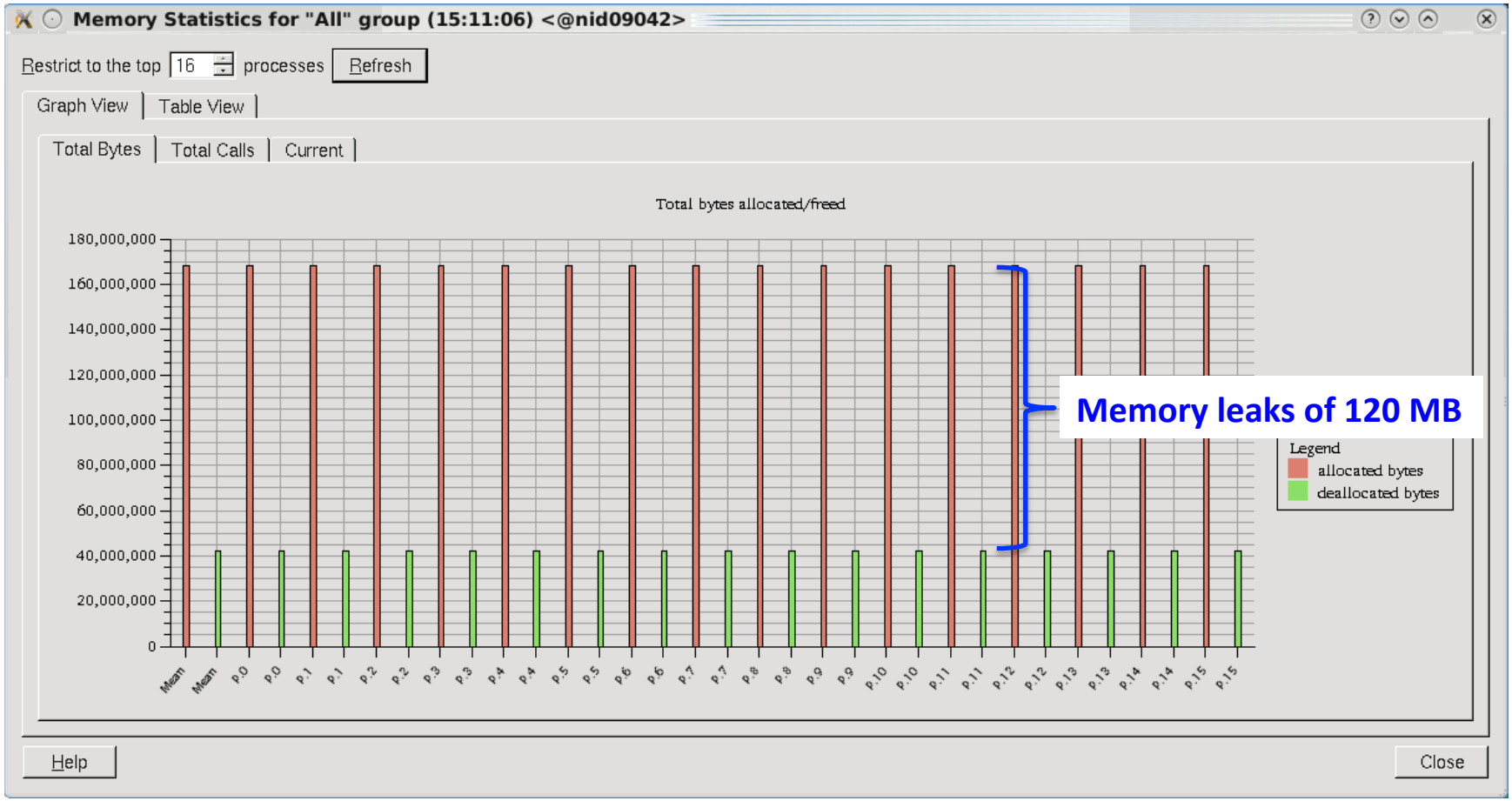


- **For a dynamically-linked binary only**
  - Check 'Preload the memory debugging library'
  - Select the appropriate one from the 'Language' pull-down menu
- **Adding guard pages (default: 4 KB) before *or* after memory blocks for detecting out-of-bound heap array references**

Memory debugging – Overall Memory Stats

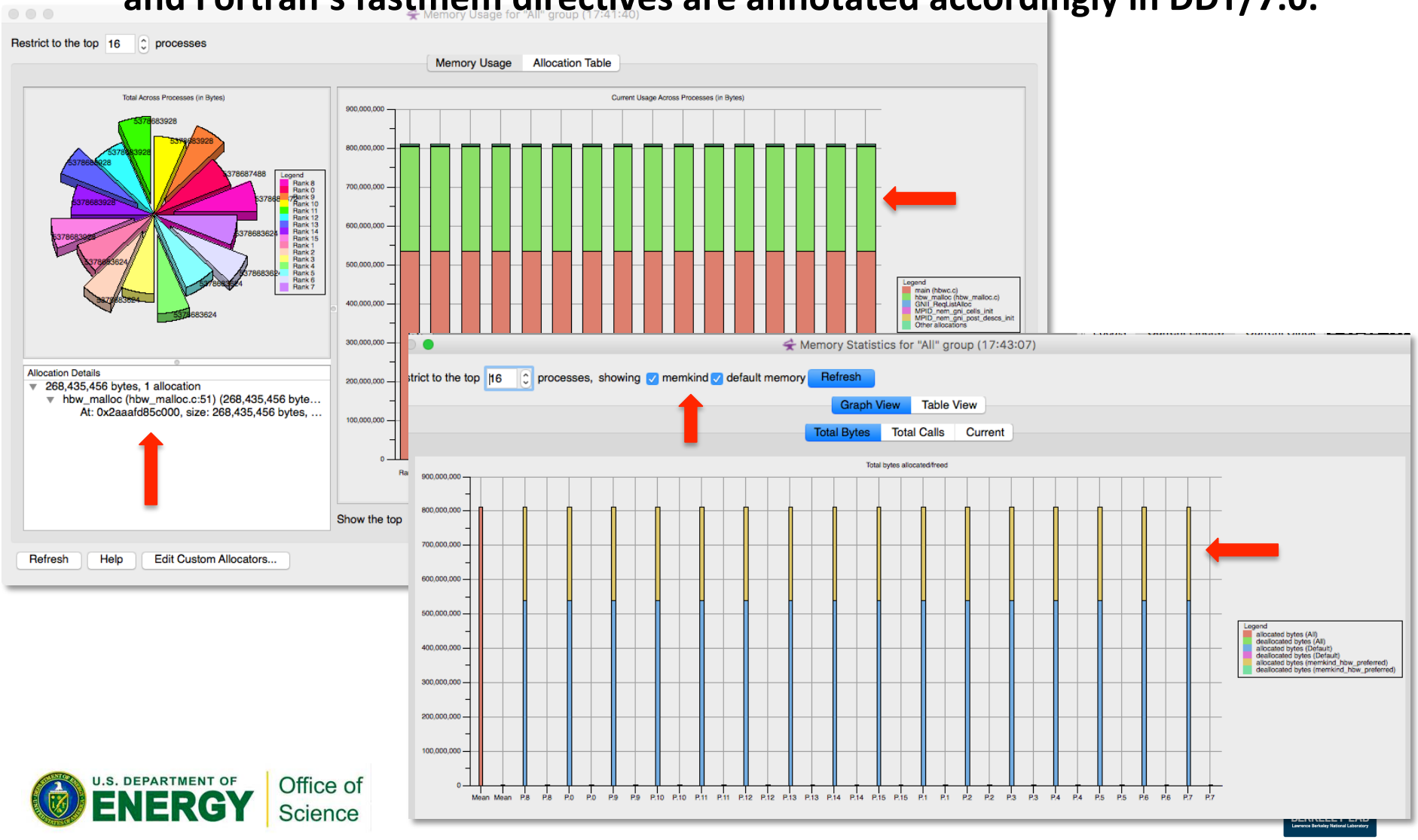
Tools > Overall Memory Stats

memory_leaks.f from NERSC DDT web page



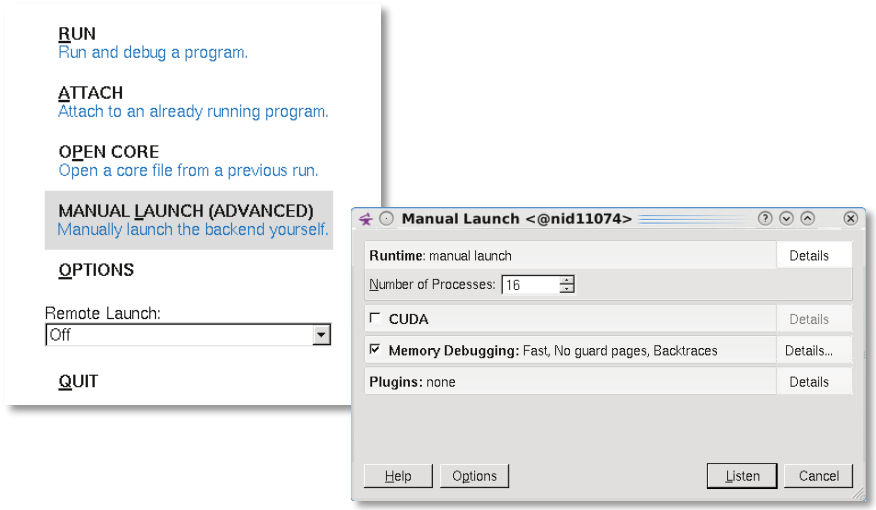
KNL MCDRAM usage on Cori

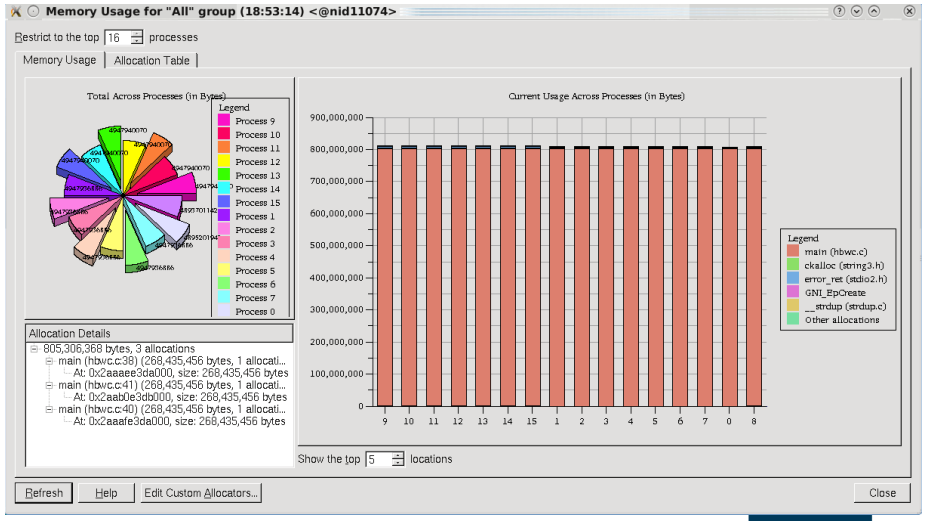
- **Memory blocks allocated in MCDRAM with memkind's hbw_malloc calls and Fortran's fastmem directives are annotated accordingly in DDT/7.0.**



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. This problem will be resolved with a new version of Slurm.



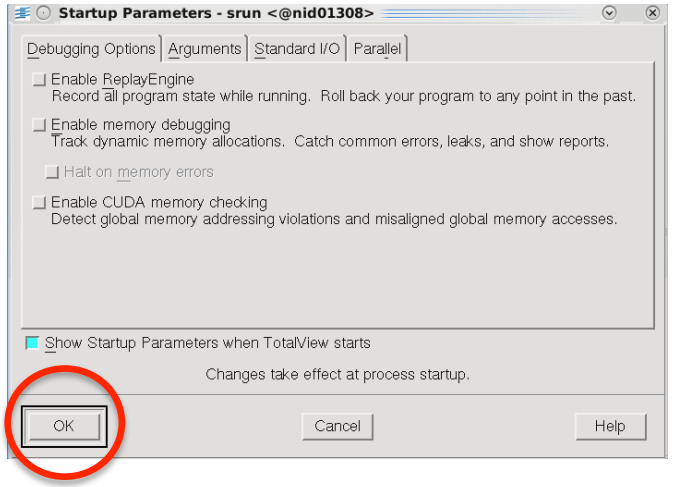


TotalView

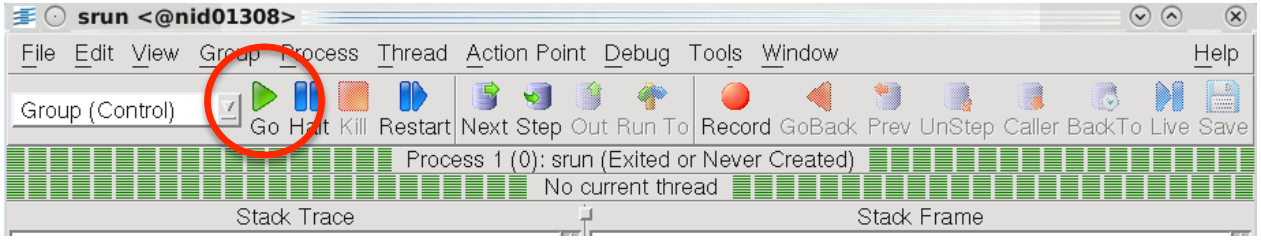
```
$ salloc -N 1 -t 30:00 -p debug
$ module load totalview
$ export OMP_NUM_THREADS=6
$ totalview srun -a -n 4 ./jacobi_mpiomp
```

Then,

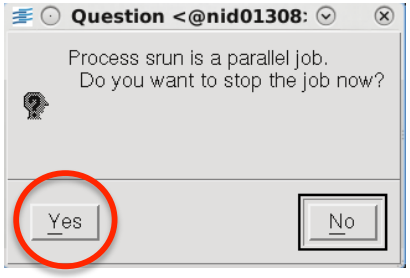
- Click OK in the 'Startup Parameters - srun' window



- Click 'Go' button in the main window

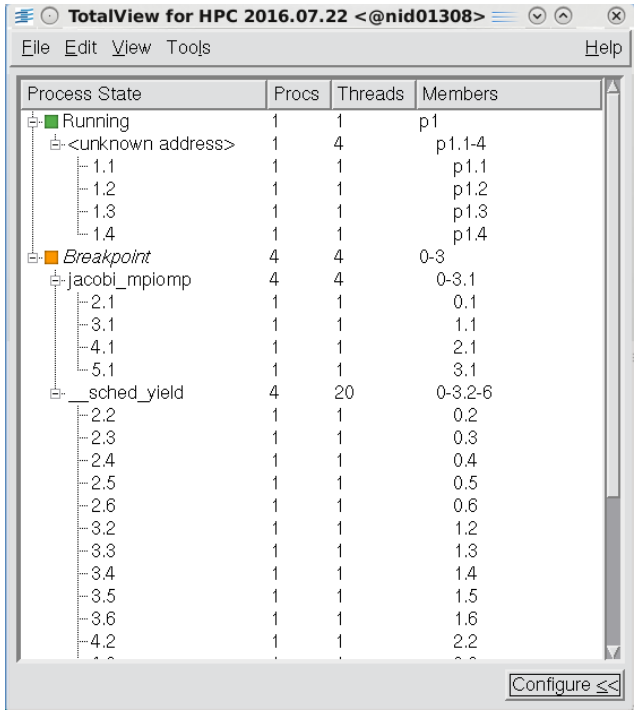


- Click 'Yes' to the question 'Process srun is a parallel job. Do you want to stop the job now?'



TotalView (cont'd)

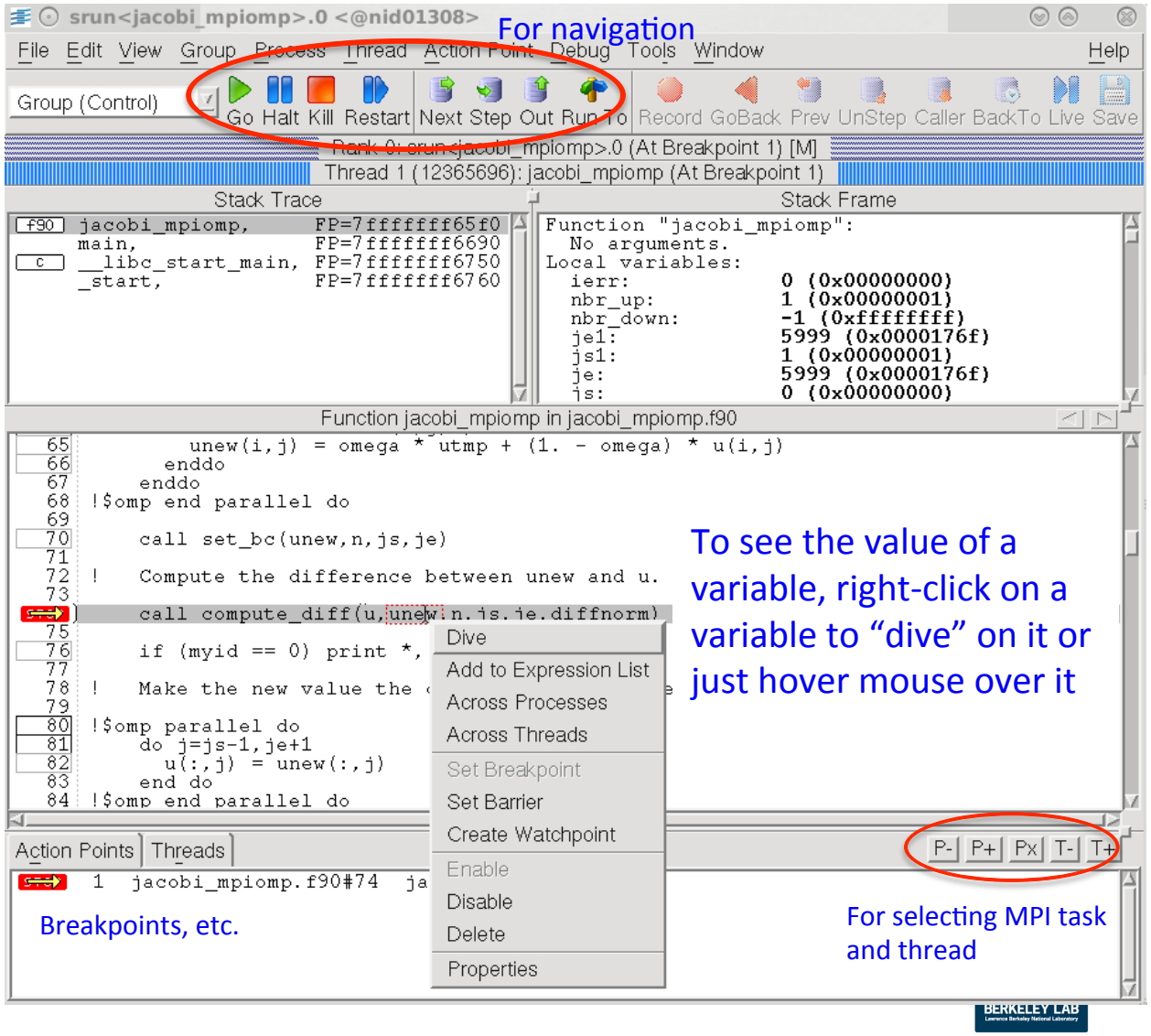
Root window



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

Process window

For navigation



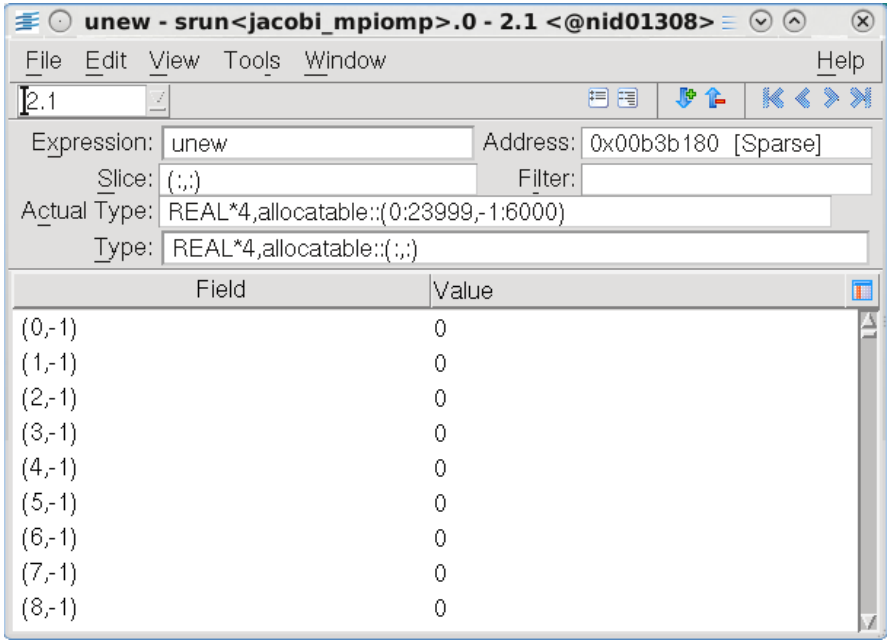
To see the value of a variable, right-click on a variable to "dive" on it or just hover mouse over it

Breakpoints, etc.

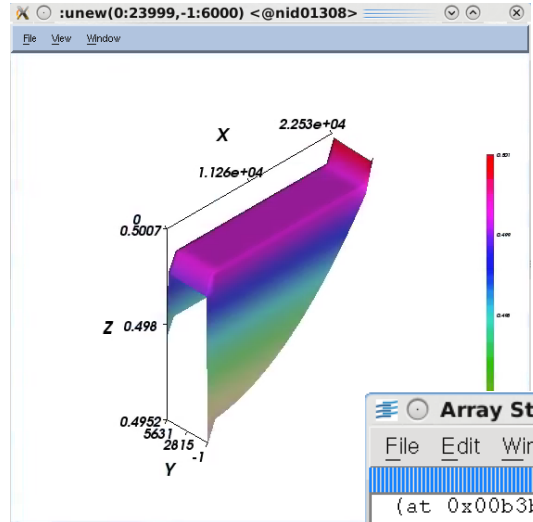
For selecting MPI task and thread

Viewing variables

- **Variable window**

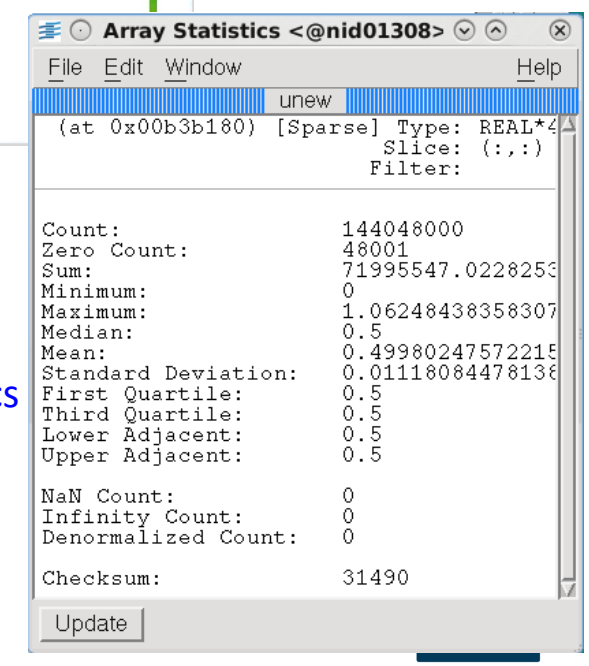


- **Visualization and stats**



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**

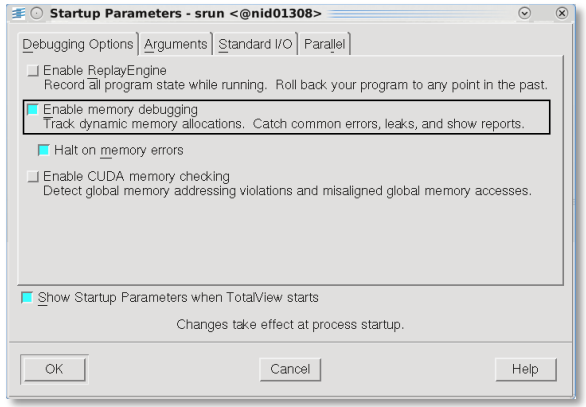
```
$ module load totalview
$ CC -g -O0 -o memry_leaks memory_leaks.o ${TVMEMDEBUG_POST_OPTS}
```

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

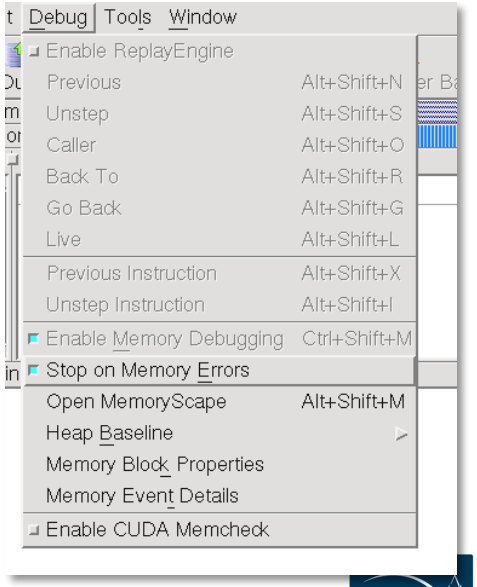
```
$ CC -dynamic -g -O0 -o memry_leaks memory_leaks.o
```

Memory debugging with MemoryScape

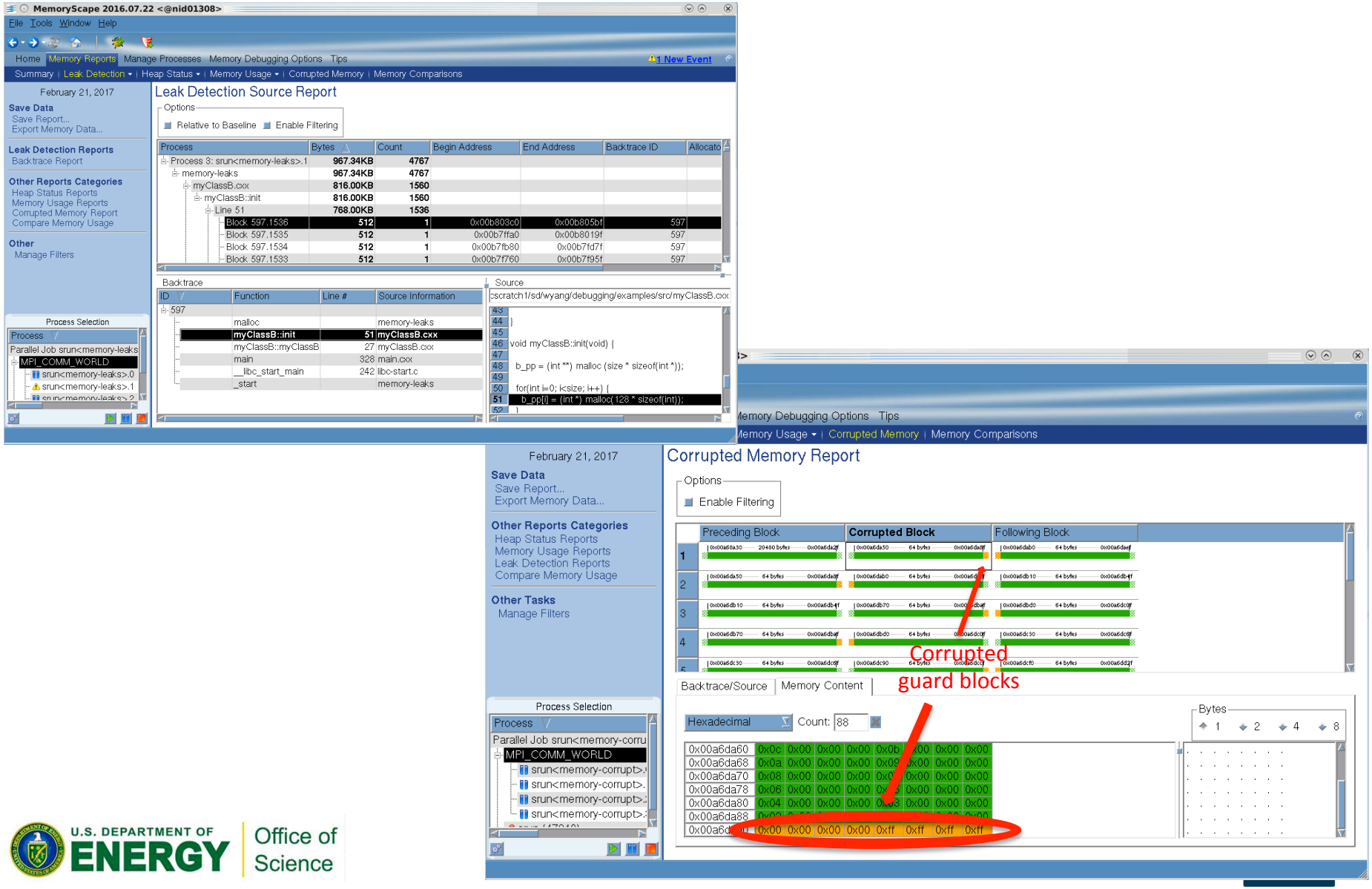
- **Start TotalView and enable memory debugging in the 'Startup Parameters' window**
- **Proceed to use TotalView as usual**



- **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

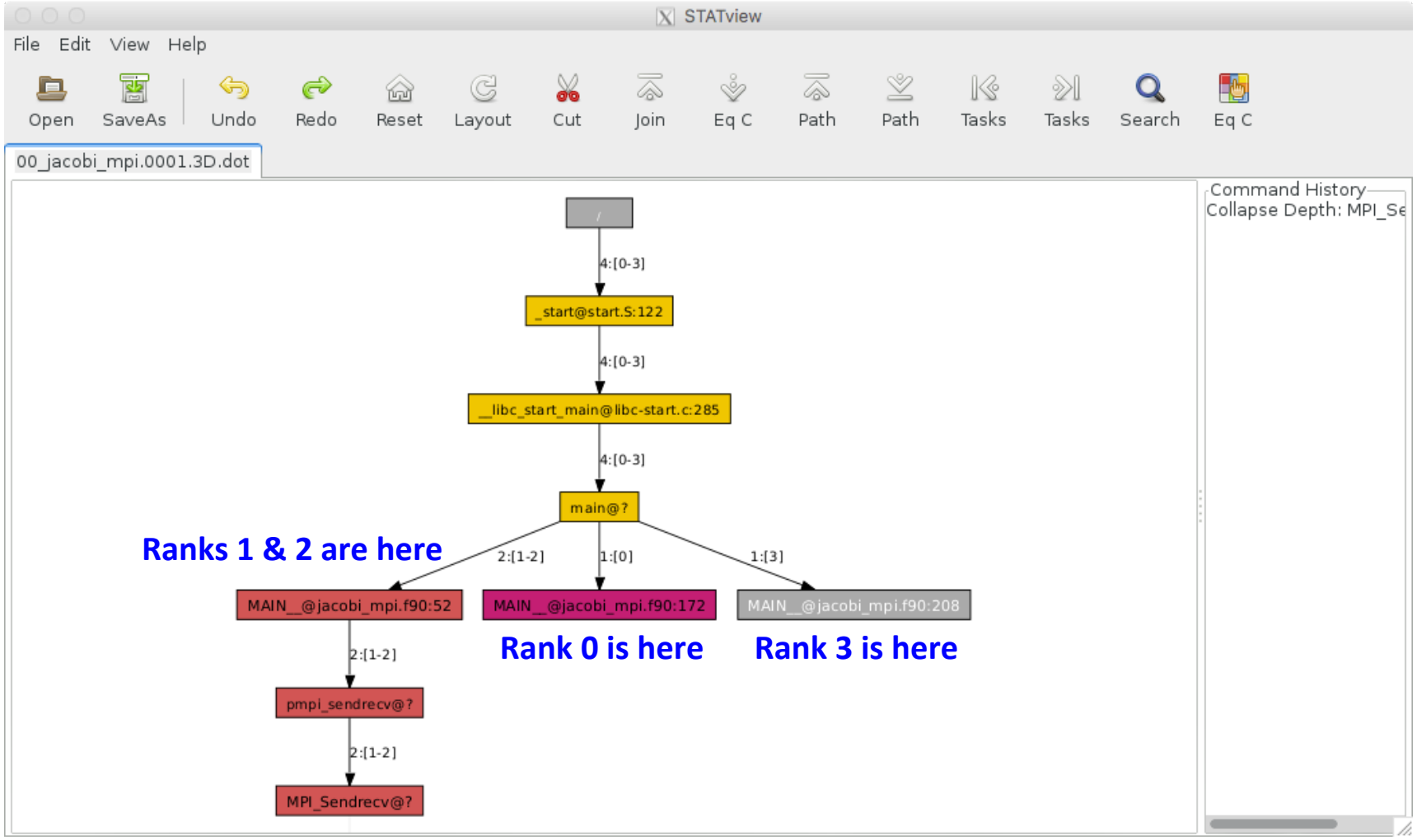
```
$ salloc -N 1 -t 30:00 -p debug -C knl,quad,cache
...
$ srun -n 4 ./jacobi_mpi &
[1] 93834
$ module load stat
$ stat-cl -i 93834
```
-i to get source line numbers

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/

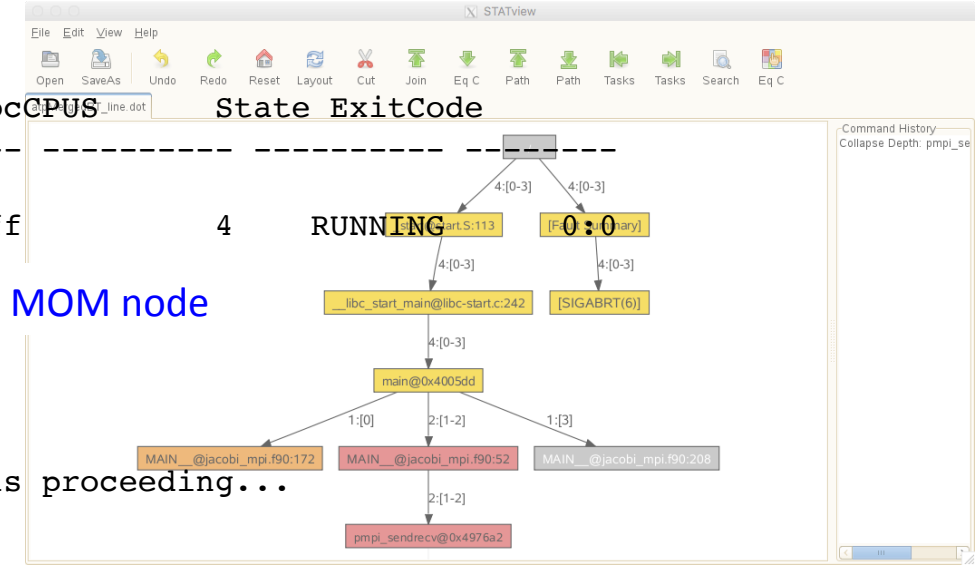
Hung application with ATP

- **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
JobID    JobName  Partition    Account  AllocCPUS      State ExitCode
------------ ---------- ---------- ---------- ---------- ---------- --------
...
4097861.0    jacobi_mp+                 nstaff          4    RUNNING      0:0
...
$ ssh edimom02
$ 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
```

Find the job step ID

Kill the application on a MOM node



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
...
 MB
120.4^                                                                #
     |                                                              :::#
     |                                                         :::: :#
     |                                                        :::: : :#
     |                                                    ::::: :: : :#
     |                                                   :: : : :: : :#
     |                                             ::@@:: : : :: : :#
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     |                                        :::: : @ :: : : :: : :#
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     |                                 ::: :: : :: : @ :: : : :: : :#
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     |                          ::@: : : :: : :: : @ :: : : :: : :#
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     |              :::::: : :: : : @: : : :: : :: : @ :: : : :: : :#
     |              @@: : :: : :: : : @: : : :: : :: : @ :: : : :: : :#
   0 +------------------------------------------------------------------------>Mi
     0                                                                 628.0
```

time (instructions executed)

```
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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