# Applying the "Whack-a-Mole" Method Using Cray's Perftools for Identifying the Moles

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# Outline

- What is the “Whack-a-mole” process?
- Short introduction to perftools-lite
- Applications to be examined
  - UMT
  - Leslie3d
  - VH1

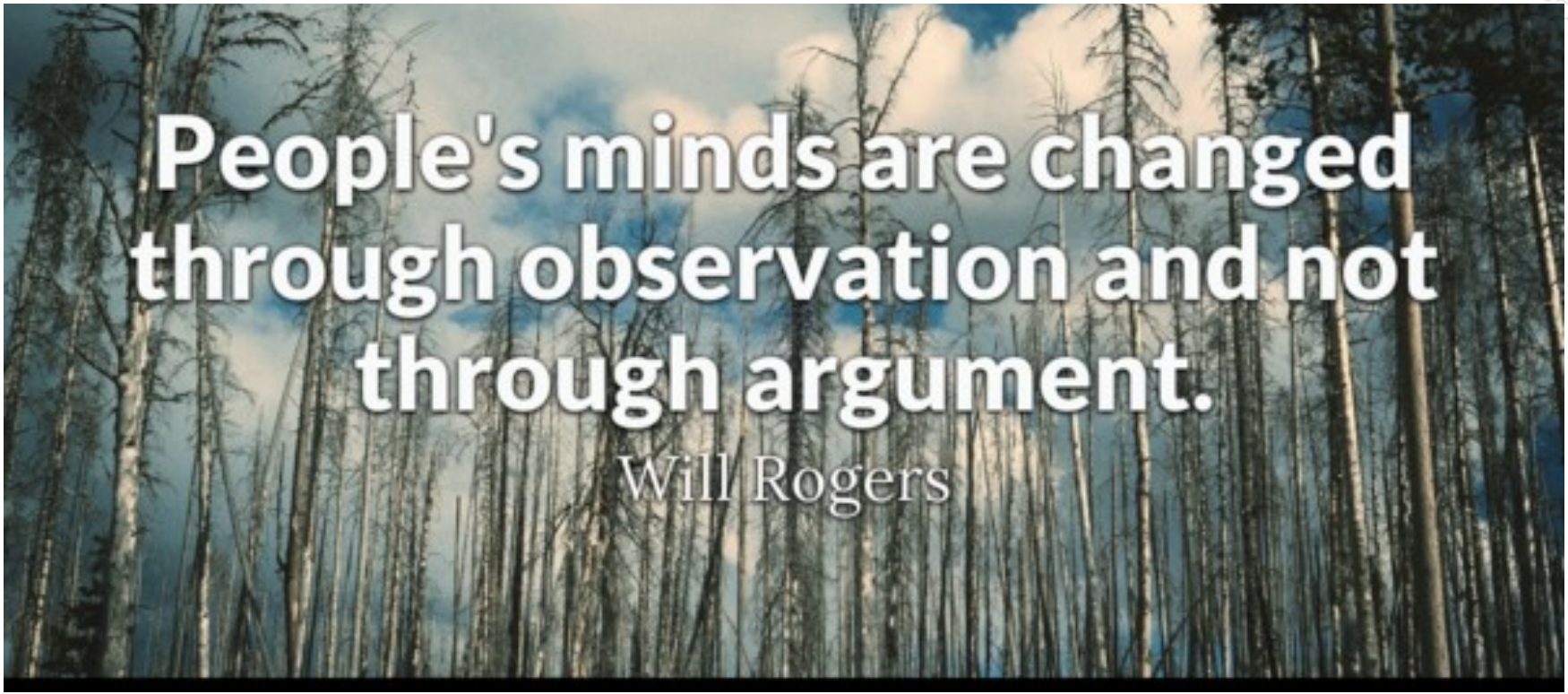
# Ricky Kendall 1961 - 2014

- John met Ricky in 1993 when he visited APR to evaluate FORGE
  - Taught him to use "." in vi
- Worked extensively with Ricky for many years at ORNL (AUG 2005 – 2014)

# Applying a “Whack-a-mole” Method Using Cray’s perftools to Identify the Moles

- Ricky Kendal used the phase extensively
- The *Mole* is the most time consuming process in the application
- *Whacking* it means you optimize the process so it no longer takes the most time

# Do Not Assume You Know Your Application Profile



# Cray Performance Tools

- Reduce the time investment associated with porting and tuning applications on Cray systems
- Analyze whole-program behavior across many nodes to identify critical performance bottlenecks within a program
- Improve your profiling experience by using simple (lite mode) and/or advanced interfaces for a wealth of capability that targets analyzing large HPC jobs

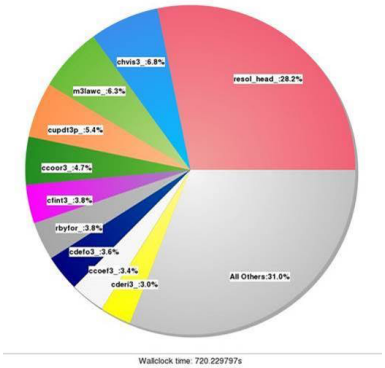
# Interfaces Available

- **Simple interface (perftools-lite modes) for convenience**
- **Advanced interface (perftools) for in-depth performance investigation and tuning assistance as well as data collection control**
- **Both offer:**
  - Whole program analysis across many nodes
  - Indication of causes of problems
  - Ability to easily switch between the two interfaces

New!

# pat_run

**Profile pre-existing, dynamically linked programs**




**Collect different performance data for same binary**

**Get basic performance information on ISV codes**

# What is it?

***Utility that allows you to profile un-instrumented, dynamically linked binaries with CrayPat!***

- **Delivers Cray performance tools profiling information for codes that cannot be rebuilt**
  - **ISV codes** (where pre-built binaries or object files are supplied instead of source)
  - **Codes with long compile times**
- **Extends perftools ease-of-use and supports an even greater range of HPC applications**
  - OpenFoam was profiled successfully with pat_run!

# pat_run Advantages

- Reduced steps to get application performance data
- No need to re-compile to obtain basic performance data
- Different performance experiments can be collected with the same binary
- No perftools modules required during compile or link
- Performance analysis on executable files stripped of their global symbol tables

# Basic Usage

- Use perftools-base/7.0.1 or later
- **aprun/srun –n 16 pat_run ./my_program**
  - Perform other experiments like
    - `pat_run -g mpi ./my_program`
- **pat_report exp_data_directory > my_report**
  - Use all of your favorite pat_report options, such as
    - `pat_report –P –O calltree`
    - `pat_report –s pe=ALL`

# Helpful perftools Experiments

- **Identify slowest areas and notable bottlenecks of a program**
  - Use **`perftools-lite`**
  - Good for examining performance characteristics of a program and for scaling analysis
- **Focus on loop optimization, including adding OpenMP with Reveal**
  - Use **`perftools-lite-loops`**
  - Use **`perftools-lite-hbm`** for memory bandwidth sensitivity study
- **Focus on MPI communication**
  - Use `perftools-lite` first to determine if MPI time is dominant or if there is a load imbalance between ranks
  - Use **`perftools`** `(pat_build –g mpi)` to collect more detailed MPI-specific information
  - Good for scaling analysis at targeted final job size

# Used in this Tutorial

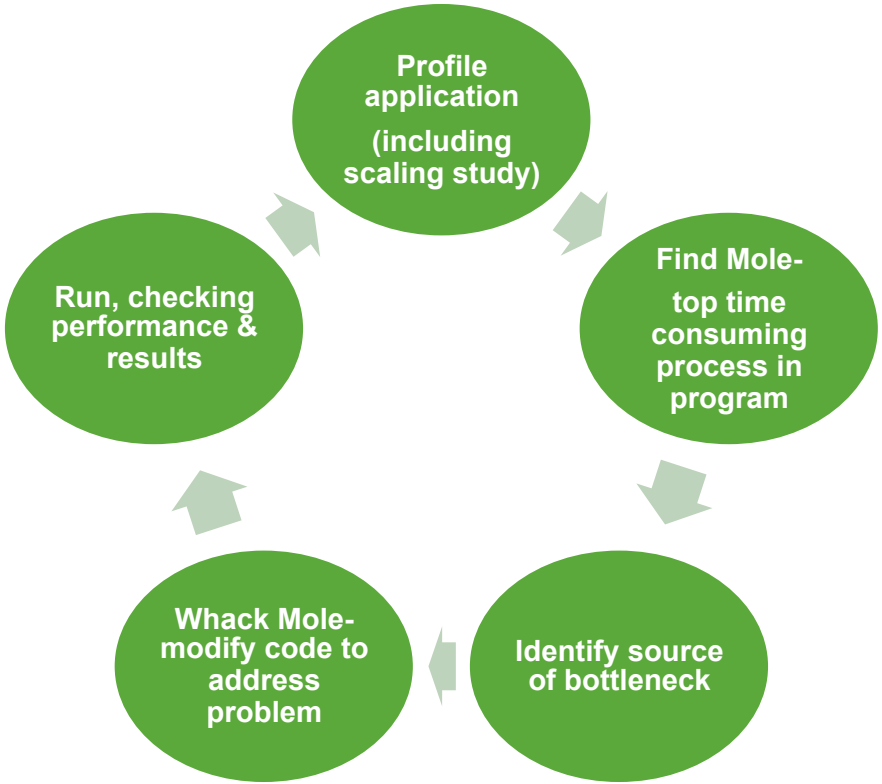
- **Several perftools-lite modes**
  - Simply load the desired module, compile, and execute program
- **Additional reports (pat_report –O calltree, etc.)**
- **perftools advanced interface**
  - Load perftools module and build program
  - Instrument program with pat_build -u -g mpi
  - Execute instrumented program
  - Create performance reports with pat_report
- **Cray compiler (CCE) listing generated by -hlist=a**
- **Levesque's and Heidi's bag of tricks**

# Whack-a-mole Process

- **Profile your *working* application**
  - On the problem of interest at the scale of interest
  - Don't think you know where the mole is and more importantly why it's the most important bottleneck in the program
  - Performance on a single node is *not* necessarily representative of performance on 1000 nodes

Unless everything scales, routines that scale will not be important at 1000 nodes

# Whack-a-mole Process (continued)



# Using the Process on Real Applications

UMT

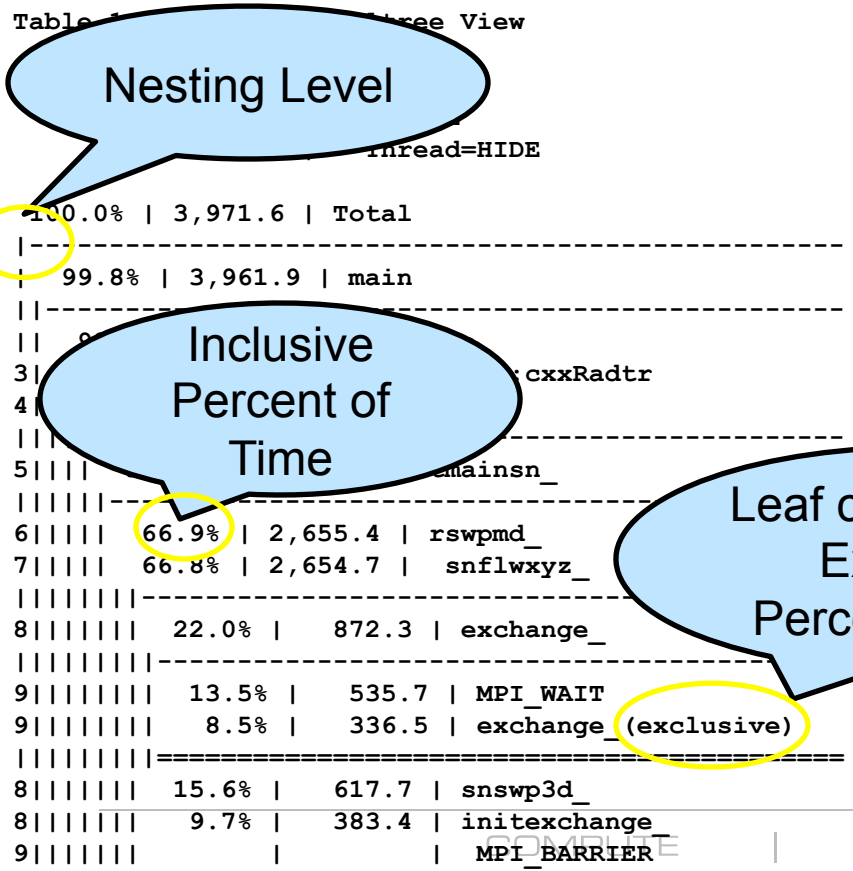
Leslie3d

VH1

# UMT

The UMT benchmark is a 3D, deterministic, multi-group, photon transport code for unstructured meshes

# UMT Call Tree on 8 Nodes

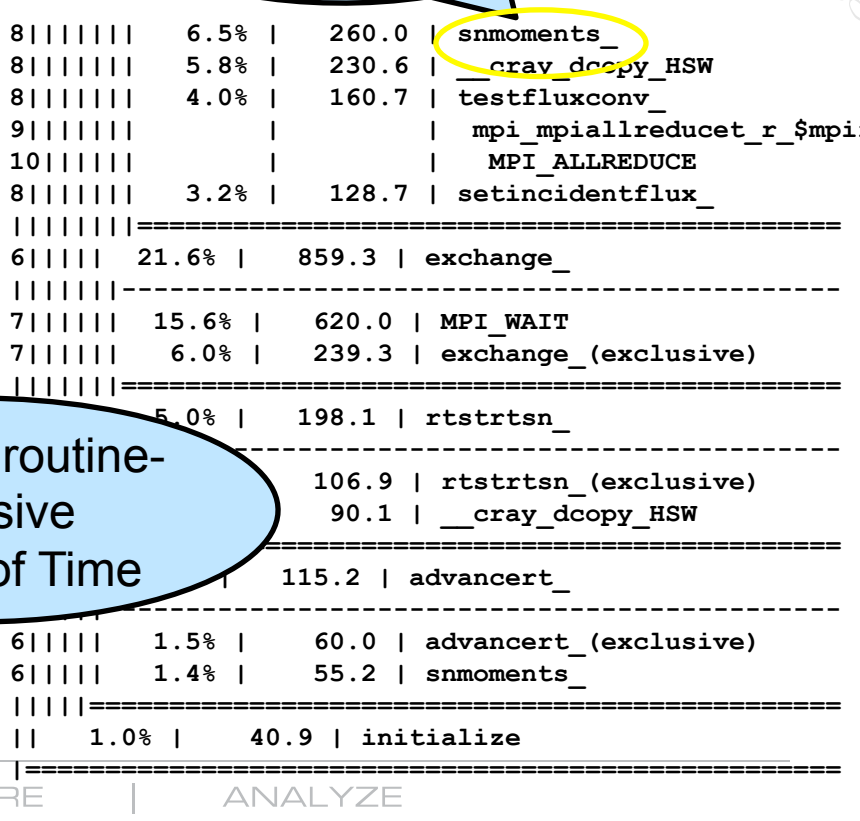



Nesting Level

Inclusive Percent of Time

Called From snflwxyz_

Leaf child routine- Exclusive Percent of Time



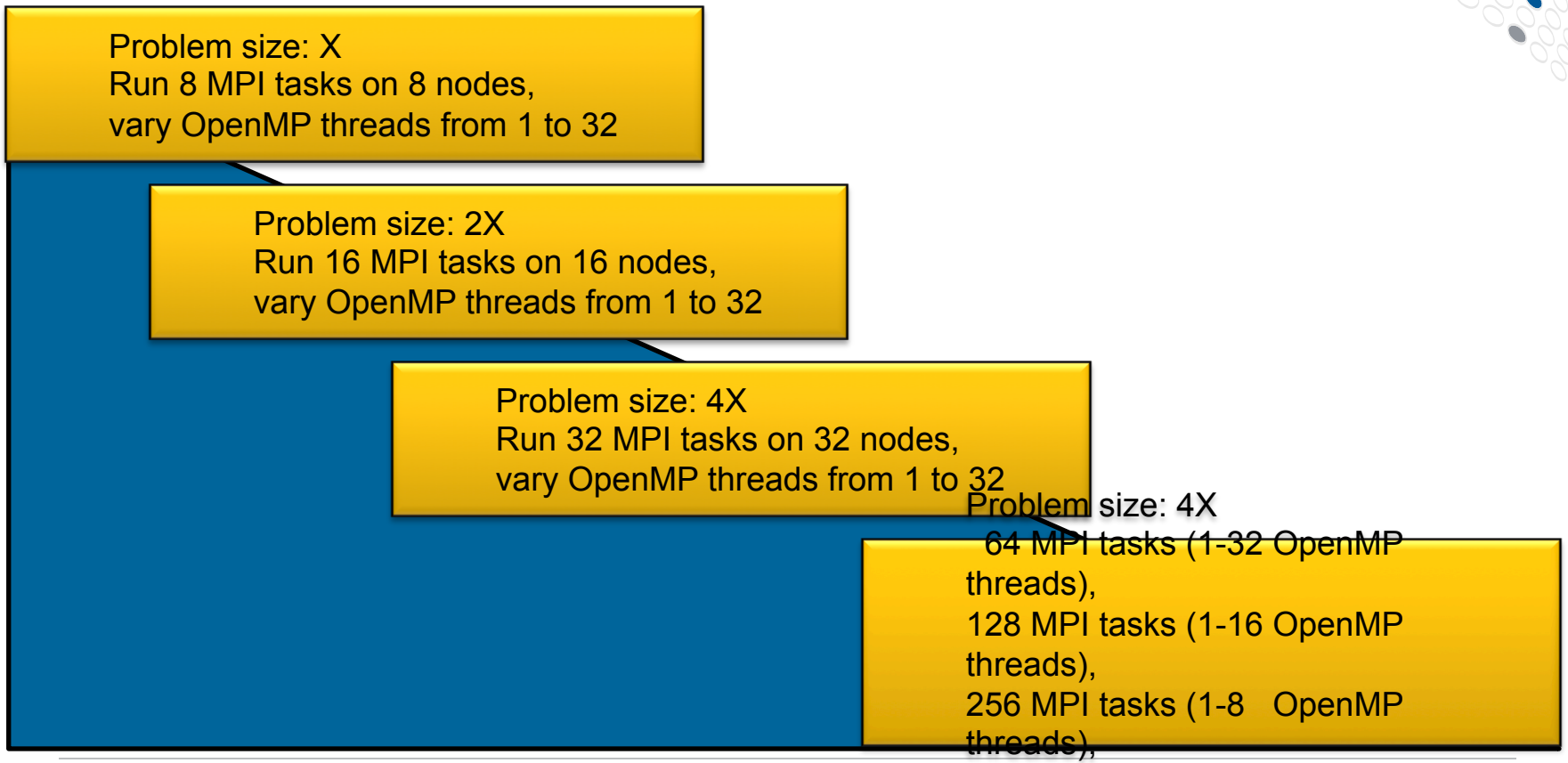
# Obtaining a Calltree

- Run pat_report with different options after collecting data with perftools-lite to get different views of the performance data

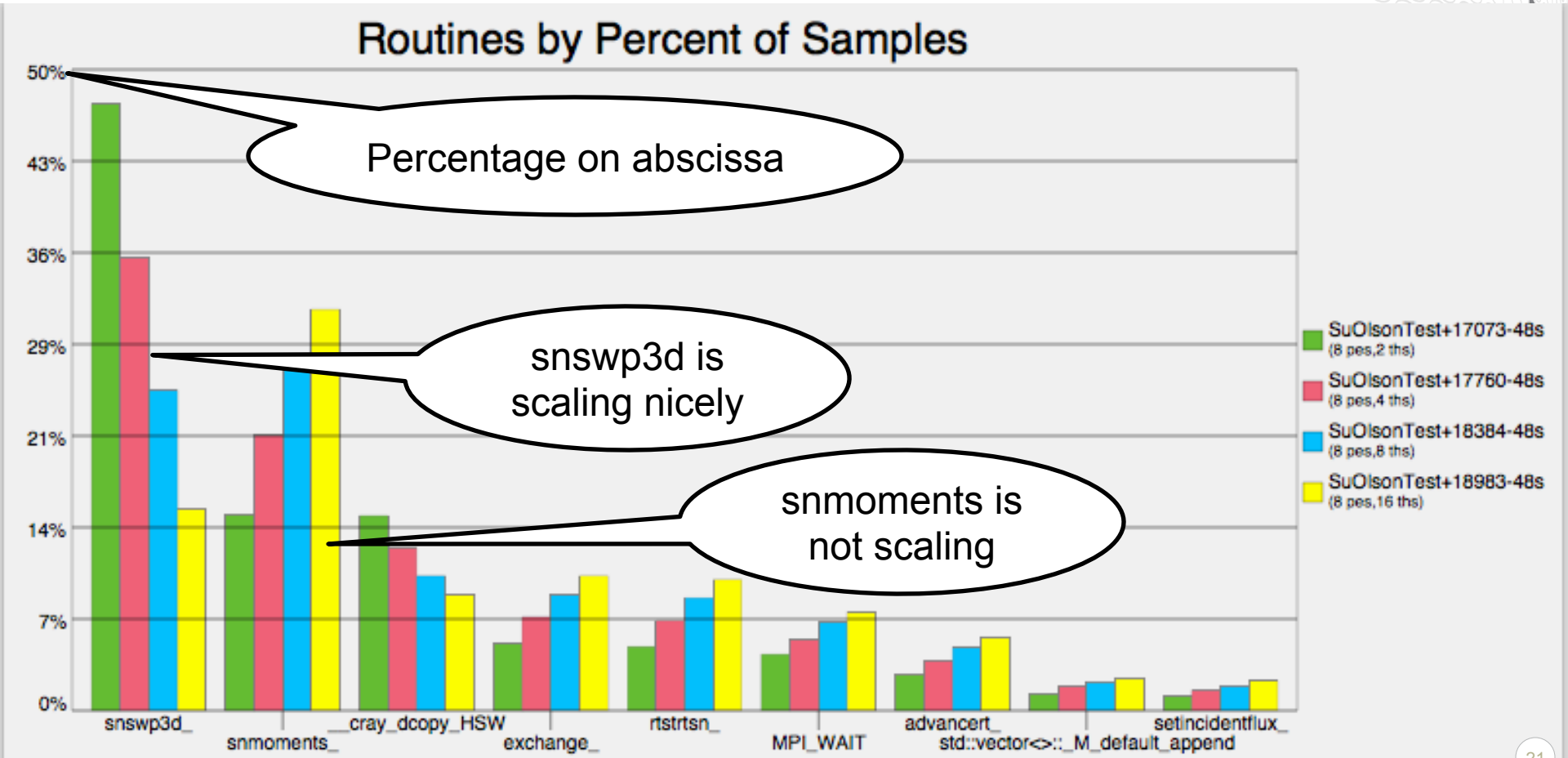
- For a calltree:

```
$ pat_report –O calltree exp_dir > rpt.calltree
```

# Plan of Attack – Run Weak/Strong Scaling Study



# UMT Scaling with MPI Tasks and OpenMP Threads



# Observations

- **OpenMP on the node is not doing well above 4 threads**
  - Need to find out why
- **MPI scaling is good, however**
  - At higher MPI counts threading slows down the application

# Using Listing: Existing OpenMP in SNSWP3D

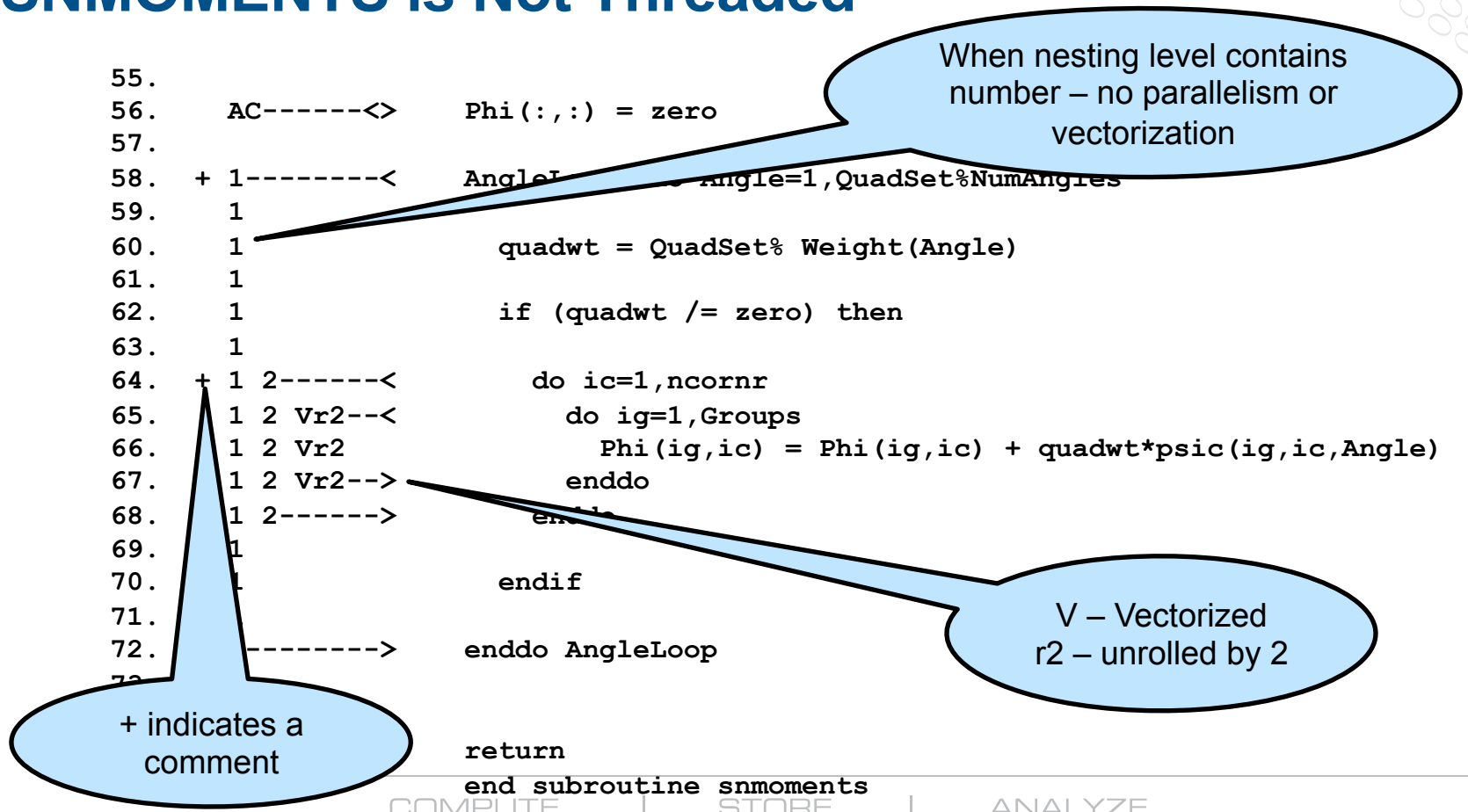
```
105.     1 2 M-----< !$OMP PARALLEL DO  PRIVATE(Angle,mm,thnum)
106.   + 1 2 M m---<        AngleLoop: do mm=1,NangBin
107.     1 2 M m
108.     1 2 M m             Angle = QuadSet% AngleOrder(mm,binSend)
109.     1 2 M m             thnum = 1
110.     1 2 M m             thnum = OMP_GET_THREAD_NUM() + 1
111.     1 2 M m
112.     1 2 M m     !       Set angular fluxes for reflected angles
113.     1 2 M m
114.   + 1 2 M m             call snreflect(Angle, PSIB)
115.     1 2 M m
116.     1 2 M m     !       Sweep the mesh, calculating PSI for each corner; the
117.     1 2 M m     !       boundary flux array PSIB is also updated here.
118.     1 2 M m     !       Mesh cycles are fixed automatically.
119.     1 2 M m
120.   + 1 2 M m             call snswp3d(Groups, Angle,                              &
121.     1 2 M m                           QuadSet%next(1,Angle),QuadSet%nextZ(1,Angle),  &
122.     1 2 M m                           PSI(1,1,Angle),PSIB(1,1,Angle))
123.     1 2 M m
124.     1 2 M m-->>       enddo AngleLoop
```

Threaded Region

Threaded loop

Outer Loop of Nest

# SNMOMENTS is Not Threaded




```
55.
56.      AC------<>     Phi(:,:) = zero
57.
58.    + 1--------<     AngleL                Angle=1,QuadSet%NumAngles
59.      1
60.      1                quadwt = QuadSet% Weight(Angle)
61.      1
62.      1                if (quadwt /= zero) then
63.      1
64.    + 1 2------<         do ic=1,ncornr
65.      1 2 Vr2--<           do ig=1,Groups
66.      1 2 Vr2                Phi(ig,ic) = Phi(ig,ic) + quadwt*psic(ig,ic,Angle)
67.      1 2 Vr2-->           enddo
68.      1 2------>         end
69.      1
70.      1                endif
71.
72.      ---------->     enddo AngleLoop


                         return
                         end subroutine snmoments
```

# Obtaining a Listing

- CCE provides loopmark, cross-references, compile options, and optimization messages in easy-to-read text files
- Just add the following flag to Makefile:

```
-h list=a …
```

- Tip: For additional information on restructuring and optimization changes made by CCE, try `-h list=d` for decompiled code

# Before Adding Loop-level Parallelism

- **Determine loop lengths by using perftools-lite-loops**
  - Can only use when existing OpenMP in program is disabled
  - Remember that loops can change with job size (as MPI ranks increase)

Load perftools-lite-loops module
Build and run
View batch job output file or lite report in expdir/rpt-files/RUNTIME.rpt

# UMT Loop Profile (perftools-lite-loops)

Table 1: Inclusive and Exclusive Time in Loops (from -hprofile_generate)

| Loop Hit | | | Loop Trips Avg | Loop Trips Min | Loop Trips Max | Function=/.LOOP[.] PE=HIDE |
|---|---|---|---|---|---|---|
| 98.9% | 5213 | 0.000069 | 1 | 7.0 | 7 | 7 | main.LOOP.1.li.1 |
| 92.4% | .848820 | 0.000154 | 7 | 4.7 | 3 | 5 | rtmainsn_.LOOP.1 49 |
| 92.2% | 52.728532 | 0.000114 | 33 | 1.0 | 1 | 1 | rtmainsn_.LOOP .li.159 |
| 92.1% | 52.647694 | 0.000214 | 33 | 1.0 | 1 | 1 | rtmainsn_.LO .li.167 |
| 71.6% | 40.965850 | 0.000417 | 33 | 1.6 | 1 | 3 | snflwxyz_ OOP.1.li.87 |
| 59.3% | 33.937160 | 0.001694 | 54 | 6.9 | 4 | 8 | snflwxyz_.LOOP.2.li.95 |
| 44.0% | 25.175652 | 0.043310 | | | | 90 | snflwxyz_.LOOP.3.li.106 |
| 41.2% | 23.541605 | 0.052865 | | | | 28 | snswp3d_.LOOP.01.li.78 |
| 28.2% | 16.146745 | 3.884386 | | | | 8 | snswp3d_.LOOP.04.li.99 |
| 19.1% | 10.931600 | 0.000059 | | | | 8 | exchange_.LOOP.06.li.120 |
| 19.1% | 10.931541 | 10.931541 | | | | 6 | exchange_.LOOP.07.li.121 |
| 14.0% | 7.993231 | 1.052804 | 7, | | | 3 | snsw |
| 11.9% | 6.800924 | 6.800924 | 10, | | | 400 | |
| 8.2% | 4.692389 | 0.135064 | 937,440 | 8.0 | 8 | 8 | |
| 8.0% | 4.557325 | 4.557325 | 7,499,520 | 400.0 | 400 | 400 | snswp3d |
| 6.9% | 3.944975 | 0.000352 | 405 | 5.0 | 3 | 6 | exchan OOP.08.li.132 |
| 6.9% | 3.944623 | 1.409580 | 2,025 | 1.6 | 1 | 8 | excha .LOOP.09.li.134 |
| 5.8% | 3.312134 | 3.312134 | 7,499,520 | 3.0 | 3 | 3 | snsw p3d_.LOOP.05.li.110 |
| 5.0% | 2.864861 | 0.003020 | 40 | 720.0 | 720 | 720 | snmoments_.LOOP.1.li.58 |
| 5.0% | 2.861841 | 0.051047 | 28,800 | 224.0 | 224 | 224 | snmoments_.LOOP.2.li.64 |
| 4.9% | 2.810795 | 2.810795 | 6,451,200 | 400.0 | 400 | 400 | snmoments_.LOOP.3.li.65 |
| 4.7% | 2.700843 | 0.000089 | 405 | 1.6 | 1 | 8 | exchange_.LOOP.01.li.71 |

Ordered by loops that take most of the time

This is the loop with OpenMP

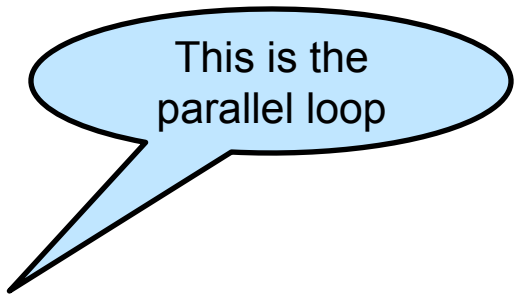
snmoments has nice loops lengths

# Profile Loops with Call Tree (1 of 2)

```
Table 1:  Function Calltree View
  Time% |      Time |     Calls | Calltree
        |           |           |  PE=HIDE

 100.0% | 57.147586 |        -- | Total
|-----------------------------------------------------
| 100.0% | 57.147550 |       2.0 | main
|  98.9% | 56.543299 |        -- |  main.LOOP.1.li.189
3        |           |           |   advance
4  98.9% | 56.538457 |        -- |    Teton<>::cxxRadtr
5  98.9% | 56.538442 |       7.0 |     radtr_
||||||-----------------------------------------------
6|||||  97.0% | 55.459264 |       7.0 | rtmainsn_
|||||||-----------------------------------------------
7||||||  92.5% | 52.838008 |        -- | rtmainsn_.LOOP.1.li.149
8||||||  92.3% | 52.719389 |        -- |  rtmainsn_.LOOP.2.li.159
9||||||  92.1% | 52.638677 |        -- |   rtmainsn_.LOOP.3.li.167
||||||||||-----------------------------------------------
10|||||||||  76.7% | 43.811029 |      33.0 | rswpmd_
11|||||||||  76.6% | 43.802991 |      33.0 |  snflwxyz_
||||||||||||-----------------------------------------------
12||||||||||  71.6% | 40.911652 |        -- | snflwxyz_.LOOP.1.li.87
|||||||||||||-----------------------------------------------
13||||||||||  59.3% | 33.883425 |        -- | snflwxyz_.LOOP.2.li.95
|||||||||||||-----------------------------------------------
14||||||||||  44.0% | 25.123658 |        -- | snflwxyz_.LOOP.3.li.106
```

Remember there is no threading in these samples



# Profile Loops with Call Tree (2 of 2)

```
14|||||||||||||  44.0% | 25.123658 |       -- | snflwxyz_.LOOP.3.li.106
15|||||||||||||  43.4% | 24.805902 | 33,480.0 |  snswp3d_
14|||||||||||||  15.3% |  8.759766 |    372.0 | exchange_
|||||||||||||||=========================================
13|||||||||||||   8.0% |  4.592279 |     54.0 | initexchange_
13|||||||||||||   2.9% |  1.654016 |     54.0 | testfluxconv_
13|||||||||||||   1.4% |  0.781868 |     54.0 | setincidentflux_
|||||||||||||||=========================================
12||||||||||||   4.1% |  2.363264 |     33.0 | snmoments_
||||||||||||||=========================================
10|||||||||  15.4% |  8.819869 |     33.0 | exchange_
|||||||||||=========================================
7|||||||   3.2% |  1.814788 |      7.0 | rtstrtsn_
|||||||||-----------------------------------------
8|||||||   1.8% |  1.002470 |      7.0 | rtstrtsn_(exclusive)
8|||||||   1.4% |  0.812278 |      7.0 | setbdy_
|||||||=========================================
6|||||   1.9% |  1.069855 |      7.0 | advancert_
|=========================================================
```

This is the parallel loop

This is the mole when snflxyz.106 is threaded

# Major Loop in SNMOMENTS (From Listing)

```
56.      AC------<>     Phi(:,:) = zero
57.
58.    + 1--------<     AngleLoop: do Angle=1,QuadSet%NumAngles
59.      1
60.      1                 quadwt = QuadSet% Weight(Angle)
61.      1
62.      1                 if (quadwt /= zero) then
63.      1
64.    + 1 2------<          do ic=1,ncornr
65.      1 2 Vr2--<            do ig=1,Groups
66.      1 2 Vr2                 Phi(ig,ic) = Phi(ig,ic) + quadwt*psic(ig,ic,Angle)
67.      1 2 Vr2-->            enddo
68.      1 2------>          enddo
69.      1
70.      1                 endif
71.      1
72.      1-------->     enddo AngleLoop
```

Notice that Phi is a reduction

# Questions About This Loop Nest

- **Do we want to parallelize on ANGLE?**
- **How do we handle a reduction operation on an array?**
  - This could be inefficient, or at least less efficient than parallelizing on a different loop

# Reductions On An Array Is An Issue

This infortmation is obtained from a perftools-lite-loops run:

```
|  5.0% |  2.864861 |  0.003020 |         40 | 720.0 |   720 |   720 | snmoments_.LOOP.1.li.58
|  5.0% |  2.861841 |  0.051047 |     28,800 | 224.0 |   224 |   224 | snmoments_.LOOP.2.li.64
|  4.9% |  2.810795 |  2.810795 |  6,451,200 | 400.0 |   400 |   400 | snmoments_.LOOP.3.li.65
```

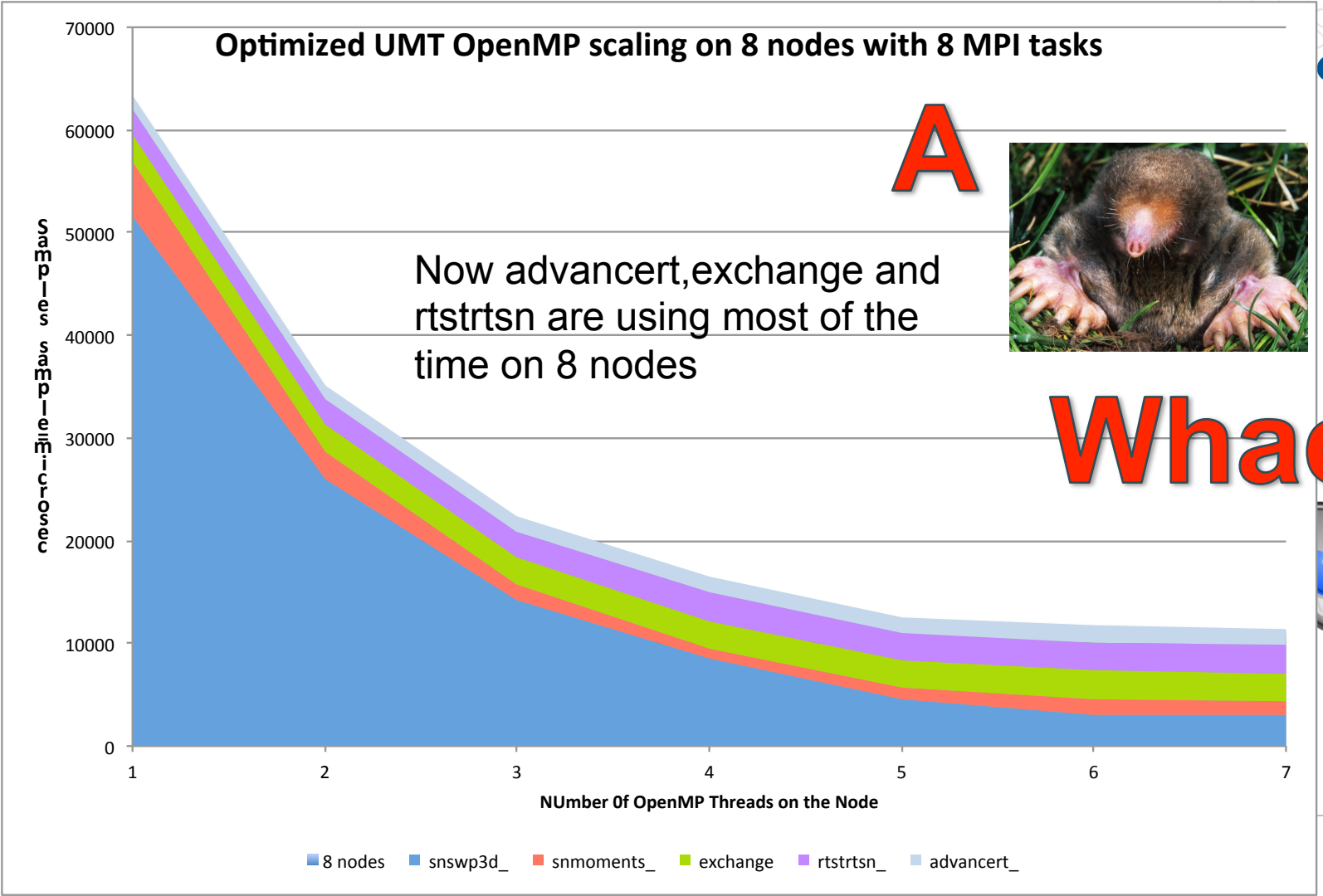
```
56.     AC---------<>    Phi(:,:) = zero
57.     MV----------< !$OMP PARALLEL DO PRIVATE(angle,quadwt,ic,ig) reduction(+:PHI(:400,:224))
58.   + MV m--------<    AngleLoop: do Angle=1,QuadSet%NumAngles
59.     MV m
60.     MV m               quadwt = QuadSet% Weight(Angle)
61.     MV m
62.     MV m               if (quadwt /= zero) then
63.     MV m
64.   + MV m 3------<        do ic=1,ncornr
65.     MV m 3 Vr2--<         do ig=1,Groups
66.     MV m 3 Vr2              Phi(ig,ic) = Phi(ig,ic) + quadwt*psic(ig,ic,Angle)
67.     MV m 3 Vr2-->         enddo
68.     MV m 3------>        enddo
69.     MV m
70.     MV m               endif
71.     MV m
72.     MV m-------->>   enddo AngleLoop
```

These do not need to be constant in new OpenMP standard

# Parallelizing on Different Loop

```
56.      AC--------<>    Phi(:,:) = zero
57.      M----------< !$OMP PARALLEL DO PRIVATE(ic,angle,quadwt,ig)
58.    + M m--------<    CornerLoop: do ic=1,ncornr
59.    + M m 3------<    AngleLoop: do Angle=1,QuadSet%NumAngles
60.      M m 3
61.      M m 3             quadwt = QuadSet% Weight(Angle)
62.      M m 3
63.      M m 3             if (quadwt /= zero) then
64.      M m 3
65.      M m 3 Vr2--<          do ig=1,Groups
66.      M m 3 Vr2               Phi(ig,ic) = Phi(ig,ic) + quadwt*psic(ig,ic,Angle)
67.      M m 3 Vr2-->          enddo
68.      M m 3
69.      M m 3             endif
70.      M m 3
71.      M m 3------>    enddo AngleLoop
72.      M m------->>    enddo CornerLoop
```

Pull the ic loop outside the angle loop…


Optimized UMT OpenMP scaling on 8 nodes with 8 MPI tasks
Samples sampled in Vtune
70000
60000
50000
40000
30000
20000
10000
0
1
2
3
4
5
6
7
NUmber 0f OpenMP Threads on the Node
8 nodes
snswp3d_
snmoments_
exchange
rtstrtsn_
advancert_
A
Now advancert,exchange and rtstrtsn are using most of the time on 8 nodes
Whacked

# Major Loop in RTSTRTSN

```
51.   + F---------------<       ZoneLoop: do zone=1,nzones
52.     F I                     Z => getZoneData(Geom, zone)
53.     F                       nCorner = Z% nCorner
54.     F                       c0      = Z% c0
55.   + F 2-------------<       do ia=1,Size%nangSN
56.     F 2 C-----------<         do c=1,nCorner
57.     F 2 C VCr2-----<>           Z% STime(:,c,ia) = tau*psir(:,c0+c,ia)
58.     F 2 C----------->         enddo
59.     F 2------------->       enddo
60.     F--------------->     enddo ZoneLoop
```

# Parallelized Using OpenMP

```
51.     M------------------< !$OMP PARALLEL DO PRIVATE(zone,nCorner,c0,ia,c)
52.   + M mF---------------<       ZoneLoop: do zone=1,nzones
53.     M mF I                      Z => getZoneData(Geom, zone)
54.     M mF                        nCorner = Z% nCorner
55.     M mF                        c0      = Z% c0
56.   + M mF 3-------------<        do ia=1,Size%nangSN
57.     M mF 3 C-----------<          do c=1,nCorner
58.     M mF 3 C VCr2-----<>            Z% STime(:,c,ia) = tau*psir(:,c0+c,ia)
59.     M mF 3 C----------->          enddo
60.     M mF 3------------->        enddo
61.     M mF-------------->>      enddo ZoneLoop
```

For the zone loop, the average length is 824 on 8 MPI Tasks and only 14 when using 512 MPI Tasks

# One of Two Major Loops in Exchange

```
 88.     1 2                  !  Loop over exiting angle, boundary element pairs for this communicat
 89.     1 2
 90.   + 1 2 3------------<           do ia=1,NangBin
 91.     1 2 3                       Angle = QuadSet% AngleOrder(ia,bin)
 92.     1 2 3                       nsend = Comm% nsend(ia)
 93.     1 2 3
 94.   + 1 2 3 4----------<           do i=1,nsend
 95.     1 2 3 4
 96.     1 2 3 4                       ib = Comm% ListSend(nsend0+i)
 97.     1 2 3 4
 98.   + 1 2 3 4 Vpr2-----<           do ig=1,ngroups
 99.     1 2 3 4 Vpr2                  Comm% psibsend(message+ig) = psib(ig,ib,Angle)
100.     1 2 3 4 Vpr2----->           enddo
101.     1 2 3 4
102.     1 2 3 4                     message = message + ngroups
103.     1 2 3 4
104.     1 2 3 4---------->          enddo
105.     1 2 3                       nsend0 = nsend0 + nsend
106.     1 2 3------------>         enddo
```

# Some Major Problems with This Exchange Loop

- **message** and **send0** illustrate loop carried dependencies
- Must restructure to enable parallelization

# Exchange Loop Restructured & Parallelized

```
 93.     1 2                  ! scalar setup loop
 94.   + 1 2 r4-------------<            do ia=1,NangBin
 95.     1 2 r4                           vmessage(ia) = message
 96.     1 2 r4                           vnsend0(ia) = nsend0
 97.     1 2 r4                           nsend = Comm% nsend(ia)
 98.     1 2 r4                           message = message + nsend * ngroups
 99.     1 2 r4                           nsend0 = nsend0 + nsend
100.     1 2 r4------------->            enddo
101.     1 2
102.     1 2 M--------------< !$OMP PARALLEL DO PRIVATE(IA,Angle,nsend,i,ib,ig,message,nsend0)
103.   + 1 2 M m------------<            do ia=1,NangBin
104.     1 2 M m                          message = vmessage(ia)
105.     1 2 M m                          nsend0 = vnsend0(ia)
106.     1 2 M m
107.     1 2 M m                          Angle = QuadSet% AngleOrder(ia,bin)
108.     1 2 M m                          nsend = Comm% nsend(ia)
109.     1 2 M m
110.   + 1 2 M m 5----------<             do i=1,nsend
111.     1 2 M m 5
112.     1 2 M m 5                          ib = Comm% ListSend(nsend0+i)
113.     1 2 M m 5
114.   + 1 2 M m 5 Vpr2-----<             do ig=1,ngroups
115.     1 2 M m 5 Vpr2                     Comm% psibsend(message+ig) = psib(ig,ib,Angle)
116.     1 2 M m 5 Vpr2----->             enddo
117.     1 2 M m 5
118.     1 2 M m 5                          message = message + ngroups
119.     1 2 M m 5
120.     1 2 M m 5---------->             enddo
121.     1 2 M m                          nsend0 = nsend0 + nsend
122.     1 2 M m----------->>            enddo
```

# Major Loop in AdvanceRT

```
136.     Fr2 I                    Z       => getZoneData(Geom, zone)
137.     Fr2
138.     Fr2                      nCorner = Z% nCorner
139.     Fr2                      c0      = Z% c0
140.     Fr2                      PhiAve  = zero
141.     Fr2
142.   + Fr2 2-----------<        do c=1,nCorner
143.     Fr2 2                      volumeRatio = Z% VolumeOld(c)/Z% Volume(c)
144.     Fr2 2 Vr2-------<>         Phi(:,c0+c) = Phi(:,c0+c)*volumeRatio
145.     Fr2 2
146.   + Fr2 2 3---------<          do ia=1,numAngles
147.     Fr2 2 3 Vr2-----<>           psir(:,c0+c,ia) = psir(:,c0+c,ia)*volumeRatio
148.     Fr2 2 3---------->         enddo
149.     Fr2 2
150.     Fr2 2                      sumRad = zero
151.     Fr2 2 Vr4--------<         do ig=1,ngr
152.     Fr2 2 Vr4                    sumRad = sumRad + Phi(ig,c0+c)
153.     Fr2 2 Vr4-------->         enddo
154.     Fr2 2
155.     Fr2 2                      PhiAve = PhiAve + Z% Volume(c)*sumRad
156.     Fr2 2
157.     Fr2 2------------>       enddo
```

# AdvanceRT Loop Parallelized with OpenMP

```
134.  + F-----------------<    ZoneLoop2: do zone=1,nzones
135.    F
136.    F M--------------< !$OMP PARALLEL PRIVATE(c,volumeRatio,ia,sumRad,ig)
137.    F M I                   Z       => getZoneData(Geom, zone)
138.    F M
139.    F M                     nCorner = Z% nCorner
140.    F M                     c0      = Z% c0
141.    F M                     PhiAve  = zero
142.    F M                  !$OMP DO  REDUCTION(+:PhiAve)
143.  + F M m------------<      do c=1,nCorner
144.    F M m                     volumeRatio = Z% VolumeOld(c)/Z% Volume(c)
145.    F M m Vr2-------<>        Phi(:,c0+c) = Phi(:,c0+c)*volumeRatio
146.    F M m
147.  + F M m 4----------<        do ia=1,numAngles
148.    F M m 4 Vr2-----<>          psir(:,c0+c,ia) = psir(:,c0+c,ia)*volumeRatio
149.    F M m 4---------->        enddo
150.    F M m
151.    F M m                     sumRad = zero
152.    F M m Vr4--------<        do ig=1,ngr
153.    F M m Vr4                   sumRad = sumRad + Phi(ig,c0+c)
154.    F M m Vr4-------->        enddo
155.    F M m
156.    F M m                     PhiAve = PhiAve + Z% Volume(c)*sumRad
157.    F M m
158.    F M m------------>      enddo
159.    F M--------------> !$OMP END PARALLEL
```

Z is a pointer in a module and it must be made threadprivate and set by all threads

# Some Results

- **Fastest 8 node configuration:**
  - 8 MPI ranks and 8 threads
- **Fastest 32 node configuration:**
  - 256 MPI tasks and 4 threads on 32 nodes

# 8 Node Configuration

Original

```
Table 1:  Profile by Function
  Samp% |      Samp |  Imb.  |  Imb.  | Group
        |           |  Samp  | Samp%  |  Function=[MAX10]
        |           |        |        |   PE=HIDE
        |           |        |        |    Thread=HIDE

 100.0% | 27,861.2 |    -- |    -- | Total
|-----------------------------------------------------
|  79.4% | 22,111.1 |    -- |    -- | USER
||----------------------------------------------------
||  27.0% |  7,508.6 |  66.4 |  1.0% | snmoments_
||  23.2% |  6,453.2 |  73.8 |  1.3% | snswp3d_
||   9.5% |  2,636.0 |  23.0 |  1.0% | exchange_
||   8.9% |  2,488.8 |  24.2 |  1.1% | rtstrtsn_
||   4.9% |  1,378.6 |   6.4 |  0.5% | advancert_
||   2.2% |    619.4 |  66.6 | 11.1% | double* std::__un
||   2.0% |    561.4 |   8.6 |  1.7% | setincidentflux_
||====================================================
|  11.6% |  3,219.2 |    -- |    -- | ETC
||----------------------------------------------------
||  10.8% |  3,011.9 | 107.1 |  3.9% | __cray_dcopy_HSW
||====================================================
|   9.0% |  2,518.9 |    -- |    -- | MPI
||----------------------------------------------------
||   7.3% |  2,033.1 | 184.9 |  9.5% | MPI_WAIT
|====================================================
```

Optimized

```
Table 1:  Profile by Function
  Samp% |      Samp | Imb.  |  Imb.  | Group
        |           | Samp  | Samp%  |  Function=[MAX10]
        |           |       |        |   PE=HIDE
        |           |       |        |    Thread=HIDE

 100.0% | 15,762.0 |   -- |    -- | Total
|-----------------------------------------------------
|  67.6% | 10,658.9 |   -- |    -- | USER
||----------------------------------------------------
||  41.3% |  6,509.0 | 37.0 |  0.6% | snswp3d_
||   5.8% |    917.6 | 10.4 |  1.3% | snmoments_.LOOP@li.58
||   3.9% |    620.6 | 65.4 | 10.9% | double* std::__uninit
||   3.5% |    557.4 |  8.6 |  1.7% | setincidentflux_
||   3.5% |    551.4 |  2.6 |  0.5% | rtstrtsn_.LOOP@li.51
||   2.2% |    350.4 |  5.6 |  1.8% | advancert_.LOOP@li.142
||   2.1% |    338.5 | 16.5 |  5.3% | exchange_.LOOP@li.103
||   2.1% |    334.6 |  9.4 |  3.1% | exchange_.LOOP@li.178
||====================================================
|  20.1% |  3,168.6 |   -- |    -- | ETC
||----------------------------------------------------
||  18.7% |  2,949.2 | 94.8 |  3.6% | __cray_dcopy_HSW
||====================================================
|  12.1% |  1,904.5 |   -- |    -- | MPI
||----------------------------------------------------
||  10.5% |  1,653.0 | 66.0 |  4.4% | MPI_WAIT
|====================================================
```

# 32 Node Configuration

Original

Optimized

```
Table 1:  Profile by Function

  Samp% |    Samp |  Imb. |  Imb. | Group
        |         |  Samp | Samp% |  Function=[MAX10]
        |         |       |       |   PE=HIDE
        |         |       |       |    Thread=HIDE

 100.0% | 4,015.1 |    -- |    -- | Total
|-----------------------------------------------
|  47.9% | 1,924.6 |    -- |    -- | MPI
||----------------------------------------------
||  29.6% | 1,190.3 | 452.7 | 27.7% | MPI_WAIT
||  13.4% |   537.8 | 616.2 | 53.6% | MPI_BARRIER
||   4.7% |   188.6 | 239.4 | 56.2% | MPI_ALLREDUCE
||==============================================
|  43.8% | 1,760.5 |    -- |    -- | USER
||----------------------------------------------
||  14.1% |   567.9 |  46.1 |  7.5% | snswp3d_
||  13.9% |   558.1 | 166.9 | 23.1% | exchange_
||   7.5% |   300.1 |  11.9 |  3.8% | snmoments_
||   3.1% |   124.6 |  41.4 | 25.1% | setincidentflux_
||   2.6% |   103.6 |   3.4 |  3.2% | rtstrtsn_
||   1.4% |    58.1 |   2.9 |  4.8% | advancert_
||==============================================
|   8.0% |   320.6 |    -- |    -- | ETC
||----------------------------------------------
||   7.7% |   310.6 |  51.4 | 14.2% | __cray_dcopy_HSW
|===============================================
```

```
Table 1:  Profile by Function

  Samp% |    Samp |  Imb. |  Imb. | Group
        |         |  Samp | Samp% |  Function=[MAX10]
        |         |       |       |   PE=HIDE
        |         |       |       |    Thread=HIDE

 100.0% | 3,651.9 |    -- |    -- | Total
|-----------------------------------------------
|  54.7% | 1,998.8 |    -- |    -- | MPI
||----------------------------------------------
||  37.2% | 1,360.0 | 444.0 | 24.7% | MPI_WAIT
||  12.3% |   447.6 | 668.4 | 60.1% | MPI_BARRIER
||   5.1% |   184.8 | 269.2 | 59.5% | MPI_ALLREDUCE
||==============================================
|  35.6% | 1,299.8 |    -- |    -- | USER
||----------------------------------------------
||  15.9% |   581.5 |  44.5 |  7.1% | snswp3d_
||   4.4% |   161.0 |  60.0 | 27.3% | exchange_.LOOP@li.103
||   4.2% |   154.4 |   3.6 |  2.3% | snmoments_.LOOP@li.58
||   3.5% |   127.8 |  50.2 | 28.3% | setincidentflux_
||   3.0% |   110.6 |  86.4 | 44.1% | exchange_.LOOP@li.178
||   1.8% |    67.0 |   2.0 |  2.9% | rtstrtsn_.LOOP@li.51
||==============================================
|   9.0% |   328.6 |    -- |    -- | ETC
||----------------------------------------------
||   8.6% |   314.5 |  39.5 | 11.2% | __cray_dcopy_HSW
|===============================================
```

# Not Real Exciting Speedup at 32 Nodes; However, ??

- **Have we looked at everything?**
  - Vectorization 
  - Parallelization 
  - Memory Utilization 

# Perftools-lite-hbm Results

```
Table 5:  Profile by Group, Function, and Line

  Samp% |  Samp | Imb. |  Imb. |  MEM_LOAD_UOPS_RETIRED |   RESOURCE_STALLS | Group
        |       | Samp | Samp% |     :HIT_LFB:precise=2 |             :ANY |  Function=[MAX10]
        |       |      |       |                        |                   |   Source
        |       |      |       |                        |                   |    Line
        |       |      |       |                        |                   |     PE=HIDE

 100.0% | 862.5 |   -- |    -- | 89,509,042,630,218,624 | 1,722,469,802,124 | Total
|-------------------------------------------------------------------------------------
|  62.4% | 537.9 |   -- |    -- | 56,224,626,618,220,104 |   991,877,756,035 | USER
||------------------------------------------------------------------------------------
||  31.2% | 269.1 |   -- |    -- | 28,464,157,033,148,192 |   608,254,074,506 | snswp3d_
3|       |       |      |       |                        |                   |  snswp3d.F90
||||---------------------------------------------------------------------------------
4|||   9.1% |  78.2 |  9.8 | 12.7% |  8,549,802,421,201,201 |   176,888,912,461 | line.92
4|||   1.2% |  10.0 |  6.0 | 42.9% |    879,609,303,122,411 |    22,751,971,753 | line.93
4|||   1.0% |   9.0 |  3.0 | 28.6% |    879,609,302,723,331 |    20,451,617,059 | line.95
4|||   1.1% |   9.9 |  7.1 | 47.9% |    879,609,302,703,468 |    22,293,446,105 | line.112
4|||   7.8% |  67.6 | 12.4 | 17.7% |  7,599,824,374,166,244 |   152,716,084,911 | line.128
4|||   1.4% |  12.2 |  2.8 | 21.0% |  1,337,006,139,902,300 |    27,724,424,302 | line.138
4|||   1.6% |  14.1 |  3.9 | 24.6% |  1,266,637,396,229,511 |    32,065,385,985 | line.206
4|||   4.6% |  39.2 |  8.8 | 20.8% |  4,151,755,908,199,040 |    88,460,785,924 | line.229
||||=================================================================================
||  15.3% | 132.2 |   -- |    -- | 14,179,301,951,169,120 |   150,304,652,642 | snmoments_
3|       |       |      |       |                        |                   |  snmoments.F90
4|  15.3% | 132.1 |  5.9 |  4.9% | 14,144,117,579,091,356 |   150,152,590,310 |   line.66
||   7.0% |  60.0 |   -- |    -- |  5,207,287,073,618,042 |   105,802,278,732 | exchange_
3|       |       |      |       |                        |                   |  exchange.F90
||||---------------------------------------------------------------------------------
4|||   5.2% |  44.9 |  4.1 |  9.6% |  3,588,805,956,844,644 |    77,368,597,030 | line.115
4|||   1.8% |  15.1 |  2.9 | 18.3% |  1,618,481,116,773,398 |    28,433,681,701 | line.190
```

# OMG – ARRAY SYNTAX

```
110.  + F 2 3-------------<        do icface=1,ncfaces
111.    F 2 3
112.    F 2 3                        afpm(icface) = omega(1)*Z%A_fp(1,icface,c) + &
113.    F 2 3                                       omega(2)*Z%A_fp(2,icface,c) + &
114.    F 2 3                                       omega(3)*Z%A_fp(3,icface,c)
115.    F 2 3
116.    F 2 3                        icfp     = Z%Connect(1,icface,c)
117.    F 2 3                        ib       = Z%Connect(2,icface,c)
118.    F 2 3
119.    F 2 3                        if ( afpm(icface) >= zero ) then
120.    F 2 3                          sumArea = sumArea + afpm(icface)
121.    F 2 3                        else
122.    F 2 3                          if (icfp == 0) then
123.    F 2 3 A----------<>              psifp(:,icface) = psib(:,ib)
124.    F 2 3                          else
125.    F 2 3 A----------<>              psifp(:,icface) = psic(:,icfp)
126.    F 2 3                          endif
127.    F 2 3
128.    F 2 3 Vr4--------<>              src(:,c)  = src(:,c) - afpm(icface)*psifp(:,icface)
129.    F 2 3                        endif
130.    F 2 3------------->        enddo
```

# OMG – ARRAY SYNTAX

```
110.  + F 2 3-------------<        do icface=1,ncfaces
111.    F 2 3
112.    F 2 3                        afpm(icface) = omega(1)*Z%A_fp(1,icface,c) + &
113.    F 2 3                                       omega(2)*Z%A_fp(2,icface,c) + &
114.    F 2 3                                       omega(3)*Z%A_fp(3,icface,c)
115.    F 2 3
116.    F 2 3                        icfp     = Z%Connect(1,icface,c)
117.    F 2 3                        ib       = Z%Connect(2,icface,c)
118.    F 2 3
119.    F 2 3                        if ( afpm(icface) >= zero ) then
120.    F 2 3                          sumArea = sumArea + afpm(icface)
121.    F 2 3                        else
122.    F 2 3                          if (icfp == 0) then
123.    F 2 3 A----------<>              psifp(:,icface) = psib(:,ib)
124.    F 2 3                          else
125.    F 2 3 A----------<>              psifp(:,icface) = psic(:,icfp)
126.    F 2 3                          endif
127.    F 2 3
128.    F 2 3 Vr4--------<>              src(:,c)  = src(:,c) - afpm(icface)*psifp(:,icface)
129.    F 2 3                        endif
130.    F 2 3------------->        enddo
```

# ARRAY SYNTAX: Good for the Cyber 205 and CM5, Not Good for Cache Based Systems

A

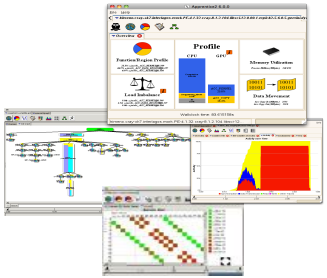
Whacked

```
109.    F 2
110.    F 2 r6------------<        do icface=1,ncfaces
111.    F 2 r6
112.    F 2 r6                       afpm(icface) = omega(1)*Z%A_fp
113.    F 2 r6                                      omega(2)*Z%A_fp
114.    F 2 r6                                      omega(3)*Z%A_fp
115.    F 2 r6
116.    F 2 r6                       icfp     = Z%Connect(1,icface,c)
117.    F 2 r6                       ib       = Z%Connect(2,icface,c)
118.    F 2 r6
119.    F 2 r6                       if ( afpm(icface) >= zero ) then
120.    F 2 r6                         sumArea = sumArea + afpm(icface)
121.    F 2 r6                       else
122.    F 2 r6 Vr2--------<           do ig = 1, Groups
123.    F 2 r6 Vr2                     if (icfp == 0) then
124.    F 2 r6 Vr2                       psifp(ig,icface) =
125.    F 2 r6 Vr2                     else
126.    F 2 r6 Vr2                       psifp(ig,icface) =
127.    F 2 r6 Vr2                     endif
128.    F 2 r6 Vr2
129.    F 2 r6 Vr2                     src(ig,c)  = src(ig,c
130.    F 2 r6 Vr2-------->           enddo
131.    F 2 r6                       endif
132.    F 2 r6------------>        enddo
```

**This simple change improved snswp3d by 50%**

# Tips When Dealing with Big Applications

**Getting a Preview**



**Speeding up Report Generation**

**Controlling Amount of Data**

# Tips: Split .ap2 and Text Report Creation

- **Suppress serial report generation to speed up pat_report processing time on compute nodes**
  - pat_report automatically executed in perftools-lite mode
- **In execution environment, set**
  - PAT_RT_REPORT_CMD='pat_report,-Q0'
  - Good for talking to pat_report when using perftools-lite
- **Works in lite and classic modes**

# Tips: Generate Report from Data Subset

- `pat_report -Q1 ...` Report from the first .ap2 file
- `pat_report -Q2 ...` Report from the first and last .ap2 file
- `pat_report -Q3 ...` Report from the first, middle, and last .ap2 file
- `-QN:` Select N .ap2 files, evenly distributed in the list of all .ap2 files

# Tips: Controlling Instrumentation and Data

- **Record Subset of PEs during execution**
  - Example: export PAT_RT_EXPFILE_PES=0,4,5,10

- **Don't instrument select binaries when using perftools-lite**
  - Good for applications that generate test or intermediate binaries with CMake and GNU Autotools

  - Use **CRAYPAT_LITE_WHITELIST** for binaries you DO want instrumented

# Leslie3D

The main purpose of this code is to model chemically reacting (i.e., burning) turbulent flows. Various different physical models are available in this algorithm but for this benchmark, only the basic conservation equations will be solved. Many, many different configurations can be modeled; however, for the sake of scalability and easy of use, only a rather simple configuration will be considered.

# Leslie3D

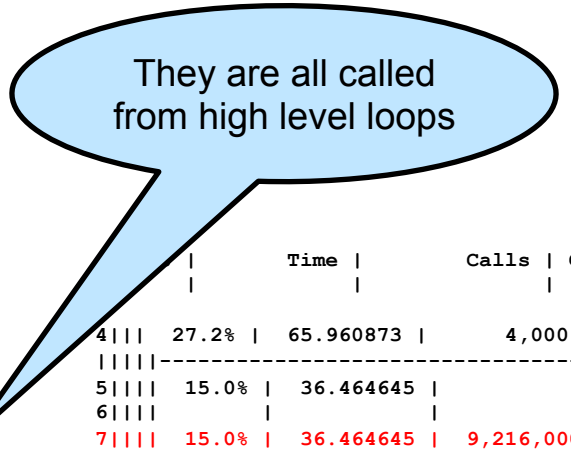
- MPI only
- Some vectorization

# Sampling Profile 64 MPI Tasks on 8 Nodes

```
 100.0% | 21,119.9 |    -- |    -- | Total
|-----------------------------------------------
|  94.1% | 19,868.2 |    -- |    -- | USER
||----------------------------------------------
||  19.3% |  4,083.9 | 117.1 |  2.8% | visck_
||  18.3% |  3,859.1 |  80.9 |  2.1% | viscj_
||  18.0% |  3,805.6 | 151.4 |  3.9% | visci_
||   6.0% |  1,273.0 |  82.0 |  6.1% | fluxk_
||   5.1% |  1,076.7 |  57.3 |  5.1% | extrapk_
||   5.1% |  1,075.2 |  84.8 |  7.4% | fluxi_
||   5.1% |  1,074.0 |  65.0 |  5.8% | extrapi_
||   5.0% |  1,050.8 |  65.2 |  5.9% | fluxj_
||   4.3% |    902.8 |  38.2 |  4.1% | update_
||   4.1% |    862.0 |  40.0 |  4.5% | extrapj_
||   1.3% |    278.9 |  77.1 | 22.0% | mpicx_
||===============================================
|   5.6% |  1,178.1 |    -- |    -- | MPI
||----------------------------------------------
||   3.2% |    676.2 | 312.8 | 32.1% | MPI_SEND
||   1.0% |    209.6 |  64.4 | 23.9% | MPI_ALLREDUCE
|===============================================
```

Three Moles

# Call Tree with Loops




```
 Time% |       Time |        Calls | Calltree
       |            |              |  PE=HIDE

 100.0% | 242.649260 |           -- | Total
|-------------------------------------------------------------
| 100.0% | 242.649223 |          2.0 | les3d_
|  99.2% | 240.654228 |           -- |  les3d_.LOOP.3.li.216
|||------------------------------------------------------------
3||  97.9% | 237.444979 |           -- | les3d_.LOOP.4.li.272
||||-----------------------------------------------------------
4|||  29.1% |  70.519335 |      4,000.0 | fluxk_
|||||---------------------------------------------------------
5||||  17.7% |  42.941276 |           -- | fluxk_.LOOP.1.li.28
6||||       |            |              |  fluxk_.LOOP.2.li.29
7||||  17.7% |  42.941276 |  9,408,000.0 |   visck_
5||||   6.6% |  16.130702 |      4,000.0 | fluxk_(exclusive)
5||||   4.7% |  11.447357 |      4,000.0 | extrapk_
|||||=========================================================
4|||  28.1% |  68.288330 |      4,000.0 | fluxj_
|||||---------------------------------------------------------
5||||  18.3% |  44.519098 |           -- | fluxj_.LOOP.1.li.28
6||||       |            |              |  fluxj_.LOOP.2.li.29
7||||  18.3% |  44.519098 |  9,408,000.0 |   viscj_
5||||   5.8% |  14.084979 |      4,000.0 | fluxj_(exclusive)
5||||   4.0% |   9.684254 |      4,000.0 | extrapj_
============
```

```
       |       Time |        Calls | Calltree
       |            |              |  PE=HIDE

4|||  27.2% |  65.960873 |      4,000.0 | fluxi_
|||||---------------------------------------------------------
5||||  15.0% |  36.464645 |           -- | fluxi_.LOOP.1.li.21
6||||       |            |              |  fluxi_.LOOP.2.li.22
7||||  15.0% |  36.464645 |  9,216,000.0 |   visci_
5||||   6.3% |  15.328236 |      4,000.0 | extrapi_
||||||-------------------------------------------------------
6|||||   3.5% |   8.424708 |      4,000.0 | extrapi_(exclusive)
6|||||   2.8% |   6.903528 |           -- | extrapi_.LOOP.1.li.128
7|||||       |            |              |  extrapi_.LOOP.2.li.129
8|||||   2.8% |   6.903528 | 10,609,000.0 |   exi4_
|||||=======================================================
5||||   5.8% |  14.167993 |      4,000.0 | fluxi_(exclusive)
|||||=========================================================
4|||   9.6% |  23.356145 |      4,000.0 | parallel_
|||||---------------------------------------------------------
5||||   7.2% |  17.457089 |           -- | parallel_.LOOP.1.li.16
6||||   7.2% |  17.457089 |     20,000.0 |  mpicx_
5||||   2.4% |   5.843909 |     20,000.0 | ghost_
|||||=========================================================
4|||   3.6% |   8.788456 |      4,000.0 | update_
||||=========================================================
3||   1.1% |   2.557943 |        401.0 | tmstep_
|===========================================================
```

# Do Loop Table

Table 1: Inclusive and Exclusive Time in Loops (from -hprofile_generate)

| Loop Incl Time% | Loop Incl Time | Loop Hit | Loop Trips Avg | Loop Trips Min | Loop Trips Max | Function=/.LOOP[.] PE=HIDE |
|---|---|---|---|---|---|---|
| 99.2% | 246.816563 | 1 | 2,000.0 | 2,000 | 2,000 | les3d_.LOOP.3.li.216 |
| 97.9% | 243.603685 | 2,000 | 2.0 | 2 | 2 | les3d_.LOOP.4.li.272 |
| 24.3% | 60.541874 | 4,000 | 48.0 | 48 | 48 | fluxk_.LOOP.1.li.28 |
| 24.1% | 60.069820 | 4,000 | 48.0 | 48 | 48 | fluxj_.LOOP.1.li.28 |
| 22.9% | 57.005766 | 192,000 | 49.0 | 49 | 49 | fluxj_.LOOP.2.li.29 |
| 22.4% | 55.615468 | 192,000 | 49.0 | 49 | 49 | fluxk_.LOOP.2.li.29 |
| 20.9% | 52.076589 | 4,000 | 48.0 | 48 | 48 | fluxi_.LOOP.1.li.21 |
| 20.9% | 52.070251 | 192,000 | 48.0 | 48 | 48 | fluxi_.LOOP.2.li.22 |
| 17.1% | 42.629610 | 9,408,000 | 48.0 | 48 | 48 | viscj_.LOOP.1.li.340 |
| 16.5% | 40.972257 | 9,408,000 | 48.0 | 48 | 48 | visck_.LOOP.1.li.344 |
| 13.9% | 34.612953 | 9,216,000 | 49.0 | 49 | 49 | visci_.LOOP.1.li.782 |
| 7.0% | 17.507682 | 4,002 | 5.0 | 5 | 5 | parallel_.LOOP.1.li.16 |
| 5.0% | 12.451170 | 4,000 | 51.5 | 51 | 52 | extrapi_.LOOP.1.li.128 |
| 5.0% | 12.448703 | 206,000 | 51.5 | 51 | 52 | extrapi_.LOOP.2.li.129 |
| 4.6% | 11.434859 | 4,000 | 49.0 | 49 | 49 | extrapk_.LOOP.1.li.138 |
| 4.6% | 11.432312 | 196,000 | 51.5 | 51 | 52 | extrapk_.LOOP.2.li.140 |
| 3.9% | 9.672461 | 4,000 | 51.5 | 51 | 52 | extrapj_.LOOP.1.li.135 |
| 3.9% | 9.668853 | 206,000 | 49.0 | 49 | 49 | extrapj_.LOOP.2.li.136 |

Mesh Loops of Reasonable Length

# Look at Threading Using OpenMP

- **First examine the loops in FLUX routines using Reveal**
  - Create program library `-hwp -hpl=leslie.pl` at build time
  - Gather DO loop statistics with perftools-lite-loops
  - Reveal <program library> <perftools statistics directory>
    - Select one of the three high level loops in fluxk, flukj, fluxi

# CCE Listing: FLUXI.lst (-h list=a)

```
19.  +                        CALL EXTRAPI ( FSI )
20.                       ! Directive inserted by Cray Reveal.  May be incomplete.
21.    M---------------< !$OMP  parallel do default(none)
22.    M                !$OMP&   private (i,j,k,l,qs,qsp,qspi)
23.    M                !$OMP&   shared  (dq,dtv,iadd,icmax,jcmax,kcmax,pav,qav,six,siy,siz,u,
24.    M                !$OMP&            uav,v,vav,w,wav)
25.    M                !$OMP&   firstprivate(fsi)
26.  + M m-------------<       DO K = 1, KCMAX
27.  + M m 3-----------<          DO J = 1, JCMAX
28.    M m 3
29.    M m 3 fV-------<>              QS(0:ICMAX) = UAV(0:ICMAX,J,K) * SIX(0:ICMAX,J,K) +
30.    M m 3                  >                    VAV(0:ICMAX,J,K) * SIY(0:ICMAX,J,K) +
31.    M m 3                  >                    WAV(0:ICMAX,J,K) * SIZ(0:ICMAX,J,K)
32.    M m 3
```

Reveal did not auto-magically do this. It pointed out several unresolved variables. In this case, the user had to scope the questionable variable as private or shared.

# FLUXI.lst (1 of 2)

```
19.  +                        CALL EXTRAPI ( FSI )
20.                        ! Directive inserted by Cray Reveal.  May be incomplete.
21.    M---------------< !$OMP  parallel do default(none)
22.    M                 !$OMP&   private (i,j,k,l,qs,qsp,qspi)
23.    M                 !$OMP&   shared  (dq,dtv,iadd,icmax,jcmax,kcmax,pav,qav,six,siy,siz,u,
24.    M                 !$OMP&            uav,v,vav,w,wav)
25.    M                 !$OMP&   firstprivate(fsi)
26.  + M m-------------<       DO K = 1, KCMAX
27.  + M m 3-----------<          DO J = 1, JCMAX
28.    M m 3
29.    M m 3 fV-------<>             QS(0:ICMAX) = UAV(0:ICMAX,J,K) * SIX(0:ICMAX,J,K)
30.    M m 3                  >                    VAV(0:ICMAX,J,K) * SIY(0:ICMAX,J,K) +
31.    M m 3                  >                    WAV(0:ICMAX,J,K) * SIZ(0:ICMAX,J,K)
32.    M m 3
33.    M m 3                        IF ( NSCHEME .EQ. 2 ) THEN
34.    M m 3 D---------<               DO I = 0, ICMAX
35.    M m 3 D                            L = I + 1 - IADD
36.    M m 3 D                            QSP = U(L,J,K) * SIX(I,J,K) +
37.    M m 3 D                  >               V(L,J,K) * SIY(I,J,K) +
38.    M m 3 D                  >               W(L,J,K) * SIZ(I,J,K)
39.    M m 3 D                            QSPI = (QSP - QS(I)) * DBLE(1 - 2 * I
40.    M m 3 D                            IF ( QSPI .GT. 0.0D0 ) QS(I) = 0.5D0 *      + QSP)
41.    M m 3 D--------->               ENDDO
42.    M m 3                        ENDIF
43.    M m 3
```

Array syntax – vectorized and fused with other loops

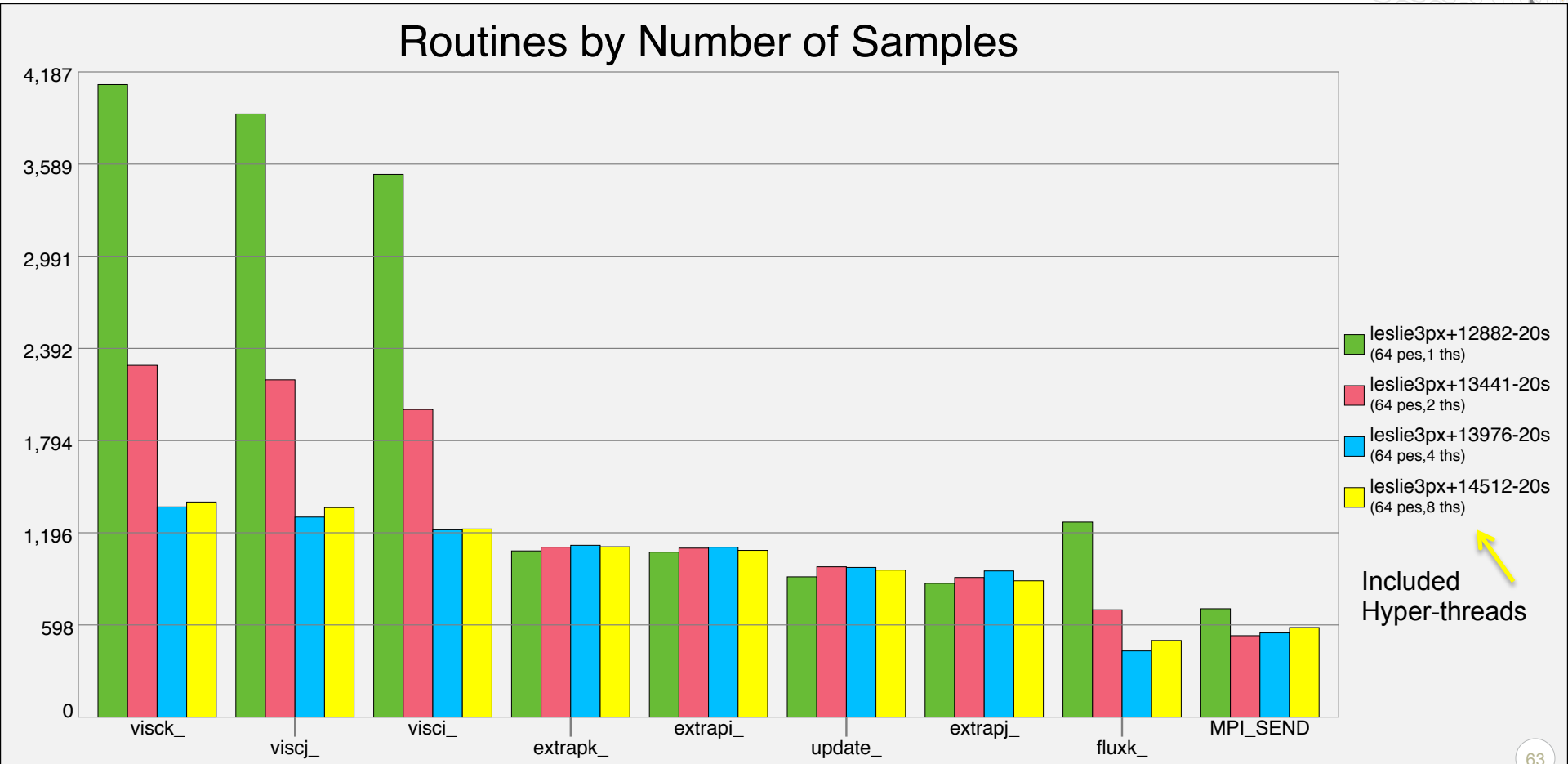
Compiler knows NSCHEME is not equal to 2

# FLUXI.lst (2 of 2)

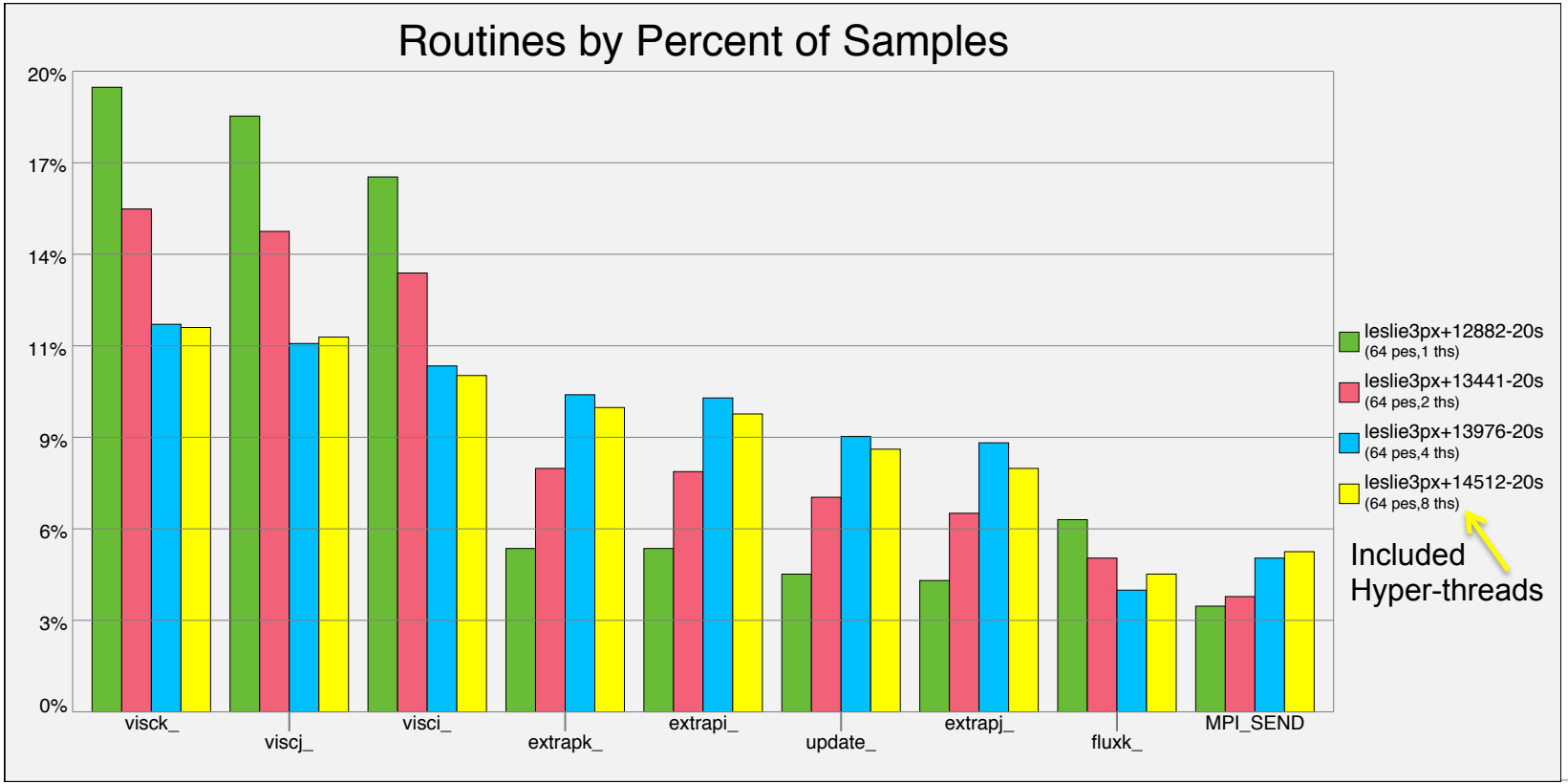
```
44.     M m 3 f--------<>            FSI(0:ICMAX,1) =  QAV(0:ICMAX,J,K,1) * QS(0:ICMAX)
45.     M m 3 f--------<>            FSI(0:ICMAX,2) =  QAV(0:ICMAX,J,K,2) * QS(0:ICMAX) +
46.     M m 3                    >                                PAV(0:ICMAX,J,K) * SIX(0:ICMAX,J,K)
47.     M m 3 f--------<>            FSI(0:ICMAX,3) =  QAV(0:ICMAX,J,K,3) * QS(0:ICMAX) +
48.     M m 3                    >                                PAV(0:ICMAX,J,K) * SIY(0:ICMAX,J,K)
49.     M m 3 fVr2-----<>            FSI(0:ICMAX,4) =  QAV(0:ICMAX,J,K,4) * QS(0:ICMAX) +
50.     M m 3                    >                                PAV(0:ICMAX,J,K) * SIZ(0:ICMAX,J,K)
51.     M m 3 f--------<>            FSI(0:ICMAX,5) = (QAV(0:ICMAX,J,K,5) + PAV(0:ICMAX,J,K)) *
52.     M m 3                    >                                              QS(0:ICMAX)
53.     M m 3
54.     M m 3                        IF ( ISGSK .EQ. 1 ) THEN
55.     M m 3                           FSI(0:ICMAX,7) = QAV(0:ICMAX,J,K,7)
56.     M m 3                        ENDIF
57.     M m 3
58.     M m 3                        IF ( ICHEM .GT. 0 ) THEN
59.     M m 3 D---------<               DO L = 8, 7 + NSPECI
60.     M m 3 D                            FSI(0:ICMAX,L) = QAV(0:ICMAX,J,K,L) * QS(0:ICMAX)
61.     M m 3 D--------->               ENDDO
62.     M m 3                        ENDIF
63.     M m 3
64.   + M m 3                        IF ( VISCOUS ) CALL VISCI ( 0, ICMAX, J, K, FSI )
65.     M m 3
```

VISCI is called from OpenMP loop

# 64 MPI Tasks on 8 Nodes



# 64 MPI Tasks on 8 Nodes



# Subroutine Timings After Parallelization of FLUXs

| | 1 Thread | 2 Threads | 4 Threads | 8 Threads |
|---|---|---|---|---|
| visck_ | 4083.90 | 2270.40 | 1348.00 | 1395.00 |
| viscj_ | 3859.10 | 2174.00 | 1292.40 | 1375.00 |
| visci_ | 3805.60 | 2137.90 | 1281.70 | 1234.00 |
| fluxk_ | 1273.00 | 696.00 | 429.90 | 492.00 |
| extrapk_ | 1076.70 | 1099.90 | 1108.40 | 1098.00 |
| fluxi_ | 1075.20 | 581.10 | 335.50 | 233.00 |
| extrapi_ | 1074.00 | 1099.80 | 1091.10 | 1090.00 |
| fluxj_ | 1050.80 | 562.70 | 318.00 | 227.00 |
| update_ | 902.80 | 966.50 | 971.30 | 957.00 |
| extrapj_ | 862.00 | 896.60 | 932.00 | 882.00 |

# Observations From Timings

- VISC(I,J,K) still using significant amount of time
- EXTRAP(I,J,K) needs to be addressed
- UPDATE needs to be addressed

# Concern with the VISCs

```
ftn-6383 ftn: VECTOR VISCK, File = fluxk.f, Line = 344
  A loop starting at line 344 requires an estimated 25 vector registers at
  line 485; 2 of these have been preemptively forced to memory.

ftn-6204 ftn: VECTOR VISCK, File = fluxk.f, Line = 344
  A loop starting at line 344 was vectorized.
```

# Modifications

- Optimization: promoted 12 scalars to arrays to enable the lengthy loop to be split into three separate loops
- Result: all three routines improved by 25%

# Modifications (continued)

```
<          DUDX = T11(I,J,K,3) * DUDXI          ---
<          DVDX = T11(I,J,K,3) * DVDXI          >                K,3) * DUDXI
<          DWDX = T11(I,J,K,3) * DWDXI          >                K,3) * DVDXI
<          DTDX = T11(I,J,K,3) * DTDXI          >                K,3) * DWDXI
<                                               >                K,3) * DTDXI
<          DUDY = T21(I,J,K,3) * DUDXI          >
<          DVDY = T21(I,J,K,3) * DVDXI          >     DUDY(I) = T21(I,J,K,3) * DUDXI
<          DWDY = T21(I,J,K,3) * DWDXI          >     DV[illegible]Y(I) = T21(I,J,K,3) * DVDXI
<          DTDY = T21(I,J,K,3) * DTDXI          >     DW[illegible]
<                                               >     DT[illegible]
<          DUDZ = T31(I,J,K,3) * DUDXI          >
<          DVDZ = T31(I,J,K,3) * DVDXI          >     DUDZ(I) = T31(I,J,K,3) * DUDXI
<          DWDZ = T31(I,J,K,3) * DWDXI          >     DVDZ(I) = T31(I,J,K,3) * DVDXI
<          DTDZ = T31(I,J,K,3) * DTDXI          >     DWDZ(I) = T31(I,J,K,3) * DWDXI
<                                               >     DTDZ(I) = T31(I,J,K,3) * DTDXI
```

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# Reveal Scoping of EXTRAP Routines

```
142.
143.                        ! Directive inserted by Cray Reveal.  May be incomplete.
144.     M----------------< !$OMP  parallel do default(none)
145.     M                 !$OMP&   private (rwrk,j,k,kg)
146.     M                 !$OMP&   shared  (i1,i2,j1,j2,kcmax,kmax,kstart,pav,qav,tav,
147.     M                 !$OMP&            uav,vav,wav)
148.   + M m-------------<       DO K = 0, KCMAX
149.     M m                        KG = K + KSTART - 1
150.   + M m 3-----------<          DO J = J1, J2
151.     M m 3
152.     M m 3                        IF ( NSCHEME .EQ. 2 .OR. (.NOT. KPERIODIC .AND.
153.     M m 3                   >                    (KG .EQ. 0 .OR. KG .EQ. KMAX-1))) THEN
154.   + M m 3                           CALL EXK2 ( I1, I2, J, K )
155.     M m 3                        ELSE
156.   + M m 3                           CALL EXK4 ( I1, I2, J, K,
157.     M m 3                   >                     RWRK(I1,1), RWRK(I1,2), RWRK(I1,3) )
158.     M m 3                        ENDIF
```

Once again Reveal needed help scoping some of the arrays that had questionable usage

# Reveal Scoping of UPDATE Routine

```
 9.                  ! Directive inserted by Cray Reveal.  May be incomplete.
10.    M--------< !$OMP  parallel do default(none)
11.    M          !$OMP&   private (i,j,k,ke)
12.    M          !$OMP&   shared  (dq,icmax,jcmax,kcmax,m,n,p,q,t,u,v,w)
13.  + M m------<       DO K = 1, KCMAX
14.  + M m 3----<          DO J = 1, JCMAX
15.    M m 3 V--<             DO I = 1, ICMAX
16.    M m 3 V
17.    M m 3 V                   IF ( N .EQ. 1 ) THEN
18.    M m 3 V                      Q(I,J,K,1,M) = Q(I,J,K,1,N) + DQ(I,J,K,1)
19.    M m 3 V                      Q(I,J,K,2,M) = Q(I,J,K,2,N) + DQ(I,J,K,2)
20.    M m 3 V                      Q(I,J,K,3,M) = Q(I,J,K,3,N) + DQ(I,J,K,3)
21.    M m 3 V                      Q(I,J,K,4,M) = Q(I,J,K,4,N) + DQ(I,J,K,4)
22.    M m 3 V                      Q(I,J,K,5,M) = Q(I,J,K,5,N) + DQ(I,J,K,5)
23.    M m 3 V                   ELSE
24.    M m 3 V                      Q(I,J,K,1,M) = 0.5D+00 * (Q(I,J,K,1,M) +
25.    M m 3 V         >                            Q(I,J,K,1,N) + DQ(I,J,K,1))
26.    M m 3 V                      Q(I,J,K,2,M) = 0.5D+00 * (Q(I,J,K,2,M) +
27.    M m 3 V         >                            Q(I,J,K,2,N) + DQ(I,J,K,2))
28.    M m 3 V                      Q(I,J,K,3,M) = 0.5D+00 * (Q(I,J,K,3,M) +
```

This one Reveal did without help

# Another Modification to UPDATE

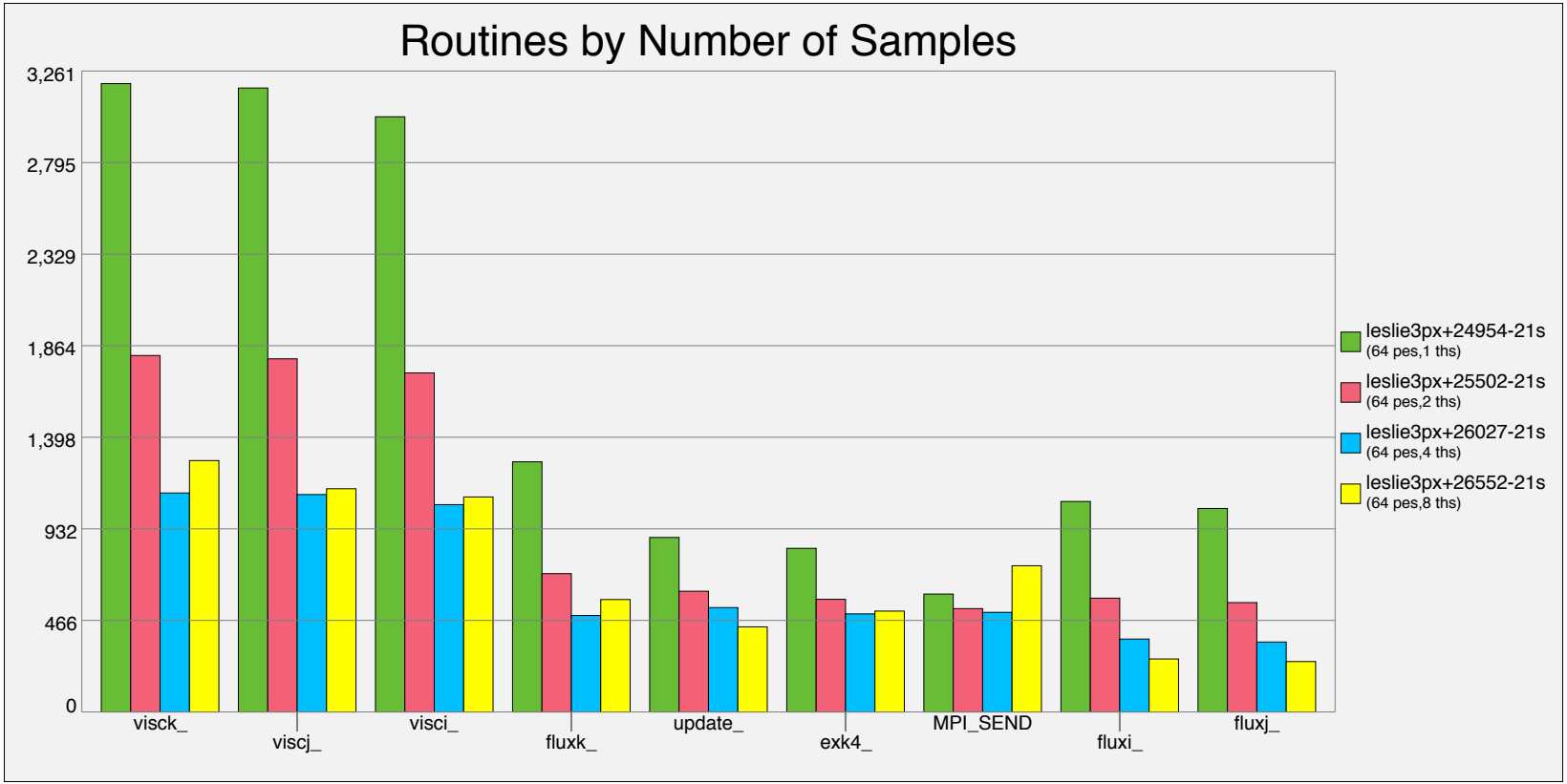
```
10.   + 1--------------<       DO K = 1, KCMAX
11.   + 1 2------------<          DO J = 1, JCMAX
12.     1 2 iVbr4------<             DO I = 1, ICMAX
13.     1 2 iVbr4
14.     1 2 iVbr4                       IF ( N .EQ. 1 ) THEN
15.   + 1 2 iVbr4 ib--<>                   Q(I,J,K,1:5,M) = (                (I,J,K,1:5)
16.     1 2 iVbr4                       ELSE
17.   + 1 2 iVbr4 ib--<>                   Q(I,J,K,1:5,M) = (                1:5,M) +
18.     1 2 iVbr4               >                                Q(I,J,K,1:5,N) + DQ(I,J,K,1:5))
19.     1 2 iVbr4                       ENDIF
20.     1 2 iVbr4
21.     1 2 iVbr4                       U(I,J,K) = Q(I,J,K,2,M) / Q(I,J,K,1,M)
22.     1 2 iVbr4                       V(I,J,K) = Q(I,J,K,3,M) / Q(I,J,K,1,M)
23.     1 2 iVbr4                       W(I,J,K) = Q(I,J,K,4,M) / Q(I,J,K,1,M)
24.     1 2 iVbr4
25.     1 2 iVbr4                       KE = 0.5D+00 * (U(I,J,K) * U(I,J,K) +
26.     1 2 iVbr4               >                           V(I,J,K) * V(I,J,K) +
27.     1 2 iVbr4               >                           W(I,J,K) * W(I,J,K))
28.     1 2 iVbr4
29.     1 2 iVbr4                       T(I,J,K) = (Q(I,J,K,5,M) / Q(I,J,K,1,M) - KE) / CVAIR
30.     1 2 iVbr4                       P(I,J,K) = Q(I,J,K,1,M) * RGAIR * T(I,J,K)
31.     1 2 iVbr4------>             ENDDO
32.     1 2------------>          ENDDO
33.     1-------------->       ENDDO
```

# Another Modification to UPDATE

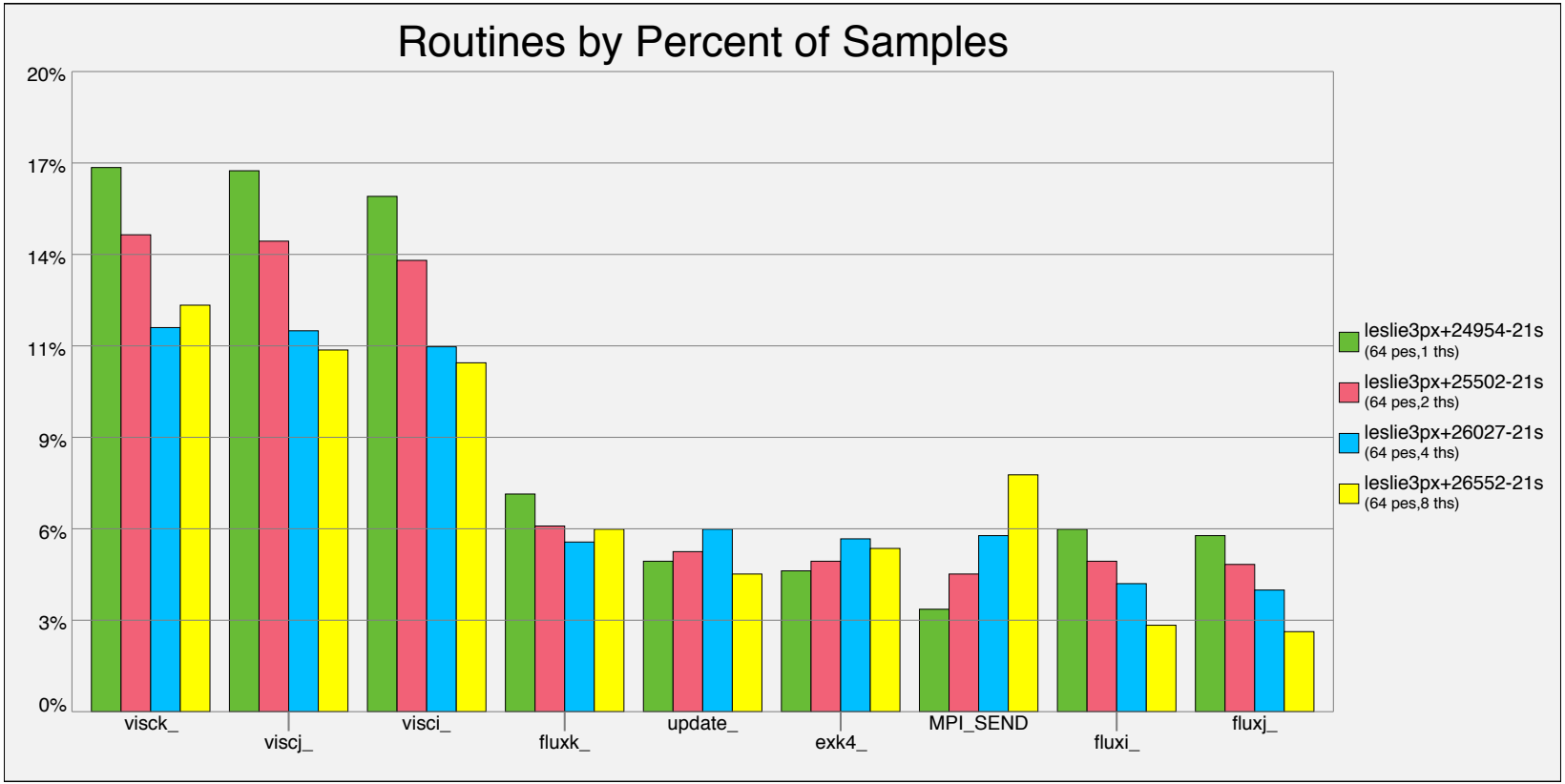
```
15c18,22
<                     Q(I,J,K,1:5,M) = Q(I,J,K,1:5,N) + DQ(I
---
>                     Q(I,J,K,1,M) = Q(I,J,K,1,N) + DQ(I,J,K
>                     Q(I,J,K,2,M) = Q(I,J,K,2,N) + DQ(I,J,K
>                     Q(I,J,K,3,M) = Q(I,J,K,3,N) + DQ(I,J,K
>                     Q(I,J,K,4,M) = Q(I,J,K,4,N) + DQ(I,J,K
>                     Q(I,J,K,5,M) = Q(I,J,K,5,N) + DQ(I,J,K,5)
17,18c24,33
<                     Q(I,J,K,1:5,M) = 0.5D+00 * (Q(I,J,K,1:5,M
<           >                           Q(I,J,K,1:5,N) + DQ(I,J,K,1:5
---
>                     Q(I,J,K,1,M) = 0.5D+00 * (Q(I,J,K,1,M) +
>           >                           Q(I,J,K,1,N) + DQ(I,J,K,1))
>                     Q(I,J,K,2,M) = 0.5D+00 * (Q(I,J,K,2,M) +
>           >                           Q(I,J,K,2,N) + DQ(I,J,K,2))
>                     Q(I,J,K,3,M) = 0.5D+00 * (Q(I,J,K,3,M) +
>           >                           Q(I,J,K,3,N) + DQ(I,J,K,3))
>                     Q(I,J,K,4,M) = 0.5D+00 * (Q(I,J,K,4,M) +
>           >                           Q(I,J,K,4,N) + DQ(I,J,K,4))
>                     Q(I,J,K,5,M) = 0.5D+00 * (Q(I,J,K,5,M) +
>           >                           Q(I,J,K,5,N) + DQ(I,J,K,5))
```

Whacked

# Optimization Results for 64 MPI Tasks on 8 Nodes



# Optimization Results for 64 MPI Tasks on 8 Nodes



# Final Sampling Profile

```
Table 1:  Profile by Function

  Samp% |    Samp |  Imb. |  Imb. | Group
        |         |  Samp | Samp% |  Function=[MAX10]
        |         |       |       |   PE=HIDE
        |         |       |       |    Thread=HIDE

 100.0% | 9,268.0 |    -- |    -- | Total
|-----------------------------------------------------
|  86.4% | 8,003.3 |    -- |    -- | USER
||----------------------------------------------------
||  12.0% | 1,114.2 |  84.8 |  7.2% | visck_
||  11.9% | 1,106.2 |  58.8 |  5.1% | viscj_
||  11.4% | 1,054.9 |  49.1 |  4.5% | visci_
||   5.7% |   531.1 |  46.9 |  8.2% | update_
||   5.4% |   499.0 |  45.0 |  8.4% | exk4_
||   5.3% |   490.8 |  65.2 | 11.9% | fluxk_
||   5.2% |   484.0 |  41.0 |  7.9% | extrapi_
||   4.6% |   424.7 |  35.3 |  7.8% | exi4_
||   4.1% |   382.4 |  50.6 | 11.9% | exj4_
||====================================================
|  11.6% | 1,078.5 |    -- |    -- | MPI
||----------------------------------------------------
||   5.5% |   507.0 | 205.0 | 29.3% | MPI_SEND
||====================================================
|   1.9% |   178.7 |    -- |    -- | ETC
|=====================================================
```

**Best time on 8 nodes is with 64 MPI tasks and 4 Threads per MPI task**

**2.3 times faster than original!**

# Pure MPI Profile

ORIGINAL

Table 1: Profile by Function

| Samp% | Samp | Imb. Samp | Imb. Samp% | Group Function PE=HIDE |
|---|---|---|---|---|
| 100.0% | 8,919.6 | -- | -- | Total |
| 84.4% | 7,532.4 | -- | -- | USER |
| 12.4% | 1,108.2 | 56.8 | 4.9% | viscj_ |
| 11.8% | 1,048.1 | 93.9 | 8.3% | visci_ |
| 11.7% | 1,047.8 | 74.2 | 6.6% | visck_ |
| 6.0% | 530.9 | 37.1 | 6.6% | update_ |
| 5.8% | 518.4 | 49.6 | 8.8% | exk4_ |
| 5.8% | 513.7 | 36.3 | 6.6% | exi4_ |
| 4.9% | 439.1 | 53.9 | 11.0% | exj4_ |
| 4.4% | 392.1 | 41.9 | 9.7% | fluxk_ |
| 4.3% | 382.1 | 53.9 | 12.4% | fluxi_ |
| 4.2% | 373.2 | 42.8 | 10.3% | fluxj_ |
| 4.0% | 359.9 | 61.1 | 14.6% | extrapi_ |
| 2.1% | 184.0 | 35.0 | 16.0% | extrapj_ |
| 1.8% | 159.8 | 39.2 | 19.8% | extrapk_ |
| 1.4% | 129.1 | 67.9 | 34.6% | mpicx_ |
| 1.4% | 120.8 | 46.2 | 27.8% | parallel_ |
| 1.3% | 114.9 | 57.1 | 33.3% | ghost_ |

Table 1: Profile by Function

| Samp% | Samp | Imb. Samp | Imb. Samp% | Group Function PE=HIDE |
|---|---|---|---|---|
| 100.0% | 9,206.9 | -- | -- | Total |
| 85.8% | 7,899.0 | -- | -- | USER |
| 18.1% | 1,662.2 | 90.8 | 5.2% | fluxj_ |
| 17.4% | 1,602.9 | 225.1 | 12.4% | fluxk_ |
| 16.8% | 1,542.4 | 109.6 | 6.7% | fluxi_ |
| 9.3% | 855.7 | 72.3 | 7.8% | extrapi_ |
| 7.1% | 652.3 | 53.7 | 7.6% | extrapk_ |
| 6.5% | 602.6 | 62.4 | 9.4% | extrapj_ |
| 5.7% | 528.0 | 60.0 | 10.2% | update_ |
| 1.4% | 130.4 | 43.6 | 25.1% | mpicx_ |
| 1.3% | 123.0 | 70.0 | 36.4% | parallel_ |
| 1.1% | 100.7 | 81.3 | 44.8% | ghost_ |
| 13.7% | 1,263.9 | -- | -- | MPI |
| 8.1% | 749.8 | 270.2 | 26.6% | MPI_SEND |
| 2.3% | 209.7 | 101.3 | 32.7% | MPI_ALLREDUCE |
| 1.5% | 136.1 | 269.9 | 66.7% | MPI_WAIT |
| 1.5% | 135.8 | 119.2 | 46.9% | MPI_REDUCE |

# All That Work for Nothing?

- We could do a lot more to optimize for cache in the VISC(I,J,K) routines
- But, a pure MPI solution runs pretty well on multicore node like haswell, broadwell, skylake and even KNL

# Memory Analysis of the Optimized Code

Table 5: Profile by Group, Function, and Line

| Samp% | Samp | Imb. Samp | Imb. Samp% | MEM_LOAD_UOPS_RETIRED :HIT_LFB:precise=2 | RESOURCE_STALLS :ANY | Group Function=[MAX10] Source Line PE=HIDE |
|---|---|---|---|---|---|---|
| 100.0% | 359.1 | -- | -- | 37,453,764,107,885,936 | 586,696,060,451 | Total |
| 90.3% | 324.2 | -- | -- | 33,675,842,152,965,068 | 538,408,160,657 | USER |
| 16.6% | 59.7 | -- | -- | 6,020,925,677,307,978 | 98,381,410,309 | fluxk_ |
| | | | | | | fluxk.f |
| 3.7% | 13.4 | 9.6 | 42.2% | 1,411,772,930,846,618 | 22,424,492,033 | line.36 |
| 1.1% | 4.0 | 7.0 | 64.9% | 369,435,907,219,731 | 6,575,931,964 | line.54 |
| 9.1% | 32.6 | 37.4 | 54.3% | 3,294,136,838,755,624 | 53,681,888,808 | line.76 |
| 14.7% | 52.8 | -- | -- | 5,770,237,024,852,115 | 88,570,460,626 | visci_ |
| | | | | | | fluxi.f |
| 1.1% | 4.1 | 4.9 | 55.7% | 452,998,790,837,684 | 6,904,792,416 | line.807 |
| 2.1% | 7.5 | 9.5 | 57.0% | 818,036,651,385,400 | 12,609,245,898 | line.822 |
| 13.8% | 49.7 | -- | -- | 5,246,869,490,559,427 | 82,777,122,645 | fluxj_ |
| | | | | | | fluxj.f |
| 2.8% | 10.2 | 18.8 | 66.0% | 1,077,521,395,774,529 | 16,750,162,451 | line.36 |
| 8.2% | 29.3 | 40.7 | 59.0% | 3,118,214,977,991,204 | 48,910,720,877 | line.76 |

# Code in FLUXK Responsible for Memory Bandwidth Utilization

```
73.     M m
74.   + M m ib----------<          DO K = 1, KCMAX
75.   + M m ib i--------<             DO L = 1, 5
76.     M m ib i Vbr4--<>                DQ(1:IND,J,K,L) = DQ(1:IND
77.     M m ib i                >             DTV(1:IND,J,K) * (FSK                O,K-1,L))
78.     M m ib i-------->             ENDDO
79.     M m ib
80.     M m ib                        IF (ISGSK .EQ. 1) THEN
81.     M m ib                           DQ(1:IND,J,K,7) = DQ(1:IND,J,K,7) -
82.     M m ib                  >             DTV(1:IND,J,K) * (FSK(1:IND,K,7) - FSK(1:IND,K-1,7))
83.     M m ib                        ENDIF
84.     M m ib
85.     M m ib                        IF ( ICHEM .GT. 0 ) THEN
86.     M m ib D--------<                DO L = 8, 7 + NSPECI
87.     M m ib D                            DQ(1:IND,J,K,L) = DQ(1:IND,J,K,L) -
88.     M m ib D                =             DTV(1:IND,J,K) * (FSK(1:IND,K,L) - FSK(1:IND,K-1,L))
89.     M m ib D-------->                ENDDO
90.     M m ib                        ENDIF
91.     M m ib
92.     M m ib---------->          ENDDO
```

# Array Syntax and Automatic Blocking by the Compiler

```
73.     M m             !dir$ noblocking
74.   + M m 3--------<          DO K = 1, KCMAX
75.     M m 3 V------<           DO I = 1, IND
76.     M m 3 V         !dir$ unroll(5)
77.     M m 3 V w----<              DO L = 1, 5
78.     M m 3 V w                      DQ(I,J,K,L) = DQ(I,J,K,L) -
79.     M m 3 V w           >                 DTV(I,J,K) * (FSK(I,K,L) - FSK(I,K-1,L))
80.     M m 3 V w---->              ENDDO
81.     M m 3 V
82.     M m 3 V                     IF (ISGSK .EQ. 1) THEN
83.     M m 3 V                        DQ(I,J,K,7) = DQ(I,J,K,7) -
84.     M m 3 V             >                 DTV(I,J,K) * (FSK(I,K,7) - FSK(I,K-1,7))
85.     M m 3 V                     ENDIF
86.     M m 3 V
87.     M m 3 V                     IF ( ICHEM .GT. 0 ) THEN
88.     M m 3 V D----<                 DO L = 8, 7 + NSPECI
89.     M m 3 V D                         DQ(I,J,K,L) = DQ(I,J,K,L) -
90.     M m 3 V D           >                DTV(I,J,K) * (FSK(I,K,L) - FSK(I,K-1,L))
91.     M m 3 V D---->                 ENDDO
92.     M m 3 V                     ENDIF
93.     M m 3 V
94.     M m 3 V------>           ENDDO
95.     M m 3-------->          ENDDO
96.     M m--------->>         ENDDO
```

A

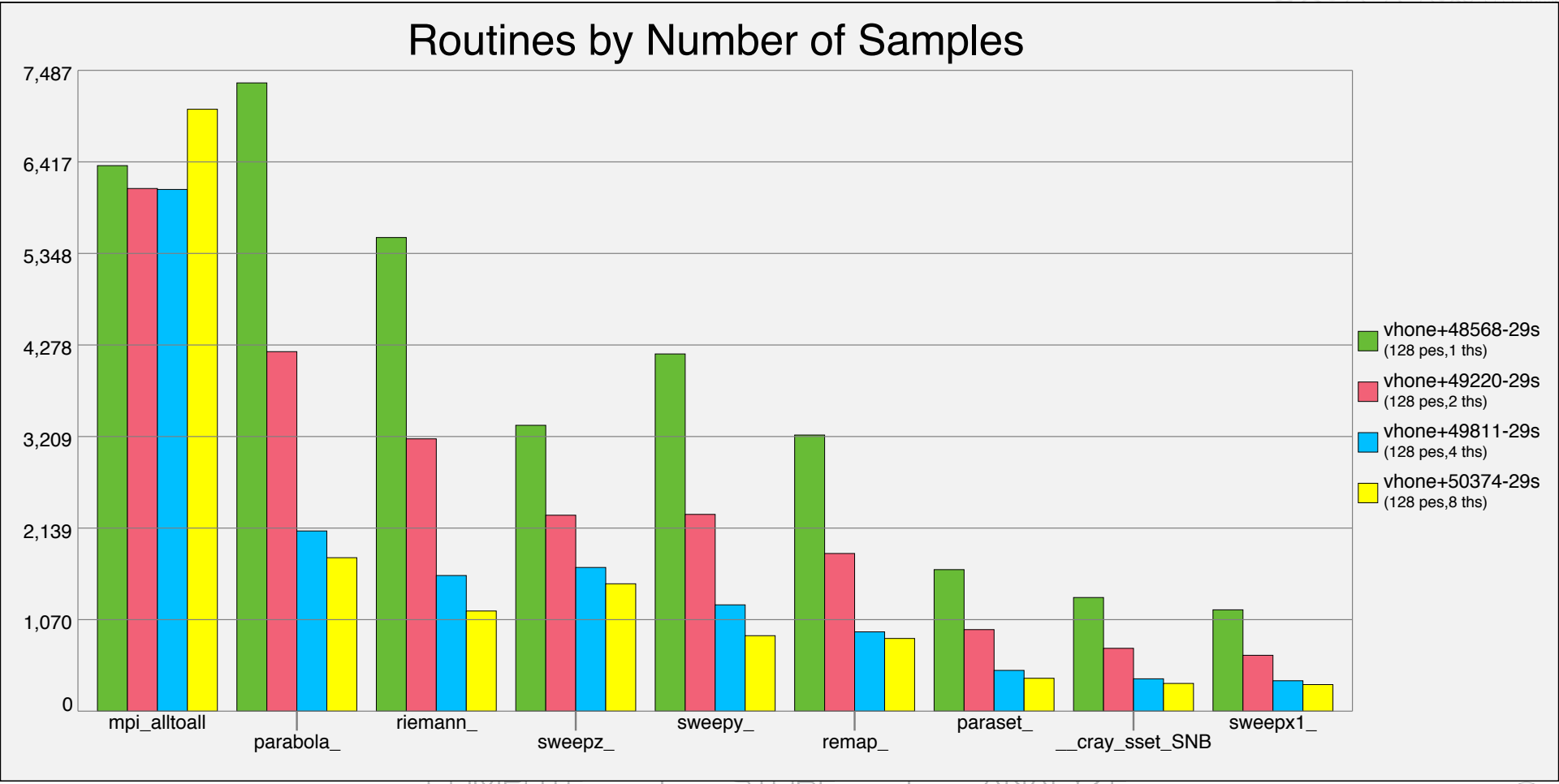
y 33% -
ere is a lot
x

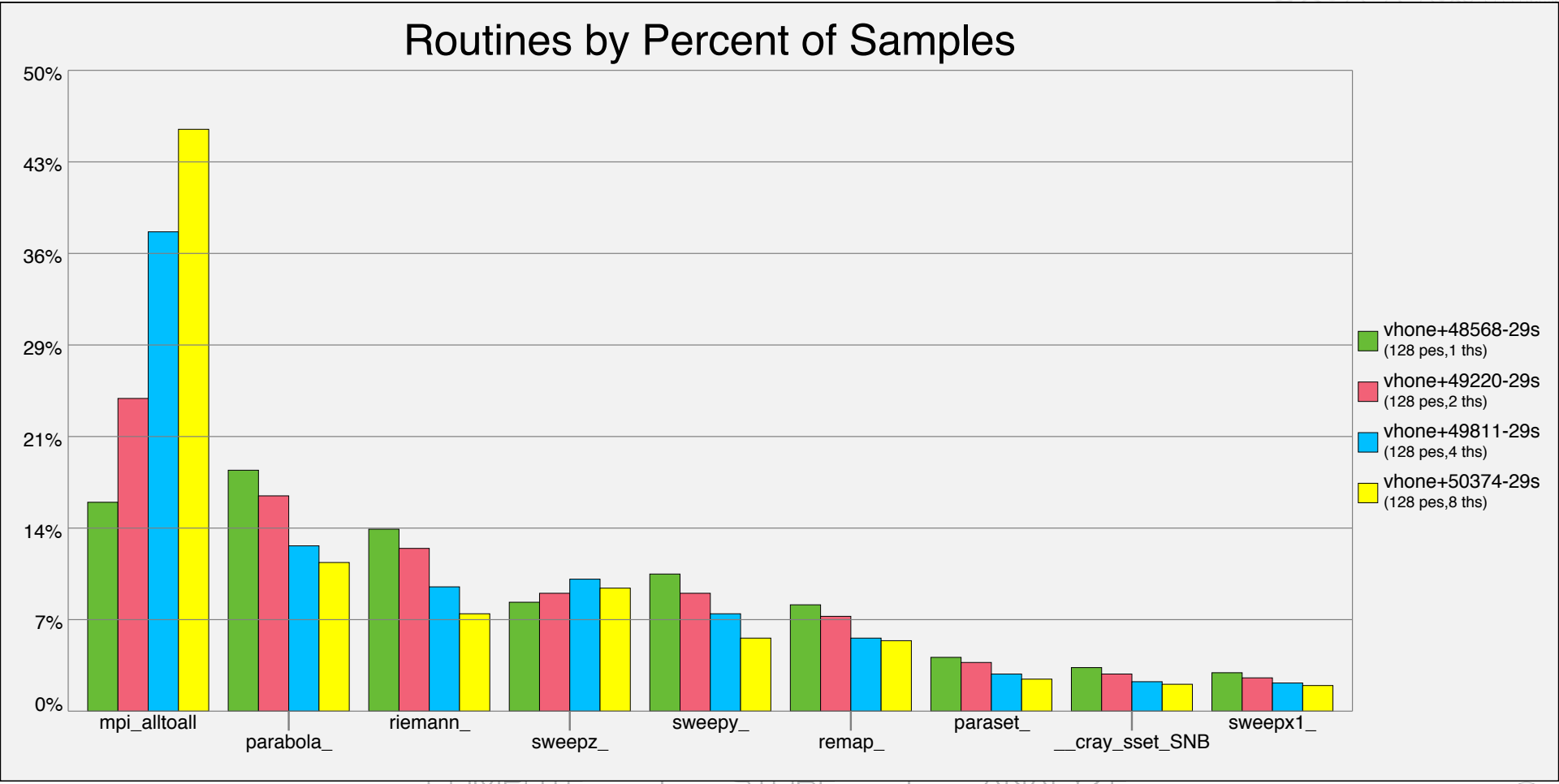
Whacked

# VH1

# VH1 Already Parallelized Using Reveal

- Need to investigate additional optimization
- Vectorization and Memory utilization optimization





# Profile for 1 Thread and 4 Threads

Table 1: Profile by Function 1 Thread

| Samp% | Samp | Imb. Samp | Imb. Samp% | Group Function=[MAX10] PE=HIDE |
|---|---|---|---|---|
| 100.0% | 39,072.1 | -- | -- | Total |
| 77.5% | 30,298.1 | -- | -- | USER |
| 18.8% | 7,340.2 | 254.8 | 3.4% | parabola_ |
| 14.2% | 5,533.8 | 362.2 | 6.2% | riemann_ |
| 10.7% | 4,173.6 | 221.4 | 5.1% | sweepy_ |
| 8.5% | 3,340.0 | 247.0 | 6.9% | sweepz_ |
| 8.3% | 3,226.1 | 173.9 | 5.2% | remap_ |
| 4.2% | 1,653.7 | 151.3 | 8.4% | paraset_ |
| 3.0% | 1,184.3 | 76.7 | 6.1% | sweepx1_ |
| 2.9% | 1,123.3 | 68.7 | 5.8% | sweepx2_ |
| 16.9% | 6,600.0 | -- | -- | MPI |
| 16.3% | 6,373.7 | 670.3 | 9.6% | mpi_alltoall |
| 5.5% | 2,160.6 | -- | -- | ETC |
| 3.4% | 1,328.0 | 110.0 | 7.7% | __cray_sset_SNB |

Table 1: Profile by Function 4 Threads

| Samp% | Samp | Imb. Samp | Imb. Samp% | Group Function=[MAX10] PE=HIDE Thread=HIDE |
|---|---|---|---|---|
| 100.0% | 16,290.4 | -- | -- | Total |
| 58.4% | 9,508.0 | -- | -- | USER |
| 12.9% | 2,105.5 | 167.5 | 7.4% | parabola_ |
| 10.3% | 1,679.0 | 107.0 | 6.0% | sweepz_ |
| 9.7% | 1,585.0 | 151.0 | 8.8% | riemann_ |
| 7.6% | 1,242.2 | 72.8 | 5.6% | sweepy_ |
| 5.7% | 926.7 | 77.3 | 7.8% | remap_ |
| 2.9% | 476.5 | 50.5 | 9.7% | paraset_ |
| 2.2% | 355.4 | 64.6 | 15.5% | sweepx1_ |
| 2.0% | 323.2 | 33.8 | 9.5% | sweepx2_ |
| 37.7% | 6,135.4 | -- | -- | MPI |
| 37.4% | 6,095.4 | 100.6 | 1.6% | mpi_alltoall |
| 3.8% | 619.9 | -- | -- | ETC |
| 2.3% | 378.2 | 65.8 | 14.9% | __cray_sset_SNB |

# Do Loop Table

Table 1: Inclusive and Exclusive Time in Loops (from -hprofile_generate)

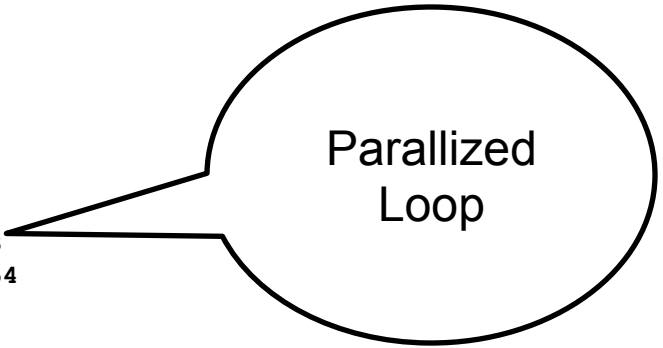
| Loop Incl Time% | Loop Incl Time | Loop Hit | Loop Trips Avg | Loop Trips Min | Loop Trips Max | Function=/.LOOP[.] PE=HIDE |
|---|---|---|---|---|---|---|
| 100.0% | 631.108612 | 1 | 50.0 | 50 | 50 | vhone_.LOOP.2.li.205 |
| 30.6% | 193.127659 | 100 | 64.0 | 64 | 64 | sweepy_.LOOP.1.li.38 |
| 30.6% | 193.127263 | 6,400 | 128.0 | 128 | 128 | sweepy_.LOOP.2.li.39 |
| 27.8% | 175.704223 | 50 | 128.0 | 128 | 128 | sweepz_.LOOP.05.li.53 |
| 27.8% | 175.703983 | 6,400 | 64.0 | 64 | 64 | sweepz_.LOOP.06.li.54 |
| 20.6% | 130.290184 | 2,457,600 | 1,031.0 | 1,031 | 1,031 | riemann_.LOOP.2.li.63 |
| 14.0% | 88.344946 | 50 | 64.0 | 64 | 64 | sweepx2_.LOOP.1.li.33 |
| 14.0% | 88.344688 | 3,200 | 128.0 | 128 | 128 | sweepx2_.LOOP.2.li.34 |
| 13.9% | 87.468636 | 50 | 64.0 | 64 | 64 | sweepx1_.LOOP.1.li.33 |
| 13.9% | 87.468481 | 3,200 | 128.0 | 128 | 128 | sweepx1_.LOOP.2.li.34 |
| 10.3% | 64.960442 | 22,118,400 | 1,028.0 | 1,026 | 1,032 | parabola_.LOOP.7.li.75 |
| 5.6% | 35.320759 | 2,533,785,600 | 12.0 | 12 | 12 | riemann_.LOOP.3.li.64 |
| 1.5% | 9.708508 | 409,600 | 16.0 | 16 | 16 | sweepz_.LOOP.07.li.61 |
| 1.5% | 9.202399 | 50 | 128.0 | 128 | 128 | sweepz_.LOOP.01.li.22 |
| 1.5% | 9.201736 | 6,400 | 8.0 | 8 | 8 | sweepz_.LOOP.02.li.23 |
| 1.5% | 9.198684 | 51,200 | 128.0 | 128 | 128 | sweepz_.LOOP.03.li.24 |
| 1.3% | 7.941815 | 50 | 64.0 | 64 | 64 | sweepz_.LOOP.12.li.116 |
| 1.3% | 7.941276 | 3,200 | 64.0 | 64 | 64 | sweepz_.LOOP.13.li.117 |
| 1.3% | 7.935293 | 204,800 | 16.0 | 16 | 16 | sweepz_.LOOP.14.li.118 |

# Call Tree with Loops

```
Table 1:  Function Calltree View

  Time% |       Time |       Calls | Calltree
        |            |             |  PE=HIDE

 100.0% | 623.115520 |          -- | Total
|-----------------------------------------------------------
| 100.0% | 623.115490 |         2.0 | vhone_
| 100.0% | 622.866674 |          -- |  vhone_.LOOP.2.li.205
|||---------------------------------------------------------
3||  37.5% | 233.441869 |        50.0 | sweepz_
||||---------------------------------------------------------
4|||  23.6% | 147.324792 |          -- | sweepz_.LOOP.05.li.53
5|||        |            |             |  sweepz_.LOOP.06.li.54
6|||        |            |             |   ppmlr_
|||||||-------------------------------------------------------
7||||||   9.5% |  58.970451 |   819,200.0 | remap_
||||||||-------------------------------------------------------
8|||||||   5.8% |  35.940023 | 4,915,200.0 | parabola_
8|||||||   2.9% |  18.356531 |   819,200.0 | remap_(exclusive)
||||||||=======================================================
7||||||   7.7% |  47.983811 |   819,200.0 | riemann_
7||||||   2.9% |  17.979033 | 2,457,600.0 | parabola_
7||||||   1.7% |  10.292367 |   819,200.0 | evolve_
|||||||=======================================================
4|||  13.8% |  86.117076 |        50.0 | sweepz_(exclusive)
||||=======================================================
```



# If it Vectorizes, Check Memory Utilization

```
44.   V----<   do n = nmin-1, nmax
45.   V         ar(n) = a(n) + para(n,1)*diffa(n) + para(n,2)*da(n+1) + para(n,3)*da(n)
48.   V         al(n+1) = ar(n)
49.   V---->    enddo
53.   fV---<   do n = nmin, nmax
54.   fV        onemfl= 1.0 - flat(n)
55.   fV        ar(n) = flat(n) * a(n) + onemfl * ar(n)
56.   fV        al(n) = flat(n) * a(n) + onemfl * al(n)
57.   fV--->   enddo
67.   f----< do n = nmin, nmax
68.   f       deltaa(n) = ar(n) - al(n)
69.   f       a6(n)     = 6. * (a(n) - .5 * (al(n) + ar(n)))
70.   f       scrch1(n) = (ar(n) - a(n)) * (a(n)-al(n))
71.   f       scrch2(n) = deltaa(n) * deltaa(n)
72.   f       scrch3(n) = deltaa(n) * a6(n)
73.   f----> enddo
74.
75.   Vr2--< do n = nmin, nmax
76.   Vr2       if(scrch1(n) <= 0.0) then
77.   Vr2         ar(n) = a(n)
78.   Vr2         al(n) = a(n)
79.   Vr2       endif
80.   Vr2       if(scrch2(n) < +scrch3(n)) al(n) = 3. * a(n) - 2. * ar(n)
81.   Vr2       if(scrch2(n) < -scrch3(n)) ar(n) = 3. * a(n) - 2. * al(n)
82.   Vr2--> enddo
83.
84.   Vr2--< do n = nmin, nmax
85.   Vr2       deltaa(n)= ar(n) - al(n)
86.   Vr2       a6(n) = 6. * (a(n) - .5 * (al(n) + ar(n)))
87.   Vr2--> enddo
```

PARABOLA

```
4|||    0.1% |      3.4 |    5.6 |   62.0% |line.44
4|||    2.5% |     88.5 |   27.5 |   23.8% |line.45
4|||    0.2% |      7.1 |    8.9 |   56.0% |line.48
4|||    0.0% |      0.1 |    1.9 |   94.9% |line.49
4|||    0.3% |      9.6 |   10.4 |   52.3% |line.53
4|||    0.3% |     10.1 |   10.9 |   51.9% |line.54
       .9% |     31.3 |   14.7 |   32.0% |line.55
       .2% |      7.3 |   11.7 |   61.6% |line.56
       .0% |      0.2 |    1.8 |   90.6% |line.57
       .4% |     13.6 |   10.4 |   43.5% |line.68
       .8% |     27.2 |   13.8 |   33.9% |line.69
       .4% |     15.4 |   11.6 |   43.2% |line.70
       .4% |     13.4 |   10.6 |   44.3% |line.71
       .4% |     14.0 |   12.0 |   46.2% |line.72
4|||    0.1% |      4.8 |    8.2 |   63.5% |line.75
4|||    0.3% |     10.2 |    9.8 |   49.1% |line.76
4|||    0.6% |     19.4 |   14.6 |   43.1% |line.77
4|||    0.5% |     17.9 |   11.1 |   38.4% |line.78
4|||    1.2% |     40.6 |   16.4 |   28.8% |line.80
4|||    1.8% |     63.9 |   24.1 |   27.5% |line.81
4|||    0.0% |      0.2 |    2.8 |   92.7% |line.82
4|||    0.1% |      4.3 |    7.7 |   64.4% |line.84
4|||    0.5% |     16.0 |   12.0 |   43.2% |line.85
4|||    0.6% |     21.3 |   13.7 |   39.4% |line.86
4|||    0.0% |      0.0 |    1.0 |   95.7% |line.87
```

# If it Vectorizes, Check Memory Utilization

```
44.  V----<   do n = nmin-1, nmax
45.  V         ar(n) = a(n) + para(n,1)*diffa(n) + para(n,2)*da(n+1) + para(n,3)*da(n)
48.  V         al(n+1) = ar(n)
49.  V---->   enddo
53.  fV---<   do n = nmin, nmax
54.  fV        onemfl= 1.0 - flat(n)
55.  fV        ar(n) = flat(n) * a(n) + onemfl * ar(n)
56.  fV        al(n) = flat(n) * a(n) + onemfl * al(n)
57.  fV--->   enddo
67.  f----< do n = nmin, nmax
68.  f       deltaa(n) = ar(n) - al(n)
69.  f       a6(n)     = 6. * (a(n) - .5 * (al(n) + ar(n)))
70.  f       scrch1(n) = (ar(n) - a(n)) * (a(n)-al(n))
71.  f       scrch2(n) = deltaa(n) * deltaa(n)
72.  f       scrch3(n) = deltaa(n) * a6(n)
73.  f----> enddo
74.
75.  Vr2--< do n = nmin, nmax
76.  Vr2     if(scrch1(n) <= 0.0) then
77.  Vr2       ar(n) = a(n)
78.  Vr2       al(n) = a(n)
79.  Vr2     endif
80.  Vr2     if(scrch2(n) < +scrch3(n)) al(n) = 3. * a(n) - 2. * ar(n)
81.  Vr2     if(scrch2(n) < -scrch3(n)) ar(n) = 3. * a(n) - 2. * al(n)
82.  Vr2--> enddo
83.
84.  Vr2--< do n = nmin, nmax
85.  Vr2     deltaa(n)= ar(n) - al(n)
86.  Vr2     a6(n) = 6. * (a(n) - .5 * (al(n) + ar(n)))
87.  Vr2--> enddo
```

Remove unnecessary arrays and fuse loops

```
52.  Vr2--<   do n = nmin, nmax
53.  Vr2       onemfl= 1.0 - flat(n)
54.  Vr2       ar(n) = flat(n) * a(n) + onemfl * ar(n)
55.  Vr2       al(n) = flat(n) * a(n) + onemfl * al(n)
56.  Vr2      deltaa(n) = ar(n) - al(n)
57.  Vr2      a6(n)     = 6. * (a(n) - .5 * (al(n) + ar(n)))
58.  Vr2      scrch1s = (ar(n) - a(n)) * (a(n)-al(n))
59.  Vr2      scrch2s = deltaa(n) * deltaa(n)
60.  Vr2      scrch3s = deltaa(n) * a6(n)
61.  Vr2      if(scrch1s <= 0.0) then
62.  Vr2        ar(n) = a(n)
63.  Vr2        al(n) = a(n)
64.  Vr2      endif
65.  Vr2      if(scrch2s < +scrch3s) al(n) = 3. * a(n) - 2. * ar(n)
66.  Vr2      if(scrch2s < -scrch3s) ar(n) = 3. * a(n) - 2. * al(n)
67.  Vr2      deltaa(n)= ar(n) - al(n)
68.  Vr2      a6(n) = 6. * (a(n) - .5 * (al(n) + ar(n)))
69.  Vr2--> enddo
```

# If it Doesn't Vectorize – Fix It

```
||||==========================================
||  10.8% |   376.9 |    -- |    -- |riemann_
3|       |       |       |       | riemann.f90
||||------------------------------------------------------------------
4|||   1.4% |    47.4 |  32.6 | 41.0% |line.77
4|||   3.9% |   135.8 |  28.2 | 17.3% |line.78
```

```
63.  + 1----< do l = lmin, lmax
64.  + 1 2--<   do n = 1, 12
65.    1 2       pmold(l) = pmid(l)
66.    1 2       wlft (l) = 1.0 + gamfac1*(pmid(l) - plft(l)) * plfti(l)
67.    1 2       wrgh (l) = 1.0 + gamfac1*(pmid(l) - prgh(l)) * prghi(l)
68.    1 2       wlft (l) = clft(l) * sqrt(wlft(l))
69.    1 2       wrgh (l) = crgh(l) * sqrt(wrgh(l))
70.    1 2       zlft (l) = 4.0 * vlft(l) * wlft(l) * wlft(l)
71.    1 2       zrgh (l) = 4.0 * vrgh(l) * wrgh(l) * wrgh(l)
72.    1 2       zlft (l) = -zlft(l) * wlft(l)/(zlft(l) - gamfac2*(pmid(l) - plft(l)))
73.    1 2       zrgh (l) =  zrgh(l) * wrgh(l)/(zrgh(l) - gamfac2*(pmid(l) - prgh(l)))
74.    1 2       umidl(l) = ulft(l) - (pmid(l) - plft(l)) / wlft(l)
75.    1 2       umidr(l) = urgh(l) + (pmid(l) - prgh(l)) / wrgh(l)
76.    1 2       pmid (l) = pmid(l) + (umidr(l) - umidl(l))*(zlft(l) * zrgh(l)) / (zrgh(l) - zlft(l))
77.    1 2       pmid (l) = max(smallp,pmid(l))
78.    1 2       if (abs(pmid(l)-pmold(l))/pmid(l) < tol ) exit
79.    1 2-->   enddo
80.    1----> enddo
```

```
ftn-6254 ftn: VECTOR RIEMANN, File = riemann.f90, Line = 64
  A loop starting at line 64 was not vectorized because a recurrence was found
  on "pmid" at line 77.
```

# If it Doesn't Vectorize – Fix It

```
63.  + 1----< do l = lmin, lmax
64.  + 1 2--<   do n = 1, 12
65.    1 2       pmold(l) = pmid(l)
66.    1 2       wlft (l) = 1.0 + gamfac1*(pmid(l) - plft(l)) * plfti(l)
67.    1 2       wrgh (l) = 1.0 + gamfac1*(pmid(l) - prgh(l)) * prghi(l)
68.    1 2       wlft (l) = clft(l) * sqrt(wlft(l))
69.    1 2       wrgh (l) = crgh(l) * sqrt(wrgh(l))
70.    1 2       zlft (l) = 4.0 * vlft(l) * wlft(l) * wlft(l)
71.    1 2       zrgh (l) = 4.0 * vrgh(l) * wrgh(l) * wrgh(l)
72.    1 2       zlft (l) = -zlft(l) * wlft(l)/(zlft(l) - gamfac2*(pmid(l) - plft(l)))
73.    1 2       zrgh (l) =  zrgh(l) * wrgh(l)/(zrgh(l) - gamfac2*(pmid(l) –
                                                                  prgh(l)))
74.    1 2       umidl(l) = ulft(l) - (pmid(l) - plft(l)) / wlft(l)
75.    1 2       umidr(l) = urgh(l) + (pmid(l) - prgh(l)) / wrgh(l)
76.    1 2       pmid (l) = pmid(l) + (umidr(l) - umidl(l))*(zlft(l) * zrgh(l)) /
                                                          (zrgh(l) - zlft(l))
77.    1 2       pmid (l) = max(smallp,pmid(l))
78.    1 2       if (abs(pmid(l)-pmold(l))/pmid(l) < tol ) exit
79.    1 2-->   enddo
80.    1----> enddo
```

```
62.    A-----<>  converged =.F.
63.  + 1------<  do n = 1, 12
64.    1 Vr2--<    do l = lmin, lmax
65.    1 Vr2       if(.not.converged(l))then
66.    1 Vr2        pmold(l) = pmid(l)
67.    1 Vr2        wlft (l) = 1.0 + gamfac1*(pmid(l) - plft(l)) * plfti(l)
68.    1 Vr2        wrgh (l) = 1.0 + gamfac1*(pmid(l) - prgh(l)) * prghi(l)
69.    1 Vr2        wlft (l) = clft(l) * sqrt(wlft(l))
70.    1 Vr2        wrgh (l) = crgh(l) * sqrt(wrgh(l))
71.    1 Vr2        zlft (l) = 4.0 * vlft(l) * wlft(l) * wlft(l)
72.    1 Vr2        zrgh (l) = 4.0 * vrgh(l) * wrgh(l) * wrgh(l)
73.    1 Vr2        zlft (l) = -zlft(l) * wlft(l)/(zlft(l) - gamfac2*(pmid(l) - plft(l)))
74.    1 Vr2        zrgh (l) =  zrgh(l) * wrgh(l)/(zrgh(l) - gamfac2*(pmid(l) - prgh(l)))
75.    1 Vr2        umidl(l) = ulft(l) - (pmid(l) - plft(l)) / wlft(l)
76.    1 Vr2        umidr(l) = urgh(l) + (pmid(l) - prgh(l)) / wrgh(l)
77.    1 Vr2        pmid (l) = pmid(l) + (umidr(l) - umidl(l))*(zlft(l) * zrgh(l)) / &
78.    1 Vr2                   (zrgh(l)-zlft(l))
79.    1 Vr2        pmid (l) = max(smallp,pmid(l))
80.    1 Vr2        if (abs(pmid(l)-pmold(l))/pmid(l) < tol ) then
81.    1 Vr2        converged(l) = .T.
82.    1 Vr2        endif
83.    1 Vr2       endif
84.    1 Vr2-->    enddo
85.  + 1          if(all(converged(lmin:lmax)))exit
86.    1------>  enddo
```

# SWEEPZ

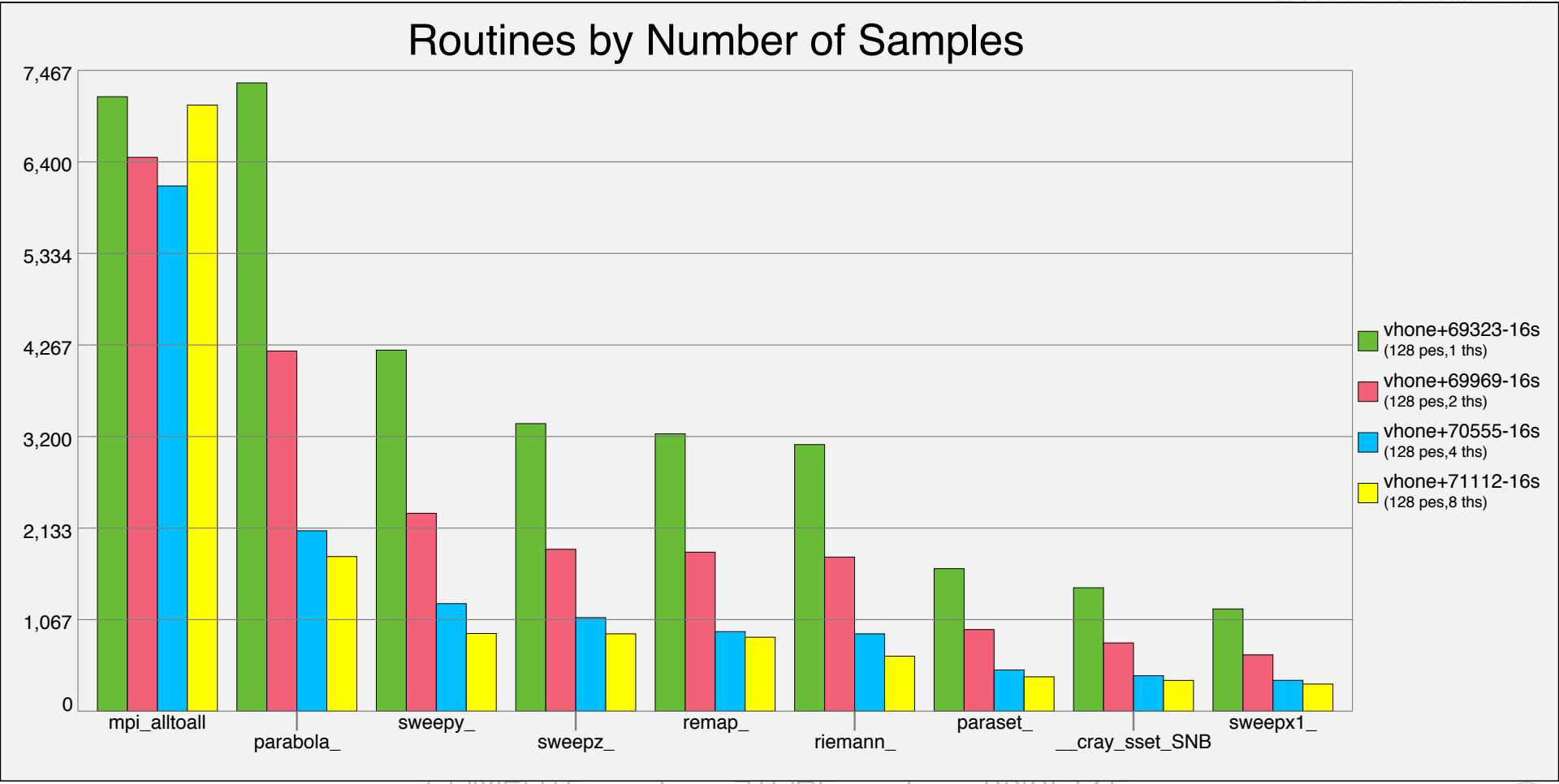
```
||  10.3% |  1,679.0 |    -- |    -- | sweepz_
3|        |          |       |       |  levesque/CUG_2018/VH1_version1/sweepz.f90
||||-------------------------------------------------------------------------
4|||   3.0% |    489.4 |  21.6 |  4.3% | line.27
4|||   1.3% |    211.9 |  38.1 | 15.4% | line.64
4|||   1.0% |    165.0 |  43.0 | 20.8% | line.104
4|||   2.7% |    447.2 |  36.8 |  7.7% | line.121
```

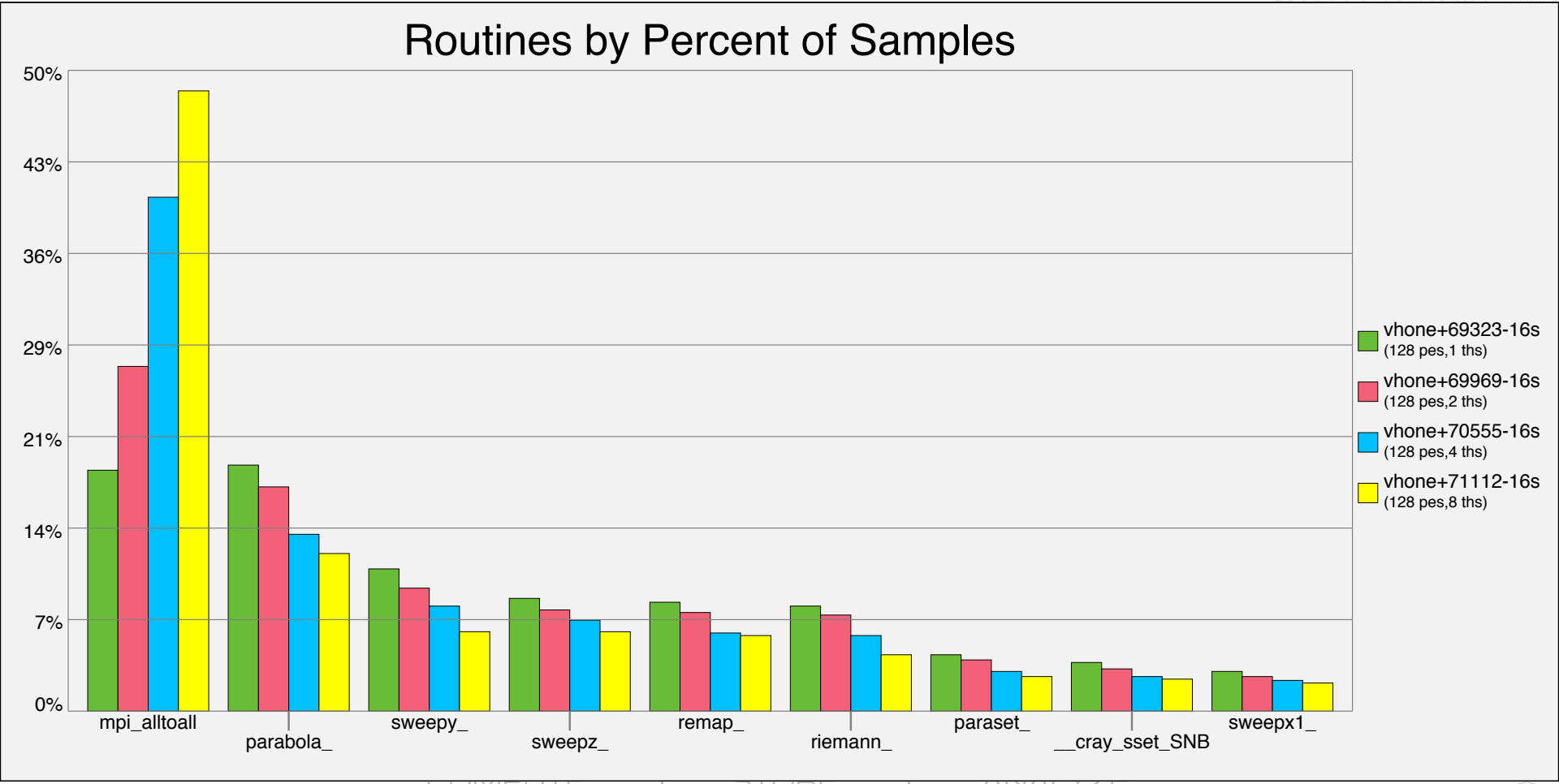
# SWEEPZ

```
22.  + i------------< do j = 1, js
23.  + i i----------<  do m = 1, npey
24.  + i i i--------<   do i = 1, isy
25.    i i i           n = i + isy*(m-1)
26.  + i i i 4------<   do k = 1, ks
27.    i i i 4 VR--<>      send3(1,j,k,n) = recv2(1,k,i,j,m)
28.    i i i 4             send3(2,j,k,n) = recv2(2,k,i,j,m)
29.    i i i 4             send3(3,j,k,n) = recv2(3,k,i,j,m)
30.    i i i 4             send3(4,j,k,n) = recv2(4,k,i,j,m)
31.    i i i 4             send3(5,j,k,n) = recv2(5,k,i,j,m)
32.    i i i 4             send3(6,j,k,n) = recv2(6,k,i,j,m)
33.    i i i 4------>   enddo
34.    i i i-------->  enddo
35.    i i---------->  enddo
36.    i------------> enddo
```

# SWEEPZ (continued)

```
21.                      !-----------------------------------------
22.    M---------------< !$OMP PARALLEL DO
23.  + M im------------< do j = 1, js
24.  + M im i----------<  do m = 1, npey
25.  + M im i i--------<   do i = 1, isy
26.    M im i i             n = i + isy*(m-1)
27.  + M im i i 5------<    do k = 1, ks
28.    M im i i 5 VR--<>       send3(1,j,k,n) = recv2(1,k,i,j,m)
29.    M im i i 5              send3(2,j,k,n) = recv2(2,k,i,j,m)
30.    M im i i 5              send3(3,j,k,n) = recv2(3,k,i,j,m)
31.    M im i i 5              send3(4,j,k,n) = recv2(4,k,i,j,m)
32.    M im i i 5              send3(5,j,k,n) = recv2(5,k,i,j,m)
33.    M im i i 5              send3(6,j,k,n) = recv2(6,k,i,j,m)
34.    M im i i 5------>    enddo
35.    M im i i-------->   enddo
36.    M im i---------->  enddo
37.    M im----------->> enddo
```





# Profile for 1 Thread and 4 Threads

Table 1: Profile by Function 1 Thread

| Samp% | Samp | Imb. Samp | Imb. Samp% | Group Function=[MAX10] PE=HIDE |
|---|---|---|---|---|
| 100.0% | 38,034.0 | -- | -- | Total |
| 73.5% | 27,936.5 | -- | -- | USER |
| 19.2% | 7,320.6 | 202.4 | 2.7% | parabola_ |
| 11.1% | 4,206.8 | 179.2 | 4.1% | sweepy_ |
| 8.8% | 3,350.8 | 233.2 | 6.6% | sweepz_ |
| 8.5% | 3,231.5 | 138.5 | 4.1% | remap_ |
| 8.2% | 3,106.3 | 2,321.7 | 43.1% | riemann_ |
| 4.4% | 1,660.7 | 105.3 | 6.0% | paraset_ |
| 3.1% | 1,190.9 | 72.1 | 5.8% | sweepx1_ |
| 3.0% | 1,136.4 | 68.6 | 5.7% | sweepx2_ |
| 20.5% | 7,814.0 | -- | -- | MPI |
| 18.8% | 7,159.8 | 835.2 | 10.5% | mpi_alltoall |

Table 1: Profile by Function 4 threads

| Samp% | Samp | Imb. Samp | Imb. Samp% | Group Function=[MAX10] PE=HIDE Thread=HIDE |
|---|---|---|---|---|
| 100.0% | 15,265.8 | -- | -- | Total |
| 54.1% | 8,260.7 | -- | -- | USER |
| 13.8% | 2,101.9 | 84.1 | 3.9% | parabola_ |
| 8.2% | 1,252.8 | 62.2 | 4.8% | sweepy_ |
| 7.1% | 1,090.2 | 63.8 | 5.6% | sweepz_ |
| 6.1% | 926.8 | 62.2 | 6.3% | remap_ |
| 5.9% | 901.4 | 712.6 | 44.5% | riemann_ |
| 3.1% | 480.2 | 71.8 | 13.1% | paraset_ |
| 2.4% | 359.3 | 49.7 | 12.3% | sweepx1_ |
| 2.2% | 329.7 | 46.3 | 12.4% | sweepx2_ |
| 41.4% | 6,326.9 | -- | -- | MPI |
| 40.1% | 6,120.0 | 209.0 | 3.3% | mpi_alltoall |

# Memory Analysis for Optimized VH1

Table 5: Profile by Group, Function, and Line

| Samp% | Samp | Imb. Samp | Imb. Samp% | MEM_LOAD_UOPS_RETIRED :HIT_LFB:precise=2 | RESOURCE_STALLS :ANY | Group Function=[MAX10] Source Line PE=HIDE |
|---|---|---|---|---|---|---|
| 100.0% | 506.4 | -- | -- | 52,444,505,648,539,880 | 810,810,111,305 | Total |
| 67.0% | 339.1 | -- | -- | 35,351,497,873,955,312 | 551,686,946,473 | USER |
| 25.6% | 129.5 | -- | -- | 13,561,376,423,707,960 | 207,864,527,154 | parabola_ 3\| parabola.f90 |
| 14.0% | 71.1 | 77.9 | 52.7% | 7,540,450,746,779,697 | 113,994,086,387 | line.26 |
| 1.0% | 5.2 | 8.8 | 63.0% | 510,173,395,620,708 | 8,400,427,348 | line.32 |
| 8.1% | 41.0 | 41.0 | 50.4% | 4,241,915,862,200,189 | 65,974,673,046 | line.46 |
| 1.3% | 6.8 | 9.2 | 58.0% | 714,682,558,419,997 | 10,882,073,895 | line.55 |
| 12.1% | 61.2 | -- | -- | 6,449,735,211,652,689 | 103,694,034,743 | sweepy_ 3\| sweepy.f90 |
| 3.2% | 16.2 | 19.8 | 55.6% | 1,653,665,489,088,910 | 27,467,001,609 | line.46 |
| 6.4% | 32.2 | 34.8 | 52.4% | 3,465,660,652,265,039 | 54,562,573,915 | line.47 |
| 10.2% | 51.9 | -- | -- | 5,479,965,955,430,281 | 81,379,551,948 | sweepz_ 3\| sweepz.f90 |
| 2.4% | 12.3 | 19.7 | 62.0% | 1,356,797,349,204,156 | 21,098,054,630 | line.28 |
| 1.8% | 8.9 | 13.1 | 60.0% | 945,580,000,330,081 | 13,804,851,073 | line.65 |
| 3.7% | 18.8 | 28.2 | 60.4% | 1,961,528,744,947,444 | 29,502,970,062 | line.66 |

# Code Responsible for Memory Bandwidth

```
24.            !-----------------------------------------------------------------------
25.    Vr4---<   do n = nmin-2, nmax+1
26.    Vr4         diffa(n) = a(n+1) - a(n)
27.    Vr4--->   enddo
28.
29.            !                                                        Equation 1.7 of C&W
30.            !     da(j) = D1 * (a(j+1) - a(j)) + D2 * (a(j) - a(j-1))
31.    fVr4--<   do n = nmin-1, nmax+1
32.    fVr4       da(n) = para(n,4) * diffa(n) + para(n,5) * diffa(n-1)
33.    fVr4       da(n) = sign( min(abs(da(n)), 2.0*abs(diffa(n-1)), 2.0*abs(diffa(n))), da(n) )
34.    fVr4-->   enddo
35.
36.            !     zero out da(n) if a(n) is a local max/min
37.    f-----<   do n = nmin-1, nmax+1
38.    f          if(diffa(n-1)*diffa(n) < 0.0) da(n) = 0.0
39.    f----->   enddo
40.
41.            !                                                        Equation 1.6 of C&W
42.            !     a(j+.5) = a(j) + C1 * (a(j+1)-a(j)) + C2 * dma(j+1) + C3 * dma(j)
43.            ! MONOT: Limit ar(n) to the range defined by a(n) and a(n+1)
44.
45.    Vr2---<   do n = nmin-1, nmax
46.    Vr2        ar(n) = a(n) + para(n,1)*diffa(n) + para(n,2)*da(n+1) + para(n,3)*da(n)
47.    Vr2     !   ar(n) = max(ar(n),min(a(n),a(n+1)))
48.    Vr2     !   ar(n) = min(ar(n),max(a(n),a(n+1)))
49.    Vr2        al(n+1) = ar(n)
50.    Vr2--->   enddo
```

Difficult to merge these loops – compiler did merge two

# Summary

- The Whack-a-mole approach was shown to be an effective recipe for using the tools to obtain results
- Cray compiler and performance tools gives customers the capability they need to identify performance issues at scale in important production codes
- Simple interfaces coupled with a wealth of capability offer the most flexibility for users who need to scale applications to larger job and problem sizes

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