Ménage à Trois: Hybrid Profiling, Performance Visualization, and Kernel Measurement

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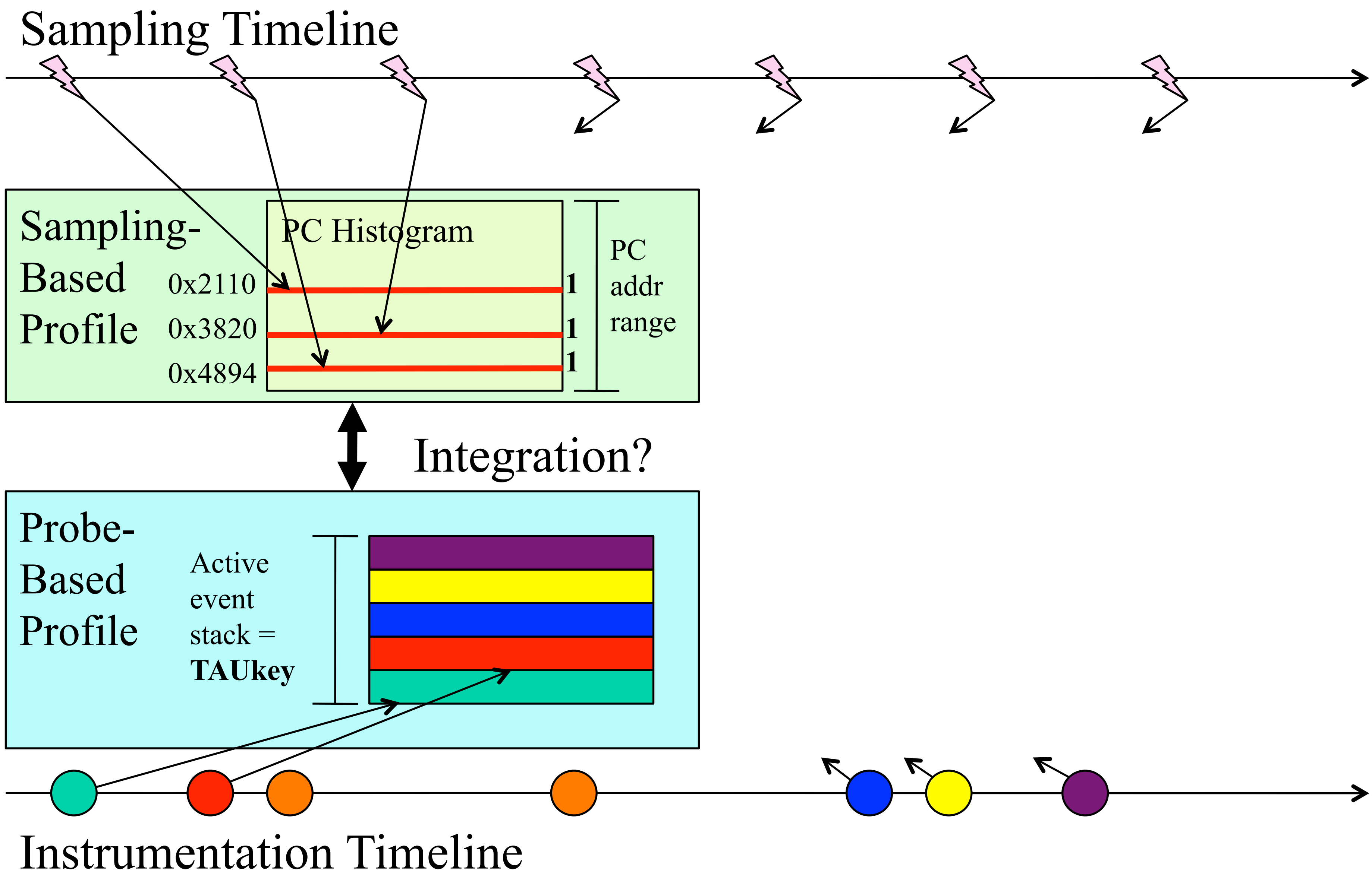
Hybrid Profiling – Motivation

- Different approaches for observing parallel performance
- ***Sampling-based measurement***
  - Event-based / instruction-based sampling (EBS / IBS)
  - Examples: PerfSuite, HPCToolkit, ...
- ***Probe-based measurement*** (PBM)
  - Instrumentation of program code
  - Example: TAU, Scalasca, ...
- Combine the two to exploits advantages of probe-based instrumentation with advantages of sampling
- TAUebs
  - TAU for probe-based instrumentation and measurement
  - Event-based sampling measurement (with callstack unwinding)

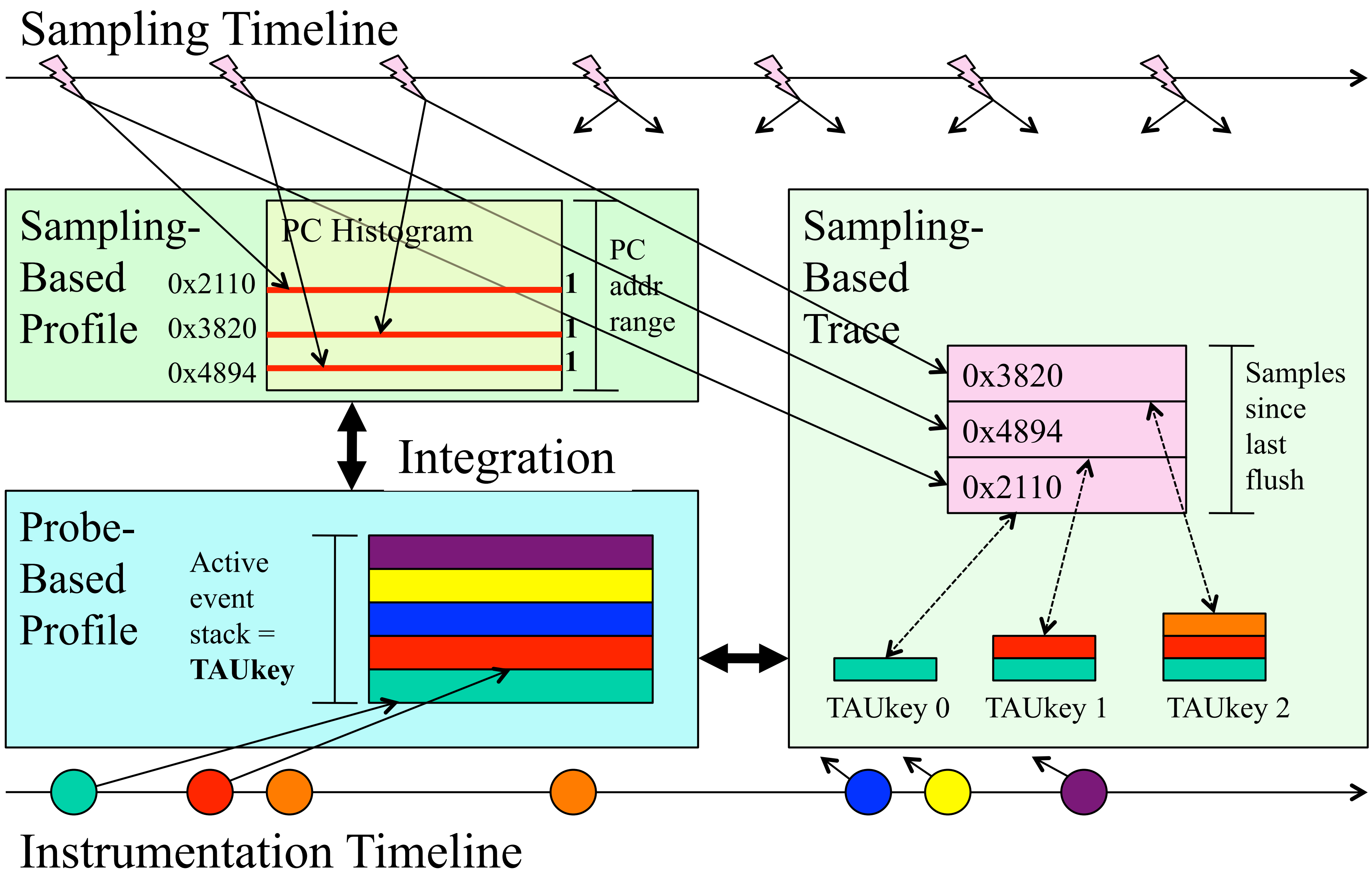
Integrated Probe + EBS Measurement Design (1)



Hmm, seems like we have seen this before …

- Previously, TAUebs:
  - Captured a trace of EBS samples
  - Post-processed the trace to recover symbol information
  - Merged sample traces with generated profiles offline
  - Paper in ICPP 2010 and discussed briefly at CScADS

Integrated Probe + EBS Measurement Design (2)

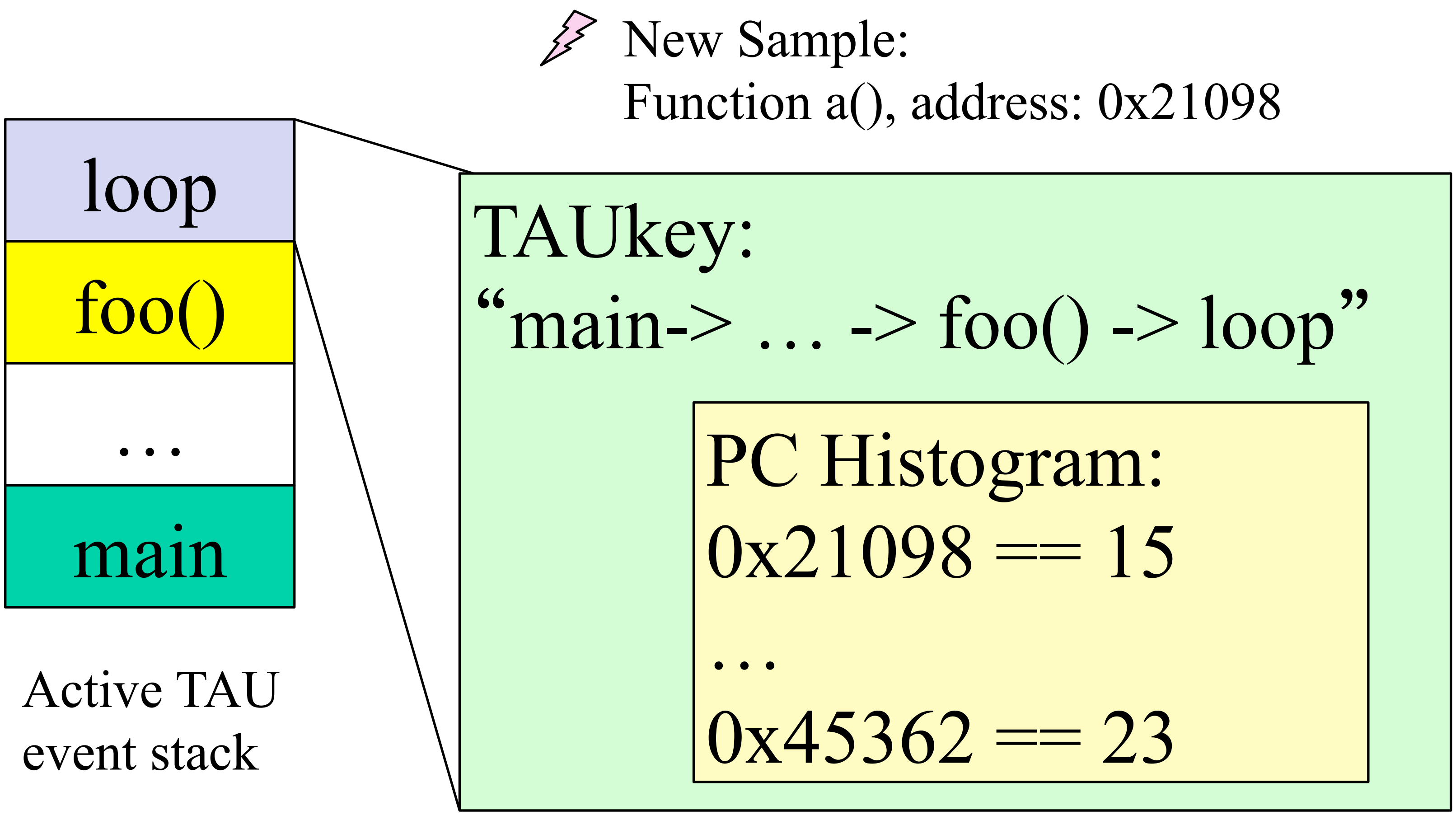


So what's new?

- Previously, TAUebs:
  - Captured a trace of EBS samples
  - Post-processed the trace to recover symbol information
  - Merged sample traces with generated profiles offline
  - Paper in ICPP 2010 and discussed briefly at CScADS
- Now, TAUebs:
  - Captures EBS sample histograms at runtime (profiling)
  - Sample histograms are associated with TAU event context
  - TAU profile output now incorporates sampled histograms
  - It is still possible to generate EBS traces

TAUebs Hybrid Profiling

- Instance of new sample contextualized by TAUkey and integrated into TAU profile structures at runtime

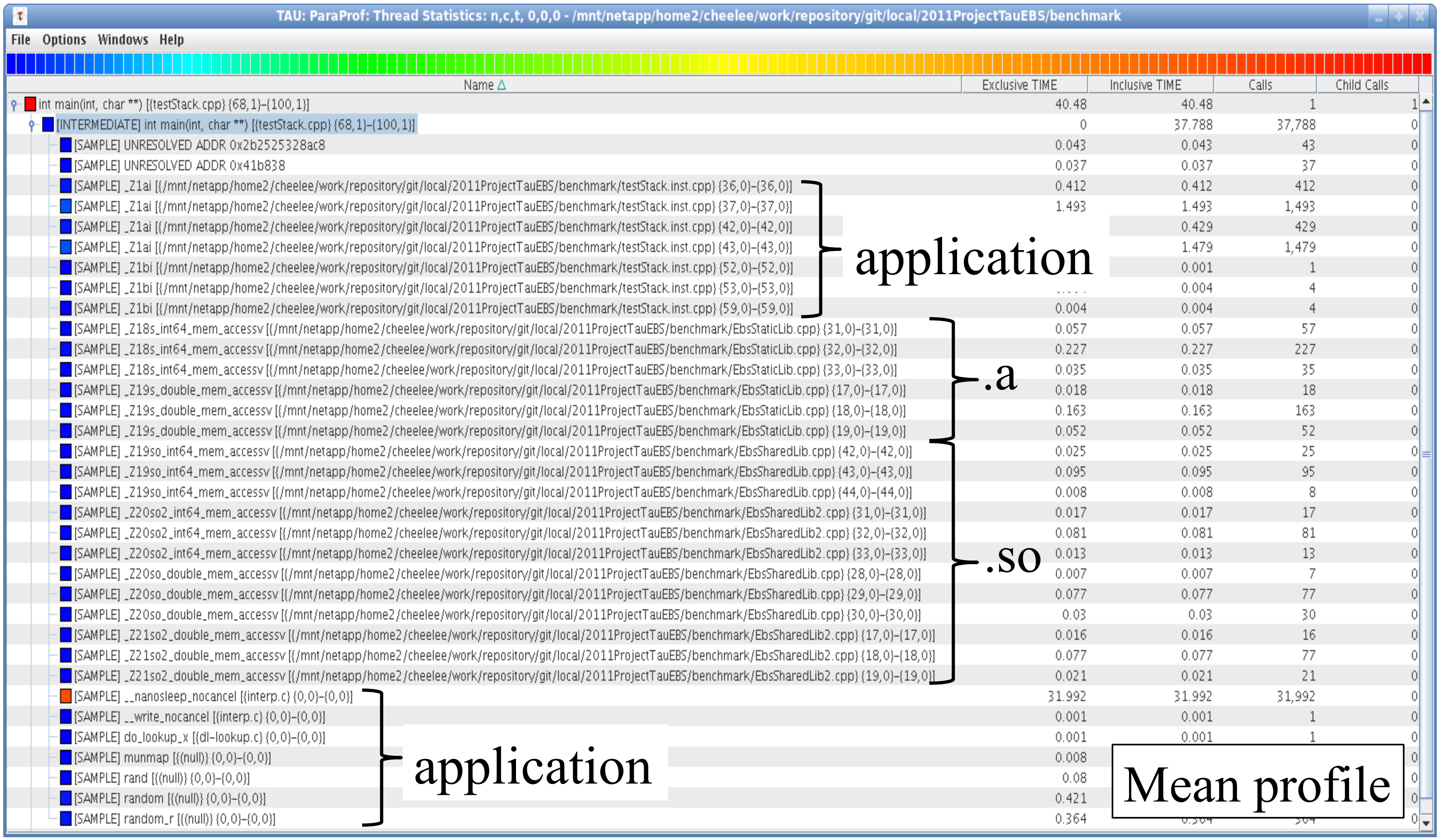


Hybrid Profiling Implementation

- Uses existing timer-interrupt framework to trigger samples
- With each sample:
  - Query active TAU event context to determine TAUkey
  - Create/update PC address histogram for the active TAU event context represented by its key
- Addresses are resolved to meaningful symbol information via BFD at the end of the run
- TAU event context can be controlled by the *event path depth*
- Caveats
  - Current implementation does not unwind the callstack
    - flat sample profile for each TAU event context
  - Works only with single-threaded processes presently

Examples: Simple Benchmark – Flat Profile

- Pure sampling – only main() is instrumented



Name △	Exclusive TIME	Inclusive TIME	Calls	Child Calls
int main(int, char **) [{testStack.cpp} {68,1}-{100,1}]	40.48	40.48	1	1
[INTERMEDIATE] int main(int, char **) [{testStack.cpp} {68,1}-{100,1}]	0	37.788	37,788	0
[SAMPLE] UNRESOLVED ADDR 0x2b2525328ac8	0.043	0.043	43	0
[SAMPLE] UNRESOLVED ADDR 0x41b838	0.037	0.037	37	0
[SAMPLE] _Z1ai [{/mnt/netapp/home2/cheelee/work/repository/git/local/2011ProjectTauEBS/benchmark/testStack.inst.cpp} {36,0}-{36,0}]	0.412	0.412	412	0
[SAMPLE] _Z1ai [{/mnt/netapp/home2/cheelee/work/repository/git/local/2011ProjectTauEBS/benchmark/testStack.inst.cpp} {37,0}-{37,0}]	1.493	1.493	1,493	0
[SAMPLE] _Z1ai [{/mnt/netapp/home2/cheelee/work/repository/git/local/2011ProjectTauEBS/benchmark/testStack.inst.cpp} {42,0}-{42,0}]	[illegible]	0.429	429	0
[SAMPLE] _Z1ai [{/mnt/netapp/home2/cheelee/work/repository/git/local/2011ProjectTauEBS/benchmark/testStack.inst.cpp} {43,0}-{43,0}]	[illegible]	1.479	1,479	0
[SAMPLE] _Z1bi [{/mnt/netapp/home2/cheelee/work/repository/git/local/2011ProjectTauEBS/benchmark/testStack.inst.cpp} {52,0}-{52,0}]	[illegible]	0.001	1	0
[SAMPLE] _Z1bi [{/mnt/netapp/home2/cheelee/work/repository/git/local/2011ProjectTauEBS/benchmark/testStack.inst.cpp} {53,0}-{53,0}]	[illegible]	0.004	4	0
[SAMPLE] _Z1bi [{/mnt/netapp/home2/cheelee/work/repository/git/local/2011ProjectTauEBS/benchmark/testStack.inst.cpp} {59,0}-{59,0}]	0.004	0.004	4	0
[SAMPLE] _Z18s_int64_mem_accessv [{/mnt/netapp/home2/cheelee/work/repository/git/local/2011ProjectTauEBS/benchmark/EbsStaticLib.cpp} {31,0}-{31,0}]	0.057	0.057	57	0
[SAMPLE] _Z18s_int64_mem_accessv [{/mnt/netapp/home2/cheelee/work/repository/git/local/2011ProjectTauEBS/benchmark/EbsStaticLib.cpp} {32,0}-{32,0}]	0.227	0.227	227	0
[SAMPLE] _Z18s_int64_mem_accessv [{/mnt/netapp/home2/cheelee/work/repository/git/local/2011ProjectTauEBS/benchmark/EbsStaticLib.cpp} {33,0}-{33,0}]	0.035	0.035	35	0
[SAMPLE] _Z19s_double_mem_accessv [{/mnt/netapp/home2/cheelee/work/repository/git/local/2011ProjectTauEBS/benchmark/EbsStaticLib.cpp} {17,0}-{17,0}]	0.018	0.018	18	0
[SAMPLE] _Z19s_double_mem_accessv [{/mnt/netapp/home2/cheelee/work/repository/git/local/2011ProjectTauEBS/benchmark/EbsStaticLib.cpp} {18,0}-{18,0}]	0.163	0.163	163	0
[SAMPLE] _Z19s_double_mem_accessv [{/mnt/netapp/home2/cheelee/work/repository/git/local/2011ProjectTauEBS/benchmark/EbsStaticLib.cpp} {19,0}-{19,0}]	0.052	0.052	52	0
[SAMPLE] _Z19so_int64_mem_accessv [{/mnt/netapp/home2/cheelee/work/repository/git/local/2011ProjectTauEBS/benchmark/EbsSharedLib.cpp} {42,0}-{42,0}]	0.025	0.025	25	0
[SAMPLE] _Z19so_int64_mem_accessv [{/mnt/netapp/home2/cheelee/work/repository/git/local/2011ProjectTauEBS/benchmark/EbsSharedLib.cpp} {43,0}-{43,0}]	0.095	0.095	95	0
[SAMPLE] _Z19so_int64_mem_accessv [{/mnt/netapp/home2/cheelee/work/repository/git/local/2011ProjectTauEBS/benchmark/EbsSharedLib.cpp} {44,0}-{44,0}]	0.008	0.008	8	0
[SAMPLE] _Z20so2_int64_mem_accessv [{/mnt/netapp/home2/cheelee/work/repository/git/local/2011ProjectTauEBS/benchmark/EbsSharedLib2.cpp} {31,0}-{31,0}]	0.017	0.017	17	0
[SAMPLE] _Z20so2_int64_mem_accessv [{/mnt/netapp/home2/cheelee/work/repository/git/local/2011ProjectTauEBS/benchmark/EbsSharedLib2.cpp} {32,0}-{32,0}]	0.081	0.081	81	0
[SAMPLE] _Z20so2_int64_mem_accessv [{/mnt/netapp/home2/cheelee/work/repository/git/local/2011ProjectTauEBS/benchmark/EbsSharedLib2.cpp} {33,0}-{33,0}]	0.013	0.013	13	0
[SAMPLE] _Z20so_double_mem_accessv [{/mnt/netapp/home2/cheelee/work/repository/git/local/2011ProjectTauEBS/benchmark/EbsSharedLib.cpp} {28,0}-{28,0}]	0.007	0.007	7	0
[SAMPLE] _Z20so_double_mem_accessv [{/mnt/netapp/home2/cheelee/work/repository/git/local/2011ProjectTauEBS/benchmark/EbsSharedLib.cpp} {29,0}-{29,0}]	0.077	0.077	77	0
[SAMPLE] _Z20so_double_mem_accessv [{/mnt/netapp/home2/cheelee/work/repository/git/local/2011ProjectTauEBS/benchmark/EbsSharedLib.cpp} {30,0}-{30,0}]	0.03	0.03	30	0
[SAMPLE] _Z21so2_double_mem_accessv [{/mnt/netapp/home2/cheelee/work/repository/git/local/2011ProjectTauEBS/benchmark/EbsSharedLib2.cpp} {17,0}-{17,0}]	0.016	0.016	16	0
[SAMPLE] _Z21so2_double_mem_accessv [{/mnt/netapp/home2/cheelee/work/repository/git/local/2011ProjectTauEBS/benchmark/EbsSharedLib2.cpp} {18,0}-{18,0}]	0.077	0.077	77	0
[SAMPLE] _Z21so2_double_mem_accessv [{/mnt/netapp/home2/cheelee/work/repository/git/local/2011ProjectTauEBS/benchmark/EbsSharedLib2.cpp} {19,0}-{19,0}]	0.021	0.021	21	0
[SAMPLE] __nanosleep_nocancel [{interp.c} {0,0}-{0,0}]	31.992	31.992	31,992	0
[SAMPLE] __write_nocancel [{interp.c} {0,0}-{0,0}]	0.001	0.001	1	0
[SAMPLE] do_lookup_x [{dl-lookup.c} {0,0}-{0,0}]	0.001	0.001	1	0
[SAMPLE] munmap [{(null)} {0,0}-{0,0}]	0.008	[illegible]	[illegible]	0
[SAMPLE] rand [{(null)} {0,0}-{0,0}]	0.08	[illegible]	[illegible]	0
[SAMPLE] random [{(null)} {0,0}-{0,0}]	0.421	[illegible]	[illegible]	0
[SAMPLE] random_r [{(null)} {0,0}-{0,0}]	0.364	[illegible]	[illegible]	0

Examples: Simple Benchmark – Hybrid Profile

- Mix of sampling and probed-based instrumentation

TAU: ParaProf: Thread Statistics: n,c,t, 0,0,0 - /mnt/netapp/home2/cheelee/work/repository/git/local/2011ProjectTauEBS/benchmark/Mix

File Options Windows Help

Name △	Exclusive TIME	Inclusive TIME	Calls	Child Calls
int main(int, char **) [{testStack.cpp} {68,1}-{100,1}]	27.546	34.078	1	4
[INTERMEDIATE] int main(int, char **) [{testStack.cpp} {68,1}-{100,1}]	0	27.498	27,498	0
[SAMPLE] UNRESOLVED ADDR 0x2b32c567aac8	0.049	0.049	49	0
[SAMPLE] UNRESOLVED ADDR 0x41b880	0.02	0.02	20	0
[SAMPLE] _Z18s_int64_mem_accessv [{/mnt/netapp/home2/cheelee/work/repositc	0.026	0.026	26	0
[SAMPLE] _Z18s_int64_mem_accessv [{/mnt/netapp/home2/cheelee/work/repositc	0.082	0.082	82	0
[SAMPLE] _Z18s_int64_mem_accessv [{/mnt/netapp/home2/cheelee/work/repositc	0.012	0.012	12	0
[SAMPLE] _Z19s_double_mem_accessv [{/mnt/netapp/home2/cheelee/work/reposi	0.012	0.012	12	0
[SAMPLE] _Z19s_double_mem_accessv [{/mnt/netapp/home2/cheelee/work/reposi	0.081	0.081	81	0
[SAMPLE] _Z19s_double_mem_accessv [{/mnt/netapp/home2/cheelee/work/reposi	0.034	0.034	34	0
[SAMPLE] _Z19so_int64_mem_accessv [{/mnt/netapp/home2/cheelee/work/reposit	0.019	0.019	19	0
[SAMPLE] _Z19so_int64_mem_accessv [{/mnt/netapp/home2/cheelee/work/reposit	0.073	0.073	73	0
[SAMPLE] _Z19so_int64_mem_accessv [{/mnt/netapp/home2/cheelee/work/reposit	0.014	0.014	14	0
[SAMPLE] _Z20so2_int64_mem_accessv [{/mnt/netapp/home2/cheelee/work/repos	[illegible]	0.016	16	0
[SAMPLE] _Z20so2_int64_mem_accessv [{/mnt/netapp/home2/cheelee/work/repos	[illegible]	0.088	88	0
[SAMPLE] _Z20so2_int64_mem_accessv [{/mnt/netapp/home2/cheelee/work/repos	[illegible]	0.019	19	0
[SAMPLE] _Z20so_double_mem_accessv [{/mnt/netapp/home2/cheelee/work/repo	0.01	0.01	10	0
[SAMPLE] _Z20so_double_mem_accessv [{/mnt/netapp/home2/cheelee/work/repo	0.082	0.082	82	0
[SAMPLE] _Z20so_double_mem_accessv [{/mnt/netapp/home2/cheelee/work/repo	0.03	0.03	30	0
[SAMPLE] _Z21so2_double_mem_accessv [{/mnt/netapp/home2/cheelee/work/rep	0.014	0.014	14	0
[SAMPLE] _Z21so2_double_mem_accessv [{/mnt/netapp/home2/cheelee/work/rep	0.085	0.085	85	0
[SAMPLE] _Z21so2_double_mem_accessv [{/mnt/netapp/home2/cheelee/work/rep	0.029	0.029	29	0
[SAMPLE] __nanosleep_nocancel [{interp.c} {0,0}-{0,0}]	26.086	26.086	26,086	0
[SAMPLE] munmap [{(null)} {0,0}-{0,0}]	0.006	0.006	6	0
[SAMPLE] puts [{(null)} {0,0}-{0,0}]	0.001	0.001	1	0
[SAMPLE] rand [{(null)} {0,0}-{0,0}]	0.05	0.05	50	0
[SAMPLE] random [{(null)} {0,0}-{0,0}]	0.318	0.318	318	0
[SAMPLE] random_r [{(null)} {0,0}-{0,0}]	0.242	0.242	242	0
double a(int) [{testStack.cpp} {30,1}-{44,1}]	0.009	3.022	1	1
[INTERMEDIATE] double a(int) [{testStack.cpp} {30,1}-{44,1}]	[illegible]	0.007	7	0
[SAMPLE] _Z1ai [{/mnt/netapp/home2/cheelee/work/repository/git/local/2011I	[illegible]	0.003	3	0
[SAMPLE] _Z1ai [{/mnt/netapp/home2/cheelee/work/repository/git/local/2011I	0.004	0.004	4	0
void main_foo() [{testStack.cpp} {23,1}-{28,1}]	[illegible]	[illegible]	1	1
[INTERMEDIATE] void main_foo() [{testStack.cpp} {23,1}-{28,1}]	[illegible]	[illegible]	2,009	0
[SAMPLE] __nanosleep_nocancel [{interp.c} {0,0}-{0,0}]	[illegible]	[illegible]	2,009	0
void main_bar() [{testStack.cpp} {18,1}-{21,1}]	1.004	1.004	1	0
[INTERMEDIATE] void main_bar() [{testStack.cpp} {18,1}-{21,1}]	[illegible]	[illegible]	[illegible]	0
[SAMPLE] __nanosleep_nocancel [{interp.c} {0,0}-{0,0}]	[illegible]	[illegible]	[illegible]	0
double b(int) [{testStack.cpp} {46,1}-{60,1}]	0.009	3.021	1	1
int main_divByZero() [{testStack.cpp} {10,1}-{16,1}]	0	0	1	0
void main_inlined_computeNest() [{testStack.cpp} {62,1}-{66,1}]	0.488	0.488	1	0

C: main

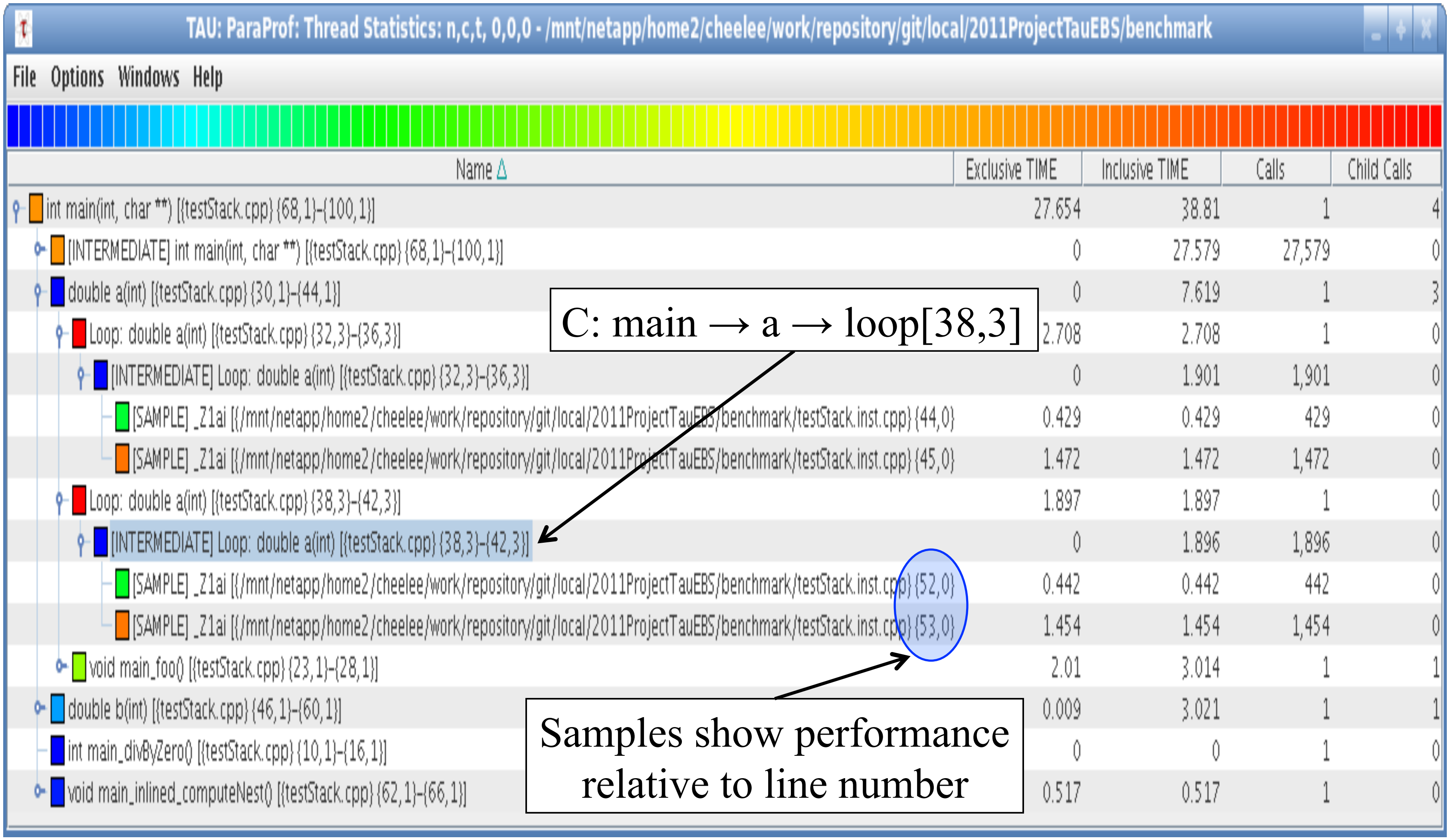
C: main → a

C: main → a → main_foo

C: main → a → main_foo → main_bar

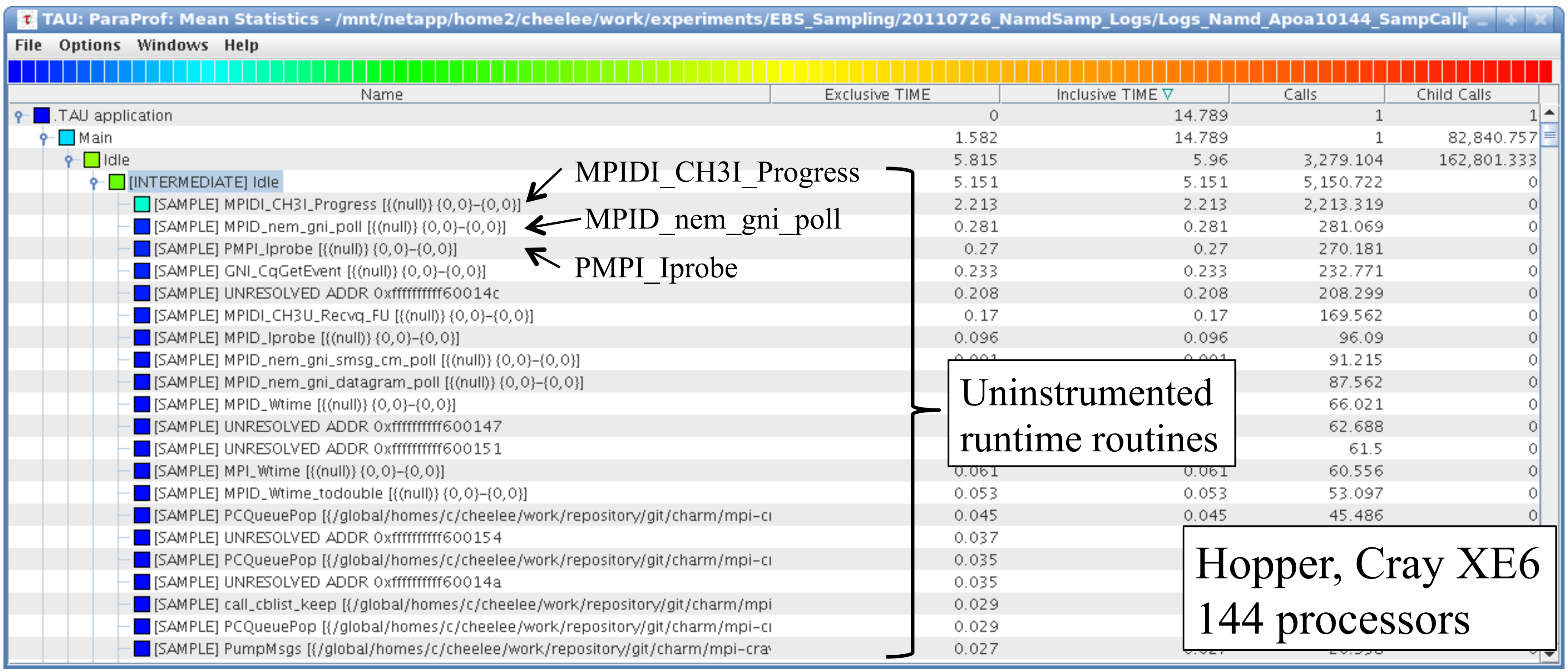
Examples: Simple Benchmark – Loops

- TAU events not restricted to routines (e.g., blocks, loops, …)



Examples: NAMD – Runtime System Contexts

- ❒ NAMD is implemented with Charm++ programming model
- ❒ Charm++ exposes its programming and runtime constructs
  - ❍ Callback system for TAU for probed-based measurement
- ❒ Hybrid profiling reveals action within Charm++ “idle” state



Examples: FLASH4 – Event Paths + Samples

TAU: ParaProf: Mean Statistics - /home/cheelee/Logs_Flash4_Cellular0144_SampCallpath50

File Options Windows Help

Name △	Exclusive TIME	Inclusive TIME	Calls	Child Calls
FLASH [{Flash.F90} {40,1}-{56,17}]	0	211.551	1	4
DRIVER_EVOLVEFLASH [{Driver_evolveFlash.F90} {40,1}-{481,33}]	0.066	209.722	1	50,027.889
COSMOLOGY_GETREDSHIFT [{Cosmology_getRedshift.F90} {28,1}-{36,36}]	0.002	0.002	2,000	0
COSMOLOGY_REDSHIFTHYDRO [{Cosmology_redshiftHydro.F90} {26,1}-{33,38}]	0.003	0.003	4,000	0
COSMOLOGY_SOLVEFRIEDMANNEQN [{Cosmology_solveFriedmannEqn.F90} {27,1}-{35,42}]	0.003	0.003	4,000	0
DIFFUSE [{Diffuse.F90} {57,1}-{66,22}]	0.003	0.003	4,000	0
DRIVER_COMPUTEDT [{Driver_computeDt.F90} {57,1}-{561,31}]	0.063	7.288	2,000	137,056.736
DRIVER_GETELAPSEDWCTIME [{Driver_getElapsedWCTime.F90} {32,1}-{46,38}]	0.002	0.002	2,000	0
DRIVER_SOURCETERMS [{Driver_sourceTerms.F90} {31,1}-{60,33}]	0.023	56.479	4,000	32,000
DR_SHORTENLASTDT [{dr_shortenLastDt.F90} {32,1}-{58,31}]	0.002	0.002	2,000	0
GRAVITY_POTENTIALLISTOFBLOCKS [{Gravity_potentialListOfBlocks.F90} {54,1}-{64,44}]	0.005	0.005	4,000	0
GRID_GETLISTOFBLOCKS [{Grid_getListOfBlocks.F90} {73,1}-{196,35}]	0.002	0.002	2,000	0
GRID_GETLOCALNUMBLKS [{Grid_getLocalNumBlks.F90} {19,1}-{30,35}]	0.003	0.003	2,000	0
GRID_UPDATEREFINEMENT [{Grid_updateRefinement.F90} {42,1}-{106,36}]	0.012	26.146	2,000	5,002
HYDRO [{Hydro.F90} {47,1}-{208,20}]	0.014	119.684	4,000	12,000
GRID_MOVECUSTOMREGION [{Grid_moveCustomRegion.F90} {26,1}-{182,36}]	0.008	0.008	4,000	0
HY_PPM_SWEEP [{hy_ppm_sweep.F90} {66,1}-{661,27}]	1.573	119.662	8,000	644,084.333
DIFFUSE_THERM [{Diffuse_therm.F90} {106,1}-{147,28}]	0.055	0.055	52,339.778	0
DIFFUSE_VISC [{Diffuse_visc.F90} {94,1}-{135,27}]	0.032	0.032	52,339.778	0
EOS_WRAPPED [{Eos_wrapped.F90} {93,1}-{210,26}]	1.274	31.851	157,019.333	1,046,795.5...
EOS [{Eos.F90} {209,1}-{304,18}]	1.3	30.577	1,046,795.5...	1,046,795.5...
EOS_HELMHOLTZ [{eos_helmholtz.F90} {228,1}-{689,28}]	28.42	29.277	1,046,795.5...	219,766.472
Loop: EOS_HELMHOLTZ [{eos_helmholtz.F90} {314,3}-{334,7}]	0.398	0.398	73,154.306	0
[INTERMEDIATE] Loop: EOS_HELMHOLTZ [{eos_helmholtz.F90} {314,3}-{334,7}]	0	0.354	353.896	0
[SAMPLE] RtsLayer::myThread() [{/global/homes/c/cheelee/work/repository/git/tau2/src/Profile/RtsThread.cpp} {100,0}-{100,0}]	0	0	0.042	0
[SAMPLE] Tau_get_tid [{/global/homes/c/cheelee/work/repository/git/tau2/src/Profile/TauCAPI.cpp} {1506,0}-{1506,0}]	0	0	0.014	0
[SAMPLE] Tau_start_timer [{/global/homes/c/cheelee/work/repository/git/tau2/src/Profile/TauCAPI.cpp} {330,0}-{330,0}]	0	0	0.083	0
[SAMPLE] Tau_stop_timer [{/global/homes/c/cheelee/work/repository/git/tau2/src/Profile/TauCAPI.cpp} {343,0}-{343,0}]	0	0	0.097	0
[SAMPLE] Tau_stop_timer [{/global/homes/c/cheelee/work/repository/git/tau2/src/Profile/TauCAPI.cpp} {344,0}-{344,0}]	0	0	0.042	0
[SAMPLE] __multispecies_data_MOD_ms_iszero [{(null)} {0,0}-{0,0}]	0.03	0.03	29.694	0
[SAMPLE] eos_helmholtz_ [{(null)} {0,0}-{0,0}]	0.015	0.015	15.292	0
[SAMPLE] ms_mapmsindex_ [{(null)} {0,0}-{0,0}]	0.021	0.021	20.514	0
[SAMPLE] multispecies_getproperty_ [{(null)} {0,0}-{0,0}]	0.099	0.099	99.292	0
[SAMPLE] multispecies_getsumfrac_ [{(null)} {0,0}-{0,0}]	0.117	0.117	116.694	0
[SAMPLE] multispecies_getsuminv_ [{(null)} {0,0}-{0,0}]	0.072	0.072	71.917	0
[SAMPLE] tau_profile_stop_ [{/global/homes/c/cheelee/work/repository/git/tau2/src/Profile/TauFAPI.cpp} {618,0}-{618,0}]	0	0	0.111	0
[SAMPLE] tau_profile_stop_ [{/global/homes/c/cheelee/work/repository/git/tau2/src/Profile/TauFAPI.cpp} {619,0}-{619,0}]	0	0	0.063	0
[SAMPLE] tau_profile_stop_ [{/global/homes/c/cheelee/work/repository/git/tau2/src/Profile/TauFAPI.cpp} {621,0}-{621,0}]	[illegible]	[illegible]	[illegible]	0
Loop: EOS_HELMHOLTZ [{eos_helmholtz.F90} {381,6}-{407,10}]	[illegible]	[illegible]	[illegible]	0
Loop: EOS_HELMHOLTZ [{eos_helmholtz.F90} {410,6}-{461,11}]	[illegible]	[illegible]	[illegible]	0
[INTERMEDIATE] EOS_HELMHOLTZ [{eos_helmholtz.F90} {228,1}-{689,28}]	[illegible]	[illegible]	[illegible]	0
[INTERMEDIATE] EOS [{Eos.F90} {209,1}-{304,18}]	[illegible]	[illegible]	[illegible]	0
[INTERMEDIATE] EOS_WRAPPED [{Eos_wrapped.F90} {93,1}-{210,26}]	0	0.895	895.201	0

Follow probed event path to end and pick up samples to highlight significant code points

Hopper, Cray XE6
144 processors

Example: FLASH4 – Reverse Event/Call Path

- Aggregate events / samples performance data

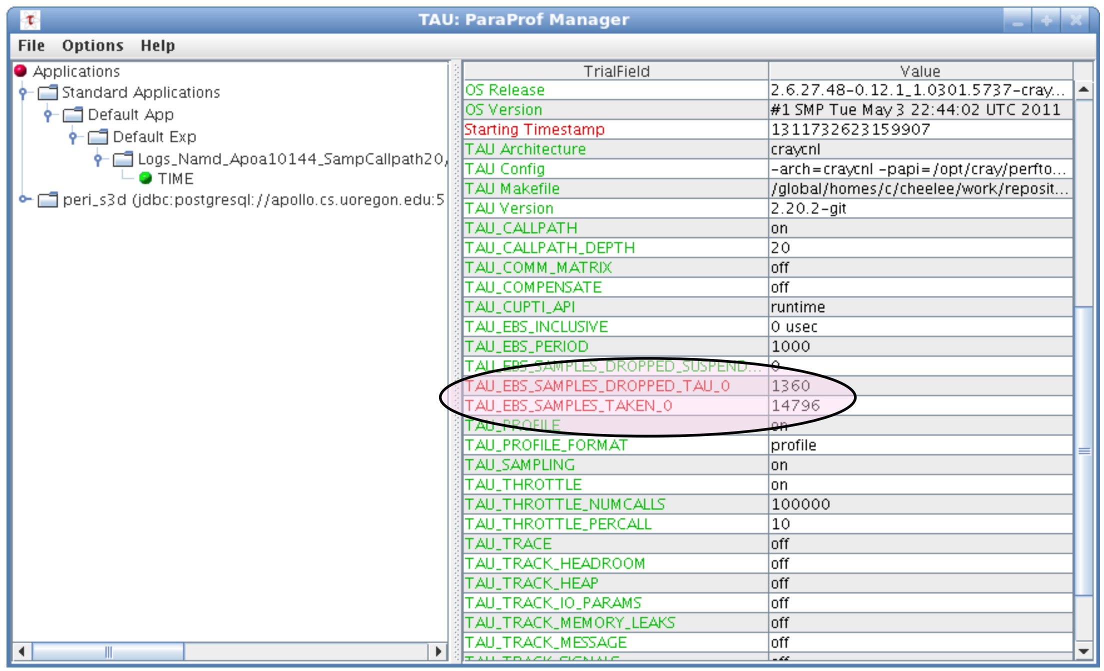
TAU: ParaProf: Mean Statistics – flash4-cellular-sampRev.hopper.0144.ppk

Name	Exclusive TIME ▽	Inclusive TIME	Calls	Child Calls
▶ HY_PPM_BLOCK [{hy_ppm_block.F90} {114,1}-{844,27}]	3.642	27.069	52,339.778	523,398.778
▶ AMR_1BLK_GUARDCELL_SRL [{amr_1blk_guardcell_srl.F90} {10,7}-{856,43}]	2.907	2.92	77,447.889	404.75
▶ [SAMPLE] amr_1blk_cc_cp_remote_ [{(null)} {0,0}-{0,0}]	2.737	2.737	2,736.556	0
▶ MPI_Waitall()	2.457	2.457	47,013.688	0
▶ [SAMPLE] interp_ [{(null)} {0,0}-{0,0}]	2.426	2.426	2,426.354	0
▼ [SAMPLE] memcpy [{/usr/src/packages/BUILD/glibc-2.9/string/../sysdeps/x86_64/memcpy.S} {267	2.408	2.408	2,408.014	0
▶ [INTERMEDIATE] MPI_Ssend()	1.727	1.727	1,726.59	0
▶ [INTERMEDIATE] MPI_AMR_READ_RESTRICT_COMM [{mpi_amr_store_comm_info.F90} {565,7}-{6	0.229	0.229	228.535	0
▶ [INTERMEDIATE] MPI_Waitall()	0.172	0.172	172.465	0
▶ [INTERMEDIATE] MPI_AMR_READ_FLUX_COMM [{mpi_amr_store_comm_info.F90} {399,7}-{477,4	0.13	0.13	130.285	0
▶ [INTERMEDIATE] MPI_AMR_READ_GUARD_COMM [{mpi_amr_store_comm_info.F90} {88,7}-{162,4	0.093	0.093	93.41	0
▶ [INTERMEDIATE] AMR_CHECK_DEREFINE [{mpi_amr_derefine_blocks.F90} {448,7}-{1176,39}]	0.023	0.023	22.562	0
▶ [INTERMEDIATE] AMR_SORT_MORTON [{mpi_amr_morton.F90} {481,7}-{631,36}]	[illegible]	[illegible]	9.174	0
▶ [INTERMEDIATE] MPI_Bcast()	[illegible]	[illegible]	4.462	0
▶ [INTERMEDIATE] MPI_AMR_WRITE_GUARD_COMM [{mpi_amr_store_comm_info.F90} {18,7}-{82,4	[illegible]	[illegible]	4.458	0
▶ [INTERMEDIATE] MPI_AMR_WRITE_RESTRICT_COMM [{mpi_amr_store_comm_info.F90} {485,7}-{5	[illegible]	[illegible]	3.923	0
▶ [INTERMEDIATE] MPI_AMR_WRITE_FLUX_COMM [{mpi_amr_store_comm_info.F90} {325,7}-{393,4	[illegible]	[illegible]	3.879	0
▶ [INTERMEDIATE] MPI_AMR_WRITE_PROL_COMM [{mpi_amr_store_comm_info.F90} {168,7}-{234,4	0.004	0.004	3.705	0
▶ [INTERMEDIATE] MPI_Allgather()	0.003	0.003	3.133	0
▶ [INTERMEDIATE] MPI_AMR_READ_PROL_COMM [{mpi_amr_store_comm_info.F90} {240,7}-{318,4	0.003	0.003	2.617	0
▶ [INTERMEDIATE] MPI_Barrier()	0.002	0.002	1.9	0
▶ [INTERMEDIATE] MPI_Irecv()	0.001	0.001	1	0
▶ [INTERMEDIATE] MPI_XCHANGE_BLOCKS [{mpi_lib.F90} {1211,7}-{1381,39}]	0.001	0.001	1	0
▶ [SAMPLE] multispecies_getsumfrac_ [{(null)} {0,0}-{0,0}]	2.389	2.389	2,389.194	0
▶ BN_NETINTEGRATE [{bn_netIntegrate.F90} {86,1}-{294,30}]	2.238	24.789	1,572,443.778	1,572,443.778
▶ [SAMPLE] rieman_ [{(null)} {0,0}-{0,0}]	2.193	2.193	2,193	0
▶ [SAMPLE] __pow [{/usr/src/packages/BUILD/glibc-2.9/math/../sysdeps/x86_64/fpu/w_pow.c} {765	2.168	2.168	2,167.75	0
▶ [SAMPLE] multispecies_getproperty_ [{(null)} {0,0}-{0,0}]	2.023	2.023	2,022.896	0
▶ EOS_WRAPPED [{Eos_wrapped.F90} {93,1}-{210,26}]	1.891	46.015	215,811.486	1,451,586.944
▶ [SAMPLE] states_ [{(null)} {0,0}-{0,0}]	1.822	1.822	1,822.16	0
▶ EOS [{Eos.F90} {209,1}-{304,18}]	1.795	44.124	1,451,798.5	1,451,798.5
▶ [SAMPLE] monot_ [{(null)} {0,0}-{0,0}]	1.73	1.73	1,730.194	0
▶ AMR_GUARDCELL [{mpi_amr_guardcell.F90} {88,7}-{485,34}]	1.713	23.099	9,006	127,343.806
▶ [SAMPLE] amr_guardcell_ [{(null)} {0,0}-{0,0}]	1.645	1.645	1,644.826	0
▶ HY_PPM_SWEEP [{hy_ppm_sweep.F90} {66,1}-{661,27}]	1.578	119.099	8,000	644,084.333
▶ [SAMPLE] hydro_1d_ [{(null)} {0,0}-{0,0}]	1.527	1.527	1,527.403	0
▶ [SAMPLE] eigensystem.1622.clone.1 [{interp_char.inst.F90} {0,0}-{0,0}]	1.5	1.5	1,499.903	0
▶ [SAMPLE] multispecies_getsuminv_ [{(null)} {0,0}-{0,0}]	1.473	1.473	1,473.479	0
▶ BURN [{Burn.F90} {51,1}-{256,19}]	1.396	55.819	4,000	1,597,228.667
▶ MPI_PACK_BLOCKS [{mpi_pack_blocks.F90} {15,7}-{281,36}]	1.273	1.273	22,272	0

TAU events within which this memcpy sample occurs

Issues – Signal Safety and Dropped Samples

- Signal safety
  - Strictly, signal handlers cannot attempt to acquire lock
  - TAUebs drops a sample if inside TAU operations for safety
  - EBS sample handler must avoid memory allocation
    - currently, use own C++ allocator and minimize calls to malloc
- Signal safety handling will drop samples
  - Keep track of # dropped samples in metadata
- Rules can be loosened to drop sample in a more intelligent way (only if unsafe)



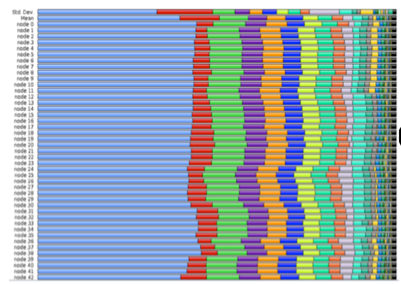
TAUebs Future Work

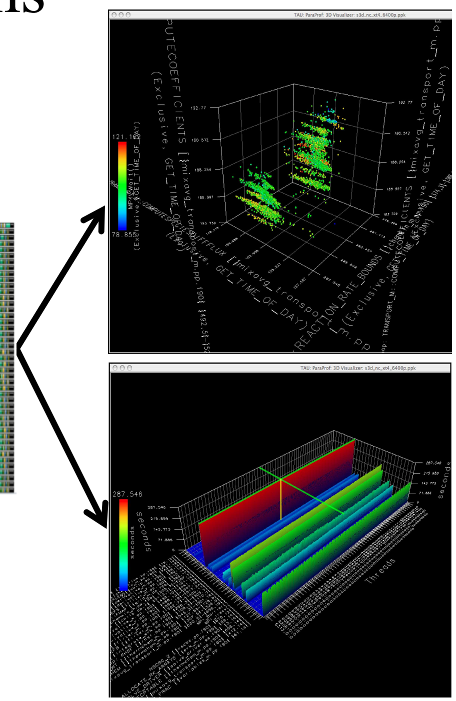
- Add callstack unwinding when sampling
  - Incorporate robust module for this
  - Control of unwinding depth with event/routine matching
  - Selective unwinding determined by event context
  - Mix of flat and structured sample blocks per context
- Rational interpretation of code structures for samples relative to non-function TAU contexts (e.g., loops)
- Improvements in data management
- Handling symbol resolution for sampled addresses at epoch transitions due to dynamic library loading and unloading
- More accurate sample timing
  - Measuring time elapsed between a sample and last probed event
- Sampling with other metrics and state (e.g., GPU counters)

DEUX

Performance Visualization – Motivation

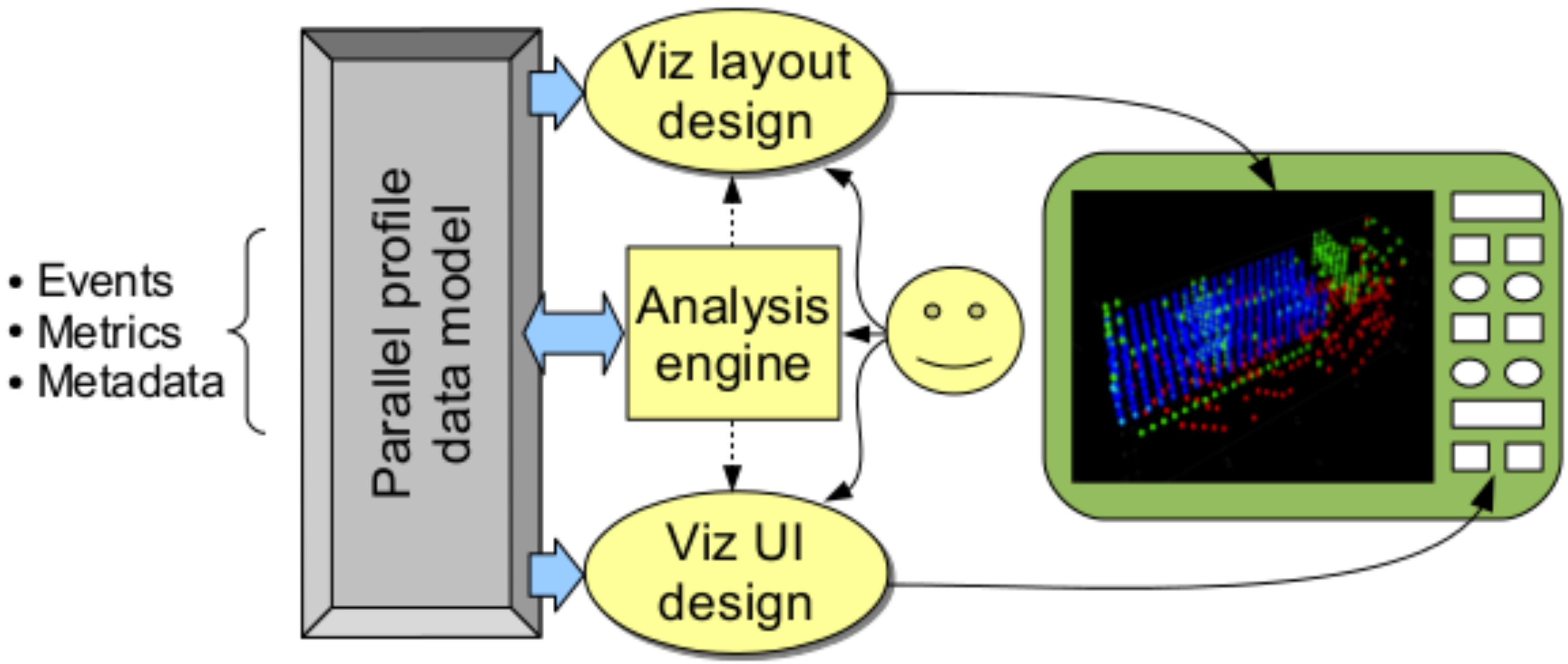
- Large performance data presents interpretation challenges
- Visualization aids in data exploration and pattern analysis
  - 3D visualization can help in identifying relations between events/metrics
- Existing tools provide "canned" views
  - TAU provides a few
    2D: bargraph, histogram
    3D: *full profile, correlation*





- Developing new visualizations is a challenge
  - Strategy 1: Create new view for each problem
  - Strategy 2: Use external visualization environment
- Provide high-level support to use within existing framework

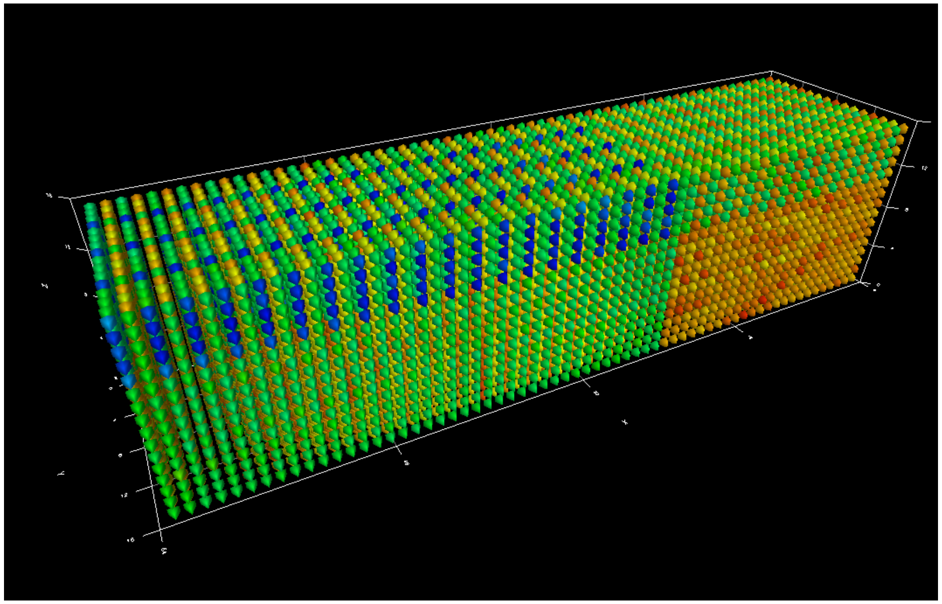
Extending Visualization Support in Profile Tool



- ❒ User defines visualization based on performance data model
- ❒ Specifies layout based on events, metrics, and metadata
- ❒ UI provides control of data binding and visualization

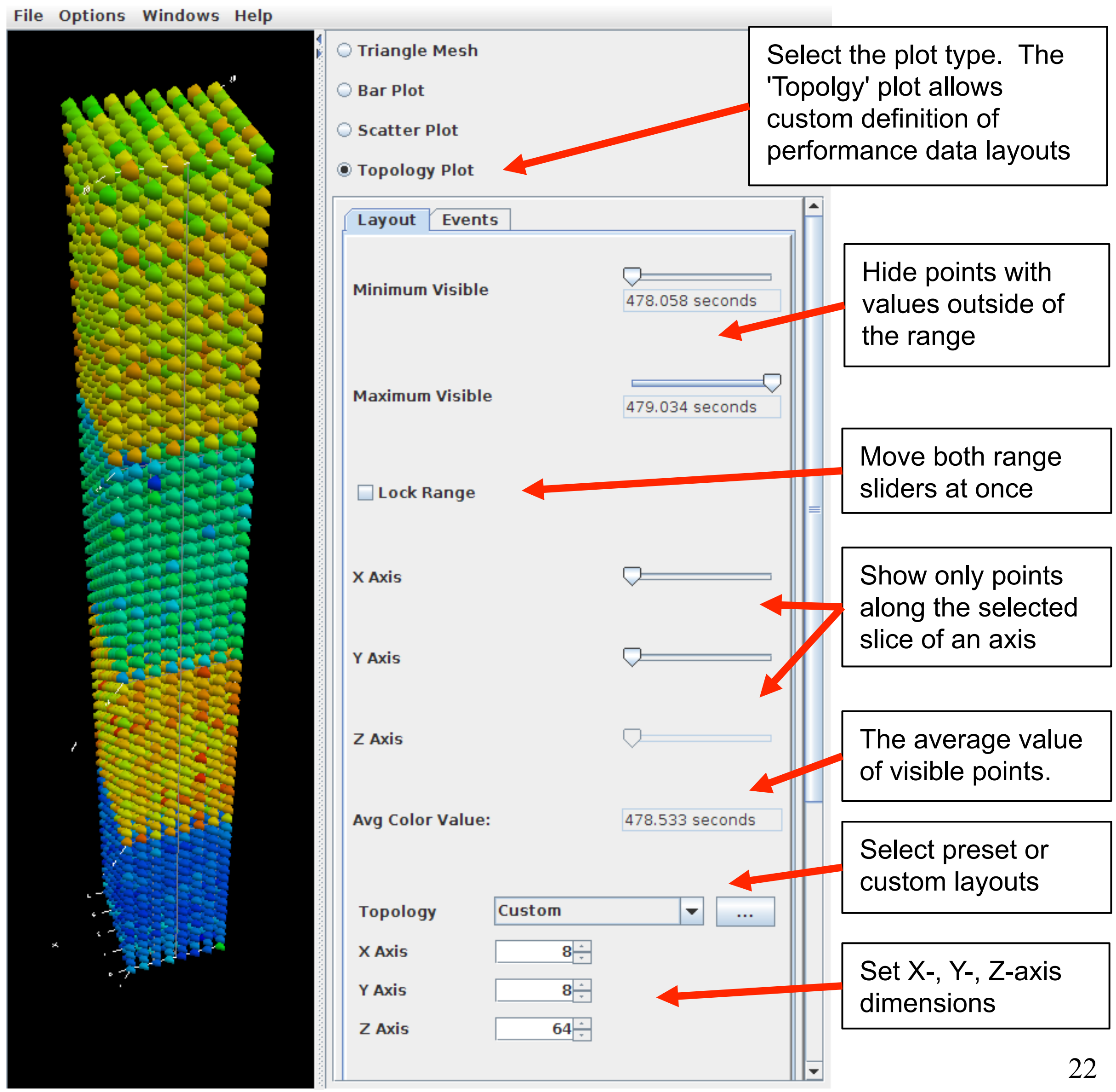
Using Process Topology Metadata

- Inspired by the CUBE topology display for BG/P
- Each point represents a thread of execution (MPI process)
  - Positioned according to the Cartesian (x,y,z,t) coordinates
- Color is determined by selected event/metric value
- Topology information can be recorded in TAU metadata
- ParaProf reads metadata to determine topology and create layout
- Sweep3D 16K run on BG/L
  - Color is exclusive time in the "sweep" function



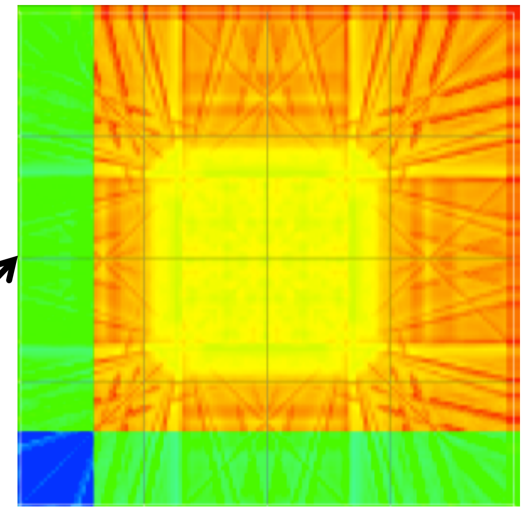
Topology Control UI

- *Layout* tab allows customization of the position and visibility of data points
- Performance event/metric data used to define color and position is selected in the *Event* tab
- Additional rendering options, such as color scale and point size are available
- 4k-core S3D run on BG/P

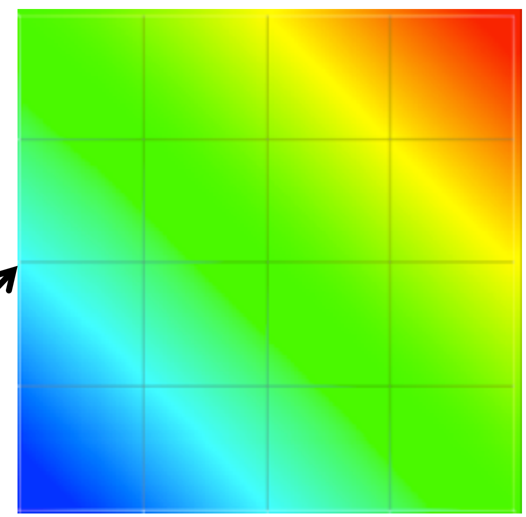


Alternate Topologies

- Certain views may hide deeper inter-process behavior
- Spatially dependent performance issues may be revealed by manipulating topology
- Sweep3D profile with alternative Cartesian mapping exposes distribution of computational effort

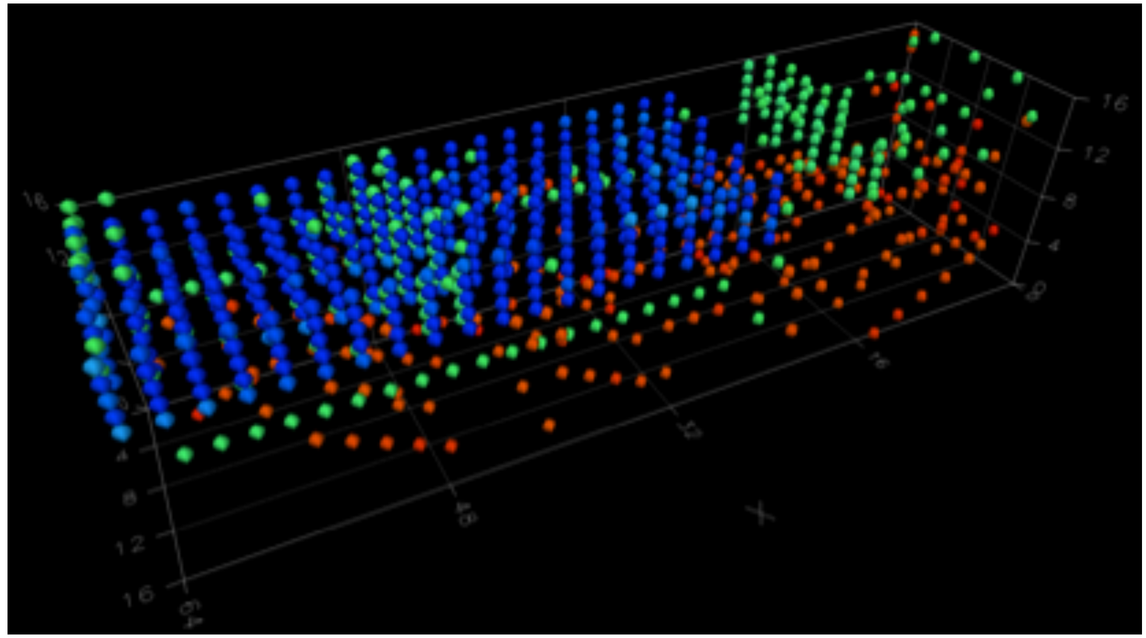


- Topology has direct effect on communication
- Visualization mapped to hardware topologies can suggest better node/rank mapping
- *MPI_AllReduce()* values for Sweep3D highlights waiting distribution from rank 0 (lower left) to the most distant rank (upper right)



Viewing Internal Structure

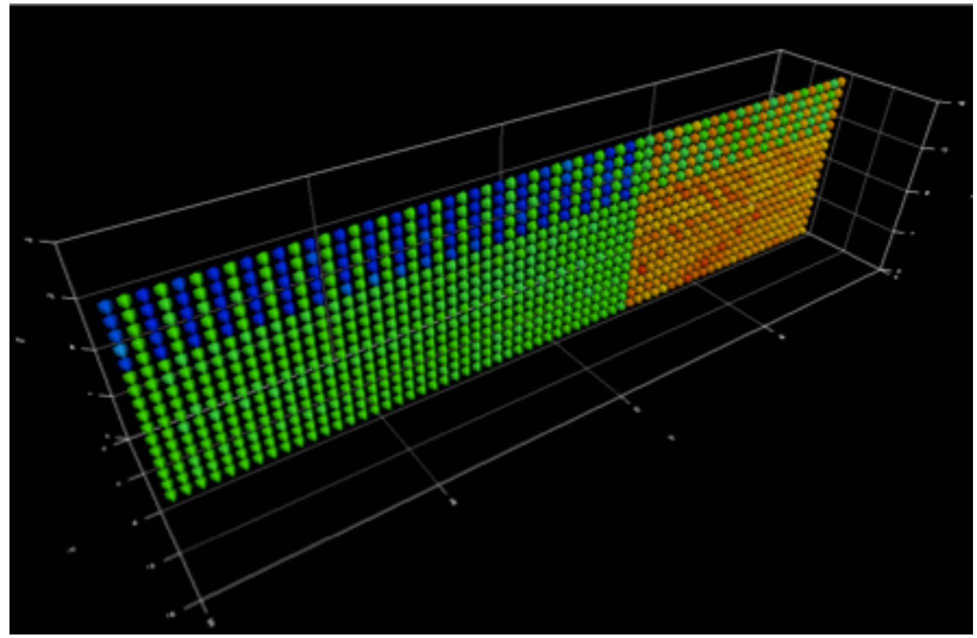
- Dense topologies can hide internal structure
- Restrict visibility by color value to expose performance patterns



- ParaProf visualization UI now allows for range filtering
  - Mid-level values can be excluded
  - Remaining points are:
    - high outliers (hotspots)
    - low outliers (underutilized nodes)

Slicing to Reduce Dimensionality

- Restrict visibility to slices along the spatial axes
- Multiple axis controls allow selection of planes, lines, or an individual point



- ParaProf visualization UI provides filtering behavior
  - Averaging the color value for all points in the selected area

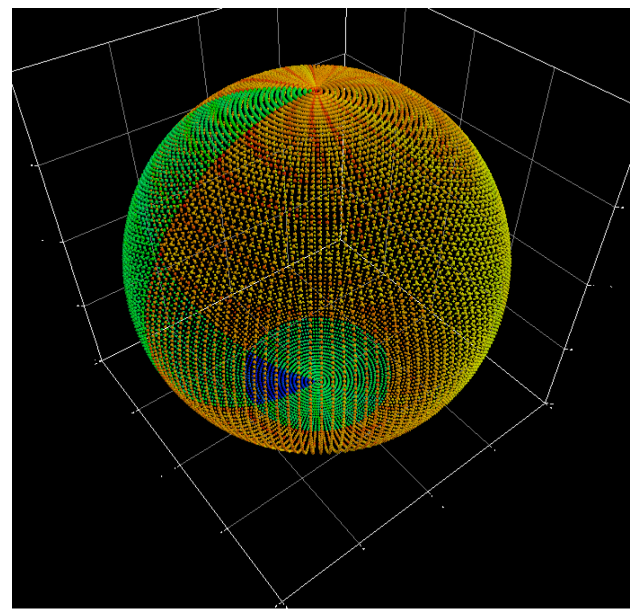
Visual Layout Specification

- Want to allow creation of explicit layouts
- Define a specification “language” that allows mathematical expressions to describe features of performance display
  - Equations define X, Y, Z coordinates and color per process
  - Event and metrics are seen as variables
    - *eventX.val* : value for *X*th specified event and metric
    - *eventX.{min,max,mean}* : global aggregate values
    - *atomicY* : *Y*th atomic event value
  - Intermediate variables can be used in the calculation
  - Defined global variables (e.g., max rank) are provided
- Specifications are loaded and processed by ParaProf
  - Use the MESP expression parser

Sphere Layout Specification

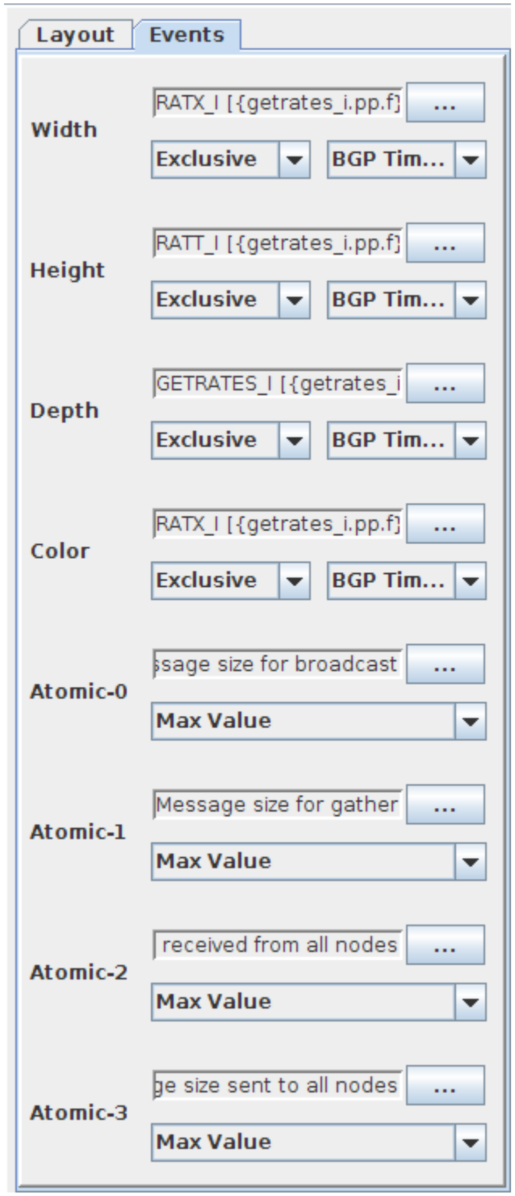
- Spatially mediated performance behavior may not be represented directly in topology metadata
  - Applications allocate resources with respect to a data-driven model
- The position of each point can be defined by custom equations in terms of event/metric, aggregate, atomic event and metadata
- Sweep3D profile mapped to a sphere

```
BEGIN_VIZ=Sphere
rootRanks=sqrt(maxRank)
theta=2*pi()/rootRanks*mod(rank,rootRanks)
phi=pi()/rootRanks*(ceil(rank/rootRanks))
x=cos(theta)*sin(phi)*100
y=sin(theta)*sin(phi)*100
z=cos(phi)*100
END_VIZ
```



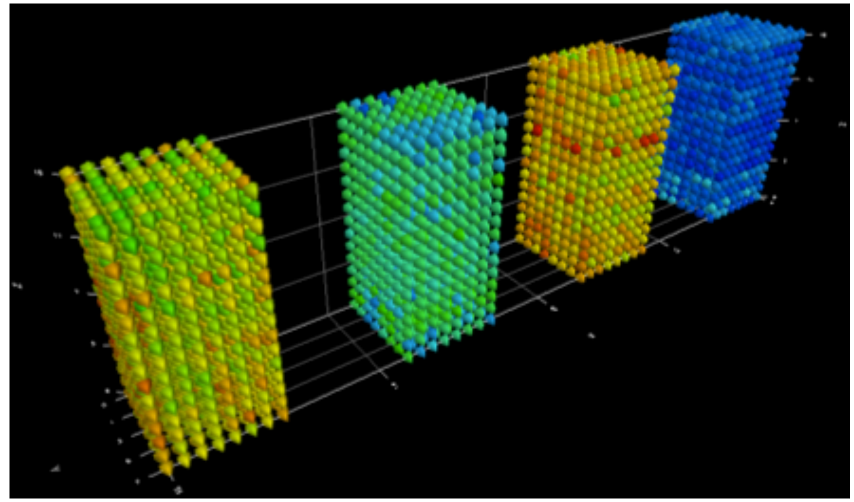
ParaProf Events Panel

- Events / metrics get bound in ParaProf UI
- Example:
  - *event0* is the FLOP count for function *foo*
  - *event1* is the time value for function *foo*
  - To set the X coordinate for each process point to the FLOPS for event *foo*:
    $x = event0.val / event1.val$
  - To set the Y coordinate for each process point to the global average FLOPS for event *foo*:
    $y = event0.mean / event1.mean$



Adding Dimensionality

- Topologies can involve more than three dimensions (e.g., intranode)
- Mirror actual machine layout to capture communication structure and cores
- Custom layouts allow specification of multiple points from a single process/rank
- 4K-core S3D run on BG/P
- Default topology only covers X, Y, Z coordinates
- A custom topology divides each *n*th core into its own block

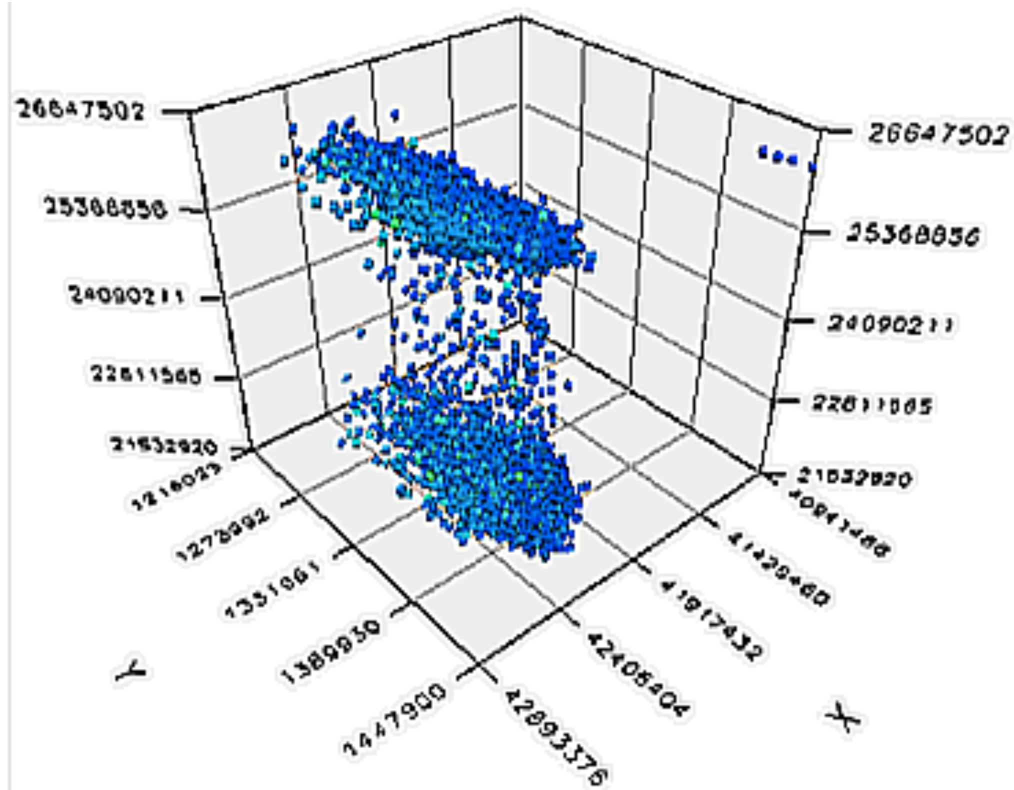


```
BEGIN_VIZ=4K_8x8x16Block
xdim=8
ydim=8
zdim=16

x=mod(rank,xdim)+16*floor(rank/
1024)
y=mod(floor(rank/xdim),ydim)
z=mod(floor(rank/xdim/ydim),zdim)
END_VIZ
```

Non-Spatial Relationships

- Positioning of points needs not be with respect to physical or data topology
- Correlation of metrics within the same events or events between processes can indicate relevant performance effects
- Partitioning or clustering of different processes based on selected performance criteria
- 3D scatterplot for 10240 core run of GCRM/ZGrd application
- Correlates four selected events, one for each spatial axis plus color




```
BEGIN_VIZ=ScatterTest
restrictDim=1
x=event0.val
y=event1.val
z=event2.val
END_VIZ
```

Visualizaton Next Steps

- Collect topology data from additional platforms (e.g. Cray)
- Expand UI for more general access to performance data model
- Allow independent manipulation of unconnected segments
- Improve presentation of data values, ranks, and metrics
- Better functionality for automatic higher-dimensional layouts
- Add representation of communication channels

TROIS

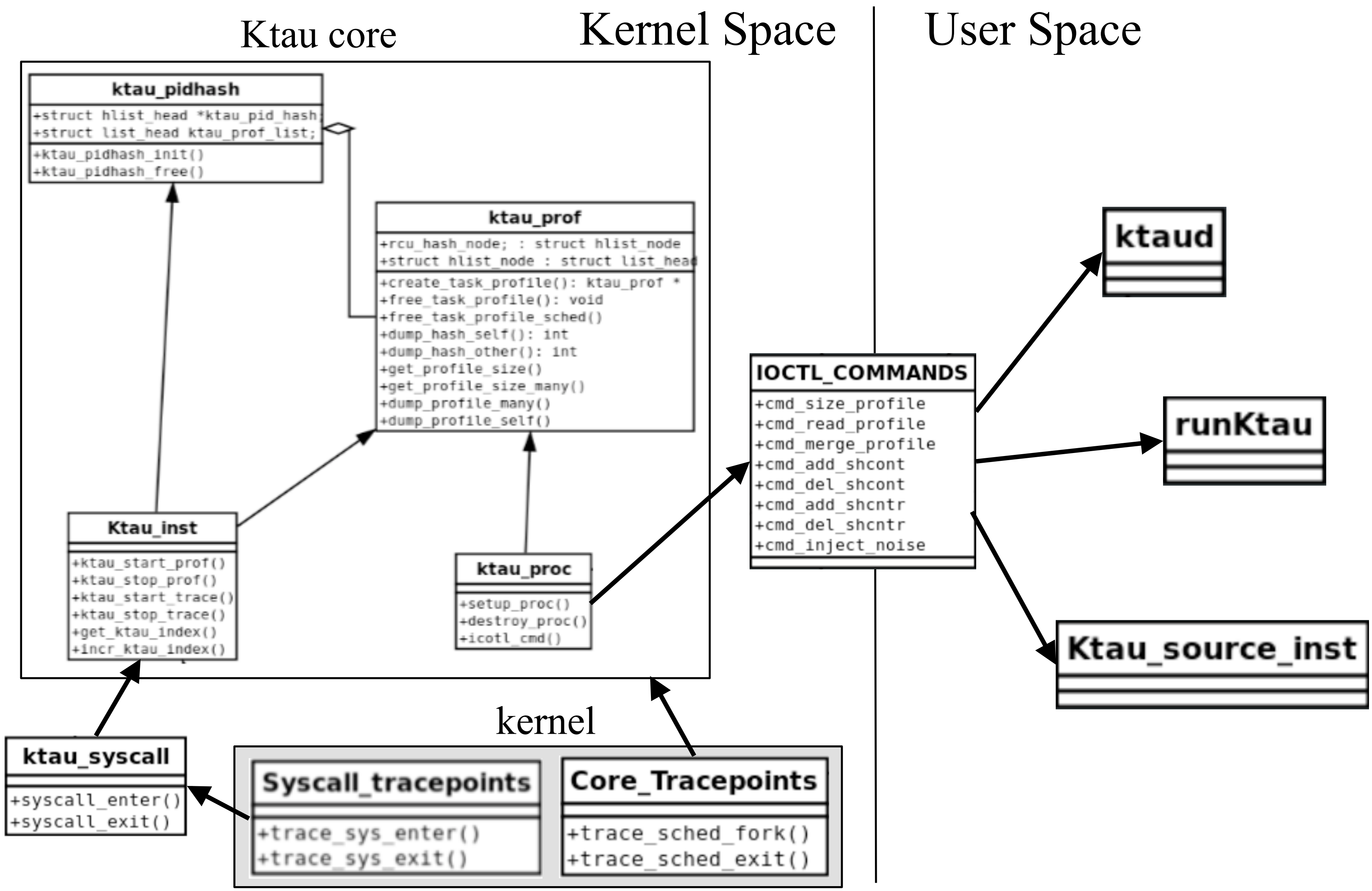
Kernel Measuremnt (KTAU) – Motivation

- Observe kernel performance and integrated with application performance measurements
- Earlier development of KTAU (Kernel TAU)
  - Profiling and tracing measurement of kernel events
  - Done via source instrumentation of Linux kernel
- Need more viable solution going forward
  - No patches or source modification
  - Easy to use and install
- Objective
  - Re-implement original KTAU features
  - Leverage work in the kernel instrumentation community

Approach

- Utilizes kernel infastructure for tracing
  - *tracepoints* and *kprobes*
- Simple user application with loadable kernel module
  - Similar to Unix “time”
- Efficient memory mapping between user and kernel space
- Minimal instructions required to record performance data
- Support for both profiling and tracing

Major Components of KTAU



KTAU and Other Projects

- What about Oprofile, LTTNG and SystemTap?
- These provide similar data from the kernel
- Way in which data is used and displayed is different perhaps
- KTAU focus is on application developers
- Comparing to LTTNG
  - Both use tracepoints, kprobes, RCU locking, kernel timestamp
  - KTAU
    - only requires kernel headers to build, root to install module
    - new development with targeted instrumentation
    - works with TAU to produce profiles and traces
  - LTTNG
    - mature with lots of instrumentation points
    - requires kernel patches
    - very basic user space instrumentation
    - no profile support

KTAU Status and Future

- Just finished initial prototype
- Undergoing more robust testing and evaluation
- Re-engineering of profile/trace merging tools

- Investigate interactions with LTTNG
  - Some movement towards including LTTNG in kernel
- Develop more efficient mechanism for accessing KTAU data
  - Use shared memory regions between kernel and user