HPCToolkit Workshop: Introduction to Application Performance Analysis on Linux Systems

or

What I learned at a recent workshop

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Why profile?

- Peak performance of modern systems is rarely achieved in practice
  - Peak rate = (cycles / second) * (flops / cycle)
  - Linpack benchmark (top 500 list) typically at 70-80% of peak flop-rate
  - Science codes generally much lower:
    - Only floating-point operations count, integer operations don't
    - Must have ordered structure (e.g., multiply, then add, for 2 flops/cycle)
    - Memory latency and bandwidth generally limiting
  - More complex architectures => bigger gap to peak performance?
- Some examples of performance:
  - *Miranda*, 65K cores on BG/L, incompressible R-T (Poisson eqn, FFT)
    - 2.76 Tflops, roughly 1% of peak rate
  - *Hybrid*, 3K cores on Cray XT-4, shock/turbulence interaction (fully explicit)
    - Estimated 1.5 Tflops, roughly 10-12% of peak rate
  - Note: different architectures and algorithms => not fair comparison

Why profile?

- Most of us have no idea of our code's performance -- profiling tells you, and points out where improvements might be made
  - Sometimes obvious, sometimes less so…
- Learn a bit about the implications of programming decisions

- Why use HPCToolkit?
  - Disclaimer: I haven't tried other profiling tools
  - No changing (instrumentation) of the source code
  - Analyze the results on my laptop afterwards
  - GUI shows source code along with profiling information
- Why not use HPCToolkit?
  - University product: support and bug-fixing?
  - Not available everywhere
    - Expected on Cray XT (CNL) later this year
    - BG/P?

HPCToolkit: how does it work?

- Uses statistical sampling:
  - No change to source code
  - During execution, interrupt 100-1000 times per second and log status of execution at that time
  - Relies on PAPI hardware performance counters
- Analyze executable:
  - Compiler may have changed code -- try to un-unroll loops etc to correlate with source code
- Analysis of final database:
  - GUI that shows performance metrics and correlates with source code

- What's needed on the cluster?
  - PAPI
  - HPCToolkit (except the viewer)

HPCToolkit: overview

- http://www.hipersoft.rice.edu/hpctoolkit/index.html (main page)
- http://hipersoft.rice.edu/hpctoolkit/SERVER/sc04/index.html (tutorial)
- 4 steps on cluster: compile; run; analyze executable; build database
- 1 step on laptop/desktop: analyze database

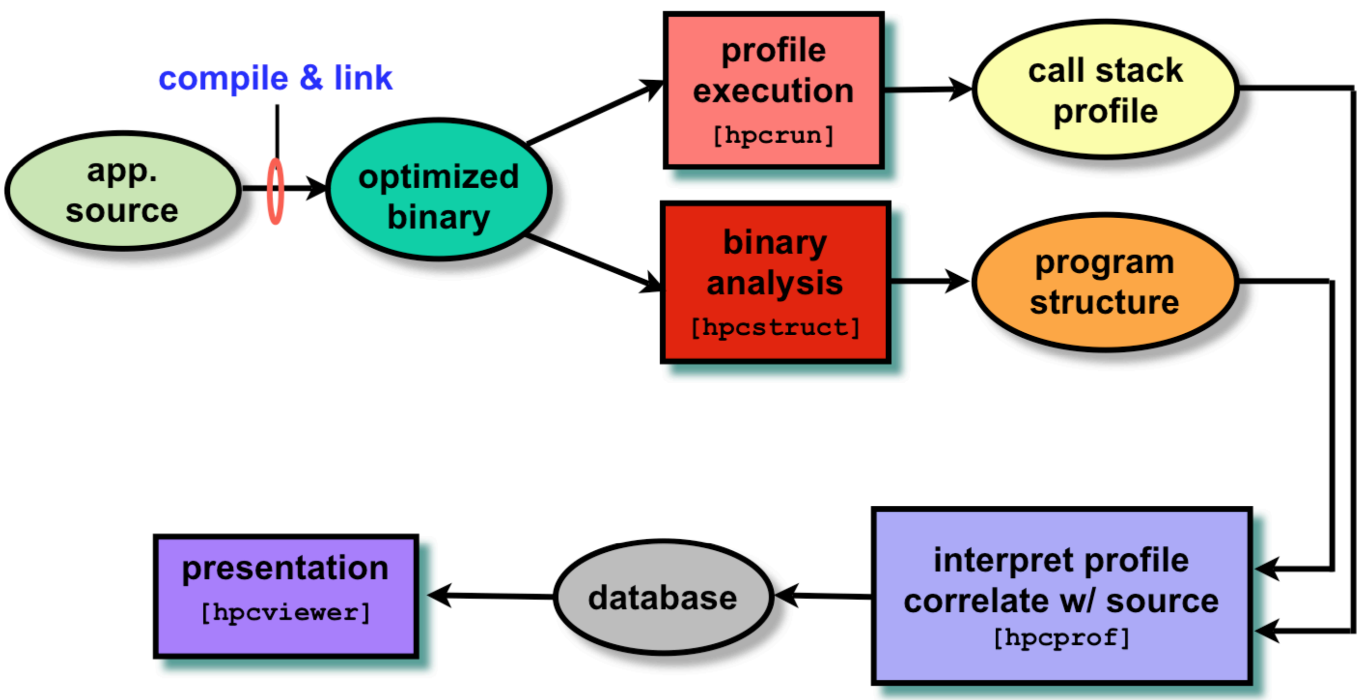
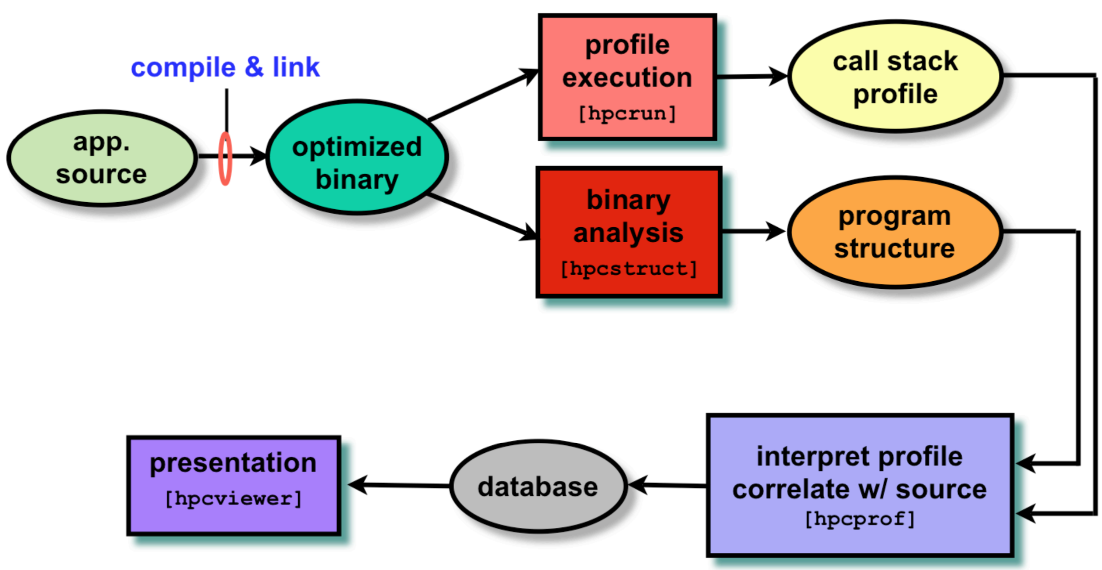


Figure taken from www.hipersoft.rice.edu/hpctoolkit/index.html

HPCToolkit: compile code

- *Module load papi/3.5.0* (on *Jacquard*)
- Compile code as per usual, except:
  - Use *-g1* (or similar) for source-code line information
  - Don't use *-ipa* (or similar) for inter-procedural optimization
  - Note that *-Ofast* may turn on *-ipa* -- instead manually set all optimizations



HPCToolkit: run code

- Can log up to 4 PAPI counters each execution
- Find available counters by (on Jacquard) *papi_avail*:

The following correspond to fields in the PAPI_event_info_t structure.

Name	Code	Avail	Deriv	Description (Note)
PAPI_L1_DCM	0x80000000	Yes	Yes	Level 1 data cache misses
PAPI_L1_ICM	0x80000001	Yes	Yes	Level 1 instruction cache misses
PAPI_L2_DCM	0x80000002	Yes	No	Level 2 data cache misses
PAPI_L2_ICM	0x80000003	Yes	No	Level 2 instruction cache misses
PAPI_L3_DCM	0x80000004	No	No	Level 3 data cache misses
PAPI_L3_ICM	0x80000005	No	No	Level 3 instruction cache misses
PAPI_L1_TCM	0x80000006	Yes	Yes	Level 1 cache misses
PAPI_L2_TCM	0x80000007	Yes	Yes	Level 2 cache misses
PAPI_L3_TCM	0x80000008	No	No	Level 3 cache misses
PAPI_CA_SNP	0x80000009	No	No	Requests for a snoop
PAPI_CA_SHR	0x8000000a	No	No	Requests for exclusive access to shared cache line
PAPI_CA_CLN	0x8000000b	No	No	Requests for exclusive access to clean cache line
PAPI_CA_INV	0x8000000c	No	No	Requests for cache line invalidation
PAPI_CA_ITV	0x8000000d	No	No	Requests for cache line intervention
PAPI_L3_LDM	0x8000000e	No	No	Level 3 load misses
PAPI_L3_STM	0x8000000f	No	No	Level 3 store misses
PAPI_BRU_IDL	0x80000010	No	No	Cycles branch units are idle
PAPI_FXU_IDL	0x80000011	No	No	Cycles integer units are idle
PAPI_FPU_IDL	0x80000012	Yes	No	Cycles floating point units are idle
PAPI_LSU_IDL	0x80000013	No	No	Cycles load/store units are idle

…

HPCToolkit: run code

- Modify your batch-script:

```
mpiexec -n 2   hpcrun -e PAPI_TOT_CYC:1000000 -e PAPI_L2_DCM:100000
  -e PAPI_FP_OPS:500000 -e PAPI_TLB_DM:100000  ./hybrid.exe
```

- Here I'm sampling:
  - Total cycles, every 1000000 cycles
  - L2 cache misses, every 100000 cycles
  - Floating point operations, every 500000 cycles
  - Translation lookaside buffer misses, every 100000 cycles
- My code ran for 50-100 seconds -- for longer runs, sample less often
- This produces a few trace-files per process, like:

```
-rw-------  1 jola jola       2649 Jul 25 22:11 hybrid.exe-10a013c-1804-2.csp
-rw-------  1 jola jola       2649 Jul 25 22:11 hybrid.exe-10a013c-1804-1.csp
-rw-------  1 jola jola       2649 Jul 25 22:11 hybrid.exe-10a013c-1795-2.csp
-rw-------  1 jola jola       2649 Jul 25 22:11 hybrid.exe-10a013c-1795-1.csp
-rw-------  1 jola jola  1945569 Jul 25 22:11 hybrid.exe-10a013c-1795-0.csp
-rw-------  1 jola jola       1564 Jul 25 22:11 hybrid.exe-10a013c-1795.csl
-rw-------  1 jola jola  1960605 Jul 25 22:11 hybrid.exe-10a013c-1804-0.csp
-rw-------  1 jola jola       1511 Jul 25 22:11 hybrid.exe-10a013c-1804.csl
```

HPCToolkit: analyze executable / build database

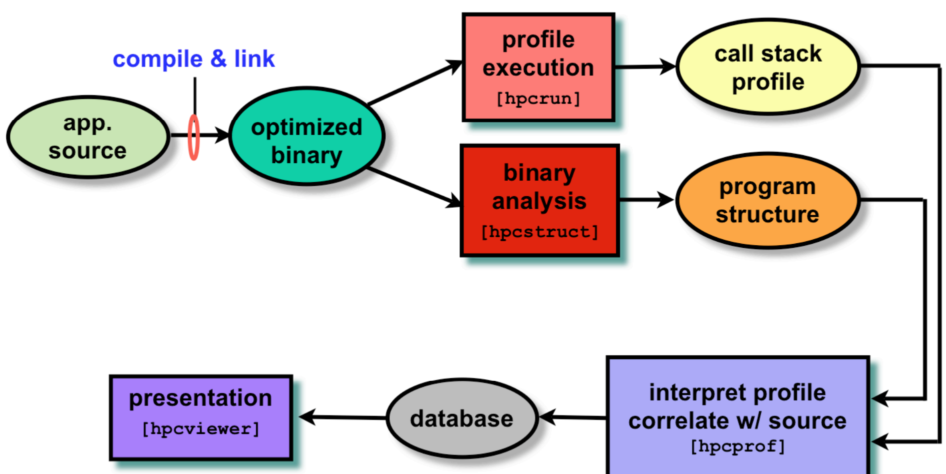
- On front-end node, analyze executable by simply running:

  hpcstruct ./hybrid.exe > ./hybrid.exe.struct

- On front-end node, build database by:

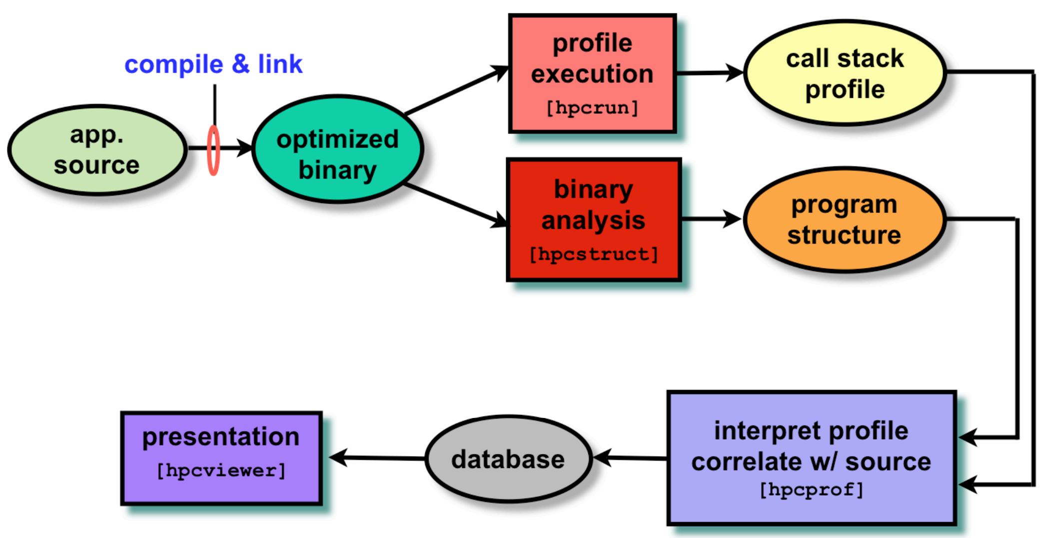
  hpcprof -S ./hybrid.exe.struct -I $HOME/hybrid_source_code/ hybrid.exe-10a013c-1804-0.csp

- Notes:
  - Use largest trace-files -- the small ones are ? (system-related?)
  - One database per process -- in reality, pick some relevant one(s)



HPCToolkit: explore database

- Move generated database to laptop
- Download *HPCViewer* from http://outreach.scidac.gov
- Open database in *HPCViewer* and explore sampled metrics and generate derived metrics
- Some useful derived metrics:
    - Percent of peak: flops / (2 * cycles)   (replace 2 by proper value)
    - L2 misses / flops -- 1 in 100 OK, higher not as good
    - …



Example: *Hybrid* code on the *Jacquard* Opteron cluster

- The *Hybrid* code:
  - Finite-differences, explicit in time/space, C++, MPI with asynchronous communication (initiate send/receive; compute interior; finalize communication; compute near-boundary points)
  - Potential for load-imbalance due to solution-adaptive algorithm
  - Excellent weak scaling due to explicitness and hidden communication