Automated Timer Generation for Empirical Tuning

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Propositions

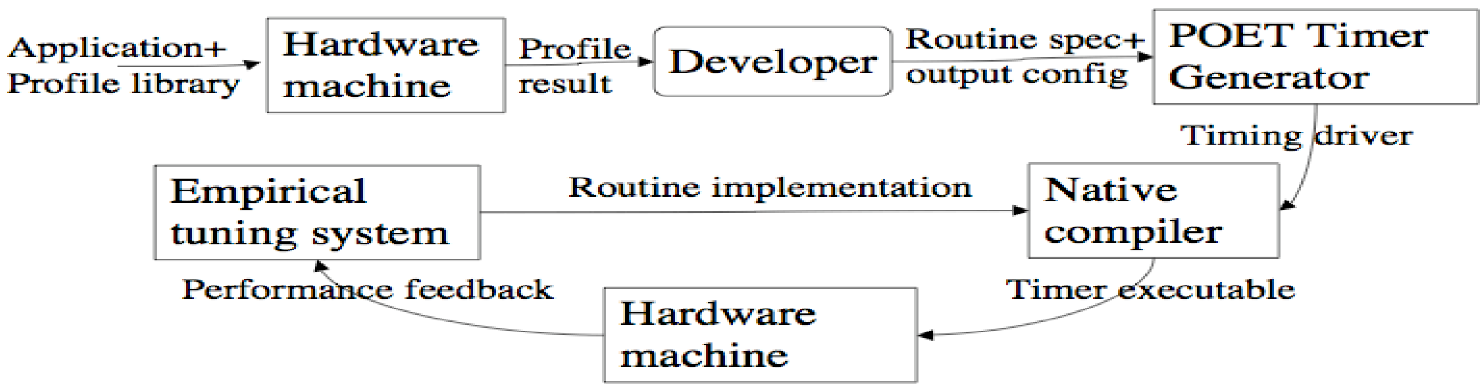
- How do we measure success for tuning?
  - The performance of the tuned code --- of course
  - But what about tuning time?
    - **How long are the users willing to wait? Given 3 more hours, how much can we improve program efficiency?**
- Auto-tuning libraries have been successful and widely used
  - ATLAS, PHiPAC, FFTW, SPIRAL...
  - Critical routines are tuned because they are invoked many many times
- What happens when tuning whole applications?
  - What the end users need and what compilers expect to see
  - But applications are often extremely large and time consuming to run
  - **Do not want to rerun entire applications to try out different optimization configurations**

Observations

- Performance of full applications critically depend on a few computation/data intensive routines
  - These routines are often small but invoked a large number of times
  - Performance analysis tools (e.g., HPC toolkit) can be used to identify these routines
- Tuning these routines can significantly improve overall performance of whole applications while reducing tuning time
  - In some SPEC benchmarks, running the whole application is about 175K times longer than running a single critical routine
- The problem: setting up execution environment of the routines
  - A driver is required to set up parameters and global variables properly and accurately measure the runtime of each routine invocation
  - The cache and memory states of the machine is very important (Whaley and Castaldo, SPE'08)
  - NOT a trivial problem as one may think

Overall goal: reduce tuning time without sacrificing tuning accuracy

Empirical tuning approach



- Instrumentation library
  - Collect details of routine execution within whole applications
  - Invoked after HPC toolkit is used to identify critical routines
- POET timer generator
  - Input: routine specification + cache config + output config
  - Output: timing driver with accurately replicated execution environment
    - Support a checkpointing approach for routines operating on irregular data
- Empirical tuning system
  - Apply optimizations to produce different routine implementations
  - Link routine implementation with the timing driver and collect performance feedback

Replicating Environment of Routine Invocations

- Goal: ensure proper input values and operand workspaces
  - Reflect common usage patterns of routine
  - Should not result in abnormal evaluation
- Data insensitive routines
  - Amount of computation determined by integer parameters controlling problem size
  - Performance not noticeably affected by values stored in input
  - Example: dense matrix multiplication
- Data sensitive routines
  - Amount of computation depends on values and positioning of data
  - Examples: sorting algorithms, complex pointer-chasing algorithms
- Replicating routine invocation environment
  - For data insensitive routines: replicate problem size and use randomly generated values
  - For data sensitive routines: use the check-pointing approach

The Default Timing Approach (for data-insensitive routines)

Routine specification for a Matrix Multiplication kernel

```
routine=void ATL_USERMM(const int M,
                   const int N, const int K,
                   const double alpha,
                  const double* A, const int lda,
                   const double* B,const int ldb,
                   const double beta,
                  double* C, const int ldc);
init={
  M=Macro(MS,72);
  N=Macro(NS,72);
  K=Macro(KS,72);
  lda=MS; ldb=KS; ldc=MS; alpha=1; beta=1;
  A=Matrix(double,M,K,RANDOM,flush|align(16));
  B=Matrix(double,K,N,RANDOM,flush|align(16));
  C=Matrix(double,M,N,RANDOM,flush|align(16));
 } ;
flop="2*M*N*K+M*N";
```

Template of auto-generated timing driver

```
for each routine parameter s in R do
     if s is a pointer or array variable then
        allocate memory for s
  end for
  for each repetition of timing do
     for each routine parameter s in R do
        if s needs to be initialized then
           initialize memory_s
     end for
     if Cache flshing = true then Flush Cache
     time_start <-  current time
     call R
     time_end <-  current time
     time_spent <- time_end - time_start
  end for
  Calculate min, max, and average of
time_spent
  if flps is defied then
     Calculate Max and average MFLOPS
  end if
  Print All timings
```

The Checkpointing Approach (for data-sensitive routines)

```
enter_checkpoint(CHECKPOINTING_IMAGE_NAME);
.....
starttime=GetWallTime();
retval = mainGtU(i1, i2, block, quadrant, nblock, budget);
endtime=GetWallTime();
.....
stop_checkpoint();
```

- Checkpoint image includes
  - All the data in memory before calling enter_checkpoint
  - All the instructions between enter_checkpoint and stop_checkpoint
- Checkpoint image is saved to a file
  - Auto-generated timers can invoke the checkpoint image via a call to restart_checkpoint
- Utilize the Berkeley Lab Checkpoint/Restart (BLCR) library
- Delayed checkpointing
  - Call enter_checkpoint several instructions/loop iterations ahead of time to restore the cache state

The POET Language

- Language for expressing parameterized program transformations
  - Parameterized code transformations and configuration space
    - Transformations controlled by tuning parameters
    - Configuration space: parameters and constraints on their values
  - Interpreted by search engine and transformation engine
- Language capabilities:
  - Able to parse/transform/output arbitrary languages
    - Have tried subsets of C/C++, Cobol, Java; going to add Fortran
  - Able to express arbitrary program transformations
    - Support optimizations by compilers or developers
    - Have implemented a large collection of compiler optimizations
    - Have achieved comparable performance to ATLAS(LCSD07)
  - Able to easily compose different transformations
    - Allow transformations to be defined easily reordered
    - Empirical tuning of transformation ordering (LCPC08)
  - Parameterization is built-in and well supported

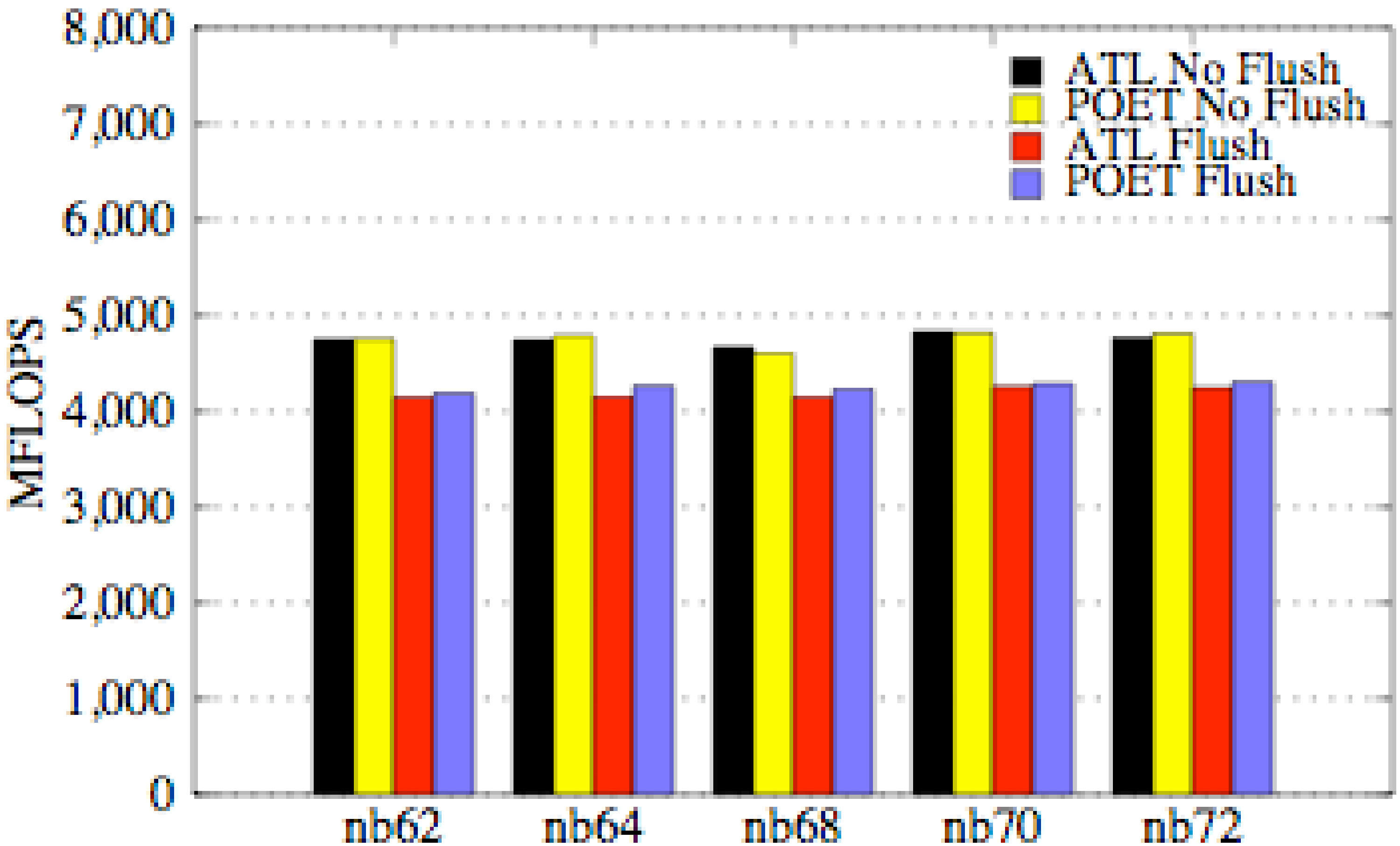
Experimental Evaluation

- Goal: verify that POET-generated timers can
  - Significantly reduce tuning time for large applications
  - Accurately reproduce performance of the tuned routines
- Methodology
  - Compare POET-generated timers with the ATLAS timers
    - Using differently optimized gemm kernels by POET
  - Compare POET-generated timers with profiling results from running whole applications
    - For both data-insensitive and data-sensitive routines
    - Verify both the default timing approach and the checkpointing approach
- Evaluation platforms
  - Two multicore platforms: a 3.0Ghz Dual-Core AMD Opteron 2222 and a 3.0Ghz Quad-Core Intel Xeon Mac Pro.
  - Timings obtained in serial mode using a single core of each machine.

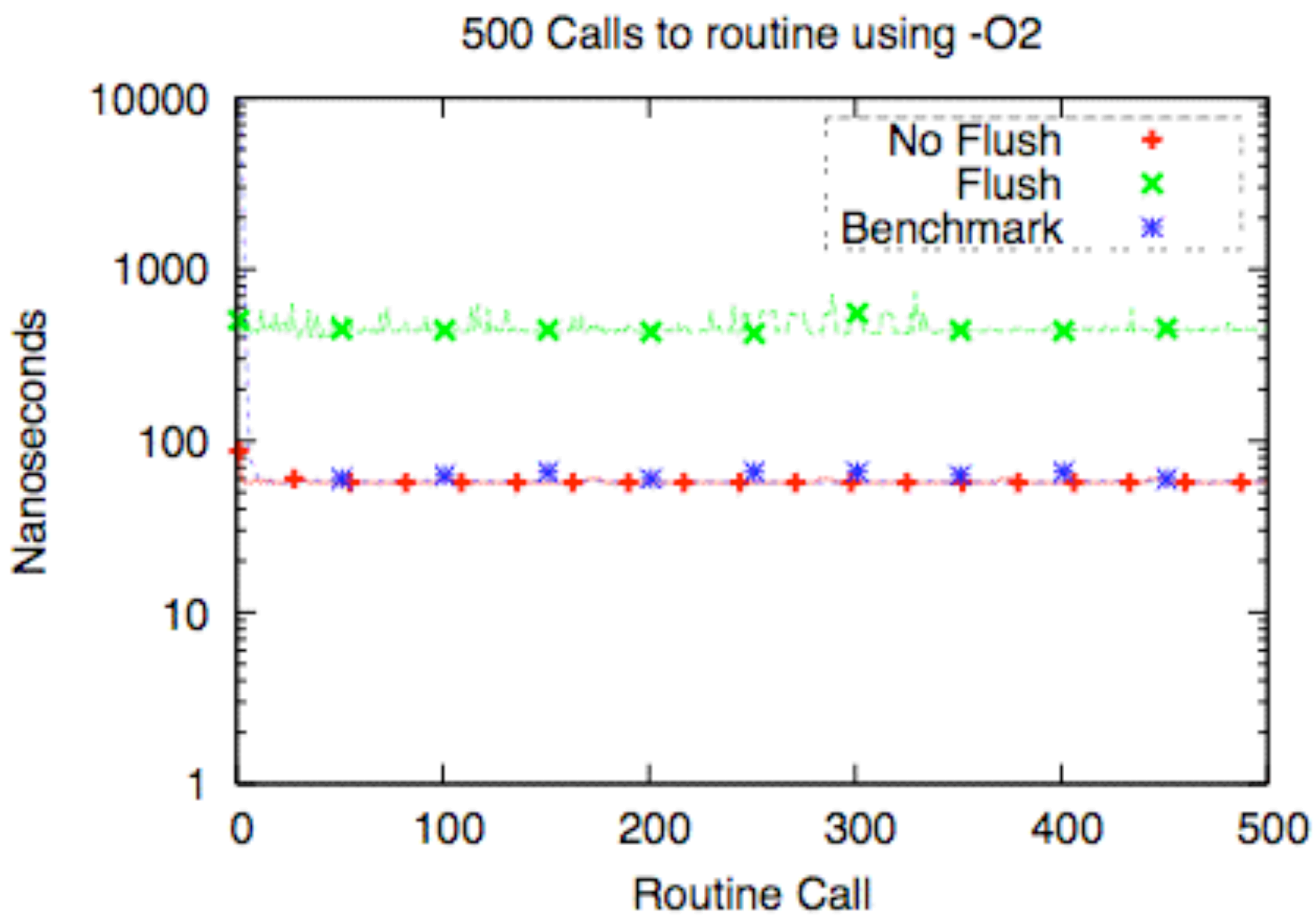
Reduction in tuning time

	Full application	Delayed checkpoint	Immediate checkpoint	Default timing via POET
mult_su3_mat_vec	877,430ms	3,502ms	3,510ms	5ms
mainGtU	45,765ms	2,019ms	1,975ms	4ms
scan_for_patterns	90,460ms	6,218ms	5,930ms	n/a

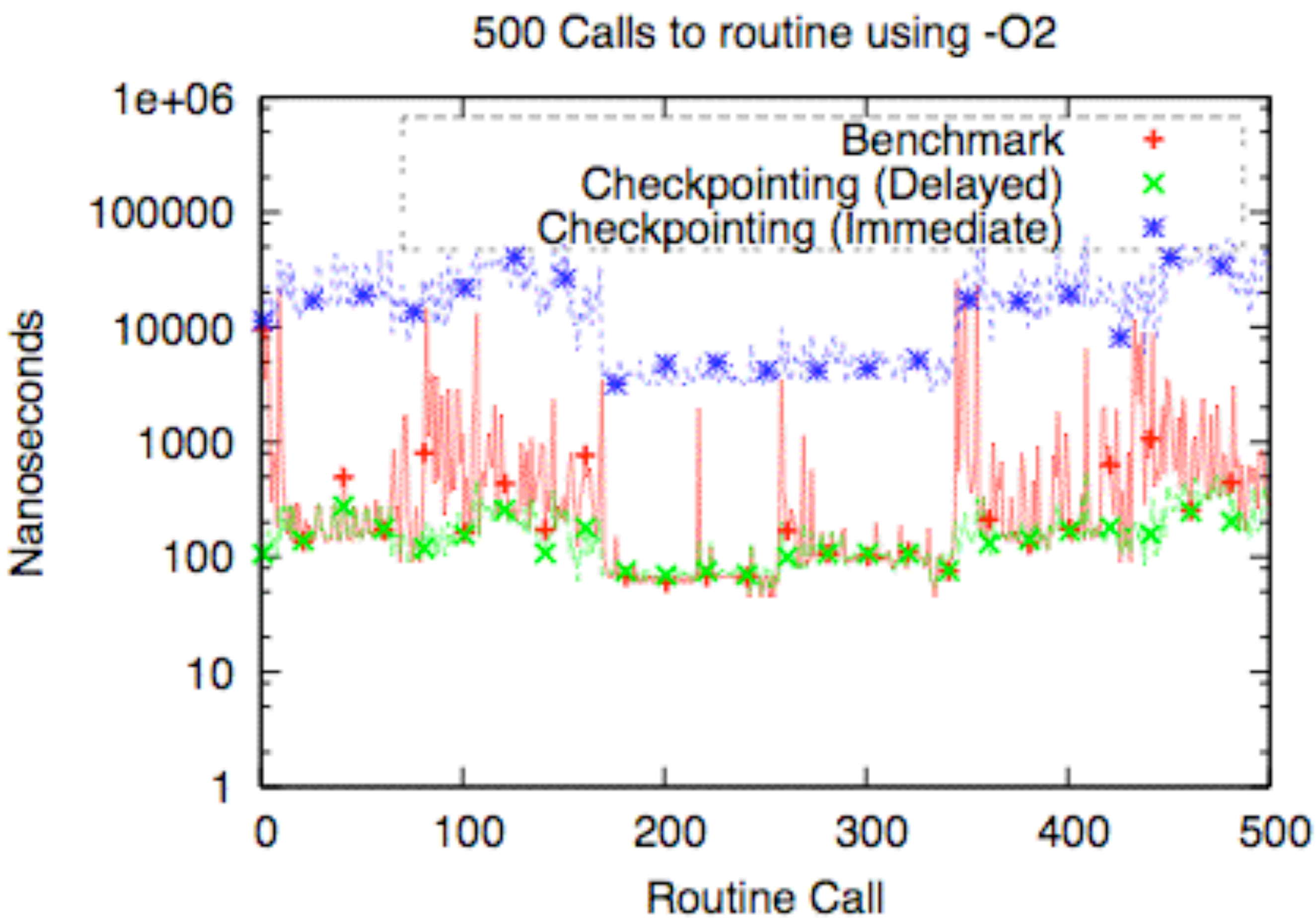
Comparing to ATLAS



Tuning Data-Insensitive Routine



Tuning Data-Sensitive Routine



Summary and Ongoing work

- Goal: reduce the tuning time of large scientific applications
  - Independently measure and tune the performance of critical routines
  - Accurately replicate the execution environment of routines
- Solutions
  - Libraries to profile and collect execution environment of critical routines
  - Use POET to automatically generate timing drivers
  - Immediate and delayed checkpointing approach
- Ongoing work
  - Reduce tuning time through the right search strategies
  - Automate the tuning process by integrating POET with advanced compiler technologies