PerfExpert :: deep dive

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Topics in this session

- Steps to use PerfExpert

- Demonstration using an example
Performance optimization using PerfExpert

1. Choosing what to measure

2. Measuring system performance

3. Selecting the application’s input data size

4. Measuring application performance

5. Diagnosis of performance problems

6. Suggestions for optimization
Performance optimization using PerfExpert

1. Choosing what to measure
2. Measuring system performance
3. Selecting the application’s input data size
4. Measuring application performance
5. Diagnosis of performance problems
6. Suggestions for optimization
#1: Choosing what to measure

- 350+ performance events on most consumer laptops, more on servers

- Often times hard to decipher

- May differ across machines

PerfExpert mines the available events and chooses relevant ones
#2: Measuring system performance

PerfExpert runs micro-benchmarks to measure:

- Cache latencies
- CPU speed
- Best-case instruction execution times

Results are used to analyze application performance on the specific hardware.
#3: Selecting application data size

- PerfExpert measures intra-node performance, hence multi-node execution does not provide useful information for profiling.

MPI tasks
#3: Selecting application data size

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#3: Selecting application data size

- For most applications, possible to use a single-node problem size that is representative of production scale

- May reduce unnecessary overhead
#4: Measuring application performance

- PerfExpert internally uses HPCToolkit. Hence all of the information that HPCToolkit measures is available to PerfExpert but only limited portion of it is used.

- PerfExpert runs application multiple (5-6) times (because of limited hardware counters).

- Summarizes measurements in experiment.xml
#5: Diagnosis of performance problems

- PerfExpert derives commonly-used analysis metrics

- Combines performance information from HPCToolkit and system latencies from PerfExpert microbenchmarks

- Six categories of performance breakdown (explained in next slide)

- Metrics are scaled so that they range from good to okay to bad to worse
Performance categories

(What do these categories indicate?)

• **Data access**: Data reuse

• **Data TLB**: Memory access patterns

• **Instruction access, TLB**: Code locality

• **Branch execution**: ‘if’ statements

• **Floating-point computation**: Arithmetic operations

http://www.tacc.utexas.edu/perfexpert/metrics/
Loop in function compute() (99.9% of the total runtime)

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ratio to total instrns  %  0........25........50.......75.......100
- floating point       :  6 ***
- data accesses        :  33 *******************
GFLOPS (% max)         :  7 ***

----------------------------------------------------------

performance assessment  LCPI good....okay....fair....poor....bad...
* overall               :  0.8 >>>>>>>>>>>>>

upper bound estimates
* data accesses         :  2.4 >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
  - L1d hits             :  1.3 >>>>>>>>>>>>>>>>>>>>>>>>>>>
  - L2d hits             :  0.3 >>>>
  - L2d misses           :  0.8 >>>>>>>>>>>>>>>>>>
* instruction accesses  :  0.3 >>>>
  - L1i hits             :  0.3 >>>>
  - L2i hits             :  0.0 >
  - L2i misses           :  0.0 >
* data TLB              :  1.5 >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
* instruction TLB       :  0.0 >
* branch instructions   :  0.0 >
  - correctly predicted  :  0.0 >
  - mispredicted         :  0.0 >
* floating-point instr   :  0.2 >>>>
  - fast FP instr        :  0.2 >>>>
  - slow FP instr        :  0.0 >
#6: Suggestions for optimization

- PerfExpert contains a database of common problems, their resulting performance metrics and solutions

- Pattern matches performance metrics of user code to those in the database

- Database is growing, not an exhaustive list yet
Demonstration

(using Matrix multiplication code on Ranger as example)

```c
void compute()
{
    register int i, j, k;
    for (i = 0; i < n; i++)
        for (j = 0; j < n; j++)
            for (k = 0; k < n; k++)
                c[i][j] += a[i][k] * b[k][j];
}
```
Discovering relevant performance events

• Automated during installation of PerfExpert

• For example, events chosen on Ranger:

  - PAPI_TOT_CYC
  - PAPI_L1_DCA
  - PAPI_L2_DCA
  - PAPI_TOT_INS
  - PAPI_L1_ICA
  - PAPI_L2_ICA
  - PAPI_L2_DCM
  - PAPI_L2_ICM
  - PAPI_TLB_DM
  - PAPI_TLB_IM
  - PAPI_BR_INS
  - PAPI_BR_MSP
  - PAPI_FML_INS
  - PAPI_FDV_INS
  - PAPI_FAD_INS
  - RETIRED_SSE_OPERATIONS:ALL
  - PAPI_L3_TCM
Measuring system performance

- Automated during installation of PerfExpert

- For example, system latencies on Ranger:

  L1_dlat = 1.02  
  L1_ilat = 1.02  
  L2_lat = 18.50  
  L3_lat = 27.39  
  mem_lat = 291.59  
  CPU_freq = 2300003000  
  FP_lat = 3.00  
  FP_slow_lat = 28.50  
  BR_lat = 3.00  
  BR_miss_lat = 22.53  
  TLB_lat = 49.52
Application performance measurement

- Load appropriate modules:
  module load papi java perfexpert

- Run measurements:
  perfexpert_run_exp ./application.exe

- Produces XML file containing measurements
Diagnosis

perfexpert <threshold> experiment.xml

Loop in function compute() (99.9% of the total runtime)

<table>
<thead>
<tr>
<th>ratio to total instrns</th>
<th>%</th>
<th>0........</th>
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0.0
Suggestion by PerfExpert

```
perfexpert --recommend <threshold> experiment.xml
```

Loop in function compute() (100% of the total runtime)
=================================================================
Change the order of loops
This optimization may improve the memory access pattern
and make it more cache and TLB friendly.
New code

```c
void compute()
{
    register int i, j, k;
    for (i = 0; i < n; i++)
        for (k = 0; k < n; k++)
            for (j = 0; j < n; j++)
                c[i][j] += a[i][k] * b[k][j];
}
```
Revised code’s performance

perfexpert <threshold> experiment-opt.xml

Loop in function compute() (99.9% of the total runtime)

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Upper Bound Estimates

| Data Accesses | 0.6 >>>>>>>>
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<th></th>
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<tbody>
<tr>
<td>L1d hits</td>
<td>0.6 &gt;&gt;&gt;&gt;&gt;&gt;&gt;&gt;</td>
</tr>
<tr>
<td>L2d hits</td>
<td>0.1 &gt;&gt;</td>
</tr>
<tr>
<td>L2d misses</td>
<td>0.0 &gt;</td>
</tr>
<tr>
<td>L3d misses</td>
<td>0.0 &gt;</td>
</tr>
<tr>
<td>Instruction Accesses</td>
<td>0.2 &gt;&gt;&gt;&gt;</td>
</tr>
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<tr>
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<td>Mispredicted</td>
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<td>0.2 &gt;&gt;&gt;&gt;</td>
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Commands to use PerfExpert

1. module load papi java perfexpert

2. perfexpert_run_exp ./application.exe

3. perfexpert <threshold-between-0-and-1> experiment.xml

4. perfexpert --recommend <threshold> experiment.xml