Titan Workshop - Vampir and VampirTrace

Trace Based Performance Analysis at Large Scale on Titan

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Disclaimer

Performance tools will not automatically make you code run faster. They help you understand, what your code does and where to put in work.
Agenda

1. Introduction
   - Sampling vs. Profiling vs. Tracing

2. The Vampir Framework Workflow
   - VampirTrace
   - Vampir

3. Advanced Topics
   - GPU support & Scalability

4. Vampir Framework on Titan

5. Summary

6. Bonus Material
1. Introduction

• Why bother with performance analysis?
  – Efficient usage of expensive and limited resources
  – Scalability to achieve next bigger simulation

• Profiling and Tracing
  – Have an optimization phase
    • just like testing and debugging phase
  – Use tools!
  – Avoid do-it-yourself-with-printf solutions, really!
1.1 Sampling vs. Tracing

Sampling

foo | bar | foo | bar | foo

2011/06/30 10:15:12.672865 Enter foo
2011/06/30 10:15:12.894341 Leave foo

Tracing

Foo: Total Time 0.0815
Bar: Total Time 0.4711
1.2 Profiling vs. Tracing

- Statistics

  ![Number of invocations](chart)

  ![Execution time](pie)

- Timelines

  ![foo bar foo bar foo](timeline)
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2.1.1 Instrumentation

What does VampirTrace do in the background?

- **Instrumentation phase (pre-run):**
  - Via compiler wrappers
  - By underlying compiler with specific options
  - MPI instrumentation with replacement lib
  - OpenMP instrumentation with Opari
  - Also binary instrumentation with Dyninst
  - Partial manual instrumentation
  - By an automatic instrumentor (TAU)
2.1.2 Measurement

What does VampirTrace do in the background?

- Measurement phase (during run):
  - Event data collection
  - Precise time measurement
  - Parallel timer synchronization
  - Collecting parallel process/thread traces
  - Collecting performance counters (from PAPI, memory usage, POSIX I/O calls and fork/system/exec calls, CUDA, and more …)
  - Monitor accelerator (like GPU, Cell SPE) usage
  - Filtering and grouping of function calls
2.1.3 Common Event Types

- Enter/leave of function/routine/region
  - time, process/thread, function ID
- Send/receive of P2P message (MPI)
  - time, sender, receiver, length, tag, comm.
- Collective communication (MPI)
  - time, process, root, communicator, # bytes
- Hardware performance counter values
  - time, process, counter ID, value
- …
2.1.4 Tracing – Pros and Cons

• Tracing Advantages
  – Preserve temporal and spatial relationships of events
  – Allow reconstruction of dynamic behavior on any required abstraction level
  – Profiles can be calculated from trace

• Tracing Disadvantages
  – Traces can become very large
  – May cause perturbation
  – Instrumentation and tracing is complex (event buffering, clock synchronization, …)
2.1.5 Application Adaptations

What do you need to do for it?

1. Change the compiler

   - CC=icc
   - CXX=icpc
   - F90=ifc
   - MPICC=mpicc

   - CC=vtcc
   - CXX=vtcxx
   - F90=vtf90
   - MPICC=vtcc -vt:cc mpicc

2. Re-compile & re-link

3. Trace Run (run the application with an appropriate test data set)
2.2 Workflow Overview

Vampir

Trace

File (OTF)

Vampir 7

Trace

Bundle

VampirServer

Multi-Core Program

Many-Core Program
2.3.1 Event Trace Visualization

• Trace Visualization
  – Alternative and supplement to automatic analysis
  – Show dynamic run-time behavior graphically
  – Provide statistics and performance metrics
    • Master timeline for parallel processes/threads
    • Process timeline plus performance counters
    • Statistics summary display
    • Message statistics
    • and more
  – Interactive browsing, zooming, selecting
    • Adapt statistics to zoom level (time interval)
    • Also for very large and highly parallel traces
2.3.2 Finding Performance Bottlenecks

- Inefficient communication patterns
- Load imbalance / serial parts of the application
- Memory bound computation
  - Inefficient cache usage
  - TLB misses
  - Use HW counters (PAPI) to detect
- I/O bottlenecks
- Most time consuming functions
- …
2.3.3 VampirClient (Vampir 7)

- GUI to analyze trace files (OTF)
- Main concept: Timeline + statistics
- GUI is QT based – available on Linux, Mac, Windows
2.3.4 Displays for a trace with 64 cores

Master Timeline

Process Timeline

Counter Data Timeline

Function Summary

Communication Matrix View

Context View

Function Legend

Process Summary

Toolbars
2.3.5 VampirServer

- Parallel analysis engine for Vampir
  - MPI parallelized for distributed memory systems
  - Pthread parallelized for shared memory systems

- Scales to > 10,000 analysis processes

- Loads the entire uncompressed trace into memory
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3.1 Challenges for VT on Titan

- Overcome I/O problems
- Find ways to show that much data

Scalability

- Hitting a moving target
- Another layer of heterogeneity to display

GPU Support
3.1.1 Limits for Tracing on Titan

- **Current limit** is (based on user experiences):
  - Tracing up to 8,000 processes
  - I/O problem (too many file creates – one per process)

- **Prototype** was already working on Jaguar
  - Tracing 200,000+ processes
  - Based on IOFSL library
  - Opened for visualisation with 20,000 VampirServer processes
3.1.2 200,000+ Processes in Vampir
3.1.3 GPU Support: CUDA (& OpenCL)

- Currently done via library wrapping

- Reuse of known metrics

Thread = Kernel

Message = cudaMemcpy

1234
„foo“
TRUE
0.98
3.1.4 Time stamps for asynchronous events

[Diagram showing event timestamps and queue transitions.]
3.1.5 Visualization of GPU Tracing

- Support for hybrid modes: GPGPU + MPI + threads
  - Function invocations in host processes (Process X) and threads
  - Kernel invocations in CUDA threads (Thread x/y)
  - Host-GPU interactions via CUDA API (light arrows)
  - Host-Host interactions via MPI (bold arrows)

*) old picture; CUDA Threads were renamed (CUDA[x] y:z)
3.2 Scalability Features in Vampir

- Fit to chart height feature of master timeline and performance radar
  - Allows visualization of more processes than pixels of screen are available

- Clustering
  - Allows detection of outlier processes and groups with similar behavior

- Performance radar
  - Highlighting performance conditions of your program in a global timeline
3.2.1 Fit to chart height: Pflotran initialization + I/O
3.2.2 Clustering: Pflotran - first iteration
3.2.3 Performance Radar

- Display objectives:
  - Identification of performance relevant trace parts
  - Assistance to users to navigate in trace data and to spot interesting sections
  - Performance of basic arithmetics on counter data
3.2.3 Performance Radar

- **Features:**
  - Detection of occurrences of functions/function groups
  - Visualization of call density of functions/function groups to help to find performance relevant candidates
  - Construction of filter based on function occurrences over time for further usage in calculations
3.2.3 Performance Radar

- **Features:**
  - Performance of arbitrary calculations on counter data, e.g. add up all floating point operations over time, differentiation of performance counter
  - Support for concatenation of several calculations
  - Utilization of filter in calculations, e.g. only add up FLOPS of function x
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4.1 VampirTrace

titan$ module load vampirtrace

• Use the appropriate compiler wrappers
  – vtcc, vtCC, vtf77, vtf90

• Pick appropriate library (seq, mpi, mt, hyb)
  – e.g. vtcc –vt:hyb (recommended)

• Pick instrumentation type
  – –vt:inst compinst (default, compiler instrumentation)
  – –vt:inst manual (MPI, OpenMP, CUDA and manual inst.)

• Tell your build system to use VampirTrace
  – ./configure –with–CC="vtcc –vt:hyb” …
4.1.1 VampirTrace

• Pitfalls & Hints (especially for Titan)
  – Make sure that the VampirTrace module is loaded
    • Either ‘qsub -V’ or ‘module load vampirtrace’ within the PBS script
  – Save traces to special directory to optimize I/O performance
    • Set VT_PFFORM_GDIR=traces
    • lfs setstripe -c 1 $VT_PFFORM_GDIR
  – Set VT flag ‘-vt:hyb’ (VT does not identify the Cray wrapper as MPI/OMP compiler)
  – Use ‘-vt:verbose’ to see the commands executed by VT
  – Run with VT_MODE=STAT to create a profile (instead of a trace) for the first overview of you program
  – Set VT_BINDIR=/tmp/work/$USER/.vt/bin if you get something like: ‘/sw/…/vtunify No such file or directory’
4.1.2 VampirTrace

• More Pitfalls & Hints
  – Increase VT_BUFFER_SIZE if necessary
  – Avoid VT_MAX_FLUSHES=0 when you don’t know how large your trace will get (you could write TBytes of data)
  – Some compiler instrument inline functions, some do not
  – Avoid ‘-vt:inst compinst’ (default) for large C++ codes with STL
    • Use TAU (-vt:inst tau) or Dyninst (-vt:inst dyninst) instead
  – Use VT_FILTER_SPEC to limit the number of recorded events
    • Reduces resulting trace size by filtering frequently called functions
  – Function filtering won’t reduce runtime dramatically
    • -finstrument-functions-exclude-function-list=… works for a small number
    • ‘-vt:inst tau’ with a include/exclude file is recommended for large projects
4.2 Vampir

titan$ module load vampir
titan$ vampirserver start –a <PROJ> –n <cores>
titan$ wait until server is running and follow the instructions
local1$ ssh –L 30XXX:nidYYYY:30ZZZ <user>@titan
local2$ ./vampir and choose 'File -> Remote Open'
titan$ vampirserver stop XXXXX

• Pitfalls & Hints:
  – Use enough cores to load the trace in memory (decompressed, 4x)
  – Avoid running Vampir on the login nodes (X11 is slow)
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- **VampirTrace**
  - Convenient instrumentation and measurement infrastructure
  - Hides away complicated details
  - Provides many options and switches for experts
  - Available as
    - Part of Open MPI 1.3 and higher
    - Stand-alone package: [www.tu-dresden.de/zih/vampirtrace](http://www.tu-dresden.de/zih/vampirtrace)
  - Further information
    - [www.nccs.gov/computing-resources/lens/software/?software=vampirtrace](http://www.nccs.gov/computing-resources/lens/software/?software=vampirtrace)
    - [www.tu-dresden.de/zih/vampirtrace](http://www.tu-dresden.de/zih/vampirtrace)
    - `chester$ /ccs/proj/trn001/vampir/manual/vampirtrace.pdf`
5. Summary

- **VampirClient & VampirServer**
  - Interactive trace visualization and analysis
  - Intuitive browsing and zooming
  - Scalable to “quite large” trace data sizes (1.5 TByte)
  - Scalable to high parallelism (200,000 processes)
  - VampirClient is available for Windows, Linux/Unix and Mac OS X
  - Further information
    - [www.nccs.gov/computing-resources/lens/software/?software=vampir](http://www.nccs.gov/computing-resources/lens/software/?software=vampir)
    - [www.vampir.eu](http://www.vampir.eu)
    - `chester$ /ccs/proj/trn001/vampir/manual/vampirtrace.pdf`
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7. Bonus Material – Bottlenecks

• Trace visualization to identify bottlenecks
  – Several displays with many options
  – Identify essential parts of an application (initialization, main iteration, I/O, finalization)
  – Identify important components of the code (serial computation, MPI P2P, collective MPI, OpenMP)
  – Make a hypothesis about performance problems
  – Consider application's internal workings if known
  – Select the appropriate displays
  – Use statistic displays in conjunction with timelines
7.1 Communication it-self

- Too much runtime share for MPI all-together

[Graph showing Vampir trace view with processes and timeline]
7.2 Bursts of large messages

- Long bursts of MPI allreduce operations

→ Replace by NBC non-blocking Allreduce plus wait
7.3 Sequential point-to-point messages

- Chains of MPI Sendrecv

→ Replace by faster overlapping series of Send, Irecv, and Waitall
7.4 Unnecessary synchronization

• Many MPI barriers are unneeded

→ Remove barriers if possible, following operations start less regular but are faster.
7.5 Low parallel efficiency

- Mostly idle OpenMP threads

(Zoom)
7.6 Inefficient L1/L2/L3 cache usage

High rate of Flop/s with low rate of L3 cache misses

Low Flop/s rate due to a high L3 miss rate