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Profiling Tutorial

Soon Yung Jun (Fermilab, SCD/Physics and Detector Simulation Group) LArSoft Tools and Technology Workshop 20 June 2017, Fermilab

Debugging is finally done! Ready for a test drive?







My program runs, but seems very slow ...

CPU Throughput Instruction stall

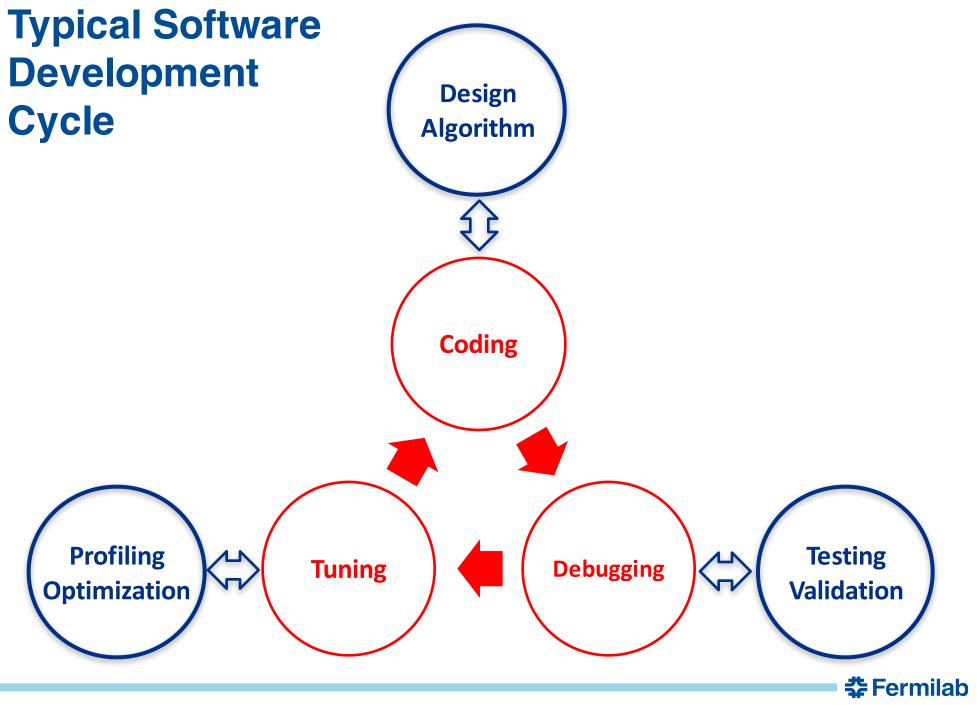
Memory Latency Cache misses



Multithreading Load balancing Scalability

Where to start?





This Tutorial

- PART-I
 - A brief introduction to computing performance profiling
 - An overview of selected profiling tools and examples
- PART-II
 - Profiling results of the LArTest application with IgProf and OpenISpeedshop
- Demos and Questions



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PART-I

Introduction to Computing Performance Profiling Overview of Selected Profiling Tools and Examples

Why Profile?

Performance tuning is an essential part of the development cycle

- Free lunch is over as modern hardware architectures are getting more complex and parallel
- HEP applications are usually complicated too
- Every \$/Watt matters (computing with a limited budget)
- Understanding the code performance is responsibility of the software developer
- Maximize CPU flop rate and minimize memory operations (balancing them is not an easy task)



Computing Performance Profiling and Analysis

- Performance benchmarking quantifies usage/changes of CPU time and memory (amount required or churn)
- Performance profiling analyzes
 - Hot spots, bottlenecks and efficient utilization of resources
 - Code efficiency (instruction/cycle, latencies, I/O and etc.)
- Identifying opportunities for optimization





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Understanding Computer Performance

- Hardware platform (processors) popularly used in HEP – CISC (x86), RISC (ARM), MIC, GPU(SIMT), FPGA
- Speed: cycle vs. frequency
 - cycle time = 1/(clock frequency)
 - -2.0 GHz = 0.5 ns per cycle
 - CPU Time = Σ (number of clock cycles)/frequency
- Memory: latency vs. bandwidth
 - latency: the time interval between the request for information and the access (to the first bit of that information)
 - Bandwidth: the number of bits per second
- Throughput vs. locality: CPI, MIPS, FLOPS, FMO
- Pipelining: instruction throughput, data dependency, ILP, ...

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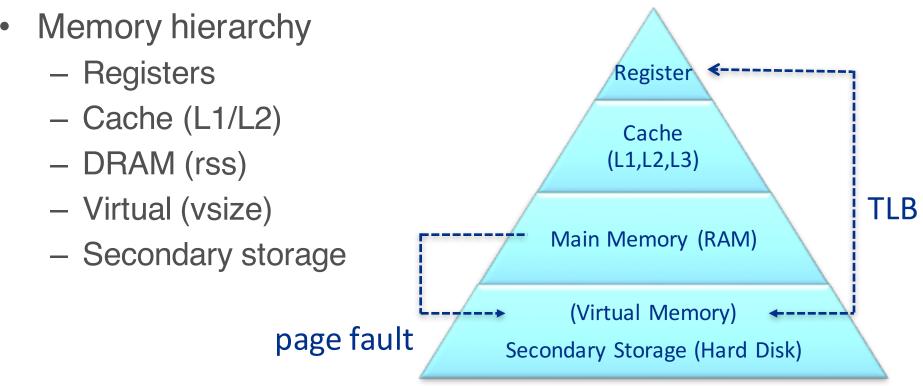
Understanding CPU Performance

- Q1: Which operation takes more cycles?
 - 1. Integer division
 - 2. Double division
 - 3. Function call
 - 4. static_cast<int>(double)

- Strategies
 - Do not mix data type
 - Avoid unnecessary divisions and function calls in the inner most loop



Understanding Memory Transaction



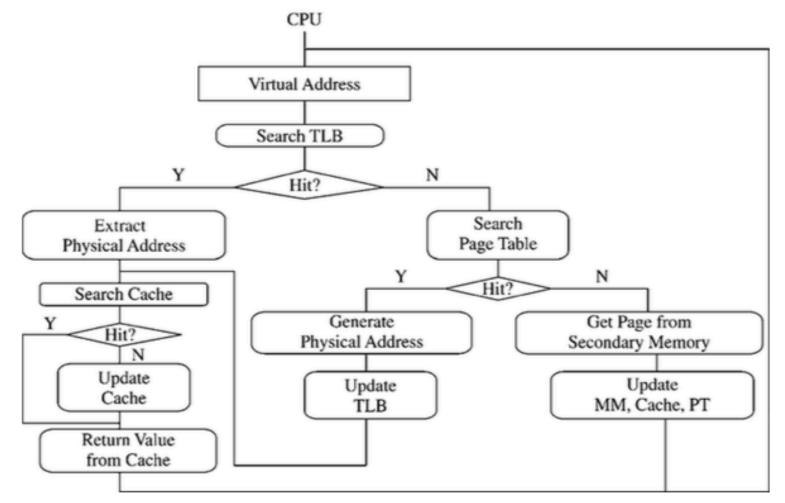
- Caching
 - Spatial locality (data storage, coalescence)
 - Temporal locality (data reusability in near future)
 - Replacement polices
 - TLB (translation look-aside buffer, the most recent page access)

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Understanding Memory Transaction

• Example of memory accesses scenarios



• Do not over-optimize by yourself, but rely on profiling first

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Understanding Memory Performance

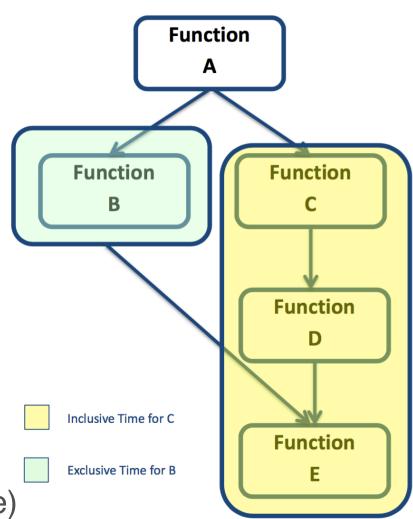
- Q2: Which ratio is the biggest in memory access?
 - 1. L1 Cache/Register
 - 2. L2 Cache/L1 Cache
 - 3. RAM/L2 Cache
 - 4. Virtual Memory/RAM

- Strategies
 - Try to fit everything in RAM
 - Try to fit essential calculations in cache



Basic Concepts of Performance Profilers

- Program segments:
 - Code
 - Stack (program)
 - Heap
- Collecting program events
 - Hardware interrupts
 - Code instrumentation
 - Instruction set simulation
 - Tracing (when)
- Periodic sampling
 - Top of the stack (exclusive)
 - Anywhere in the stack (inclusive)



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Classification of Profilers by Techniques used

- Instrumentation: inserts extra code at each function call to count how many times the function is called and how much time it takes.
- Sampling: The profiler tells the operating system to generate an interrupt and counts how many times an interrupt occurs in each part of the program
 - no modification of the program
 - time-based
 - event-based
- Debugging tools: The profiler inserts temporary debug breakpoints at every function or every code line (valgrind)



Examples of Profilers

- Basic OS tools:
 - gprop/perf
 - cachegrind/callgrind
- Hardware counter
 - PAPI and tools set
- Vendor tools
 - Intel VTune Amplifier XE, Inspector, Advisor, ITAC
 - AMD CodeAnalyst
 - Allinea (map and DDD)

- ASCR tools (Open source)
 - HPCToolkit (Rice Univ.)
 - TAU (Oregon Univ.)
 - OpenISpeedshop (Krell)
- HEP
 - FAST (FNAL)
 - IgProf
 - Gooda



gprof: demo

- Compile your program with gcc using -pg flag
- Run your program (as usual) will produce gmon.out
- Run gprof

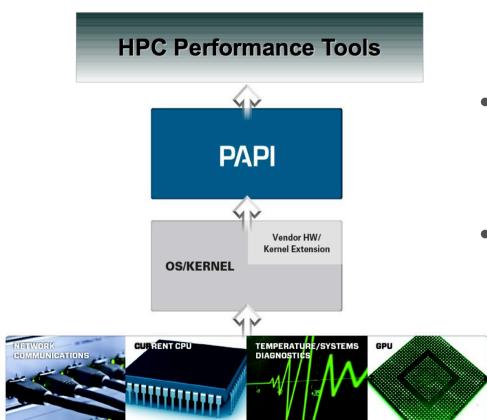
> wget https://g4cpt.fnal.gov/g4p/demos/demo.cc > g++ -pg demo.cc -o demo > time ./demo > gprof ./demo

Each sample counts as 0.01 seconds.

% cumulative self self total
time seconds seconds calls ms/call ms/call name
36.49 0.51 0.51 1 514.51 514.51 Function_C()
34.34 1.00 0.48 1 484.25 998.76 Function_B()
30.05 1.42 0.42 1 423.72 423.72 Function_A()
0.00 1.42 0.00 1 0.00 0.00 global constructors keyed to _Z10Function_Cv
0.00 1.42 0.00 1 0.00 0.00 _static_initialization_and_destruction_0(int, int)

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PAPI (Performance API)



- A standard API to access hardware performance counters
- Relation between software performance and processor events
- Event metrics
 - FLOPS, Load/Store
 - cache hit/miss, TLB miss
 - power consumption (MuMMI)
 - platform specific metrics



Hardware Counters

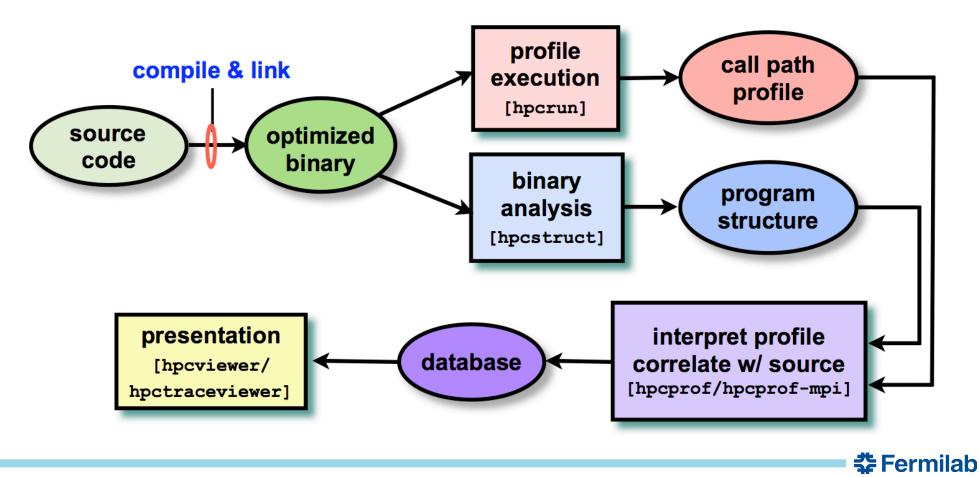
- Operating systems support both non-derived and derived PAPI presets: papi_avail –a for listing
- A list of some possible hardware counter combinations

For Xeon processors:	
PAPI_FP_INS, PAPI_LD_INS, PAPI_SR_INS	Load store info, memory bandwidth needs
PAPI_L1_DCM, PAPI_L1_TCA	L1 cache hit/miss ratios
PAPI_L2_DCM, PAPI_L2_TCA	L2 cache hit/miss ratios
LAST_LEVEL_CACHE_MISSES,	L3 cache info
LAST_LEVEL_CACHE_REFERENCES	
MEM_UNCORE_RETIRED:REMOTE_DRAM,	Local/nonlocal memory access
MEM_UNCORE_RETIRED:LOCAL_DRAM	
For Opteron processors:	
PAPI_FAD_INS, PAPI_FML_INS	Floating point add multiply
PAPI_FDV_INS, PAPI_FSQ_INS	Square root and divisions
PAPI_FP_OPS, PAPI_VEC_INS	Floating point and vector instructions
READ_REQUEST_TO_L3_CACHE:ALL_CORES,	L3 cache
L3_CACHE_MISSES:ALL_CORES	

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Example of Sampling Tools and Workflow: HPCToolkit

- Typically unmodified binary and call stack analysis
- Code centric view, GUI and text-based flat profile



Example of Integrated Tools: TAU (Tuning Analysis Utilities)

- Dynamic, compiler based, source based Instrumentation
- Analysis tools
 - ParaProf
 - PerfExplorer
 - Tracer (Jumpshot, vampir)
- Various built-in graphical tools
- Dis/advantage: compiler/source-based instrumentation



Understanding Sampling Profilers

- Q3: What are the disadvantages of sampling profilers?
 - 1. Sampling uncertainty (\rightarrow statistical analysis with repetition)
 - 2. Non-Reproducibility (\rightarrow use definitive tools)
 - 3. Interference from other processes (\rightarrow standalone nodes)
 - 4. Jumping between cores (\rightarrow setting NUMA affinity, pinning)
 - 5. All of above
- Strategies
 - Understand your program first (intensity: arithmetic vs. memory)
 - Overview with sampling experiments
 - Focus on critical parts of code: Rule of 80:20
 - Detailed optimization with hardware counter experiments
 - Benchmarking and monitoring of every minor/major update

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PART-II

Profiling Results of LArTest with IgProf and OpenISpeedshop

Application for this Tutorial: LArTest

- A standalone Geant4 application (developed by H. Wenzel)
 - Cubic (5mx5mx5m) LAr fiducial volume
 - GDML to assign step limits and sensitive detector to volumes
 - Optical (scintillation) photons produced in sensitive detector
- Computing performance monitoring features
 - Event time
 - Memory (IgProf, statm)
 - Statistics of the number for tracks/steps per particle type
- Profiling examples with IgProf and OpenISpeedshop



Installing and Running IgProf

- Installation: <u>http://igprof.org/install.html</u>
- Implementation

```
if(void *sym = dlsym(0, "igprof_dump_now")) {
    dump_ = __extension__ (void(*)(const char *)) sym;
} else { /* message */; }
```

 Running igprof on your application (-mp: memory profiling) <u>http://igprof.org/running.html</u>

igprof -d -mp -z -o \${IG_OUT} \$exe {args...}

• Analysis (web-navigable version of the report, -r for \$mode)

cmd="igprof-analyse --sqlite -d -v -g -r" \$cmd \${mode} \${IG_OUT} | sqlite3 out.sql3

- ${mode} = MEM_LIVE, MEM_MAX, MEM_TOTAL$



lgProf

• Snapshot live memory on the heap (for every N-events)

if (dump_ && evt->GetEventID() % 25 == 0) {
 sprintf(outfile,"|gzip -9c > IgProf.%d.gz",evt->GetEventID()+1);
 dump_(outfile);

cmd="igprof-analyse --sqlite -d -v -g -r" \$cmd \${mode} -b out1.gz --diff-mode out2.gz| sqlite3 diff.sql3

- Performance report formats
 - ascii text (flat file)
 - sqlite database files
- Demo for the web-navigable report <u>https://g4cpt.fnal.gov/g4p/oss_10.3.r04_IArTest_01/index_igprof.html</u>

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LArTest: IgProf (TOTAL MEM)

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33 55 60 41 95 87 129 159 183	7.25 0.19 0.12 0.08 0.07 0.04 0.03 0.02 0.02	2,686,965,840 70,819,840 45,809,937 30,122,056 26,610,929 13,487,544 12,453,440 8,700,314 6,534,144	50,115 8,645 210 190 16 80,283 311,336 5,834 2,070	deflateInit2_ llvm::raw_ostream:: TBuffer::TBuffer(TBu TKey::TKey(TObject of TStorage::ReAllocCha G4InuclCollider::col std::pair <std::_rb_ llvm::SmallVectorBas llvm::DenseMap<clarget< td=""><td>SetBuffered() uffer::EMode, const*, char (ar(char*, unsi llide(G4Inuclf tree_iterator se::grow_pod(v g::Identifier] std::allocato</td><td>int) const*, int, i igned long, u Particle*, G4 <unsigned lon<br="">void*, unsign Info*, llvm:: pr<double> >:</double></unsigned></td><td>Directory*) signed long nuclParticl >, bool> st d long, uns mallVector< _M_fill_ins</td><td>) <u>e*, G4C</u> igned l clang:: ert(g</td><td><u>collisi</u> <u>tree<u< u=""> .ong) .Decl*, nu_cxx</u<></u></td><td>ionOutput&) Insigned long, . 2u>, llvm::E (::_normal_it</td><td>unsigned long, MenseMapInfo<clan< td=""><td>std::_Id</td><td>entity ifierI</td><td><unsig< td=""><td>gned 1 >:::g1</td><td>long>,</td><td>std::1</td></unsig<></td></clan<></td></clarget<></std::_rb_ 	SetBuffered() uffer::EMode, const*, char (ar(char*, unsi llide(G4Inuclf tree_iterator se::grow_pod(v g::Identifier] std::allocato	int) const*, int, i igned long, u Particle*, G4 <unsigned lon<br="">void*, unsign Info*, llvm:: pr<double> >:</double></unsigned>	Directory*) signed long nuclParticl >, bool> st d long, uns mallVector< _M_fill_ins) <u>e*, G4C</u> igned l clang:: ert(g	<u>collisi</u> <u>tree<u< u=""> .ong) .Decl*, nu_cxx</u<></u>	ionOutput&) Insigned long, . 2u>, llvm::E (::_normal_it	unsigned long, MenseMapInfo <clan< td=""><td>std::_Id</td><td>entity ifierI</td><td><unsig< td=""><td>gned 1 >:::g1</td><td>long>,</td><td>std::1</td></unsig<></td></clan<>	std::_Id	entity ifierI	<unsig< td=""><td>gned 1 >:::g1</td><td>long>,</td><td>std::1</td></unsig<>	gned 1 >:::g1	long>,	std::1
33 55 60 41 95 87 129 159 183 222	7.25 0.19 0.12 0.08 0.07 0.04 0.03 0.02 0.02 0.02	2,686,965,840 70,819,840 45,809,937 30,122,056 26,610,929 13,487,544 12,453,440 8,700,314 6,534,144 5,788,928	50,115 8,645 210 190 16 80,283 311,336 5,834 2,070 1,523	deflateInit2_ llvm::raw_ostream:: TBuffer::TBuffer(TBu TKey::TKey(TObject of TStorage::ReAllocCha G4InuclCollider::co std::pair <std::_rb llvm::SmallVectorBas llvm::DenseMap<clang std::vector<double,< td=""><td>SetBuffered() uffer::EMode, const*, char of ar(char*, unsi llide(G4Inuclf tree_iteratoro se::grow_pod(v g::Identifier] std::allocato or new(unsigne</td><td><u>int)</u> const*, int, igned long, u Particle*, G4 <unsigned lon<br="">void*, unsign Info*, llvm:: pr<double> >: ed long, clan</double></unsigned></td><td>Directory*) signed long nuclParticl >, bool> st d long, uns mallVector< <u>M fill_ins</u> ::ASTContex</td><td>) e*, G4C d::_Rb_ igned l clang:: ert(g t const</td><td>Collisi tree<u .ong) Decl*, nu_cxx</u </td><td>ionOutput&) Insigned long, . 2u>, llvm::E (::_normal_it</td><td>unsigned long, MenseMapInfo<clan< td=""><td>std::_Id</td><td>entity ifierI</td><td><unsig< td=""><td>gned 1 >:::g1</td><td>long>,</td><td>_std::l</td></unsig<></td></clan<></td></double,<></clang </std::_rb 	SetBuffered() uffer::EMode, const*, char of ar(char*, unsi llide(G4Inuclf tree_iteratoro se::grow_pod(v g::Identifier] std::allocato or new(unsigne	<u>int)</u> const*, int, igned long, u Particle*, G4 <unsigned lon<br="">void*, unsign Info*, llvm:: pr<double> >: ed long, clan</double></unsigned>	Directory*) signed long nuclParticl >, bool> st d long, uns mallVector< <u>M fill_ins</u> ::ASTContex) e*, G4C d::_Rb_ igned l clang:: ert(g t const	Collisi tree <u .ong) Decl*, nu_cxx</u 	ionOutput&) Insigned long, . 2u>, llvm::E (::_normal_it	unsigned long, MenseMapInfo <clan< td=""><td>std::_Id</td><td>entity ifierI</td><td><unsig< td=""><td>gned 1 >:::g1</td><td>long>,</td><td>_std::l</td></unsig<></td></clan<>	std::_Id	entity ifierI	<unsig< td=""><td>gned 1 >:::g1</td><td>long>,</td><td>_std::l</td></unsig<>	gned 1 >:::g1	long>,	_std::l
33 55 60 41 95 87 129 159 183 222 269 273	7.25 0.19 0.12 0.08 0.07 0.04 0.03 0.02 0.02 0.02 0.02 0.01	2,686,965,840 70,819,840 45,809,937 30,122,056 26,610,929 13,487,544 12,453,440 8,700,314 6,534,144 5,788,928 4,321,280 4,125,032	50,115 8,645 210 190 16 80,283 311,336 5,834 2,070 1,523 250	deflateInit2 llvm::raw_ostream::S TBuffer::TBuffer(TBu TKey::TKey(TObject of TStorage::ReAllocCha G4InuclCollider::col std::pair <std::_rb_f llvm::SmallVectorBas llvm::DenseMap<clang std::vector<double, clang::Decl::operate std::vector<double,< td=""><td>SetBuffered() uffer::EMode, const*, char (ar(char*, unsi llide(G4Inuclf tree_iterator« se::grow_pod(v g::Identifier] std::allocato or new(unsigne std::allocato</td><td>int) igned long, u Particle*, G4 <unsigned long<br="">void*, unsigned Info*, llvm::: pr<double> >: ed long, clan- pr<double> >:</double></double></unsigned></td><td>Directory*) signed long nuclParticl >, bool> st d long, uns mallVector< <u>M fill_ins</u> ::ASTContex reserve(uns</td><td>) d::_Rb_ igned l clang:: ert(g t_const igned l</td><td>Collisi _tree<u _ong) Decl*, _nu_cxx _&, uns _ong)</u </td><td>ionOutput&) unsigned long, 2u>, llvm::C (::normalit signedint,ur</td><td>unsigned long, PenseMapInfo<clan rerator<double*, signed long)</double*, </clan </td><td>std::_Id ng::Ident std::vec</td><td>entity ifierI</td><td><unsig< td=""><td>gned 1 >:::g1</td><td>long>,</td><td>_std::l</td></unsig<></td></double,<></double, </clang </std::_rb_f 	SetBuffered() uffer::EMode, const*, char (ar(char*, unsi llide(G4Inuclf tree_iterator« se::grow_pod(v g::Identifier] std::allocato or new(unsigne std::allocato	int) igned long, u Particle*, G4 <unsigned long<br="">void*, unsigned Info*, llvm::: pr<double> >: ed long, clan- pr<double> >:</double></double></unsigned>	Directory*) signed long nuclParticl >, bool> st d long, uns mallVector< <u>M fill_ins</u> ::ASTContex reserve(uns) d::_Rb_ igned l clang:: ert(g t_const igned l	Collisi _tree <u _ong) Decl*, _nu_cxx _&, uns _ong)</u 	ionOutput&) unsigned long, 2u>, llvm::C (::normalit signedint,ur	unsigned long, PenseMapInfo <clan rerator<double*, signed long)</double*, </clan 	std::_Id ng::Ident std::vec	entity ifierI	<unsig< td=""><td>gned 1 >:::g1</td><td>long>,</td><td>_std::l</td></unsig<>	gned 1 >:::g1	long>,	_std::l
33 55 60 41 95 87 129 159 183 222 269 273 277	7.25 0.19 0.12 0.08 0.07 0.04 0.03 0.02 0.02 0.02 0.01 0.01	2,686,965,840 70,819,840 45,809,937 30,122,056 26,610,929 13,487,544 12,453,440 8,700,314 6,534,144 5,788,928 4,321,280 4,125,032 4,023,395	50,115 8,645 210 190 16 80,283 311,336 5,834 2,070 1,523 250 4,650	deflateInit2 llvm::raw_ostream::: TBuffer::TBuffer(TBu TKey::TKey(TObject of TStorage::ReAllocCha G4InuclCollider::col std::pair <std::_rb_ llvm::SmallVectorBas llvm::DenseMap<clang std::vector<double, clang::Decl::operato std::vector<double, llvm::BumpPtrAlloca</double, </double, </clang </std::_rb_ 	SetBuffered() uffer::EMode, const*, char (ar(char*, unsi llide(G4Inuclf tree_iterator< se::grow_pod() g::Identifier] std::allocato or_new(unsigne std::allocato torImpl <llvm::< td=""><td>int) const*, int, ' igned long, u Particle*, G4 <unsigned long<br="">void*, unsigned Info*, llvm::: or<double> >: ed long, clane or<double> >: :MallocAlloca</double></double></unsigned></td><td>Directory*) signed long nuclParticl >, bool> st d long, uns mallVector< <u>M fill_ins</u> ::ASTContex reserve(uns</td><td>) d::_Rb_ igned l clang:: ert(g t_const igned l</td><td>Collisi _tree<u _ong) Decl*, _nu_cxx _&, uns _ong)</u </td><td>ionOutput&) unsigned long, 2u>, llvm::C (::normalit signedint,ur</td><td>unsigned long, PenseMapInfo<clan rerator<double*, signed long)</double*, </clan </td><td>std::_Id ng::Ident std::vec</td><td>entity ifierI</td><td><unsig< td=""><td>gned 1 >:::g1</td><td>long>,</td><td>_std::l</td></unsig<></td></llvm::<>	int) const*, int, ' igned long, u Particle*, G4 <unsigned long<br="">void*, unsigned Info*, llvm::: or<double> >: ed long, clane or<double> >: :MallocAlloca</double></double></unsigned>	Directory*) signed long nuclParticl >, bool> st d long, uns mallVector< <u>M fill_ins</u> ::ASTContex reserve(uns) d::_Rb_ igned l clang:: ert(g t_const igned l	Collisi _tree <u _ong) Decl*, _nu_cxx _&, uns _ong)</u 	ionOutput&) unsigned long, 2u>, llvm::C (::normalit signedint,ur	unsigned long, PenseMapInfo <clan rerator<double*, signed long)</double*, </clan 	std::_Id ng::Ident std::vec	entity ifierI	<unsig< td=""><td>gned 1 >:::g1</td><td>long>,</td><td>_std::l</td></unsig<>	gned 1 >:::g1	long>,	_std::l
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Hint from IgProf

• Q4: How to improve performance of this function? Avoid ...

```
MaterialPropertyVector*
MaterialProperty esTable::GetProperty(const char *key)
{
    // Returns a Material Property Vector corresponding to a key
    if (string(key) == "GROUPVEL") return SetGROUPVEL();
    MPTiterator i;
    i = MPT.find(string(key));
    if ( i != MPT.end() ) return i->second;
    return nullptr;
}
```

- 1. String comparison
- 2. String conversion
- 3. String search (find)
- 4. Race condition (map)



Introduction to OpenISpeedshop (OSS)

- Comprehensive performance analysis of sequential, multithreaded, and MPI applications
- Open source (the Krell institute, <u>https://openspeedshop.org</u>) and one of ASCR profiling tools
- The base functionality includes
 - Sampling experiment (light-weighted)
 - Support call stack analysis
 - Hardware performance (PAPI) counters
 - Multi-threaded, MPI profiling and tracing
 - Memory function tracing, I/O profiling and tracing, etc...
- Tested on a variety of Linux clusters and supports parallel hardware architectures (Intel MIC, NVIDIA CUDA) as well as HPC systems (Cray, Blue Gene)

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OSS: Installation and Performance Measurement

• Installation: a typical build (with the version 2.2)

- Running an experiment: unmodified binary instrumentation osspcsamp "IArTest IArBox.gdml profile.pi-5GeV" [frequency]
- Performance analysis: command-line (-cli) or GUI (-f) openss -cli IArTest-pcsamp.openss



Demo: OSS Command-line Analysis (-cli)

> openss –cli	Open the CLI.
openss>> expcreate –f "mutatee 2000" pcsamp	Create an experiment using pcsamp with this application.
openss>> expgo	Run the experiment and create the database
openss>> expview	Display the default view of the performance data.

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	•		
help or help commands	list –v obj		
expview	list –v ranks		
expview -v statements	list –v hosts		
expview -v loops	expview –m <metric></metric>		
expview -v linkedobjects	expview –v calltrees,fullstack		
expview -v calltrees,fullstack	<experiment type=""> <number></number></experiment>		
expview -m loadbalance	expview –v calltrees,fullstack		
	usertime2		
expview –r <rank_num></rank_num>	expview <experiment-name><number></number></experiment-name>		
expcompare –r 1 –r 2 –m time			
	expview pcsamp2		
list –v metrics	expview –v statements		
list –v src	<experiment-name><number></number></experiment-name>		

S.Y. Jun (SCD/PDS) | Profiling Tutorial | LArSoft Workshop 6/20/17 31

OSS (GUI): Default View and Statistical Panel

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Sampling Experiments in OSS

- pcsamp (periodic sampling of program counters)
 - low overhead overview of time distribution
- usertime (call path profiling)
 - inclusive and exclusive timing data
 - call paths, caller and callee relationships
- hwcsamp (periodic sampling hardware counters)
 - profiling of hardware counter events (PAPI events)
- pthreads (POSIX thread tracing)
- mem (memory tracing)
 - call paths of memory related function call events
 - aggregate and individual rank, thread, or processing times

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- io (I/O tracing)
- Many other useful experiments

OSS: Measurement Overheads and Output Size

 pcsamp: exclusive time - insensitive to sampling frequency (default 100Hz)

Frequency	Time(sec)	OverHead(%)	DB size(MB)
base :	52.20	-	
50 Hz:	52.27	0.13	0.376832
100 Hz:	52.62	0.80	0.486400
200 Hz	52.36	0.31	0.607232
500 Hz	52.98	1.49	0.811008
1000 Hz:	52.65	0.86	0.971776
10000 Hz:	52.76	1.07	1.012736

 usertime: inclusive time and call paths – large overhead (default 35): similar overhead for hwcsamp

Freque	ency	Time(sec)	OverHead(%)	DB size(MB)
bas	se :	52.80	-	
35	Hz:	53.89	2.06	1.087488
50	Hz:	54.33	2.90	1.430528
100	Hz:	56.21	6.46	2.355200
200	Hz	60.25	14.11	4.208640
1000	Hz:	92.84	75.83	18.725888

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Preliminary Performance Experiments with LArTest

- LArTest configuration
 - Beam: 5 GeV pi-
 - Step limit: 0.01 cm
 - Physics list: FTFP_BERT (uses standard EM)
 - 1000 events
- osspcsamp (100 Hz)
 - I/O (digitization) ON
 - Analysis ON
- ossusertime and osshwcsamp (35 Hz)
 - I/O (digitization) OFF
 - Analysis OFF



osspcsamp : Functions

• Exclusive CPU time - an overall performance view

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	-115.790000	5.793237	deflate_fast(internal_state*, int) (libG4zlib.so: deflate.cc,1572)
	-107.070000	5.356955	G4UniversalFluctuation::SampleFluctuations(G4MaterialCutsCouple const*, G4DynamicParti
	-104.000000	5.203356	longest_match(internal_state*, unsigned int) (libG4zlib.so: deflate.cc,1102)
	-89.730000	4.489396	TBranch::Fill() (libTree.so: TBranch.cxx,716)
	-69.050000	3.454728	compress_block(internal_state*, ct_data_s const*, ct_data_s const*) (libG4zlib.so: trees.cc,10
	-58.390000	2.921384	fill_window(internal_state*) (libG4zlib.so: deflate.cc,1337)
	-52.180000	2.610684	std::string::compare(char const*) const (libstdc++.so.6: basic_string.tcc,948)
	-51.060000	2.554648	_GI_memcmp (libc-2.12.so)
	-50.690000	2.536136	G4PhysicsVector::Value(double, unsigned long&) const (libG4global.so: G4PhysicsVector.cc,4
	-46.790000	2.341010	G4UrbanMscModel::SampleCosineTheta(double, double) (libG4processes.so: G4UrbanMscM
	-38.340000	1.918237	TrackerSD::ProcessHits(G4Step*, G4TouchableHistory) (liblAr.so: TrackerSD.cc,56)
	-36.200000	1.811168	TBranch::FillLeavesImpl(TBuffer&) (libTree.so: TBranch.cxx,1854)
	-35.170000	1.759635	TTree::Fill() (libTree.so: TTree.cxx,4079)
	-34.250000	1.713605	TBufferFile::WriteFastArray(double const*, int) (libRIO.so: TBufferFile.cxx,2095)
	-33.080000	1.655068	_strlen_sse2 (libc-2.12.so)
	-32.650000	1.633554	CLHEP::RanecuEngine::flat() (libG4clhep.so: RanecuEngine.cc,197)
	-30.250000	1.513476	G4VEnergyLossProcess::PostStepGetPhysicalInteractionLength(G4Track const&, double, G4F
	-29.970000	1.499467	$G4SteppingManager:: DefinePhysicalStepLength()\ (libG4tracking.so:\ G4SteppingManager2.cc,$
	-28.540000	1.427921	G4SteppingManager::InvokePSDIP(unsigned long) (libG4tracking.so: G4SteppingManager2.cc
	-27.750000	1.388396	CLHEP::RanecuEngine::flatArray(int, double*) (libG4clhep.so: RanecuEngine.cc,220)
	23 990000	1 200274	TLeafD:FillRasket(TRuffer&) (libTree so: TLeafD cxx 78)
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Fermilab

osspcsamp: Statements (Line Numbers)

- Select statement level granularity
- List line numbers in program that took most of time

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	-31.210000	1.741902	deflate.cc(1601)		
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	-24.740000	1.380796	TBranch.cxx(742)		
	-23.290000	1.299868	deflate.cc(1595)		
	-19.310000	1.077735	TBufferFile.cxx(2101)		
	-19.080000	1.064899	TBranch.cxx(1859)		
	-18.590000	1.037551	deflate.cc(1236)		
	-17.520000	0.977831	deflate.cc(1649)		
	-17.080000	0.953274	deflate.cc(1195)		
	-16.270000	0.908066	TObjArray.h(91)		
	-15.620000	0.871788	TLeaf.cxx(276)		
	-14.100000	0.786953	char_traits.h(263)		
	-14.010000	0.781930	G4UniversalFluctuation.cc(317)		
	-13.400000	0.747885	deflate.cc(1381)		
	-13.170000	0.735048	basic_string.tcc(956)		
	-13.150000	0.733932	basic_string.tcc(959)		
	-12.830000	0.716072	deflate.cc(1388)		
	-12.530000	0.699328	deflate.cc(1389)		
	-12.330000	0.688166	TrackerSD.cc(87)		
	-11.670000	0.651329	deflate.cc(1380)		
	-10.940000	0.610586	deflate.cc(1240)		
	10.870000	0.606680	adler32.cc(106)		
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osspcsamp: Linked Objects

• The library in which the associated function is located (aggregated by shared objects)

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-147.650000	7.387265	libc-2.12.so	
-104.650000	5.235877	libG4tracking.so	
-88.490000	4.427356	libG4clhep.so	
- 83.840000	4.194706	libG4track.so	
-74.360000	3.720400	libstdc++.so.6	
-71.790000	3.591817	libG4geometry.so	
66.000000	3.302130	libRIO.so	
-50.950000	2.549144	libG4global.so	
-48.790000	2.441074	liblAr.so	
-46.120000	2.307488	libG4materials.so	
-35.890000	1.795658	libm-2.12.so	
-20.420000	1.021659	libG4digits_hits.so	
-17.720000	0.886572	libG4particles.so	
-11.800000	0.590381	libCore.so	
-6.810000	0.340720	libG4event.so	
-5.820000	0.291188	libpthread-2.12.so	
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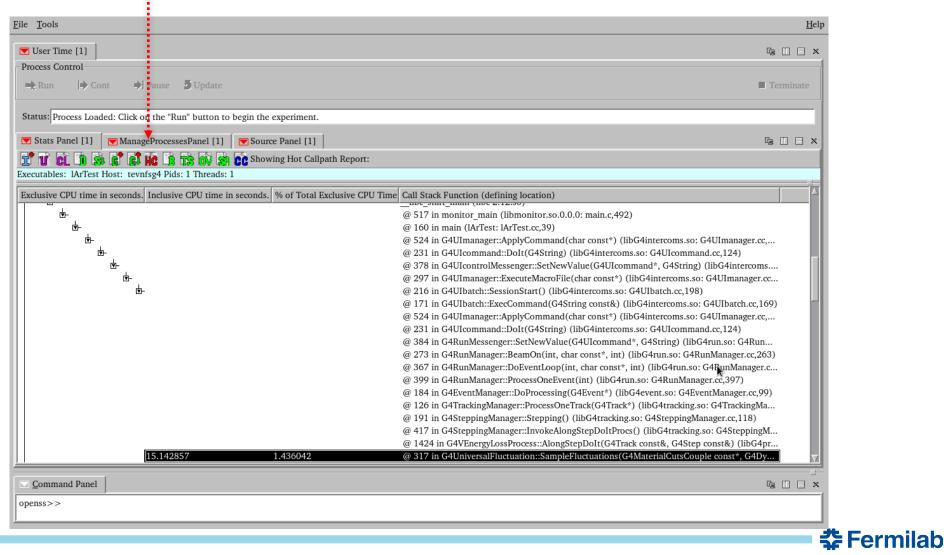
ossusertime: Call Path (Functions)

- Function calls observed anywhere in the stack
- The inclusive time taken by the function and all its callees

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-51.542856 51.542856 4.887962 G4PhysicsVector::Value(double, unsigned long&) const (libG4glob)
-46.428570 62.942856 4.402959 G4UrbanMscModel::SampleCosineTheta(double, double) (libG4pro
- 30.142857 316.314279 2.85836 G4SteppingManager::DefinePhysicalStepLength() (libG4tracking.so
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-26.514285 316.999994 2.514428 G4SteppingManager::InvokePSDIP(unsigned long) (libG4tracking.s
-24.685714 24.685714 2.341019 _GI_memcmp (libc-2.12.so)
-20.685714 35.428571 1.961687 G4Navigator::ComputeStep(CLHEP::Hep3Vector const&, CLHEP::H
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-13.257143 26.799999 1.257214 _libc_malloc (libc-2.12.so)
nd Panel

ossusertime: Hot Call Path

- Relationship between caller and callee
- The paths through the application that take the most time



ossusertime: Hot Call (Source)

 Exclusive time on highlighted lines that indicate relatively high CPU times

Process Control		
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	304 }	A
0.057143	305 $306 G4double w2 = alfa*e0;$	
0.485714	307 G4double w = (tmax-w2)/tmax;	
	$\begin{array}{llllllllllllllllllllllllllllllllllll$	
0.742857	310 if(nb > 0) {	
0.171429	311 if(nb > sizearray) { 312 sizearray = nb;	
	313 delete [] rndmarray;	
	314 rndmarray = new G4double[nb]; 315 }	
0.514286	316 rndmEngineF->flatArray(nb, rndmarray);	
>> 15.142857	317 for (G4int k=0; k <nb; +="w2/(1w*rndmarray[k]);" ++k)="" loss="" th="" {="" }<=""> 318 }</nb;>	
	319 }	
0.742857	320 if(emean > 0.0) { SampleGauss(rndmEngineF, emean, sig2e, loss); } 321 }	
0.657143	322 losstot + = loss;	
	323 } 324 //G4cout << "Vavilov: " << losstot << " Nstep= " << nstep << G4endl;	
	325	
0.485714	326 return losstot;	V
1		
Command Panel		⊊ 🛛 🗆 ×
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Experiments with Hardware Counters

- Periodic sampling of hardware counters (hwcsamp)
- Supports both derived and non-derived PAPI presets
- Metrics for instructions, FLOPS, memory and resource patterns

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HWCSamp Parrocess Control		Update	PA	۹ PI h۱	NC	te ⊡ × ■ Terminate	
atus: Process L	oaded: Click on the "Run" l	button to begin the exi	periment				
Stats Panel [1]		anel [1]				Image: Statements ✓ Linked Objects	
	e) Host: tevnfsg4 Pids: 1					v Functions v Statements v Linked Objects	
	Exclusive CPU time in se	conds. % of CPU Time	e papi tot cyc	papi_tot_ins	papi_fp_ops	Function (defining location)	
	-103.844443	9.880537	238072285947			G4UniversalFluctuation::SampleFluctuations(G4MaterialCutsCoup	
	-55.111111	5.243683	126318620429	102749596516		G4PhysicsVector::Value(double, unsigned long&) const (libG4glol	
	-46.555555	4.429644	106775342756	86543030788	7919089722	G4UrbanMscModel::SampleCosineTheta(double, double) (libG4p	
	-31.444444	2.991860	72048169097	58654838134	5042279306	G4SteppingManager::DefinePhysicalStepLength() (libG4tracking.s	
	-28.955555	2.755048	66430726872	54158585775	4639678425	G4VEnergyLossProcess::PostStepGetPhysicalInteractionLength(G4	
	-28.488889	2.710646	65348816099	53202548312	4609499319	CLHEP::RanecuEngine::flat() (libG4clhep.so: RanecuEngine.cc,197	
	-27.955555	2.659901	64028514071	52208146862	4480292193	CLHEP::RanecuEngine::flatArray(int, double*) (libG4clhep.so: Rar	
	-26.622222	2.533037	61110837179	49772120291	4327842442	G4SteppingManager::InvokePSDIP(unsigned long) (libG4tracking.	
	-24.44444	2.325827	56020565509	45584419721	3972397216	GI_memcmp (libc-2.12.so)	
	-19.733333	1.877577	45257897510	36798636053	3148575513	ieee754_log (libm-2.12.so)	
	-19.355555	1.841632	44392061033	36175379636	3100280785	G4Navigator::ComputeStep(CLHEP::Hep3Vector const&, CLHEP::H	
	-16.400000	1.560419	37599864927	30652840846	2624429457	G4ParticleChange::CheckIt(G4Track const&) (libG4track.so: G4Pa	
	-15.644444	1.488529	35836916031	29148246541	2526679670	strlen_sse2 (libc-2.12.so)	
	-15.466667	1.471614	35422081311	28829396851	2495986647	G4SteppingManager::Stepping() (libG4tracking.so: G4SteppingMa	
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Code Performance by Hardware Counter Metrics

• Derivatives: examples

Hardware Counter Metrics Derivatives	Performance
IPC (Instruction/Cycle)	Large values suggest good balance with minimal stalls.
FPC (FLOPS/Cycle)	Large values for floating point intensive code suggests efficient CPU utilization
FMO (FLOPS/Memory Ops)	Good data locality, Computational Intensity
LPC (Loads/Cycle)	Useful for calculating FMO, may indicate good stride through arrays.
SPC (Stores/Cycle)	Useful for calculating FMO, may indicate good stride through arrays.

LArTest (Overall): 5 GeV pi- (Intel Xeon X5650@2.67GHz)

5 Fermilab

- IPC = 0.79 (relatively small)
- FMO = 0.32

Other useful OSS Features

- Flexible analysis options (GUI, command line, online)
- Export report data in different formats (text, cvs, chart)
- Multi-threading capability
- Compare two experiments (osscompare): examples
 - two releases
 - two experiments with the different numbers of threads
- Call path analysis based on DB
- Experiments for parallel code (MPI tracing)



Demo: Example of Performance Profiling Report

- Monitor Geant4 part of performance changes for LAr-based detectors by
 - Beam energy/Particle type/Physics list
 - Geant4 (reference) release

https://g4cpt.fnal.gov/g4p/oss_10.3.r04_IArTest_01/index_sprof.html https://g4cpt.fnal.gov/g4p/oss_10.3.r04_IArTest_01/index_igprof.html

OpenISpeedshop

Geant4.10.3.r04 IArTest

Sample	Physics List	B-Field	Energy
e-	FTFP_BERT	OFF (0 T)	<u>1 GeV_5 GeV</u>
e+	FTFP_BERT	OFF (0 T)	<u>1 GeV 5 GeV</u>
mu-	FTFP_BERT	OFF (0 T)	<u>1 GeV 5 GeV</u>
mu+	FTFP_BERT	OFF (0 T)	<u>1 GeV 5 GeV</u>
pi-	FTFP_BERT	OFF (0 T)	<u>1 GeV 5 GeV</u>
pi+	FTFP_BERT	OFF (0 T)	<u>1 GeV 5 GeV</u>
K-	FTFP_BERT	OFF (0 T)	<u>1 GeV 5 GeV</u>
K+	FTFP_BERT	OFF (0 T)	<u>1 GeV 5 GeV</u>
р	FTFP_BERT	OFF (0 T)	<u>1 GeV 5 GeV</u>

Memory Profiler/IgProf

Memory profiling reports

- MEM_LIVE: memory that has not been freed snapshot of the heap, i.e. a heap profile.
- MEM_MAX: the largest single allocation by any function
- MEM_TOTAL: the total amount of memory allocated by any function a snapshot of poor memory locality
- N: memory snapshot at the end of N-th event
- Diff(N-M): memory difference between N-th and M-th event direct memory leakage
- End of Run: memory snapshot at the End of Run

Geant4.10.3.r04 IArTest B=4.0T

Sample	Physics List	Energy	MEM_LIVE	MEM_MAX	MEM_TOTAL	
e-	FTFP BERT	1 GeV	<u>1</u> <u>Diff(1001-1)</u> <u>1001</u> <u>End of Run</u>	<u>1</u> <u>Diff(1001-1)</u> <u>1001</u> <u>End of Run</u>	<u>1</u> <u>Diff(1001-1)</u> <u>1001</u> <u>End of Run</u>	
6-	FIFF_DENI	5 GeV	<u>1</u> <u>Diff(1001-1)</u> <u>1001</u> <u>End of Run</u>	<u>1</u> <u>Diff(1001-1)</u> <u>1001</u> <u>End of Run</u>	<u>1</u> <u>Diff(1001-1)</u> <u>1001</u> <u>End of Run</u>	
e+	FTFP_BERT	FTFP_BERT	1 GeV	<u>1</u> <u>Diff(1001-1)</u> <u>1001</u> <u>End of Run</u>	<u>1</u> <u>Diff(1001-1)</u> <u>1001</u> <u>End of Run</u>	<u>1</u> <u>Diff(1001-1)</u> <u>1001</u> <u>End of Run</u>
64			5 GeV	<u>1</u> <u>Diff(1001-1)</u> <u>1001</u> <u>End of Run</u>	<u>1</u> <u>Diff(1001-1)</u> <u>1001</u> <u>End of Run</u>	<u>1</u> <u>Diff(1001-1)</u> <u>1001</u> <u>End of Run</u>
mu-	J- FTFP_BERT		1 GeV	<u>1</u> <u>Diff(1001-1)</u> <u>1001</u> <u>End of Run</u>	<u>1</u> <u>Diff(1001-1)</u> <u>1001</u> <u>End of Run</u>	<u>1</u> <u>Diff(1001-1)</u> <u>1001</u> <u>End of Run</u>
mu-		5 GeV	<u>1</u> <u>Diff(1001-1)</u> <u>1001</u> <u>End of Run</u>	<u>1</u> Diff(1001-1) 1001 End of Run	<u>1 Diff(1001-1)</u> <u>1001 End of Run</u>	

Summary

- Performance profiling and analysis is an essential part of the software development cycle
 - Modern hardware architectures are demanding (parallelism)
 - HEP applications are big and complex
 - Profilers will helps to identify critical parts of code, monitor changes of performance and provide opportunities of optimization
- Where you can start:
 - Try profiling your programs with basic tools
 - IgProf: http://igprof.org/index.html
 - OpenISpeedshop: https://openspeedshop.org/
 - HPCToolkits: http://hpctoolkit.org/index.html
 - TAU: <u>http://www.cs.uoregon.edu/research/tau/home.php</u>
- Above tools are quite suitable for continuous integration tests

Acronym

- CISC: Complicated instruction set computer)
- RISC: Reduced instruction set computer)
- ARM: Advanced RISC Machines
- CPI: Cycles per instruction
- IPC: Instructions per cycle
- MIPS: Million instructions per second
- FMO: Floating point operations per memory operation
- DRAM: Dynamic random-access memory
- ASCR: Advanced Scientific Computing Research
- MuMMI: Multiple Metrics Modeling Infrastructure



Answer sheet

- Q1:
- Q2:
- Q3:
- Q4:

