NUMA characterization on Xeon® Processors using the Intel® VTune™ Profiler

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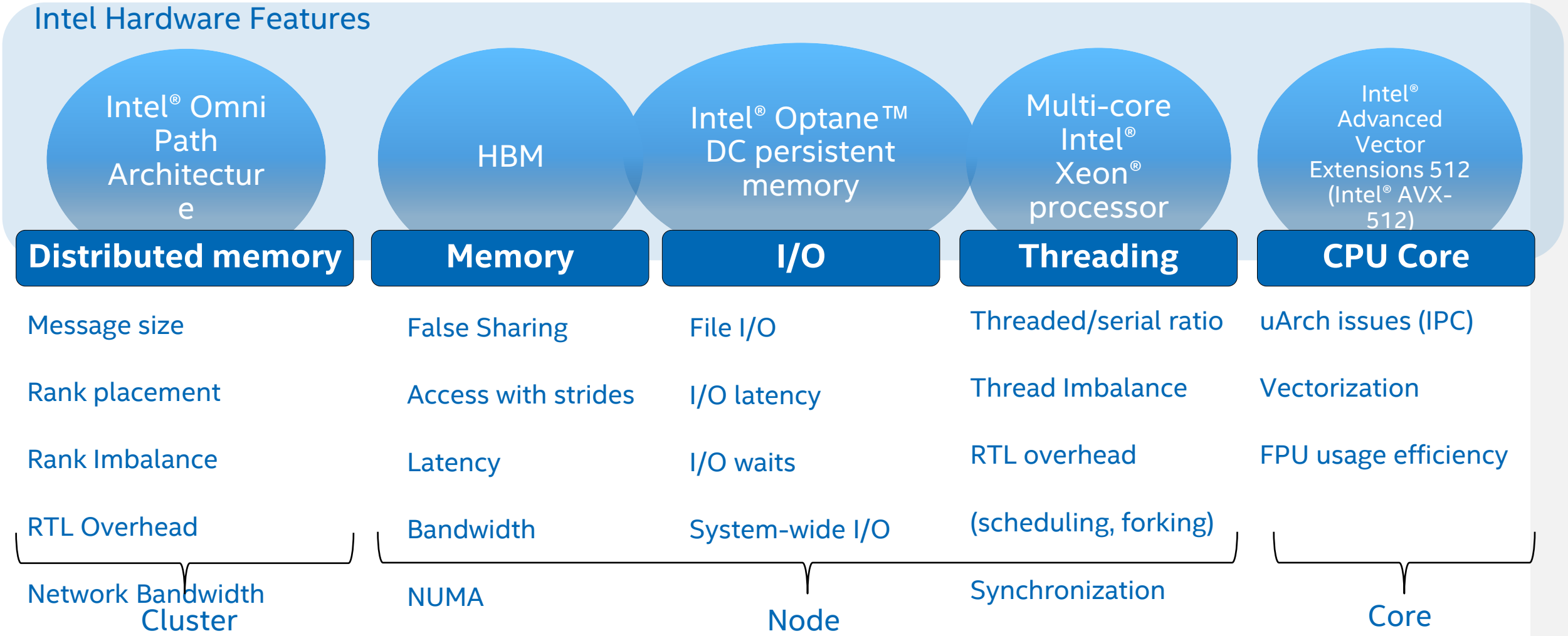
Agenda

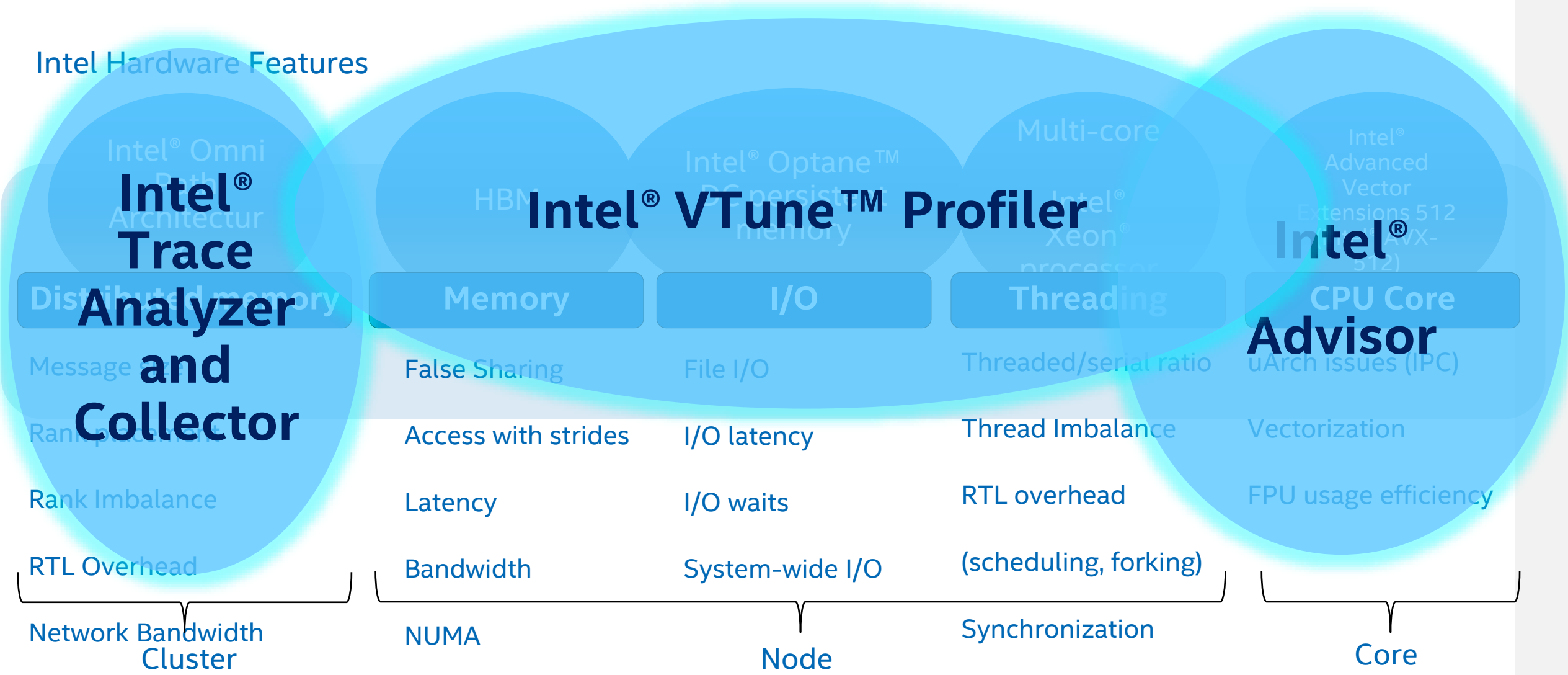
1. Introduction to the Intel® VTune Profiler
2. Hands-On
   1. The Stream Benchmark
   2. Compilation
   3. A modified version of Stream?
   4. Running Stream / vs Mod
   5. Collecting Hotspots with and w/o EBS
   6. HPC Perf
   7. Memory Analysis

Introduction to the Intel® VTune Profiler

ASPECTS OF HPC/THROUGHPUT APPLICATION PERFORMANCE



INTEL PARALLEL STUDIO TOOLS COVERING THE ASPECTS



THE LONG & SHORT OF PERFORMANCE ANALYSIS

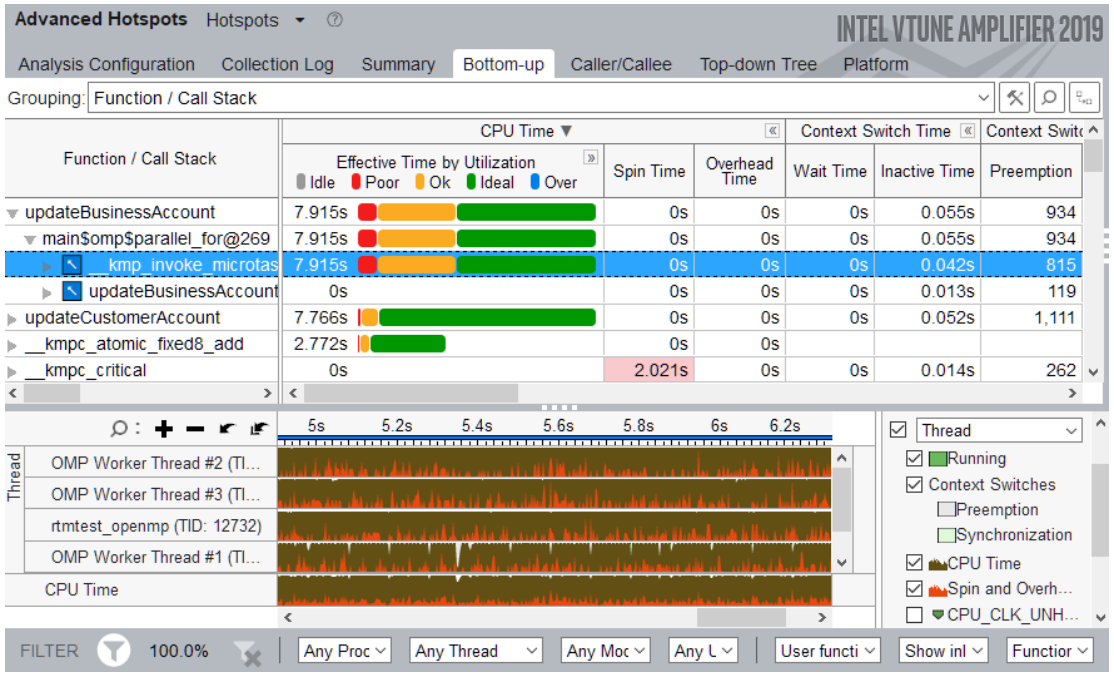
Get the big picture first with a Snapshot or Platform Profiler

	Snapshot Quickly size potential performance gain. Run a test "during a coffee break".	**In-Depth** Advanced collection & analysis. Insight for effective optimization.
Application Focus • HPC App developer focus • 1 app running during test	**Intel® VTune™ Amplifier** **Application Performance Snapshot** L🕑	**Intel® VTune™ Amplifier** • Many profiles S-M🕑 **Intel® Advisor** • Vectorization S🕑 **Intel® Trace Analyzer and Collector** S-L🕑 • MPI Optimization
System Focus • Deployed system focus • Full system load test	**Intel® VTune™ Amplifier's** **Storage Performance Snapshot** L🕑	**Intel® VTune™ Amplifier** **- System-wide sampling** **- Platform Profiler** S-M🕑 L🕑

Maximum collection times: L🕑=long (hours) M🕑=medium (minutes) S🕑=short (seconds-few minutes)

Analyze & Tune Application Performance

Intel® VTune™ Amplifier—Performance Profiler



Learn More: software.intel.com/intel-vtune-amplifier-xe

- Save Time Optimizing Code
- Accurately profile C, C++, Fortran*, Python*, Go*, Java*, or any mix
- Optimize CPU, threading, memory, cache, storage & more
- Save time: rich analysis leads to insight
- Take advantage of Priority Support
  - Connects customers to Intel engineers for confidential inquiries (paid versions)
- What's New in 2019 Release (partial list)
- New Platform Profiler! - Longer Data Collection
- A more accessible user interface provides a simplified profiling workflow
- Smarter, faster Application Performance Snapshot: Analyze CPU utilization of physical cores, pause/resume, more... (Linux*)
- Improved JIT profiling for server-side/cloud applications

Two Great Ways to Collect Data

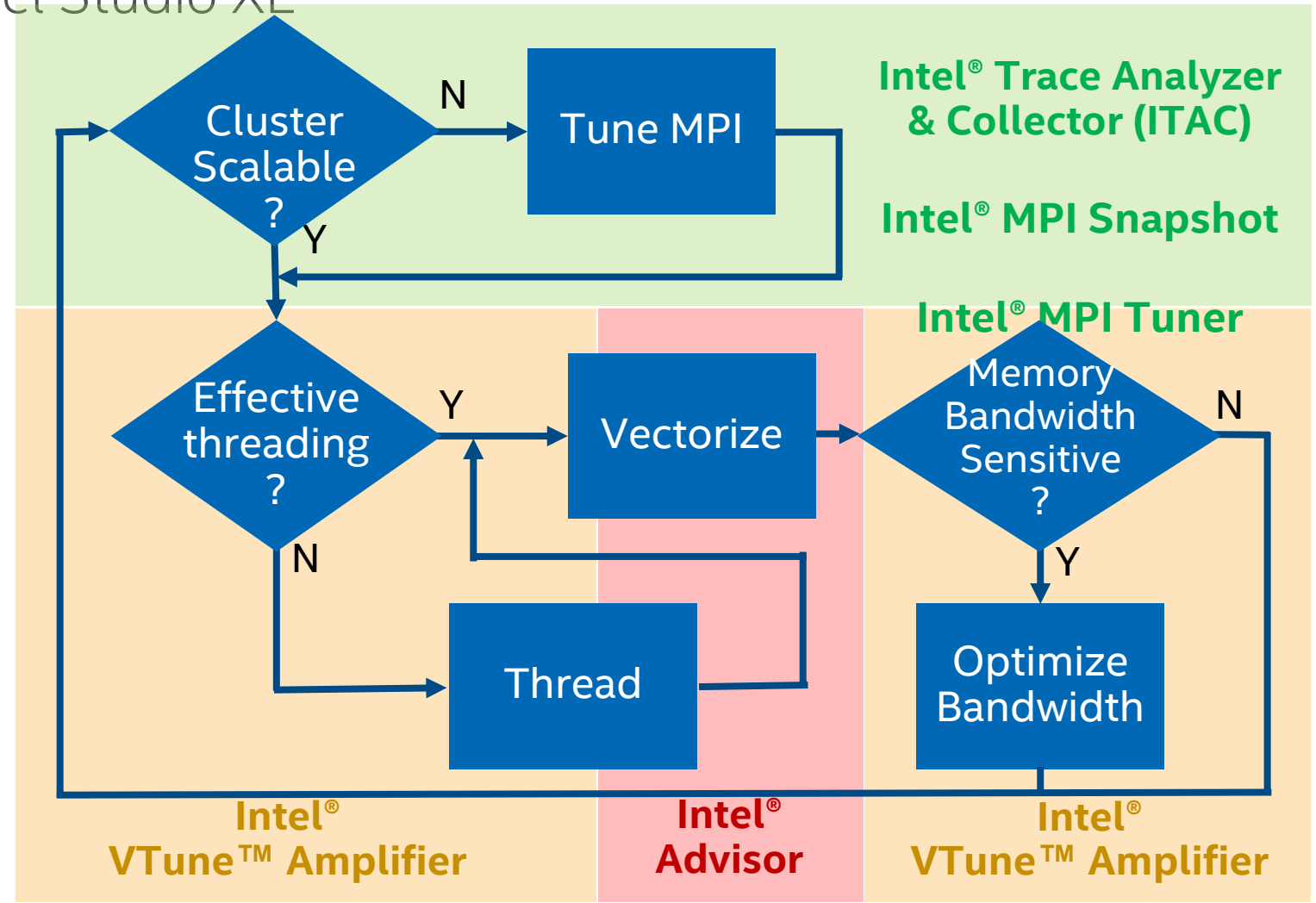
Intel® VTune™ Amplifier

Software Collector	Hardware Collector
Uses OS interrupts	Uses the on chip Performance Monitoring Unit (PMU)
Collects from a single process tree	Collect system wide or from a single process tree.
~5ms default resolution	~1ms default resolution (finer granularity - finds small functions)
Either an Intel® or a compatible processor	Requires a genuine Intel® processor for collection
Call stacks show calling sequence	Optionally collect call stacks
Works in virtual environments	Works in a VM only when supported by the VM (e.g., vSphere*, KVM)
No driver required	Uses Intel driver or perf if driver not installed

No special recompiles – C, C++, C#, Fortran, Java, Python, Assembly

Performance Analysis Tools for Diagnosis

Intel® Parallel Studio XE



The Stream Benchmark

The Stream Benchmark – John D. McCalpin (TACC)

Arithmetic intensity (>9 for peak DP DRAM)

```
#pragma omp parallel for
        for (j=0; j<STREAM_ARRAY_SIZE; j++)
            c[j] = a[j];
```

Copy

0 Flop / 2 * 8 Bytes = 0

```
#pragma omp parallel for
        for (j=0; j<STREAM_ARRAY_SIZE; j++)
            b[j] = scalar*c[j];
```

Scale

1 Flop / 3 * 8 Bytes = 0.042

```
#pragma omp parallel for
        for (j=0; j<STREAM_ARRAY_SIZE; j++)
            c[j] = a[j]+b[j];
```

Add

1 Flop / 3 * 8 Bytes = 0.042

```
#pragma omp parallel for
        for (j=0; j<STREAM_ARRAY_SIZE; j++)
            a[j] = b[j]+scalar*c[j];
```

Triad

2 Flop / 4 * 8 Bytes = 0.0625

Note that Stream is reporting the best Bandwidth rate out of 10 iterations per default

Performance Note

- Xeon Scalable 2nd Generation 8260

  Name: Intel(R) Xeon(R) Processor code named Cascadelake

  Frequency: 2.4 GHz

  Logical CPU Count: 96

  Max DRAM Single-Package Bandwidth: 128.0 GB/s

Performance figures are reported OOB without further optimizations like hugepages

We modified Stream

```
$ diff ./stream.c ./stream_mod.c | wc -l
4

$ icc -qopenmp -DSTREAM_ARRAY_SIZE=1000000000 -mcmodel
large ../stream.c -O2 -g -xHost -o stream.x

$ icc -qopenmp -DSTREAM_ARRAY_SIZE=1000000000 -mcmodel
large ../stream_mod.c      -O2 -g -xHost -o stream_mod.x

$ export OMP_PLACES=threads
```

STREAM Baseline vs Modified

stream.x

```
-------------------------------------------------------------
STREAM version $Revision: 5.10 $
-------------------------------------------------------------
This system uses 8 bytes per array element.
-------------------------------------------------------------
Array size = 1000000000 (elements), Offset = 0 (elements)
Memory per array = 7629.4 MiB (= 7.5 GiB).
Total memory required = 22888.2 MiB (= 22.4 GiB).
Each kernel will be executed 10 times.
 The *best* time for each kernel (excluding the first iteration)
 will be used to compute the reported bandwidth.
-------------------------------------------------------------
Number of Threads requested = 96
Number of Threads counted = 96
-------------------------------------------------------------
Your clock granularity/precision appears to be 1 microseconds.
Each test below will take on the order of 80675 microseconds.
   (= 80675 clock ticks)
Increase the size of the arrays if this shows that
you are not getting at least 20 clock ticks per test.
-------------------------------------------------------------
WARNING -- The above is only a rough guideline.
For best results, please be sure you know the
precision of your system timer.
-------------------------------------------------------------
Function    Best Rate MB/s  Avg time     Min time     Max time
Copy:          179386.1     0.089317     0.089193     0.089479
Scale:         187742.8     0.085394     0.085223     0.085636
Add:           201301.6     0.119386     0.119224     0.119830
Triad:         200889.1     0.119528     0.119469     0.119599
-------------------------------------------------------------
Solution Validates: avg error less than 1.000000e-13 on all three
arrays
-------------------------------------------------------------
```

stream_mod.x

```
-------------------------------------------------------------
STREAM version $Revision: 5.10 $
-------------------------------------------------------------
This system uses 8 bytes per array element.
-------------------------------------------------------------
Array size = 1000000000 (elements), Offset = 0 (elements)
Memory per array = 7629.4 MiB (= 7.5 GiB).
Total memory required = 22888.2 MiB (= 22.4 GiB).
Each kernel will be executed 10 times.
 The *best* time for each kernel (excluding the first iteration)
 will be used to compute the reported bandwidth.
-------------------------------------------------------------
Number of Threads requested = 96
Number of Threads counted = 96
-------------------------------------------------------------
Your clock granularity/precision appears to be 1 microseconds.
Each test below will take on the order of 223591 microseconds.
   (= 223591 clock ticks)
Increase the size of the arrays if this shows that
you are not getting at least 20 clock ticks per test.
-------------------------------------------------------------
WARNING -- The above is only a rough guideline.
For best results, please be sure you know the
precision of your system timer.
-------------------------------------------------------------
Function    Best Rate MB/s  Avg time     Min time     Max time
Copy:           95325.4     0.205046     0.167846     0.230016
Scale:          84390.4     0.214661     0.189595     0.275163
Add:           107456.1     0.263129     0.223347     0.317161
Triad:         100594.8     0.289895     0.238581     0.347999
-------------------------------------------------------------
Solution Validates: avg error less than 1.000000e-13 on all three
arrays
-------------------------------------------------------------
```

Problem Investigation

What causes the memory bandwidth drop?

Hands-On

1. $ cp -r /lrz/sys/courses/hcow1w21/vtune_labs . && cd vtune_labs
2. Don’t compile ☺
3. Study run.sh – don’t just run it, instead study vtune --help
4. Allocate a node (e.g. salloc -N 1 --exclusive -t 1:00:00)
5. Run steam and stream_mod in order to see the performance difference
6. Follow the analysis types discussed by the trainer – don’t jump ahead in the slides – generate results (./run.sh)
7. Open the VTune-backend web-server on your allocated node (use an ssh tunnel:

   $ssh lxlogin3.lrz.de –L local_port:compute_node:remote_port

Collecting Hotspots

$ vtune -c hotspots -r r_hs_mod -- ./stream_mod.x

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r_hs_mod

Hotspots | Hotspots by CPU Utilization

INTEL VTUNE AMPLIFIER 2019

Analysis Configuration | Collection Log | Summary | Bottom-up | Caller/Callee | Top-down Tree | Platform

Elapsed Time: 22.803s

CPU Time:	1116.020s
Effective Time:	979.859s
Spin Time:	136.098s
Imbalance or Serial Spinning:	123.784s
Lock Contention:	0s
Other:	12.314s
Overhead Time:	0.063s
Total Thread Count:	96
Paused Time:	0s

Hotspots Insights

If you see significant hotspots in the Top Hotspots list, switch to the Bottom-up view for in-depth analysis per function. Otherwise, use the Caller/Callee view to track critical paths for these hotspots.

Explore Additional Insights

Parallelism : 44.8%

Use Threading to explore more opportunities to increase parallelism in your application.

Microarchitecture Usage : 6.1%

Use Microarchitecture Exploration to explore how efficiently your application runs on the used hardware.

INSIGHTS

Top Hotspots

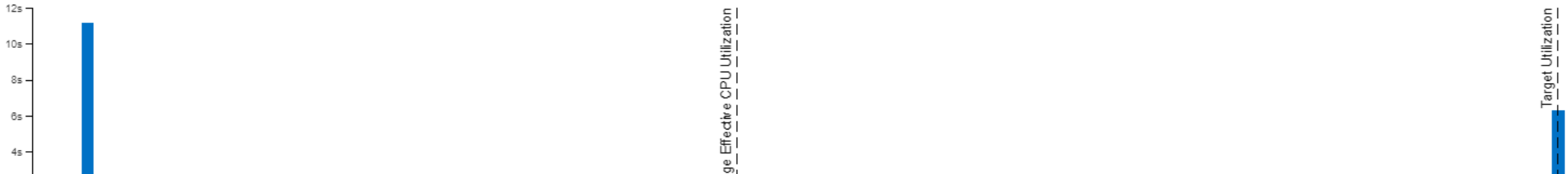
This section lists the most active functions in your application. Optimizing these hotspot functions typically results in improving overall application performance.

Function	Module	CPU Time
mainompparallel_for@343	stream_mod.x	273.620s
mainompparallel_for@333	stream_mod.x	257.123s
__intel_avx_rep_memcpy	libintlc.so.5	210.412s
mainompparallel_for@323	stream_mod.x	206.630s
__kmp_fork_barrier	libiomp5.so	132.014s
[Others]		36.221s

*N/A is applied to non-summable metrics.

Effective CPU Utilization Histogram

This histogram displays a percentage of the wall time the specific number of CPUs were running simultaneously. Spin and Overhead time adds to the Idle CPU utilization value.



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r_hs_mod

Hotspots Hotspots by CPU Utilization

INTEL VTUNE AMPLIFIER 2019

Analysis Configuration | Collection Log | Summary | Bottom-up | Caller/Callee | Top-down Tree | Platform

Grouping: Function / Call Stack

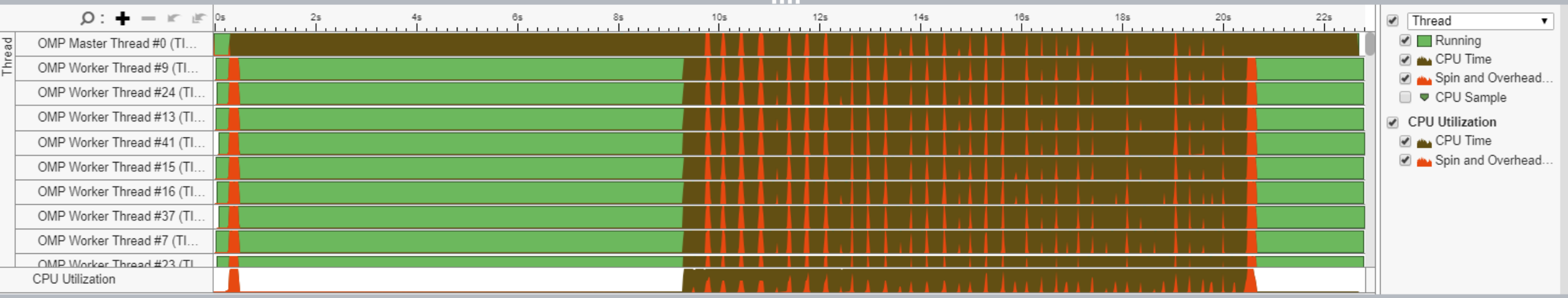
Function / Call Stack	CPU Time: Effective Time	CPU Time: Spin Time	CPU Time: Overhead Time	Module	Function (Full)	Source File	Start
mainompparallel_for@343	273.620s	0s	0s	stream_mod.x	mainompparallel...	stream_mod.c	0x401
mainompparallel_for@333	257.123s	0s	0s	stream_mod.x	mainompparallel...	stream_mod.c	0x401
__intel_avx_rep_memcpy	210.412s	0s	0s	libintlc.so.5	__intel_avx_rep_m...		0x465
mainompparallel_for@323	206.630s	0s	0s	stream_mod.x	mainompparallel...	stream_mod.c	0x401
mainompparallel_for@286	20.914s	0s	0s	stream_mod.x	mainompparallel...	stream_mod.c	0x402
main	8.940s	0s	0s	stream_mod.x	main	stream_mod.c	0x400
checkSTREAMresults	2.200s	0s	0s	stream_mod.x	checkSTREAMresults	stream_mod.c	0x402
[Outside any known module]	0.010s	0s	0s		[Outside any known...		0
[Import thunk sched_yield]	0.010s	0s	0s	libiomp5.so	[Import thunk sched...		0x281
__kmp_get_global_thread_id_reg	0s	0s	0.020s	libiomp5.so	__kmp_get_global_...	kmp_runtime.cpp	0xa96
__kmp_join_call	0s	1.286s	0s	libiomp5.so	__kmp_join_call	kmp_runtime.cpp	0xb2c
__kmp_join_barrier	0s	2.798s	0s	libiomp5.so	__kmp_join_barrier(...	kmp_barrier.cpp	0x6b4
__kmp_fork_barrier	0s	132.014s	0s	libiomp5.so	__kmp_fork_barrier...	kmp_barrier.cpp	0x6c1
__kmp_finish_implicit_task	0s	0s	0.023s	libiomp5.so	__kmp_finish_impli...	kmp_tasking.cpp	0xd97
_INTERNAL_25_____src_kmp_runtime_cpp_16bf24c5::__k	0s	0s	0.020s	libiomp5.so	_INTERNAL_25___...	kmp_itt.inl	0xadf

CPU Time

Viewing 1 of 1 selected stack(s)

100.0% (273.620s of 273.620s)

stream_mod.x!mainompparallel_for@343 - stream_mod.c
libiomp5.so![OpenMP dispatcher]+0x125 - kmp_runtime.cpp:7540
libiomp5.so!__kmp_fork_call+0x16a8 - kmp_runtime.cpp:2494
libiomp5.so![OpenMP fork]+0x17f - kmp_csupport.cpp:365
stream_mod.x!main+0xd74 - stream_mod.c:343
libc.so.6!__libc_start_main+0xf4 - [unknown source file]
stream_mod.x!_start+0x28 - [unknown source file]



Thread
Running
CPU Time
Spin and Overhead...
CPU Sample
CPU Utilization
CPU Time
Spin and Overhead...

FILTER 100.0% | Process: Any Process | Thread: Any Thread | Module: Any Module | Any Utilization | Call Stack Mode: User function | Loop Mode: Functions on | Inline Mode: Show inline fu

Intel VTune Amplifier

r_hs_mod

Hotspots Hotspots by CPU Utilization

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mainompparallel_for@	257.123s	0s	0s	stream_mod.x	mainompparallel...	stream_mod.c	0x401
__intel_avx_rep_memcp	210.412s	0s	0s	libintlc.so.5	__intel_avx_rep_m...		0x465
mainompparallel_for@	206.630s	0s	0s	stream_mod.x	mainompparallel...	stream_mod.c	0x401
mainompparallel_for@	20.914s	0s	0s	stream_mod.x	mainompparallel...	stream_mod.c	0x402
main	8.940s	0s	0s	stream_mod.x	main	stream_mod.c	0x400
checkSTREAMresults	2.200s	0s	0s	stream_mod.x	checkSTREAMresults	stream_mod.c	0x402
[Outside any known mod	0.010s	0s	0s		[Outside any known...		0
[Import thunk sched_yiel	0.010s	0s	0s	libiomp5.so	[Import thunk sched...		0x281
__kmp_get_global_threa	0s	0s	0.020s	libiomp5.so	__kmp_get_global_...	kmp_runtime.cpp	0xa96
__kmp_join_call	0s	1.286s	0s	libiomp5.so	__kmp_join_call	kmp_runtime.cpp	0xb2c
__kmp_join_barrier	0s	2.798s	0s	libiomp5.so	__kmp_join_barrier(...	kmp_barrier.cpp	0x6b4
__kmp_fork_barrier	0s	132.014s	0s	libiomp5.so	__kmp_fork_barrier...	kmp_barrier.cpp	0x6c1
__kmp_finish_implicit_ta	0s	0s	0.023s	libiomp5.so	__kmp_finish_impli...	kmp_tasking.cpp	0xd97
_INTERNAL_25_____	0s	0s	0.020s	libiomp5.so	_INTERNAL_25___...	kmp_itt.inl	0xadf

CPU Time

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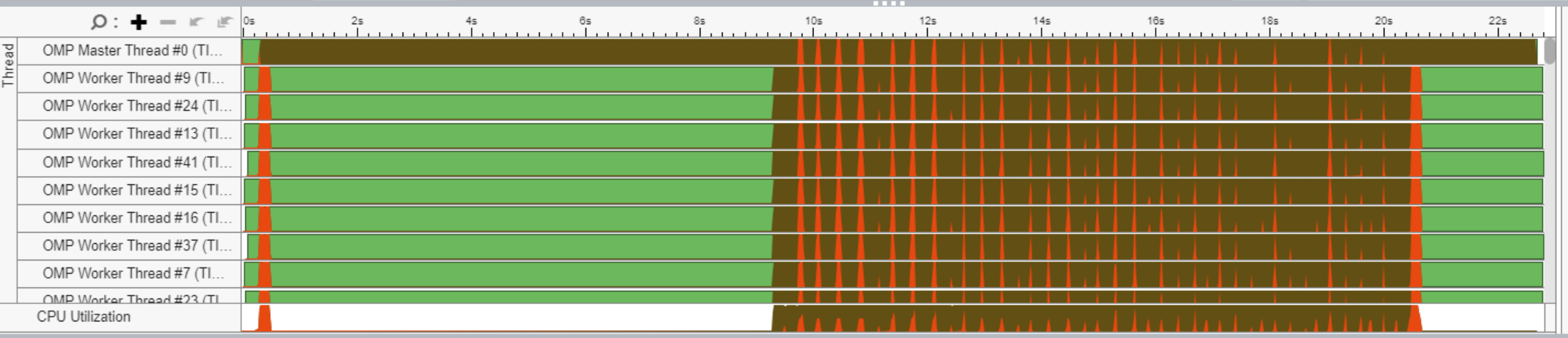
stream_mod.x!main+0xd74 - stream_mod.c:343
libc.so.6!__libc_start_main+0xf4 - [unknown source file]
stream_mod.x!_start+0x28 - [unknown source file]



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CPU Time
Spin and Overhead...
CPU Sample
CPU Utilization
CPU Time
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libc.so.6!__libc_start_main+0xf4 - [unknown source file]
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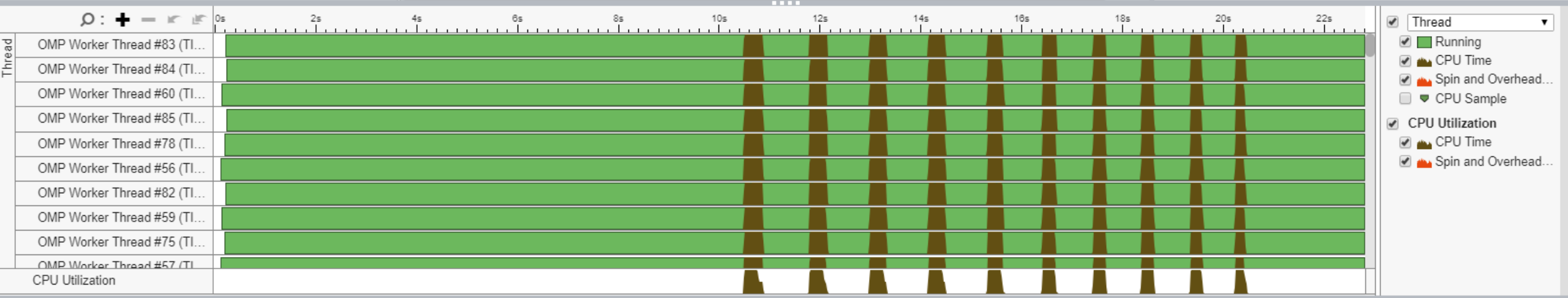

Thread
Running
CPU Time
Spin and Overhead...
CPU Sample
CPU Utilization
CPU Time
Spin and Overhead...

FILTER 24.5% | Process Any Process | Thread Any Thread | Module Any Module | Any Utilization | Call Stack Mode User functions | Loop Mode Functions onl | Inline Mode Show inline fu

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mainompparallel_for@286	20.914s	0s	0s	stream_mod.x	mainompparallel...	stream_mod.c	0x402
main	8.940s	0s	0s	stream_mod.x	main	stream_mod.c	0x400
checkSTREAMresults	2.200s	0s	0s	stream_mod.x	checkSTREAMresults	stream_mod.c	0x402
[Outside any known module]	0.010s	0s	0s		[Outside any known...		0
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__kmp_finish_implicit_task	0s	0s	0.023s	libiomp5.so	__kmp_finish_impli...	kmp_tasking.cpp	0xd97
_INTERNAL_25_____src_kmp_runtime_cpp_16bf24c5::__k	0s	0s	0.020s	libiomp5.so	_INTERNAL_25___...	kmp_itt.inl	0xadf

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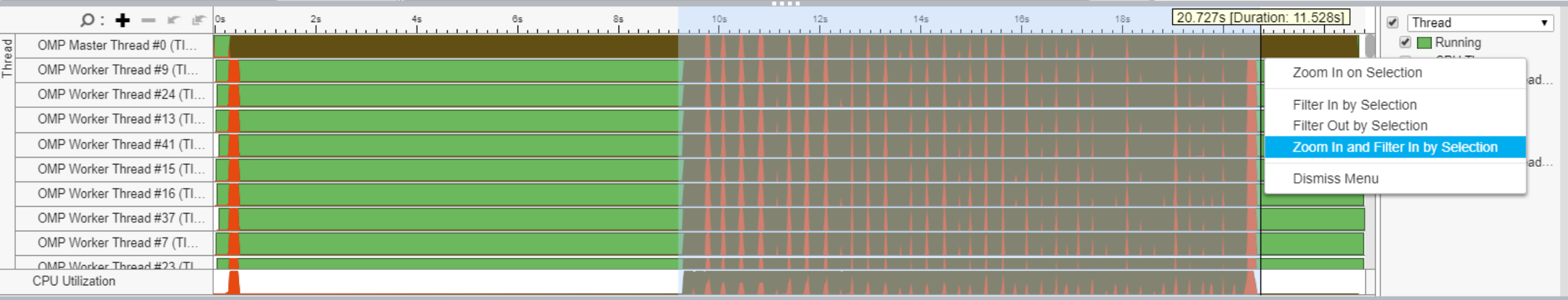

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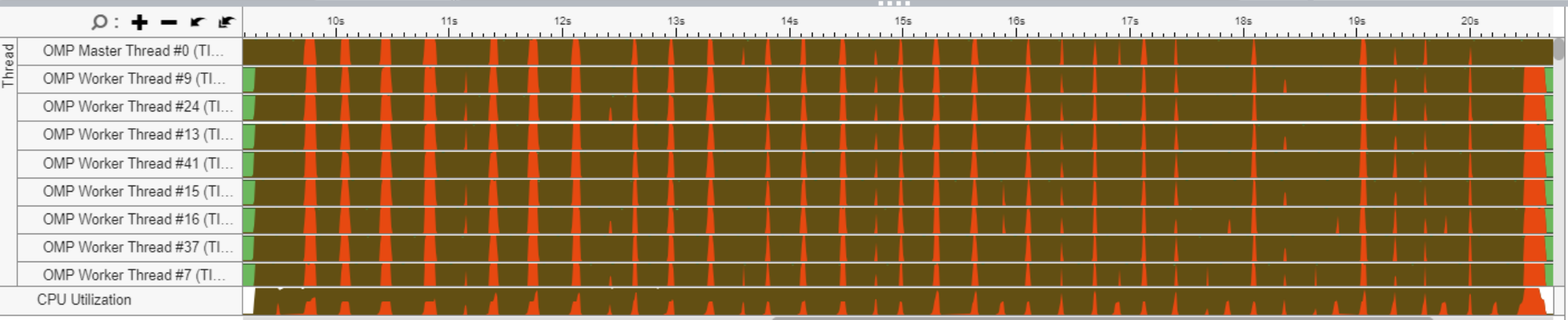
Function / Call Stack	CPU Time: Effective Time	CPU Time: Spin Time	CPU Time: Overhead Time	Module	Function (Full)	Source File	Start
mainompparallel_for@343	273.620s	0s	0s	stream_mod.x	mainompparallel...	stream_mod.c	0x401
mainompparallel_for@333	257.123s	0s	0s	stream_mod.x	mainompparallel...	stream_mod.c	0x401
__intel_avx_rep_memcpy	210.412s	0s	0s	libintlc.so.5	__intel_avx_rep_m...		0x465
mainompparallel_for@323	206.630s	0s	0s	stream_mod.x	mainompparallel...	stream_mod.c	0x401
mainompparallel_for@286	20.914s	0s	0s	stream_mod.x	mainompparallel...	stream_mod.c	0x402
checkSTREAMresults	0.250s	0s	0s	stream_mod.x	checkSTREAMresults	stream_mod.c	0x402
main	0.100s	0s	0s	stream_mod.x	main	stream_mod.c	0x400
[Outside any known module]	0.010s	0s	0s		[Outside any known...		0
[Import thunk sched_yield]	0.010s	0s	0s	libiomp5.so	[Import thunk sched...		0x281
__kmp_join_call	0s	1.266s	0s	libiomp5.so	__kmp_join_call	kmp_runtime.cpp	0xb2c
__kmp_join_barrier	0s	2.706s	0s	libiomp5.so	__kmp_join_barrier(...	kmp_barrier.cpp	0x6b4
__kmp_fork_barrier	0s	111.939s	0s	libiomp5.so	__kmp_fork_barrier...	kmp_barrier.cpp	0x6c1
__kmp_finish_implicit_task	0s	0s	0.010s	libiomp5.so	__kmp_finish_impli...	kmp_tasking.cpp	0xd97
_INTERNAL_25_____src_kmp_runtime_cpp_16bf24c5::__k	0s	0s	0.020s	libiomp5.so	_INTERNAL_25___...	kmp_itt.inl	0xadf

CPU Time

Viewing 1 of 1 selected stack(s)

100.0% (273.620s of 273.620s)

stream_mod.x!mainompparallel_for@343 - stream_mod.c
libiomp5.so![OpenMP dispatcher]+0x125 - kmp_runtime.cpp:7540
libiomp5.so!__kmp_fork_call+0x16a8 - kmp_runtime.cpp:2494
libiomp5.so![OpenMP fork]+0x17f - kmp_csupport.cpp:365
stream_mod.x!main+0xd74 - stream_mod.c:343
libc.so.6!__libc_start_main+0xf4 - [unknown source file]
stream_mod.x!_start+0x28 - [unknown source file]



Thread
Running
CPU Time
Spin and Overhead...
CPU Sample
CPU Utilization
CPU Time
Spin and Overhead...

FILTER 97.2% | Process: Any Process | Thread: Any Thread | Module: Any Module | Any Utilization | Call Stack Mode: User functions | Loop Mode: Functions onl | Inline Mode: Show inline fu

Intel VTune Amplifier

r_hs_mod

Hotspots | Hotspots by CPU Utilization

INTEL VTUNE AMPLIFIER 2019

Analysis Configuration | Collection Log | Summary | Bottom-up | Caller/Callee | Top-down Tree | Platform | stream_mod.c

Source | Assembly | Assembly grouping: Address

...	Source	CPU Time: Total	CPU Tim
327	times[1][k] = mysecond() - times[1][k];		
328			
329	times[2][k] = mysecond();		
330	#ifdef TUNED		
331	tuned_STREAM_Add();		
332	#else		
333	#pragma omp parallel for		
334	for (j=0; j<STREAM_ARRAY_SIZE; j++)		
335	c[j] = a[j]+b[j];		
336	#endif		
337	times[2][k] = mysecond() - times[2][k];		
338			
339	times[3][k] = mysecond();		
340	#ifdef TUNED		
341	tuned_STREAM_Triad(scalar);		
342	#else		
343	#pragma omp parallel for	25.3%	
344	for (j=0; j<STREAM_ARRAY_SIZE; j++)		
345	a[j] = b[j]+scalar*c[j];	25.1%	
346	#endif		
347	times[3][k] = mysecond() - times[3][k];		
348	}		
349			
350	/* --- SUMMARY --- */		
351			
352	for (k=1; k<NTIMES; k++) /* note -- skip first iteration		
353	{		
354	for (j=0; j<4; j++)		
355	{		
356	avgtime[j] = avgtime[j] + times[j][k];		
357	mintime[j] = MIN(mintime[j], times[j][k]);		
358	maxtime[j] = MAX(maxtime[j], times[j][k]);		
359	}		
360	}		

Address ▲	Sour...	Assembly	CPU Time: Total	CPI
0x401c0a	343	xor %r15d, %r15d		
0x401c0d	343	sub %rdx, %r8		
0x401c10	343	xor %r14d, %r14d		
0x401c13	343	and $0x3, %r8		
0x401c17	343	neg %r8		
0x401c1a	343	add %r9, %r8		
0x401c1d	343	cmp $0x1, %rdx		
0x401c21	343	jnb 0x403053		
0x401c3b		**Block 7:**		
0x401c3b	343	vbroadcastsdq 0x20(%rsp), %ymm0		
0x401c42		**Block 8:**		
0x401c42	345	leaq (%r10,%rdx,1), %rax	0.0%	
0x401c46	343	add $0x4, %rdx	0.0%	
0x401c4a	345	vmovupdy (%rcx,%rax,8), %ymm1	0.2%	
0x401c4f	345	vfmadd213pdy (%r13,%rax,8), %ymm0, %ymm1	14.7%	
0x401c56	345	vmovntpdy %ymm1, (%r11,%rax,8)	10.3%	
0x401c5c	343	cmp %r8, %rdx	0.1%	
0x401c5f	343	jb 0x401c42 <Block 8>		
0x401c61		**Block 9:**		
0x401c61	343	mfence		
0x401c64	343	leaq 0x1(%r8), %rax		
0x401c68	343	cmp %r9, %rax		
0x401c6b	343	jbe 0x403002 <Block 12>		
0x401c71		**Block 10:**		
0x401c71	343	mov $0x400a60, %rax		
0x401c7b	343	mov %rbx, %rdi		
0x401c7e	343	mov %r12d, %esi		
0x401c81	343	vzeroupper		
0x401c84	343	callq %rax		
0x401c86		**Block 11:**		
0x401c86	343	xor %eax, %eax		
0x401c88	343	movq 0x2c0(%rsp), %r15		
0x401c90	343	movq 0x2c8(%rsp), %r14		
0x401c98	343	movq 0x2d0(%rsp), %r13		

Collecting Hotspots via EBS

$ vtune -c hotspots -knob sampling-mode=hw -r r_hshw_mod -- ./stream_mod.x

Intel VTune Amplifier

r_hshw_mod

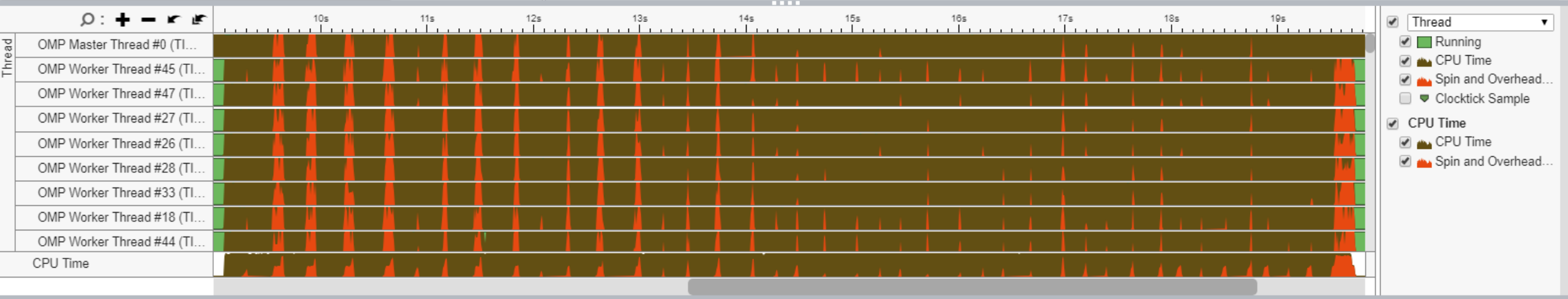
Hotspots | Hotspots by CPU Utilization

INTEL VTUNE AMPLIFIER 2019

Analysis Configuration | Collection Log | Summary | Bottom-up | Caller/Callee | Top-down Tree | Platform

Grouping: Function / Call Stack

Function / Call Stack	CPU Time ▼	Instructions Retired	Microarchitecture Usage	Module	Function (Full)	Source File	Start Address
mainompparallel_for@343	255.238s	17,844,000,000	1.4%	stream_mod.x	mainompparallel...	stream_mod.c	0x401ada
mainompparallel_for@333	230.836s	17,400,000,000	1.6%	stream_mod.x	mainompparallel...	stream_mod.c	0x401cb5
mainompparallel_for@323	186.121s	15,012,000,000	1.7%	stream_mod.x	mainompparallel...	stream_mod.c	0x401e70
__intel_avx_rep_memcpy	185.084s	7,728,000,000	0.8%	libintlc.so.5	__intel_avx_rep_m...		0x46580
_INTERNAL_25_____src_kmp_barrier_cpp_38a91946::__kmp_wait_template<kmp	78.815s	130,584,000,000	44.5%	libiomp5.so	bool _INTERNAL_2...	kmp_wait_release.h	0x628e0
[vmlinux]	48.674s	18,984,000,000	11.5%	vmlinux	[vmlinux]		0
mainompparallel_for@286	17.892s	1,884,000,000	1.8%	stream_mod.x	mainompparallel...	stream_mod.c	0x40218b
_INTERNAL_25_____src_kmp_barrier_cpp_38a91946::__kmp_wait_template<kmp	2.817s	4,476,000,000	45.6%	libiomp5.so	bool _INTERNAL_2...	kmp_wait_release.h	0x63435
kmp_flag_native<unsigned long long>::get	0.922s	8,064,000,000	63.6%	libiomp5.so	kmp_flag_native<u...	kmp_wait_release.h	0x62c3f
sched_yield	0.301s	36,000,000	37.0%	libc-2.17.so	sched_yield		0xe2e00
checkSTREAMresults	0.271s	540,000,000	0.0%	stream_mod.x	checkSTREAMresults	stream_mod.c	0x4029da
main	0.035s	12,000,000	6.2%	stream_mod.x	main	stream_mod.c	0x400c90
__kmp_x86_pause	0.025s	0	0.0%	libiomp5.so	__kmp_x86_pause	kmp.h	0x62b18
kmp_basic_flag_native<unsigned long long>::notdone_check	0.025s	24,000,000	0.0%	libiomp5.so	kmp_basic_flag_nat...	kmp_wait_release.h	0x62c3f
__kmp_finish_implicit_task	0.020s	0	0.0%	libiomp5.so	__kmp_finish_impli...	kmp_tasking.cpp	0xd97a0
_INTERNAL_25_____src_kmp_barrier_cpp_38a91946::__kmp_hyper_barrier_gathe	0.015s	216,000,000	100.0%	libiomp5.so	_INTERNAL_25___...	kmp_barrier.cpp	0x632a0
__kmp_yield	0.015s	0	0.0%	libiomp5.so	__kmp_yield	z_Linux_util.cpp	0xf0ef0
__kmpc_for_static_fini	0.015s	0	0.0%	libiomp5.so	__kmpc_for_static_...	kmp_csupport.cpp	0x70a00



FILTER 97.2% | Process: Any Process | Thread: Any Thread | Module: Any Module | Any Utilization | Call Stack Mode: User functio | Loop Mode: Functions o | Inline Mode: Show inline f

Intel VTune Amplifier

r_hshw_mod

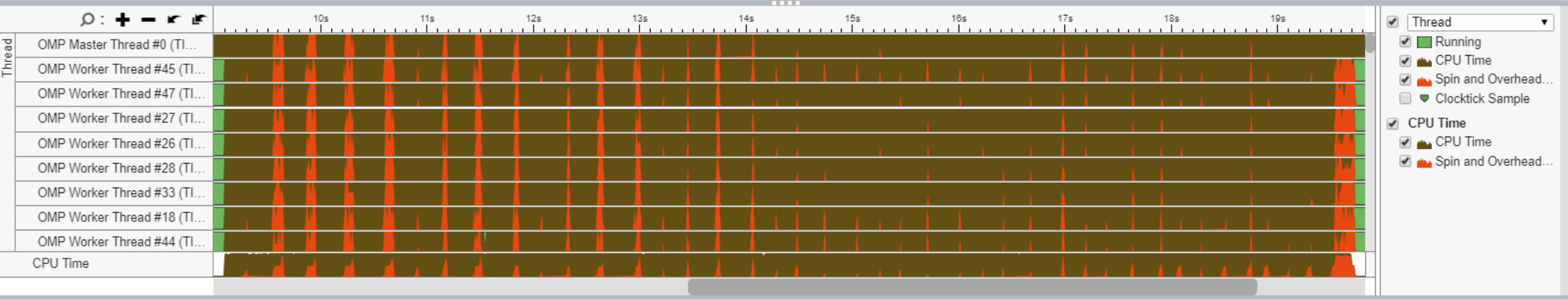
Hotspots | Hotspots by CPU Utilization

INTEL VTUNE AMPLIFIER 2019

Analysis Configuration | Collection Log | Summary | Bottom-up | Caller/Callee | Top-down Tree | Platform

Grouping: Core / Thread / Function / Call Stack

Core / Thread / Function / Call Stack ▲	CPU Time	Instructions Retired	Microarchitecture Usage	Module	Function (Full)	Source File	Start Address	PID	TID
core_0	21.205s	4,968,000,000	4.2%				0	0	0
OMP Master Thread #0 (TID: 418857)	10.695s	2,604,000,000	4.4%				0	418…	418…
OMP Worker Thread #1 (TID: 418971)	10.510s	2,364,000,000	4.0%				0	418…	418…
core_1	20.959s	5,784,000,000	5.7%				0	0	0
core_2	21.044s	4,716,000,000	9.8%				0	0	0
core_3	21.024s	4,680,000,000	4.2%				0	0	0
core_4	21.049s	4,656,000,000	3.9%				0	0	0
OMP Worker Thread #8 (TID: 418978)	10.525s	2,352,000,000	4.0%				0	418…	418…
OMP Worker Thread #9 (TID: 418979)	10.525s	2,304,000,000	3.8%				0	418…	418…
core_5	21.034s	4,692,000,000	4.2%				0	0	0
core_6	21.024s	4,692,000,000	9.8%				0	0	0
core_7	21.024s	4,680,000,000	4.2%				0	0	0
OMP Worker Thread #14 (TID: 418984)	10.505s	2,328,000,000	4.1%				0	418…	418…
OMP Worker Thread #15 (TID: 418985)	10.520s	2,352,000,000	4.2%				0	418…	418…
core_8	20.959s	4,668,000,000	4.1%				0	0	0
OMP Worker Thread #16 (TID: 418986)	10.454s	2,340,000,000	4.1%				0	418…	418…
OMP Worker Thread #17 (TID: 418987)	10.505s	2,328,000,000	4.1%				0	418…	418…
core_9	21.059s	5,808,000,000	5.4%				0	0	0



FILTER 97.2% | Process: Any Process | Thread: Any Thread | Module: Any Module | Any Utilization | Call Stack Mode: User functio | Loop Mode: Functions o | Inline Mode: Show inline f

Collecting HPC Performance

$ vtune -c hpc-performance -r r_hpc_mod -- ./stream_mod.x

Intel VTune Amplifier

r_hpc_mod

HPC Performance Characterization | HPC Performance Characterization | INTEL VTUNE AMPLIFIER 2019

Analysis Configuration | Collection Log | Summary | Bottom-up

Elapsed Time: 21.772s

SP GFLOPS:	0.000
DP GFLOPS:	0.990
x87 GFLOPS:	0.000
CPI Rate:	9.293
Average CPU Frequency:	2.4 GHz
Total Thread Count:	96

Effective Physical Core Utilization: 44.3% (21.274 out of 48)

Effective Logical Core Utilization: 43.9% (42.101 out of 96)

Serial Time (outside parallel regions): 11.449s (52.6%)

Top Serial Hotspots (outside parallel regions)

This section lists the loops and functions executed serially in the master thread outside of any OpenMP region and consuming the most CPU time. Improve overall application performance by optimizing or parallelizing these hotspot functions. Since the Serial Time metric includes the Wait time of the master thread, it may significantly exceed the aggregated CPU time in the table.

Function	Module	Serial CPU Time
[vmlinux]	vmlinux	4.962s
[Loop at line 268 in main]	stream_mod.x	4.210s
[Loop at line 462 in checkSTREAMresults]	stream_mod.x	2.225s
func@0x7d340	libittnotify_collector.so	0.005s
[sep5]	sep5	0.005s

*N/A is applied to non-summable metrics.

Parallel Region Time: 10.323s (47.4%)

Effective CPU Utilization Histogram

Memory Bound: 86.7% of Pipeline Slots

Cache Bound:	32.5% of Clockticks
DRAM Bound:	**51.1% of Clockticks**
DRAM Bandwidth Bound:	43.9% of Elapsed Time
NUMA: % of Remote Accesses:	32.8%

Bandwidth Utilization Histogram

Vectorization: 100.0% of Packed FP Operations

[Loop at line 462 in checkSTREAMresults]	stream_mod.x	2.225s
func@0x7d340	libittnotify_collector.so	0.005s
[sep5]	sep5	0.005s

*N/A is applied to non-summable metrics.

Parallel Region Time: 10.323s (47.4%)

Effective CPU Utilization Histogram

Memory Bound: 86.7% of Pipeline Slots

Cache Bound: 32.5% of Clockticks

DRAM Bound: 51.1% of Clockticks

DRAM Bandwidth Bound: 43.9% of Elapsed Time

NUMA: % of Remote Accesses: 32.8%

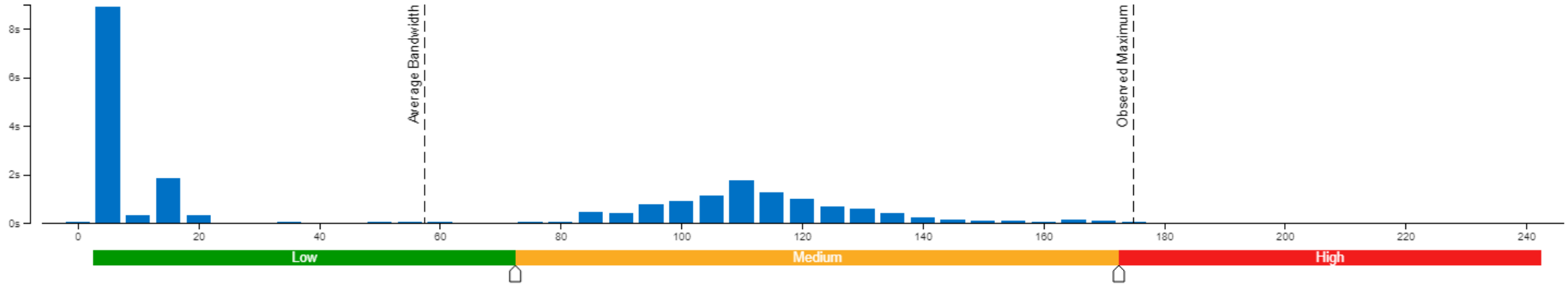
Bandwidth Utilization Histogram

Explore bandwidth utilization over time using the histogram and identify memory objects or functions with maximum contribution to the high bandwidth utilization.

Bandwidth Domain: DRAM, GB/sec

Bandwidth Utilization Histogram

This histogram displays the wall time the bandwidth was utilized by certain value. Use sliders at the bottom of the histogram to define thresholds for Low, Medium and High utilization levels. You can use these bandwidth utilization types in the Bottom-up view to group data and see all functions executed during a particular utilization type. To learn bandwidth capabilities, refer to your system specifications or run appropriate benchmarks to measure them; for example, Intel Memory Latency Checker can provide maximum achievable DRAM and Interconnect bandwidth.



Top Functions with High Bandwidth Utilization

Intel VTune Amplifier

r_hpc_mod

HPC Performance Characterization HPC Performance Characterization

INTEL VTUNE AMPLIFIER 2019

Analysis Configuration | Collection Log | Summary | Bottom-up

Grouping: Function / Call Stack

Function / Call Stack	CPU Time ▼				Serial CPU Time	Memory Bound	NUMA: % of Remote Accesses	% of FP Ops
	Effective Time by Utilization (Idle Poor Ok Ideal Over)	Spin Time	Overhead Time					
[Loop at line 343 in mainompparallel_for@343]	249.314s	0s	0s		0s	96.5%	30.9%	22.7%
[Loop at line 333 in mainompparallel_for@333]	226.390s	0s	0s		0s	96.2%	36.0%	8.3%
[Loop at line 323 in mainompparallel_for@323]	183.530s	0s	0s		0s	96.5%	16.7%	0.8%
[Loop@0x466d0 in __intel_avx_rep_memcpy]	179.866s	0s	0s		0s	98.2%	0.0%	0.0%
[Loop at line 361 in _INTERNAL_25_____src_k	0s	96.326s	0s		0s	9.4%	0.0%	0.0%
[vmlinux]	53.415s	0s	0s		4.962s	69.5%	0.0%	0.0%
[Loop at line 286 in mainompparallel_for@286]	17.471s	0s	0s		0s	98.5%	0.0%	0.0%
[Loop at line 268 in main]	4.210s	0s	0s		4.210s	90.3%	0.0%	0.0%
_INTERNAL_25_____src_kmp_barrier_cpp_38	0s	2.777s	0s		0s	8.1%	0.0%	0.0%
[Loop at line 462 in checkSTREAMresults]	2.225s	0s	0s		2.225s	55.9%	66.7%	0.0%
kmp_flag_native<unsigned long long>::get	0s	1.103s	0s		0s	0.0%	0.0%	0.0%
sched_yield	0s	0.346s	0s		0s	0.0%	0.0%	0.0%
[sep5]	0.150s	0s	0s		0.005s	0.0%	0.0%	0.0%
[Loop at line 841 in _INTERNAL_25_____src_k	0s	0.020s	0s		0s	0.0%	0.0%	0.0%
__kmp_x86_pause	0s	0.015s	0s		0s	0.0%	0.0%	0.0%
[Loop at line 2073 in __kmp_join_barrier]	0s	0.015s	0s		0s	0.0%	0.0%	0.0%

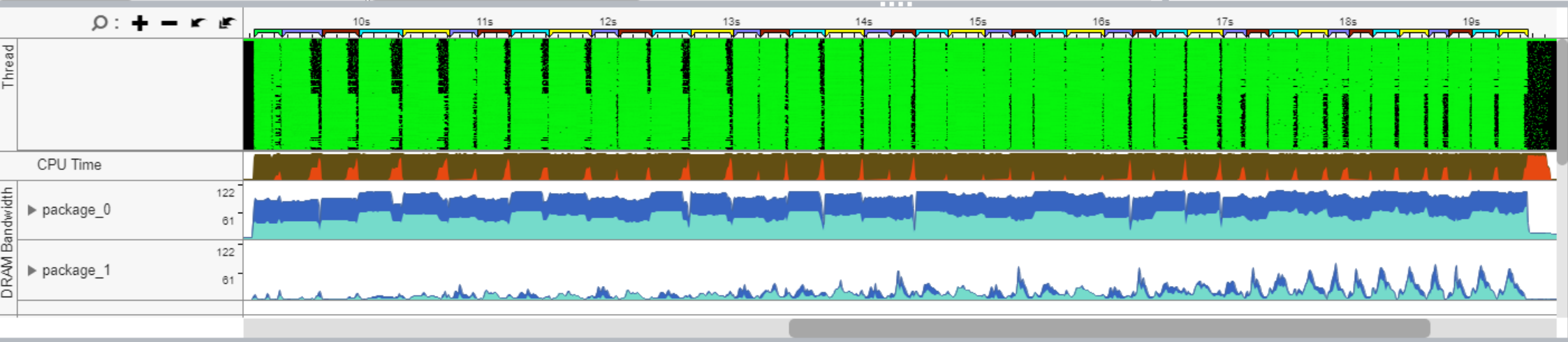
Elapsed Time: 21.772s

SP GFLOPS: 0.000
DP GFLOPS: 0.990
x87 GFLOPS: 0.000
CPI Rate: 9.293
Average CPU Frequency: 2.4 GHz
Total Thread Count: 96

Effective Physical Core Utilization: 44.3% (21.274 out of 48)
Effective Logical Core Utilization: 43.9% (42.101 out of 96)
Serial Time (outside parallel regions): 11.449s (52.6%)
Parallel Region Time: 10.323s (47.4%)
Effective CPU Utilization Histogram

Memory Bound: 86.7% of Pipeline Slots
Cache Bound: 32.5% of Clockticks
DRAM Bound: 51.1% of Clockticks
DRAM Bandwidth Bound: 43.9% of Elapsed Time
NUMA: % of Remote Accesses: 32.8%
Bandwidth Utilization Histogram

Vectorization: 100.0% of Packed FP Operations



Scale Markers:
Region Instance
OpenMP Barrier-to-Barrier Segment
Thread
Effective Time
Spin and Overhead...
CPU Time
CPU Time
Spin and Overhead...
DRAM Bandwidth
Average Bandwidth, ...
Read
Write

FILTER 100.0% | Process: Any Process | Module: Any Module | Call Stack Mode: User functions + 1 | Loop Mode: Loops and functions | Inline Mode: Show inline functions

Intel VTune Amplifier

r_hpc_mod

HPC Performance Characterization HPC Performance Characterization

INTEL VTUNE AMPLIFIER 2019

Analysis Configuration | Collection Log | Summary | Bottom-up

Grouping: Function / Call Stack

Function / Call Stack	CPU Time ▼				Serial CPU Time	Memory Bound	NUMA: % of Remote Accesses	% of FP Ops
	Effective Time by Utilization (Idle, Poor, Ok, Ideal, Over)	Spin Time	Overhead Time					
[Loop@0x466d0 in __intel_avx_rep_memcpy]	179.866s	0s	0s		0s	98.2%	0.0%	0.0%

```
313 #pragma omp parallel for
314         for (j=0; j<STREAM_ARRAY_SIZE; j++)
315             c[j] = a[j];
```

Elapsed Time: N/A*

SP GFLOPS:	0.000
DP GFLOPS:	0.000
x87 GFLOPS:	0.000
CPI Rate:	56.084
Average CPU Frequency:	2.4 GHz
Total Thread Count:	96

**N/A is applied to metrics with undefined value. Suggestion: Make sure the proper filtering is applied.*

See the Troubleshooting help topic for more details.

Effective Physical Core Utilization:

Effective Logical Core Utilization: N/A*

**N/A is applied to metrics with undefined value. Suggestion: Make sure the proper filtering is applied.*

See the Troubleshooting help topic for more details.

Serial Time (outside parallel regions): N/A*

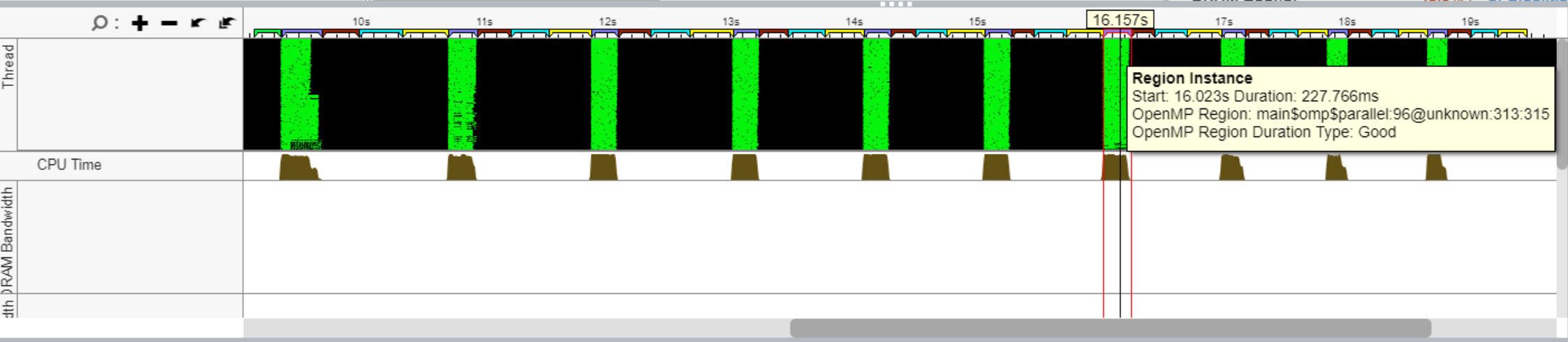
Parallel Region Time: [Unknown] (0.0%)

Effective CPU Utilization Histogram

Memory Bound: 98.2% of Pipeline Slots

Cache Bound: 44.4% of Clockticks

DRAM Bound: 43.9% of Clockticks



Scale Markers:

- Region Instance
- OpenMP Barrier-to-Barrier Segment
- Thread
  - Effective Time
  - Spin and Overhead...
- CPU Time
  - CPU Time
  - Spin and Overhead...
- DRAM Bandwidth
- Interconnect Bandwidth
- Interconnect Packet R...

FILTER 17.7% | Process: Any Process | Module: Any Module | Call Stack Mode: User functions + 1 | Loop Mode: Loops and functions | Inline Mode: Show inline functions

Intel VTune Amplifier

r_hpc_mod

HPC Performance Characterization HPC Performance Characterization

INTEL VTUNE AMPLIFIER 2019

Analysis Configuration | Collection Log | Summary | Bottom-up

Grouping: Function / Call Stack

Function / Call Stack	CPU Time ▼						
	Effective Time by Utilization (Idle, Poor, Ok, Ideal, Over)	Spin Time	Overhead Time	Serial CPU Time	Memory Bound	NUMA: % of Remote Accesses	% of FP Ops
[vmlinux]	46.699s	0s	0s	0.045s	68.3%	0.0%	0.0%

Elapsed Time: N/A*

SP GFLOPS:	0.000
DP GFLOPS:	0.000
x87 GFLOPS:	0.000
CPI Rate:	5.422
Average CPU Frequency:	2.4 GHz
Total Thread Count:	96

**N/A is applied to metrics with undefined value. Suggestion: Make sure the proper filtering is applied.*

See the Troubleshooting help topic for more details.

Effective Physical Core Utilization:

Effective Logical Core Utilization: N/A*

**N/A is applied to metrics with undefined value. Suggestion: Make sure the proper filtering is applied.*

See the Troubleshooting help topic for more details.

Serial Time (outside parallel regions): N/A*

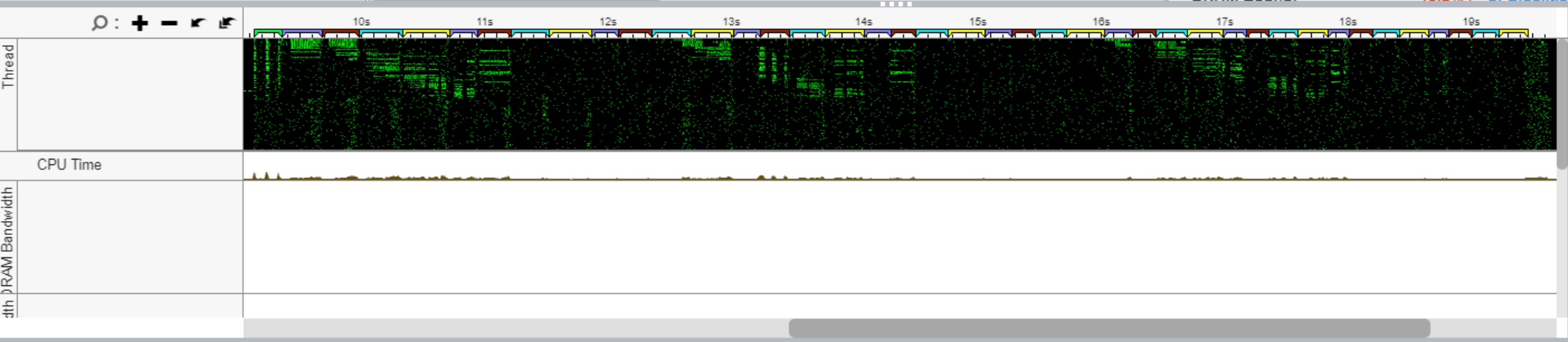
Parallel Region Time: [Unknown] (0.0%)

Effective CPU Utilization Histogram

Memory Bound: 68.3% of Pipeline Slots

Cache Bound: 47.5% of Clockticks

DRAM Bound: 19.8% of Clockticks



Scale Markers:

- Region Instance
- OpenMP Barrier-to-Barrier Segment
- Thread
  - Effective Time
  - Spin and Overhead...
- CPU Time
  - CPU Time
  - Spin and Overhead...
- DRAM Bandwidth
- Interconnect Bandwidth
- Interconnect Packet R...

FILTER 4.6% | Process: Any Process | Module: Any Module | Call Stack Mode: User functions + 1 | Loop Mode: Loops and functions | Inline Mode: Show inline functions

Intel VTune Amplifier

r_hpc_mod

HPC Performance Characterization HPC Performance Characterization

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Analysis Configuration | Collection Log | Summary | Bottom-up

Grouping: Function / Call Stack

Function / Call Stack	CPU Time ▼ Effective Time by Utilization (Idle / Poor / Ok / Ideal / Over)	Spin Time	Overhead Time	Serial CPU Time	Memory Bound	NUMA: % of Remote Accesses	% of FP Ops
[Loop@0x466d0 in __intel_avx_rep_memcpy]	31.338s	0s	0s	0s	99.6%	0.0%	0.0%
[Loop at line 343 in mainompparallel_for@343]	27.129s	0s	0s	0s	97.6%	40.0%	0.0%
[Loop at line 333 in mainompparallel_for@333]	25.971s	0s	0s	0s	97.1%	50.0%	0.0%
[Loop at line 323 in mainompparallel_for@323]	21.540s	0s	0s	0s	98.4%	0.0%	0.0%
[Loop at line 361 in _INTERNAL_25_____src_k	0s	18.503s	0s	0s	8.8%	0.0%	0.0%
[vmlinux]	11.166s	0s	0s	0s	74.8%	0.0%	0.0%
[Loop at line 286 in mainompparallel_for@286]	1.168s	0s	0s	0s	98.0%	0.0%	0.0%
_INTERNAL_25_____src_kmp_barrier_cpp_38	0s	0.581s	0s	0s	0.0%	0.0%	0.0%
kmp_flag_native<unsigned long long>::get	0s	0.205s	0s	0s	0.0%	0.0%	0.0%
sched_yield	0s	0.085s	0s	0s	0.0%	0.0%	0.0%
[sep5]	0.040s	0s	0s	0s	0.0%	0.0%	0.0%
[Loop at line 841 in _INTERNAL_25_____src_k	0s	0.015s	0s	0s		0.0%	0.0%
__kmp_fork_barrier	0s	0.010s	0s	0s	0.0%	0.0%	0.0%
__kmpc_for_static_fini	0s	0s	0.005s	0s	100.0%	0.0%	0.0%
__kmp_x86_pause	0s	0.005s	0s	0s	0.0%	0.0%	0.0%

Elapsed Time: 1.465s

SP GFLOPS: 0.000
DP GFLOPS: 0.000
x87 GFLOPS: 0.000
CPI Rate: 7.496
Average CPU Frequency: 2.4 GHz
Total Thread Count: 96

Effective Physical Core Utilization: 84.1% (40.382 out of 48)

Effective Logical Core Utilization: 84.1% (80.763 out of 96)

Serial Time (outside parallel regions): 0.001s (0.0%)

Parallel Region Time: 1.465s (6.7%)

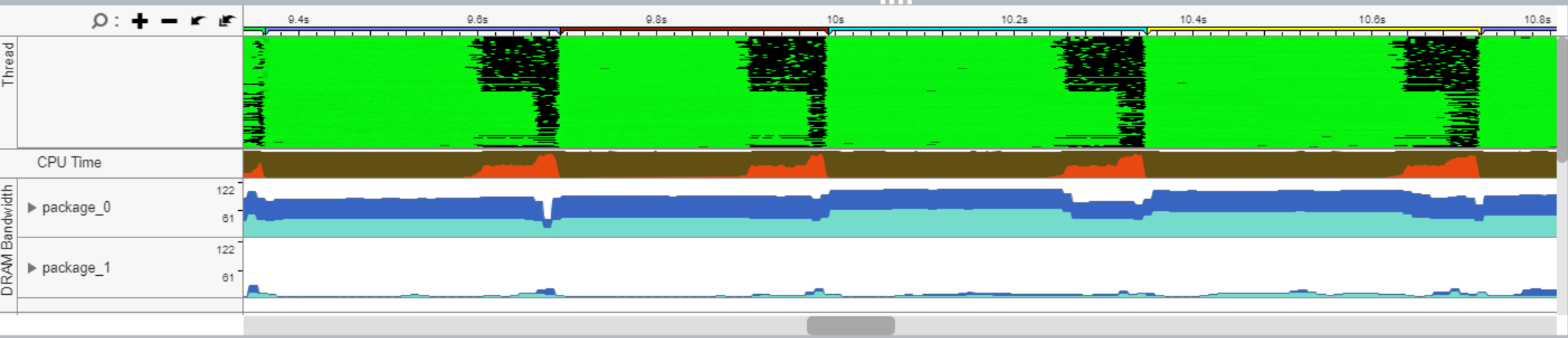
Effective CPU Utilization Histogram

Memory Bound: 85.0% of Pipeline Slots

Cache Bound: 28.9% of Clockticks
DRAM Bound: 48.4% of Clockticks
DRAM Bandwidth Bound: 74.1% of Elapsed Time
NUMA: % of Remote Accesses: 44.0%

Bandwidth Utilization Histogram

Vectorization: 0.0% of Packed FP Operations



Scale Markers:
Region Instance
OpenMP Barrier-to-Barrier Segment
Thread
Effective Time
Spin and Overhead...
CPU Time
CPU Time
Spin and Overhead...
DRAM Bandwidth
Average Bandwidth, ...
Read
Write

FILTER 13.5% | Process: Any Process | Module: Any Module | Call Stack Mode: User functions + 1 | Loop Mode: Loops and functions | Inline Mode: Show inline functions

Intel VTune Amplifier

r_hpc_mod

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Grouping: Function / Call Stack

Function / Call Stack	CPU Time ▼			Serial CPU Time	Memory Bound	NUMA: % of Remote Accesses	% of FP Ops
	Effective Time by Utilization (Idle Poor Ok Ideal Over)	Spin Time	Overhead Time				
[Loop@0x466d0 in __intel_avx_rep_memcpy]	31.338s	0s	0s	0s	99.6%	0.0%	0.0%
[Loop at line 343 in mainompparallel_for@343]	27.129s	0s	0s	0s	97.6%	40.0%	0.0%
[Loop at line 333 in mainompparallel_for@333]	25.971s	0s	0s	0s	97.1%	50.0%	0.0%
[Loop at line 323 in mainompparallel_for@323]	21.540s	0s	0s	0s	98.4%	0.0%	0.0%
[Loop at line 361 in _INTERNAL_25_____src_k	0s	18.503s	0s	0s	8.8%	0.0%	0.0%
[vmlinux]	11.166s	0s	0s	0s	74.8%	0.0%	0.0%
[Loop at line 286 in mainompparallel_for@286]	1.168s	0s	0s	0s	98.0%	0.0%	0.0%
_INTERNAL_25_____src_kmp_barrier_cpp_38	0s	0.581s	0s	0s	0.0%	0.0%	0.0%
kmp_flag_native<unsigned long long>::get	0s	0.205s	0s	0s	0.0%	0.0%	0.0%
sched_yield	0s	0.085s	0s	0s	0.0%	0.0%	0.0%
[sep5]	0.040s	0s	0s	0s	0.0%	0.0%	0.0%
[Loop at line 841 in _INTERNAL_25_____src_k							
__kmp_fork_barrier							
__kmpc_for_static_fini							
__kmp_x86_pause							

```
313 #pragma omp parallel for
314         for (j=0; j<STREAM_ARRAY_SIZE; j++)
315             c[j] = a[j];
```

Elapsed Time: 1.465s

SP GFLOPS:	0.000
DP GFLOPS:	0.000
x87 GFLOPS:	0.000
CPI Rate:	7.496
Average CPU Frequency:	2.4 GHz
Total Thread Count:	96

Effective Physical Core Utilization: 84.1% (40.382 out of 48)

Effective Logical Core Utilization: 84.1% (80.763 out of 96)

Serial Time (outside parallel regions): 0.001s (0.0%)

Parallel Region Time: 1.465s (6.7%)

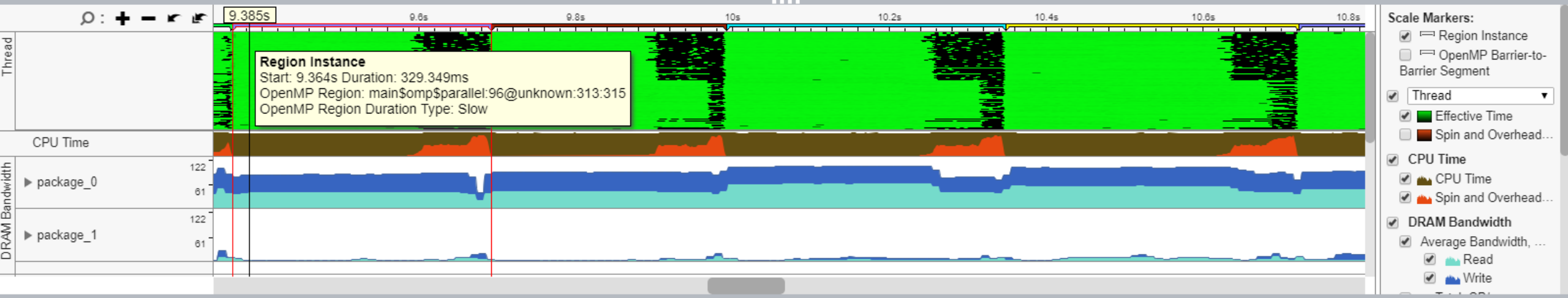
Effective CPU Utilization Histogram

Memory Bound: 85.0% of Pipeline Slots

Cache Bound:	28.9% of Clockticks
DRAM Bound:	**48.4% of Clockticks**
DRAM Bandwidth Bound:	74.1% of Elapsed Time
NUMA: % of Remote Accesses:	44.0%

Bandwidth Utilization Histogram

Vectorization: 0.0% of Packed FP Operations



FILTER 13.5% | Process: Any Process | Module: Any Module | Call Stack Mode: User functions + 1 | Loop Mode: Loops and functions | Inline Mode: Show inline functions

Intel VTune Amplifier

r_hpc_mod

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Grouping: Function / Call Stack

Function / Call Stack	CPU Time ▼ Effective Time by Utilization (Idle, Poor, Ok, Ideal, Over)	Spin Time	Overhead Time	Serial CPU Time	Memory Bound	NUMA: % of Remote Accesses	% of FP Ops
[Loop@0x466d0 in __intel_avx_rep_memcpy]	31.338s	0s	0s	0s	99.6%	0.0%	0.0%
[Loop at line 343 in mainompparallel_for@343]	27.129s	0s	0s	0s	97.6%	40.0%	0.0%
[Loop at line 333 in mainompparallel_for@333]	25.971s	0s	0s	0s	97.1%	50.0%	0.0%
[Loop at line 323 in mainompparallel_for@323]	21.540s	0s	0s	0s	98.4%	0.0%	0.0%
[Loop at line 361 in _INTERNAL_25_____src_k	0s	18.503s	0s	0s	8.8%	0.0%	0.0%
[vmlinux]	11.166s	0s	0s	0s	74.8%	0.0%	0.0%
[Loop at line 286 in mainompparallel_for@286]	1.168s	0s	0s	0s	98.0%	0.0%	0.0%
_INTERNAL_25_____src_kmp_barrier_cpp_38	0s	0.581s	0s	0s	0.0%	0.0%	0.0%
kmp_flag_native<unsigned long long>::get	0s	0.205s	0s	0s	0.0%	0.0%	0.0%
sched_yield	0s	0.085s	0s	0s	0.0%	0.0%	0.0%
[sep5]	0.040s	0s	0s	0s	0.0%	0.0%	0.0%
[Loop at line 841 in _INTERNAL_25_____src_k							
__kmp_fork_barrier							
__kmpc_for_static_fini							
__kmp_x86_pause							

```
323 #pragma omp parallel for
324         for (j=0; j<STREAM_ARRAY_SIZE; j++)
325             b[j] = scalar*c[j];
```

Elapsed Time: 1.465s

SP GFLOPS:	0.000
DP GFLOPS:	0.000
x87 GFLOPS:	0.000
CPI Rate:	7.496
Average CPU Frequency:	2.4 GHz
Total Thread Count:	96

Effective Physical Core Utilization: 84.1% (40.382 out of 48)

Effective Logical Core Utilization: 84.1% (80.763 out of 96)

Serial Time (outside parallel regions): 0.001s (0.0%)

Parallel Region Time: 1.465s (6.7%)

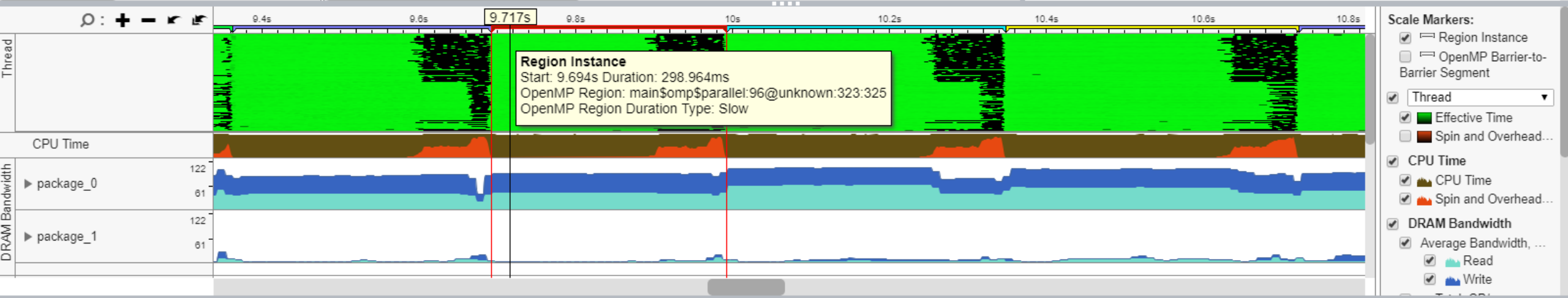
Effective CPU Utilization Histogram

Memory Bound: 85.0% of Pipeline Slots

Cache Bound:	28.9% of Clockticks
DRAM Bound:	**48.4% of Clockticks**
DRAM Bandwidth Bound:	74.1% of Elapsed Time
NUMA: % of Remote Accesses:	44.0%

Bandwidth Utilization Histogram

Vectorization: 0.0% of Packed FP Operations



Scale Markers:
- Region Instance
- OpenMP Barrier-to-Barrier Segment

Thread
- Effective Time
- Spin and Overhead...

CPU Time
- CPU Time
- Spin and Overhead...

DRAM Bandwidth
- Average Bandwidth, ...
  - Read
  - Write

FILTER 13.5% | Process: Any Process | Module: Any Module | Call Stack Mode: User functions + 1 | Loop Mode: Loops and functions | Inline Mode: Show inline functions

Intel VTune Amplifier

r_hpc_mod

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Grouping: Function / Call Stack

Function / Call Stack	CPU Time ▼ Effective Time by Utilization (Idle, Poor, Ok, Ideal, Over)	Spin Time	Overhead Time	Serial CPU Time	Memory Bound	NUMA: % of Remote Accesses	% of FP Ops
[Loop@0x466d0 in __intel_avx_rep_memcpy]	31.338s	0s	0s	0s	99.6%	0.0%	0.0%
[Loop at line 343 in mainompparallel_for@343]	27.129s	0s	0s	0s	97.6%	40.0%	0.0%
[Loop at line 333 in mainompparallel_for@333]	25.971s	0s	0s	0s	97.1%	50.0%	0.0%
[Loop at line 323 in mainompparallel_for@323]	21.540s	0s	0s	0s	98.4%	0.0%	0.0%
[Loop at line 361 in _INTERNAL_25_____src_k	0s	18.503s	0s	0s	8.8%	0.0%	0.0%
[vmlinux]	11.166s	0s	0s	0s	74.8%	0.0%	0.0%
[Loop at line 286 in mainompparallel_for@286]	1.168s	0s	0s	0s	98.0%	0.0%	0.0%
_INTERNAL_25_____src_kmp_barrier_cpp_38	0s	0.581s	0s	0s	0.0%	0.0%	0.0%
kmp_flag_native<unsigned long long>::get	0s	0.205s	0s	0s	0.0%	0.0%	0.0%
sched_yield	0s	0.085s	0s	0s	0.0%	0.0%	0.0%
[sep5]	0.040s	0s	0s	0s	0.0%	0.0%	0.0%
[Loop at line 841 in _INTERNAL_25_____src_k							
__kmp_fork_barrier							
__kmpc_for_static_fini							
__kmp_x86_pause							

```
333 #pragma omp parallel for
334         for (j=0; j<STREAM_ARRAY_SIZE; j++)
335             c[j] = a[j]+b[j];
```

Elapsed Time: 1.465s

SP GFLOPS:	0.000
DP GFLOPS:	0.000
x87 GFLOPS:	0.000
CPI Rate:	7.496
Average CPU Frequency:	2.4 GHz
Total Thread Count:	96

Effective Physical Core Utilization: 84.1% (40.382 out of 48)

Effective Logical Core Utilization: 84.1% (80.763 out of 96)

Serial Time (outside parallel regions): 0.001s (0.0%)

Parallel Region Time: 1.465s (6.7%)

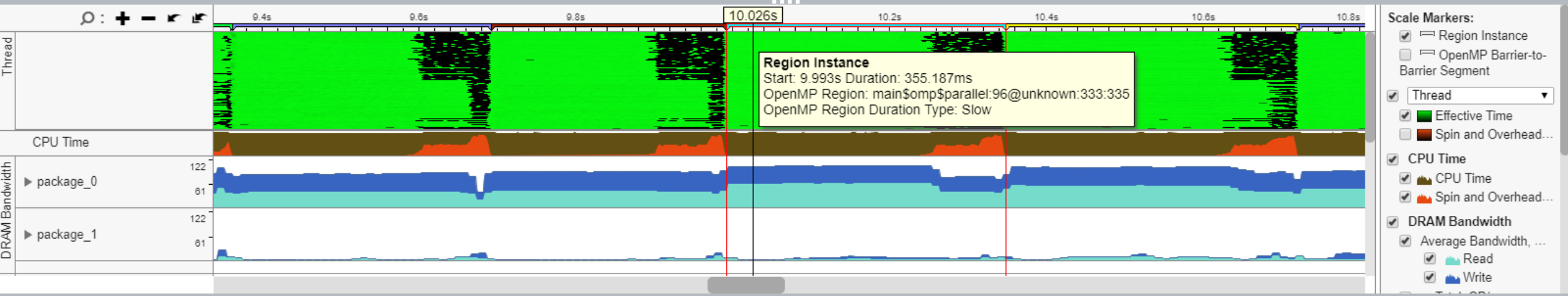
Effective CPU Utilization Histogram

Memory Bound: 85.0% of Pipeline Slots

Cache Bound:	28.9% of Clockticks
DRAM Bound:	**48.4% of Clockticks**
DRAM Bandwidth Bound:	74.1% of Elapsed Time
NUMA: % of Remote Accesses:	44.0%

Bandwidth Utilization Histogram

Vectorization: 0.0% of Packed FP Operations



Scale Markers:
- Region Instance
- OpenMP Barrier-to-Barrier Segment

Thread
- Effective Time
- Spin and Overhead...

CPU Time
- CPU Time
- Spin and Overhead...

DRAM Bandwidth
- Average Bandwidth, ...
  - Read
  - Write

FILTER 13.5% | Process: Any Process | Module: Any Module | Call Stack Mode: User functions + 1 | Loop Mode: Loops and functions | Inline Mode: Show inline functions

Intel VTune Amplifier

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Grouping: Function / Call Stack

Function / Call Stack	CPU Time ▼ Effective Time by Utilization (Idle, Poor, Ok, Ideal, Over)	Spin Time	Overhead Time	Serial CPU Time	Memory Bound	NUMA: % of Remote Accesses	% of FP Ops
[Loop@0x466d0 in __intel_avx_rep_memcpy]	31.338s	0s	0s	0s	99.6%	0.0%	0.0%
[Loop at line 343 in mainompparallel_for@343]	27.129s	0s	0s	0s	97.6%	40.0%	0.0%
[Loop at line 333 in mainompparallel_for@333]	25.971s	0s	0s	0s	97.1%	50.0%	0.0%
[Loop at line 323 in mainompparallel_for@323]	21.540s	0s	0s	0s	98.4%	0.0%	0.0%
[Loop at line 361 in _INTERNAL_25_____src_k	0s	18.503s	0s	0s	8.8%	0.0%	0.0%
[vmlinux]	11.166s	0s	0s	0s	74.8%	0.0%	0.0%
[Loop at line 286 in mainompparallel_for@286]	1.168s	0s	0s	0s	98.0%	0.0%	0.0%
_INTERNAL_25_____src_kmp_barrier_cpp_38	0s	0.581s	0s	0s	0.0%	0.0%	0.0%
kmp_flag_native<unsigned long long>::get	0s	0.205s	0s	0s	0.0%	0.0%	0.0%
sched_yield	0s	0.085s	0s	0s	0.0%	0.0%	0.0%
[sep5]	0.040s	0s	0s	0s	0.0%	0.0%	0.0%
[Loop at line 841 in _INTERNAL_25_____src_k							
__kmp_fork_barrier							
__kmpc_for_static_fini							
__kmp_x86_pause							

```
343 #pragma omp parallel for
344         for (j=0; j<STREAM_ARRAY_SIZE; j++)
345             a[j] = b[j]+scalar*c[j];
```

Elapsed Time: 1.465s

SP GFLOPS:	0.000
DP GFLOPS:	0.000
x87 GFLOPS:	0.000
CPI Rate:	7.496
Average CPU Frequency:	2.4 GHz
Total Thread Count:	96

Effective Physical Core Utilization: 84.1% (40.382 out of 48)

Effective Logical Core Utilization: 84.1% (80.763 out of 96)

Serial Time (outside parallel regions): 0.001s (0.0%)

Parallel Region Time: 1.465s (6.7%)

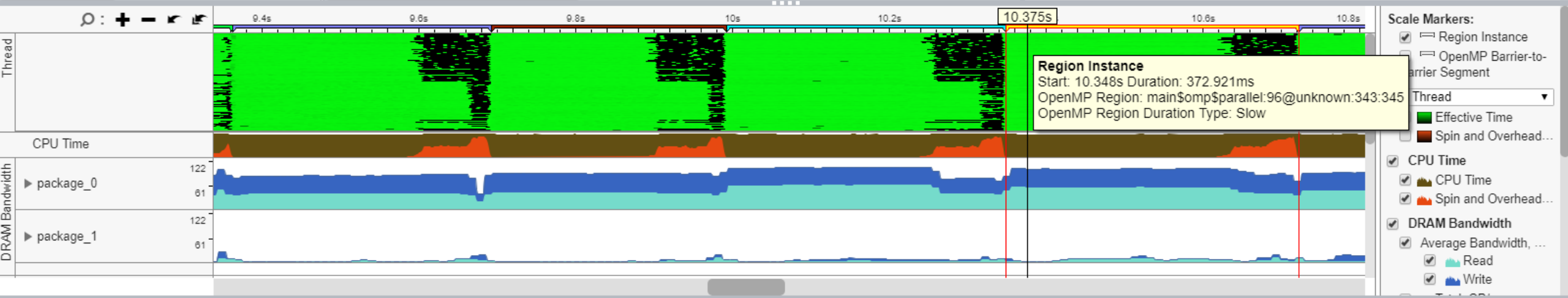
Effective CPU Utilization Histogram

Memory Bound: 85.0% of Pipeline Slots

Cache Bound:	28.9% of Clockticks
DRAM Bound:	**48.4% of Clockticks**
DRAM Bandwidth Bound:	74.1% of Elapsed Time
NUMA: % of Remote Accesses:	44.0%

Bandwidth Utilization Histogram

Vectorization: 0.0% of Packed FP Operations



FILTER 13.5% | Process: Any Process | Module: Any Module | Call Stack Mode: User functions + 1 | Loop Mode: Loops and functions | Inline Mode: Show inline functions

Collecting Memory Access

$ vtune -c memory-access -r ./r_ma_mod -- ./stream_mod.x

Intel VTune Amplifier

r_ma_mod

Memory Access Memory Usage

INTEL VTUNE AMPLIFIER 2019

Analysis Configuration | Collection Log | Summary | Bottom-up | Platform

Elapsed Time: 21.897s

CPU Time:	1028.961s	
Memory Bound:	**87.0%**	**of Pipeline Slots**
L1 Bound:	21.2%	of Clockticks
L2 Bound:	0.2%	of Clockticks
L3 Bound:	10.9%	of Clockticks
DRAM Bound:	**51.6%**	**of Clockticks**
DRAM Bandwidth Bound:	43.8%	of Elapsed Time
UPI Bandwidth Bound:	45.5%	of Elapsed Time
Memory Latency:		
Local DRAM:	24.5%	of Clockticks
Remote DRAM:	19.9%	of Clockticks
Remote Cache:	0.0%	of Clockticks
NUMA: % of Remote Accesses:	34.4%	
Loads:	89,315,679,390	
Stores:	19,964,598,920	
LLC Miss Count:	**2,121,148,470**	
Average Latency (cycles):	219	
Total Thread Count:	96	
Paused Time:	0s	

**N/A is applied to metrics with undefined value. There is no data to calculate the metric.*

Bandwidth Utilization Histogram

Explore bandwidth utilization over time using the histogram and identify memory objects or functions with maximum contribution to the high bandwidth utilization.

Bandwidth Domain: DRAM, GB/sec

Bandwidth Utilization Histogram

This histogram displays the wall time the bandwidth was utilized by certain value. Use sliders at the bottom of the histogram to define thresholds for Low, Medium and High utilization levels. You can use these bandwidth utilization types in the Bottom-up view to group data and see all functions executed during a particular utilization type. To learn bandwidth capabilities, refer to your system specifications or run appropriate benchmarks to measure them; for example, Intel Memory Latency Checker can provide maximum achievable DRAM and Interconnect bandwidth.

Intel VTune Amplifier

r_ma_mod

Memory Access Memory Usage

INTEL VTUNE AMPLIFIER 2019

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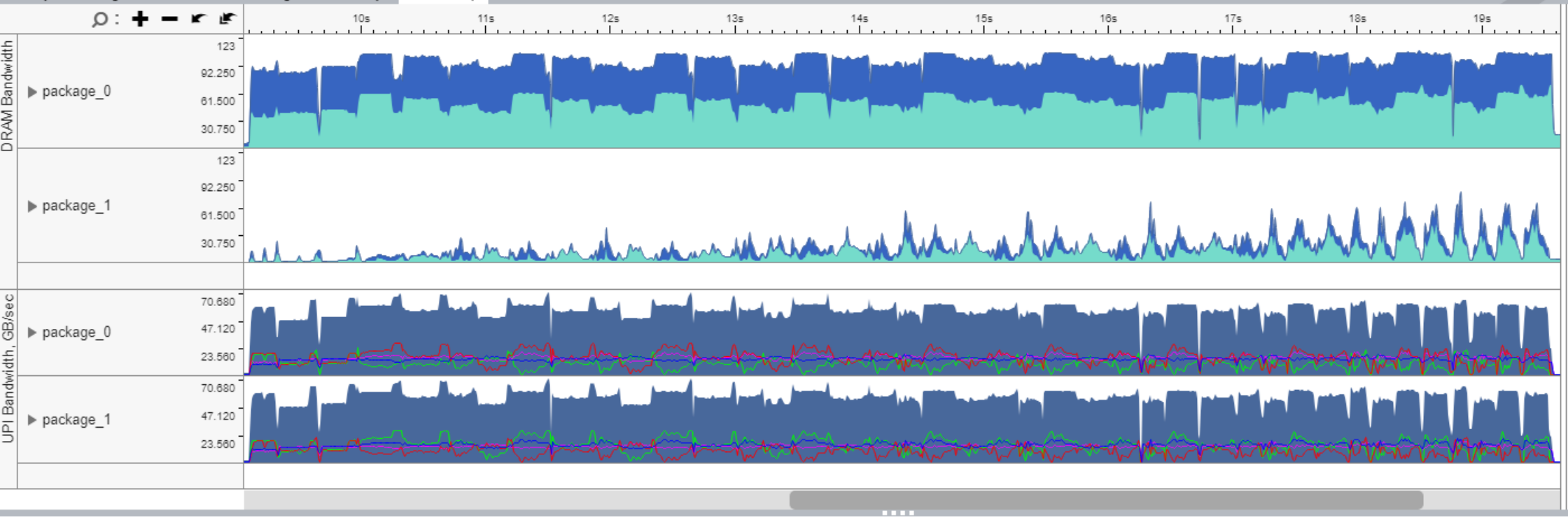


- DRAM Bandwidth
  - Average Bandwidth, G...
    - Read
    - Write
  - Total, GB/sec
- UPI Bandwidth, GB/sec
  - Total, GB/sec
  - Incoming Data, GB/sec
  - Incoming Non-Data, ...
  - Outgoing Data, GB/sec
  - Outgoing Non-Data, ...

Grouping: Memory Object / Function / Allocation Stack

Memory Object / Function / Allocation Stack	CPU Time	Memory Bound	Loads	Stores	LLC Miss Count	Average Latency (cycles)	Module
[Unknown]			66,067,981,980	14,147,424,410	2,058,144,060	308	
[vmlinux]			5,243,157,290	3,010,090,300	7,000,490	63	
[sep5]			21,000,630	0	0	0	

FILTER 96.0% | Process: Any Process | Thread: Any Thread | Module: Any Module | Loop Mode: Functions only | Inline Mode: Show inline functions

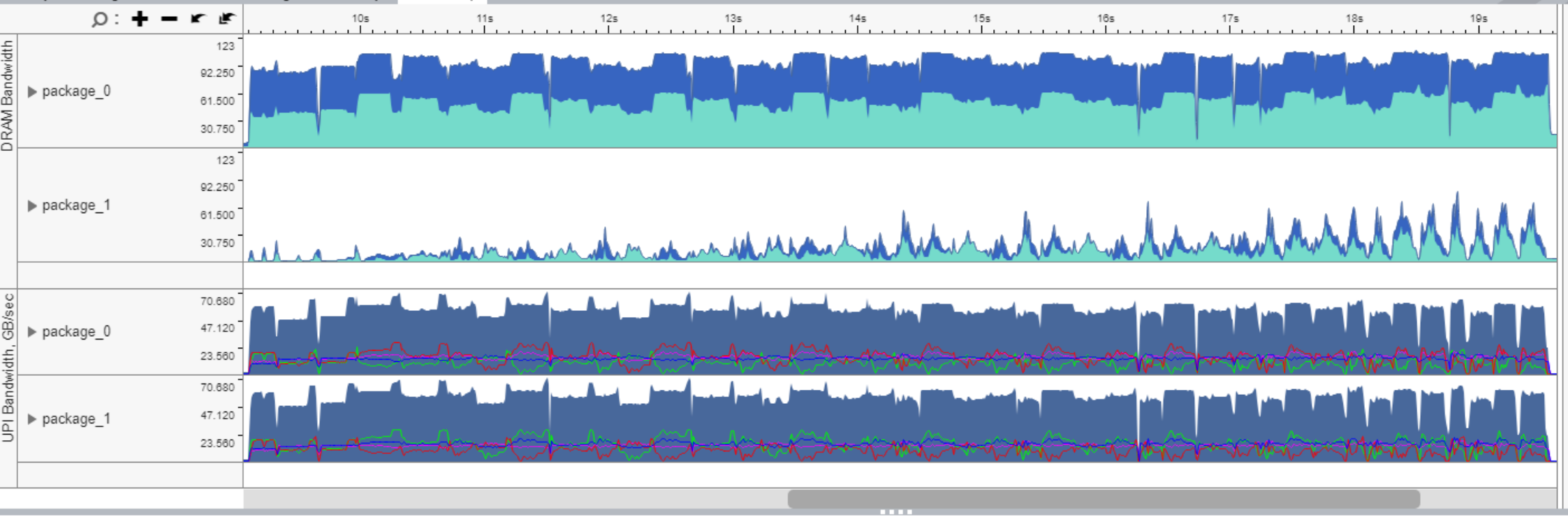
Intel VTune Amplifier

r_ma_mod

Memory Access Memory Usage

INTEL VTUNE AMPLIFIER 2019

Analysis Configuration | Collection Log | Summary | Bottom-up | Platform



- DRAM Bandwidth
  - Average Bandwidth, G...
    - Read
    - Write
  - Total, GB/sec
- UPI Bandwidth, GB/sec
  - Total, GB/sec
  - Incoming Data, GB/sec
  - Incoming Non-Data, ...
  - Outgoing Data, GB/sec
  - Outgoing Non-Data, ...

Grouping: Memory Object / Function / Allocation Stack

Memory Object / Function / Allocation Stack	CPU Time	Memory Bound	Loads	Stores	LLC Miss Count	Average Latency (cycles)	Module	
[Unknown]			66,067,981,980	14,147,424,410	2,058,144,060	308		
mainompparallel_for@343	250.863s	96.7%	4,984,149,520	2,408,072,240	945,066,150	1,402	stream_mod.x	mair
mainompparallel_for@333	228.440s	96.3%	4,921,147,630	2,450,073,500	882,061,740	1,557	stream_mod.x	mair
mainompparallel_for@323	184.673s	96.3%	2,422,072,660	2,464,073,920	224,015,680	1,487	stream_mod.x	mair
mainompparallel_for@286	17.476s	98.0%	168,005,040	189,005,670	7,000,490	1,937	stream_mod.x	mair
sched_yield	0.216s	0.0%	21,000,630	0	0	16	libc-2.17.so	sche
__intel_avx_rep_memcpy	182.668s	98.5%	3,682,110,460	2,408,072,240	0	1,353	libintlc.so.5	__in
main	0.025s	0.0%	0	0	0	0	stream_mod.x	mair
[hfi1]	0.005s	0.0%	0	0	0	0	hfi1	[hfi1
[sep5]	0.065s	100.0%	0	0	0	0	sep5	[sep
[Unknown stack frame(s)]	0s	0.0%	28,000,840	0	0	0		[Unk

FILTER 96.0% | Process: Any Process | Thread: Any Thread | Module: Any Module | Loop Mode: Functions only | Inline Mode: Show inline functions

Collecting Memory Access with Objects

$ vtune -c memory-access -knob analyze-mem-objects=true -r ./r_mao_mod -- ./stream_mod.x

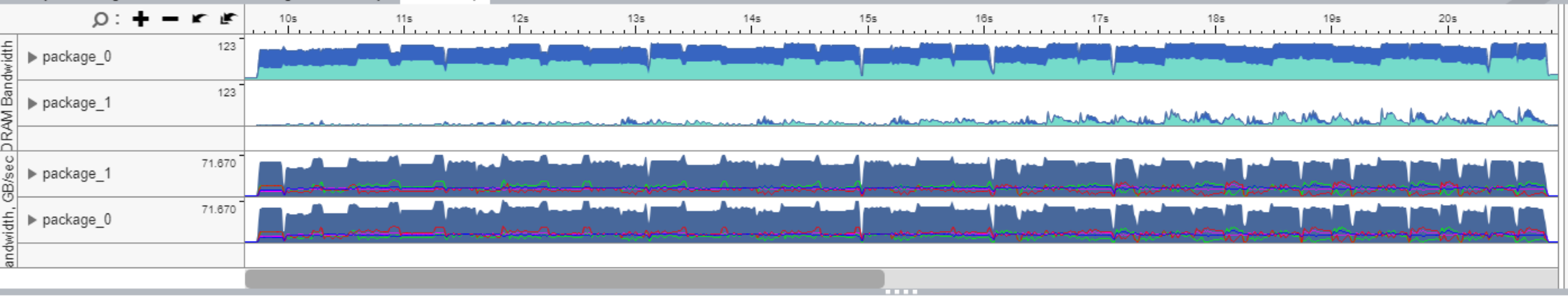
Intel VTune Amplifier

r_mao_mod

Memory Access Memory Usage

INTEL VTUNE AMPLIFIER 2019

Analysis Configuration | Collection Log | Summary | Bottom-up | Platform



Grouping: Memory Object / Function / Allocation Stack

Memory Object / Function / Allocation Stack	CPU Time	Memory Bound	Loads	Stores	LLC Miss Count	Average Latency (cycles)	Module	Function (Ful
stream_mod.x!c (7 GB)			5,530,165,900	4,942,148,260	840,058,800	1,773		
stream_mod.x!b (7 GB)			3,570,107,100	2,443,073,290	714,049,980	1,716		
stream_mod.x!a (7 GB)			6,986,209,580	2,618,078,540	560,039,200	1,599		
mainompparallel_for@333	0s	0.0%	3,143,094,290	0	518,036,260	1,656	stream...	mainompp
mainompparallel_for@286	0s	0.0%	189,005,670	203,006,090	28,001,960	0	stream...	mainompp
__intel_avx_rep_memcpy	0s	0.0%	3,654,109,620	0	14,000,980	1,531	libintlc....	__intel_avx_r
mainompparallel_for@343	0s	0.0%	0	2,415,072,450	0	0	stream...	mainompp
[vmlinux]			5,887,176,610	3,773,113,190	7,000,490	58		
[Unknown]			266,007,980	0	0	0		
stream_mod.x!main (2 MB)			140,004,200	637,019,110	0	7		
libiomp5.so![OpenMP fork] (1 MB)			182,005,460	581,017,430	0	7		
libiomp5.so![OpenMP fork] (1 MB)			1,582,047,460	1,232,036,960	0	7		
[Stack]			32,823,984,690	2,492,074,760	0	7		
[libiomp5.so]			26,488,794,640	0	0	7		
libiomp5.so!__kmp_global (128 B)			70,002,100	0	0	7		
libiomp5.so!__kmp_nth (4 B)			105,003,150	0	0	7		
libiomp5.so!__kmp_itt_fsync_prepare_ptr__3_0 (8 B)			49,001,470	0	0	7		
libiomp5.so!__kmp_tasking_mode (4 B)			0	0	0	7		
libiomp5.so!__kmp_dflt_blocktime (4 B)			245,007,350	0	0	6		
libiomp5.so!__kmp_avail_proc (4 B)			21,000,630	0	0	7		

FILTER 96.3% | Process: Any Process | Thread: Any Thread | Module: Any Module | Loop Mode: Functions only | Inline Mode: Show inline functions

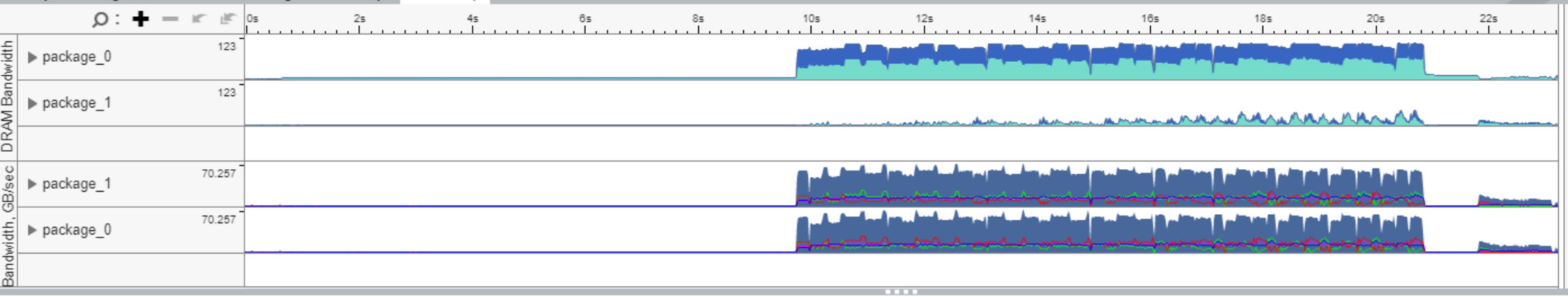
Intel VTune Amplifier

r_mao_mod

Memory Access Memory Usage

INTEL VTUNE AMPLIFIER 2019

Analysis Configuration | Collection Log | Summary | Bottom-up | Platform



Grouping: Memory Object / Function / Allocation Stack

Memory Object / Function / Allocation Stack	CPU Time	Memory Bound	Loads	Stores	LLC Miss Count ▼	Average Latency (cycles)	Module	
stream_mod.x!c (7 GB)			5,908,177,240	5,019,150,570	847,059,290	1,695		
stream_mod.x!b (7 GB)			3,801,114,030	2,548,076,440	714,049,980	1,552		
stream_mod.x!a (7 GB)			8,337,250,110	3,073,092,190	581,040,670	1,501		
mainompparallel_for@333	0s	0.0%	3,143,094,290	0	518,036,260	1,656	stream_mod.x	main$
mainompparallel_for@286	0s	0.0%	189,005,670	203,006,090	28,001,960	0	stream_mod.x	main$
checkSTREAMresults	0s	0.0%	1,351,040,530	0	21,001,470	61	stream_mod.x	check
__intel_avx_rep_memcpy	0s	0.0%	3,654,109,620	0	14,000,980	1,531	libintlc.so.5	__inte
main	0s	0.0%	0	455,013,650	0	0	stream_mod.x	main
mainompparallel_for@343	0s	0.0%	0	2,415,072,450	0	0	stream_mod.x	main$
[vmlinux]			9,128,273,840	5,656,169,680	7,000,490	50		
[Unknown]			441,013,230	14,000,420	0	0		
stream_mod.x!main (2 MB)			161,004,830	756,022,680	0	7		
libiomp5.so![OpenMP fork] (1 MB)			210,006,300	728,021,840	0	7		
libiomp5.so![OpenMP fork] (1 MB)			1,862,055,860	1,610,048,300	0	7		
[Stack]			40,475,214,220	3,178,095,340	0	7		
[ld-linux-x86-64.so.2]			245,007,350	147,004,410	0	0		
[libiomp5.so]			32,403,972,090	0	0	7		
libiomp5.so!__kmp_global (128 B)			84,002,520	0	0	7		
libiomp5.so!__kmp_nth (4 B)			119,003,570	0	0	7		
libiomp5.so!__kmp_itt_fsync_prepare_ptr__3_0 (8 B)			56,001,680	0	0	7		

FILTER 100.0% | Process: Any Process | Thread: Any Thread | Module: Any Module | Loop Mode: Functions only | Inline Mode: Show inline functions

Intel VTune Amplifier

r_mao_mod

Memory Access Memory Usage

INTEL VTUNE AMPLIFIER 2019

Analysis Configuration | Collection Log | Summary | Bottom-up | Platform | stream_mod.c

Source | Assembly

...	Source	CPU Time: Total	CPU Time: Self	Memory Bound: Total
253	printf ("Number of Threads requested = %i\n",k);			
254	}			
255	}			
256	#endif			
257				
258	#ifdef _OPENMP			
259	k = 0;			
260	#pragma omp parallel			
261	#pragma omp atomic			
262	k++;			
263	printf ("Number of Threads counted = %i\n",k);			
264	#endif			
265				
266	/* Get initial value for system clock. */			
267	//#pragma omp parallel for			
268	for (j=0; j<STREAM_ARRAY_SIZE; j++) {			
269	a[j] = 1.0;	0usec	0usec	0.0%
270	b[j] = 2.0;			
271	c[j] = 0.0;			
272	}			
273				
274	printf(HLINE);			
275				
276	if ((quantum = checktick()) >= 1)			
277	printf("Your clock granularity/precision appears to be "			
278	"%d microseconds.\n", quantum);			
279	else {			
280	printf("Your clock granularity appears to be "			
281	"less than one microsecond.\n");			
282	quantum = 1;			
283	}			
284				
285	t = mysecond();			
286	#pragma omp parallel for			

Linux first touch policy

- Memory is assigned to NUMA domains
  - not during the (default) allocation
  - but when the memory is being touched by the first time
- The NUMA domain that will get the memory assigned as local memory, is therefore the domain from where the corresponding thread touched the memory for the first time

Let’s fix it!

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r_hpc_baseline

HPC Performance Characterization | HPC Performance Characterization | INTEL VTUNE AMPLIFIER 2019

Analysis Configuration | Collection Log | Summary | Bottom-up

Elapsed Time: 7.490s

SP GFLOPS:	0.000
DP GFLOPS:	3.818
x87 GFLOPS:	0.000
CPI Rate:	10.039
Average CPU Frequency:	2.4 GHz
Total Thread Count:	96

Effective Physical Core Utilization: 61.1% (29.339 out of 48)

Effective Logical Core Utilization: 60.8% (58.327 out of 96)

Serial Time (outside parallel regions): 2.872s (38.3%)

Top Serial Hotspots (outside parallel regions)

This section lists the loops and functions executed serially in the master thread outside of any OpenMP region and consuming the most CPU time. Improve overall application performance by optimizing or parallelizing these hotspot functions. Since the Serial Time metric includes the Wait time of the master thread, it may significantly exceed the aggregated CPU time in the table.

Function	Module	Serial CPU Time
[Loop at line 462 in checkSTREAMresults]	stream.x	2.140s
[vmlinux]	vmlinux	0.692s
func@0x7d340	libittnotify_collector.so	0.005s
strcmp	ld-2.17.so	0.005s

*N/A is applied to non-summable metrics.

Parallel Region Time: 4.618s (61.7%)

Effective CPU Utilization Histogram

Memory Bound: 88.7% of Pipeline Slots

Cache Bound:	29.0% of Clockticks
DRAM Bound:	**50.2% of Clockticks**
DRAM Bandwidth Bound:	56.2% of Elapsed Time
NUMA: % of Remote Accesses:	0.3%

Bandwidth Utilization Histogram

Vectorization: 100.0% of Packed FP Operations

Instruction Mix:

Intel VTune Amplifier

r_hpc_baseline

HPC Performance Characterization HPC Performance Characterization

INTEL VTUNE AMPLIFIER 2019

Analysis Configuration | Collection Log | Summary | Bottom-up

Grouping: Function / Call Stack

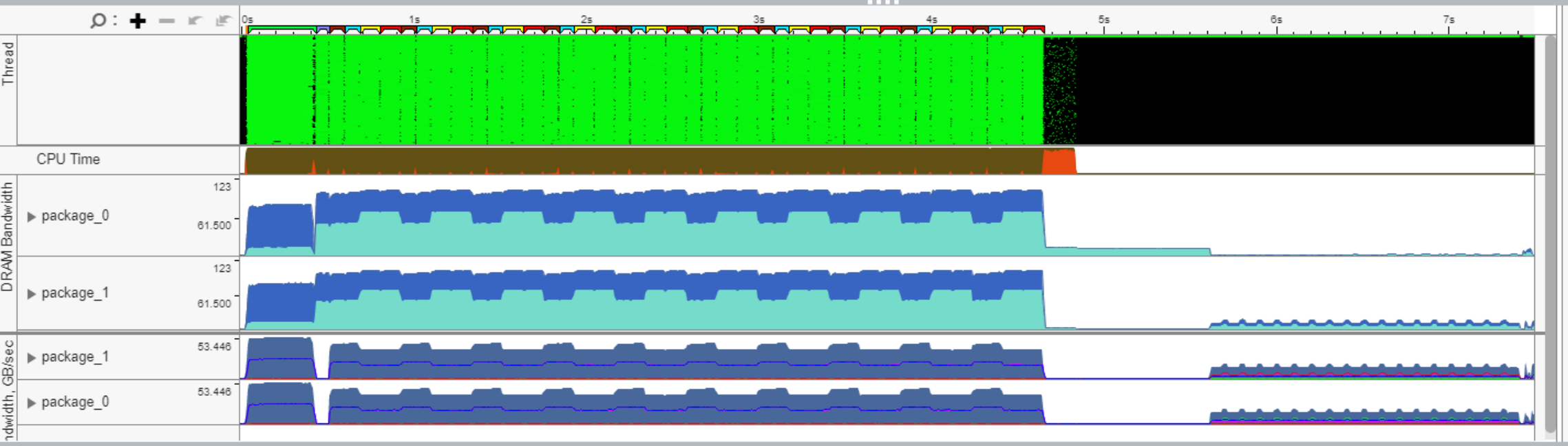
Function / Call Stack	CPU Time ▼			Serial CPU Time	Memory Bound	NUMA: % of Remote Accesses	% of
	Effective Time by Utilization (Idle Poor Ok Ideal Over)	Spin Time	Overhead Time				
[Loop at line 333 in mainompparallel_for@333]	110.564s	0s	0s	0s	93.5%	0.0%	
[Loop at line 343 in mainompparallel_for@343]	110.409s	0s	0s	0s	93.1%	0.0%	
[Loop@0x466d0 in __intel_avx_rep_memcpy]	80.814s	0s	0s	0s	95.9%	0.0%	
[Loop at line 323 in mainompparallel_for@323]	78.820s	0s	0s	0s	91.5%	0.0%	
[vmlinux]	29.414s	0s	0s	0.692s	83.4%	50.0%	
[Loop at line 361 in _INTERNAL_25_____src_kmp_bar	0s	21.255s	0s	0s	11.3%	0.0%	
[Loop at line 267 in mainompparallel_for@267]	17.451s	0s	0s	0s	91.7%	0.0%	
[Loop at line 286 in mainompparallel_for@286]	7.207s	0s	0s	0s	88.9%	0.0%	
[Loop at line 462 in checkSTREAMresults]	2.140s	0s	0s	2.140s	70.0%	0.0%	
_INTERNAL_25_____src_kmp_barrier_cpp_38a91946	0s	0.957s	0s	0s	5.5%	0.0%	
kmp_flag_native<unsigned long long>::get	0s	0.281s	0s	0s	0.0%	0.0%	

Elapsed Time: 7.490s

SP GFLOPS: 0.000
DP GFLOPS: 3.818
x87 GFLOPS: 0.000
CPI Rate: 10.039
Average CPU Frequency: 2.4 GHz
Total Thread Count: 96

Effective Physical Core Utilization: 61.1% (29.339 out of 48)
Effective Logical Core Utilization: 60.8% (58.327 out of 96)
Serial Time (outside parallel regions): 2.872s (38.3%)
Parallel Region Time: 4.618s (61.7%)
Effective CPU Utilization Histogram

Memory Bound: 88.7% of Pipeline Slots
Cache Bound: 29.0% of Clockticks
DRAM Bound: 50.2% of Clockticks



Scale Markers:
- Region Instance
- OpenMP Barrier-to-Barrier Segment
- Thread
  - Effective Time
  - Spin and Overhe…
- CPU Time
  - CPU Time
  - Spin and Overhe…
- DRAM Bandwidth
  - Average Bandwidth,…
    - Read
    - Write
  - Total, GB/sec
- Interconnect Bandwi…
  - Interconnect Out…
  - Interconnect Inco…
- Interconnect Packet …

FILTER 100.0% | Process: Any Process | Module: Any Module | Call Stack Mode: User functions + 1 | Loop Mode: Loops and functions | Inline Mode: Show inline functions

Fine, but what about the mem BW increase on socket #2?

Linux Kernel page migration

- New in RHEL 7 / SLES 12
- Default configuration is ON
- Introduces background noise, bad for benchmarking
- Check status via

```
$ cat /proc/sys/kernel/numa_balancing
```

What if we would increase the runtime from 10 iterations to 100?

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r_hpc_mod_long

HPC Performance Characterization HPC Performance Characterization

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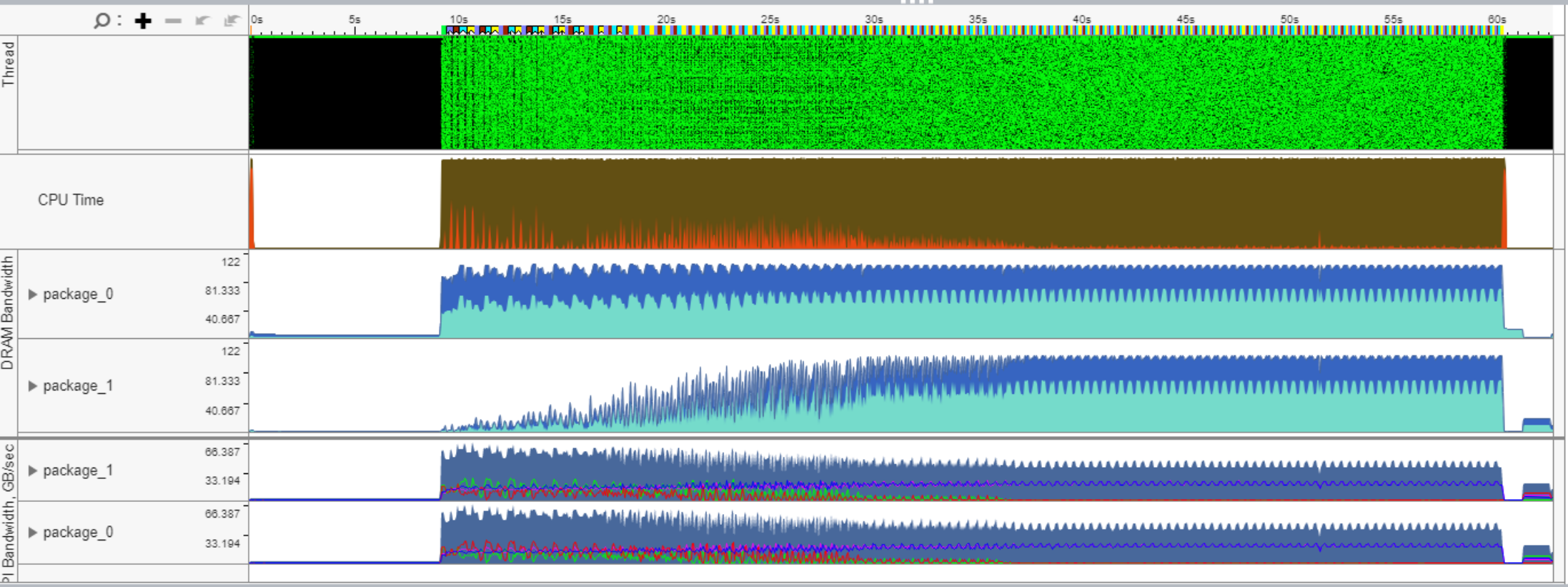
Analysis Configuration | Collection Log | Summary | Bottom-up

Grouping: Function / Call Stack

Function / Call Stack	CPU Time ▼			Serial CPU Time	Memory Bound	NUMA: % of Remote Accesses	% of FP Ops	FP Op
	Effective Time by Utilization (Idle Poor Ok Ideal Over)	Spin Time	Overhead Time					
[Loop at line 343 in mainompparallel_for@343]	1291.256s	0s	0s	0s	93.3%	5.6%	27.4%	
[Loop at line 333 in mainompparallel_for@333]	1259.391s	0s	0s	0s	93.4%	7.1%	15.0%	
[Loop at line 323 in mainompparallel_for@323]	943.471s	0s	0s	0s	92.4%	3.1%	13.9%	
[Loop@0x466d0 in __intel_avx_rep_memcpy]	926.731s	0s	0s	0s	96.3%	5.3%	0.0%	
[Loop at line 361 in _INTERNAL_25_____src_kmp_barrier_cpp_38a91946::	0s	274.293s	0s	0s	9.3%	0.0%	0.0%	
[vmlinux]	145.461s	0s	0s	5.122s	65.2%	33.3%	0.0%	



Segment
- Thread
  - Effective Time
  - Spin and Overhead Time
- CPU Time
  - CPU Time
  - Spin and Overhead Time
- DRAM Bandwidth
  - Average Bandwidth, GB/sec
    - Read
    - Write
  - Total, GB/sec
- Interconnect Bandwidth
  - Interconnect Outgoing Ba…
  - Interconnect Incoming Ba…
- Interconnect Packet Rate
  - Interconnect Outgoing Pa…
  - Interconnect Incoming Pa…
- UPI Bandwidth, GB/sec
  - Total, GB/sec
  - Incoming Data, GB/sec
  - Incoming Non-Data, GB/s…
  - Outgoing Data, GB/sec
  - Outgoing Non-Data, GB/s…

FILTER 100.0% | Process: Any Process | Module: Any Module | Call Stack Mode: User functions + 1 | Loop Mode: Loops and functions | Inline Mode: Show inline functions

Some earlier problem indicators we missed?

Besides being fooled by filters and zoom

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r_hs_mod

Hotspots | Hotspots by CPU Utilization

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Analysis Configuration | Collection Log | Summary | Bottom-up | Caller/Callee | Top-down Tree | Platform

Grouping: Function / Call Stack

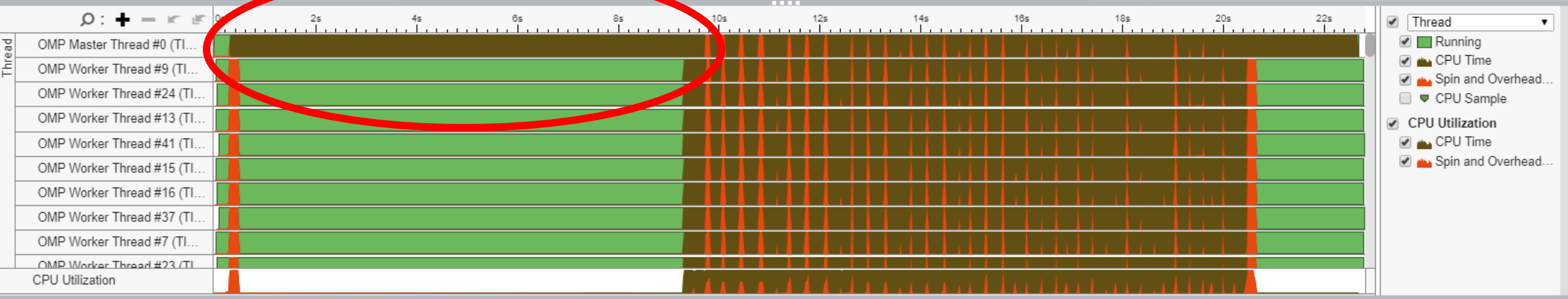
Function / Call Stack	CPU Time: Effective Time	CPU Time: Spin Time	CPU Time: Overhead Time	Module	Function (Full)	Source File	Start
mainompparallel_for@343	273.620s	0s	0s	stream_mod.x	mainompparallel...	stream_mod.c	0x401
mainompparallel_for@333	257.123s	0s	0s	stream_mod.x	mainompparallel...	stream_mod.c	0x401
__intel_avx_rep_memcpy	210.412s	0s	0s	libintlc.so.5	__intel_avx_rep_m...		0x465
mainompparallel_for@323	206.630s	0s	0s	stream_mod.x	mainompparallel...	stream_mod.c	0x401
mainompparallel_for@286	20.914s	0s	0s	stream_mod.x	mainompparallel...	stream_mod.c	0x402
main	8.940s	0s	0s	stream_mod.x	main	stream_mod.c	0x400
checkSTREAMresults	2.200s	0s	0s	stream_mod.x	checkSTREAMresults	stream_mod.c	0x402
[Outside any known module]	0.010s	0s	0s		[Outside any known...		0
[Import thunk sched_yield]	0.010s	0s	0s	libiomp5.so	[Import thunk sched...		0x281
__kmp_get_global_thread_id_reg	0s	0s	0.020s	libiomp5.so	__kmp_get_global_...	kmp_runtime.cpp	0xa96
__kmp_join_call	0s	1.286s	0s	libiomp5.so	__kmp_join_call	kmp_runtime.cpp	0xb2c
__kmp_join_barrier	0s	2.798s	0s	libiomp5.so	__kmp_join_barrier(...	kmp_barrier.cpp	0x6b4
__kmp_fork_barrier	0s	132.014s	0s	libiomp5.so	__kmp_fork_barrier...	kmp_barrier.cpp	0x6c1
__kmp_finish_implicit_task	0s	0s	0.023s	libiomp5.so	__kmp_finish_impli...	kmp_tasking.cpp	0xd97
_INTERNAL_25_____src_kmp_runtime_cpp_16bf24c5::__k	0s	0s	0.020s	libiomp5.so	_INTERNAL_25___...	kmp_itt.inl	0xadf

CPU Time

Viewing 1 of 1 selected stack(s)

100.0% (273.620s of 273.620s)

stream_mod.x!mainompparallel_for@343 - stream_mod.c
libiomp5.so![OpenMP dispatcher]+0x125 - kmp_runtime.cpp:7540
libiomp5.so!__kmp_fork_call+0x16a8 - kmp_runtime.cpp:2494
libiomp5.so![OpenMP fork]+0x17f - kmp_csupport.cpp:365
stream_mod.x!main+0xd74 - stream_mod.c:343
libc.so.6!__libc_start_main+0xf4 - [unknown source file]
stream_mod.x!_start+0x28 - [unknown source file]



Thread
- Running
- CPU Time
- Spin and Overhead...
- CPU Sample

CPU Utilization
- CPU Time
- Spin and Overhead...

FILTER 100.0% | Process: Any Process | Thread: Any Thread | Module: Any Module | Any Utilization | Call Stack Mode: User functions | Loop Mode: Functions on | Inline Mode: Show inline fu

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r_hpc_mod

HPC Performance Characterization | HPC Performance Characterization | INTEL VTUNE AMPLIFIER 2019

Analysis Configuration | Collection Log | Summary | Bottom-up

Elapsed Time: 21.772s

SP GFLOPS:	0.000
DP GFLOPS:	0.990
x87 GFLOPS:	0.000
CPI Rate:	9.293
Average CPU Frequency:	2.4 GHz
Total Thread Count:	96

Effective Physical Core Utilization: 44.3% (21.274 out of 48)

Effective Logical Core Utilization: 43.9% (42.101 out of 96)

Serial Time (outside parallel regions): 11.449s (52.6%)

Top Serial Hotspots (outside parallel regions)

This section lists the loops and functions executed serially in the master thread outside of any OpenMP region and consuming the most CPU time. Improve overall application performance by optimizing or parallelizing these hotspot functions. Since the Serial Time metric includes the Wait time of the master thread, it may significantly exceed the aggregated CPU time in the table.

Function	Module	Serial CPU Time
[Loop at line 268 in main]	stream_mod.x	4.210s
func@0x7d340	libittnotify_collector.so	0.005s
[sep5]	sep5	0.005s

*N/A is applied to non-summable metrics.

Parallel Region Time: 10.323s (47.4%)

Effective CPU Utilization Histogram

Memory Bound: 86.7% of Pipeline Slots

Cache Bound:	32.5% of Clockticks
DRAM Bound:	**51.1% of Clockticks**
DRAM Bandwidth Bound:	43.9% of Elapsed Time
NUMA: % of Remote Accesses:	32.8%

Bandwidth Utilization Histogram

Vectorization: 100.0% of Packed FP Operations

[Loop at line 462 in checkSTREAMresults]	stream_mod.x	2.225s
func@0x7d340	libittnotify_collector.so	0.005s
[sep5]	sep5	0.005s

*N/A is applied to non-summable metrics.

Parallel Region Time: 10.323s (47.4%)

Effective CPU Utilization Histogram

Memory Bound: 86.7% of Pipeline Slots

Cache Bound: 32.5% of Clockticks

DRAM Bound: 51.1% of Clockticks

DRAM Bandwidth Bound: 43.9% of Elapsed Time

NUMA: % of Remote Accesses: 32.8%

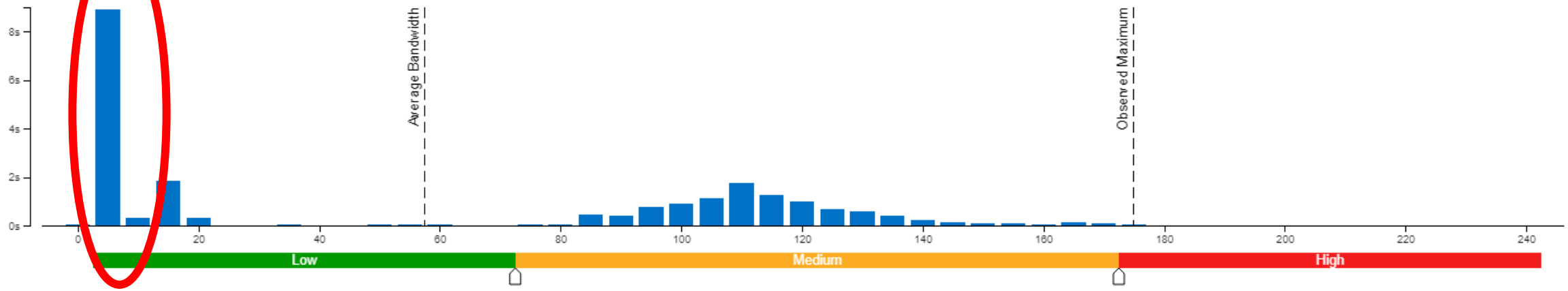
Bandwidth Utilization Histogram

Explore bandwidth utilization over time using the histogram and identify memory objects or functions with maximum contribution to the high bandwidth utilization.

Bandwidth Domain: DRAM, GB/sec

Bandwidth Utilization Histogram

This histogram displays the wall time the bandwidth was utilized by certain value. Use sliders at the bottom of the histogram to define thresholds for Low, Medium and High utilization levels. You can use these bandwidth utilization types in the Bottom-up view to group data and see all functions executed during a particular utilization type. To learn bandwidth capabilities, refer to your system specifications or run appropriate benchmarks to measure them; for example, Intel Memory Latency Checker can provide maximum achievable DRAM and Interconnect bandwidth.

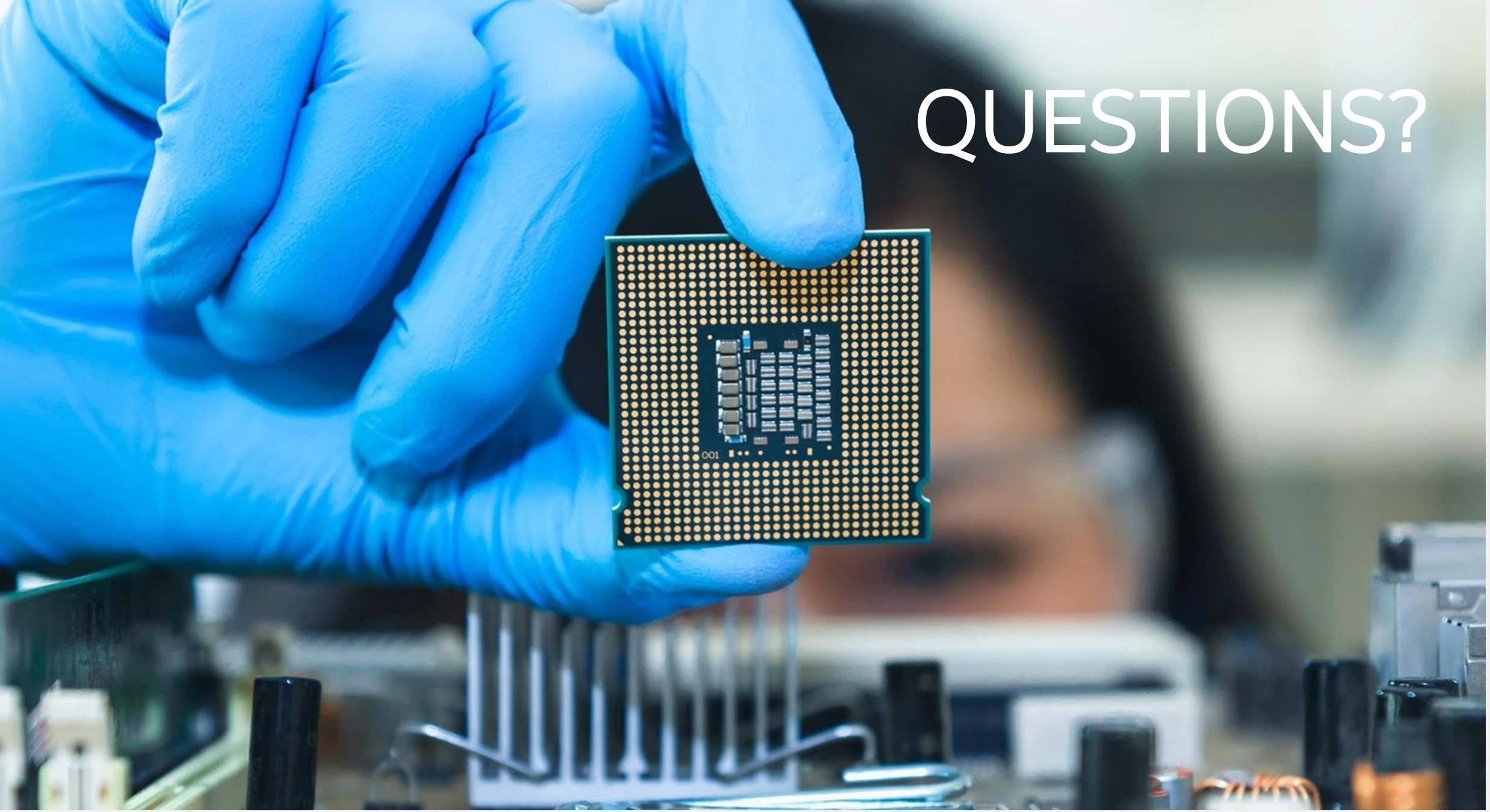


Top Functions with High Bandwidth Utilization

Summary / Getting Started

- Check Kernel permissions for off-core counters in /proc/sys/kernel/perf_event_paranoid - should <= 1
- Get started with the VTune command line help: vtune –h / vtune –h collect / etc.
- Run the VTune collections discussed.:

```
$ vtune -c hotspots -r r_hs_mod -- ./stream_mod.x
$ vtune -c hotspots -knob sampling-mode=hw -r r_hshw_mod -- ./stream_mod.x
$ vtune -c hpc-performance -r r_hpc_mod -- ./stream_mod.x
$ vtune -c memory-access -r ./r_ma_mod -- ./stream_mod.x
$ vtune -c memory-access -knob analyze-mem-objects=true -r ./r_mao_mod -- ./stream_mod.x
```


QUESTIONS?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