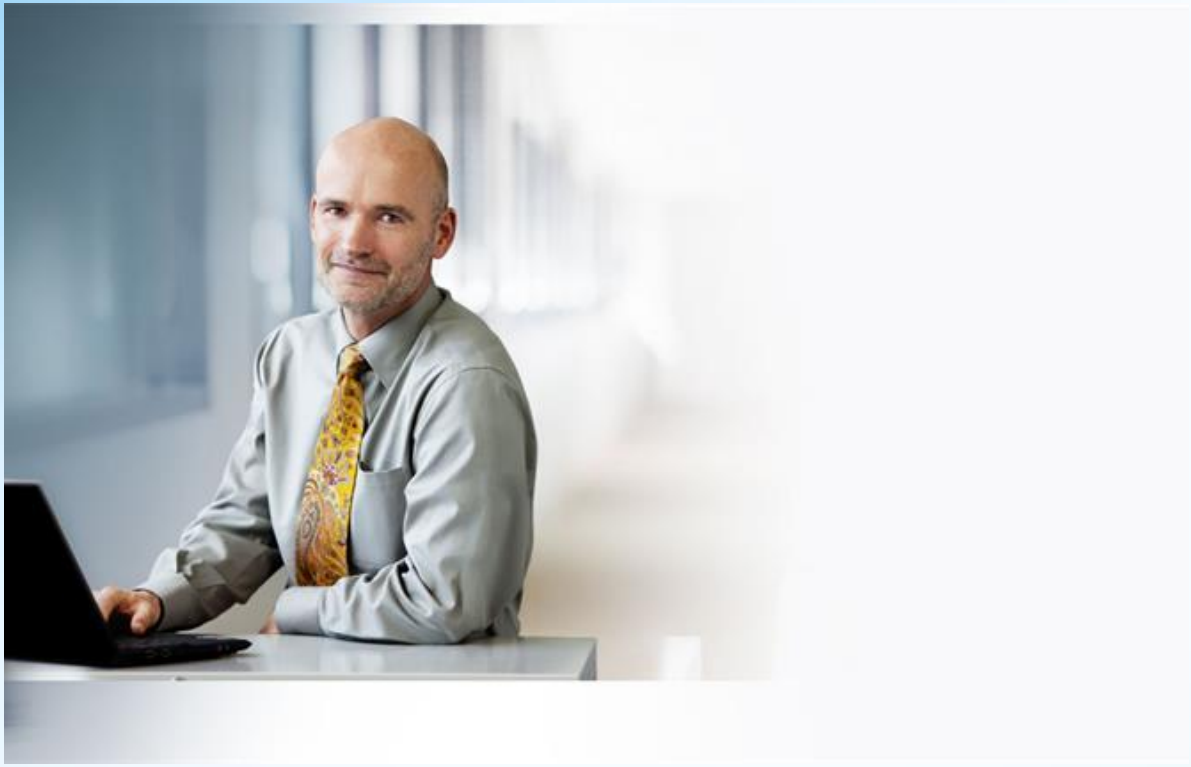


# A Performance Tuning Methodology: From the System Down to the Hardware - Introduction

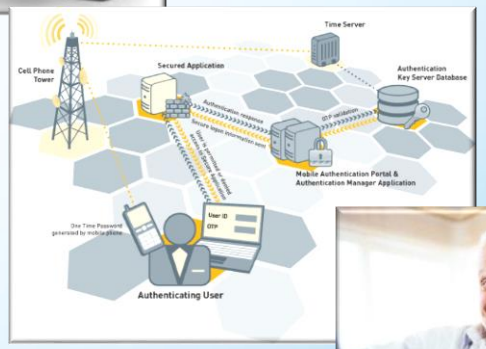
Jackson Marusarz
Intel Corporation
ATPESC 2014

# Why performance profiling?

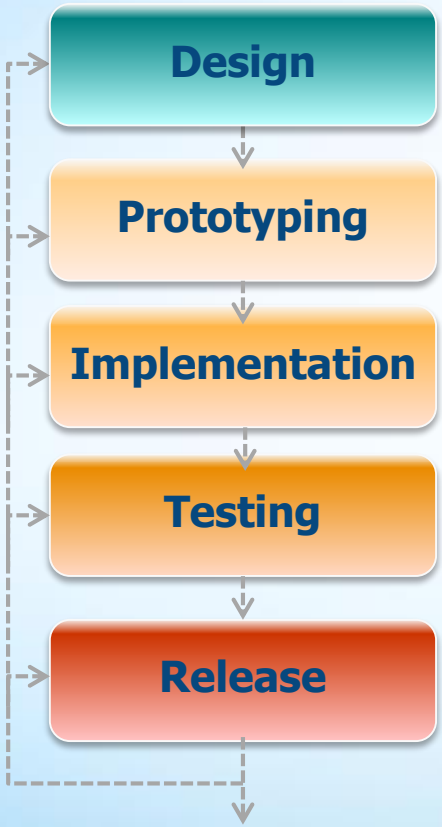
**Project performance tuning for:**

- Reducing direct compute time costs
- Decreasing indirect costs
- Better user/customer experience

If you are not in that business, don't bother




# Project development cycle and performance analysis




Think performance wise (app/sys level)

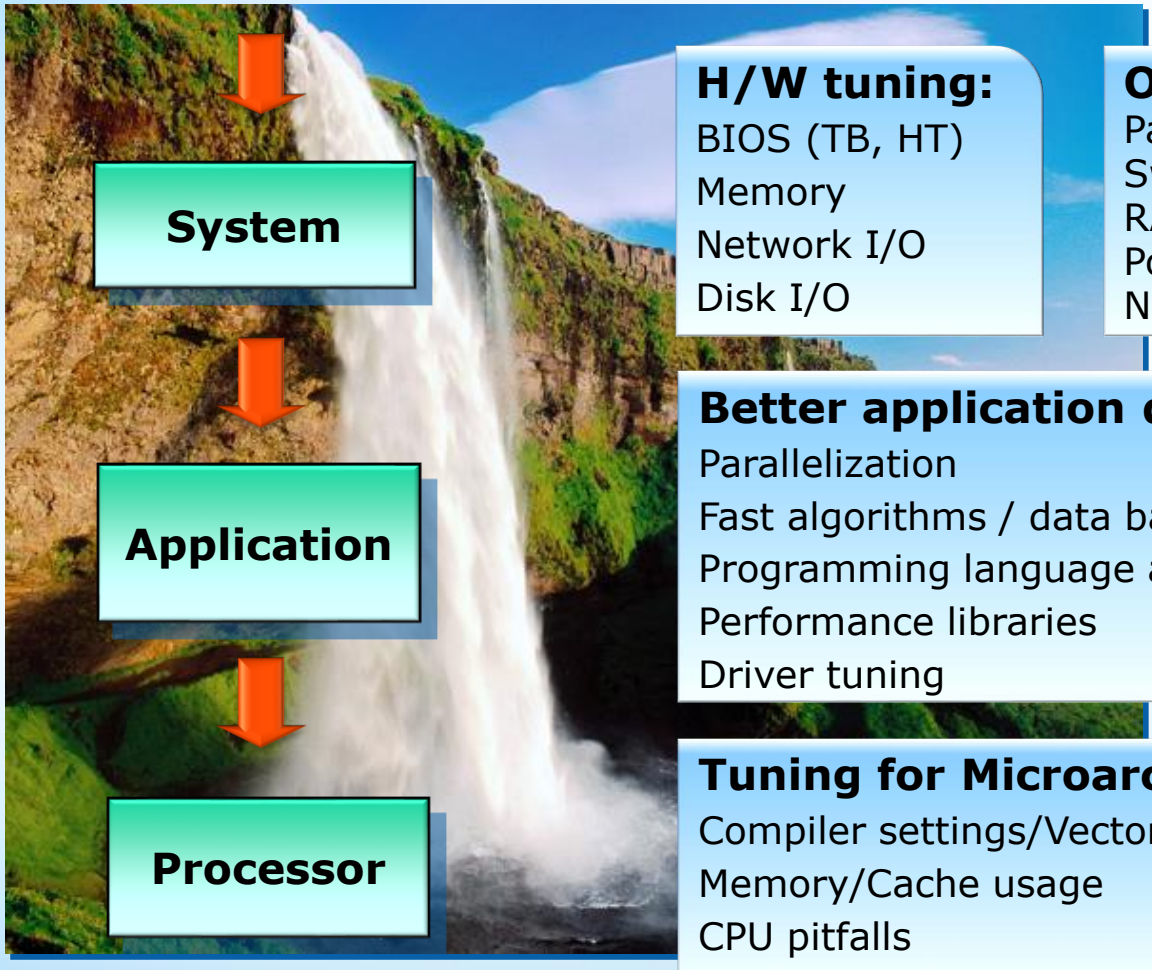
Choose perf. effective solutions

Apply perf. optimization and check results

Add perf. regression phase to test stage

Collect and analyze perf. related complaints from users of your product

# Optimization: A Top-down Approach




**H/W tuning:**
BIOS (TB, HT)
Memory
Network I/O
Disk I/O

**OS tuning:**
Page size
Swap file
RAM Disk
Power settings
Network protocols

**Better application design:**
Parallelization
Fast algorithms / data bases
Programming language and RT libs
Performance libraries
Driver tuning

**Tuning for Microarchitecture:**
Compiler settings/Vectorization
Memory/Cache usage
CPU pitfalls

OS, System **Expertise** SW/uArch

https://software.intel.com/en-us/articles/de-mystifying-software-performance-optimization

# Performance profiling tools
## Level wise selection

| | | |
|---|---|---|
| **System** | System profiler | OS embedded |
| | Universal (for OS, HW) | Windows: Perf mon, Proc mon |
| | Proprietary (OS+HW) | Linux: top, vmstat, OProfile |
| **Application** | Supported languages | Windows: WPT, Xperf, VTune |
| IDE based | .Net/C#, Java | Managed: .Net, Java tools, VTune |
| | Python, Java Script, HTML | Linux: gprof, Valgrind, Google perftools, Crxprof, VTune |
| Command Line | C, C++, Fortran | |
| **Microarchitcture** | Provided by CPU/Platform manufacturer | |

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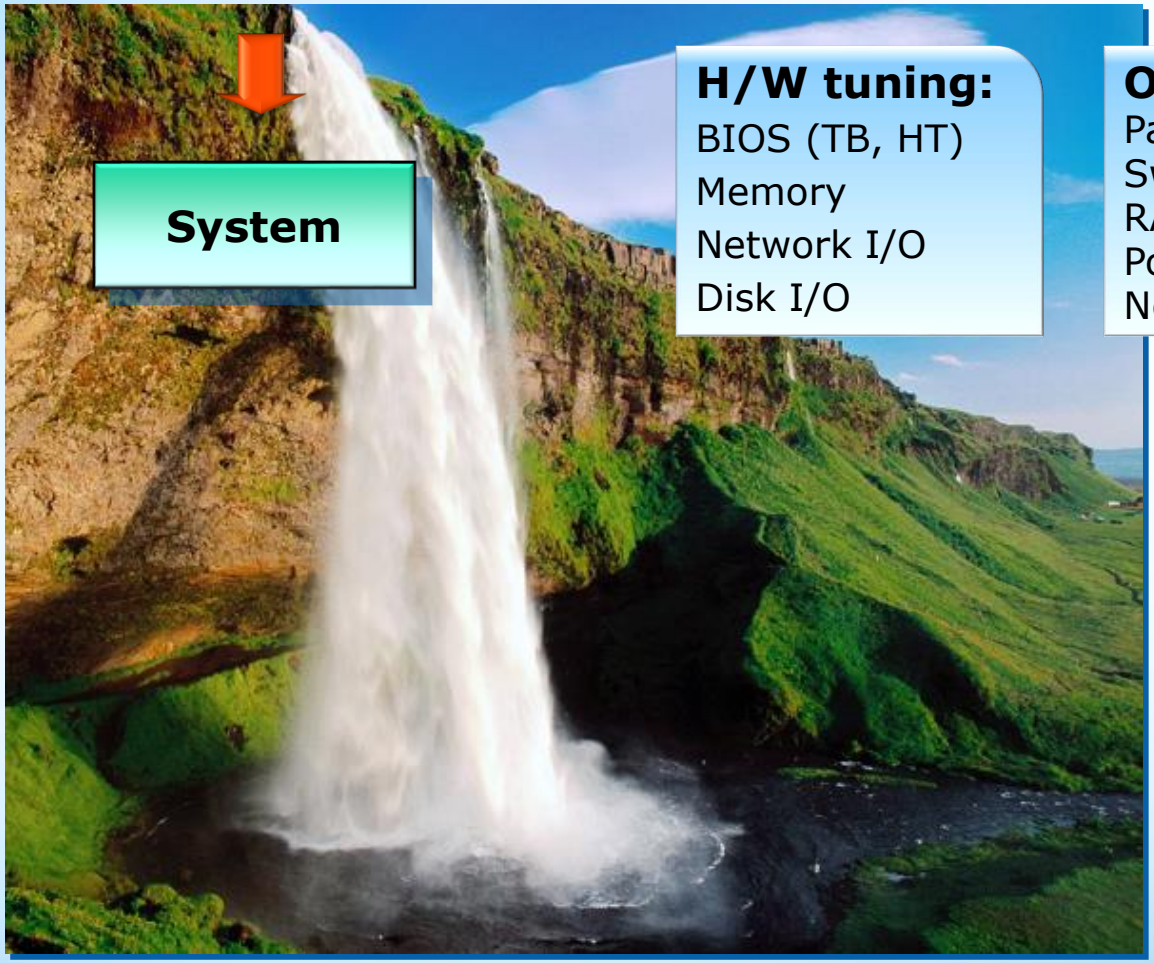
Tools are essential for efficient performance analysis.

# Optimization: A Top-down Approach




**H/W tuning:**
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Power settings
Network protocols

OS, System

# System Tuning

**Who: System Administrators, Performance Engineers, Machine Owners, etc…**

**How:**

- Benchmarks
  - Stream: www.cs.virginia.edu/stream/
  - Numerous FLOPS benchmarks
  - Network/MPI Benchmarks: www.intel.com/go/imb
  - <insert your favorite here>
- Tools
  - vmstat, top, sysprof, iostat, sar, Task Manager, etc…
  - Many vendor/platform specific tools

- Fixes
  - Upgrade Hardware - **$$$**
  - Check BIOS and OS configurations
    - Prefetchers, NUMA, Memory Configuration, Power Management, SMT

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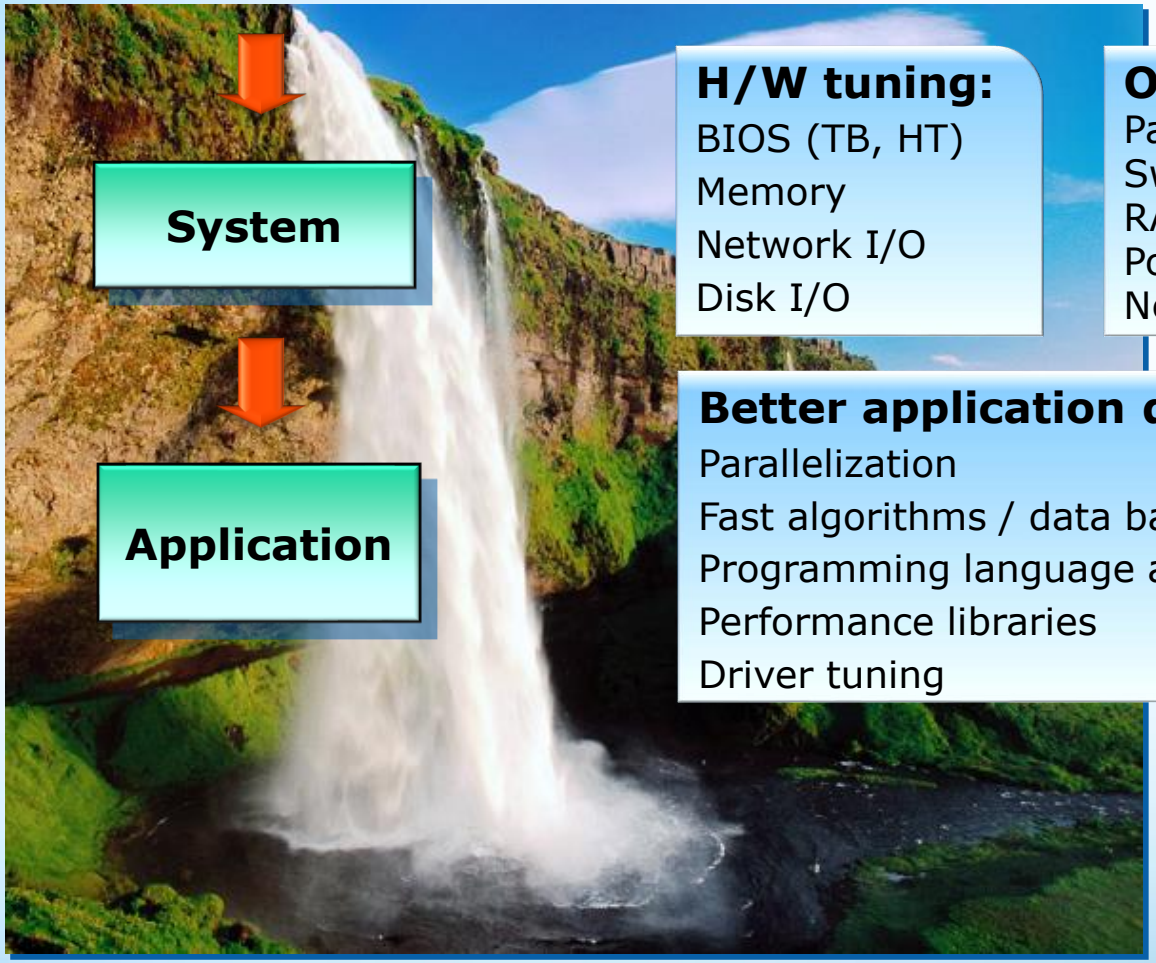
This is often outside the capabilities of most users

# Optimization: A Top-down Approach

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**Better application design:**
Parallelization
Fast algorithms / data bases
Programming language and RT libs
Performance libraries
Driver tuning

OS, System **Expertise**

# Application Tuning

## Who: Software Developers, Performance Engineers, Domain Experts

**How:**

- Workload selection
  - Repeatable results
  - Steady state
- Define Metrics and Collect Baseline
  - Wall-clock time, FLOPS, FPS
  - <insert your metric here>
- Identify Hotspots
  - Focus effort where it counts
  - Use Tools

- Determine inefficiencies
  - Is there parallelism?
  - Are you memory bound?
  - Will better algorithms or programming languages help?

This step often requires some knowledge of the application and its algorithms

# Application Tuning
## Find Hotspots

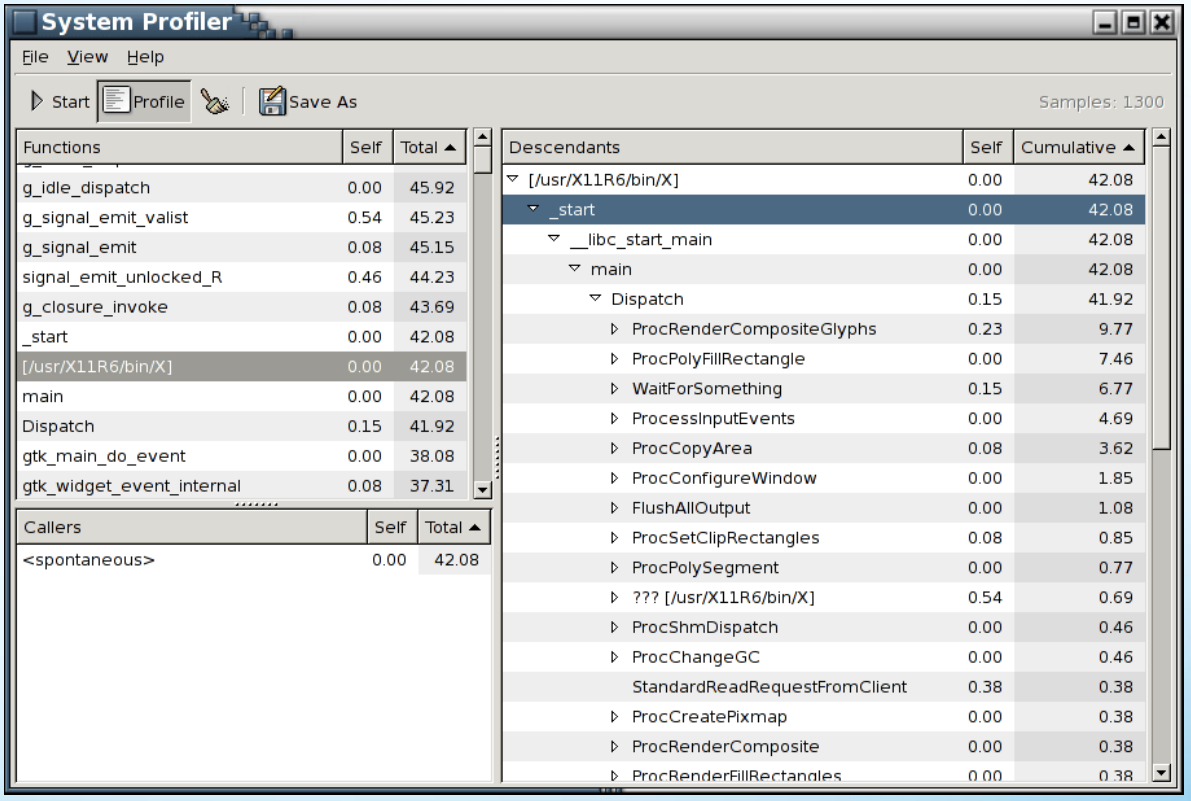
- This could be at the module, function, or source code level
- Determine your own granularity

```
$ opreport --exclude-dependent --demangle=smart --symbols `which lyx`
CPU: PIII, speed 863.195 MHz (estimated)
Counted CPU_CLK_UNHALTED events (clocks processor is not halted) with a unit mask of 0x00 (No unit mask)
vma      samples  %           symbol name
081ec974 5016      8.5096     _Rb_tree<unsigned short, pair<unsigned short const, int>,  unsigned short
0810c4ec 3323      5.6375     Paragraph::getFontSettings(BufferParams const&, int) const
081319d8 3220      5.4627     LyXText::getFont(Buffer const*, Paragraph*, int) const
080e45d8 3011      5.1082     LyXFont::realize(LyXFont const&)
080e3d78 2623      4.4499     LyXFont::LyXFont()
081255a4 1823      3.0927     LyXText::singleWidth(BufferView*, Paragraph*, int, char) const
080e3cf0 1804      3.0605     operator==(LyXFont::FontBits const&, LyXFont::FontBits const&)
081128e0 1729      2.9332     Paragraph::Pimpl::getChar(int) const
081ed020 1380      2.3412     font_metrics::width(char const*, unsigned, LyXFont const&)
08110d60 1310      2.2224     Paragraph::getChar(int) const
081ebc94 1227      2.0816     qfont_loader::getfontinfo(LyXFont const&)
...
```

oprofile: http://oprofile.sourceforge.net/

# Application Tuning
## Find Hotspots

- This could be at the module, function, or source code level
- Determine your own granularity




sysprof: http://sysprof.com

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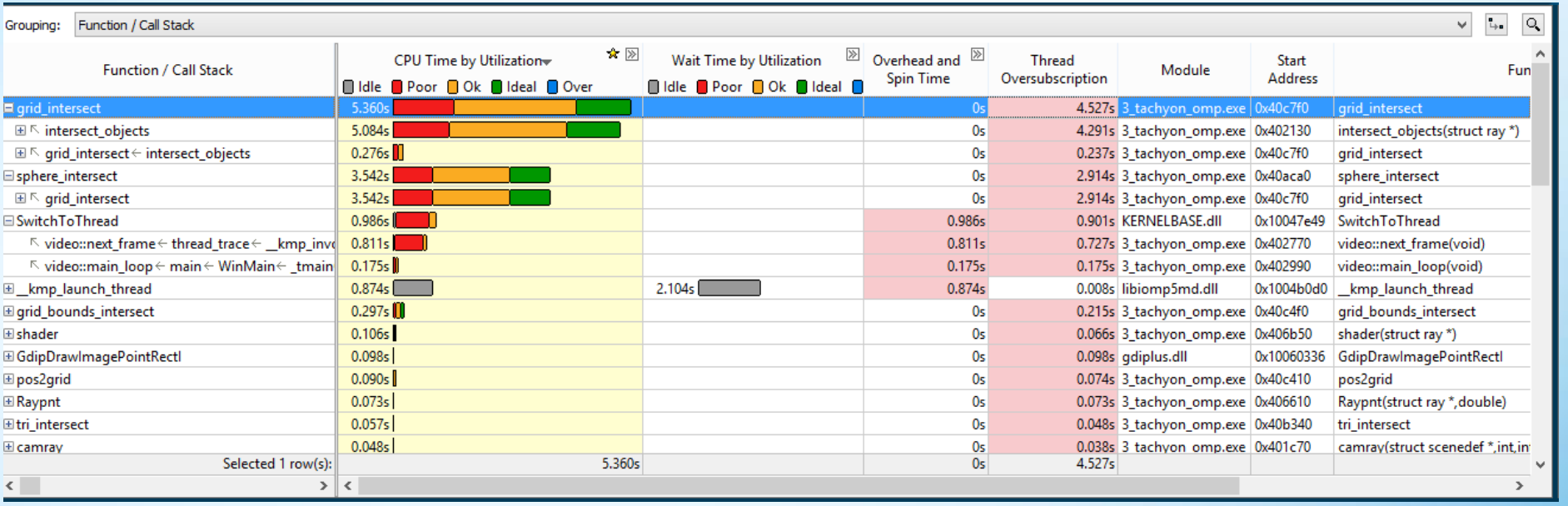


| Function / Call Stack | CPU Time by Utilization (Idle Poor Ok Ideal Over) | Wait Time by Utilization (Idle Poor Ok Ideal) | Overhead and Spin Time | Thread Oversubscription | Module | Start Address | Fun |
|---|---|---|---|---|---|---|---|
| grid_intersect | 5.360s | | 0s | 4.527s | 3_tachyon_omp.exe | 0x40c7f0 | grid_intersect |
| intersect_objects | 5.084s | | 0s | 4.291s | 3_tachyon_omp.exe | 0x402130 | intersect_objects(struct ray *) |
| grid_intersect ← intersect_objects | 0.276s | | 0s | 0.237s | 3_tachyon_omp.exe | 0x40c7f0 | grid_intersect |
| sphere_intersect | 3.542s | | 0s | 2.914s | 3_tachyon_omp.exe | 0x40aca0 | sphere_intersect |
| grid_intersect | 3.542s | | 0s | 2.914s | 3_tachyon_omp.exe | 0x40c7f0 | grid_intersect |
| SwitchToThread | 0.986s | | 0.986s | 0.901s | KERNELBASE.dll | 0x10047e49 | SwitchToThread |
| video::next_frame ← thread_trace ← __kmp_invc | 0.811s | | 0.811s | 0.727s | 3_tachyon_omp.exe | 0x402770 | video::next_frame(void) |
| video::main_loop ← main ← WinMain ← _tmain | 0.175s | | 0.175s | 0.175s | 3_tachyon_omp.exe | 0x402990 | video::main_loop(void) |
| __kmp_launch_thread | 0.874s | 2.104s | 0.874s | 0.008s | libiomp5md.dll | 0x1004b0d0 | __kmp_launch_thread |
| grid_bounds_intersect | 0.297s | | 0s | 0.215s | 3_tachyon_omp.exe | 0x40c4f0 | grid_bounds_intersect |
| shader | 0.106s | | 0s | 0.066s | 3_tachyon_omp.exe | 0x406b50 | shader(struct ray *) |
| GdipDrawImagePointRectI | 0.098s | | 0s | 0.098s | gdiplus.dll | 0x10060336 | GdipDrawImagePointRectI |
| pos2grid | 0.090s | | 0s | 0.074s | 3_tachyon_omp.exe | 0x40c410 | pos2grid |
| Raypnt | 0.073s | | 0s | 0.073s | 3_tachyon_omp.exe | 0x406610 | Raypnt(struct ray *,double) |
| tri_intersect | 0.057s | | 0s | 0.048s | 3_tachyon_omp.exe | 0x40b340 | tri_intersect |
| camray | 0.048s | | 0s | 0.038s | 3_tachyon_omp.exe | 0x401c70 | camray(struct scenedef *,int,in |
| Selected 1 row(s): | 5.360s | | 0s | 4.527s | | | |

Intel® VTune™ Amplifier XE: http://intel.ly/vtune-amplifier-xe

# Application Tuning
## Find Hotspots

- This could be at the module, function, or source code level
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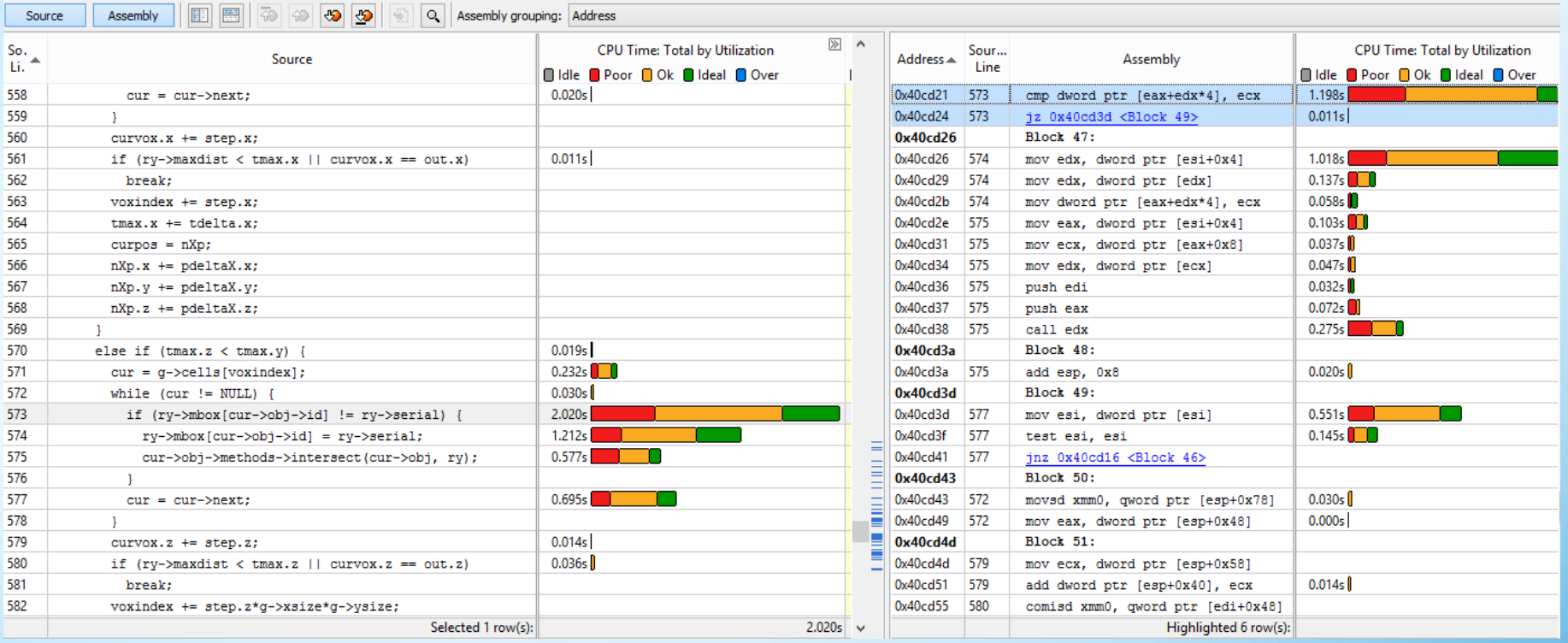


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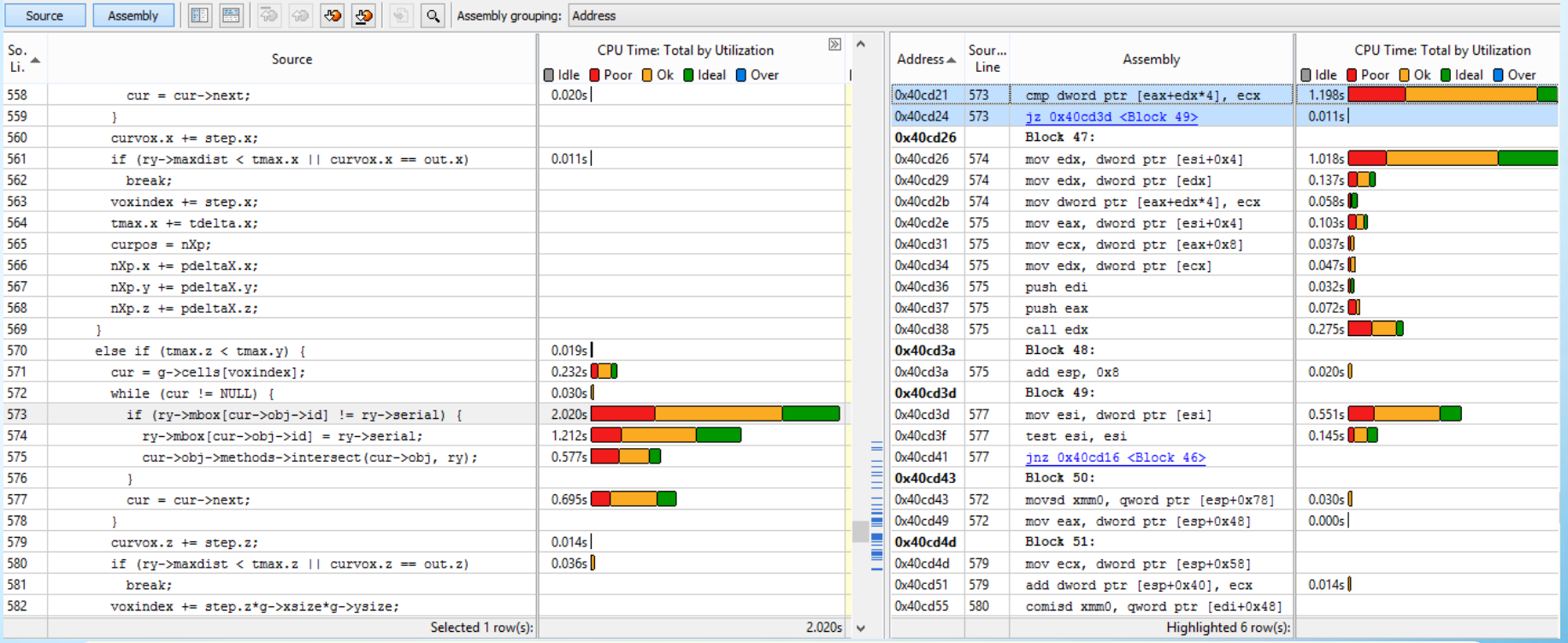



This may reinforce your understanding of the application but often reveals surprises

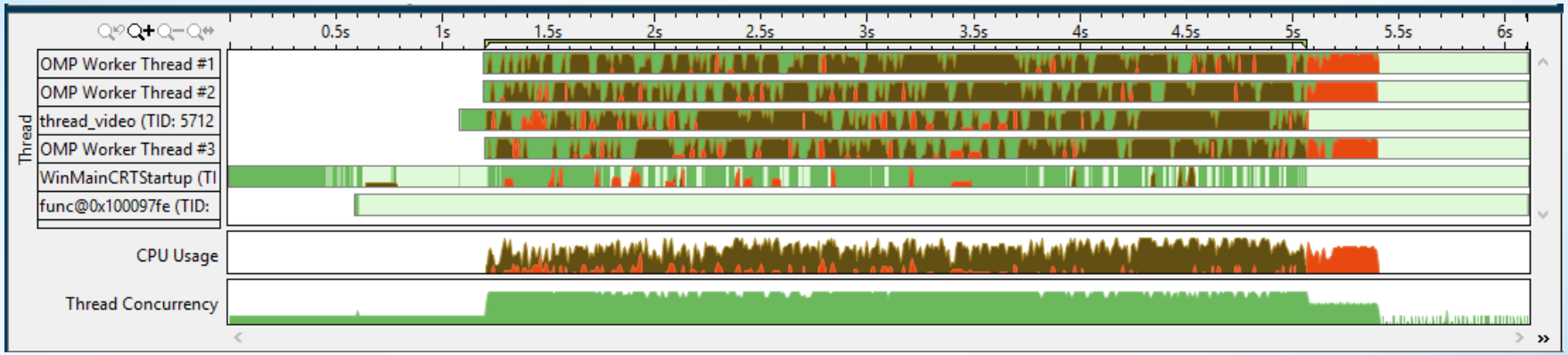
# Application Tuning
## Resource Utilization

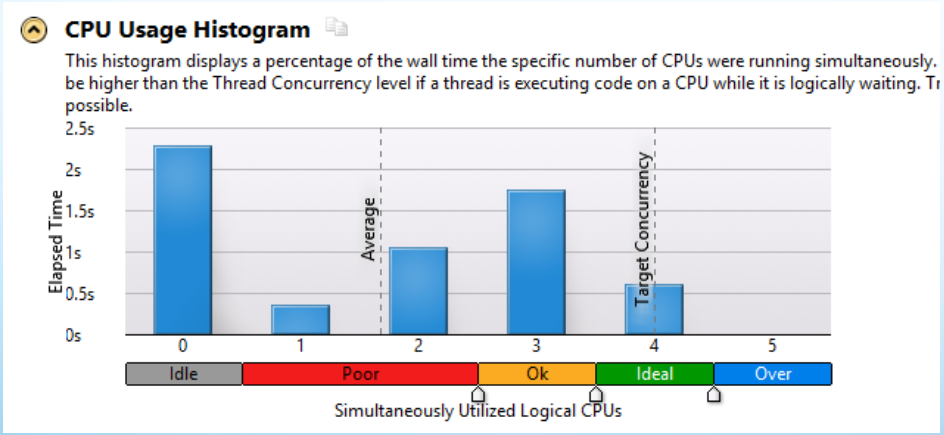
- Is the application parallel?
- Multi-thread vs. Multi-process
- Memory Bound?

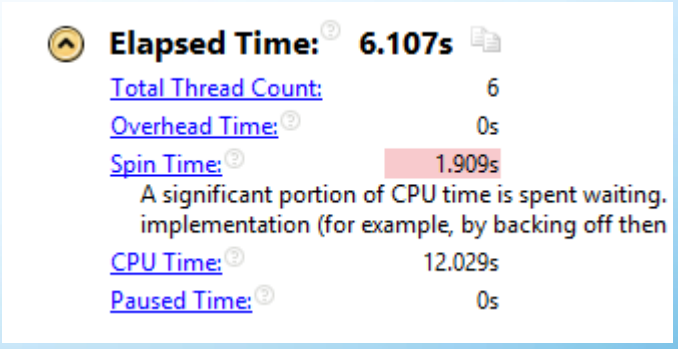
```
last pid: 86494;  load averages:  0.83,  0.65,  0.69   up 67+22:48:43  14:44:15
227 processes: 1 running, 224 sleeping, 2 zombie
CPU: 20.2% user,  0.0% nice,  6.5% system,  0.2% interrupt, 73.1% idle
Mem: 1657M Active, 1868M Inact, 273M Wired, 190M Cache, 112M Buf, 11M Free
Swap: 4500M Total, 249M Used, 4251M Free, 5% Inuse

  PID USERNAME  THR PRI NICE   SIZE    RES STATE  C   TIME   WCPU COMMAND
86460 www         1   4    0   150M 30204K accept 1   0:02 11.18% php-cgi
86458 www         1   4    0   150M 29912K accept 0   0:02  8.98% php-cgi
86463 pgsql       1   4    0   949M    99M sbwait 1   0:01  7.96% postgres
85885 www         1   4    0   150M 35204K accept 2   0:07  7.57% php-cgi
85274 www         1   4    0   149M 40868K sbwait 3   0:27  5.18% php-cgi
85267 www         1   4    0   151M 40044K sbwait 2   0:33  4.59% php-cgi
85884 www         1   4    0   150M 41584K accept 2   0:14  4.59% php-cgi
85887 pgsql       1   4    0   951M   128M sbwait 1   0:04  4.20% postgres
85886 pgsql       1   4    0   949M   161M sbwait 0   0:08  3.37% postgres
86459 pgsql       1   4    0   949M 75960K sbwait 2   0:01  3.37% postgres
85279 pgsql       1   4    0   950M   192M sbwait 2   0:14  2.39% postgres
85269 pgsql       1   4    0   950M   199M sbwait 1   0:19  2.20% postgres
85268 www         1   4    0   152M 44356K sbwait 2   0:32  1.17% php-cgi
85273 pgsql       1   4    0   950M   215M sbwait 0   0:19  1.17% postgres
97082 pgsql       1  44    0 26020K  6832K select 0  46:55  0.00% postgres
  892 root        1   4    0  3160K     8K -      2  13:33  0.00% nfsd
 1796 root        1  44    0 19780K 13660K select 3  12:43  0.00% Xvfb
```

# Application Tuning
## Resource Utilization

- Is the application parallel?

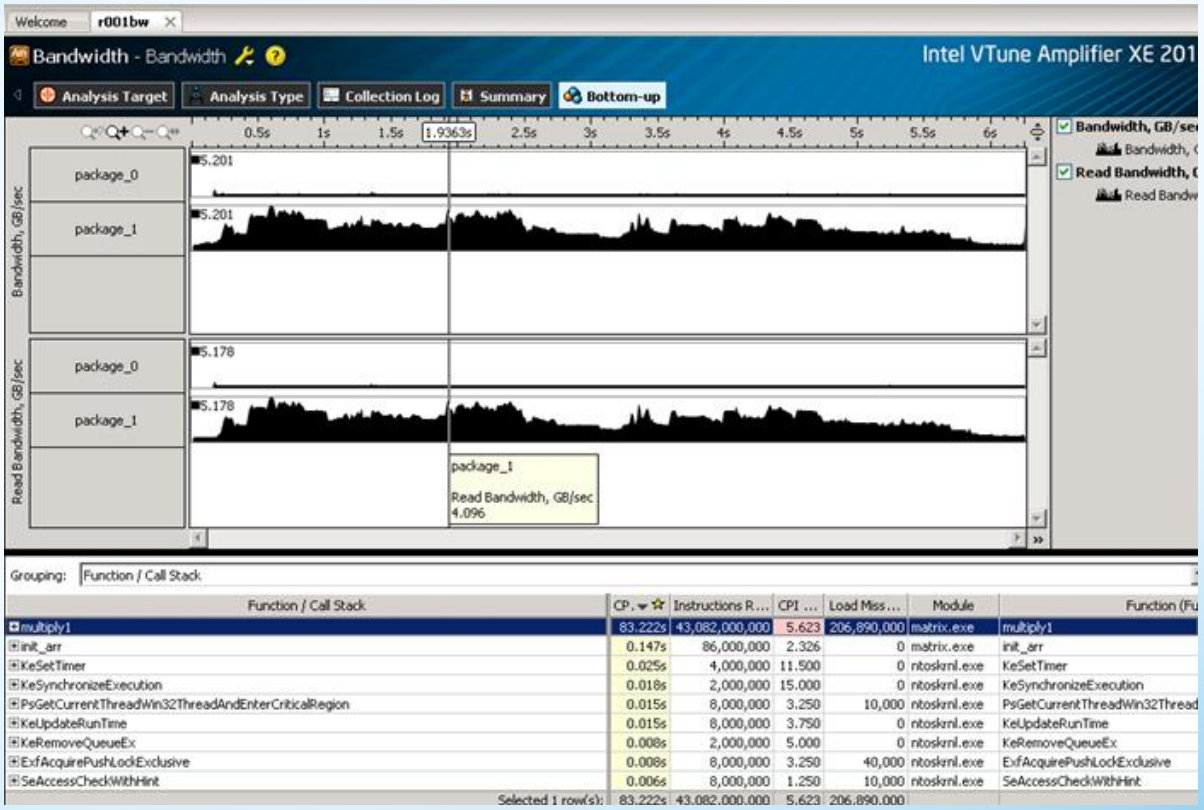


# Application Tuning
## Resource Utilization

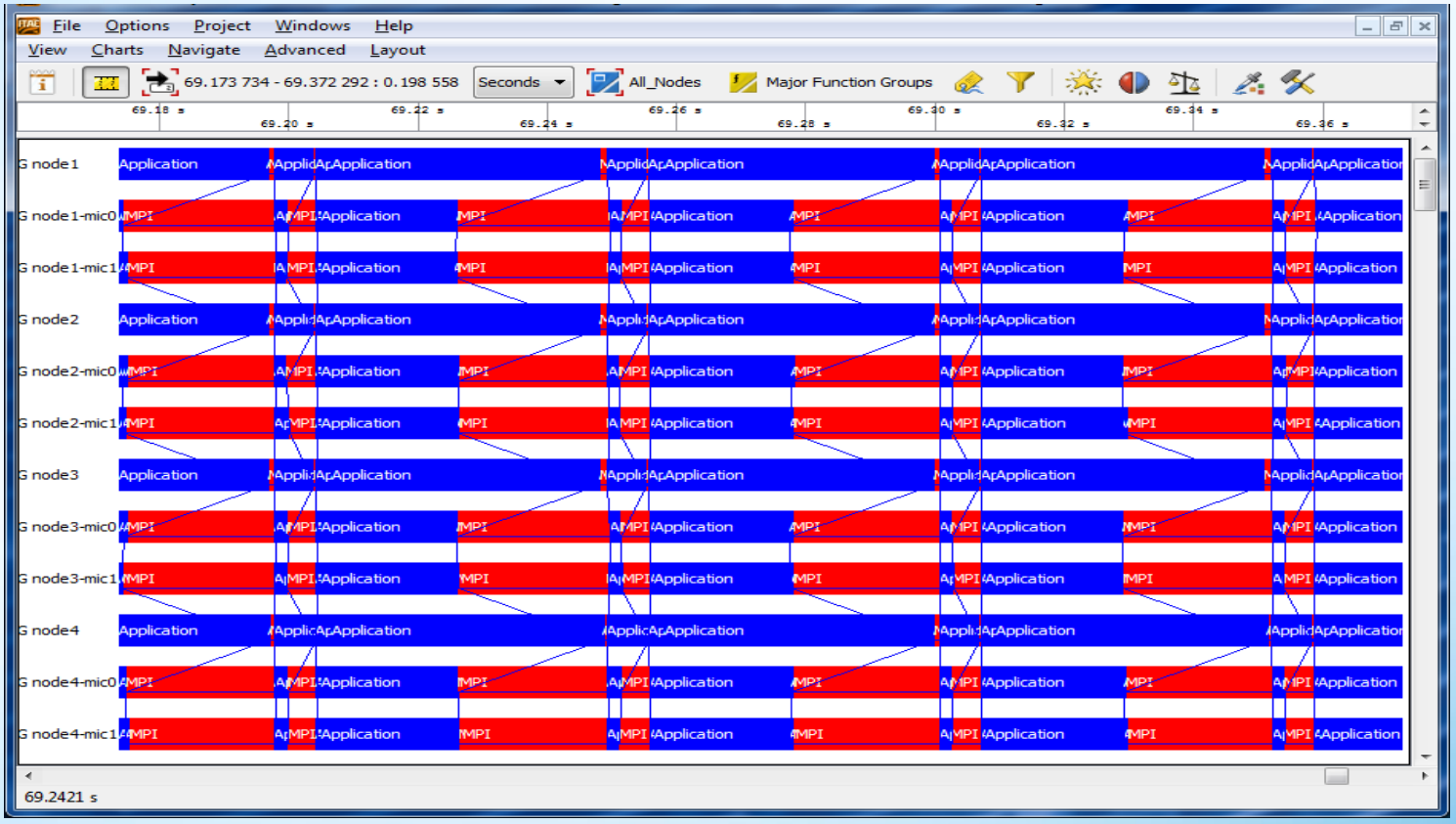
- Memory Bound?




- Know your max theoretical memory bandwidth

# Application Tuning
## Resource Utilization

MPI applications have added communication complexity




Intel® Trace Analyzer and Collector: http://intel.ly/traceanalyzer-collector

# Application Tuning
## What's Next?

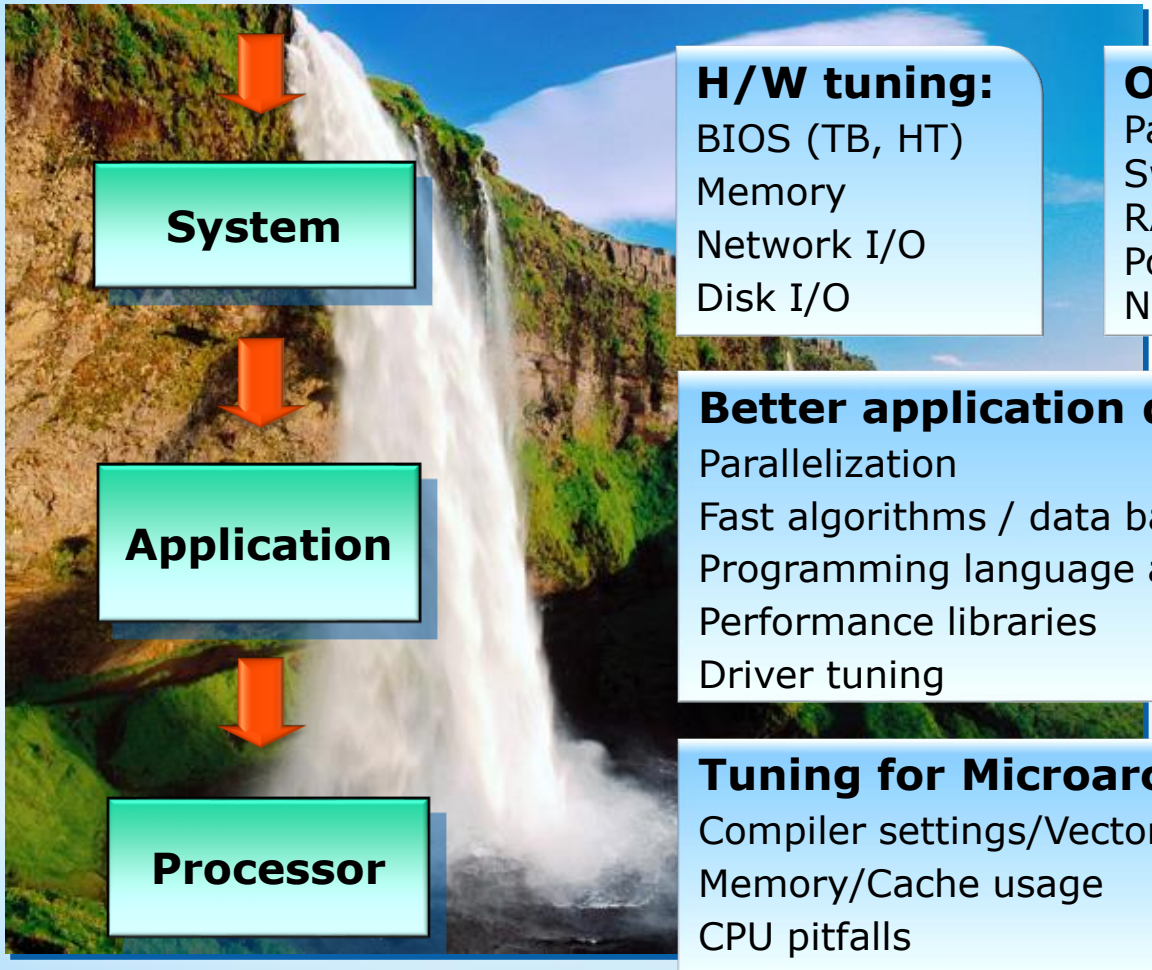
- If your Hotspots are common algorithms:
  - Look for optimized libraries

- If your Hotspots are uncommon:
  - Compiler optimizations
  - Expert analysis and refactoring of an algorithm
    - The opposite of "low-hanging fruit"
  - Deeper analysis of hardware performance
    - More on this later

- If the system is underutilized:
  - Add parallelism - multi-thread or multi-process
    - OpenMP, TBB, Cilk, MPI, etc…

- Tools can help you determine where to look and may identify some issues.
- Some tools may provide suggestions for fixes.
- In the end – the developer and/or expert has to make the changes and decisions – there is no sliver bullet.

# Optimization: A Top-down Approach

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Compiler settings/Vectorization
Memory/Cache usage
CPU pitfalls

OS, System **Expertise** SW/uArch

# Microarchitecture Tuning

**Who: ~~Architecture Experts~~**
**Software Developers, Performance Engineers, Domain Experts**

**How:**

- Use architecture specific hardware events
- Use predefined metrics and best known methods
  - Often hardware specific
  - (Hopefully) provided by the vendor

- Tools make this possible for the non-expert
  - Linux perf
  - Intel® VTune™ Amplifier XE

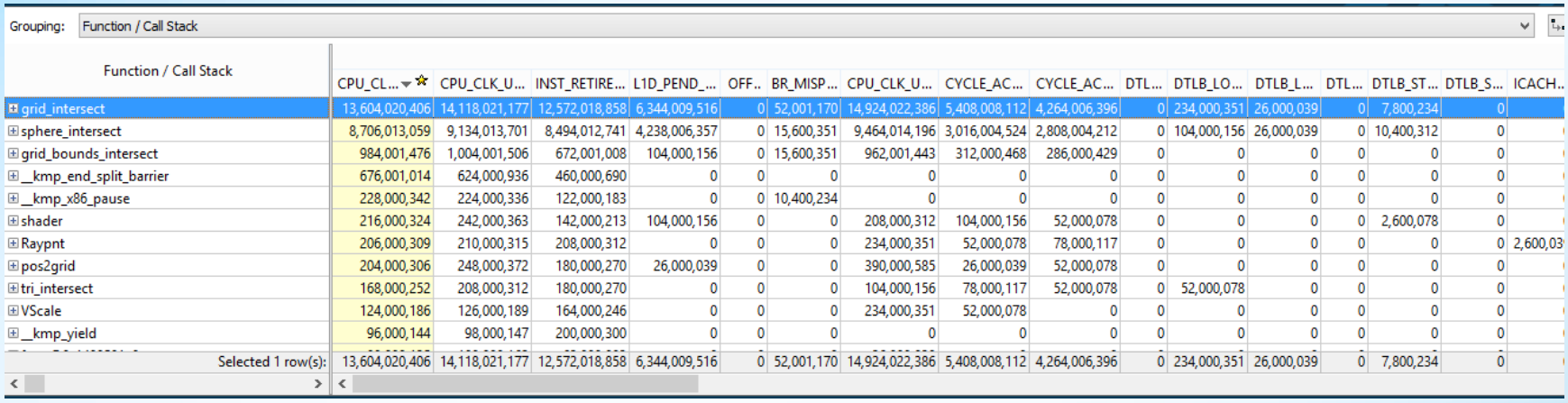
- Follow the Top-Down Characterization
  - Locate the hardware bottlenecks
  - Whitepaper here: https://software.intel.com/en-us/articles/how-to-tune-applications-using-a-top-down-characterization-of-microarchitectural-issues

Now we're getting into Intel specific tuning

# Introduction to Performance Monitoring Unit (PMU)

- Registers on Intel CPUs to count architectural events
  - E.g. Instructions, Cache Misses, Branch Mispredict
- Events can be counted or sampled
  - Sampled events include Instruction Pointer
- Raw event counts are difficult to interpret
  - Use a tool like VTune or Perf with predefined metrics

# Raw PMU Event Counts vs Metrics



Grouping: Function / Call Stack

| Function / Call Stack | CPU_CL... | CPU_CLK_U... | INST_RETIRE... | L1D_PEND_... | OFF.. | BR_MISP... | CPU_CLK_U... | CYCLE_AC... | CYCLE_AC... | DTL... | DTLB_LO... | DTLB_L... | DTL... | DTLB_ST... | DTLB_S... | ICACH.. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| grid_intersect | 13,604,020,406 | 14,118,021,177 | 12,572,018,858 | 6,344,009,516 | 0 | 52,001,170 | 14,924,022,386 | 5,408,008,112 | 4,264,006,396 | 0 | 234,000,351 | 26,000,039 | 0 | 7,800,234 | 0 | |
| sphere_intersect | 8,706,013,059 | 9,134,013,701 | 8,494,012,741 | 4,238,006,357 | 0 | 15,600,351 | 9,464,014,196 | 3,016,004,524 | 2,808,004,212 | 0 | 104,000,156 | 26,000,039 | 0 | 10,400,312 | 0 | |
| grid_bounds_intersect | 984,001,476 | 1,004,001,506 | 672,001,008 | 104,000,156 | 0 | 15,600,351 | 962,001,443 | 312,000,468 | 286,000,429 | 0 | 0 | 0 | 0 | 0 | 0 | |
| __kmp_end_split_barrier | 676,001,014 | 624,000,936 | 460,000,690 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| __kmp_x86_pause | 228,000,342 | 224,000,336 | 122,000,183 | 0 | 0 | 10,400,234 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| shader | 216,000,324 | 242,000,363 | 142,000,213 | 104,000,156 | 0 | 0 | 208,000,312 | 104,000,156 | 52,000,078 | 0 | 0 | 0 | 0 | 2,600,078 | 0 | |
| Raypnt | 206,000,309 | 210,000,315 | 208,000,312 | 0 | 0 | 0 | 234,000,351 | 52,000,078 | 78,000,117 | 0 | 0 | 0 | 0 | 0 | 0 | 2,600,03 |
| pos2grid | 204,000,306 | 248,000,372 | 180,000,270 | 26,000,039 | 0 | 0 | 390,000,585 | 26,000,039 | 52,000,078 | 0 | 0 | 0 | 0 | 0 | 0 | |
| tri_intersect | 168,000,252 | 208,000,312 | 180,000,270 | 0 | 0 | 0 | 104,000,156 | 78,000,117 | 52,000,078 | 0 | 52,000,078 | 0 | 0 | 0 | 0 | |
| VScale | 124,000,186 | 126,000,189 | 164,000,246 | 0 | 0 | 0 | 234,000,351 | 52,000,078 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| __kmp_yield | 96,000,144 | 98,000,147 | 200,000,300 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Selected 1 row(s): | 13,604,020,406 | 14,118,021,177 | 12,572,018,858 | 6,344,009,516 | 0 | 52,001,170 | 14,924,022,386 | 5,408,008,112 | 4,264,006,396 | 0 | 234,000,351 | 26,000,039 | 0 | 7,800,234 | 0 | |

Grouping: Function / Call Stack

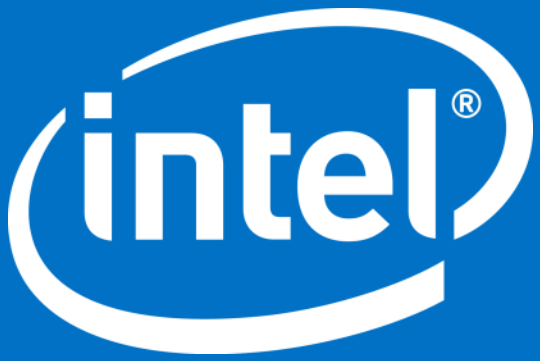
| Function / Call Stack | Clocktic... | Instructions Retired | CPI Rate | MUX Reliability | Filled Pipeline Slots | | Unfilled Pipeline Slots (Stalls) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Retiring | Bad Speculation | Back-End Bound | Front-end Bound | |
| | | | | | | | | Front-End Latency | Front-End Bandwidth |
| grid_intersect | 14,118,021,177 | 12,572,018,858 | 1.123 | 0.946 | 0.246 | 0.033 | 0.647 | 0.063 | 0.012 |
| sphere_intersect | 9,134,013,701 | 8,494,012,741 | 1.075 | 0.965 | 0.250 | 0.065 | 0.619 | 0.057 | 0.009 |
| grid_bounds_intersect | 1,004,001,506 | 672,001,008 | 1.494 | 0.958 | 0.227 | 0.000 | 0.715 | 0.104 | 0.000 |
| __kmp_end_split_barrier | 624,000,936 | 460,000,690 | 1.357 | 0.000 | 0.000 | 0.000 | 0.792 | 0.167 | 0.042 |
| pos2grid | 248,000,372 | 180,000,270 | 1.378 | 0.636 | 0.367 | 0.000 | 0.633 | 0.000 | 0.131 |
| shader | 242,000,363 | 142,000,213 | 1.704 | 0.860 | 0.322 | 0.000 | 0.946 | 0.000 | 0.027 |
| __kmp_x86_pause | 224,000,336 | 122,000,183 | 1.836 | 0.000 | 0.000 | 0.000 | 0.971 | 0.000 | 0.029 |
| Raypnt | 210,000,315 | 208,000,312 | 1.010 | 0.897 | 0.093 | 0.279 | 0.567 | 0.000 | 0.062 |
| Selected 1 row(s): | 14,118,021,177 | 12,572,018,858 | 1.123 | 0.946 | 0.246 | 0.033 | 0.647 | 0.063 | 0.012 |

# Adding Regression Tests for Performance

- Regression testing isn't just for bugs

1. Create a baseline performance characterization
2. After each change or at a regular interval
    1. Compare new results to baseline
    2. Compare new results to previous results
    3. Evaluate the change
3. goto (1)

- Performance tuning is easier if it's always on your mind and integrated into your development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