Code that Outperforms

Intel® oneAPI Analyzers

Intel VTune Profiler and Intel Advisor

Agenda

1

Intel® oneAPI Overview

Introduction to the Intel oneAPI Base and HPC Toolkits

2

Intel VTune Profiler and Intel Advisor Overview

Overview of the oneAPI analyzers

3

MandelbrotOMP Sample Configuration

Configure the sample used in the exercises

4

CPU Profiling Exercises

Running the sample on midway3 with Intel Advisor and Intel VTune Profiler.

5

GPU Profiling Demo

Demo profiling the iso3dfd sample on Intel DevCloud with Intel Advisor and Intel VTune Profiler

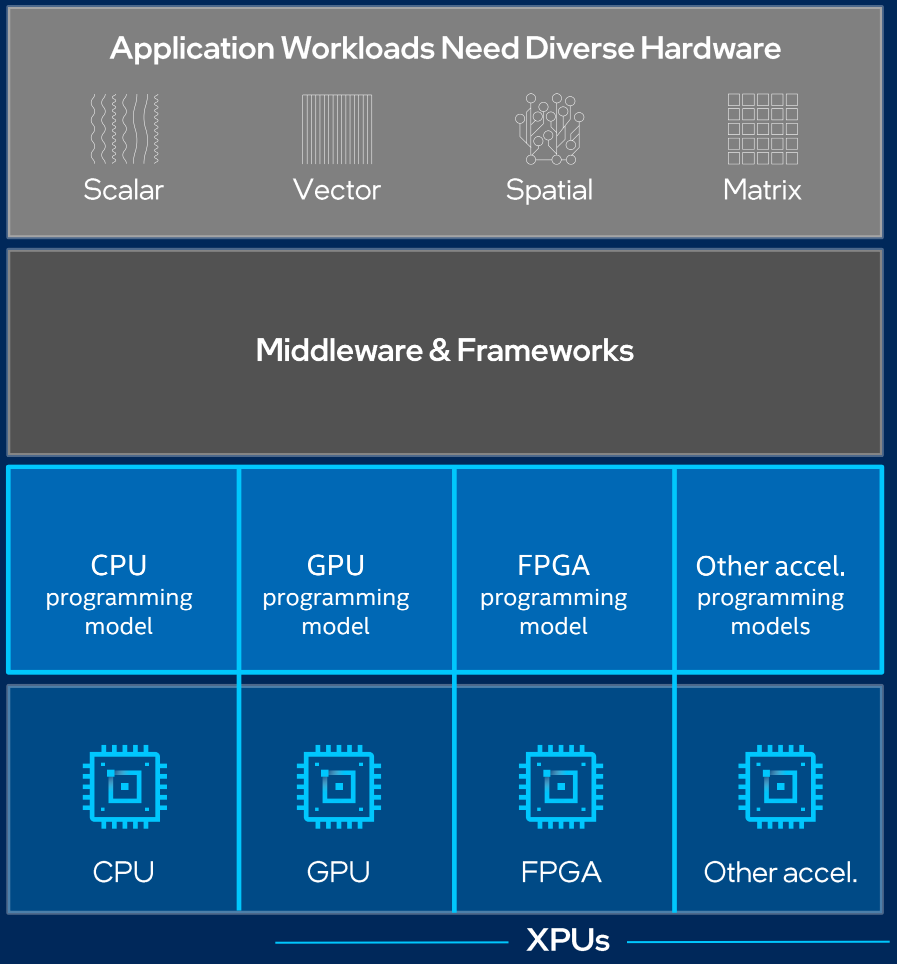
Programming Challenges
for Multiple Architectures

Growth in specialized workloads

Variety of data-centric hardware required

Separate programming models and toolchains for each architecture are required today

Software development complexity limits freedom of architectural choice



oneAPI

One Programming Model for Multiple Architectures and Vendors

Freedom to Make Your Best Choice

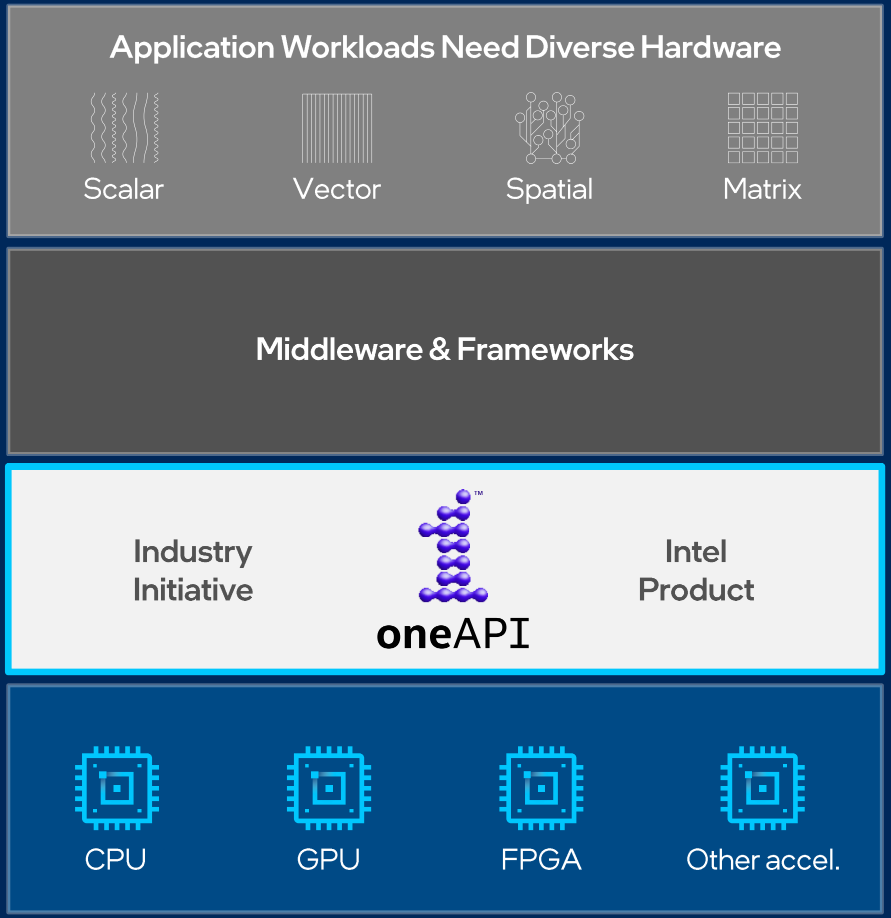
- Choose the best accelerated technology the software doesn't decide for you

Realize all the Hardware Value

- Performance across CPU, GPUs, FPGAs, and other accelerators

Develop & Deploy Software with Peace of Mind

- Open industry standards provide a safe, clear path to the future
- Compatible with existing languages and programming models including C++, Python, SYCL, OpenMP, Fortran, and MPI

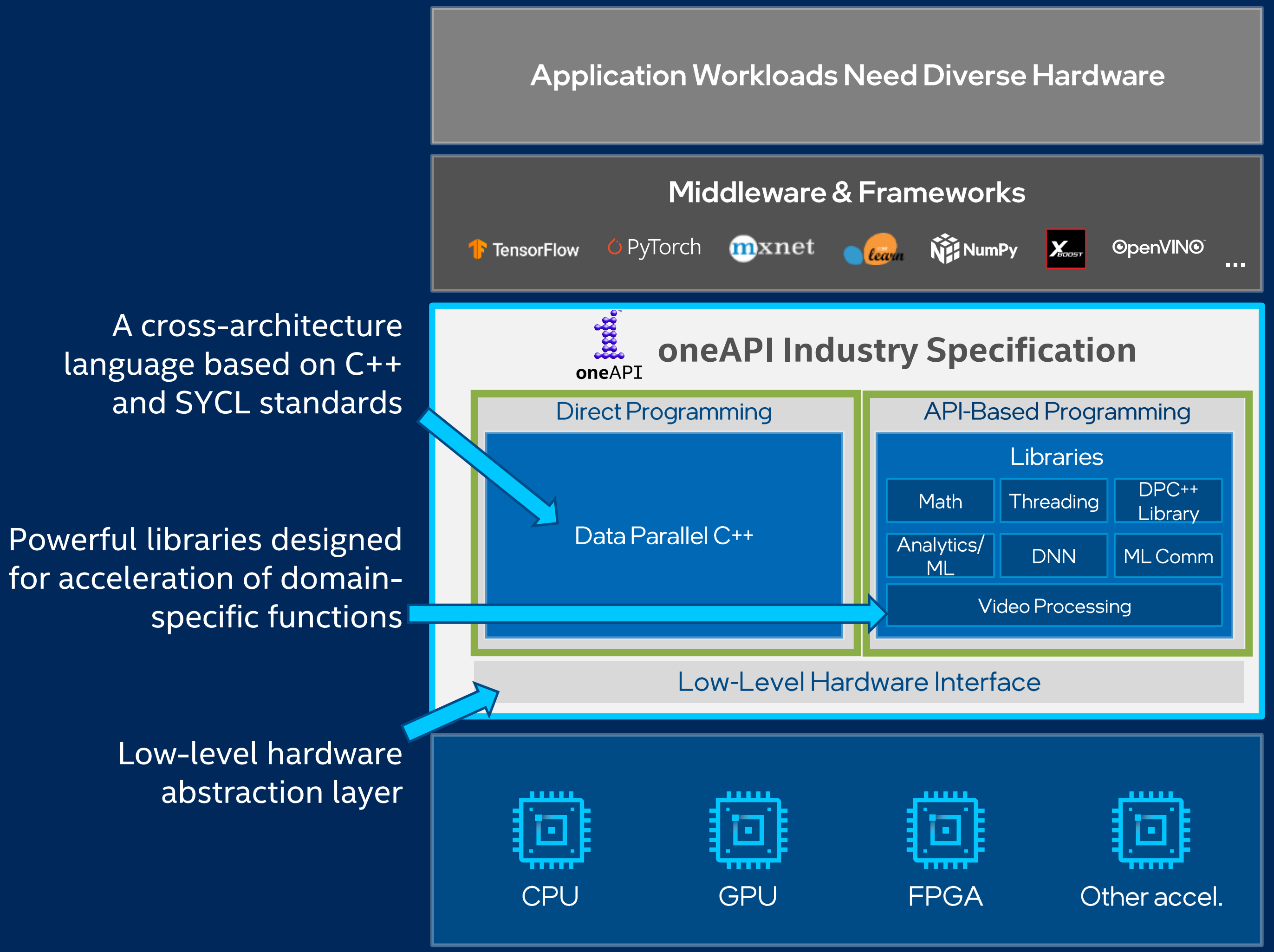


oneAPI Industry Initiative

Break the Chains of Proprietary Lock-in

Open to promote community and industry collaboration

Enables code reuse across architectures and vendors



oneAPI

The productive, smart path to freedom for accelerated computing from the economic and technical burdens of proprietary programming models

Data Parallel C++

Standards-based, Cross-architecture Language

DPC++ = ISO C++ and Khronos SYCL and community extensions

Freedom of Choice: Future-Ready Programming Model

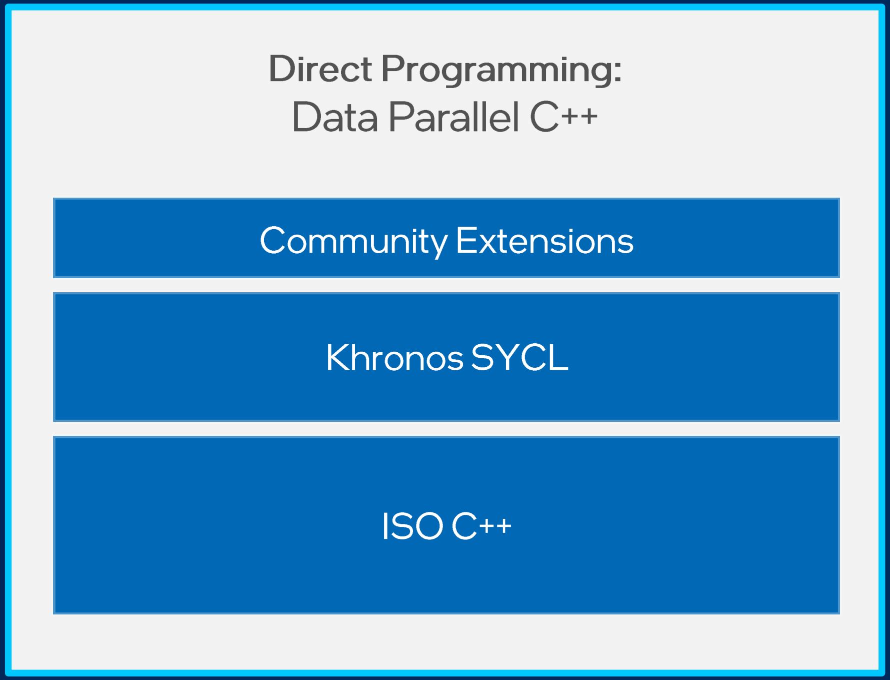
- Allows code reuse across hardware targets
- Permits custom tuning for a specific accelerator
- Open, cross-industry alternative to proprietary language

DPC++ = ISO C++ and Khronos SYCL and community extensions

- Delivers C++ productivity benefits, using common, familiar C and C++ constructs
- Adds SYCL from the Khronos Group for data parallelism and heterogeneous programming

Community Project Drives Language Enhancements

- Provides extensions to simplify data parallel programming
- Continues evolution through open and cooperative development



The open source and Intel DPC++/C++ compiler supports Intel CPUs, GPUs, and FPGAs.
Codeplay announced a [DPC++ compiler that targets Nvidia GPUs](#).

Powerful oneAPI Libraries

Realize all the Hardware Value

Designed for acceleration of key domain-specific functions

Freedom of Choice

Pre-optimized for each target platform for maximum performance

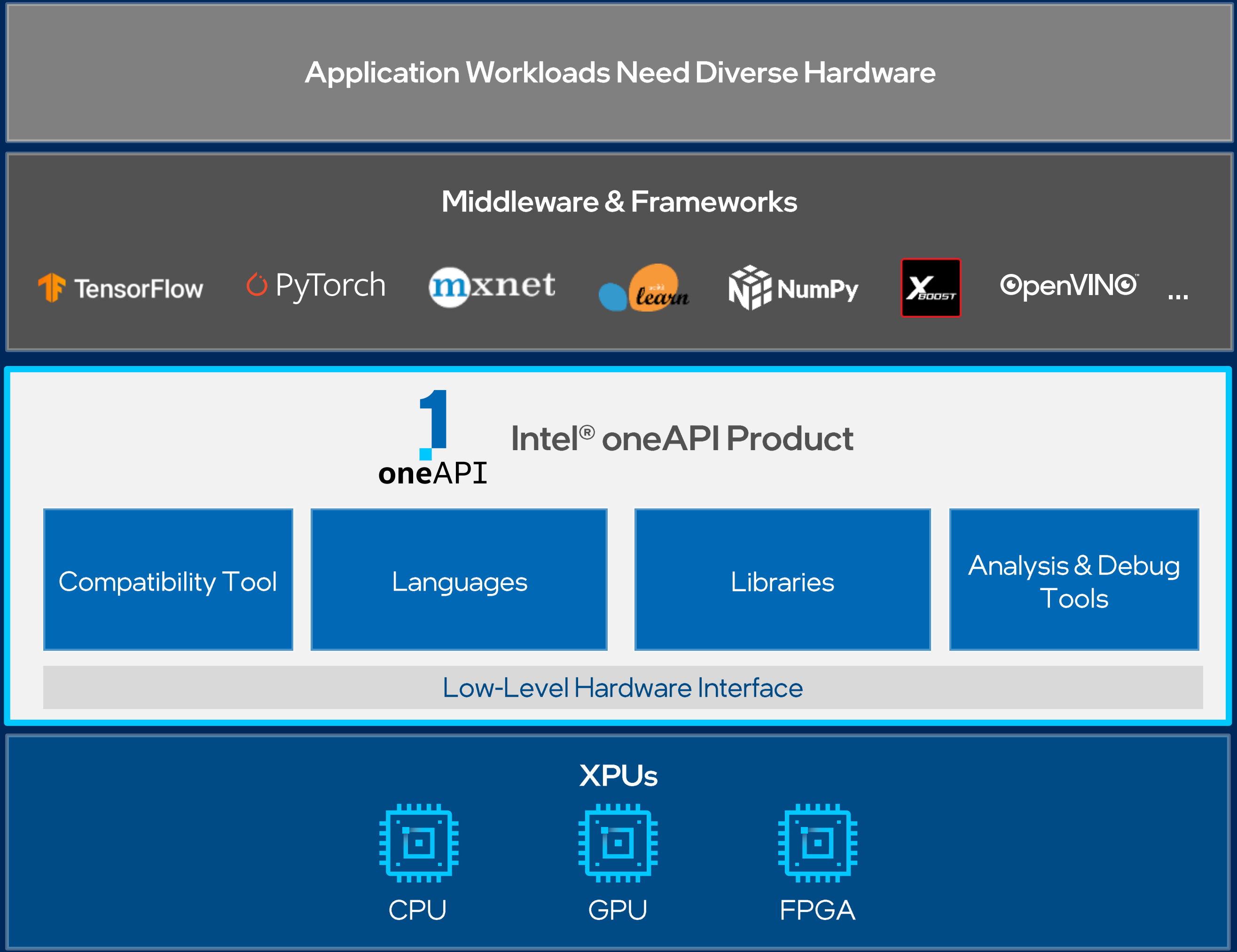
oneAPI Math Kernel Library **oneMKL**	oneAPI Deep Neural Network Library **oneDNN**
oneAPI Video Processing Library **oneVPL**	oneAPI Data Analytics Library **oneDAL**
oneAPI Threading Building Blocks **oneTBB**	oneAPI Collective Communications Library **oneCCL**
oneAPI DPC++ Library **oneDPL**	

Intel® oneAPI Product

Built on Intel's Rich Heritage of CPU Tools Expanded to XPUs

A complete set of advanced compilers, libraries, and porting, analysis and debugger tools

- Accelerates compute by exploiting cutting-edge hardware features
- Interoperable with existing programming models and code bases (C++, Fortran, Python, OpenMP, etc.), developers can be confident that existing applications work seamlessly with oneAPI
- Eases transitions to new systems and accelerators—using a single code base frees developers to invest more time on innovation



Available Now

Latest version is 2021.1

Visit software.intel.com/oneapi for more details
Some capabilities may differ per architecture and custom-tuning will still be required. Other accelerators to be supported in the future.

Intel® oneAPI Base Toolkit

Accelerate Data-centric Workloads

A core set of core tools and libraries for developing high-performance applications on Intel® CPUs, GPUs, and FPGAs.

Who Uses It?

- A broad range of developers across industries
- Add-on toolkit users since this is the base for all toolkits

Top Features/Benefits

- Data Parallel C++ compiler, library and analysis tools
- DPC++ Compatibility tool helps migrate existing code written in CUDA
- Python distribution includes accelerated scikit-learn, NumPy, SciPy libraries
- Optimized performance libraries for threading, math, data analytics, deep learning, and video/image/signal processing

Intel® oneAPI Base Toolkit

Direct Programming	API-Based Programming	Analysis & debug Tools
Intel® oneAPI DPC++/C++ Compiler	Intel® oneAPI DPC++ Library oneDPL	Intel® VTune™ Profiler
Intel® DPC++ Compatibility Tool	Intel® oneAPI Math Kernel Library - oneMKL	Intel® Advisor
Intel® Distribution for Python	Intel® oneAPI Data Analytics Library - oneDAL	Intel® Distribution for GDB
Intel® FPGA Add-on for oneAPI Base Toolkit	Intel® oneAPI Threading Building Blocks - oneTBB	
	Intel® oneAPI Video Processing Library - oneVPL	
	Intel® oneAPI Collective Communications Library oneCCL	
	Intel® oneAPI Deep Neural Network Library - oneDNN	
	Intel® Integrated Performance Primitives - Intel® IPP	

intel. 1 oneAPI BASE TOOLKIT

Learn More: intel.com/oneAPI-BaseKit

Intel® oneAPI Tools for HPC

Intel® oneAPI HPC Toolkit

Deliver Fast Applications that Scale

What is it?

A toolkit that adds to the Intel® oneAPI Base Toolkit for building high-performance, scalable parallel code on C++, SYCL, Fortran, OpenMP & MPI from enterprise to cloud, and HPC to AI applications.

Who needs this product?

- OEMs/ISVs
- C++, Fortran, OpenMP, MPI Developers

Why is this important?

- Accelerate performance on Intel® Xeon® and Core™ Processors and Intel® Accelerators
- Deliver fast, scalable, reliable parallel code with less effort built on industry standards

Intel® oneAPI Base & HPC Toolkits

Direct Programming	API-Based Programming	Analysis & debug Tools
Intel® C++ Compiler Classic	Intel® MPI Library	Intel® Inspector
Intel® Fortran Compiler Classic	Intel® oneAPI DPC++ Library oneDPL	Intel® Trace Analyzer & Collector
Intel® Fortran Compiler	Intel® oneAPI Math Kernel Library - oneMKL	Intel® Cluster Checker
Intel® oneAPI DPC++/C++ Compiler	Intel® oneAPI Data Analytics Library - oneDAL	Intel® VTune™ Profiler
Intel® DPC++ Compatibility Tool	Intel® oneAPI Threading Building Blocks - oneTBB	Intel® Advisor
Intel® Distribution for Python	Intel® oneAPI Video Processing Library - oneVPL	Intel® Distribution for GDB
Intel® FPGA Add-on for oneAPI Base Toolkit	Intel® oneAPI Collective Communications Library oneCCL	
	Intel® oneAPI Deep Neural Network Library - oneDNN	
	Intel® Integrated Performance Primitives – Intel® IPP	

Intel® oneAPI **HPC** Toolkit +
Intel® oneAPI **Base** Toolkit

intel 1 oneAPI HPC TOOLKIT

Learn More: intel.com/oneAPI-HPCKit

Intel Analysis Tools for GPU Compute Analysis

Intel® Advisor

Offload Advisor

- Identify high-impact opportunities to offload
- Detect bottlenecks and key bounding factors
- Get your code ready even before you have the hardware by modeling performance, headroom, and bottlenecks

Roofline Analysis

- See performance headroom against hardware limitations
- Determine performance optimization strategy by identifying bottlenecks and which optimizations will pay off the most
- Visualize optimization progress

Flow Graph Analyzer

- Visualize your CPU/GPU code and get recommendations for the CPU device

Intel® VTune™ Profiler

Offload Performance Tuning

- Explore code execution on your platform's various CPU and GPU cores
- Correlate CPU and GPU activity
- Identify whether your application is GPU- or CPU-bound

GPU Compute/Media Hotspots

- Analyze the most time-consuming GPU kernels, characterize GPU usage based on GPU hardware metrics
- GPU code performance at the source-line level and kernel-assembly level

Intel® VTune™ Profiler Overview

Optimize Performance

Intel® VTune™ Profiler

Get the Right Data to Find Bottlenecks

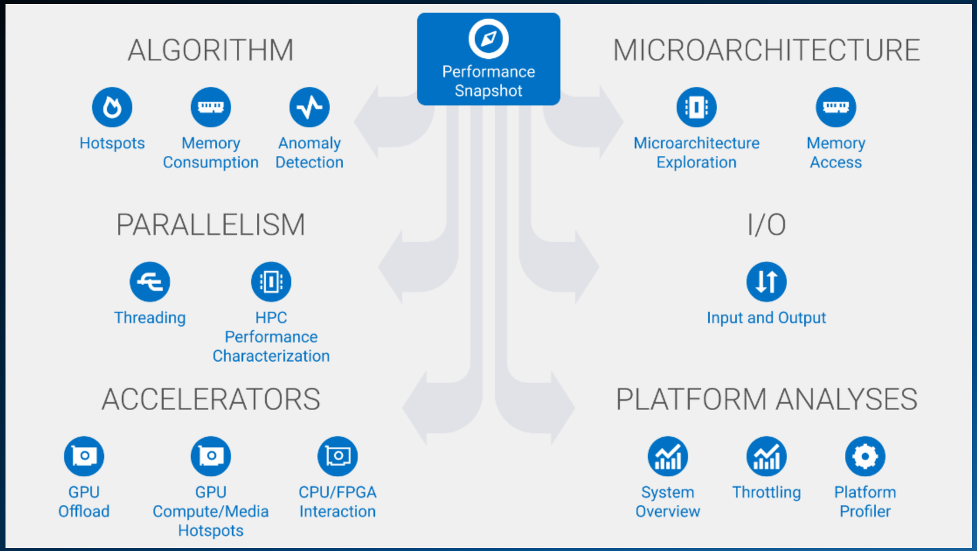
- A suite of profiling for CPU, GPU, FPGA, threading, memory, cache, storage, offload, power…
- Application or system-wide analysis
- DPC++, C, C++, Fortran, Python*, Go*, Java*, or a mix
- Linux, Windows, FreeBSD, Android, Yocto and more
- Containers and VMs

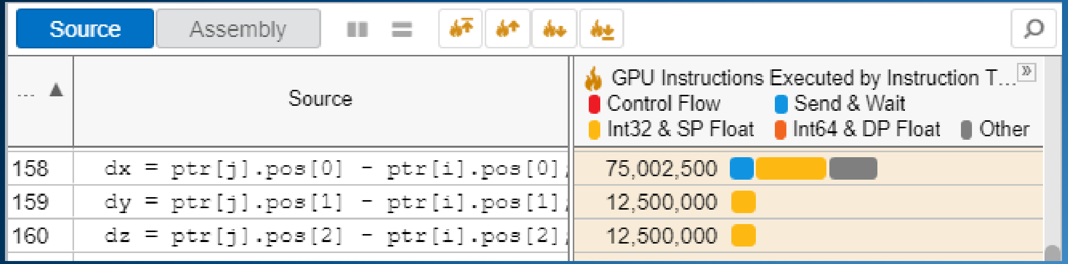
Analyze Data Faster

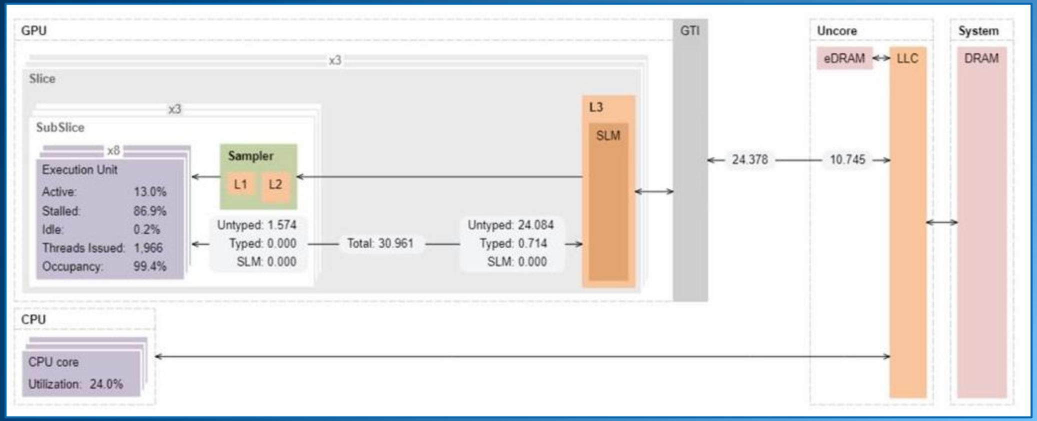
- Collect data HW/SW sampling and tracing w/o re-compilation
- See results on your source, in architecture diagrams, as a histogram, on a timeline…
- Filter and organize data to find answers

Work Your Way

- User interface or command line
- Profile locally and remotely
- GUI (desktop or web) or command line

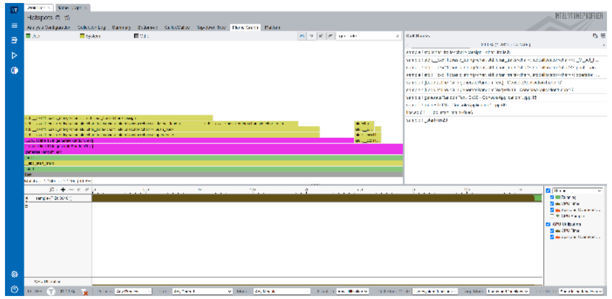






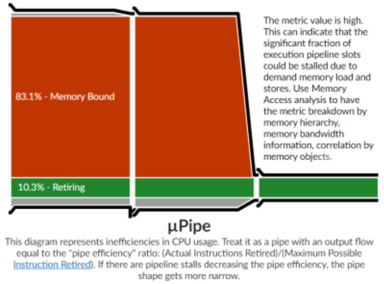
Rich Set of Profiling Capabilities

Intel® VTune™ Profiler



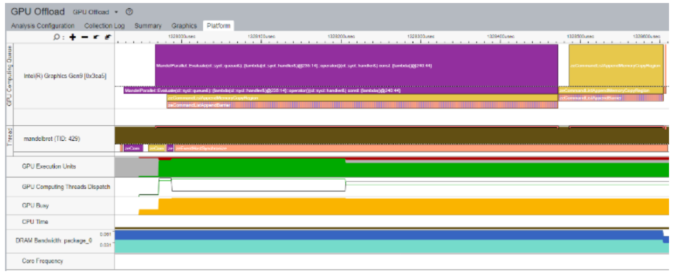
Algorithm Optimization

- ✓ Hotspots
- ✓ Anomaly Detection
- ✓ Memory Consumption



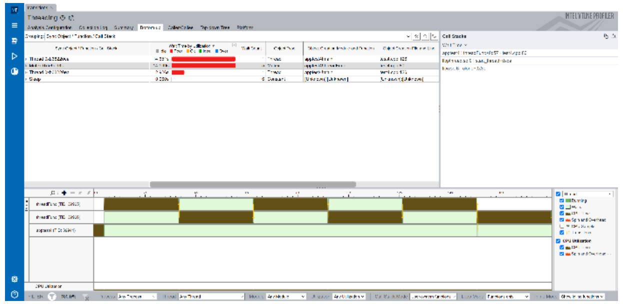
Microarch.&Memory Bottlenecks

- ✓ Microarchitecture Exploration
- ✓ Memory Access



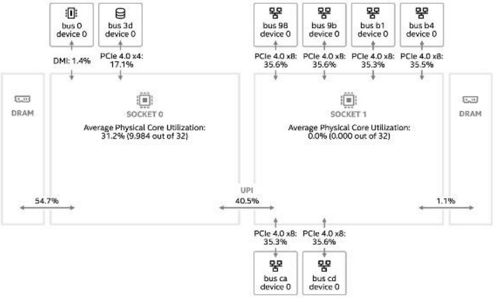
Accelerators / xPU

- ✓ GPU Offload
- ✓ GPU Compute / Media Hotspots
- ✓ CPU/FPGA Interaction



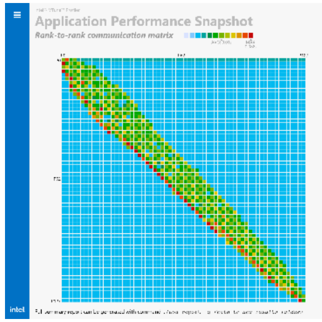
Parallelism

- ✓ Threading
- ✓ HPC Performance Characterization



Platform & I/O

- ✓ Input and Output
- ✓ System Overview
- ✓ Platform Profiler



Multi-Node

- ✓ Application Performance Snapshot

Find Answers Fast

Intel® VTune™ Profiler

Adjust Data Grouping

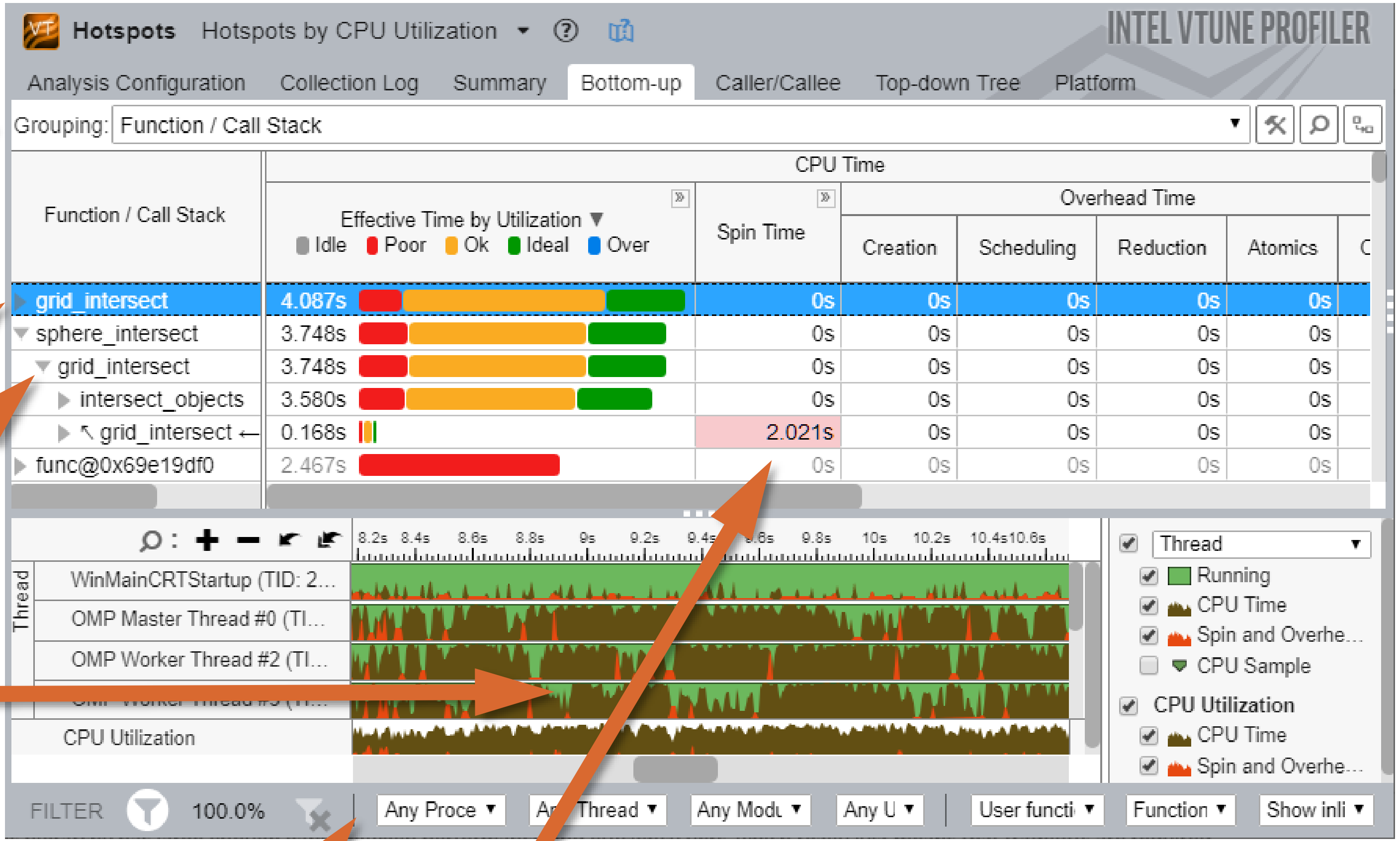
Function / Call Stack
Source Function / Function / Call Stack
Sync Object / Function / Call Stack
Sync Object / Thread / Function / Call Stack
... (Partial list shown)

Double Click Function to View Source

Click [▶] for Call Stack

Filter by Timeline Selection (or by Grid Selection)

Zoom In And Filter On Selection
Filter In by Selection
Remove All Filters



Filter by Process & Other Controls

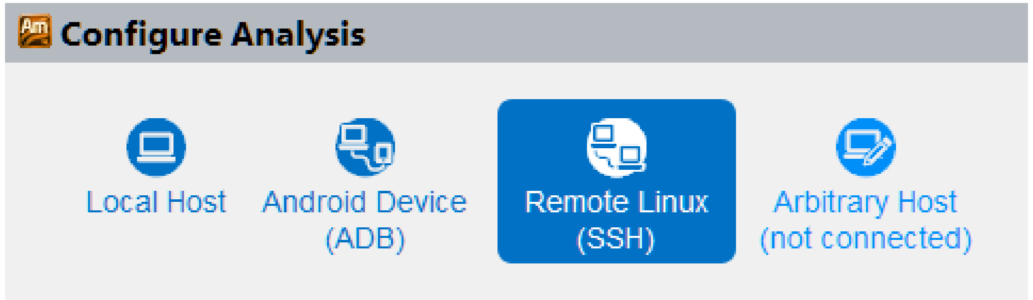
Tuning Opportunities Shown in Pink. Hover for Tips

Interactive Remote Data Collection

Performance analysis of remote systems just got a lot easier

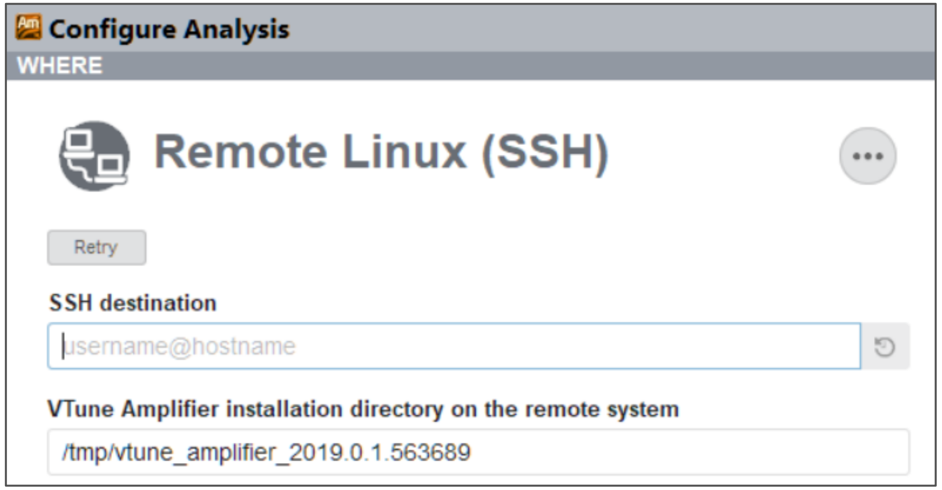
Interactive analysis

1) Configure SSH to a remote Linux* target
2) Choose and run analysis with the UI



Command line analysis

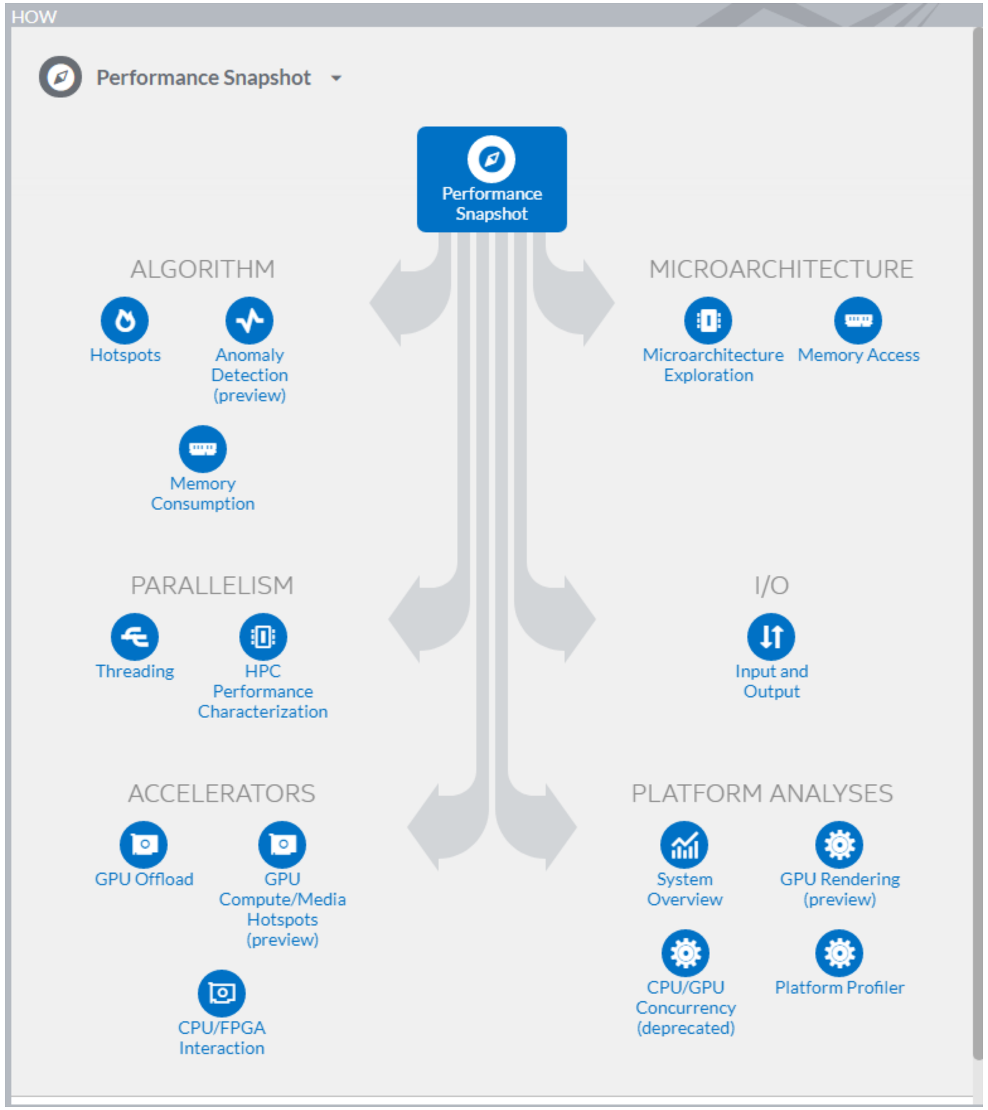
1) Run command line remotely on Windows* or Linux* target
2) Copy results back to host and open in UI



Conveniently use your local UI to analyze remote systems

Analysis Types

- Performance Snapshot:
  - Used as a starting point to determine areas for deeper focus.
- Algorithm:
  - Hotspots: investigate call paths and find where your code spends the most time.
  - Anomaly Detection (preview): identify performance anomalies in frequently recurring intervals of code like loop iterations.
  - Memory Consumption: analyze memory consumption by app [Linux* only]
- Microarchitecture:
  - Microarchitecture Exploration: deep dive into the CPU pipeline stage and hardware units responsible for your hardware bottlenecks.
  - Memory Access: analyze CPU cache and main memory usage
- Parallelism:
  - Threading: visualize thread parallelism on available cores.
- I/O:
  - Input and Output: monitor utilization of the IO subsystems, CPU, and buses.
- Platform Analyses:
  - System Overview: monitors general behavior of the target system and identifies platform-level factors that limit performance
  - Platform Profiler: provides insights into overall system configuration, performance, and behavior.



More details: https://software.intel.com/content/www/us/en/develop/documentation/vtune-help/top/set-up-project/analysis-types.html

Optimize Memory Access

Memory Access Analysis - Intel® VTune™ Profiler

Tune data structures for performance

- Attribute cache misses to data structures (not just the code causing the miss)
- Support for custom memory allocators

Optimize NUMA latency & scalability

- True & false sharing optimization
- Auto detect max system bandwidth
- Easier tuning of inter-socket bandwidth

Easier install, Latest processors

- No special drivers required on Linux*
- Intel® Xeon Phi™ processor MCDRAM (high bandwidth memory) analysis

Top Memory Objects by Latency

This section lists memory objects that introduced the highest latency to the overall application execution.

Memory Object	Total Latency	Loads	Stores	LLC Miss Count
alloc_test.cpp:157 (30 MB)	65.6%	4,239,327,176	4,475,334,256	0
alloc_test.cpp:135 (305 MB)	6.8%	411,212,336	441,613,248	0
alloc_test.cpp:109 (305 MB)	6.3%	439,213,176	449,613,488	0
alloc_test!l_data_init.436.0.6 (576 B)	5.2%	742,422,272	676,820,304	0
[vmlinux]	4.6%	173,605,208	116,003,480	0
[Others]	11.5%	1,533,646,008	1,674,450,232	0

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

Grouping: Function / Memory Object / Allocation Stack

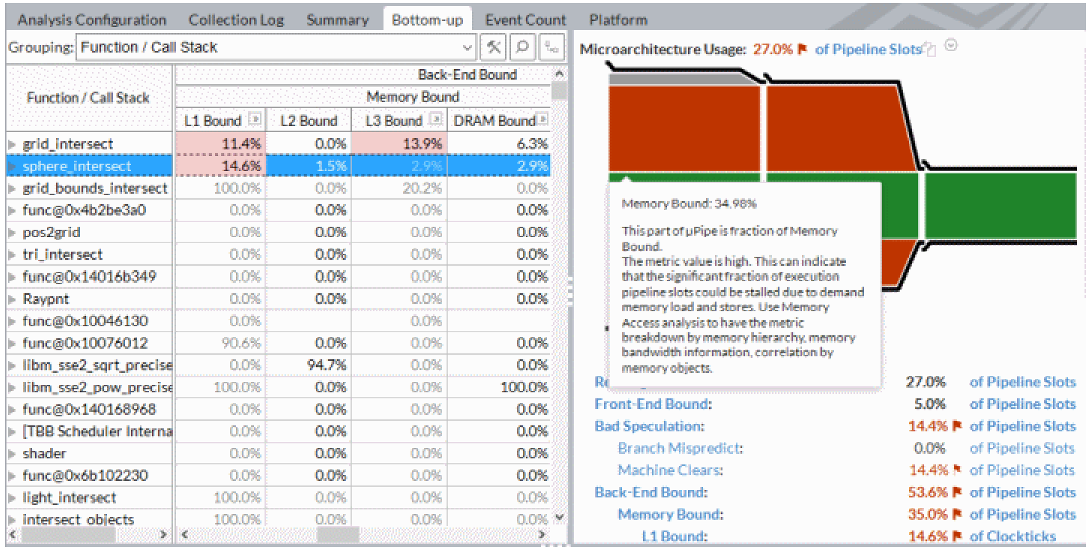
Function / Memory Object / Allocation Stack	Stores	LLC Miss Count	
		Local DRAM Access Count	Remote DRAM Access Count
doTriadompparallel_for@2	40,307,609,1...	2,439,273,176	2,430,472,912
triad!c (152 MB)	19,200,576	1,821,654,648	1,864,855,944
triad!b (152 MB)	10,400,312	615,218,456	560,816,824
[Unknown]	7,200,216	2,400,072	3,200,096
triad!doTriad (2 MB)	15,200,456	0	0
[Stack]	2,120,063,600	0	1,600,048
triad!a (152 MB)	38,135,544,0...	0	0
update_blocked_averages	6,400,192	2,400,072	0

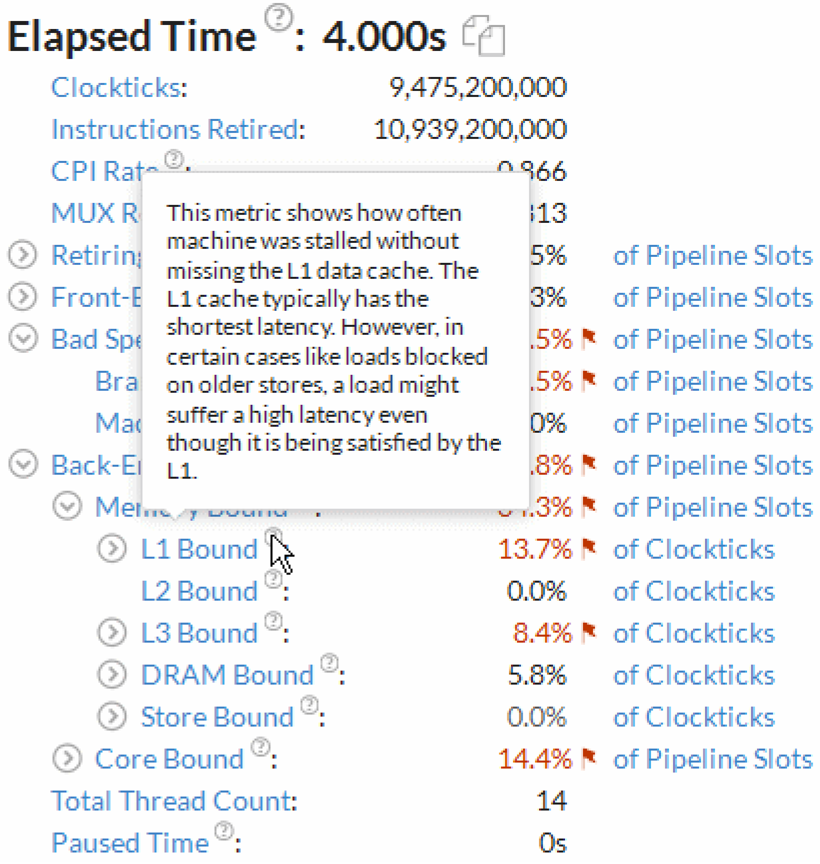
Microarchitecture Exploration

Hierarchical view of the execution pipeline

- Pinpoint sections of the pipeline with performance problems flagged by VTune
- Hover over metrics for a detailed description

Visualize the pipeline at the function level in the bottom-up tab

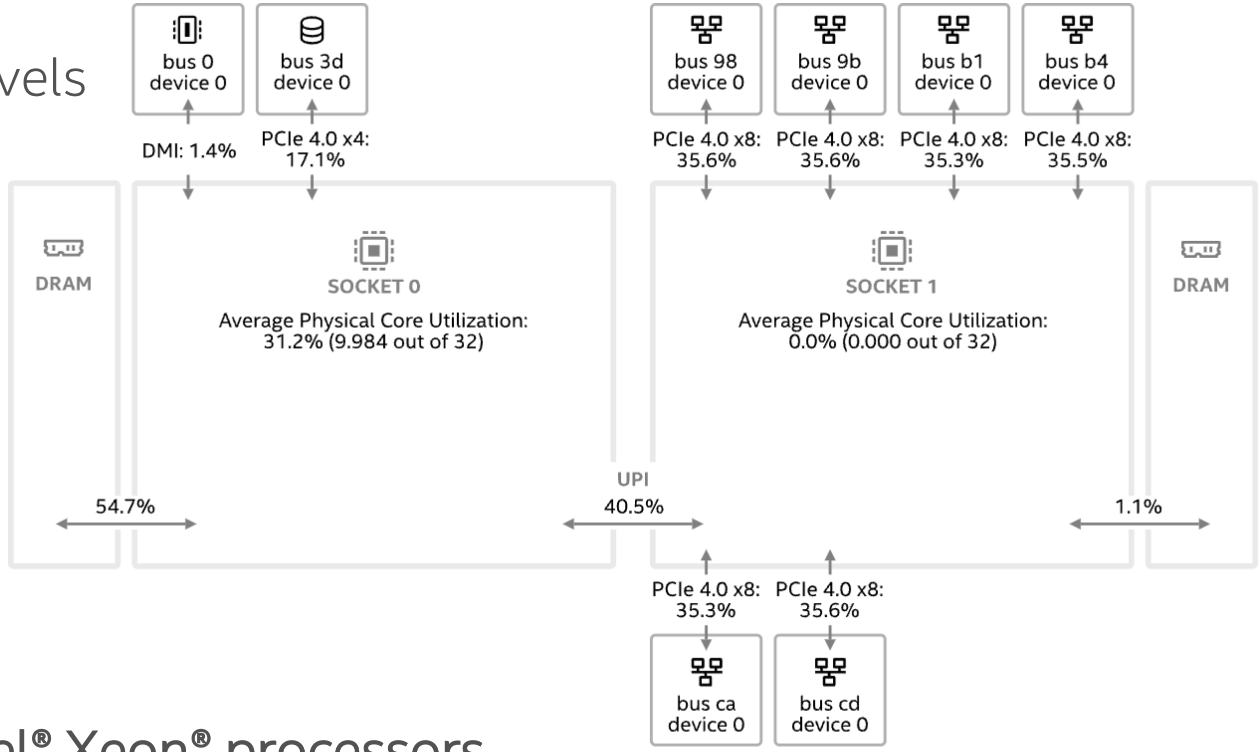




Intel® VTune™ Profiler

Input and Output Analysis

- Provides uncore- and device-centric view to locate performance bottlenecks in I/O-intensive apps at both HW and SW levels
- Two types of metrics to analyze:
  - **Platform I/O:** application- and device-agnostic hardware event-based metrics for DRAM, PMEM, Intel UPI, PCIe, Intel DDIO, MMIO traffic consumption
  - **API and OS I/O**: DPDK, SPDK, kernel I/O
- **Linux and FreeBSD** targets are supported
- The full set of I/O metrics is available on **Intel® Xeon® processors**, including 3rd Generation Intel® Xeon® Scalable Processors



Easily Identify Hot Code Paths

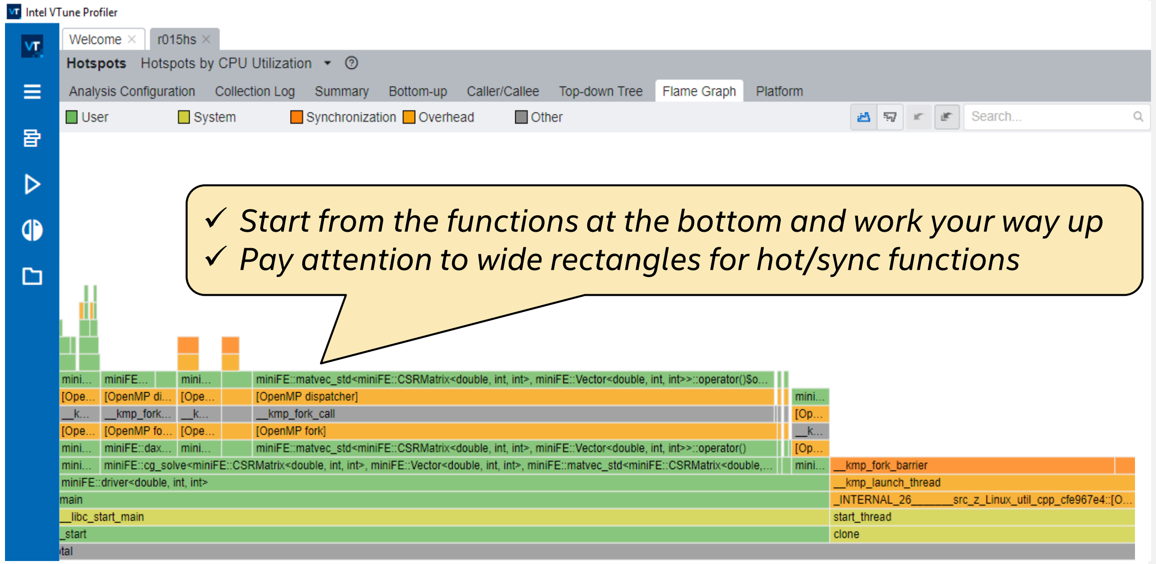
Flame Graphs* for Hotspots Analysis

Visualize Total Function CPU time spent

- Explore stacks and stack frames
  - Aggregation
  - Side-by-side visualization
  - Function bar as fraction of CPU Time
  - Different colors per function type
- Identify the time spent in each function and its callees

Rich Experience with Intel® VTune™ Profiler UI

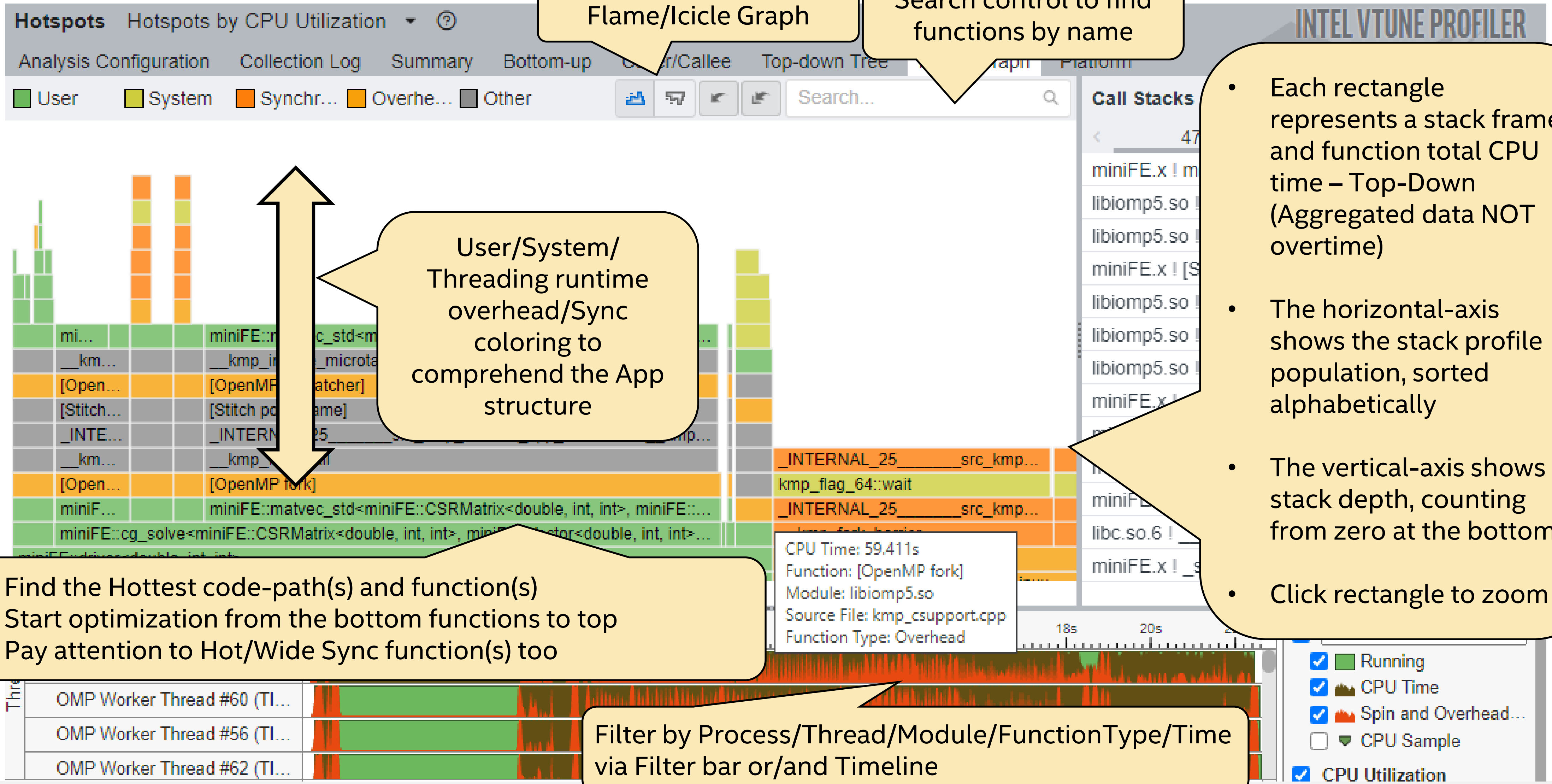
- Select your visualization of choice
  - Flame or Icicle Graph
- Filter data by process, thread, time region, and more
- Jump to the function source code via stack pane



*Adapted based on Brendan Gregg's Flame Graphs

Intel® VTune™ Profiler

Flame Graph



Flame/Icicle Graph

Search control to find functions by name

User/System/ Threading runtime overhead/Sync coloring to comprehend the App structure

- Each rectangle represents a stack frame and function total CPU time – Top-Down (Aggregated data NOT overtime)
- The horizontal-axis shows the stack profile population, sorted alphabetically
- The vertical-axis shows stack depth, counting from zero at the bottom
- Click rectangle to zoom

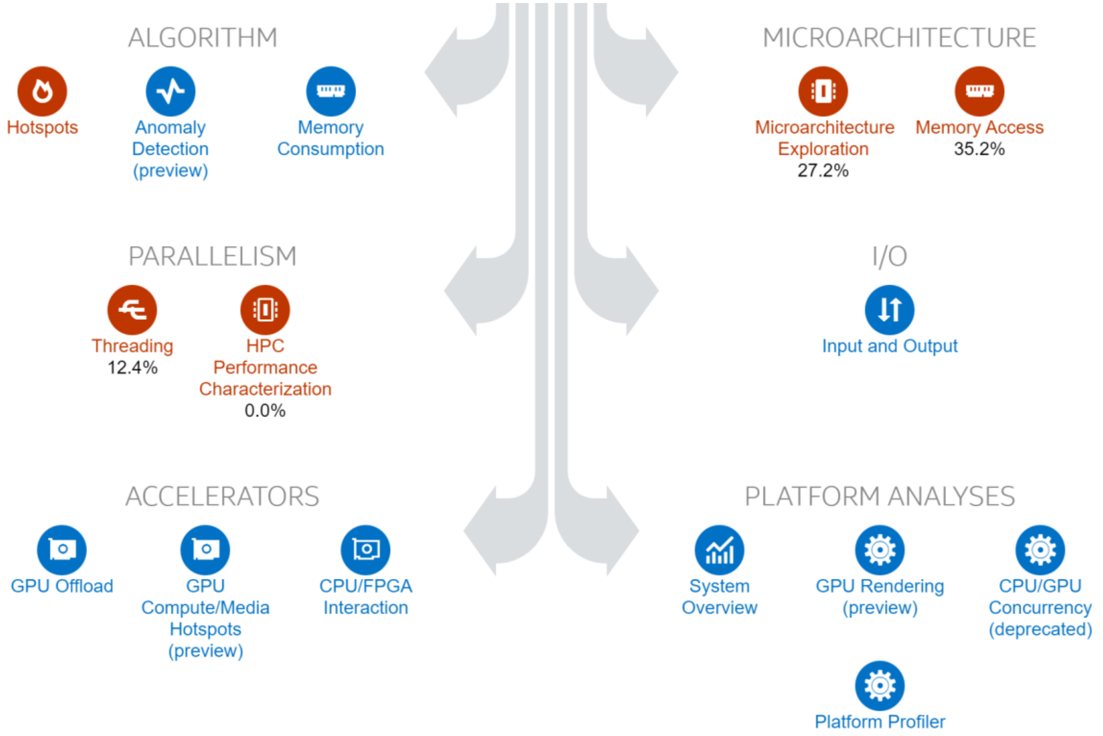
- Find the Hottest code-path(s) and function(s)
- Start optimization from the bottom functions to top
- Pay attention to Hot/Wide Sync function(s) too

Filter by Process/Thread/Module/FunctionType/Time via Filter bar or/and Timeline

Intel® VTune™ Profiler

Performance Snapshot Analysis

Choose your next analysis:



Characterize high-level aspects:

Elapsed Time: 7.906s

Logical Core Utilization: 12.4% (0.990 out of 8)

Microarchitecture Usage: 27.2% of Pipeline Slots

- Retiring: 27.2% of Pipeline Slots
- Front-End Bound: 5.5% of Pipeline Slots
- Bad Speculation: 3.7% of Pipeline Slots
- **Back-End Bound: 63.6% of Pipeline Slots**
  - **Memory Bound: 35.2% of Pipeline Slots**
  - Core Bound: 28.4% of Pipeline Slots

Memory Bound: 35.2% of Pipeline Slots

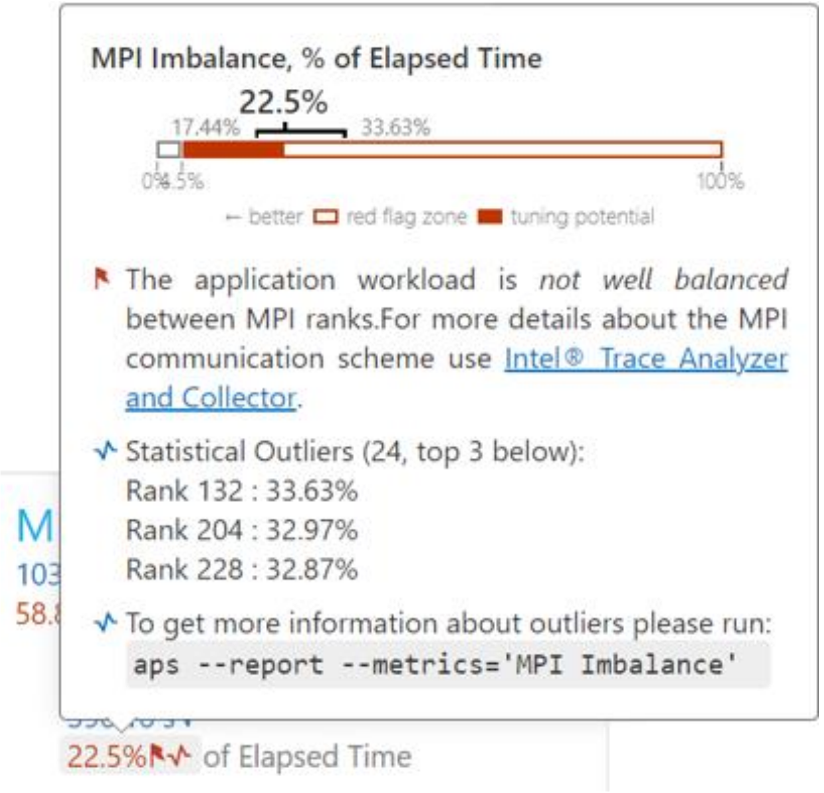
Vectorization: 0.0% of Packed FP Operations

Roman Khatko

Intel® VTune™ Profiler

Application Performance Snapshot for MPI

- Outlier analysis for MPI applications at scale
  - Explore on source of imbalance
  - Choose nodes/ranks for detailed profiling with VTune



Intel® Advisor Overview

Intel® Advisor

Design code for modern hardware

Offload Modelling

- Efficiently offload your code to GPUs even before you have the hardware

Automated Roofline Analysis

- Optimize your GPU/CPU code for memory and compute

Vectorization Optimization

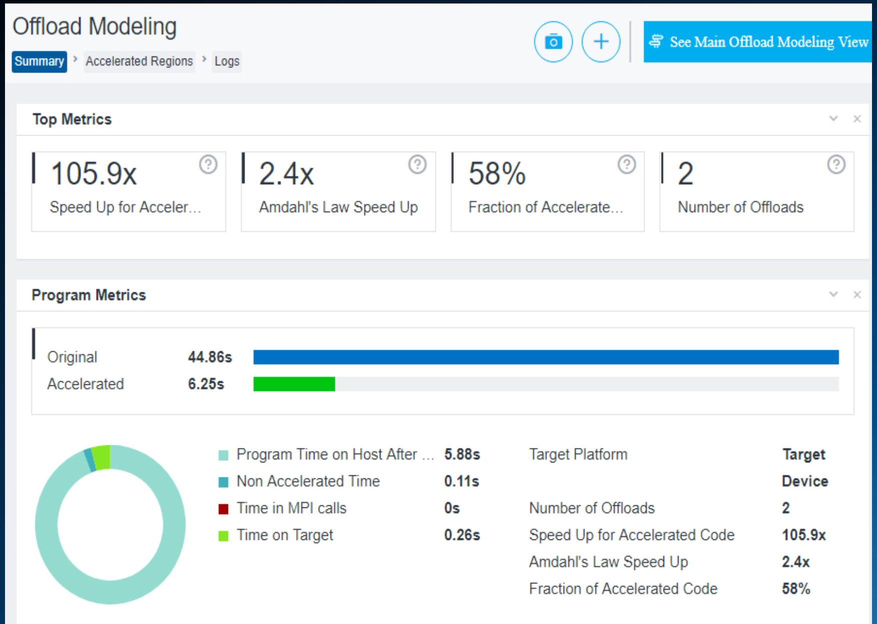
- Enable more vector parallelism and improve its efficiency

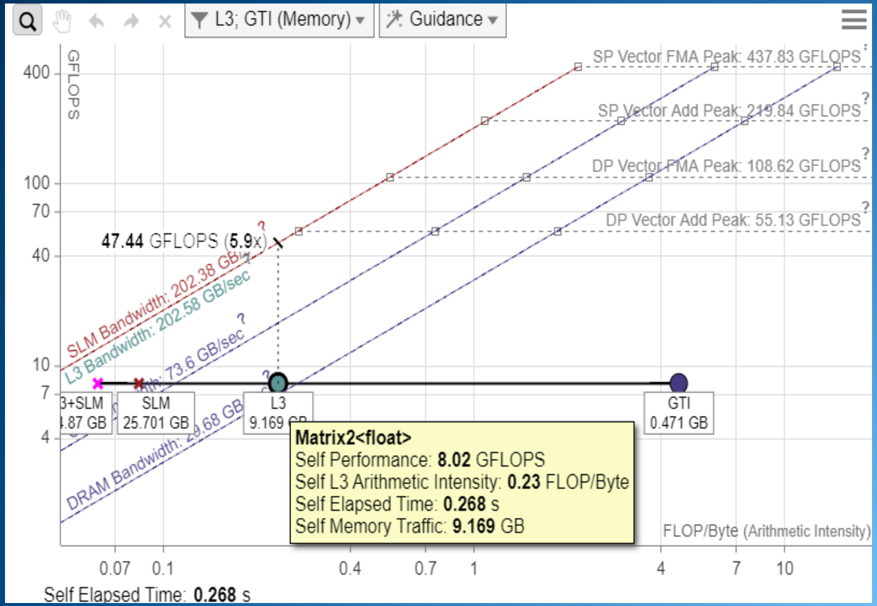
Thread Prototyping

- Add effective threading to unthreaded applications

Flow Graph Analyzer

- Create, visualize and analyze task and dependency computation graphs





Learn more: Intel.com/advisor

“Automatic” Vectorization Often Not Enough

A good compiler can still benefit greatly from vectorization optimization

Compiler will not always vectorize

- Check for Loop Carried Dependencies using Intel® Advisor
- All clear? Force vectorization.
  C++ use: pragma simd, Fortran use: SIMD directive

Not all vectorization is efficient vectorization

- Stride of 1 is more cache efficient than stride of 2 and greater. Analyze with Intel® Advisor.
- Consider data layout changes
  Intel® SIMD Data Layout Templates can help

Arrays of structures are great for intuitively organizing data, but are much less efficient than structures of arrays. Use the Intel® SIMD Data Layout Templates (Intel® SDLT) to map data into a more efficient layout for vectorization.

Get Breakthrough Vectorization Performance

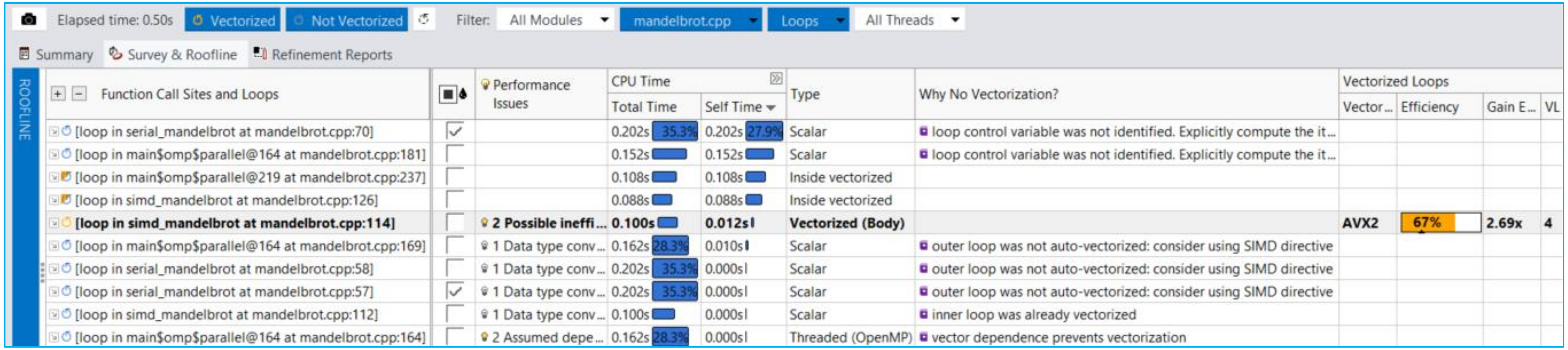
Intel® Advisor—Vectorization Advisor

Faster Vectorization Optimization

- Vectorize where it will pay off most
- Quickly ID what is blocking vectorization
- Tips for effective vectorization
- Safely force compiler vectorization
- Optimize memory stride

Data & Guidance You Need

- Compiler diagnostics + Performance Data + SIMD efficiency
- Detect problems & recommend fixes
- Loop-Carried Dependency Analysis
- Memory Access Patterns Analysis



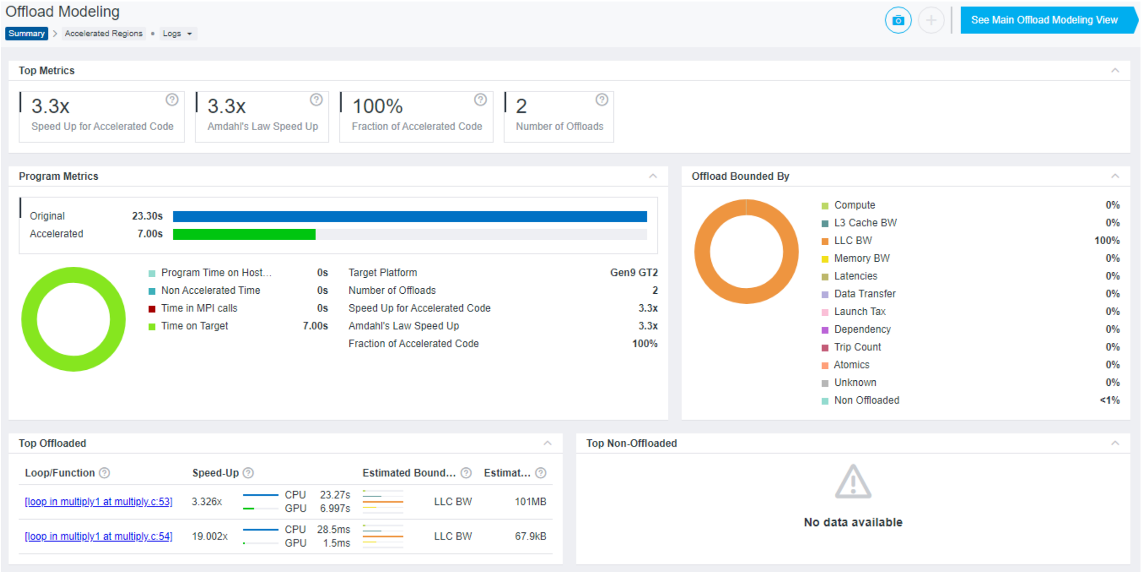
Optimize for Intel® AVX-512 with or without access to AVX-512 hardware

Intel.com/advisor

Design your code for efficient offload

Intel® Advisor - Offload Modeling

- Will your code benefit from GPU porting?
- How much performance acceleration will your code get from moving to the next-generation GPU?



Results can be reviewed in HTML reports.

With Offload Modeling, you can:

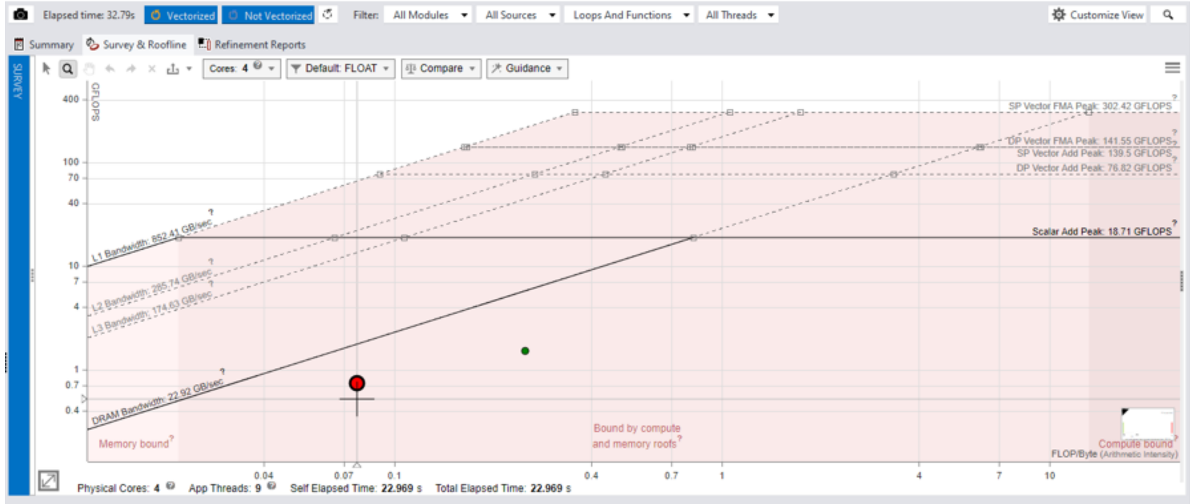
- Pinpoint offload opportunities where it pays off the most.
- Project the performance on GPU.
- Identify bottlenecks and potential performance gains.
- Get guidance for optimizing a data transfer between host and target devices.

Find Effective Optimization Strategies

Intel® Advisor—Automated Roofline Analysis

Optimize for memory and compute

- Highlights poor performing loops
- Shows performance 'headroom' for each loop
  - Which can be improved
  - Which are worth improving
- Shows likely causes of bottlenecks
- Suggests next optimization steps



> *"I am enthusiastic about the new "integrated roofline" in Intel® Advisor. It is now possible to proceed with a step-by-step approach with the difficult question of memory transfers optimization & vectorization which is of major importance."*

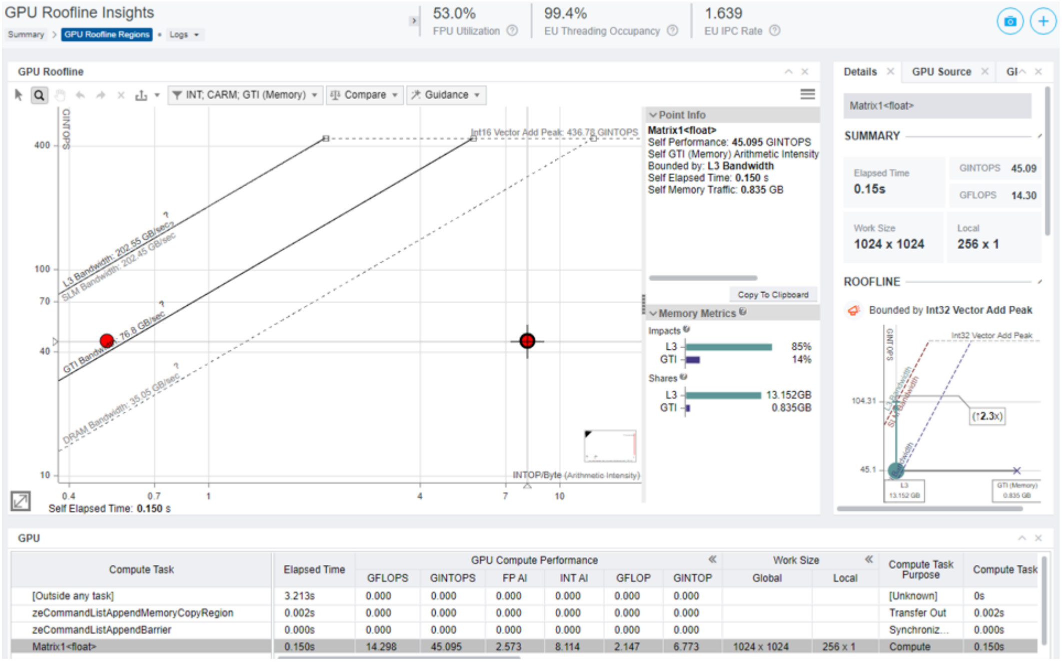
Nicolas Alferez, Software Architect
Onera – The French Aerospace Lab

Find Effective Optimization Strategies

Intel® Advisor - Roofline Analysis on GPU

GPU Roofline Performance Insights

- Highlights poor performing loops
- Shows performance ‘headroom’ for each loop
  - Which can be improved
  - Which are worth improving
- Shows likely causes of bottlenecks
  - Memory bound vs. compute bound
- Suggests next optimization steps



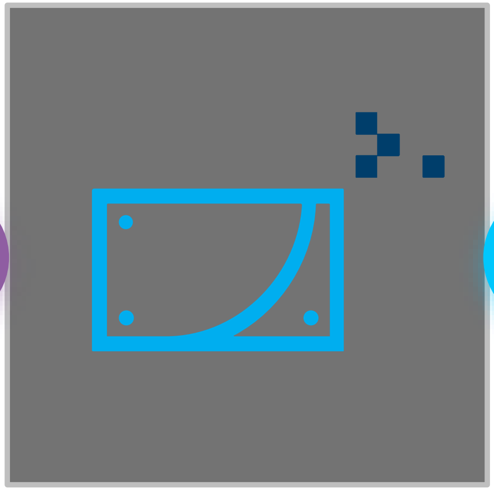
CPU Performance Profiling Exercises

MandelbrotOMP Sample

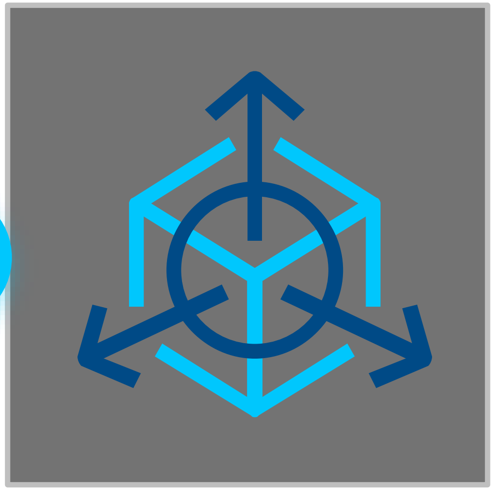
Workflow

Log into an Intel® **DevCloud** GPU node and configure the **MandelbrotOMP** sample

Run Intel Advisor: **Offload Advisor** to estimate performance on Gen9 GT2 GPU



Run Intel Advisor: **GPU Roofline** on offloaded implementation to visualize GPU performance



Run Intel VTune Profiler: **GPU Hotspots** for deeper insights into GPU kernels and device metrics

DevCloud Setup

Log into DevCloud via ssh

Start interactive gpu node:

```
$ qsub -I -l
nodes=1:gpu:ppn=2
```

Create MandelbrotOMP sample:

https://github.com/oneapi-src/oneAPI-samples

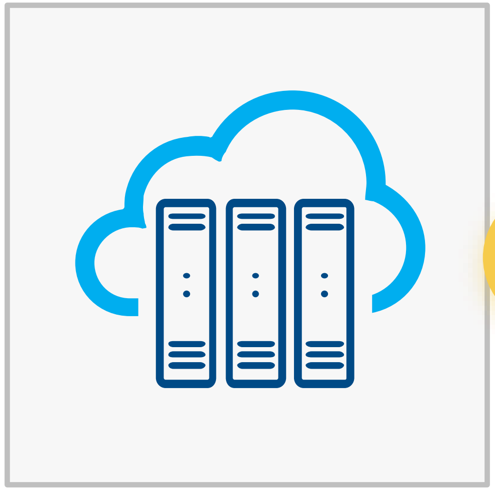
Start Intel VTune Profiler Server in second ssh terminal

DevCloud Setup

Intel DevCloud provides a free environment for testing the latest Intel CPUs and GPUs. Intel oneAPI toolkits are already installed and set up for use.

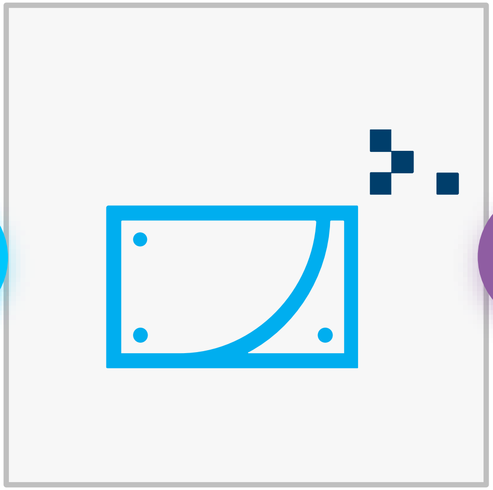
To create a DevCloud account, follow these steps:
https://www.intel.com/content/www/us/en/forms/idz/devcloud-enrollment/oneapi-request.html

Workflow – CPU Profiling

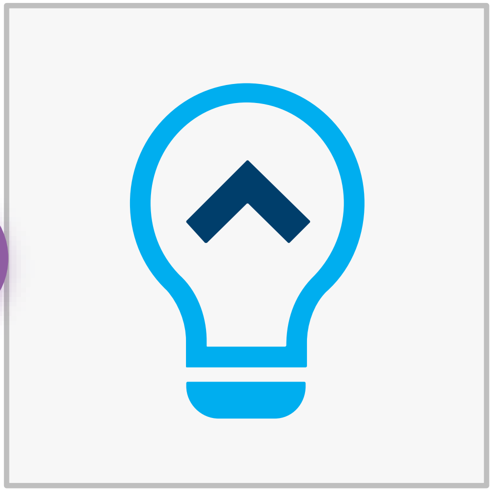


Configure the **MandelbrotOMP** sample

Run Intel VTune Profiler: **Hotspots** and **HPC Performance Characterization** to get a high level view of performance



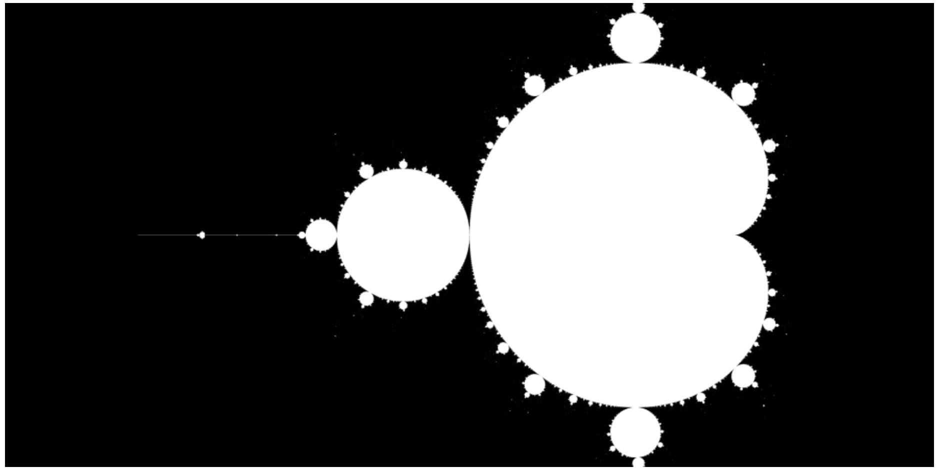
Run Intel Advisor: **CPU Roofline** to get a deeper understanding of vectorization performance



Run Intel Advisor: **Offload Advisor** to estimate performance on Gen9 GT2 GPU

MandelbrotOMP

- This sample runs one or all of four algorithms for generating a Mandelbrot image. Each algorithm has an increasing level of optimization, from a serial implementation to using OpenMP for parallelization and simd vectorization.
- From oneapi-cli: oneAPI Direct Programming -> C++ -> Combinational Logic -> Mandelbrot OMP
- Github link: https://github.com/oneapi-src/oneAPI-samples/tree/master/DirectProgramming/C%2B%2B/CombinationalLogic/MandelbrotOMP



MandelbrotOMP Makefile

Change options to use LLVM-based Intel C++ compiler

- Change compiler from `icpc` to `icpx`
- Remove `-ipo` from CFLAGS and LIBFLAGS and add: `-g -D__INTEL_COMPILER`
- Comment out ifdef defining `PERFNUM`

```
CXX := icpx
SRCDIR := src
BUILDDIR := release
CFLAGS := -O3 -ipo -qopenmp -std=c++11
-g -D__INTEL_COMPILER
EXTRA_CFLAGS :=
LIBFLAGS := -qopenmp
ifdef perf_num
	EXTRA_CFLAGS += -D PERF_NUM
endif
TARGET := $(BUILDDIR)/Mandelbrot
icpx: $(TARGET)
```

MandelbrotOMP main.cpp

Increase workload size

- src/main.cpp
  - Change the `max_depth` from 100 to 5000

```
//Modifiable parameters:
int height = 1024;
int width = 2048 //Width should be a multiple of 8
int max_depth = 5000;
```

All commands

- `$ cd MandelbrotOMP`
- `$ vim Makefile`
    - Make the changes from slide 25
- `$ vim src/main.cpp`
    - Make the change from slide 25
- `$ make`
- `$ make run`

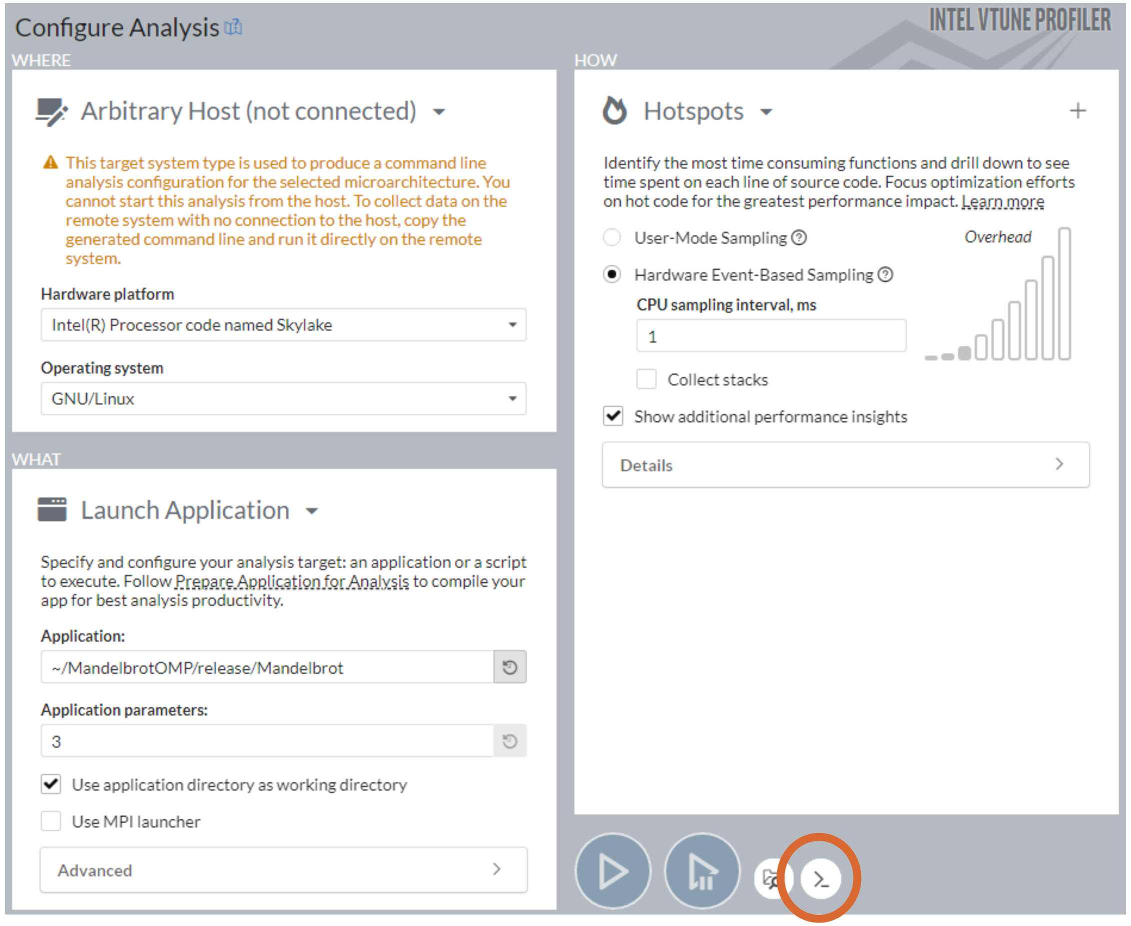
Intel® VTune™ Profiler Exercise

MandelbrotOMP Sample

Collect CPU Hotspots

Generate VTune Command Line

1. Open Intel VTune Profiler on local host
2. In “Where” select “Arbitrary Host”
   - This is just for generating command lines
3. In “What”:
   - Application: ~/MandelbrotOMP/release/Mandelbrot
   - Application parameters: 3
4. In “How” select “Hotspots”
   - Hardware event-based Sampling
   - Show additional performance insights enabled
5. Press Command Line button

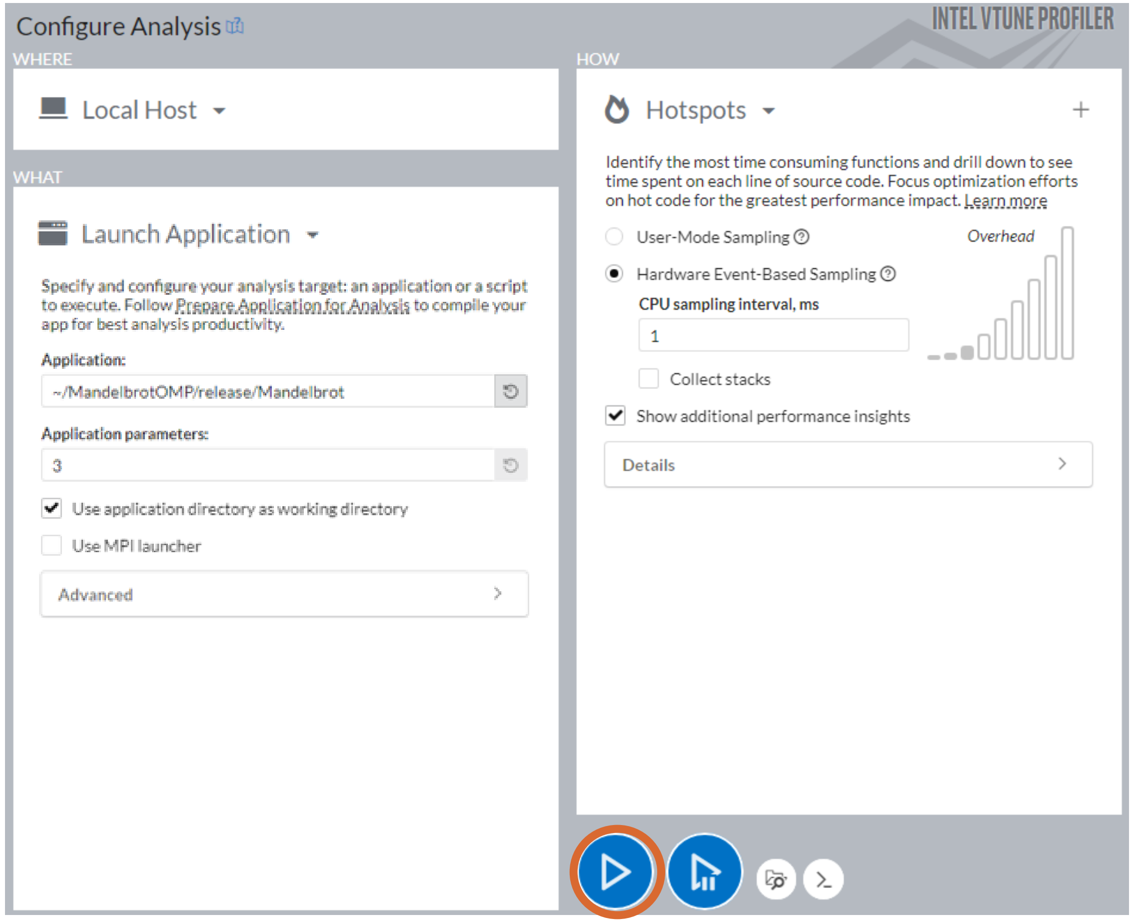



```
$ vtune -collect hotspots -knob sampling-mode=hw --app-working-dir=~/MandelbrotOMP/release --
~/MandelbrotOMP/release/Mandelbrot 3
```

Collect CPU Hotspots

Run from GUI

1. Run `vtune-gui`
2. In “Where” select “Local Host”
3. In “What”:
   - Application: ~/MandelbrotOMP/release/Mandelbrot
   - Application parameters: 3
4. In “How” select “Hotspots”
   - Hardware event-based Sampling
   - Show additional performance insights enabled
5. Press Start button

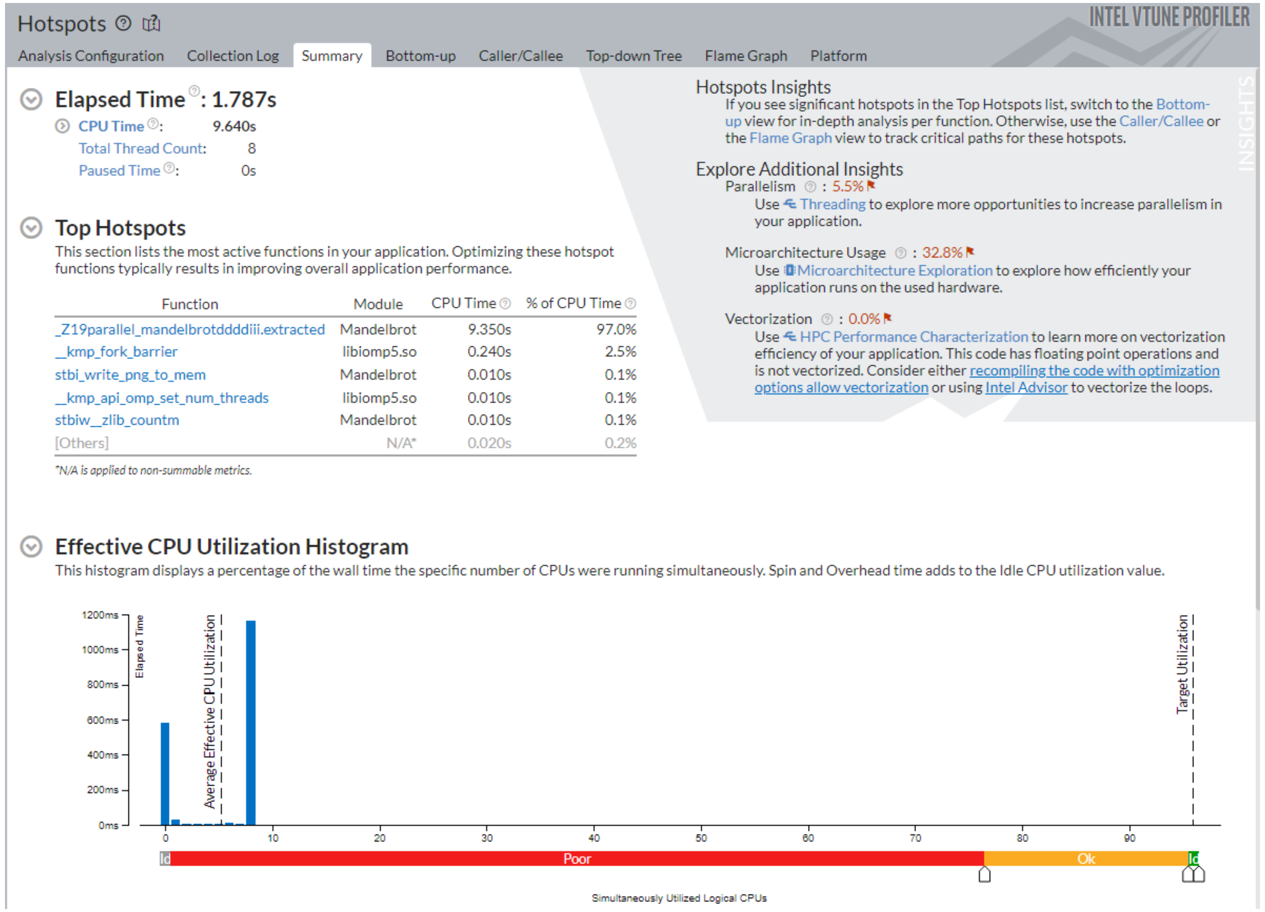



```
$ vtune -collect hotspots -knob sampling-mode=hw --app-working-dir=~/MandelbrotOMP/release --
~/MandelbrotOMP/release/Mandelbrot 3
```

Collect CPU Hotspots

View Results – Summary Tab

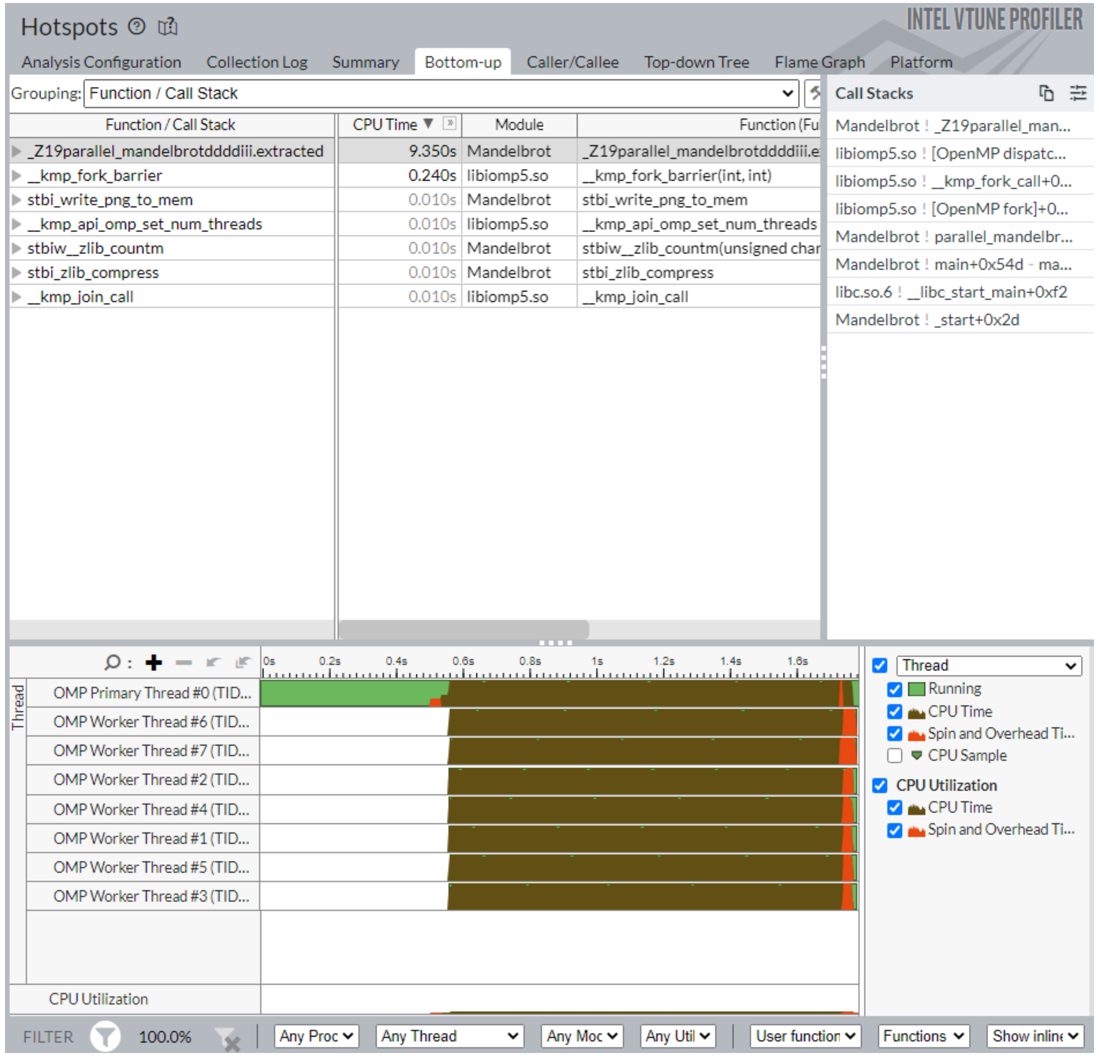
- Top hotspot is the parallel_mandelbrot function
- Effective CPU Utilization Histogram shows majority of time running on 8 logical CPUs
  - There are only 8 threads, so this is expected
- Insights highlights problems with the following:
  - Parallelism – This number is low due to the number of threads defined in the application code. Increasing the number of threads should scale.
  - Microarchitecture Usage – This number is low, indicating poor use of hardware resources.
  - Vectorization – This number is very low, meaning that there are floating point operations in the code but none are vectorized. This is a good place to start.
- Next Step: Run the recommended HPC Performance Characterization Analysis for more vectorization insights



Collect CPU Hotspots

View Results – Bottom-up Tab

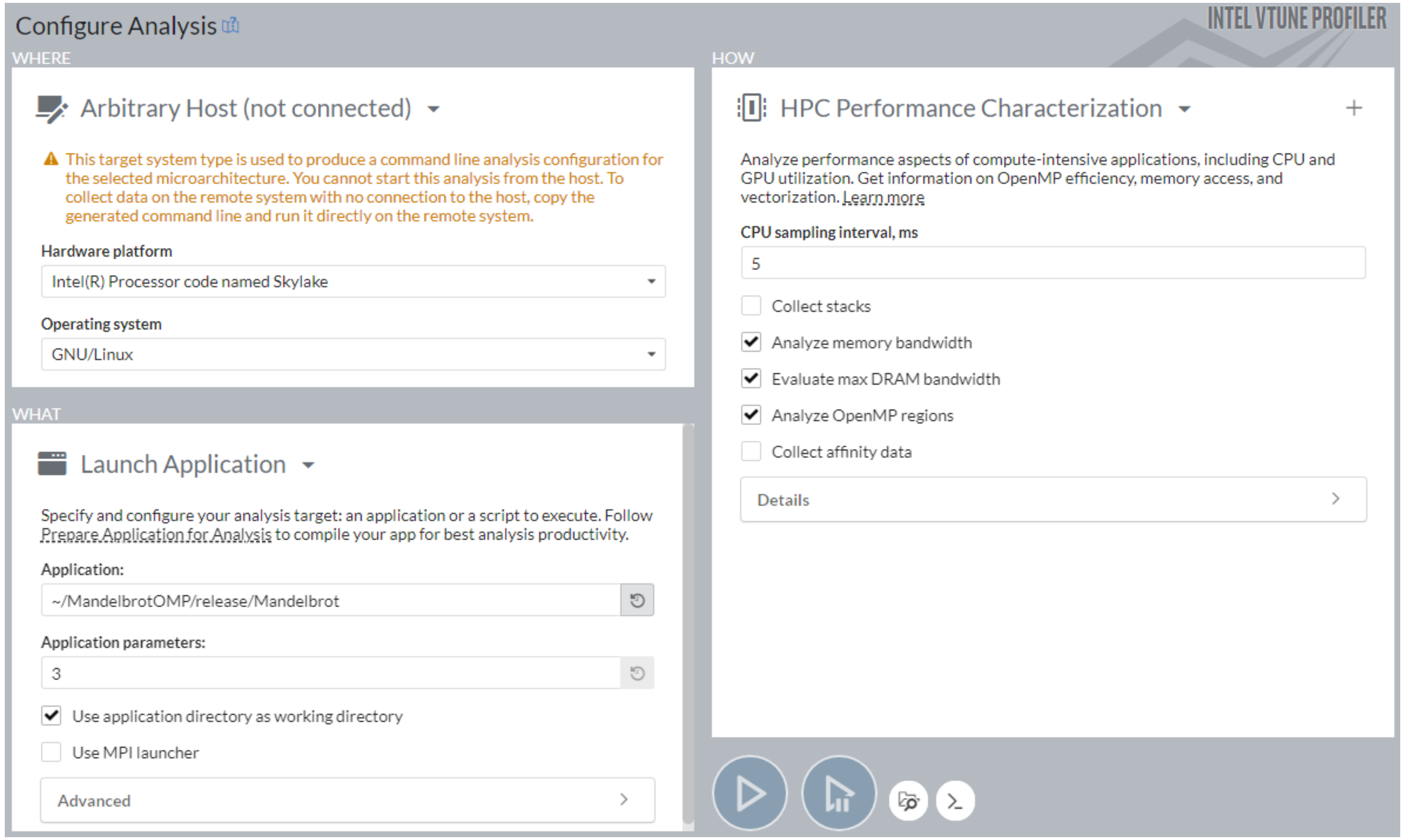
- The thread timeline view at the bottom shows that there are 8 OMP threads, and all of them are primarily colored in brown
  - Green indicates that the thread is running, but brown is where the thread was actively using the CPU
  - Red indicates spin and overhead time, and in this case the threads are waiting for all of them to finish.
- Overall, thread performance has good concurrency with no real problems. The only issue is that the application limits itself to 8 threads instead of taking advantage of more available CPUs.
- Next Step: Run the recommended HPC Performance Characterization Analysis for more vectorization insights



Collect HPC Performance Characterization

Generate VTune Command Line

1. In “How” select “HPC Performance Characterization”
   - Use default options
2. Press Command Line button

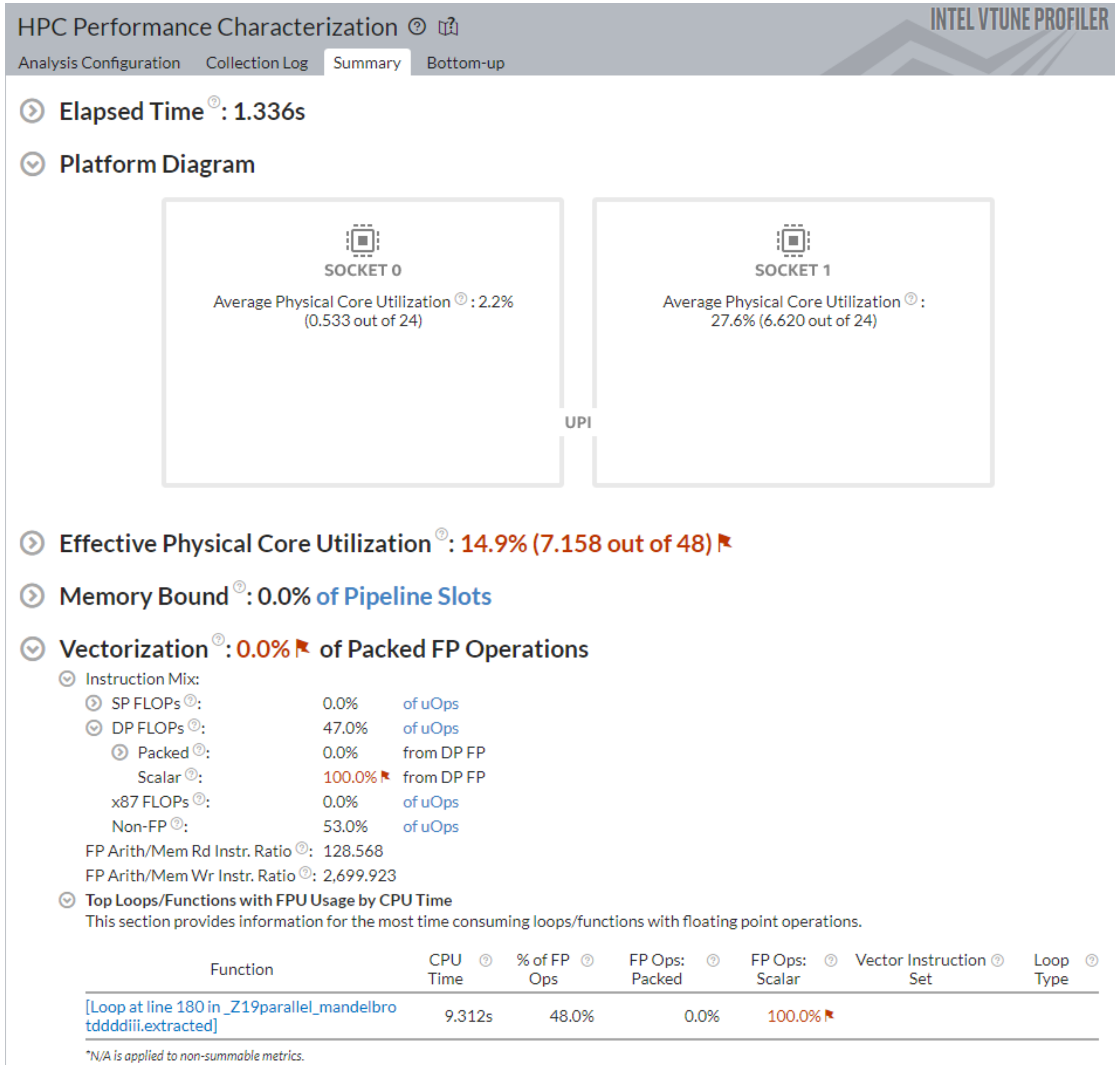



```
$ vtune -collect hpc-performance --app-working-dir=~/MandelbrotOMP/release --
~/MandelbrotOMP/release/Mandelbrot 3
```

Collect HPC Performance Characterization

View Results – Summary Tab

- Platform Diagram shows majority of CPU utilization is on Socket 1, with no UPI or memory traffic
- Effective Physical Core Utilization is low due to the number of threads defined in the application
- There are no issues due to memory accesses
- Vectorization shows that 47% of uOps are floating point, but none are vectorized (packed). Adding vectorization could significantly improve performance.
- Next Step: Run CPU Roofline with Intel Advisor



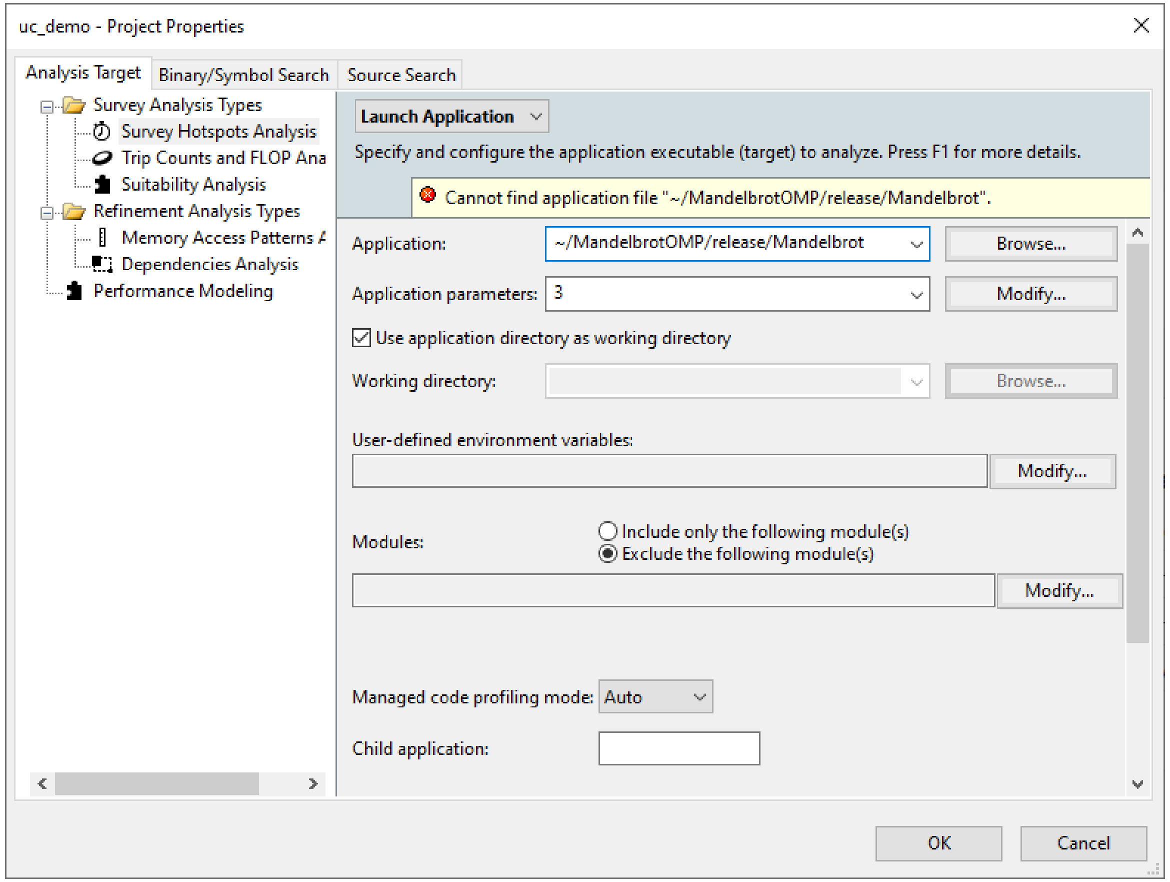
Intel® Advisor Exercise

MandelbrotOMP Sample

Collect CPU Roofline

Run from GUI

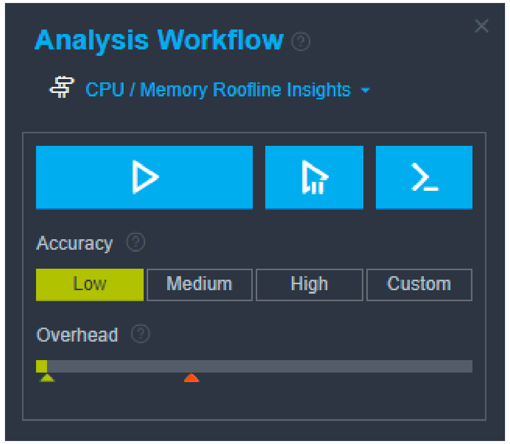
1. Run `advixe-gui`
2. Create a new project
   - Application: ~/MandelbrotOMP/release/Mandelbrot
   - Application parameters: 3
3. Press OK

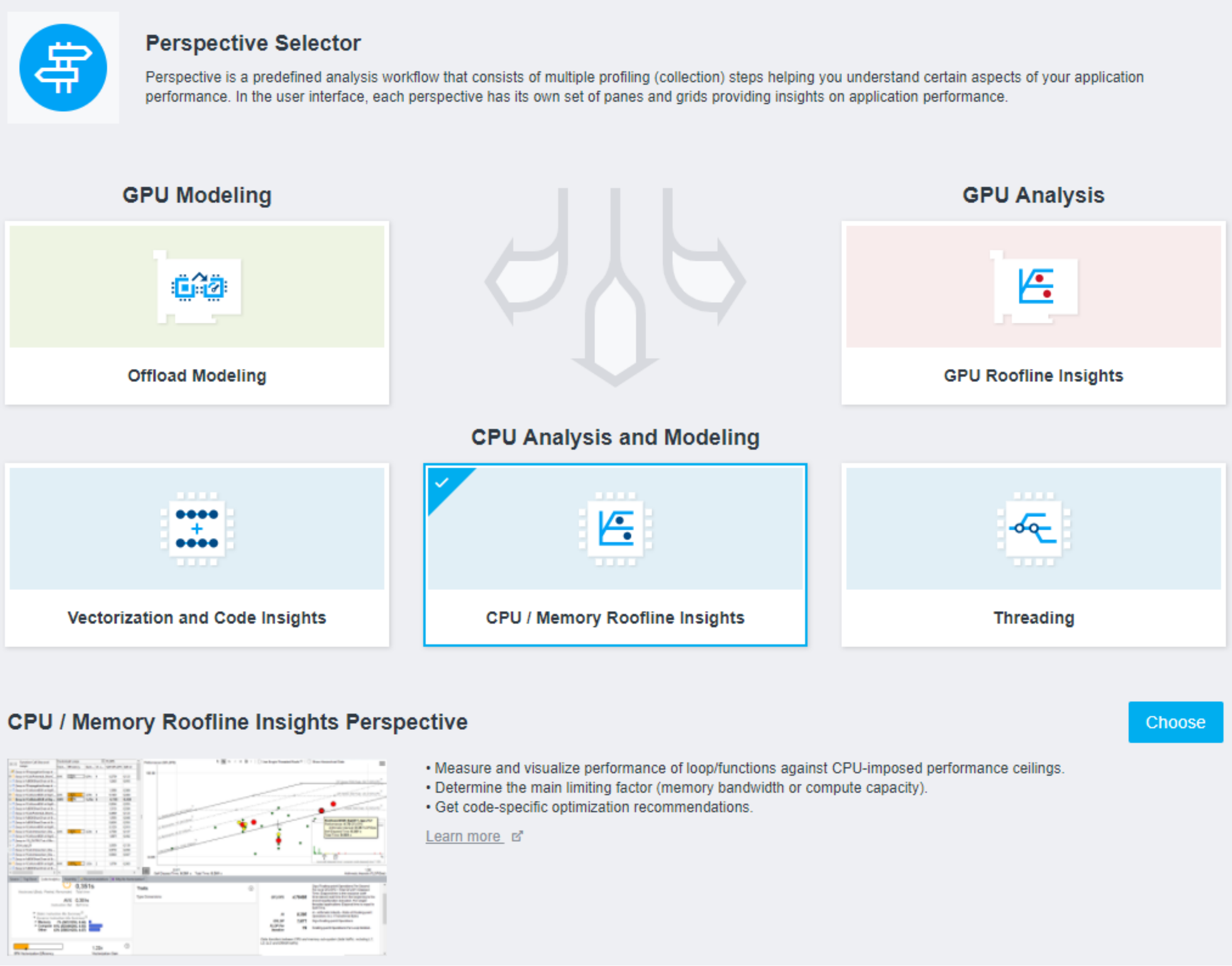


Collect CPU Roofline

Run from GUI - cont

1. From the Perspective Selector, select CPU/Memory Roofline Insights
2. Press Choose button
3. From the new Analysis Workflow panel, press the Run button





Collect CPU Roofline

Run Advisor in the remote CLI

1. Run the roofline collection:

```
$ advisor --collect=roofline --project-dir=./cpu_roofline
-- ./release/Mandelbrot 3
```

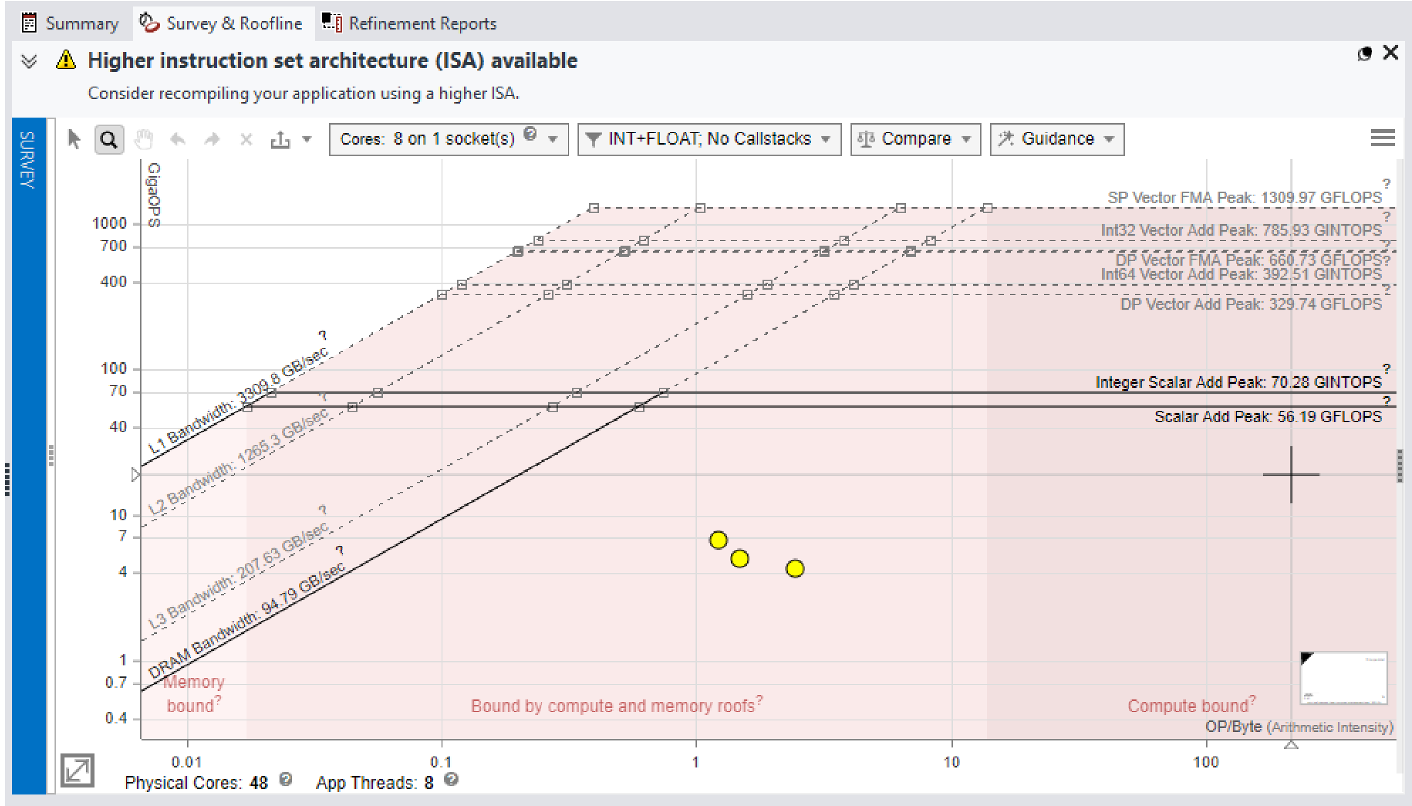
2. Package results for viewing on the local host:

```
$ advisor --snapshot --project-dir=./cpu_roofline --pack -
-cache-sources --cache-binaries -- ./cpu_roofline_snapshot
```

Collect CPU Roofline

View Results – Roofline

- There are a few loops shown for INT data, but FLOAT is the one doing the compute.
- The FLOAT loop points to line 168, which is the inner for loop. It is compute bound.

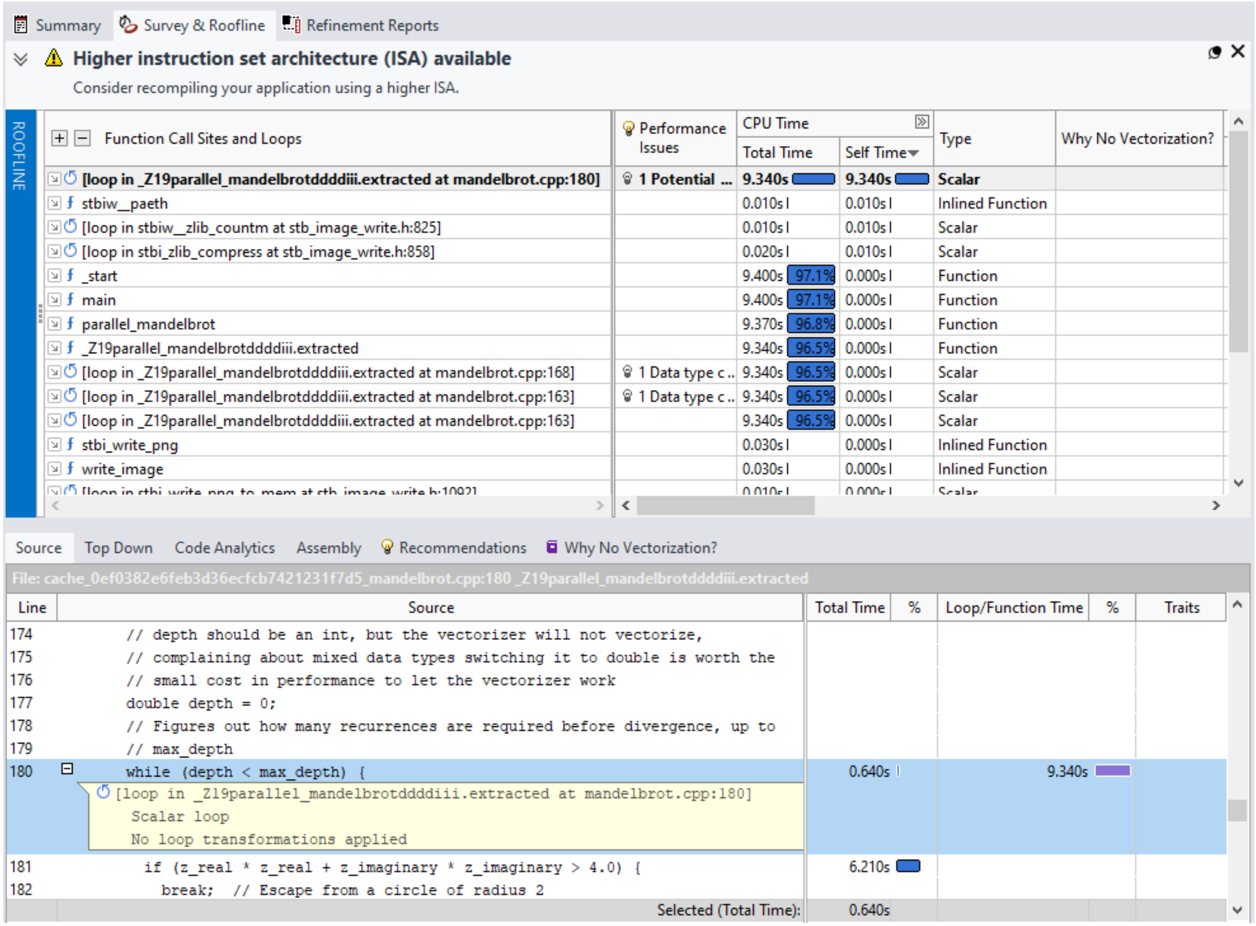


Note that there is no large loop dot for the main while loop. This is likely due to the arithmetic intensity of the while loop getting applied to the earlier for loop. There are also issues with the compiler being unable to determine the number of iterations in the while loop due to the break statement.

Collect CPU Roofline

View Results – Survey

- The top loop uses the while command, and the compiler won't vectorize it due to unknown iterations.
- The loop identified in the roofline view at line 168 is an inner for loop, which wasn't vectorized because of the added complexity of the while loop. The compiler determined it would hurt performance.

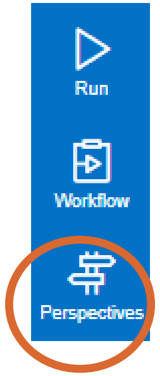


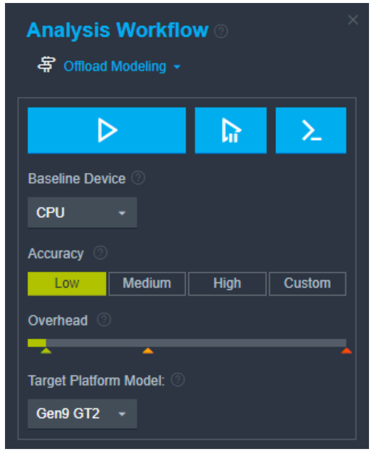
Note that Advisor currently lacks support for the vectorization report from icpx – the new LLVM-based compiler - which is why some vectorization details are missing. This is being worked on.

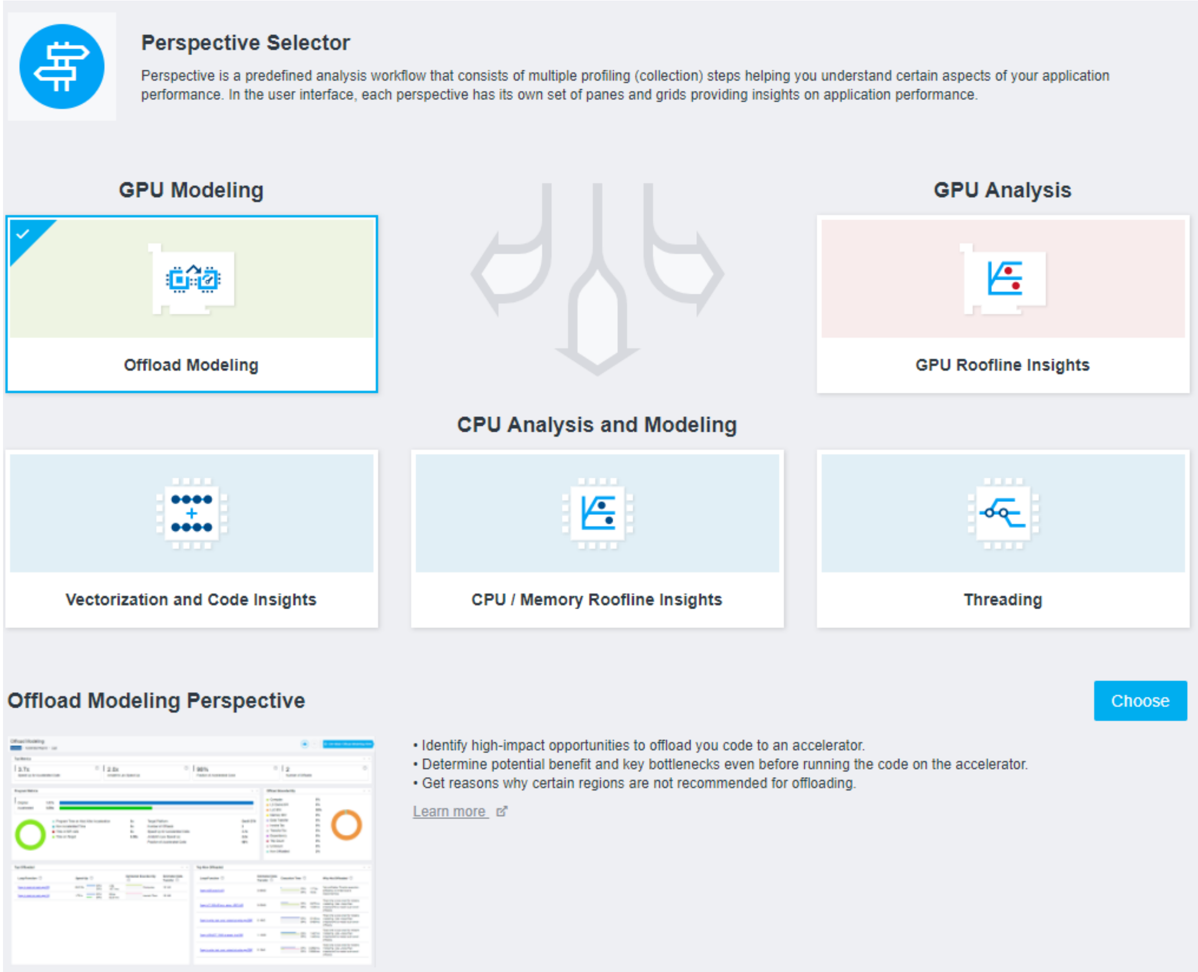
Collect Offload Advisor

Run from GUI - cont

1. Go back to the Perspective Selector and select Offload Modeling
2. Press Choose button
3. From the new Analysis Workflow panel:
    1. Select Low for Accuracy
    2. Select Gen9 GT2 from the Target Platform Model drop-down
    3. Press the Run button







Collect Offload Advisor

Run Advisor in the remote CLI

1. Run the offload collection:

```
$ advisor --collect=offload --accuracy=low --target-
device=gen9_gt2 --project-dir=./offload_advisor
./release/Mandelbrot 3
```

2. Package results for viewing on the local host:

```
$ advisor --snapshot --project-dir=./offload_advisor --
pack --cache-sources --cache-binaries --
./offload_advisor_snapshot
```

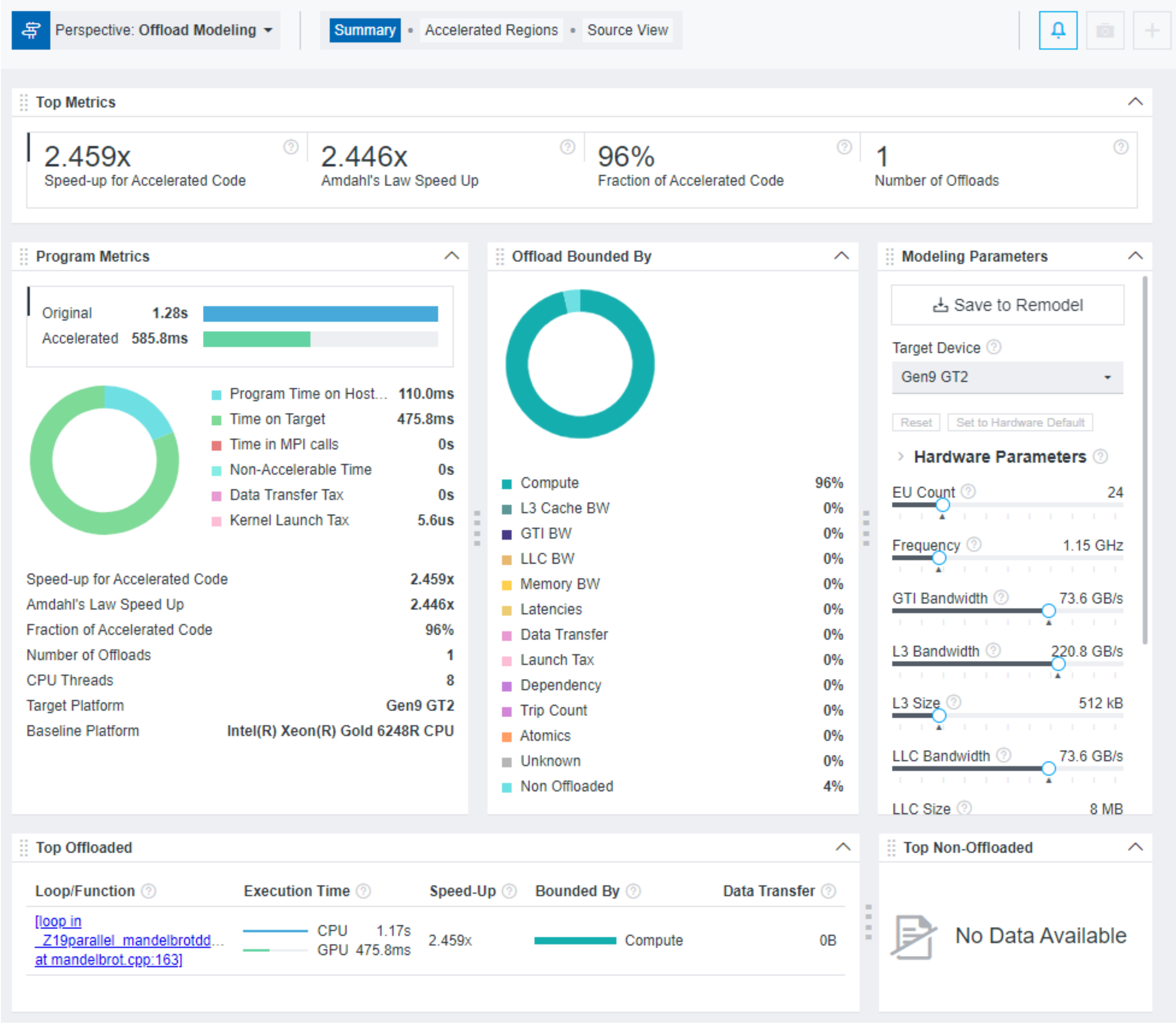
Collect Offload Advisor

View Results – Summary

- **Top Metrics** shows that the speed-up for accelerated code and Amdahl's Law are very close, indicating that the offloaded code makes up most of the workload. If accelerated code speed up is high but the Amdahl's law speed up is close to 1.000x, then offloading likely isn't worth it.
- **Program Metrics** contains more details about the accelerated code and how much program time will remain on the host.
- **Offload Bounded By** shows the items that may impact performance of the code once it is offloaded. In this case the offloaded code will be compute bound.
- **Modeling Parameters** are the hardware characteristics of the target device. Advisor provides configurations for many Intel GPUs.
- **Top Offloaded / Non-Offloaded** – these are loops or functions that have the potential to be offloaded. If the speed-up is significant enough, Advisor will recommend offloading. Some loops or functions will incur too much overhead to make offloading profitable. In this case, the main OMP compute loop is recommended for offloading.

Note that this report is from the non-vectorized implementation of the Mandelbrot function. With vectorization and parallelism, Offload Advisor will not recommend offloading as the overhead will be more than the performance gain.

Optimizing for CPU is still a good idea!



MandelbrotOMP with GPU Offload

- To help demonstrate the capabilities of Intel Offload Advisor, we added a fifth function to use OpenMP offload to a GPU target:

- src/mandelbrot.cpp
  - Copy the `omp_mandelbrot (..)` function and rename to `offload_mandelbrot (..)`
  - Change #pragma omp parallel for schedule to:
    - ```
      #pragma omp target teams distribute \
       parallel for simd collapse(2) \
      map(from:output[0:width*height])
      map(to:height,width,xstep,ystep,max_depth)
      ```

- src/mandelbrot.hpp
  - Copy the `omp_mandelbrot (..)` function and rename to `offload_Mandelbrot (..)`
      ```

MandelbrotOMP with GPU Offload

- Add a fifth option to enable the new offload_mandelbrot function

- src/main.cpp
  - Change the `max_depth` from 100 to 5000
  - Add variable `offload_time` to
    - ```
      double serial_time,
      omp_simd_time,
      omp_parallel_time,
      omp_both_time;
      ```
  - Add section for offload_mandelbrot under `printf("\nRunning all tests\n")`
  - Add case 5 with offload_Mandelbrot to switch (option)
  - Not using PERF_NUM
      ```

MandelbrotOMP Makefile

- Change options to use OpenMP offload capability
  - Change compiler from icpc to icpx
  - Remove qopenmp from CFLAGS and LIBFLAGS and add: `-fiopenmp -fopenmp-targets=spir64`
  - Add `-g -D__INTEL_COMPILER` to CFLAGS

View how we are running compared to system max

- Use Intel® Advisor CLI to generate a GPU Roofline report on the offload implementation (option 5):

  - `advisor --collect=survey --project-dir=./offload_mandel --profile-gpu -- /home/uxxxxx/MandelbrotOMP/release/Mandelbrot 5`
  - `advisor --collect=tripcounts --project-dir=./offload_mandel --flop --profile-gpu -- /home/uxxxxx/MandelbrotOMP/release/Mandelbrot 5`
  - `advisor -report=roofline -gpu -project-dir=./offload_mandel --report-output=./gpu_roofline.html`

- Create a snapshot for download to the local GUI:

  - `advisor --snapshot --project-dir=./offload_mandel --pack --cache-sources --cache-binaries -- ./offload_mandel_snapshot`

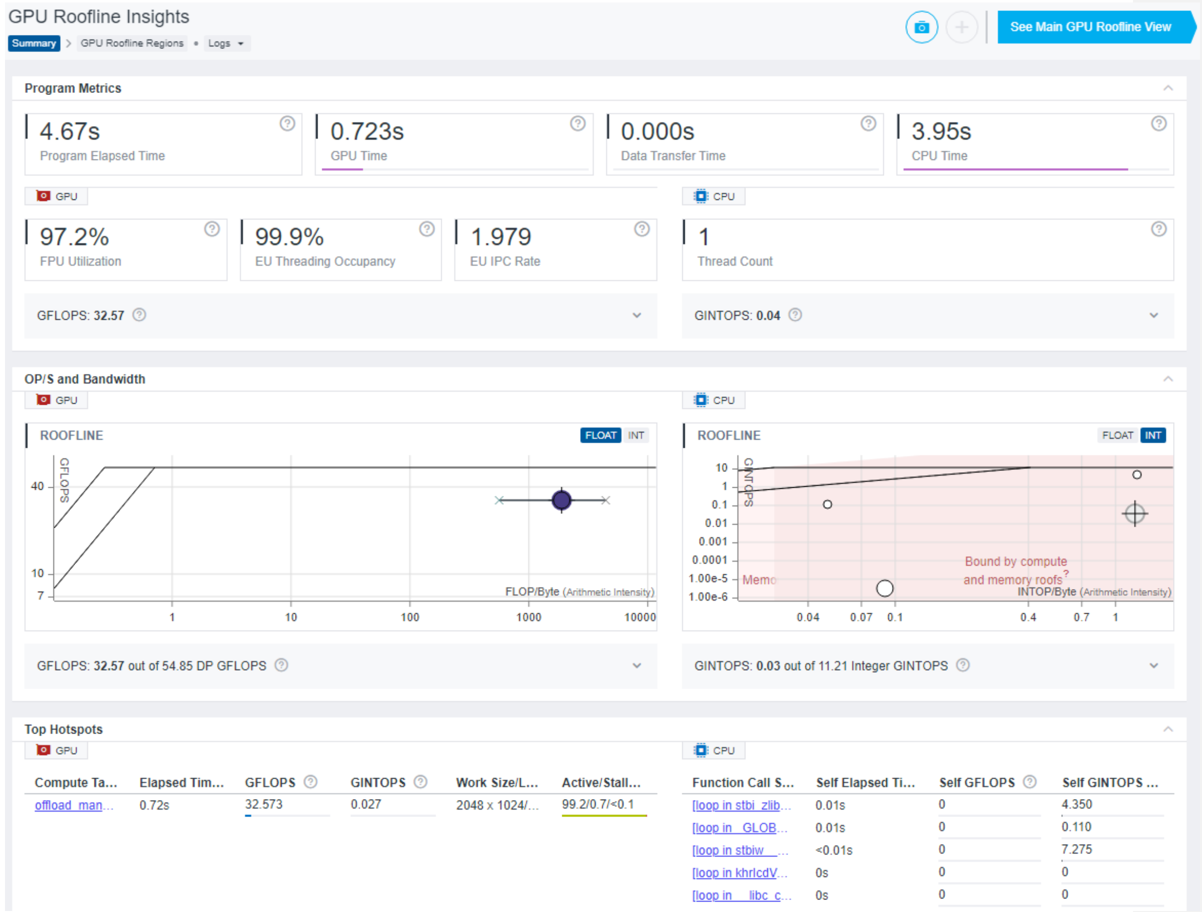
GPU Roofline

- The overall elapsed time of 4.67s is much higher in the offloaded version than the parallel CPU implementation (1.49s). But the compute task has a speed-up:
  - From 1.03s in parallel_mandelbrot to 0.72s in offload_Mandelbrot. Not quite hitting the estimate of 538.2ms.
  - Nearly 4s is spent on the CPU

Top Hotspots

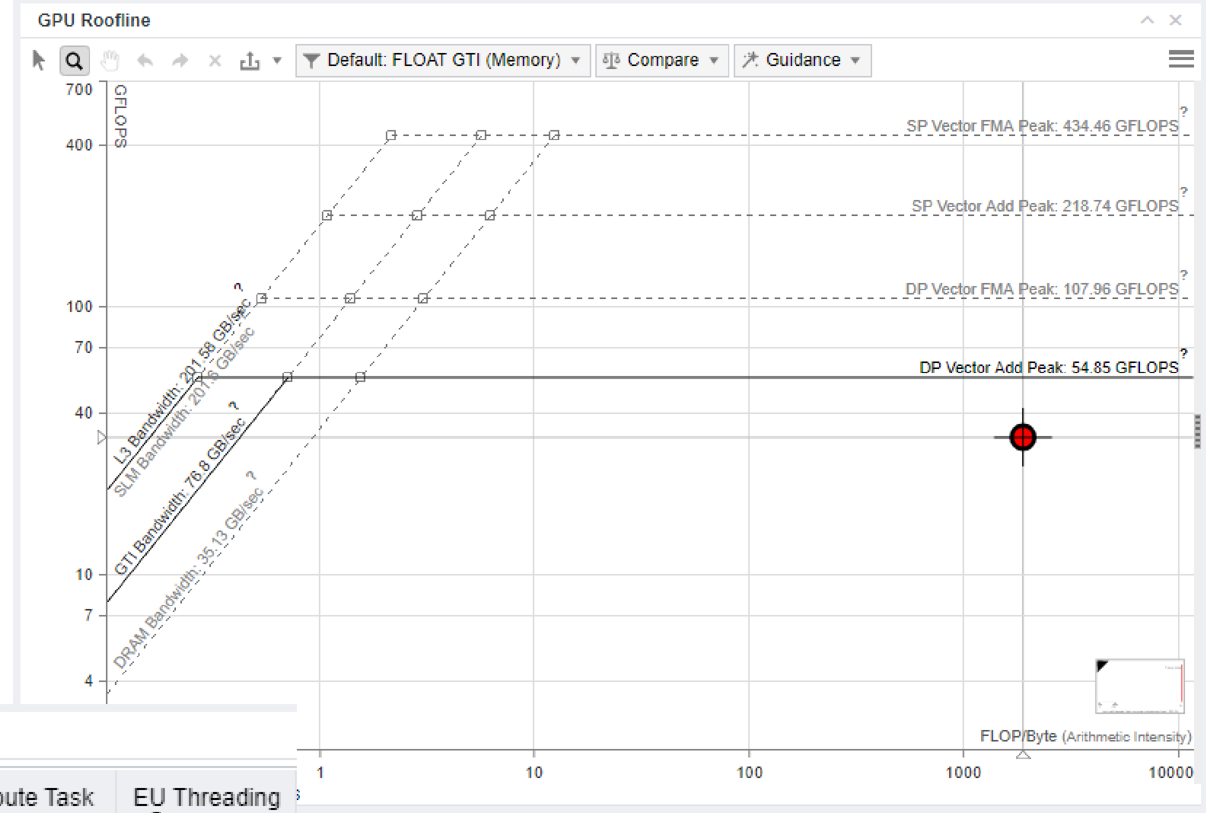
GPU

Compute Ta...	Elapsed Tim...	GFLOPS	GINTOPS	Work Size/L...	Active/Stall...
offload_man...	0.72s	32.573	0.027	2048 x 1024/...	99.2/0.7/<0.1



GPU Roofline continued

- The offload task appears to be bounded by the DP Vector Add Peak. Otherwise, it appears to make good use of the GPU.
  - EU Array is 99.2% active, and the threading occupancy is almost 100%
  - There is an unknown task consuming 3.951s of CPU time with 100% idle GPU time.



GPU

Compute Task	Elapsed Time	GPU Compute Performance	EU Array Active	EU Array Stalled	EU Array Idle	Compute Task Purpose	EU Threading Occupancy
[Outside any task]	3.951s	0.000	0.0%	0.0%	100.0%	[Unknown]	0.0%
zeCommandListAppendMemoryCopy	0.000s	0.000	0.0%	0.0%	100.0%	Transfer In	0.0%
zeCommandListAppendBarrier	0.000s	0.000	0.0%	0.0%	100.0%	Synchroniz…	0.0%
offload_mandelbrotompoffloading:266	0.723s	32.573	99.2%	0.7%	0.0%	Compute	99.9%

Intel VTune Profiler: GPU Hotspots

command-line

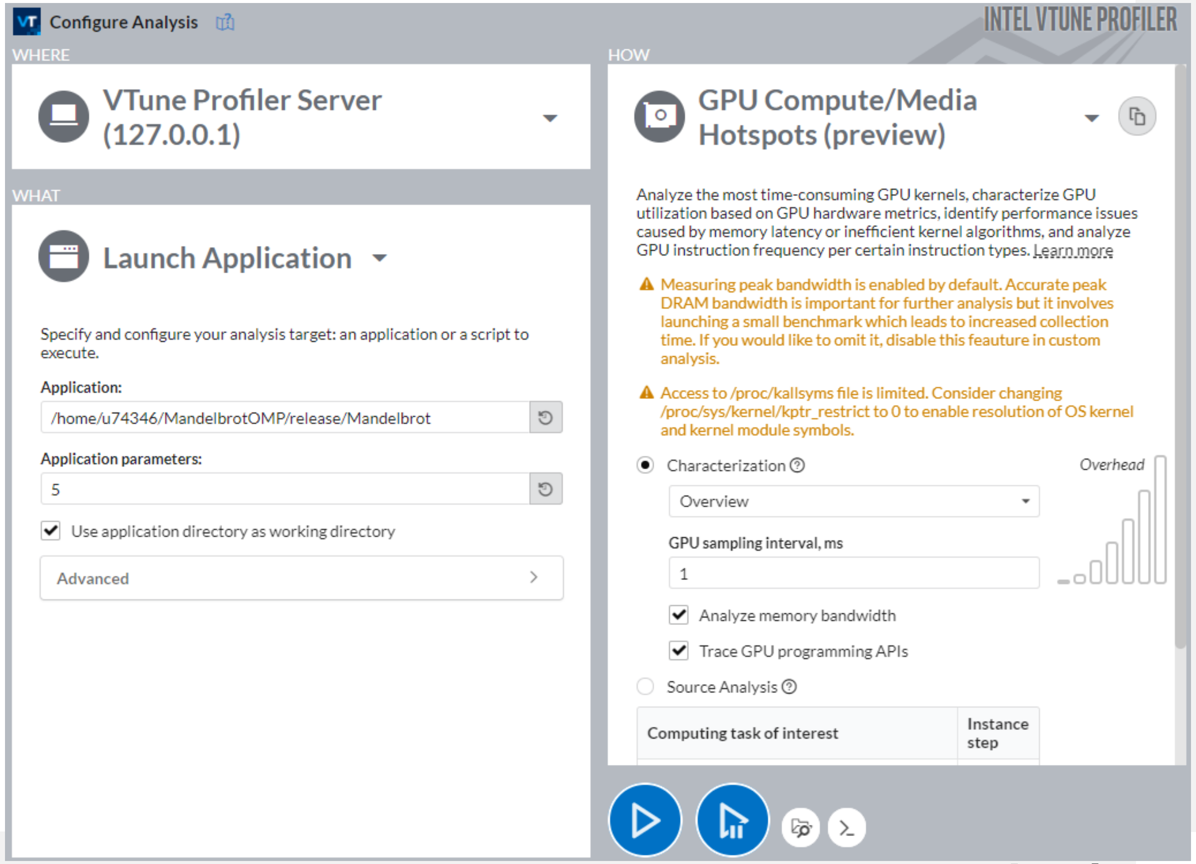
- Running gpu-hotspots on the command-line
- vtune –collect gpu-hotspots ./Mandelbrot 5

- Generating a report Elapsed Time: 4.386s
- GPU Time: 0.682s
- EU Array Stalled/Idle: 0.8%
- GPU L3 Bandwidth Bound: 0.3%
- Hottest GPU Computing Tasks Bound by GPU L3 Bandwidth
- Computing Task Total Time
- -------------- ----------
- Sampler Busy: 0.0%
- Hottest GPU Computing Tasks with High Sampler Usage
- Computing Task Total Time
- -------------- ----------
- FPU Utilization: 96.3%
- Hottest GPU Computing Tasks with High FPU Utilization

Copy result directory to local system

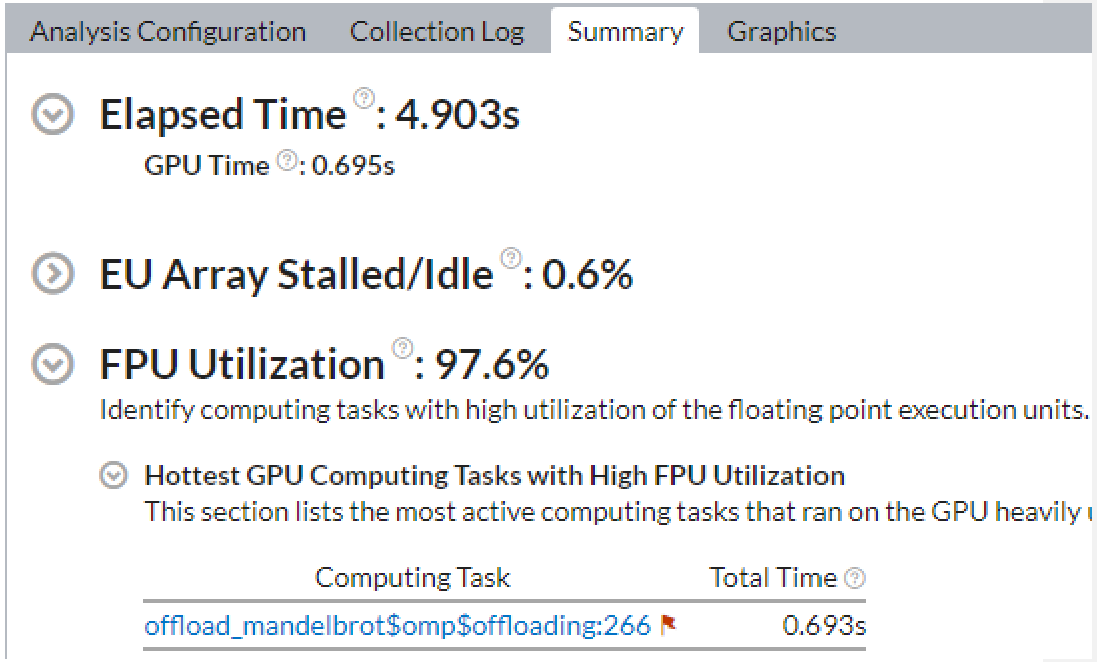
Intel VTune Profiler: GPU Hotspots

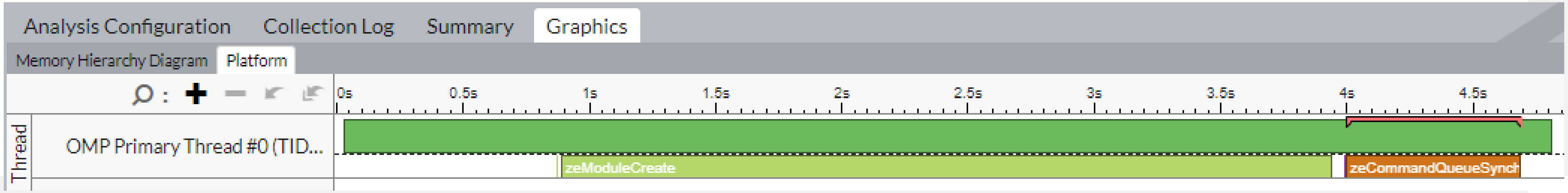
- Once the Intel VTune Profiler is running with the vtune-backend command, open the URL in the browser for the GUI.
  - Set the application to /home/uxxxxx/MandelbrotOMP/release/Mandelbrot and set the application parameter to 5.
  - Run the GPU Compute/Media Hotspots analysis type



GPU Hotspots

- The Summary tab shows that although only a small percentage of the overall elapsed time is spent on the GPU, the offload task performs well on the GPU.
- The Graphics tab doesn't indicate any major problems. Under the Platform sub-tab, there is an OpenMP task called zeModuleCreate that runs for about 3.5s. That explains the high CPU utilization time.





Related Content

GPU Offloading and Profiling Webinars

- Offload Excellence – Designing for GPU Performance
- Is your code GPU offload ready?
  - Presentation slides
- Design and tune your applications for GPUs
  - Presentation slides – this continues the MandelbrotOMP sample and adds GPU offloading
- High performance GPU acceleration
  - This uses the iso3dfd sample in a similar workflow to today's training

Additional Advisor Content

- Roofline: Optimize for Compute, Memory, or Both?
- Remove Memory Bottlenecks
  - Older, but includes Memory Access Pattern analysis
- Vectorization Advisor
  - Also older, but includes AoS->SoA

Additional VTune Content

- Pump up your scaling

More Resources

Intel® VTune™ Profiler – Performance Profiler

- Product page – overview, features, FAQs…
- Training materials – Cookbooks, User Guide, Processor Tuning Guides
- Support Forum
- Online Service Center - Secure Priority Support
- What's New?

Additional Analysis Tools

- Intel® Advisor – Design and optimize for efficient vectorization, threading, memory usage, and accelerator offload. Roofline and flow graph analysis.
- Intel® Inspector – memory and thread checker/ debugger
- Intel® Trace Analyzer and Collector - MPI Analyzer and Profiler

Additional Development Products

- Intel® oneAPI Toolkits
- Intel® Software Development Products

How to get

- As part of the oneAPI Base Toolkit:
  - https://software.intel.com/content/www/us/en/develop/tools/oneapi/base-toolkit/download.html
- Standalone component:
  - https://software.intel.com/content/www/us/en/develop/articles/oneapi-standalone-components.html#vtune
- Linux:
  - Package managers:
    - https://software.intel.com/content/www/us/en/develop/articles/oneapi-repo-instructions.html
  - Containers:
    - https://github.com/intel/oneapi-containers