# Intel® Advisor Vectorization

Dmitry Tarakanov

Software Technical Consulting Engineer

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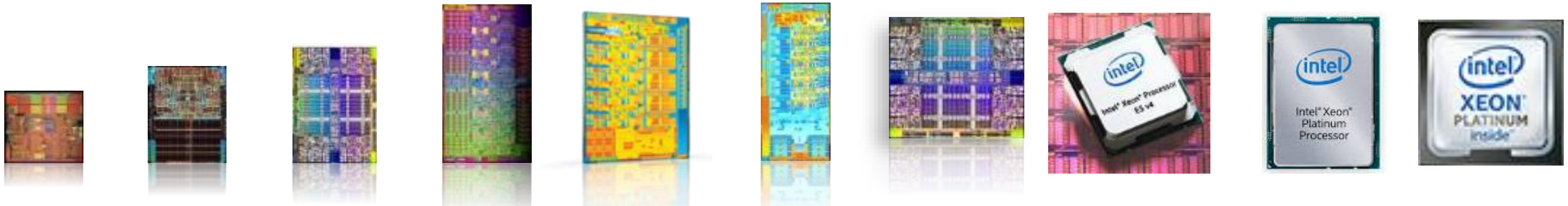
Performance results are based on testing as of dates shown in configurations and may not reflect all publicly available updates. See configuration disclosure for details.

Your costs and results may vary.

Intel technologies may require enabled hardware, software or service activation.

# World is changing: HW and SW change, too!

## More Cores → More Threads → Wider Vectors




| | Intel® Xeon® Processor | | | | | | | | Intel® Xeon® Scalable Processor | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 64-bit | 5100 series | 5500 series | 5600 series | E5-2600 | E5-2600 V2 | E5-2600 V3 | E5-2600 V4 | Platinum 8180 | Platinum 9282 |
| Core(s) | 1 | 2 | 4 | 6 | 8 | 12 | 18 | 22 | 28 | 56 |
| Threads | 2 | 2 | 8 | 12 | 16 | 24 | 36 | 44 | 56 | 112 |
| SIMD Width | 128 | 128 | 128 | 128 | 256 | 256 | 256 | 256 | 512 | 512 |

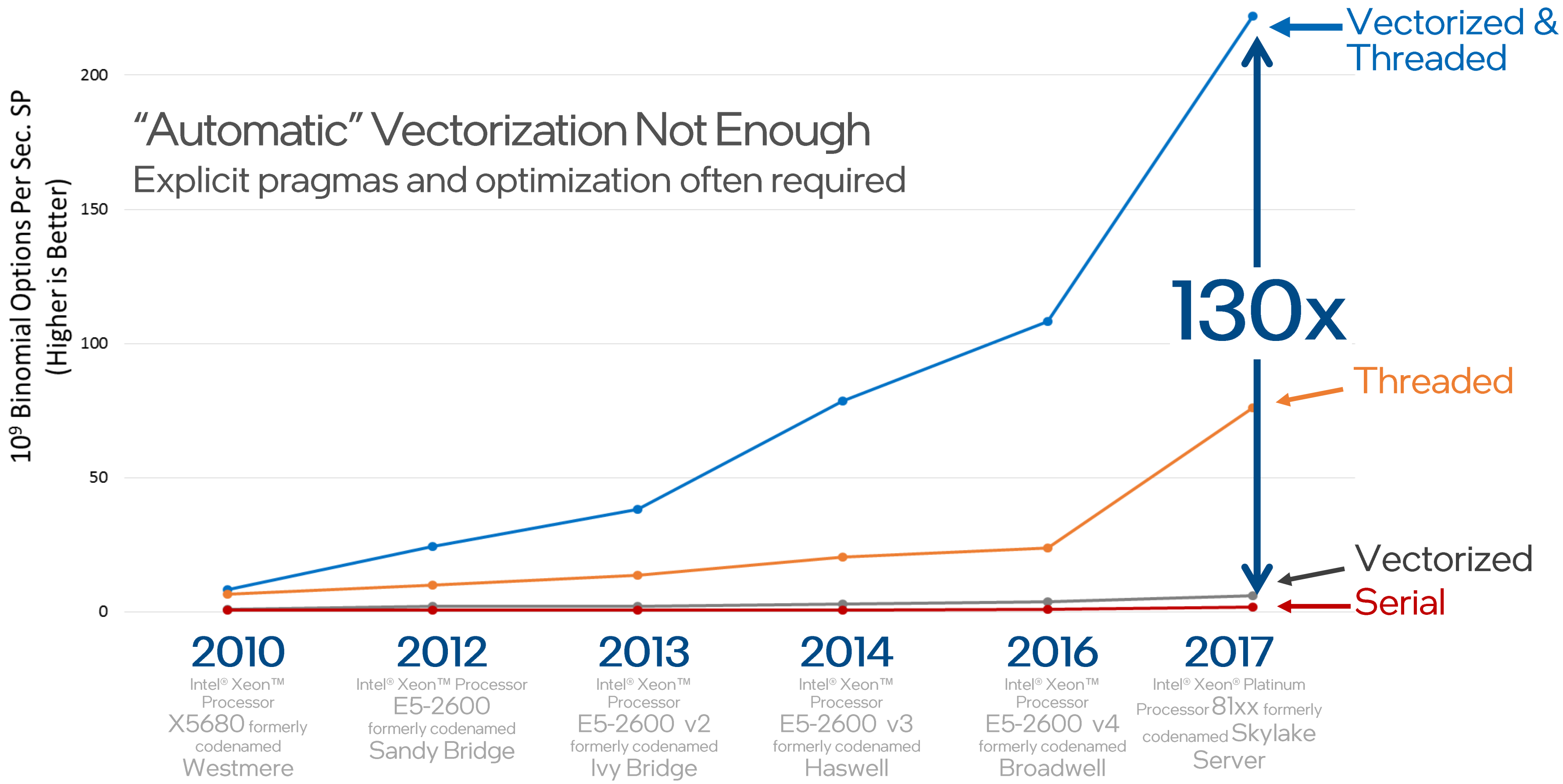
High performance software must be both

- Parallel (multi-thread, multi-process)
- Vectorized

*Product specification for launched and shipped products available on ark.intel.com.

# Intel® Advisor: Vectorize & Thread or Performance Dies

## Threaded + Vectorized Can Be Much Faster that Either One Alone




**The Difference is Growing with Each New Generation of Hardware**

**Testing Date:** Performance results are **based on testing by Intel employees as of 2017** and may not reflect all publicly available security updates.

**Configuration Details and Workload Setup:** See Vectorize & Thread or Performance Dies Configurations for 2010-2016 Benchmarks in Backup.

Performance results are based on testing as of dates shown in configurations and may not reflect all publicly available updates. See configuration disclosure for details. No product or component can be absolutely secure.

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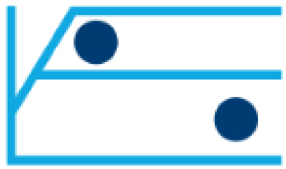
# Rich Set of Capabilities for High Performance Code Design

## Intel® Advisor

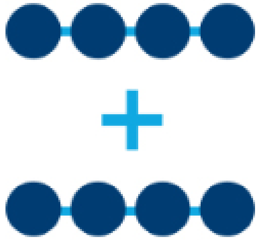
### Offload Modelling

Design offload strategy and model performance on GPU.



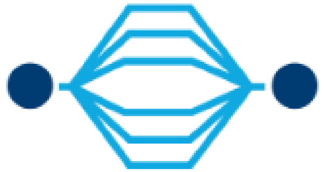
### Roofline Analysis

Optimize your application for memory and compute.



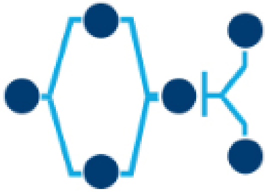
### Vectorization Optimization

Enable more vector parallelism and improve its efficiency.



### Thread Prototyping

Model, tune, and test multiple threading designs.



### Build Heterogeneous Algorithms

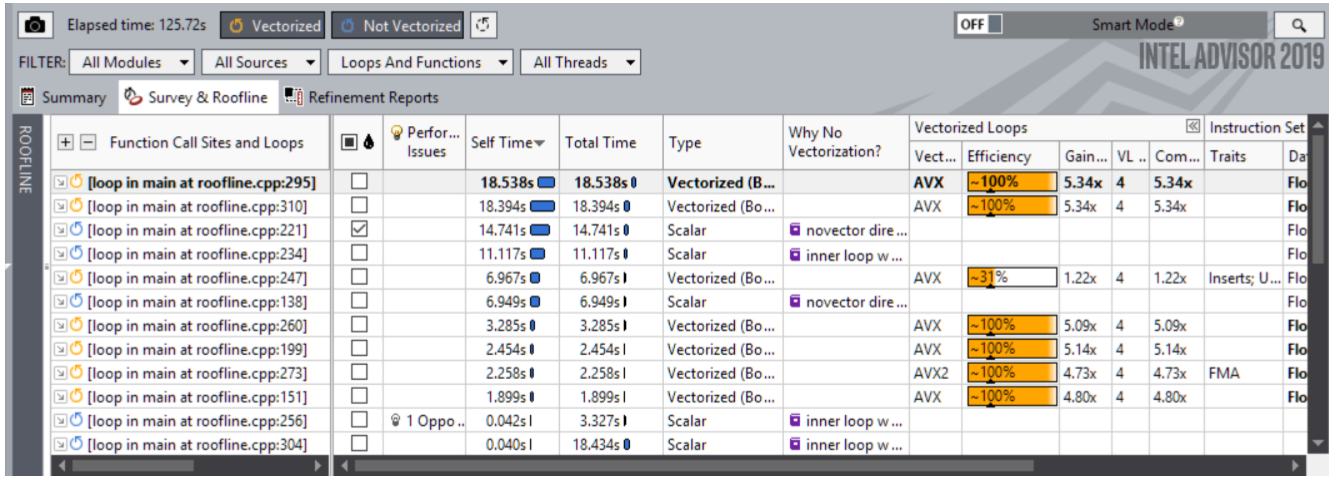
Create and analyze data flow and dependency computation graphs.

# Get Faster Code Faster! Intel® Advisor

## Vectorization Optimization

- Have you:
  - Recompiled for AVX2 with little gain
  - Wondered where to vectorize?
  - Recoded intrinsics for new arch.?
  - Struggled with compiler reports?

- Data Driven Vectorization:
  - What vectorization will pay off most?
  - What's blocking vectorization? Why?
  - Are my loops vector friendly?
  - Will reorganizing data increase performance?
  - Is it safe to just use pragma simd?




| Function Call Sites and Loops | Perfor... Issues | Self Time | Total Time | Type | Why No Vectorization? | Vectorized Loops: Vect... | Efficiency | Gain... | VL .. | Com... | Instruction Set: Traits | Da |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **[loop in main at roofline.cpp:295]** | | **18.538s** | **18.538s** | **Vectorized (B...** | | **AVX** | **~100%** | **5.34x** | **4** | **5.34x** | | **Flo** |
| [loop in main at roofline.cpp:310] | | 18.394s | 18.394s | Vectorized (Bo... | | AVX | ~100% | 5.34x | 4 | 5.34x | | Flo |
| [loop in main at roofline.cpp:221] | | 14.741s | 14.741s | Scalar | novector dire... | | | | | | | Flo |
| [loop in main at roofline.cpp:234] | | 11.117s | 11.117s | Scalar | inner loop w... | | | | | | | Flo |
| [loop in main at roofline.cpp:247] | | 6.967s | 6.967s | Vectorized (Bo... | | AVX | ~31% | 1.22x | 4 | 1.22x | Inserts; U... | Flo |
| [loop in main at roofline.cpp:138] | | 6.949s | 6.949s | Scalar | novector dire... | | | | | | | Flo |
| [loop in main at roofline.cpp:260] | | 3.285s | 3.285s | Vectorized (Bo... | | AVX | ~100% | 5.09x | 4 | 5.09x | | Flo |
| [loop in main at roofline.cpp:199] | | 2.454s | 2.454s | Vectorized (Bo... | | AVX | ~100% | 5.14x | 4 | 5.14x | | Flo |
| [loop in main at roofline.cpp:273] | | 2.258s | 2.258s | Vectorized (Bo... | | AVX2 | ~100% | 4.73x | 4 | 4.73x | FMA | Flo |
| [loop in main at roofline.cpp:151] | | 1.899s | 1.899s | Vectorized (Bo... | | AVX | ~100% | 4.80x | 4 | 4.80x | | Flo |
| [loop in main at roofline.cpp:256] | 1 Oppo... | 0.042s | 3.327s | Scalar | inner loop w... | | | | | | | |
| [loop in main at roofline.cpp:304] | | 0.040s | 18.434s | Scalar | inner loop w... | | | | | | | |

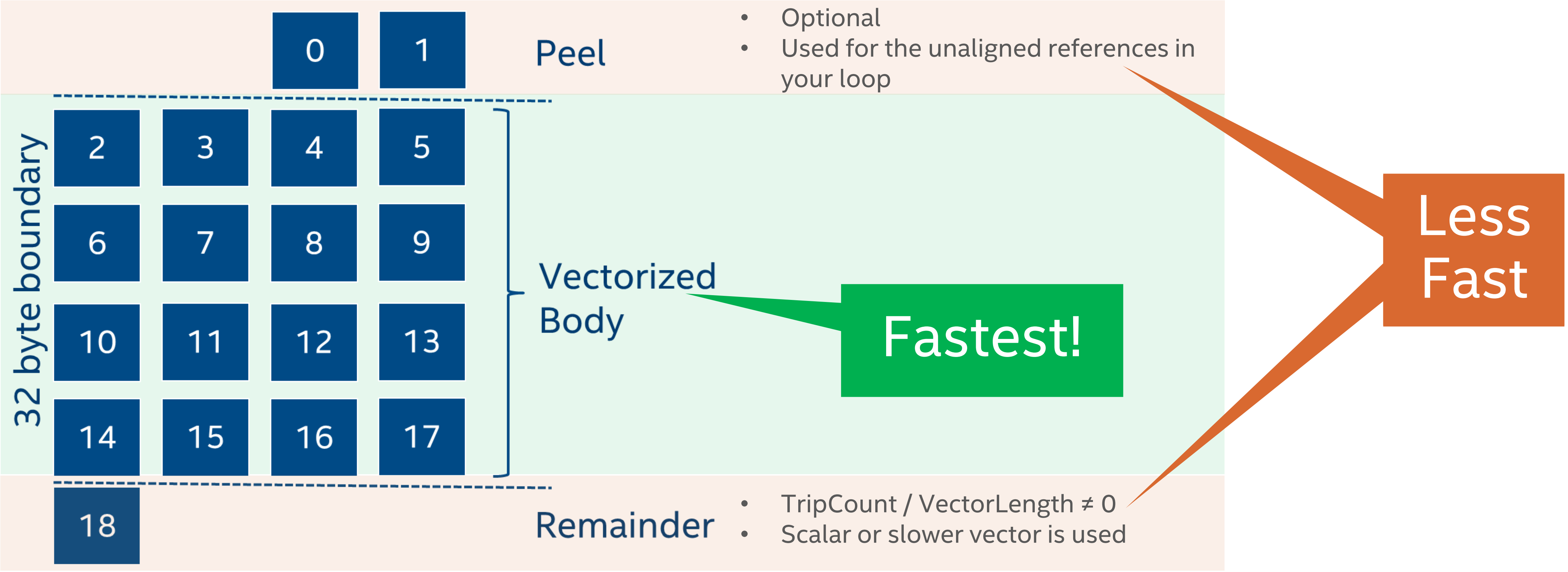
"Intel® Advisor's Vectorization Advisor permitted me to focus my work where it really mattered. When you have only a limited amount of time to spend on optimization, it is invaluable."

*Gilles Civario*

*Senior Software Architect*

***Irish Centre for High-End Computing***

# Spend your time in the most efficient place!
# A typical vectorized loop consists of…

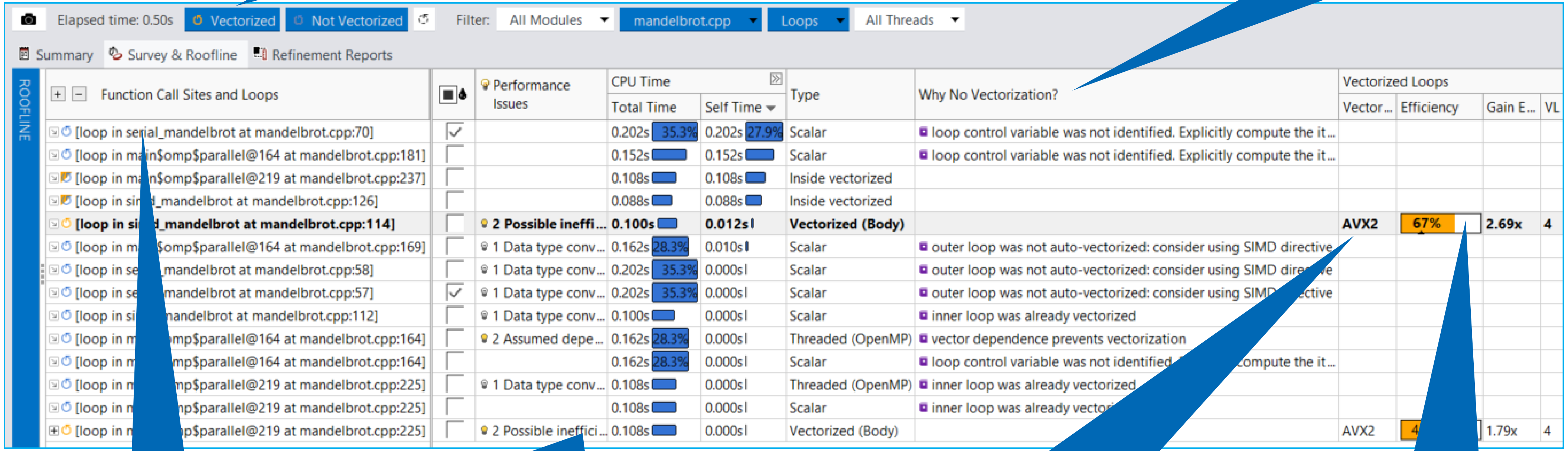


# The Right Data At Your Fingertips

## Get all the data you need for high impact vectorization

Filter vectorized loops

What prevents vectorization?




Focus on hot loops

What vectorization issues do I have?

Which Vector instructions are used?

How efficient is the code?

**Get Faster Code Faster!**

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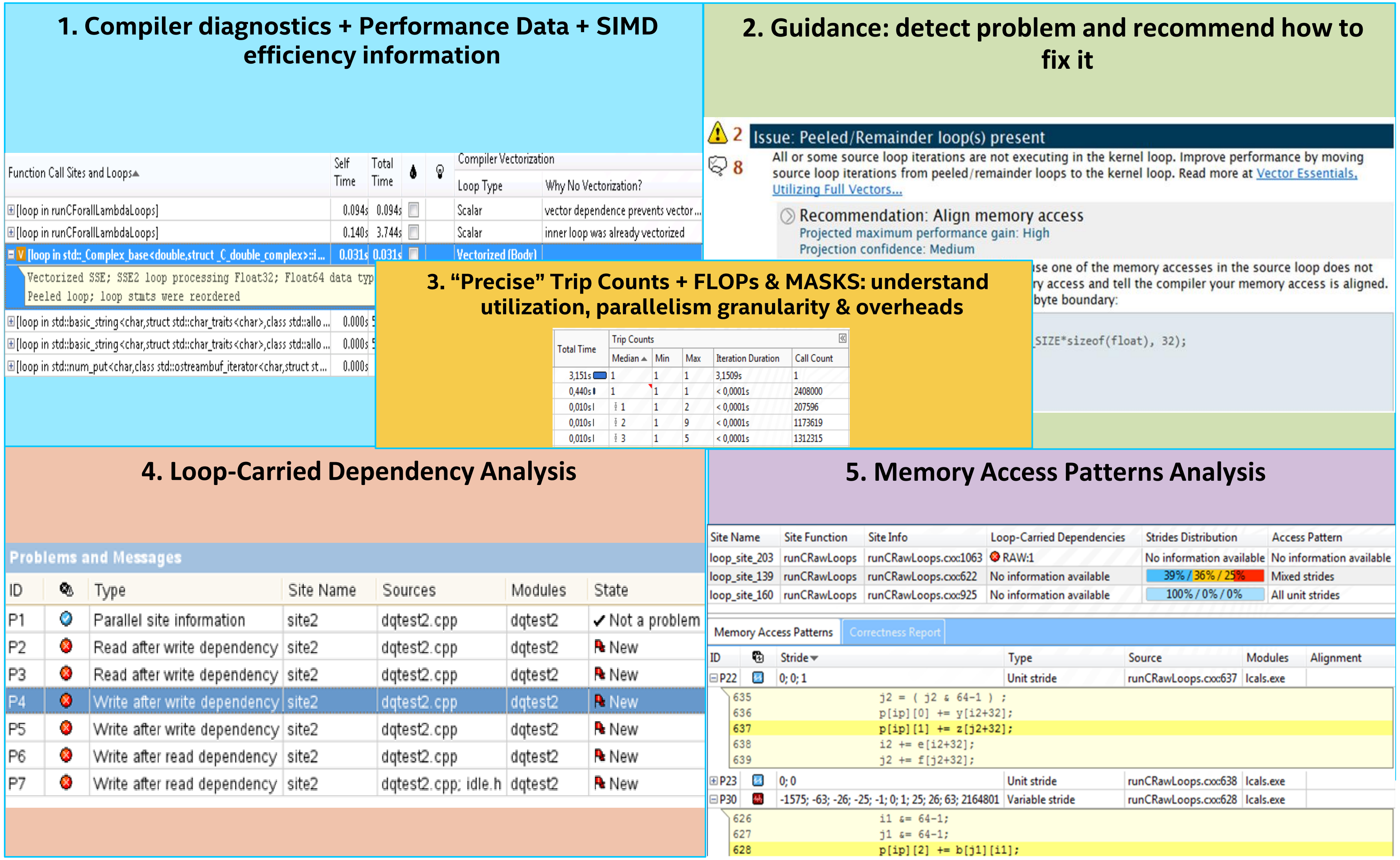
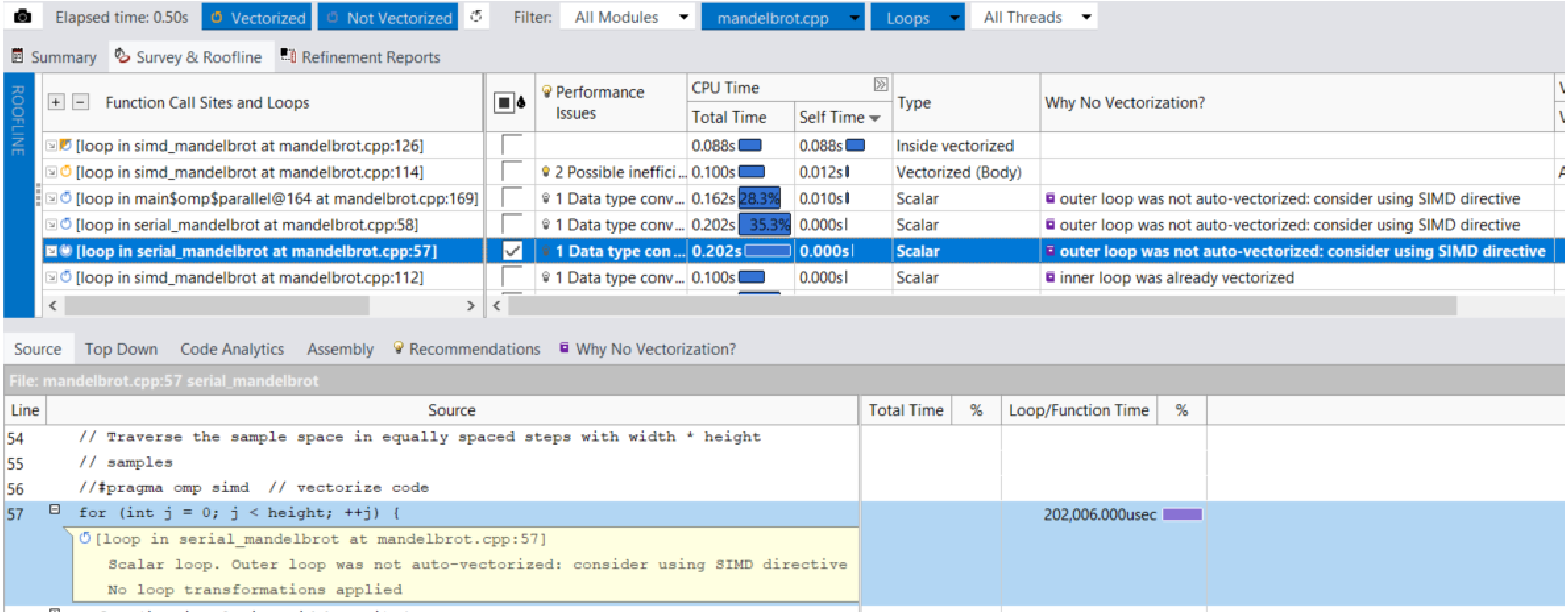
# 5 Steps to Efficient Vectorization



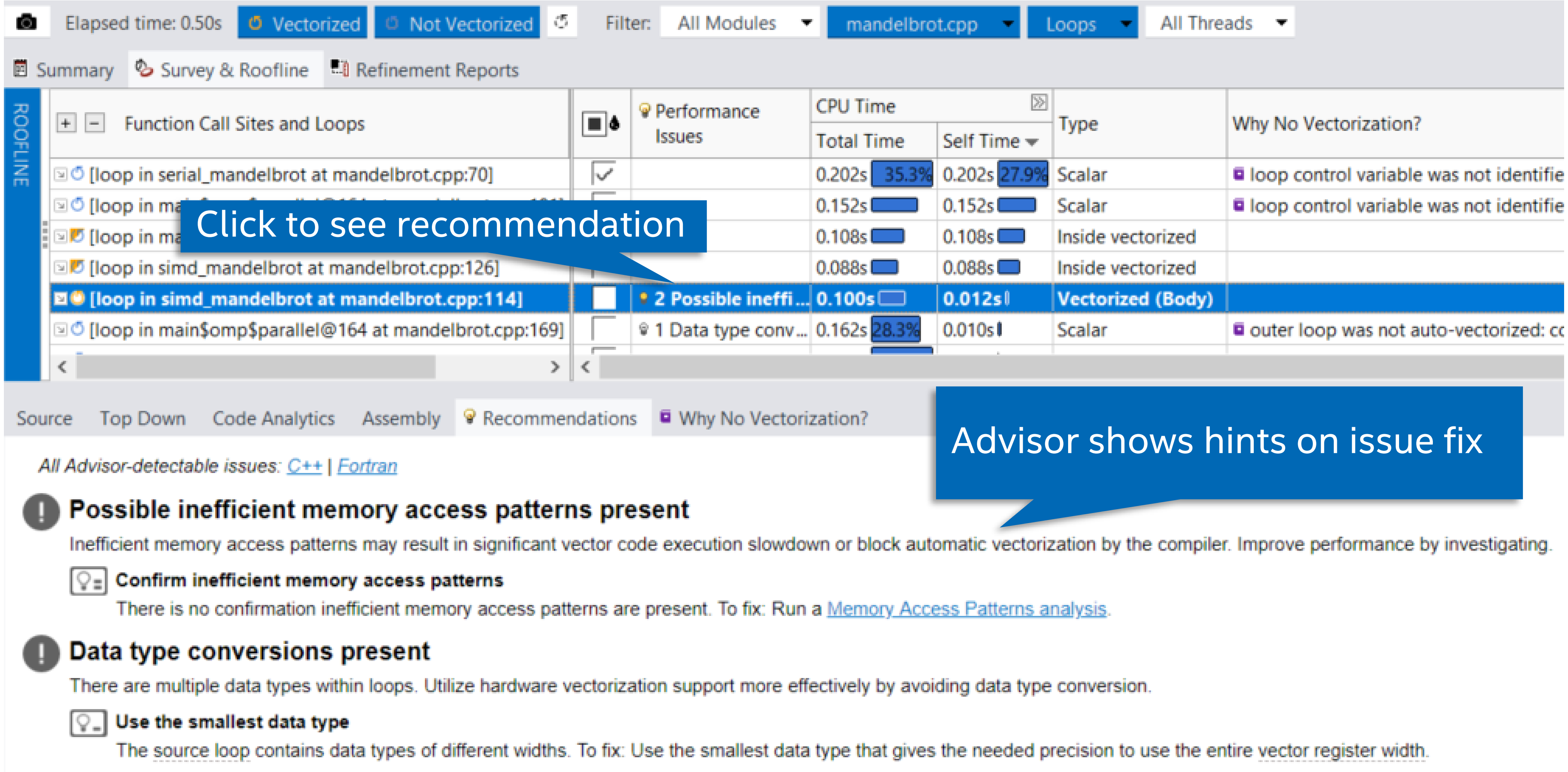
1. Compiler diagnostics + Performance Data + SIMD efficiency information

# Efficiently Vectorize your code



**2. Guidance: detect problem and recommend how to fix it**

# Get Specific Advice For Improving Vectorization

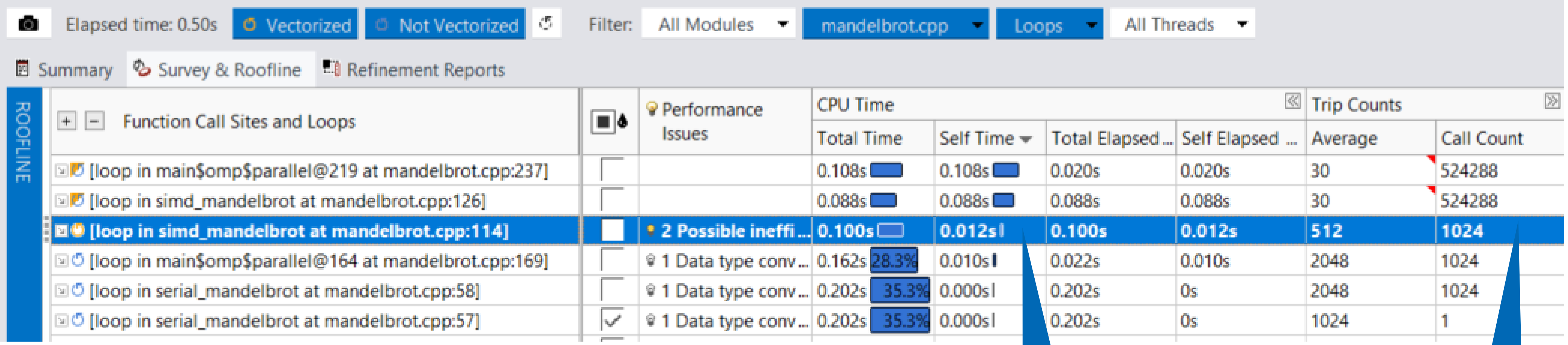



Click to see recommendation

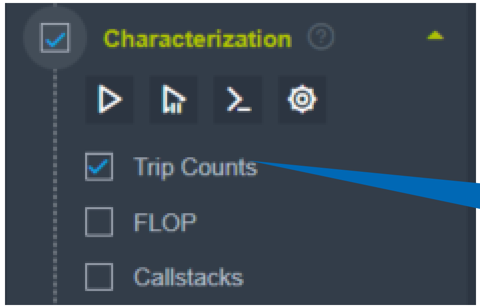
Advisor shows hints on issue fix

**3. “Precise” Trip Counts + FLOPs & MASKS: understand utilization, parallelism granularity & overheads**

# Identify how many times the loop executes & collect loop trip counts data




| Function Call Sites and Loops | | Performance Issues | CPU Time | | | | Trip Counts | |
|---|---|---|---|---|---|---|---|---|
| | | | Total Time | Self Time | Total Elapsed... | Self Elapsed ... | Average | Call Count |
| [loop in main$omp$parallel@219 at mandelbrot.cpp:237] | | | 0.108s | 0.108s | 0.020s | 0.020s | 30 | 524288 |
| [loop in simd_mandelbrot at mandelbrot.cpp:126] | | | 0.088s | 0.088s | 0.088s | 0.088s | 30 | 524288 |
| **[loop in simd_mandelbrot at mandelbrot.cpp:114]** | | **2 Possible ineffi...** | **0.100s** | **0.012s** | **0.100s** | **0.012s** | **512** | **1024** |
| [loop in main$omp$parallel@164 at mandelbrot.cpp:169] | | 1 Data type conv... | 0.162s 28.3% | 0.010s | 0.022s | 0.010s | 2048 | 1024 |
| [loop in serial_mandelbrot at mandelbrot.cpp:58] | | 1 Data type conv... | 0.202s 35.3% | 0.000s | 0.202s | 0s | 2048 | 1024 |
| [loop in serial_mandelbrot at mandelbrot.cpp:57] | ✓ | 1 Data type conv... | 0.202s 35.3% | 0.000s | 0.202s | 0s | 1024 | 1 |




Check actual trip counts

Not enough to know the time spent in a loop

Need to know the number of iterations, too

4. Loop-Carried Dependency Analysis

# Factors that **prevent** Vectorizing your code

## 1. Loop-carried dependencies

```
DO I = 1, N
   A(I + M) = A(I) + B(I)
ENDDO
```

M >= SIMDlength?

### 1a. Pointer aliasing (compiler-specific)

```
void scale(int *a, int *b)
{
   for (int i = 0; i < 1000; i++)
          b[i] = z * a[i];
}
```

## 2. Function calls (incl. indirect)

```
for (i = 1; i < nx; i++) {
  x = x0 + i * h;
  sumx = sumx + func(x, y, xp);
}
```

## 3. Loop structure, boundary condition

```
struct _x { int d; int bound; };

void doit(int *a, struct _x *x)
{
  for(int i = 0; i < x->bound; i++)
    a[i] = 0;
}
```

## 4. Outer vs. inner loops

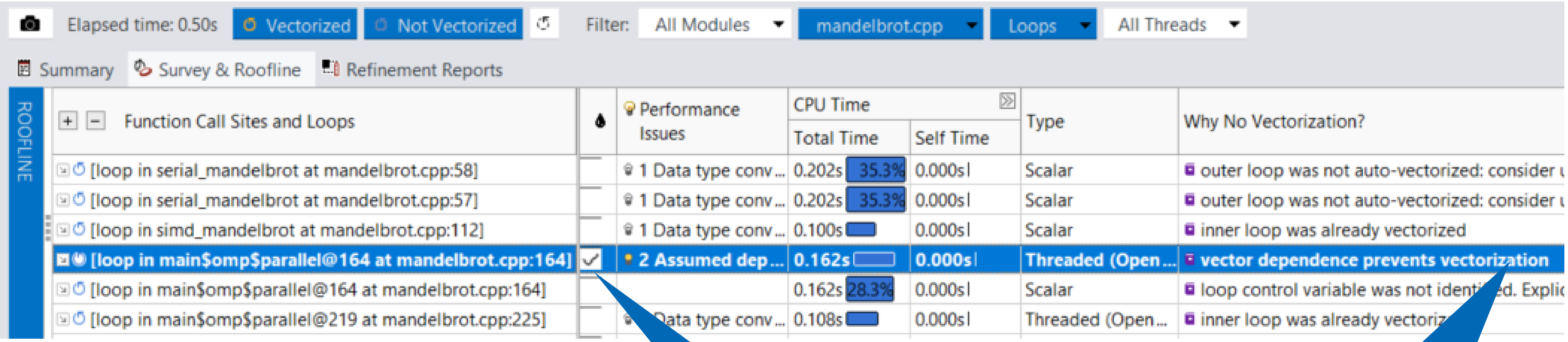
```
for(i = 0; i <= MAX; i++) {
  for(j = 0; j <= MAX; j++) {
    D[j][i] += 1;
  }
}
```

## 5. Cost-benefit (compiler specific..)

**4. Loop-Carried Dependency Analysis**

# Is It Safe to Vectorize?

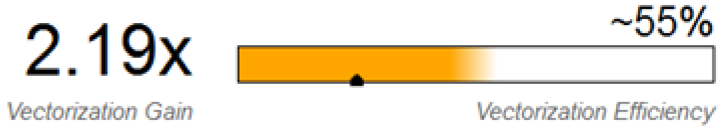
## Dependencies Analysis to identify and explore loop-carried dependencies




Select loop and run Dependency Analysis

Vector Dependence prevents Vectorization

# Factors that slow-down your Vectorized code




1a. Indirect memory access

```
for (i=0; i<N; i++)

         A[B[i]] = C[i]*D[i]
```

1b. Memory sub-system Latency / Throughput

```
void scale(int *a, int *b)
{
   for (int i = 0; i < VERY_BIG; i++)
          c[i] = z * a[i][j];
          b[i] = z * a[i];
}
```

2. Serialized or "sub-optimal" function calls

```
for (i = 1; i < nx; i++) {
          sumx = sumx +
serialized_func_call(x, y,xp);
}
```

**Why 45% lost?**

**Run MAP analysis**


3. Small trip counts not multiple of VL

```
void doit(int *a, int *b, int
unknown_small_value)
{
  for(int i = 0; i <
unknown_small_value; i++)
      a[i] = z*b[i];
}
```

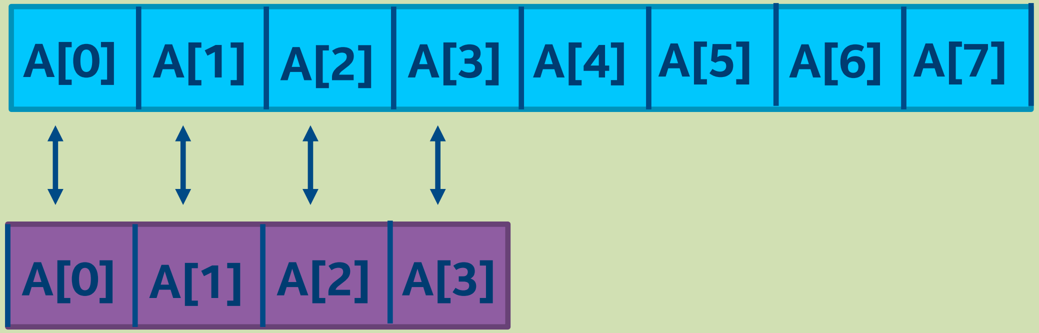
4. Branchy codes, *outer vs. inner loops*

```
for(i = 0; i <= MAX; i++) {
         if ( D[i] < N)
                 do_this(D);
         else if (D[i] > M)
                 do_that();
         //…
 }
```

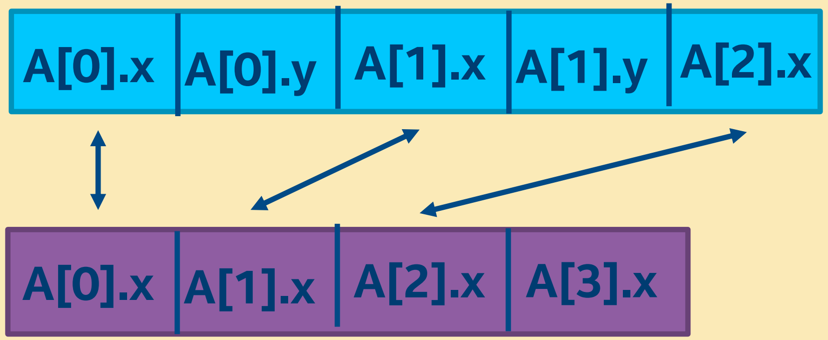
5. MANY others: spill/fill, floating-point accuracy trade-offs, FMA, DIV/SQRT, Unrolling

# Memory access patterns

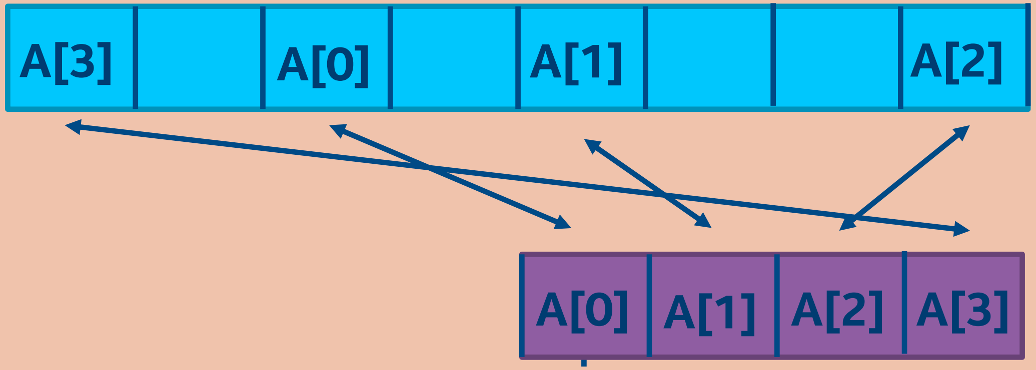
**Unit strided (contiguous):** Efficient




**Constant strided:** Less efficient




**Arbitrary access:** Inefficient



# Vectorization Accuracy Levels

| Comparison / Accuracy Level | Low | Medium | High |
|---|---|---|---|
| **Overhead** | 1.1x | 5 - 8x | 10 - 40x |
| **Goal** | Get basic insights about how well your application is vectorized and how you can improve vectorization efficiency | Get more insights about how well your application is vectorized and the number of iterations in loops/functions | Get detailed insights about your application performance, including performance issues and detailed optimization recommendations |
| **Analyses** | Survey | Survey + Characterization (Trip Counts) | Survey + Characterization (Trip Counts, FLOP, Call Stacks) + Memory Access Patterns |
| **Result** | Basic Survey report | Survey report extended with trip count data | Extended Survey report with trip counts and floating-point and integer operations (FLOP and INTOP)<br>Memory Access Patters with memory traffic data and memory usage issues |

# Vectorization Lab – Prepare Data

1. Build C++ application

```
cd ./base && make
```

2. Run Survey analysis to find hotspots and get performance data for your application

```
advisor --collect=survey --project-dir=./advisor_results -- ./release/Mandelbrot
```

3. Collect more detailed data
   1. Determine the number of loop iterations and collect data about floating-point and integer operations

      ```
      advisor --collect=tripcounts --flop --project-dir=./advisor_results
      -- ./release/Mandelbrot
      ```

   2. Get IDs and locations of loops

      ```
      advisor --report=survey --project-dir=./advisor_results
      -- ./release/Mandelbrot
      ```

   3. Mark up loops for deeper analysis (e.g. 2 scalar loops)

      ```
      advisor --mark-up-loops --select=mandelbrot.cpp:57,mandelbrot.cpp:69
      --project-dir=./advisor_results -- ./release/Mandelbrot
      ```

   4. Check for possible dependencies

      ```
      advisor --collect=dependencies --project-dir=./advisor_results
      --search-dir src:r=./src -- ./release/Mandelbrot
      ```

   5. Check memory access patterns

      ```
      advisor --collect=map --project-dir=./advisor_results
      --search-dir src:r=./src -- ./release/Mandelbrot
      ```

# Vectorization Lab – Analyze Results (Serial)

Check details on the loops of interest

- Dependencies? – No. Can vectorize!

Refinement Analysis Data

These loops were analyzed for memory access patterns and dependencies:

| Site Location | Dependencies |
|---|---|
| loop in serial_mandelbrot at mandelbrot.cpp:60 | No dependencies found |
| loop in serial_mandelbrot at mandelbrot.cpp:71 | No dependencies found |

- Vectorized? – No. Try to vectorize!

| Function Call Sites and Loops | | Performance Issues | CPU Time | | Type | Why No Vectorization? |
|---|---|---|---|---|---|---|
| | | | Total Time | Self Time | | |
| [loop in serial_mandelbrot at mandelbrot.cpp:69] | ✓ | | 0.180s | 0.180s 85.7% | Scalar | loop control variable was not identified. Explicitly compute the iteration count |
| serial_mandelbrot | | | 0.180s | 0.000s | Inlined Function | |
| [loop in serial_mandelbrot at mandelbrot.cpp:57] | ✓ | 1 Data type con… | 0.180s | 0.000s | Scalar | outer loop was not auto-vectorized: consider using SIMD directive |
| [loop in serial_mandelbrot at mandelbrot.cpp:56] | | 1 Data type conv… | 0.180s | 0.000s | Scalar | outer loop was not auto-vectorized: consider using SIMD directive |

# Vectorization Lab – Vectorize

Run Advisor for SIMD implementation (with `#pragma omp simd` used) of application

| Function Call Sites and Loops | | Performance Issues | CPU Time | | Type | Why No Vectorization? | Vectorized Loops | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Total Time | Self Time | | | Vector... | Efficiency | Gain E... | VL ( |
| [loop in simd_mandelbrot at mandelbrot.cpp:125] | | | 0.082s 91.2% | 0.082s 63.1% | Inside vectorized | | | | | |
| [loop in simd_mandelbrot at mandelbrot.cpp:113] | ✓ | 1 Data type con... | 0.090s | 0.008s | Vectorized (Body) | | AVX2 | 67% | 2.69x | 4 |
| simd_mandelbrot | | 1 Data type conv... | 0.090s 100.0% | 0.000s | Inlined Function | | | | | |
| [loop in simd_mandelbrot at mandelbrot.cpp:111] | | 1 Data type conv... | 0.090s 100.0% | 0.000s | Scalar | inner loop was already v... | | | | |

`mandelbrot.cpp:113` loop is vectorized

Total Time is 2 times less than in scalar case