Implications of a Metric for Performance Portability: Necessity of Specialization and Application-Specific Abstractions

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Defining “Performance Portability” (1/2)

“Let us not get tied up in definitions. **Performance portability means different things to different people and we need to accept that.** Both performance and portability are poorly defined and depend on the applications. Every app has different constraints and there is no way to get around it.”

- Unnamed Participant
  DOE COE Meeting 2016
  (Emphasis mine)
Defining “Performance Portability” (2/2)

“An approach to application development, in which developers focus on providing portability between platforms without sacrificing performance.”

“The ability of an application to obtain the same (or nearly the same) performance as a variant of the code that is written specifically for that device.”

“The ability of the same source code to run productively on a variety of different architectures.”

“The ability of an application to execute with a performance difference of less than 2x on two different systems, without significant software changes.”

“The ability of an application to achieve a similar high fraction of peak performance across target devices.”

Existing definitions are subjective and may not reflect application performance.
Our Proposed Definition

Performance Portability
“A measurement of an application’s performance efficiency for a given problem that can be executed correctly on all platforms in a given set.”

Architectural Efficiency = observed : achievable
Application Efficiency = observed : best-known

Performance results are for illustration purposes only and not intended to express or imply real world results.
Our Proposed Metric

\[
\Phi(a, p, H) = \begin{cases} 
\frac{|H|}{\sum_{i \in H} e_i(a, p)} & \text{if } i \text{ is supported } \forall i \in H \\
0 & \text{otherwise}
\end{cases}
\]

\[e_i(a, p) = \text{efficiency of application } a \text{ for input problem } p.\]

“The harmonic mean of an application’s performance efficiency on a set of platforms for a given problem.”

Performance results are for illustration purposes only and not intended to express or imply real world results.
Wait! What About “Productivity”?  

- Our definition is orthogonal to productivity, **not** incompatible with it:  
  - “How many source code changes are required to achieve PP of \( y \)?”

- Productivity is even more subjective than PP!  
  - Developers have different skill levels.
  - Codes differ in size and complexity.
  - Libraries and frameworks hide development costs.

- Attend our **Breakout Session**:  
  “Performance, Portability and Productivity: Definitions & Metrics”
PP(a,p,H) Case Study: The BabelStream Benchmark

- Developed at University of Bristol; implements STREAM Triad in 7 programming languages/models:
  - **SYCL**: C++ wrappers for OpenCL
  - **RAJA**: Loop abstractions from Lawrence Livermore
  - **Kokkos**: Device/memory abstractions from Sandia
  - **OpenMP* (with C++)**: Standard pragmas for parallel programming
  - **OpenACC***: Standard pragmas for accelerator programming
  - **CUDA***: Proprietary language for stream programming
  - **OpenCL***: Standard language for stream programming

- Results published for 12 platforms (incl. CPUs and GPUs) [1], of which we focus on 9. Ongoing investigations into performance portability improvements [2,3].

Performance Portability of BabelStream (2016)

PP(a,p,H) where H = x86 CPUs

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Performance Portability of BabelStream (2016)

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Performance Portability of BabelStream (2016)

PP(a,p,H) where H = x86 CPUs and NVIDIA GPUs

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Implications of a Metric for Performance Portability

- Enables users to:
  - Compare PP applications/libraries/framework support for their platforms
  - Reason about which of many PP options to choose
  - Pressure developers to focus on platforms with poor support

- Enables developers to ask:
  - What value of PP is realistic/achievable?
  - What value of PP should we be aiming for?
  - What are the best development practices for achieving high values of PP?
Performance Portability => Specialization

1. Exploit domain knowledge (e.g. particle properties)
   - Particle List
     - Sorted List
     - Uns sort List
   - Exploit application knowledge (e.g. list representation)
     - Particle Sort
     - std::sort
     - Merge Sort
     - Radix Sort
   - Exploit library knowledge (e.g. argument types)
     - OpenMP*
     - CUDA*
       - SSE
       - AVX
       - AVX-512
       - Kepler
       - Maxwell
       - Pascal
2. Exploit compiler knowledge (e.g. instruction latencies)

All approaches to PP specialize code for a target platform; the distinction is how/where.
Disclaimer

- My level of familiarity with languages frequently associated with PP is:
  - OpenMP*
  - CUDA* / OpenCL*
  - Kokkos
  - Thrust
  - C++17
  - RAJA
  - OpenACC*
  - ...all the others

- Focus (and correctness) of remaining slides follows from the above.
Specialization Case Study (1/2)

- Developed four variants of several benchmarks from the CUDA* SDK:
  
  1. CUDA
  2. OpenMP*
  3. Kokkos
  4. Kokkos (Specialized)

- 4 is a “single-source” code augmented with specialized variants of some functions.
  
  - All functions have the same API irrespective of target device
  - Each application uses a different API: “Application-Specific Abstraction”
  - Specializations include: data layout, data accessors, functors, execution policies
Left-most path is the “base” version, a generic implementation that can run on any device.
Impact of Specialization on PP(a,p,H)

PP(a,p,H) for H = \{P100, KNL\}, using Application Efficiency

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User-Driven Specialization Today†

- **CUDA*/OpenCL*: Query API + Just-in-Time (JIT) compilation.

- **OpenMP**: Override function calls by SIMD/allocator traits.
  - #pragma omp declare simd [clauses]
  - #pragma omp declare alloc [clauses]‡

- **Kokkos**: Specialize functionality by “Device” (“Backend”)
  - template <class Device>
  - void operator(Tag& tag, ...) (...)

- **RAJA/C++/Thrust**: Specialize functionality by “Policy” (“Runtime”/”Schedule”)
  - void ParallelFor(ExecutionPolicy& policy, int begin, int end, Functor f);

† Inexact syntax used to highlight similarities/differences between approaches.
‡ Under consideration for OpenMP TR6.
User-Driven Specialization Tomorrow†? (1/2)

- Directives: Override function calls by matching traits.
  - #pragma pp declare variant(variant-name) implements(base-name)
    match(trait-name:trait-value[,trait-name:trait-value]*)
  - #pragma pp dispatch match(trait-name[,trait-name]*)

- Example:
  #pragma pp declare function match(isa)
  #pragma pp declare function variant(_mm_add) match(isa:sse)
  double add(double a, double b);

  #pragma pp declare function implements(add) match(isa:avx512)
  __m512 _mm512_add(__m512 a, __m512 b);

  #pragma pp dispatch match(isa)
  c = add(a, b);

† Syntax proposed here is at the draft/prototype stage and has not been accepted by any standards or language committee.
User-Driven Specialization Tomorrow†? (2/2)

- C++ (and C++ Frameworks): Override functionality by matching traits.
  - Traits could be standardized (C++20XX) or specific to PP framework(s).

- Example:
  ```cpp
  struct functor : public pp::base
  {
    // inherits isa = pp::traits();
  };

  struct functor_avx512 : public pp::specialization
  {
    static constexpr auto isa = pp::traits(avx512);
  };

  pp::dispatch<functor, Context> f;
  ParallelFor(policy, start, end, f);
  ```

† Syntax proposed here is at the draft/prototype stage and has not been accepted by any standards or language committee.
Summary

- Shared definitions and metrics have many benefits and we should develop them
  - Agree or disagree at “Performance, Portability and Productivity: Definitions & Metrics”

- Proposed a realistic approach to achieving high performance portability PP(a,p,H)
  - Maintain a single “base” code that is expected to work anywhere (portability)
  - User-driven specialization to override functionality for important cases (performance)
  - Add support for this approach to standard programming languages/frameworks (productivity / maintainability)

- For more detail, see:
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Experimental Setup (1)

Results on Slides 8-10 from:

Experimental Setup (2)

Results on Slide 11 are a combination of results from:


Experimental Setup (3)

Results on Slide 17 and 26 use the following experimental setup:

- **P100**: Intel® Xeon® processor E5-1697 v4, 2.3 GHz, 2 sockets x 18 cores + Tesla P100-PCIE-16GB, BIOS: 86.00.26.00.01, ECC Enabled, Persistence Mode Disabled, Graphics/SM 405 MHz, Memory 715 MHz, CUDA 8.0.44

- **KNL**: Intel® Xeon Phi™ processor 7250, 68 core, 272 threads, 1400 MHz core freq. (turbo on), 1700 MHz uncore freq., MCDRAM 16 GB 7.2 GT/s, DDR4 96GB 2400 MHz, CentOS 7.2.1511, Quad cluster mode, MCDRAM Flat memory mode

- **Versions**:
  - Kokkos: git commit da3144
  - gcc: 4.8.5 20150623
  - icc: 18.0.0 20170510

- **Compiler Flags**:
  - P100: KOKKOS_ARCH=Maxwell KOKKOS_DEVICES=Cuda
  - KNL: KOKKOS_ARCH=KNL KOKKOS_DEVICES=OpenMP, icpc -O3 -xMIC-AVX512
Impact of Specialization on PP(a,p,H)

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For configuration details, see Slide 25.