A Roofline Visualization Framework

Wyatt Spear and Boyana Norris
University of Oregon

Abstract. The Roofline Model and its derivatives provide an intuitive representation of the best achievable performance on a given architecture. The Roofline Toolkit project is a collaboration among researchers at Argonne National Laboratory, Lawrence Berkeley National Laboratory, and the University of Oregon and consists of three main parts: hardware characterization, software characterization, and data manipulation and visualization interface. These components address the different aspects of performance data acquisition and manipulation required for performance analysis, modeling and optimization of codes on existing and emerging architectures. In this paper we introduce an initial implementation of the third component, a system for visualizing roofline charts and managing roofline performance analysis data. We discuss the implementation and rationale for the integration of the roofline visualization system into the Eclipse IDE. An overview of our continuing efforts and goals in the development of this project is provided.

1 Introduction

The Roofline model [9] enables programmers to visualize the performance potential of algorithms by introducing a simple way to quantify the computations’ locality and parallelism and present them in the context of a given architecture’s capabilities. At present Roofline models are typically laboriously created through (1) collection of hardware performance data, e.g., with micro benchmarks; (2) manual code analysis to determine the arithmetic intensity of the algorithm(s) being studies; and (3) visualizing both the architectural rooflines and the kernel’s expected performance under different optimization assumptions. Automating most of this process is the goal of the Roofline Toolkit Project. The development of portable microbenchmarks that automate the first step is discussed in [7]. In this paper we introduce the data representation and visualization infrastructure required to automate the third step. We also discuss ongoing work on partially automating the generation of performance models in the second step.

1.1 Roofline Analysis

For any machine model, we can evaluate the upper bound on performance by using the roofline model introduced by Williams et al [9]. Given the arithmetic intensity of an algorithm, the roofline model defines an upper limit on kernel performance $P_k$ with the equation, $P_k = \min P_f, BA$, where $P_f$ is the peak
hardware floating-point performance, $B$ is peak bandwidth, and $A_i$ is the arithmetic intensity, typically expressed as the ratio of floating-point operations to bytes transferred to/from memory.

The Roofline model and its extensions (e.g., for energy [5]) provide a compact representation of the architectural capabilities as a context that enables visualization of a kernel’s current and potential performance within the algorithm and architectural constraints.

1.2 Eclipse

Eclipse [1] is a popular software platform with support for customized IDE functionality. Its default set of plugins is designed for Java development, but the Eclipse community has provided support for other languages such as C/C++ and Fortran. Support for high performance computing has also been provided via the Parallel Tools Platform (PTP) [2]. Two distinct advantages of the Eclipse platform are its portability and extensibility. The former is provided largely by Eclipse’s Java-based implementation, which means it can be run consistently on Windows, Macintosh and many Unix based OSes. Because Eclipse is open source, users are free to modify and extend its functionality as they see fit.

The value added by the Eclipse platform, both in terms of features available to end users of the Roofline visualization framework and APIs useful in the development of the framework made it an appealing environment for integration of roofline visualization functionality.

2 Visualization Implementation

The initial roofline visualizations were implemented using general purpose scientific charting tools such as GnuPlot. This was adequate for developing and testing the roofline system and for the performance analysis activities of experts. However it was determined early on that general adoption of the roofline system would benefit from a simpler automated means of visualizing the performance data. Furthermore, given the intended major use case of comparing the performance of multiple applications or application routines to establish performant behavior with respect to the roofline model a means of rapidly and easily managing this process would be of benefit even to experts with other visualization techniques at their disposal.

We implemented the charting system using JavaFX [3]. The new graphing functionality provided in the JavaFX API allow reasonably sophisticated visualizations without relying on external libraries so long as a relatively recent version of Java is available. The specific requirements of the roofline chart include a log2 scale axis, necessary for the charted metrics to exhibit a parallel spatial relationship which simplifies comparison between metrics. This had to be implemented manually based on JavaFX’s natural log scale axis.

The data for visualizing Roofline architectural profiles is generated by a collection of portable micro benchmarks [7]. Currently the roofline visualization
supports a single set of roofline data. Multiple roofline datasets may be loaded simultaneously, either from the local file-system or from an online repository, to allow rapid switching between the data being visualized. The intersection points and the inflection points on the roofline chart may be selected to display the specific recorded metric values.

Figure 1 shows the rooflines generated for three architectures. Different rooflines reflect peak capabilities of different hardware components with respect to the operational intensity (x-axis) of the computation. For example, we can see that on Hopper, a kernel whose operational intensity is 2 Flops/Byte can achieve near peak performance if it has relatively good L2 locality (but perhaps not L1) and takes advantage of fused multiply-add instructions. On the other hand, on Mira, the same kernel with 2 Flops/Byte operational intensity and an implementation with good L2 locality and fused add-multiply use would achieve only a small fraction of the potential peak (dark blue line vs orange horizontal line) unless it also has good L1 locality.

3  Data Management

There are two primary elements to roofline charting data. The systems where the roofline is being modeled are typified by the benchmarked upper bounds on memory throughput and computational intensity. These values and metric names are stored as name value pairs. The applications being examined with respect to the system roofline are similarly stored as simple pairs of recorded performance values and the name of the application or subroutine. The simplicity of these data accommodate a wide range of data presentation options. We have selected JSON [4] for roofline data storage because it is simple to work with and there is strong support for it in Java and Python.

In addition to the core metrics of roofline system and application performance data, the data format must accommodate a flexible system for storing metadata for systems and experimental trials. This is necessary to establish the provenance of collected data, to avoid of duplicate trials and to allow searching and comparison of task specific data from what may be a very large general collection of system models and application trials. A robust metadata system will also support more advanced analytical features as those are provided in future development.

The nature of roofline analysis lends itself to central, publicly available data repositories. Because the system benchmarks are useful to all developers working in the same environment it make sense to make these a common resource. Publicly available application performance data facilitates collaboration on performance tuning within a project but also provides useful reference data for other users and developers on the same system. Because of this the roofline visualization system supports accessing roofline data from a remote repository. A preliminary roofline data library is being assembled, hosted by the University of Oregon.
(a) Roofline plot for Mira, an IBM Blue Gene/Q supercomputer. Nodes are 16-core PowerPC A2 (1.6 GHz) processors with 16GB.

(b) Roofline plot for Edison, a Cray XC30 supercomputer. Nodes are 12-core Intel "Ivy Bridge" processors (2.4 GHz) with 64 GB memory.

(c) Roofline plot for Hopper, a Cray XE6 supercomputer. Nodes are two twelve-core AMD 'MagnyCours' (2.1-GHz) processors with 32 GB memory.

Fig. 1: Automatically generated roofline chart visualization. The top GFLOP/s rate for the included benchmark data is indicated with an orange line and markers. In some cases lines corresponding to different hardware components overlap.
4 Future Work

The roofline visualization system remains under heavy development and there are a number of features we anticipate adding as the project proceeds. These will dovetail with the continuing development of the roofline data collection and analytical utilities also under development.

Improved and expanded visualization options are a fundamental component of this undertaking. Comparison between systems and between multiple sets of application trial data within a single chart will be useful in performance engineering operations that incorporate roofline data. This ties directly into the necessity for expanded and improved roofline data search and storage capabilities.

It is also our goal to increase the level of integration between the Eclipse framework and the visualization system. In particular, for developers working on projects in an Eclipse workspace, we would like to allow direct navigation between source elements and the associated roofline visualization. Using the Eclipse UI to control roofline data collection and management is a feature which will be developed as stable command line based roofline analytics tools become available.

We will also integrate the computation and visualization of arithmetic intensity (and other emerging algorithmic metrics) into the Eclipse environment, so that users can easily visualize the current and potential performance of selected computations as they are developing them. To accomplish this we will implement two main components of the Roofline Toolkit – developer-aided static model generation and empirical performance data integration. For static model generation, we will adapt the approaches used by source-based tools such as PBound [8] and binary analyzers such as MAQAO [6]. The static approach allows the generation of more abstract models, which can then be modified by the user to reflect planned or necessary optimizations, with the resulting performance visualized in the context of architectural rooflines. Current performance stored in TAUdb databases will also be plotted in the new interface. Because while developing the software users focus on specific code portions, this will require automated extraction and agglomeration of performance data corresponding only to the selected code segments; in addition to GFLOPS/byte achieved, if more detailed hardware counter metrics are available, they will also be included in a separate detailed view.

5 Conclusion

As the systems for conducting roofline analysis on high performance computing systems improve and become more widely available we anticipate a significant quantity of roofline data becoming publicly available to support the performance engineering activities of software engineers. The ability to easily conduct roofline analysis on local systems will likewise improve as the project progresses. The ability to visualize and make immediate use of this approach to performance analysis will be simplified and streamlined by this visualization system.
References

1. Eclipse IDE. \url{http://www.eclipse.org}. Accessed: 2014-10-20.

2. Eclipse Parallel Tools Platform. \url{http://www.eclipse.org/ptp/}. Accessed: 2014-10-20.

3. JavaFX. \url{http://www.oracle.com/technetwork/java/javase/overview/javafx-overview-2155820.html}. Accessed: 2014-10-20.

4. JSON. \url{http://www.json.org}. Accessed: 2014-10-20.

5. J. W. Choi, D. Bedard, R. Fowler, and R. Vuduc. A roofline model of energy. In Parallel Distributed Processing (IPDPS), 2013 IEEE 27th International Symposium on, pages 661–672, May 2013.

6. L. Djoudi, D. Barthou, P. Carribault, C. Lemuet, J.-T. Acquaviva, , and W. Jalby. MAQAO: Modular assembler quality analyzer and optimizer for Itanium 2. In Proceedings of the Workshop on Explicitly Parallel Instruction Computing Techniques, Santa Jose, California, March, 2005.

7. Y. J. Lo, S. Williams, B. V. Straalen, T. J. Ligocki, M. J. Cordery, L. Oliker, and M. W. Hall. Roofline Model Toolkit: A practical tool for architectural and program analysis. In Proceedings of the Workshop on Performance Modeling, Benchmarking and Simulation of High Performance Computer Systems (PMBS), Nov. 2014.

8. S. H. K. Narayanan, B. Norris, and P. D. Hovland. Generating performance bounds from source code. In Proceedings of the First International Workshop on Parallel Software Tools and Tool Infrastructures (PSTI 2010), 9 2010. Also available as Preprint ANL/MCS-P1685-1009.

9. S. Williams, A. Waterman, and D. Patterson. Roofline: An insightful visual performance model for multicore architectures. Commun. ACM, 52(4):65–76, 2009.