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Cover Letter

Parallelization of Butterfly Counting on Hierarchical Memory

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Dear Editor and Fellow Reviewers,

We are delighted to submit our paper entitled "Parallelization of Butterfly Counting on Hierarchical Memory" to the prestigious journal, *VLDB Journal*, for possible publication.

This submission is a substantial extension of the conference version "I/O-Efficient Butterfly Counting at Scale", which is accepted by the ACM SIGMOD 2023 Conference.

We summarize the major new materials in this submission as follows:

1. In Section 7, we have introduced substantial updates, detailing a parallel framework, PIOBufs. This framework provides a unified abstraction, facilitating the adaptation of IOBufs using different parallelization approaches on diverse hardware platforms, including both CPUs and GPUs. Our exploration on CPUs resulted in the development of FG, a fine-grained parallelization approach on PIOBufs.
2. We have added Section 8 to discuss the implementation of PIOBufs on GPUs, which is grounded the fine-grained parallelization strategy, FG, employed on CPUs. In implementing FG on GPUs, we identify that only "warps" and "blocks" are feasible choices for workers. Consequently, we introduce two unique kernels: FG-BaaW and FG-WaaW. The FG-BaaW kernel utilizes a GPU block as its worker (BaaW) and is found to be suited for processing *large* workloads. Conversely, the FG-WaaW kernel, which leverages a GPU warp (WaaW) as its worker, is inherently tailored for *small* workloads. The selection between these kernels is then adaptively made based on the workload size, which is determined by vertex degrees.
3. We have introduced a new section, Section 11, dedicated to evaluate the performance of IOBufs on GPUs. Particularly, in our evaluations, IOBufs demonstrated a performance improvement, running 30× faster than the state-of-the-art solution, G-BFC. Then, we benchmark the impact of configurations including the `NumThreadsPerSubWarp` and the use of shared memory in FG-BaaW. Finally, we analyze the tradeoff of two kernels, FG-BaaW and FG-WaaW, according to the size of the workload.
4. We have revised the abstract, introduction, related work, experiment setting and conclusion for the new materials.

We have reformatted our original SIGMOD paper using the VLDB Journal template in about 16 pages, and incorporated substantial new content with nearly 10 pages of new material. Thus, the submission contains enough new materials with novel insights. We also attach our SIGMOD paper for your reference. We sincerely appreciate your invaluable reviews and thoughtful comments.

Sincerely yours,

Zhibin Wang, Longbin Lai, Yixue Liu, Bing Shui, Chen Tian, Sheng Zhong