ParLOT: Efficient Whole-Program Call Tracing for HPC Applications

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Outline

- HPC Debugging
  - Tracing Challenges
- ParLOT Design
  - Binary Instrumentation
  - Compression Mechanism
- Evaluation
- Conclusion

HPC Debugging

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In this work, we propose an **efficient whole-program tracing** infrastructure to help the HPC debugging community.

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- "Always-on" tracing capability
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MINDSET: ***Pay a little bit more upfront to significantly reduce the number of overall debug iterations***

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Towards automated debugging/tracing system

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Studying behavior of application at runtime

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Regardless of system, OS, compiler and hardware

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Main goal of our work

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Contribution 1: We use *Pin*, a dynamic binary instrumentation tool by Intel, to instrument binaries (regardless of source language and compiler) and capture all functions` entry/exit points including library calls for every thread/process.

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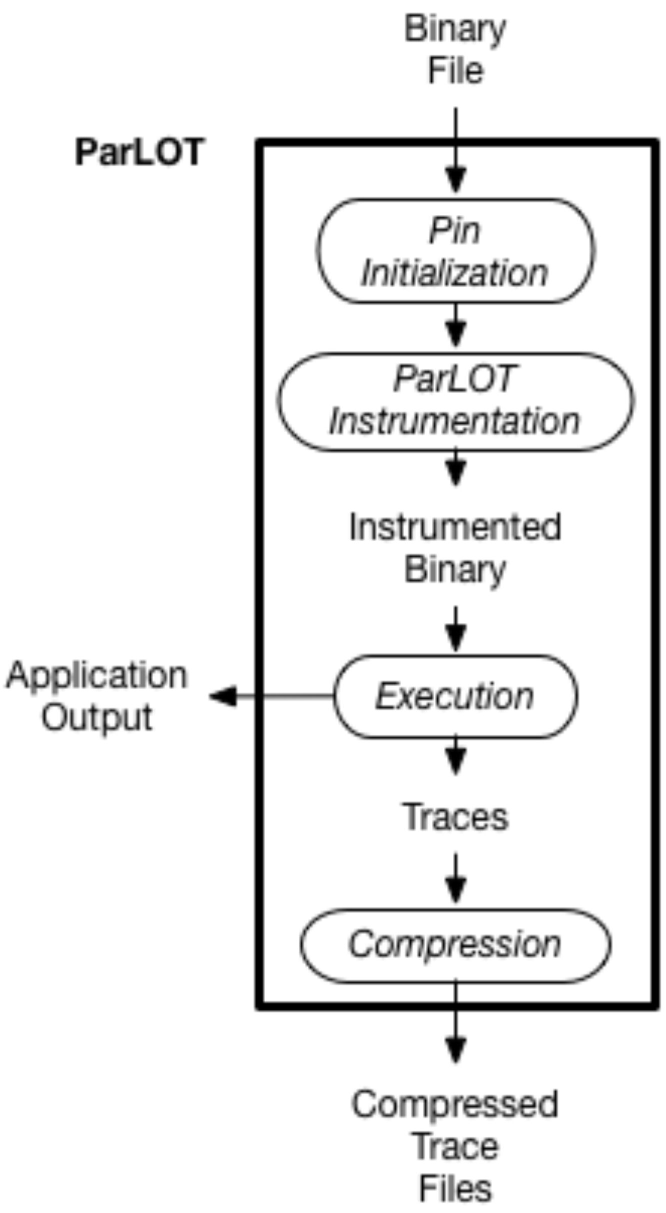
Contribution 2: An incremental data compression algorithm that drastically reduces the overhead of on-the-fly whole-program tracing

ParLOT Design

- **Par**allel **L**ow **O**verhead **T**racing Tool
  - Tracing Operations
  - Incremental Compression
  - Compression Algorithm
  - Call-stack Correction



Binary Instrumentation

- ParLOT instrumentation
  - Every thread launch and termination
  - Every function entry and exit
- Separate trace file for each thread
  - Each file contains ordered sequence of function calls and returns

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  - Each file contains ordered sequence of function calls and returns
- Per-thread information
  - Thread ID
  - Current function ID
  - Current call stack
  - Current SP value (for stack correction)

Incremental Compression

- Conventional compression approaches
  - Trace first written to buffer (in memory), buffer is compressed once full
  - Threads sporadically block to compress data → highly non-uniform latency
  - Distorts trace when one thread polls data from another blocked thread
- Incremental Compression
  - Every trace element is compressed right away before writing it to memory
  - Resulting compression latency is much more uniform
  - Greatly improves fidelity of trace data

Compression Algorithm

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  - Trained on traces from the Mantevo miniapps
  - Resulting best algorithm: LZ followed by ZE
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  - Records the SP value at each function entry and exit
  - Pops the internal call stack until consistent with SP value
- Other DBIs might [not] need such correction

Evaluation

- MPI-based NAS Parallel Benchmarks (input classes B and C)
- San Diego Supercomputer Center – Comet
- 1, 4, 16 and 64 compute nodes (each with 16 cores)
- Compute nodes: Xeon E5-2680 v3 processors – 28 cores – 128 GB memory
- Measured metrics
  - **Tracing overhead**
  - **Tracing bandwidth**
  - **Compression ratio**

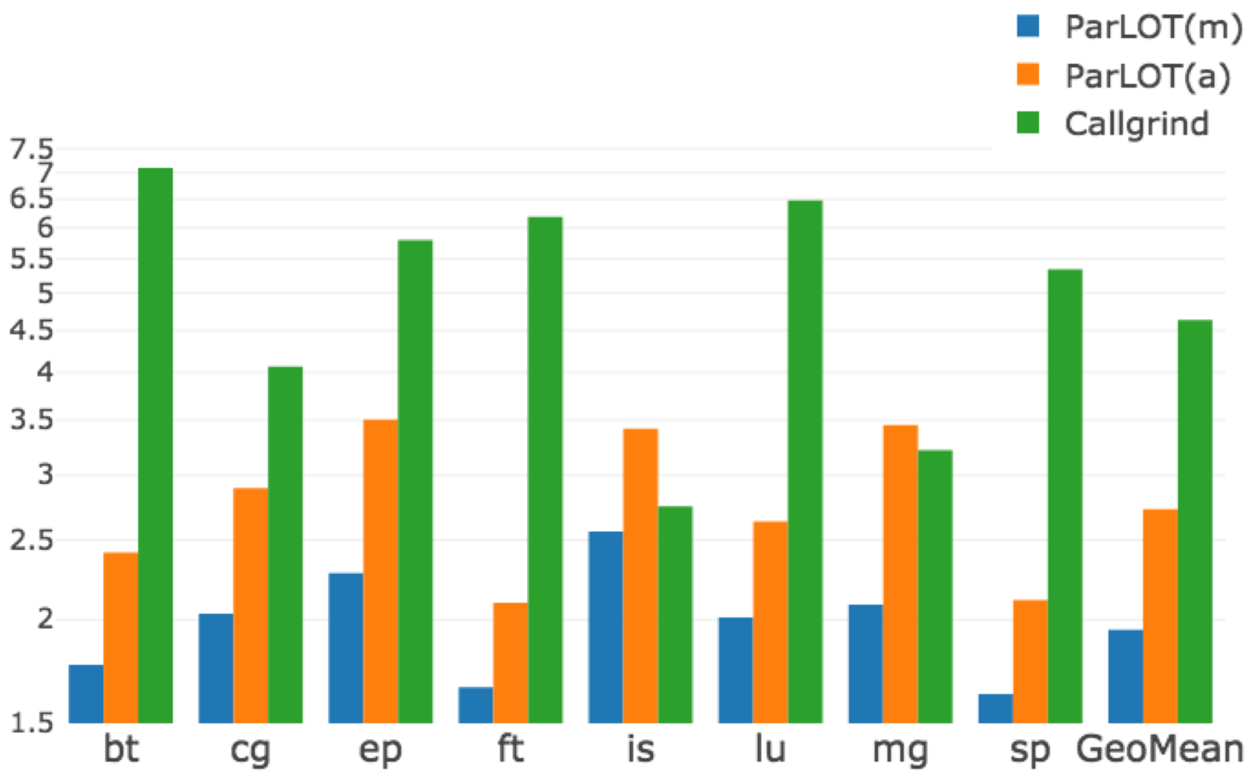
Tracing Overhead

ParLOT(m): collects traces from the main image

ParLOT(a): collects traces from all images (including library function calls)

Callgrind: DBI-based tracing tool that collects function-call graphs and performance data

Average overheads (input C)
- ParLOT(m): **1.94**
- ParLOT(a): **2.73**
- Callgrind: **4.63**



Required Bandwidth

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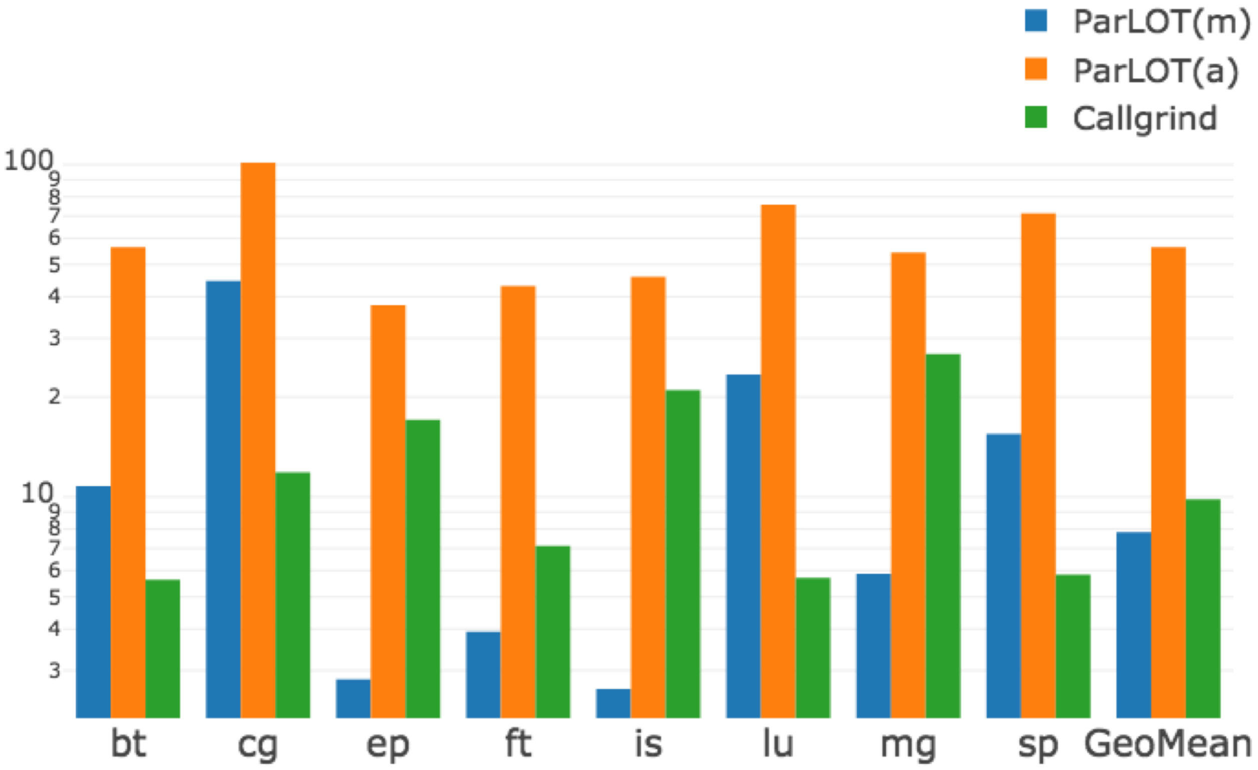
Average required bandwidth on input C
- ParLOT(m): **7.8** kB/s
- ParLOT(a): **56.4** kB/s
- Callgrind: **9.8** kB/s



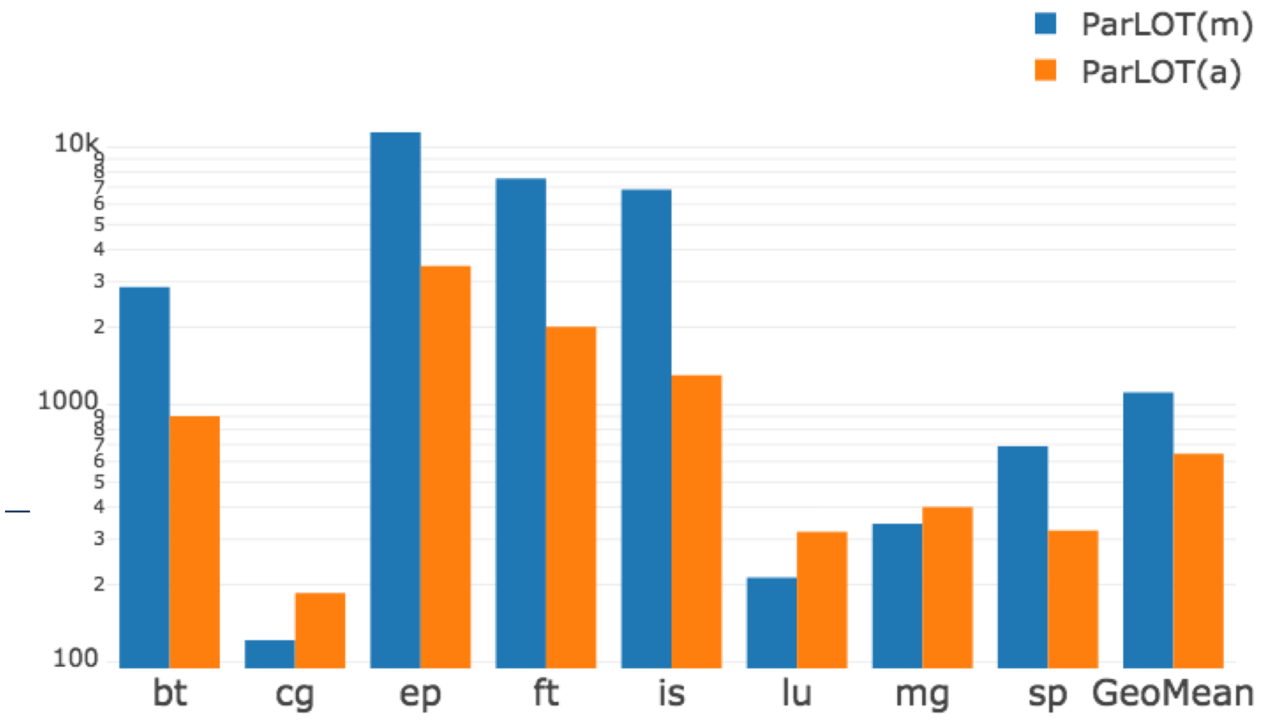
Compression Ratio

Average compression ratio of ParLOT(a) on input C: **644.3**

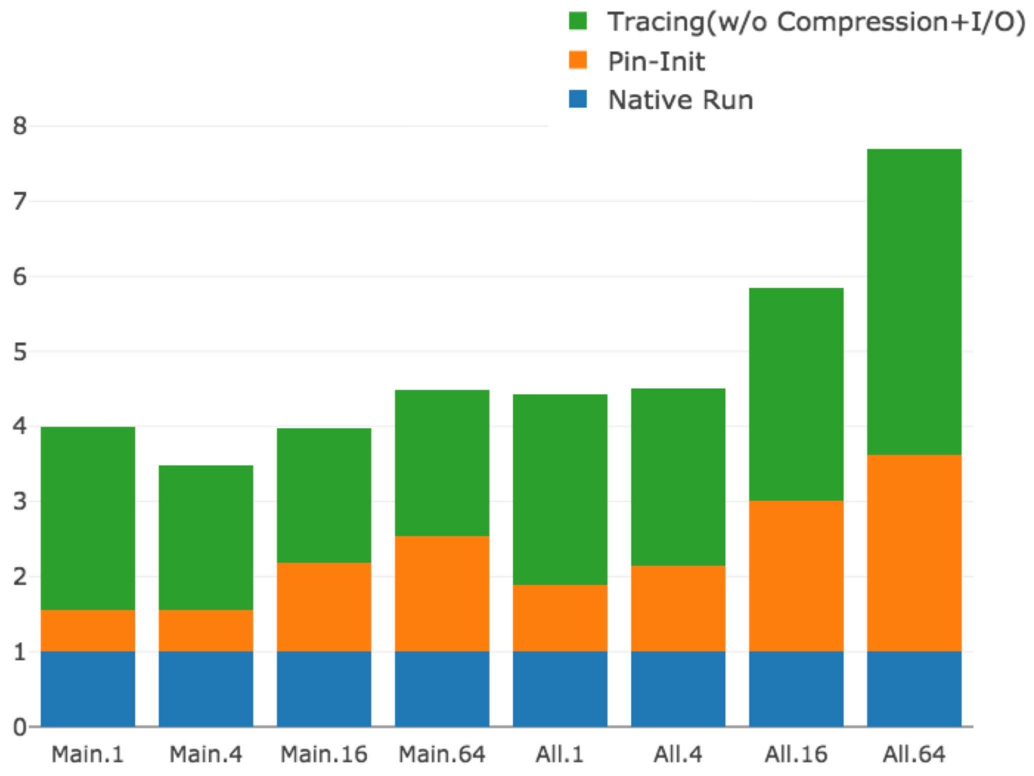
Corresponding required bandwidth: **56.4** kB/s

ParLOT can collect **36 MB worth of data** per core per second while only requiring **56 kB/s**

CG behavior: conjugate gradient method with irregular memory accesses and communication – larger number of distinct calls with more complex patterns



Overheads



Breakdown of average ParLOT overhead on NAS - Input C – 1, 4, 16 and 64 nodes

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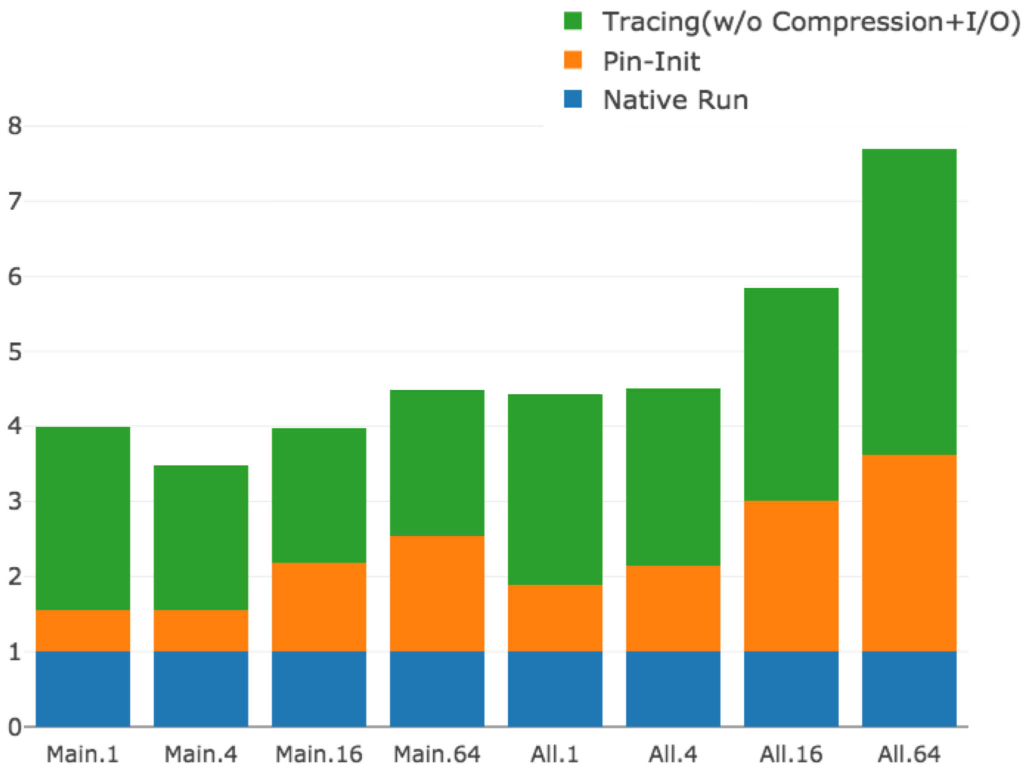

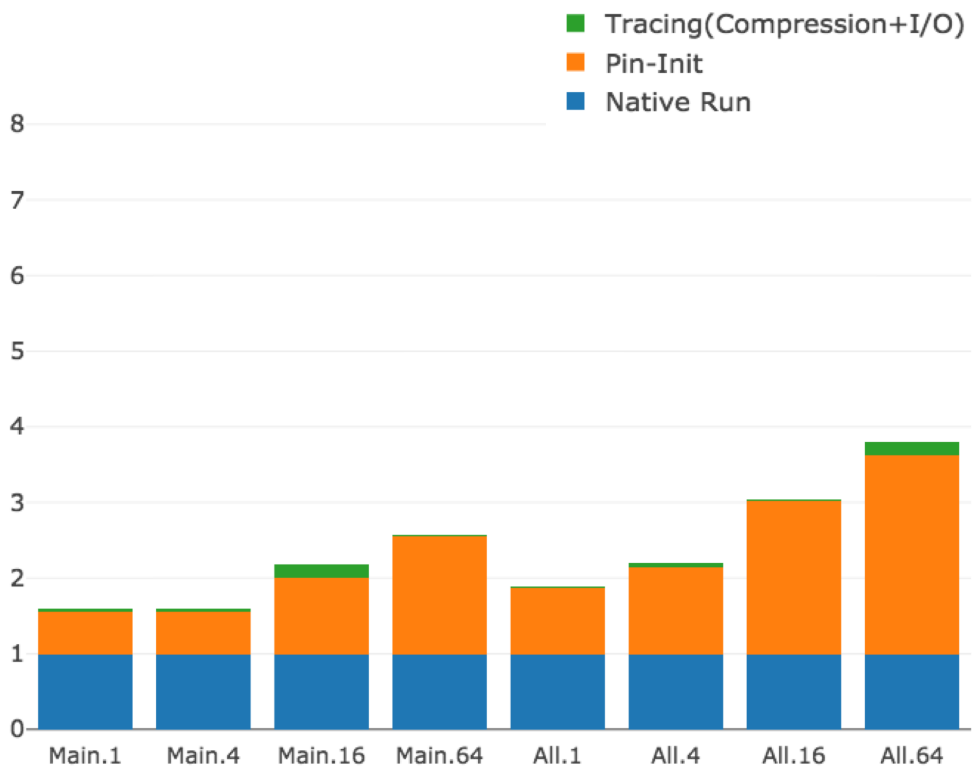

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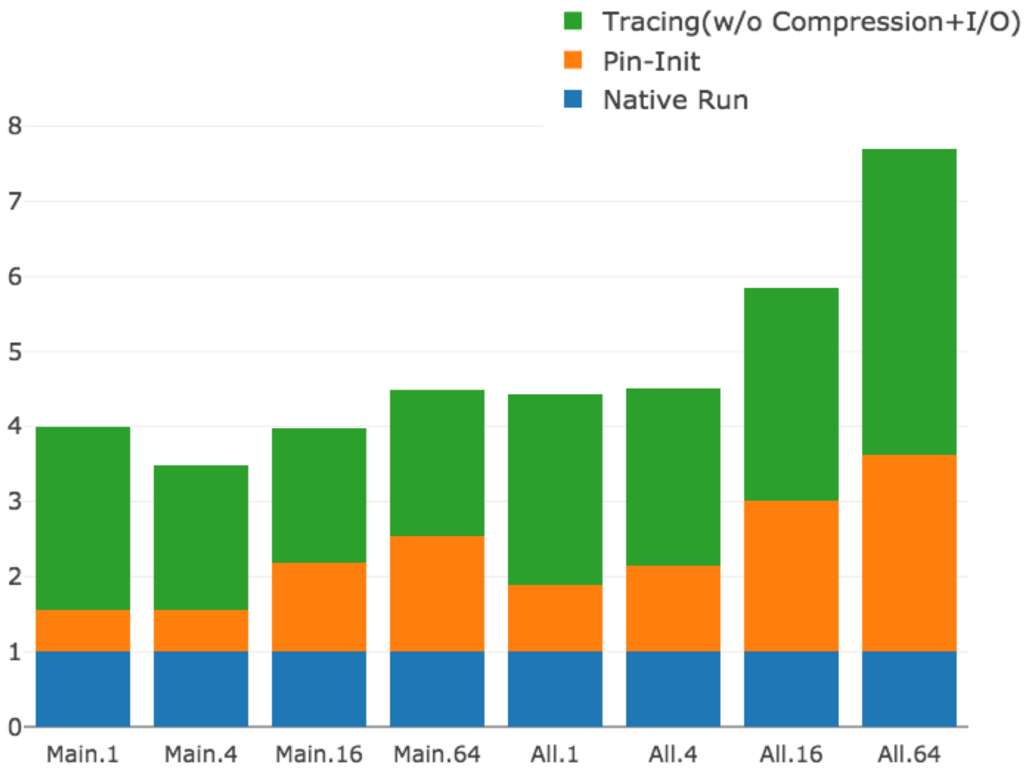

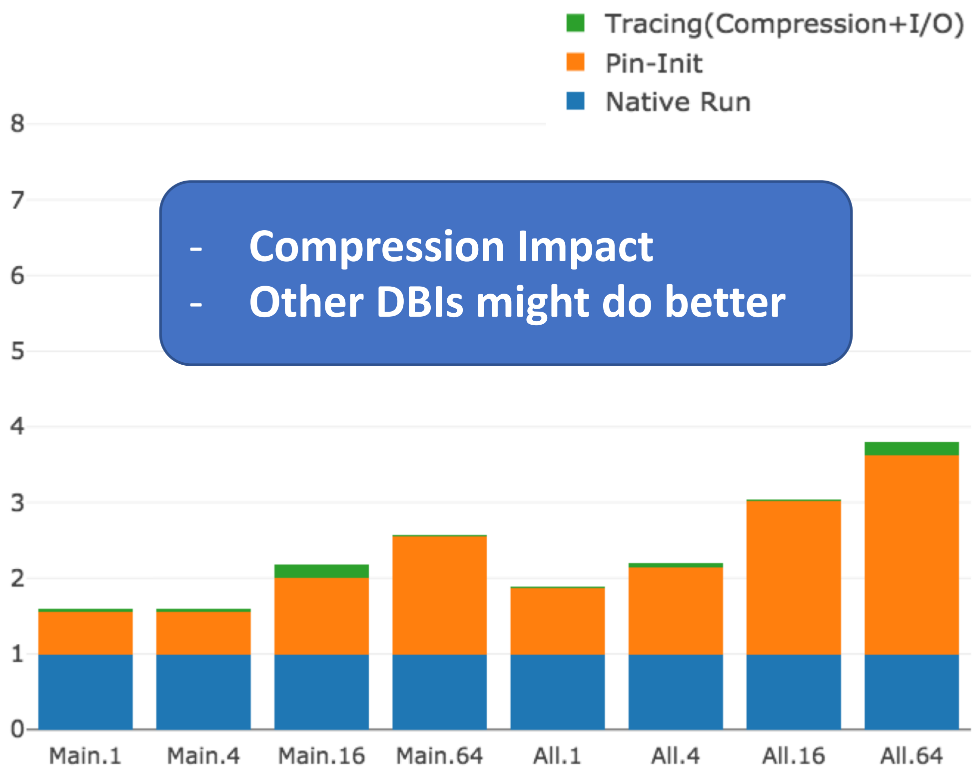

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- Includes new trace compression approach
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  - Yields high compression ratio to drastically reduce bandwidth and storage requirement
  - Efficiently implemented to minimize runtime overhead
- Enables comprehensive post-mortem analysis on traces (debugging, performance analysis, program understanding, etc.)

Thanks.
Any questions?