An Asynchronous Many-Task Implementation of In-Situ Statistical Analysis using Legion

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(with special thanks to the Legion team @ Stanford)
Motivation

- Design, develop, and evaluate unified data-driven approach for programming applications and in situ analysis and visualization;

- Study interplay between data-centric programming model requirements at extreme-scale;

- Assess impact of those requirements on design, capabilities, and implementation details for both applications and supporting in situ infrastructure.
Scope of this work

• Describe our first effort, using Legion, to:
  • support data-centric in situ data analysis,
  • provide foundation for efficient workflow handling.
• Report on:
  • proof-of-concept implementation,
  • current challenges with Legion.
MiniAero

- Compressible Navier-Stokes, 3 D, unstructured mesh, finite volume, explicit CFD mini-application;
- Implements 1D shock tube problem set up in 3D domain discretized in rectilinear finite volume cells;
- MiniAero/Legion implementation used as basis for this study: surrogate for “real” scientific application.
Titan Statistics

- Set of C++ classes, part of VTK
- Parallel implementation using MPI.
- Learn/Derive/Assess model
SPMD Implementation

Scales optimally with up to $O(10^5)$ processes for:

- moment-based statistics,
- quanta-based statistics when quantization is adapted.

<table>
<thead>
<tr>
<th>Process 0</th>
<th>Process 1</th>
<th>Process 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>a, c, d, e, d, a</td>
<td>c, c, b, e, c, e</td>
<td>b, b, d, b, a</td>
</tr>
<tr>
<td>a, c, d, e</td>
<td>b, c, e</td>
<td>a, b, d</td>
</tr>
<tr>
<td>2, 2, 2, 1</td>
<td>2, 7, 4</td>
<td>3, 6, 1</td>
</tr>
</tbody>
</table>

Raw observations

Count observations

Process-local histogram

Union all keys

Sum values for each key

Global histogram

\[ \text{Weak Scaling, } R(p) = \frac{\text{theory}}{\text{obs}} \]

Learn

Derive

Assess

Learn

Derive

Assess

New raw observations

Assessed observations

Probability of observations from empirical probability distribution

Global histogram and empirical PDF, quantiles, etc.

Count total observations, etc.

\(|5.8, 9, 3.5| = 30 \]

\(|5.8, 9, 3.5| = 30 \]

\(|5.8, 9, 3.5| = 30 \]

Legend

- \([0.167], (0.167), (0.633), f (0)\)
- \([0.267], (0.267), (0.633), (0.167)\)

Theoretical optimum

\[ \sigma = 5 \]
AMT Approach

- Retain L/D/A work flow;
- Parallel Assess processes become tasks
- Replace MPI collectives with aggregation region;
- Implement with Legion regions (logical/physical);
- Derive and Assess are single tasks launched from top-level driver.
Implementation details

- Changes to MiniAero/Legion limited to a few files:
  - TaskIDs.h
  - main.cc
  - Interface.h/cc
  - toplevel.cc
  - Mapper.cc
- Most changes (aggregation regions) in toplevel.cc
- Total ~ 80 lines of code
Algorithm correctness

- “3D SOD” test case with 128x4x4 grid
- 2-core Intel Core i7
- Shared-memory LLRTS

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Reference</th>
<th>1 task</th>
<th>4 tasks</th>
<th>64 tasks</th>
<th>Octave</th>
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<tbody>
<tr>
<td>Cardinality</td>
<td>2048</td>
<td>2048</td>
<td>2048</td>
<td>2048</td>
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<tr>
<td>Minimum</td>
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<td>0.1039304</td>
<td>0.1039304</td>
<td>0.1039304</td>
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<tr>
<td>Maximum</td>
<td>0.8314390</td>
<td>0.8314390</td>
<td>0.8314390</td>
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<tr>
<td>Mean</td>
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<tr>
<td>Std. dev.</td>
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Algorithm Scalability

- “3D SOD” test case with 128x4x4 grid
- 2-core Intel Core i7
- Shared-memory LLRTS

![Graph showing parallel scaling](attachment:parallel_scaling.png)
Main Findings

- Proof-of-concept approach for AMT in situ analysis appears valid; additional tests under way with several test clusters.

- Algorithm correctness in theory — but in practice there are some issues to be resolved.

- Sub-optimal scaling, confirmed with larger studies. This requires further investigation.

- Legion API improvements to be discussed.