**PERFORMANCE, POWER, AND ENERGY OF IN-SITU AND POST-PROCESSING VISUALIZATION: A CASE STUDY IN CLIMATE SIMULATION**

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**Introduction**

- Off-chip data movement can consume hundreds of times as much energy as on-chip data movement.
- More data produced from high-resolution simulation to increase fidelity. More power/energy for storage subsystem.
- Problematic because future supercomputers will be power-limited.

**Hypothesis**

Reducing disk reads and writes using the following techniques will save significant amount of energy and power:

- Temporal sampling: Write output only every few time steps.
- In-situ visualization: Produce images during simulation (without writing raw data to the disk) and write only the compact image representation.

**Key Findings**

- **55% energy savings for in-situ visualization**
- **6.3% improvement in performance for MPAS-O using RAPL interface**

**Results**

- **Visualization Pipelines Evaluated**
  1. **Baseline** — "Traditional" post-processing without any sampling
  2. **Post-processing** — "Modern" post-processing with temporal sampling (i.e., write every n iterations — in this case, n = 24)
  3. **In-situ** — Produce images in-situ alongside simulation and write compact image representation once every 24 iterations

**Key Findings**

1. **In-situ Visualization vs. Baseline ("Traditional" Post-Process)**
   - Serves 93% energy for MPAS-O for the given problem size
     - Despite consuming 3% more power on average
     - But amortized by 94% faster execution from reduced I/O wait

2. **In-situ Visualization vs. Post-processing ("Modern" Post-Process)**
   - Serves 4% energy for MPAS-O for the given problem size
     - Despite consuming 3% more power on average
     - But amortized by 7% faster execution from reduced I/O wait

3. **Energy saved from disk subsystem almost negligible**
   - Nearly all energy saved from reduced system idling

4. **97.5% lower storage requirement for in-situ pipeline**

**Preliminary Results at Scale**

- **Problem size**: 60-km grid size
- **Sampling rate**: One output per simulated day
- **Key finding**: 55% energy savings for in-situ pipeline (vs. modern post-processing pipeline)
- **More aggressive sampling possible to save more energy, but risks missing important events of simulation**

**Experimental Setup**

- **Single-Node Setup**
  
<table>
<thead>
<tr>
<th>Component</th>
<th>Detail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processor</td>
<td>2x Intel Xeon E5-2665 @ 2.4GHz</td>
</tr>
<tr>
<td>DRAM</td>
<td>4x 16GB DR3-J3-333</td>
</tr>
<tr>
<td>Disk</td>
<td>500GB Seagate 7200rpm</td>
</tr>
</tbody>
</table>

**Power Measurement**

- Power measured at 1-Hz frequency using the following methods for different components:
  - **Full system** — WatsUp Pro power meter
  - **Processor and DRAM** — Intel RAPL interface (statistical model based on performance counters)
  - **Disk** — Statistical power model based on iostat statistics

**MPAS Ocean simulation**

- **HPC System Setup**
  - Compute cluster
    - 128 nodes of Caddy supercomputer
    - 2x Intel E5-2670 CPU/node
    - 64 GB RAM/node
    - Power measured for 10 nodes using cage power meter and extrapolated
  - Storage cluster
    - 5 nodes running Lustre file system
    - 1 master node, 2 metadata servers, 2 object storage servers
    - Intelligent PDU's for power measurement

**Application**

- Same cognitive value for both visualization pipelines

**Conclusion**

- In-situ visualization offers the following advantages:
  - Reduced energy consumption (by reducing system idling or I/O wait time)
  - Reduced power (by using fewer storage nodes)
  - Improved performance (by reducing I/O wait time and by making more power available for compute nodes)

**Bibliography**


**Implications**

- **Lower storage requirements**
  - Fewer I/O nodes
  - Fewer I/O nodes — More power for compute nodes
    - Assuming 10% nodes reserved in a HPC data center for storage,
    - Data center power goes down by ~ 10%
    - Estimated increase in power budget for compute nodes ~ 10%
    - 6.3% improvement in performance for MPAS-O using RAPL interface

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