Application of Numerical Accuracy to the Selection of Lossy Compression Error Tolerances

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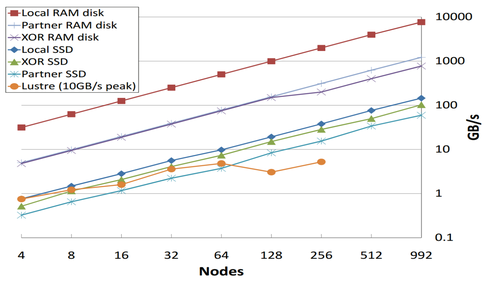
Why lossy compression?

Data movement is a major bottleneck

Next generation of HPC machines
- 5-10x system memory
- 1x system bandwidth (1 TB/s)

File system performance is limiting



Aggregate system bandwidth
Just a few nodes can saturate the parallel file system [Moody et al. 2010]

Reducing file size can improve performance:

- **Lossless compression:** small compression factors for floating-point data, no error [Son et al. 2014]
- **Lossy compression:** higher compression factors, small but controllable error [Di and Cappello 2016]

How to interpret "error"?

Lossy compression on variable u:

$$\tilde{u} = u + \varepsilon$$

- $\tilde{u}$: Variable with error after decompression
- u: Original variable
- ε: User controllable compression error

Absolute Bound

$$\varepsilon > |u - \tilde{u}|$$

Relative Bound

$$\varepsilon > \left|\frac{u - \tilde{u}}{u}\right|$$

This introduces a type of *numerical* error

$$u(x+h) = u(x) + u'(x)h + \underbrace{\frac{u''(x)h^2}{2}}_{\text{Truncation Point}} + O(h^3)$$

Taylor Series expansion of $u(x+h)$ is truncated to second order accuracy

Error less than second order is determined to be insignificant to the approximation of $u(x+h)$

Idea: *Set compression error tolerance less than truncation error to add high order error that is considered insignificant to accuracy*

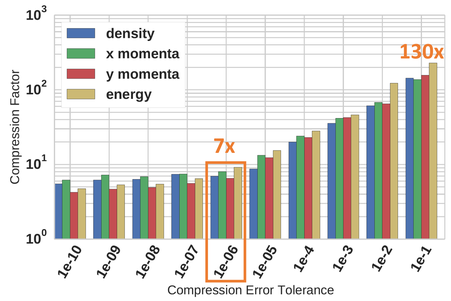
Practical Application CFD

Does compression error exceed truncation error in PlasComCM (https://bitbucket.org/xpacc/plascomcm) after restarting?

- 2D Navier-Stokes flow past a fixed cylindrical object (white circle near center of domain)
- Restart simulation from lossy checkpoint at time-step 15000, 30000, and 45000 (MTBF 18 mins)

- **Simulation Accuracy:** 1.8e-5
- **Compression Error:** 1e-6
- **Compressor:** SZ ver. 1.3 [Di and Cappello 2016]

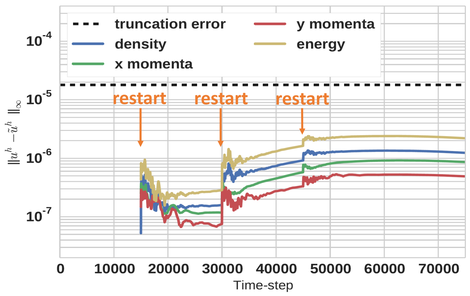
Compression Factor: 7x for $\varepsilon = 1e\text{-}6$



Average compression factor over 500 time-steps

Compression factor varies directly with compression tolerance

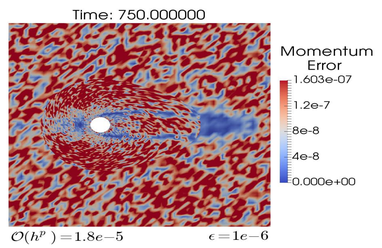
Same Solution: Error in the lossy compressed variables remains less than truncation error



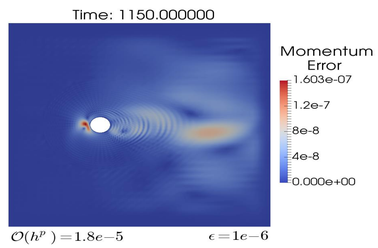
Error in numerical solution u^h and compressed numerical solution $\tilde{u}^h$

Spike in error at restart, but error remains less than the simulation's accuracy (truncation error)

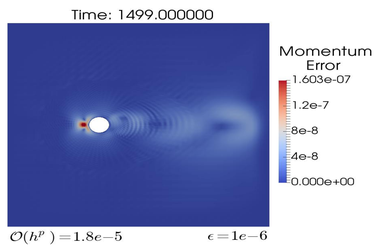
Error Propagation (time-steps 15000-29999): Error expands through domain, but is removed over time



Error starts distributed though domain



Error exits the domain due to boundary conditions



Error that remains is in regions of low momentum

More results and videos
http://web.engr.illinois.edu/~jccalho2/compression/compression.php

Future Work

Create performance model to study runtime benefits of lossy compression

Evaluate other methods of selecting compression tolerances

Investigate using multiple compression tolerances based on physical/simulation properties

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