Simulation of the Taylor-Green Vortex at Re=1600 Using the CPR Method

Takanori Haga and Z.J. Wang
Iowa State University

1st International Workshop on High-Order CFD Methods
Jan. 8, 2012

CPR-3D Code Description

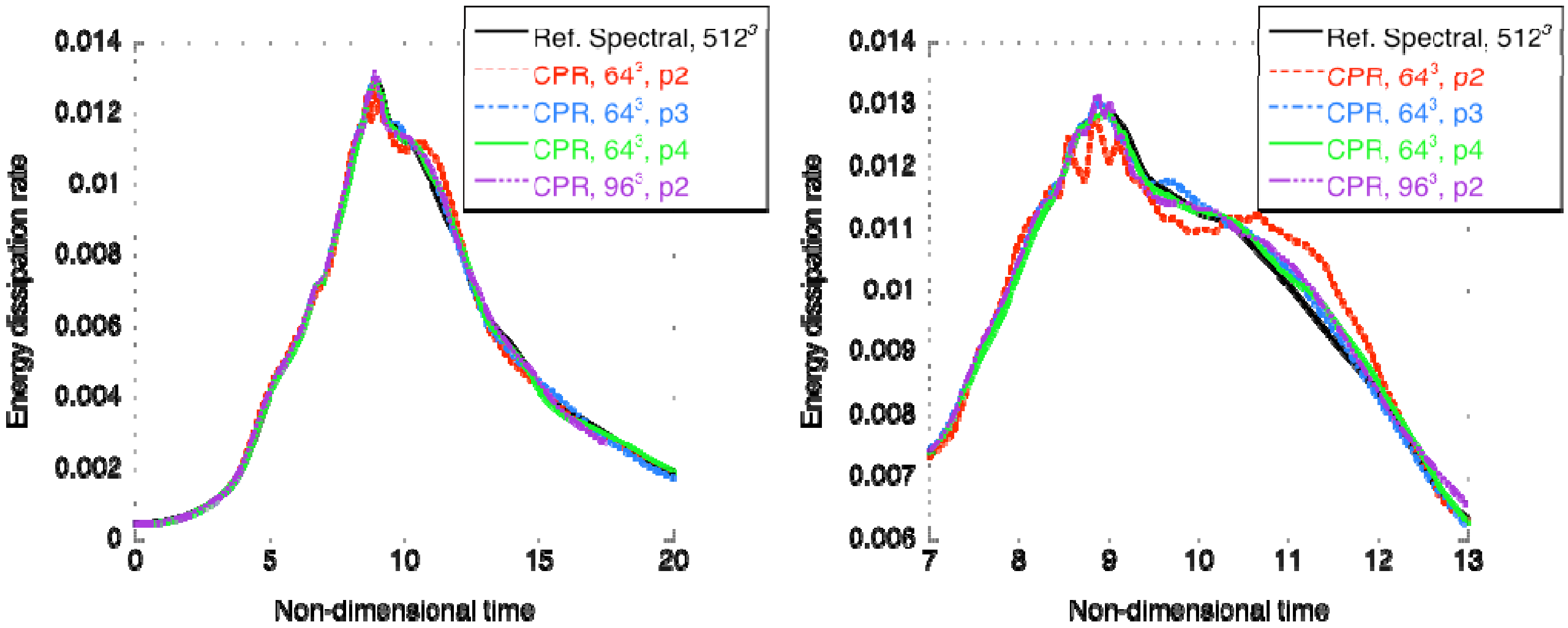
Correction Procedure via Reconstruction code

- Finite difference like formulation
  - DG coefficients are employed
  - Solution points at Gauss-Lobatto nodes (flux points are collocated at cell boundary)
- Hybrid mesh capability: Hex, Tet, Prism, (Pyramid)
- Roe scheme and BR-2 scheme for inviscid and viscous fluxes
- Explicit 3-stage RK scheme for time integration
- MPI parallelization with domain decomposition

Simulation Details

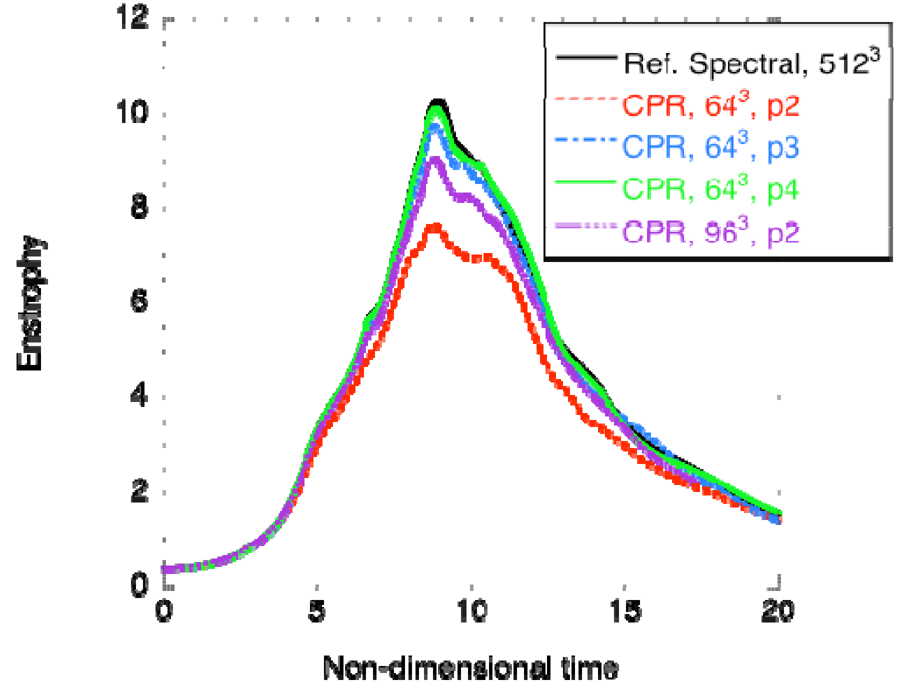
	Grid (Hex)	p	DOF	Time step
comp. 1	64x64x64	2	7,077,888	3.92e-04
comp. 2	64x64x64	3	16,777,216	3.92e-04
comp. 3	64x64x64	4	32,768,000	2.63e-04
comp. 4	96x96x96	2	23,887,872	3.92e-04

Energy Dissipation Rate



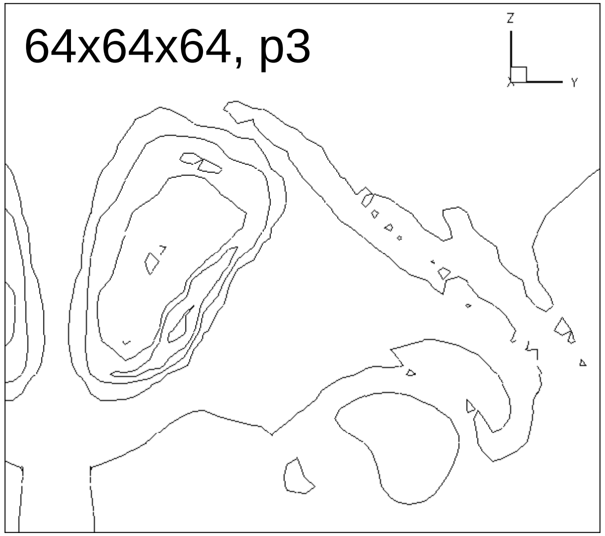
- Time derivative is approximated by one-sided finite difference

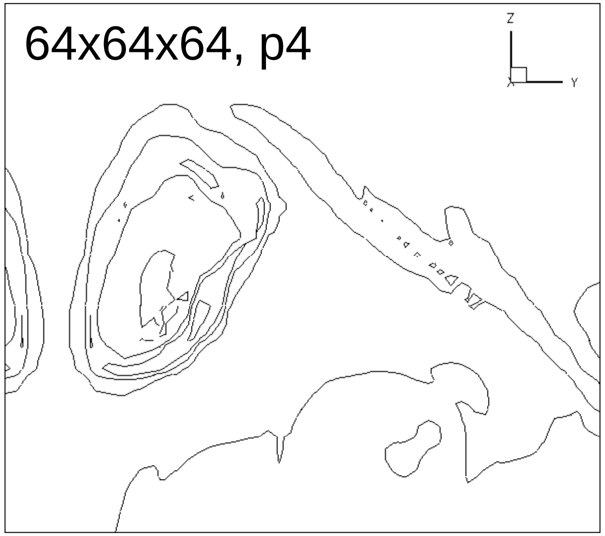
Enstrophy

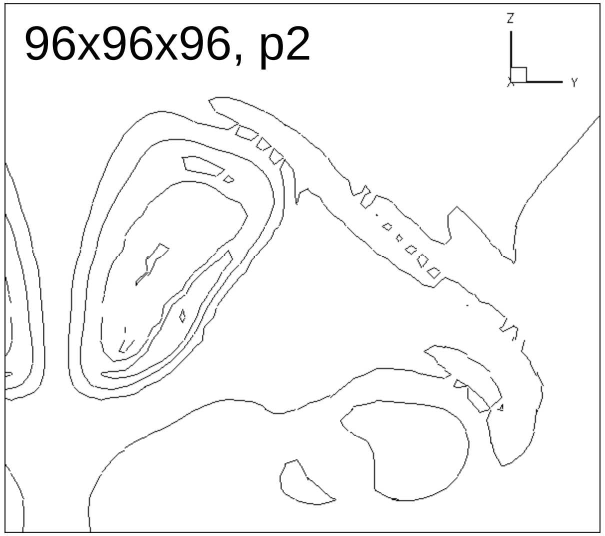


- *p*3 on 64^3 grid has 30% less DOFs than p2 on 96^3
- Large discrepancy comparing to the energy dissipation rate indicates error due to compressible discretization

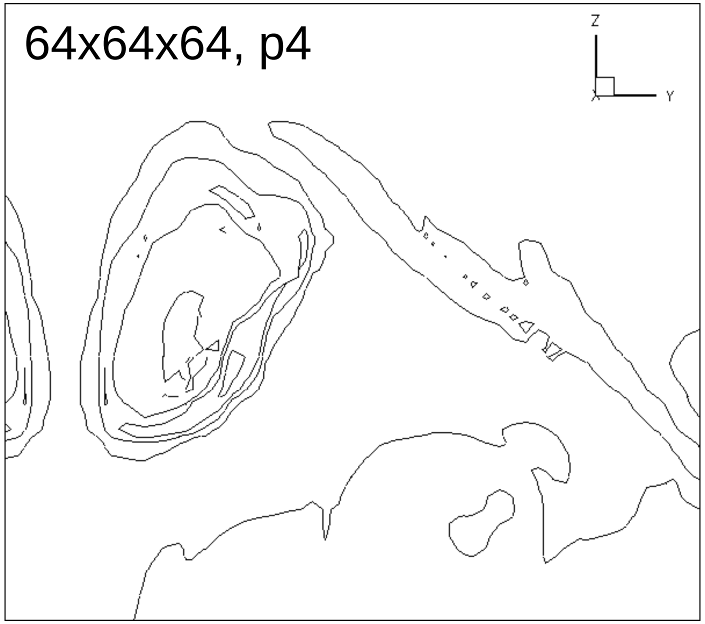
Vorticity Contours







Vorticity Contours (Cont.)



Ref. spectral & DG 96x96x96, p3

Figure 3: Iso-contours of the dimensionless vorticity norm, $\frac{L}{V_0}|\boldsymbol{\omega}| = 1, 5, 10, 20, 30$, on a subset of the periodic face $\frac{x}{L} = -\pi$ at time $\frac{t}{t_c} = 8$. Comparison between the results obtained using the pseudo-spectral code (black) and those obtained using a DG code with $p = 3$ and on a 96^3 mesh (red).

Work Units

- Machine spec
  - 8 nodes, 8 cores per node (64 cores in total)
  - CPU: Intel Xeon E5530 @ 2.4GHz
  - Memory: 24 GB per node
- Measured TauBench wall clock time = 9.554 [s]
- Work Units for 100 residual evaluations with 250,000 DOFs
  - 64x64x64 grid was used and scaled to the same number of DOFs
  - 16 cores were used and run as 32 processes using Hyperthreading

p	Work units
1	10.24
2	7.22
3	6.30
4	5.21

Computational Costs

	Grid	p	DOF	# of cores (# of processes)	Memory(MB)/ processes	Work units /Iteration
comp. 1	64x64x64	2	7,077,888	16(32)	155	8.56
comp. 2	64x64x64	3	16,777,216	16(32)	310	12.55
comp. 3	64x64x64	4	32,768,000	64(64)	292	40.62
comp. 4	96x96x96	2	23,887,872	64(64)	258	42.02
comp. 5	64x64x64	4	32,768,000	32(64)	292	22.90

Note: Work units is computed as
(Elapsed time x Number of cores)/TauBench time

- Benefit of using Hyperthreading is observed (comp.3 vs comp. 5)

Conclusions

- Increasing the degree of polynomial, *p* (at most *p*4 in this work) is the right way rather than grid refinement with lower *p*
  - *p*3 solution on 64^3 grid is much better than *p*2 solution on 96^3 grid with 30% less DOFs
  - Residual evaluation for higher *p* is more efficient in terms of the same DOFs
- Error due to the compressible flow discretization was pronounced in the cases of insufficient resolution
- Aliasing error related to the location of the solution and flux points needs to be studied further