Complete quantum inspired framework for computational fluid dynamics

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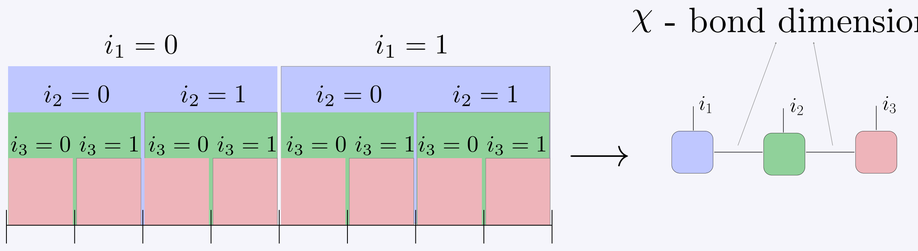
Motivation

$f(x) \longrightarrow$ MPS w/ small χ

χ - bond dimension/rank



"Many functions admit a low-rank MPS(or TT) approximation"

Signal Processing
Image Compression[1]
Fourier Transform[12]

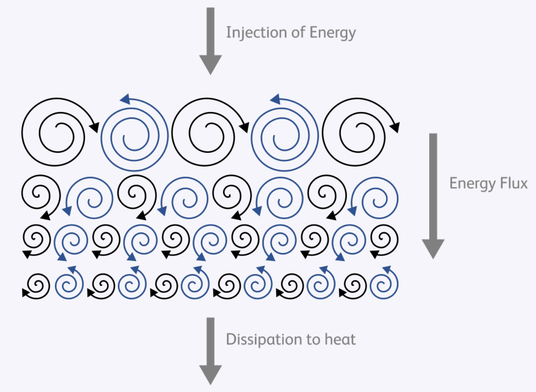
Finance
Option Pricing[2]

Solutions of PDEs
Plasma Dynamics[4], Neutron Transport[5]
Fluid Dynamics[6,7,8]

Quantum Physics
Many-body states[9,10]

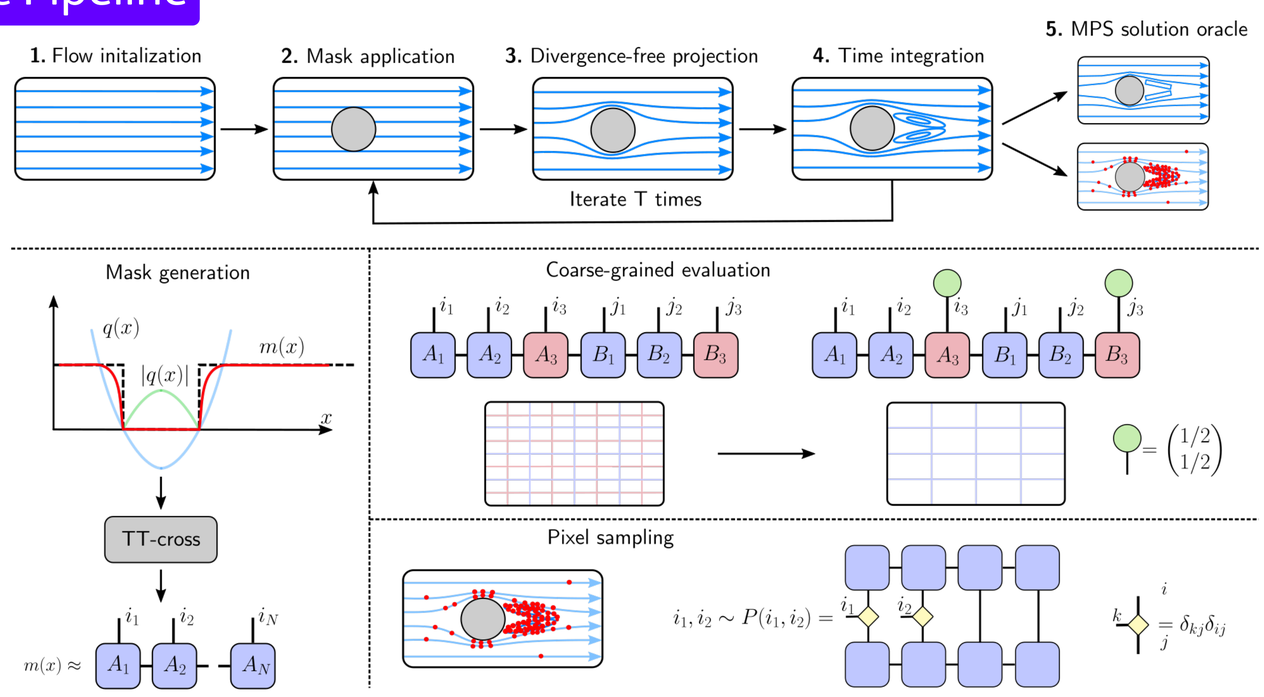
Quantum Computing
Circuit simulation[11]
State tomography[3]

Turbulent Flows



Energy cascade = low-interscale correlations
Qubits = different scales
Entanglement = inter-scale correlations

Algorithmic Pipeline



$$\frac{\partial \boldsymbol{v}}{\partial t} + (\boldsymbol{v} \cdot \nabla)\, \boldsymbol{v} = -\frac{1}{\varrho}\nabla p + \nu\, \nabla^2\, \boldsymbol{v},$$
$$\nabla \cdot \boldsymbol{v} = 0,$$

Navier-Stokes Equations

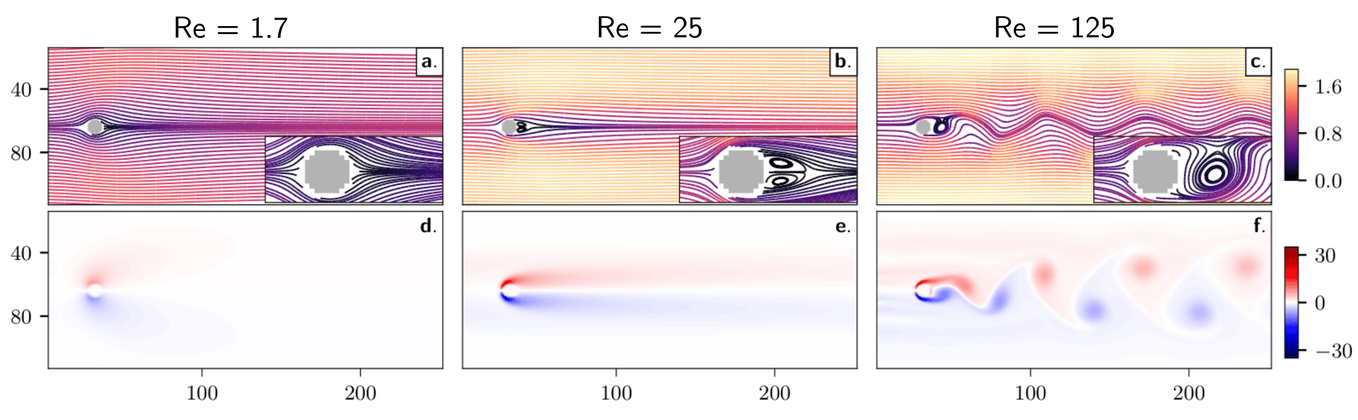
Complete CFD Framework

MPS encoding of arbitrary geometries

Time evolution w/ divergence-free projection method

Efficient access of solutions with MPS oracle

Numerical Results

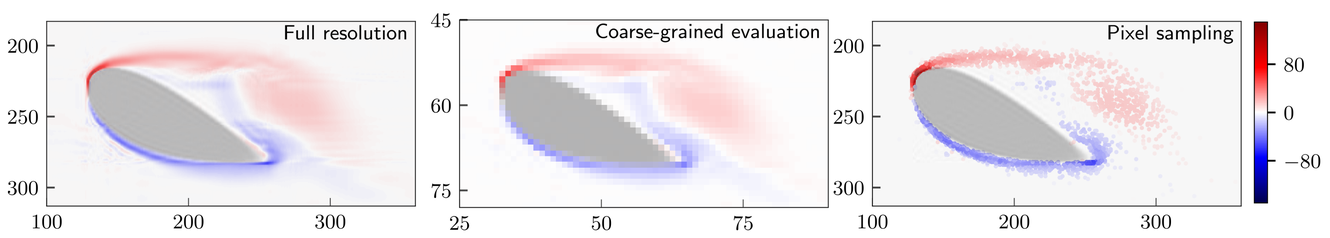


Flow around a cylinder

- Flow behaviour within the laminar regime
- 15-bit MPS encoding with χ = 30
- Reproduced the Karman Vortex Street phenomena

Flow around squares

- MPS encoding of a collection of squares
- 15-bit MPS encoding with χ = 30
- Qualitative comparison with Ansys Fluent - a commercial CFD solver



Flow around NACA airfoil

- MPS encoding of NACA 0040 inclined at 22°
- 19-bit MPS encoding with χ = 45
- Various modes of the MPS solution oracle encoding the vorticity field

References

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