Real-time implementation of an iterative solver for atmospheric tomography

WAVEFRONT SENSING IN THE VLT/ELT ERA V
AO WORKSHOP WEEK II

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joint work with Ronny Ramlau (JKU) and Roberto Biasi (Microgate)

Reduced Order Modelling, Simulation and Optimization of Coupled Systems (ROMSOC)

October 15, 2020

Funded by the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie Grant Agreement No. 765374.

Outline

1. Problem description
2. Parallel implementation on RTC hardware
3. Ongoing work
4. Summary

Atmospheric tomography

- **goal:** reconstruct turbulent layers ϕ from sensor measurements s

$$s = A\phi$$

$\Rightarrow$ inverse problem

- **regularization:** Bayesian framework and maximum a-posteriori estimate

$$(A^T C_\eta^{-1} A + C_\phi^{-1})\phi = A^T C_\eta^{-1} s$$

- **challenges:** demanding operations to be solved in real-time

Solvers:

- standard: MVM
- iterative: FD-PCG, FrIM, Kaczmarz, **FEWHA**

Finite Element Wavelet Hybrid Algorithm

$$(A^T C_\eta^{-1} A + C_\phi^{-1})\phi = A^T C_\eta^{-1} s$$

$$\Downarrow$$

- **dual domain discretization:** wavelet domain + finite element domain

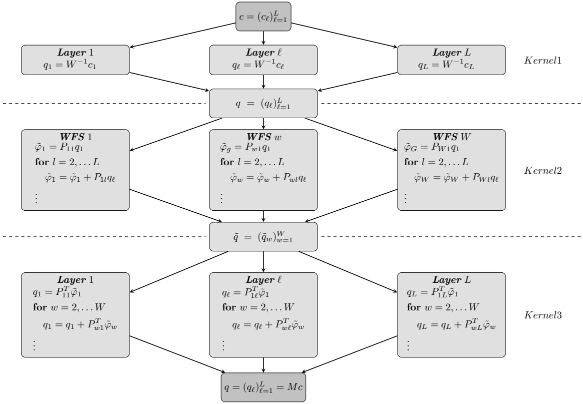
$$(W^{-T}\hat{A}^T C_\eta^{-1}\hat{A}W^{-1} + \alpha D)c = W^{-T}\hat{A}^T C_\eta^{-1} s$$

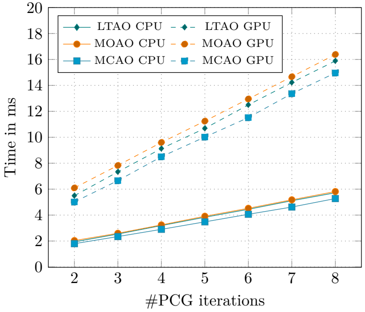
- solve with **preconditioned conjugate gradient method**
- **matrix-free implementation** decreases FLOPs and memory usage

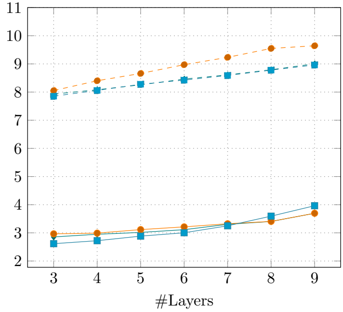
M. Yudytskiy and T. Helin and R. Ramlau. Finite element-wavelet hybrid algorithm for atmospheric tomography. J. Opt. Soc. Am. 2014.

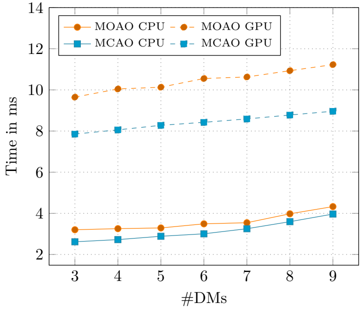
Parallel implementation on RTC hardware

- on CPU: in C++ using OpenMP and TBB
  one node of Radon 1 with two 8-core Intel Haswell processors
- on GPU: in Cuda on a NVIDIA Tesla V100

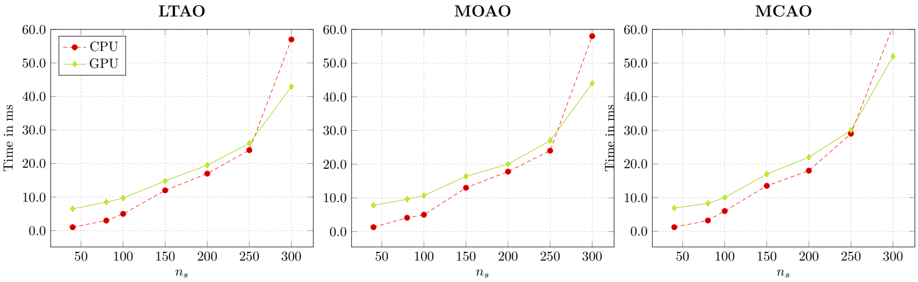








Description	Value
Numb. of WFS	9
Subapertures WFS 1-6	80^2
Subapertures WFS 7	2^2
Subapertures WFS 8-9	1^2
Numb. of LGS	6
Numb. of NGS	3
Numb. of Layers	3 — 9
Layer discretization points	128^2
Numb. of DMs	3 — 9
Actuators for DM 1	81^2
Actuators for DM 2-5	48^2
Actuators for DM 6-9	54^2
PCG iterations	4 — 8



⇒ bottleneck memory latency not computational throughput

⇒ not able to meet the real-time requirements of 2 ms

B. Stadler, R. Biasi, M. Manetti and R. Ramlau. Real-time implementation of an iterative solver for atmospheric tomography. Submitted.

Ongoing work

- **goal:** reduce number of PCG iterations while keeping the quality
- right-hand side does not change significantly in every time step
- **idea:** recycle information from previous time steps
- adds additional dot-products, but no matrix-vector multiplications

$\Rightarrow$ save half the PCG iterations with augmented FEWHA

$\Rightarrow$ augmented FEWHA for 3-layer MCAO ELT configuration: **1.9 ms**

Why FEWHA instead of MVM?

- MVM becomes very demanding for large telescopes
  ⇒ meeting real-time requirements only possible with expensive hardware

- for FEWHA due to matrix-free implementation FLOPs and memory usage significantly smaller

  B. Stadler et al., Feasibility of standard and novel solvers for atmospheric tomography. In proc. AO4ELT6 2019.

- with augmented FEWHA real-time requirements fulfilled on a CPU

- with "better" CPU run-time improvements possible

⇒ Why not?

Thank you for your attention!

Funded by the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie Grant Agreement No. 765374.