A new multi-tracer transport scheme for NCAR's Community Atmosphere Model – Spectral Elements

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Community Atmosphere Model – Spectral Elements

- based on NCAR's High-Order Method Modeling Environment
- cubed-sphere grids resulting from equi-angular gnomonic projection
- domain decomposition (horizontal), $\mathcal{O}(170k)$ cores, that means parallel strategy over elements, highly scalable

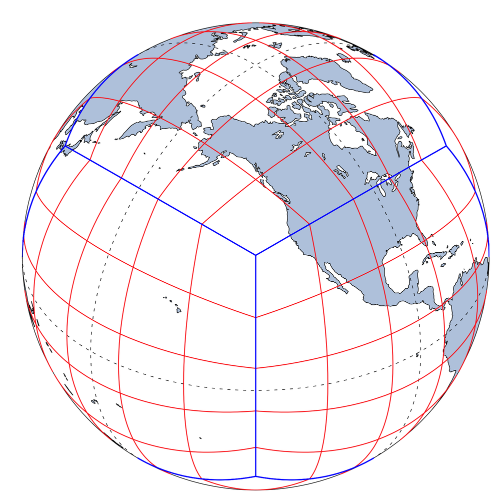

Figure: *Cubed-sphere grid.*

Conservative Semi-LAgrangian Multi-tracer transport scheme

Two-dimensional transport equation on the sphere (no sources/sinks):

$$\frac{d}{dt}\int_{A(t)} \psi \, dx = 0,$$

where ψ is the tracer density, t the time and $A(t)$ a Lagrangian area.

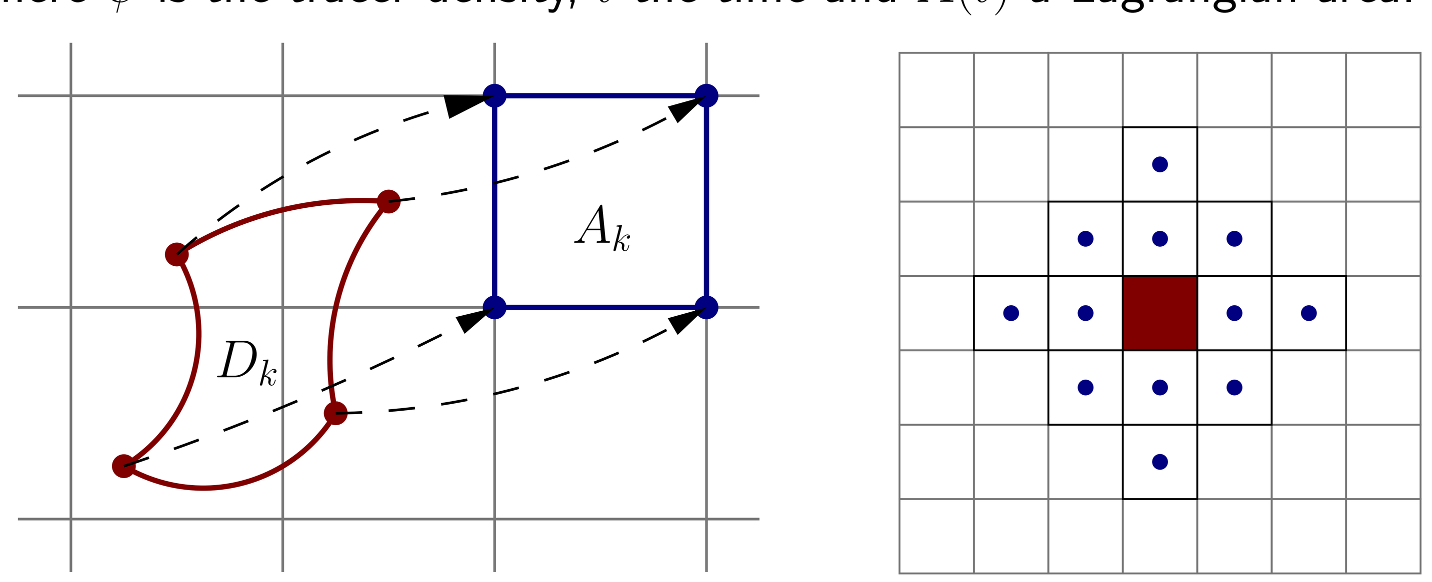

Figure: *Left: the departure cell D_k is deformed depending on the time step and moves to the (Eulerian) static arrival cell A_k. Right: the stencil for the two-dimensional polynomial reconstruction (filled cell) of degree two.*

The semi-Lagrangian finite-volume discretization reads:

$$\overline{\psi_k}^{n+1}|A_k| = \int_{D_k} \psi^n_{k,rec} \, dx$$

with $\overline{\psi_k}^{n+1}$ average tracer in A_k at time step $n+1$, $\psi^n_{k,rec}$ is a reconstruction in D_k.

$\psi^n_{k,rec}$ is approximated from $\overline{\psi_\omega}^n$ (tracer values from the previous time step, ω is a patch around D_k), separated in weights (depending on mesh) and reconstruction coefficients (depending on tracers).

Weights can be reused for additional tracers!

Integrating CSLAM in CAM-SE

CSLAM works on a different mesh, has its own data structure, but uses the cubed-sphere structure of CAM-SE. Communication differs significant because of a different halo zone.

Apply CSLAM on the element + halo zone for each element:

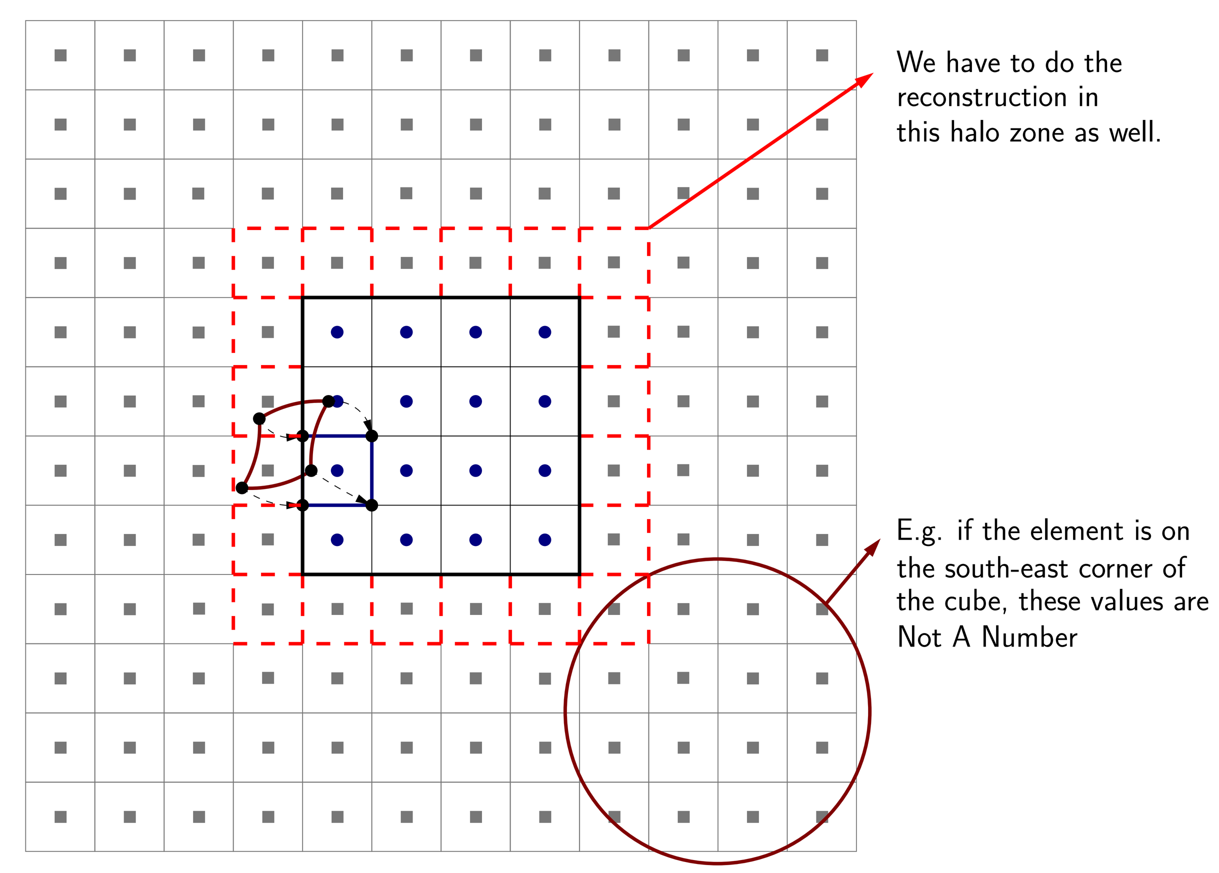

Figure: *One element (bold square) with its cells and cells in the halo zone (grey cells) of depth four build the extended element. This is needed on one processor. The small filled circles and squares represent the cell-center. Since the departure cell can be outside the element (here CFL<1), we also calculate the reconstruction in the halo zone (dashed cells) to avoid additional communication of the reconstruction coefficients.*

- departure grid defines the depth of the halo zone
- departure and arrival cells are always on the same processor
- the weights are calculated local on the element + halo zone (search of the overlap areas of the departure cell with respect to the Eulerian grid), no communication necessary!

> Reconstruction coefficients depend on the tracer value, only ONE nearest neighbour communication for each time step (array of multiple tracer values) is needed, cf. spectral elements advection time step needs three communications (Runge Kutta).

- for higher order reconstruction extend the halo zone
- limiting with finite volume methods is more straight forward and can be more accurate than with spectral elements

This strategy in HOMME ensures mass conservation and monotonicity!

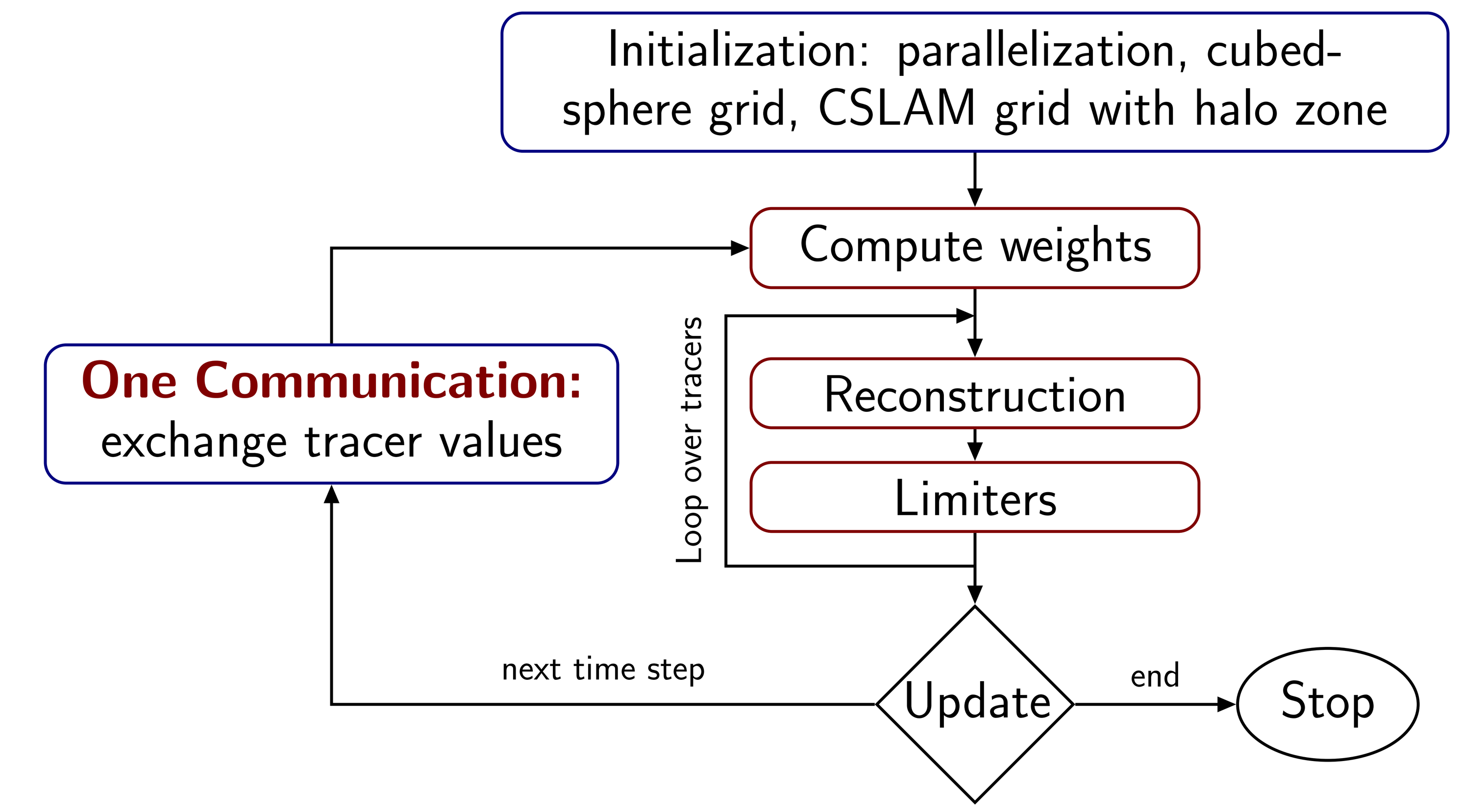

Figure: *Algorithm of CSLAM in HOMME.*

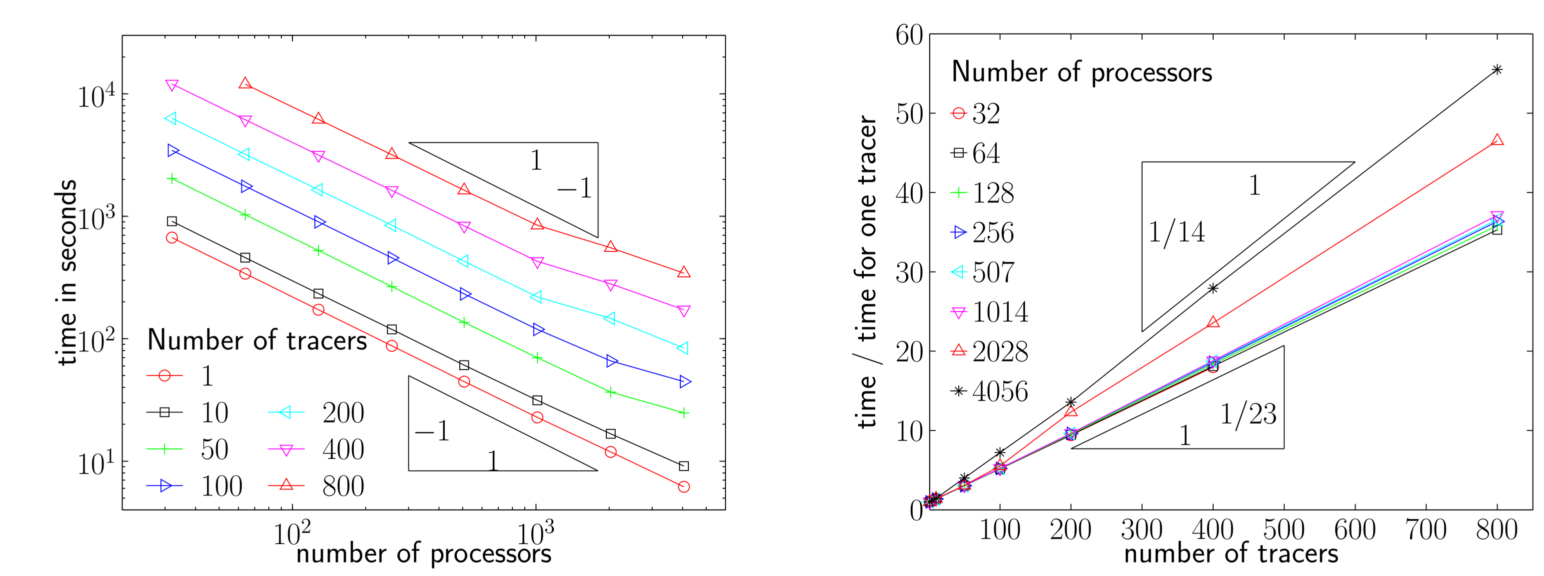

Figure: *Left: the scalability of our algorithm for a variety of tracer counts on NCAR/CU Blue Gene/L system. The right most marker corresponds to one element per processor in the chosen benchmark example. Right: the additional costs for adding one tracer compared to one tracer. This ratio increases the fewer elements we have on a processor.*

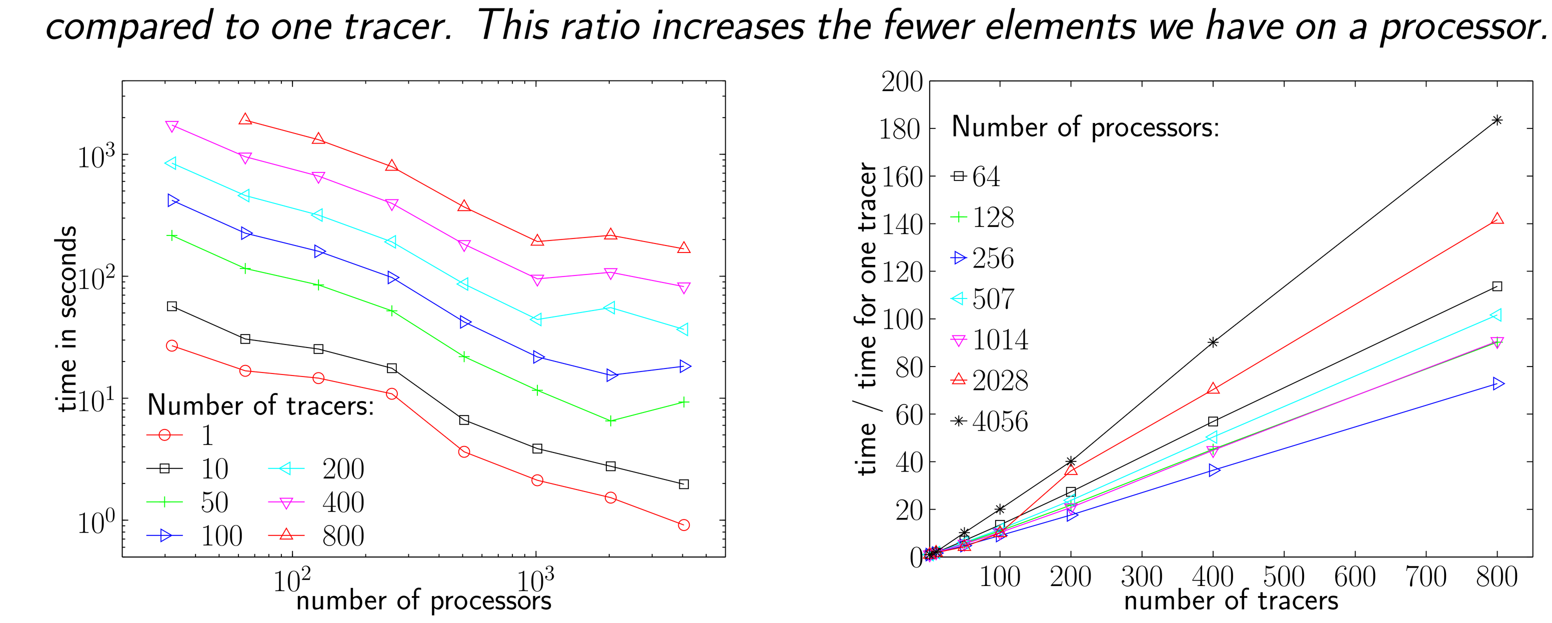

Figure: *Left: the communication is dominant for large numbers of tracers and few elements per processor. Right: the communication cost normalized by the communication cost for one tracer.*

Acknowledgment

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C. Erath, P. H. Lauritzen, J. H. Garcia, H. M. Tufo, Integrating a scalable and efficient semi-Lagrangian multi-tracer transport scheme in HOMME, *to appear in Procedia Computer Science.*