TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

Dipartimento di Fisica

European Research Council
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# *A Series of Seminars*

# *Dr. Maurizio Carbone*

*(CNR-Roma)*

*Sala Struttura della Materia (Dipartimento di Fisica) – h: 14:00*

**9 APRIL 2025 - Numerical simulation of two-dimensional scalar turbulence: an overview of Fourier pseudospectral methods**

Navier-Stokes turbulence exhibits complex dynamics over a wide range of scales, from the largest vortices, comparable to the domain size, down to tiny swirls dominated by viscous effects. Due to this large number of degrees of freedom, direct numerical simulation (DNS) of turbulence is extremely challenging. In this talk, we discuss the Fourier pseudospectral method for simulating turbulence in a periodic domain, exploring equation formulations optimized to reduce the number of Fast Fourier Transforms. We then address code optimization and parallelization strategies. As an application, we consider a DNS code that simulates two-dimensional turbulence advecting a passive scalar field. The code is used to generate high-resolution datasets, which serve as training data for machine-learning algorithms in olfactory search, which is the main focus of this seminar series.

**28 MAY 2025 - Backtracking turbulent scalar fields: learning and sampling the propagator**

Olfactory search is crucial for biological organisms and robotic applications, such as search-and-rescue. In turbulent environments, odor cues are sparse and intermittent, making localization difficult. Traditional methods rely on the Bayesian update of a probability map over the entire domain, which is robust but memory-intensive. We explore a backtracking-based approach inspired by simpler heuristics like casting and surging, avoiding large probability maps. The agent learns the spatiotemporal dynamics of turbulence, estimating the time-dependent probability distribution of an odor particle's position at an earlier time given an odor detection at the current time and agent's position, conditional on the local fluid velocity and possibly other local observables. This propagator constitutes the building block of the backtracking algorithm.

**11 JUNE 2025 - Backtracking turbulent scalar fields: from the Fokker-Planck equation to casting and surging**

We construct a backtracking-based approach for odor source localization in turbulent environments based on learning the propagator of odor particles inferred via machine learning using a normalizing flow. When engaged in source localization, the agent samples the learned probability distribution through an associated Fokker-Planck equation, which includes an explicitly time-dependent drift, a component parallel to the probability gradient, and an orthogonal component. These contributions correspond to a surge in the probability gradient direction and a cast perpendicular to it, mirroring natural olfactory search strategies. We analyze typical trajectories produced by the learned strategy for various odor cue sparsity conditions and mean wind speeds.

**7 JULY 2025 - Backtracking turbulent scalar fields: comparison with classic heuristics**

We evaluate a backtracking-based approach for odor source localization, which relies on learning the odor particle propagator via a normalizing flow and sampling it through an associated Fokker-Planck equation. The resulting model is trained on a passive scalar field emitted from a point source and advected by a two-dimensional turbulent flow in the inverse cascade regime. We show that the agent can effectively backtrack odor detections, reconstructing trajectories that resemble passive scalar plumes, thus efficiently localizing the source. We explore how the mean arrival time and success rate depend on characteristic parameters, such as the mean wind speed relative to the agent speed and turbulence intensity. Finally, we compare the arrival times with well-established heuristics, including infotaxis and casting-and-surging strategies.

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***(P.I. Prof. Luca Biferale)***
Dipartimento di Fisica - Università degli Studi di Roma "Tor Vergata"
C.F. n. 80213750583 – Partita IVA n. *02133971008* - Via della Ricerca Scientifica, 1 – 00133 ROMA