# Fast identification of Lagrangian Coherent Structures

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## ABSTRACT

In fluid mechanics' experiments, it is common to put particles in a fluid, in a way to reveal some topologies of the flow. More precisely, time-lines somehow are "Lagrangian fronts" : as seeding particles are assimilated to fluid particles, one can follow their trajectories. Time-lines are advected and wringed up by the fluid flow, so the chaotic mixing local properties are revealed. Strong mixing manifolds, where the divergence rate between trajectories of initially close particles is maximum, are coherent structures of the flows shown in [2]. These structures are a way to analyze and to have a better understanding of the underlying physics of the fluid flows as, on each side of its, fluid particles will have different behaviors and fates. In [1], these structures are defined as Lagrangian Coherent Structures (LCS).

LCS are the ridge of a scalar field, the Finite Time Lyapunov Exponent (FTLE) field. It is defined, at each space point, as the largest eigenvalue of the Cauchy-Green strain tensor. When the horizon time is well-defined, in respect with the time scales of the fluid flows, then the LCS are true material frontiers in the fluid flow, there is no mass flux through these frontiers. Therefore, one can see LCS as a good way to separate the fluid flows into different areas, physically relevant, driven by different dynamics.

One of the drawbacks of tracking LCS is the computing time, as [] trajectories of all the particules have to be computed, at each time. In this contribution, we present some improvements to the classical way to compute such structures. One improvement is a vectorization of the algorithm. Instead of following, one by one, each particle of the fluid flow, while computing their trajectories, one can follow a huge number in one computation cycle. Another improvement, as suggested in [3], is to compute flow maps instead of trajectories, from snapshot to snapshot. It increases drastically, on one hand, the algorithm's versatility, and it suppresses, on the other hand, some redundant computations. By composition of the flow maps, the trajectories to any chosen time horizon are easily and promptly figured out. The last gain is a material optimization, achieved through the NT2 software [4]. It generates a high level parallel sequencing of the code, optimized for the computer architecture, i.e. processor's multicore and SIMD extensions. For the sake of illustration, we will present some results of LCS identification, on a 3D unsteady, oscillating and self-maintained fluid flows.

## REFERENCES

[1] G. HALLER *Distinguished material surfaces and coherent structures in three-dimensional fluid flows*, Physica D **149**, 248-277, 2001.

[2] F. LEKIEN, S.C. SHADDEN and J.E. MARSDEN *Lagrangian coherent structures in n-dimensional systems*, Journal of mathematical physics **28**, 2007.

[3] S.L. BRUNTON and C.W. ROWLEY *Fast computation of finite-time Lyapunov exponent fields of unsteady flows*, Chaos **20**, 2010.

[4] J. FALCOU, J. SEROT, L. PECH and JT. LAPRESTE *Meta-programming Applied to Automatic SMP Parallelization of Linear Algebra Code*, Euro-Par, 729-738, 2008.