A new hybrid optimization algorithm for variational data assimilation of unsteady wake flows

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Abstract
In typical variational data assimilation (DA) applications for unsteady flows the search space is large and multidimensional, while prior information about the control vector function is not available. Stochastic optimization algorithms like genetic algorithms (GA) perform global optimization but waste computational effort by doing a random search. On the other hand, deterministic algorithms like gradient descent converge rapidly but may get stuck in local minima of multimodal functions. Here, we present a new hybrid global optimization technique, where a gradient-based local search method is combined with a genetic algorithm to achieve faster convergence and better accuracy of final solution without getting trapped in local minima. The proposed methodology is applied to the reconstruction of unsteady bidimensional flows past a rotationally oscillating cylinder. More precisely, the possibility of reconstructing the rotational speed of the cylinder given observations of a reference flow was investigated via variational DA (Fig. 1).

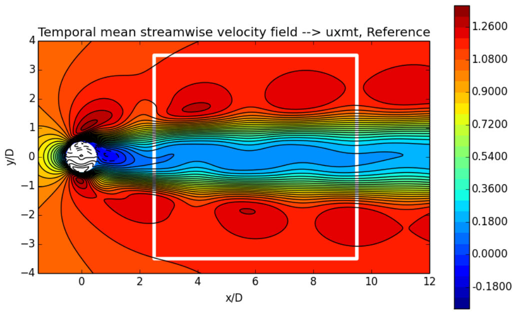

Fig. 1 Temporal mean streamwise velocity field for Reference flow, the observation domain is delineated in white lines.

In order to decrease memory and computational time requirements, we used an alternative formulation of the optimization procedure proposed by Tsoulos *et al.* (2008). This formulation avoids the execution of the local search process each time a local minimum is found progressively by the genetic operations step (Fig. 2-left). Accordingly, the genetic algorithm was first used to approximately locate a good global minimum. Then a gradient based local search was done with the best solution found by the genetic algorithm as its starting point (Fig. 2-right). Thus, the GA was used to go near the vicinity of a good global minima and the gradient descent scheme was used to find the global minimum accurately. This approach is advantageous because it allows for exploration of new regions of the search space while retaining the ability to improve good solutions already found. The stochastic approach utilizes the grammatical evolution (GE) procedure to create trial solutions, while the GA utilizes the operations of crossover and mutation to create the evolving generations.

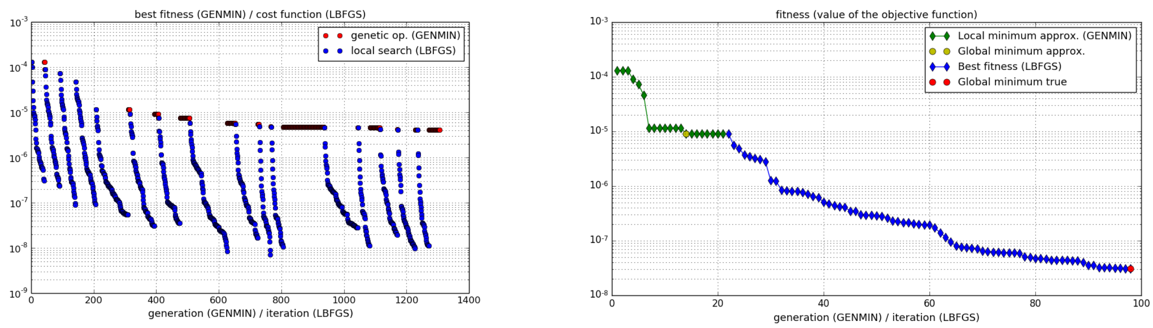

Fig. 2 Typical convergence histories for the Hybrid approach by Tsoulos et al. (2008) (left) and present formulation (right).

Contrary to Gronskis *et al.* (2013) where the cylinder was not modeled in the numerical experiments and the inflow was a control parameter, here we imposed the characteristic velocity at the boundaries of the computational domain. The control vector for the DA problem was thus formed by the solid boundary conditions for the cylinder, that meant its rotational speed at all times where no particular form was prescribed to the rotary movement of the body. We considered a configuration of reference flow in the lock-on regime given by Mons *et al.* (2017). Two categories of numerical experiments were identified. The first one corresponds to experiments where the first-guess flow was assumed to be known (as depicted in Mons *et al.,* 2017), while for the second set of numerical tests a first generation of flow solutions was created where each individual was initialized at random from a uniform distribution inside a feasible region subject to a continuity constraint (hybrid framework).

The present results suggest that in both hybrid and pure deterministic approaches the assimilated flows correctly fitted the observations of the velocity field, but the later context did not correctly identify the associated rotational speed. As shown in Fig. 3, the reconstructed rotational speed appeared globally closer to the reference one, compared to the solution obtained by running the DA problem using a pure local search based procedure.

This DA experiment thus confirmed that the addition of the stochastic process in the formulation may improve the reconstruction of quantities of interest such as the wall conditions in this high-dimensional problem, encouraging the application of the proposed methodology to more complex and realistic flows, like 3D turbulent flow reconstructions from sparse observations.

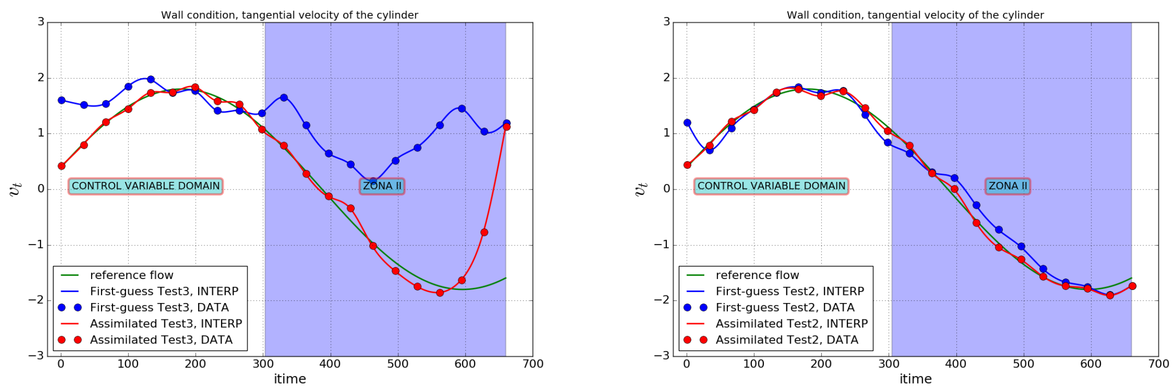

Fig. 3 Dimensionless rotational speed of the cylinder for reference (green), first-guess (blue) and assimilated (red) runs obtained by pure Deterministic (left) and Hybrid present approach (right).

References

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