Agnostic Multi-Fidelity Gaussian Process Regression for Modeling Complex Systems in Aerospace Applications

(and future perspectives)

Giulio Gori[a,c], Olivier Le Maître[b,c] and Pietro M. Congedo[c]

[a] Department of Aerospace Science and Technology, Politecnico di Milano, Via La Masa 34, 20156, Milano, Italy
[b] CNRS
[c] Platon Team, INRIA/CMAP, École Polytechnique, IPP, Route de Saclay, 91128 Palaiseau, France.

Multi-fidelity modeling methods leverage on the concatenation of data sets presenting enormous diversity in terms of information, size, and behavior. Pieces of information of diverse fidelity and complexity complement each other, leading to improved estimate accuracy. Multi-fidelity regression models bring clear advantages to the aircraft preliminary design phase, when data from computer simulations and preliminary experimental tests are exploited to define the best feasible configuration. At this stage, prediction errors i.e., the difference between a predicted parameter and its actual value after product completion and testing, should ideally not exceed a few percent.

In a multi-fidelity setting, it is fundamental to establish the correct hierarchy in terms of data credibility w.r.t. the reality of interest. Unfortunately, the complexity characterizing aerospace applications generally makes the direct estimation of data fidelity difficult, if not intractable, leaving ground to modeling biases. A resounding example is the NASA Common Research Model (CRM) [4], a wind-tunnel test devised for the purpose of validating specific applications of Computational Fluid Dynamics (CFD). In fact, the aircraft model underwent significant aeroelastic deformations during the experimental campaigns [1], thus frustrating the design efforts which target the fostering of fluid dynamic phenomena of interest for research and development e.g., flow separation.

Credits: NASA Common Research Model (CRM) test model https://commonresearchmodel.larc.nasa.gov

For the CRM case, CFD possibly outperforms wind-tunnel tests in predicting the reality of interest i.e., the aerodynamic performances of the unbent design. Surely, the establishing of any specific fidelity hierarchy among computation and wind-tunnel data is at least questionable. In other words, the Modeler's belief plays a prominent role, making the modeling approach strongly hypotheses-driven and, hence, inherently biased [2].

The current state-of-the-art offers a plethora of modeling techniques. We focus on multi-fidelity co-kriging methods which allow to surrogate a complex physical system using data from approximated models, proposing an extension of the formulation developed in [3]. The goal is to overcome possible limitations inherent the sequential construction of multi-fidelity surrogates models, developing a methodology robust to prior modeling biases concerning the alleged fidelity of the available data sets.
That is, we aim at developing an agnostic framework which is capable of recognizing the coherence of models predictions w.r.t. the reality of interest and, at the same time, capable of neglecting inaccurate, or wrong, information. It will be shown that this capability is particularly relevant whenever the Modeler does not select the appropriate ordering for the sequential construction of the multi-level surrogate. Moreover, we will show how the proposed formulation can also be exploited to obtain invaluable insights about the physics underlying the reality of interest.
Eventually, we also provide perspectives concerning the future deployment of the proposed methodology, with particular reference to Bayesian optimization methods and to the efficient construction of databases.

References

[1] Levy D. et al. *Summary of data from the fifth computational fluid dynamics drag prediction workshop*. J. of Aircraft, 51:1194–1213, 07 2014.
[2] Montáns F. J. et al. *Data-driven modeling and learning in science and engineering*. Comptes Rendus Mécanique, 347(11):845–855, 2019. Data-Based Engineering Science and Technology.
[3] Loic Le Gratiet. *Multi-fidelity Gaussian process regression for computer experiments*. Theses, Université Paris-Diderot - Paris VII, October 2013.
[4] Melissa Rivers. *Nasa common research model: A history and future plans*. 01 2019.