A data-driven uncertainty quantification framework for mechanistic epidemic models

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Abstract. Mechanistic epidemic models are frequently used to predict the evolution of infectious disease outbreaks. However, the uncertain nature of the model parameters (epidemiological parameters, initial conditions, etc.) and the limited horizon of predictability of this dynamic phenomenon make it essential to quantify the underlying uncertainties. In this sense, this work presents a cross-entropy approximate Bayesian computation framework for uncertainty quantification that is particularly interesting for use in epidemic models. The new methodology is tested with actual data from a COVID-19 outbreak, presenting a great capacity to capture the variability and dynamic evolution of the disease records.

Introduction

This work presents a data-driven framework for UQ of mechanistic epidemic models [1, 2] based on the combination of two probabilistic ingredients: (i) cross-entropy method for optimization, used to obtain a baseline calibration of the model parameters; and (ii) approximate Bayesian computation, employed to update the calibration of the parameters and propagate the uncertainties of the parameters through the dynamic model. This framework inherits the good features of the two techniques, gaining meaningful information from the epidemic data. It is tested with the aid of actual data related to the COVID-19 outbreak in Rio de Janeiro (Brazil), using an SEIR(+AHD) compartmental model (Fig. 1 left) as a predictive tool [1, 2].

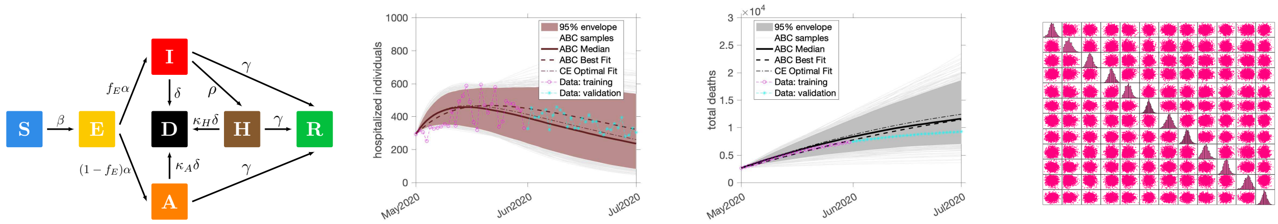

Figure 1: SEIR(+AHD) epidemic model considering susceptible, exposed, infectious, asymptomatic, hospitalized, recovered, and deceased compartments (left); evolution of the number of hospitalized individuals (center left) and total deaths (center right), with the respective 95% credible intervals and actual outbreak data; and the statistical characterization of dynamic model parameters. Further details about these results can be seen in the reference [2].

Results and discussion

The dynamic model is calibrated with epidemiological surveillance data (number of hospitalizations and deaths caused by COVID-19) for one month (1st to 31st of May 2020). Then it is used to extrapolate the behavior of these quantities of interest in a horizon of 30 days ahead, as can be seen in Fig.1 (center), which shows the evolution of these quantities of interest and the corresponding 95% credible intervals. In this effectiveness test of the data-driven UQ methodology, we can note that the quantitative forecasts are excellent in a horizon of up to two weeks, and a good qualitative agreement between data and model response prevails in the 30 days forecast horizon. Fig.1 (right) presents the statistical characterization (marginal histograms and scatter plots) of the parameters of the epidemic model. The unimodal shape of all marginal histograms indicates the effective information gain resulting from the model calibration. These results show the robustness and effectiveness of the proposed framework, which is another tool to assist in modeling epidemic outbreaks when using mechanistic mathematical models (compartmental models).

References

[1] Ritto, T. G., Cunha, Jr A., Barton, D. A. W., (2021) Parameter calibration and uncertainty quantification in an SEIR-type COVID-19 model using approximate Bayesian computation. In: *42nd Ibero-Latin-American Congress on Computational Methods in Engineering (CILAMCE, 2021)*, Rio de Janeiro.

[2] Cunha, Jr A., Barton, D. A. W. , Ritto, T. G., (2022) Uncertainty quantification in mechanistic epidemic models via cross-entropy approximate Bayesian computation, *arXiv preprint arXiv:2207.12111* https://arxiv.org/abs/2207.12111