Developing Efficient Models for Shape Optimization using Heuristic Algorithms and Machine Learning

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Introduction

- The number of tall, slender, and lightweight high-rise buildings worldwide has increased exponentially.
- The race toward new heights makes these tall buildings more sensitive to the action of wind.
- A building's shape is one of the earliest design decisions and has a decisive impact on the building's performance.
- Through an NSF recently funded collaborative project between the University of Florida and San Francisco State University, we are working to leverage wind tunnel testing, machine learning, and advanced manufacturing to advance shape optimization of high-rises.
- As development of the optimization framework is critical to the success of the project, this study focuses on evaluating the efficiency of different frameworks through a simplified application (optimization of isolated airfoils).

Methodology

- Xfoil, a program developed for the design and analysis of airfoils, is used to generate data that describes the relationship between the airfoils dimensions (thickness) and their performance (drag coefficient over lift coefficient - CD/CL).
- A polynomial interpolation model was created to enable the continuity of the data points generated by Xfoil to be fed into the algorithms.
- Two frameworks (Figs. 1 & 2) are being investigated, and the most efficient framework will be used later in the project to test the complex problem.

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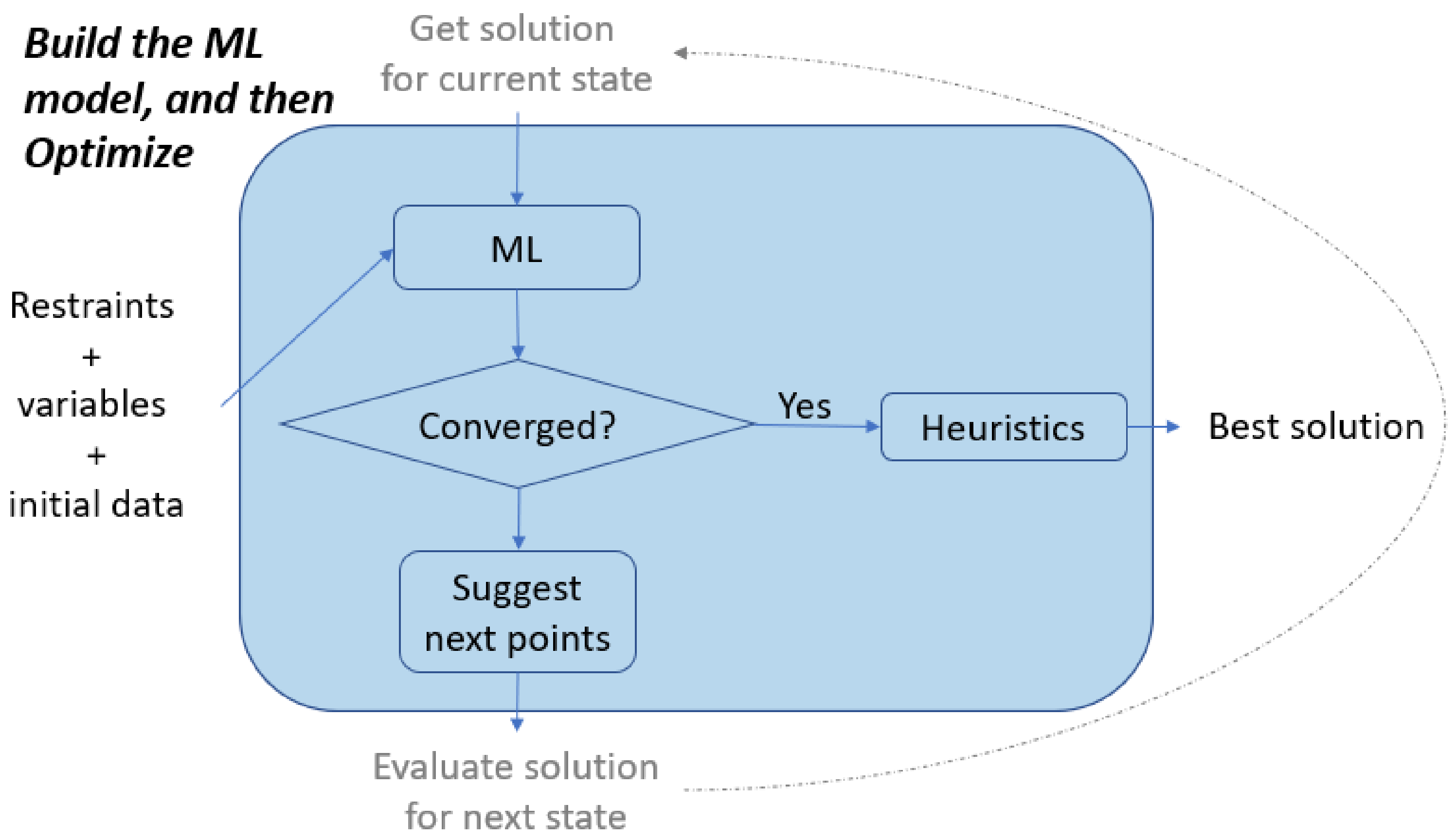
Framework Comparison

- Framework 1: Input data is fed into a machine learning model to approximate the airfoil data. Once the model converges, the results are evaluated by a heuristic algorithm to determine the best solution.
- Framework 2: Inputs are fed into the heuristic algorithm and machine learning model simultaneously. The heuristic algorithm seeks next possible candidates to try, while the machine learning model is used to evaluate the suggested candidates and filter out unrealistic ones.
- Both frameworks utilize support vector regression (SVR) as the machine learning model and a Genetic Algorithm as the heuristic algorithm.



Build the ML model, and then Optimize

Get solution for current state

Restraints + variables + initial data

ML

Converged?

Yes

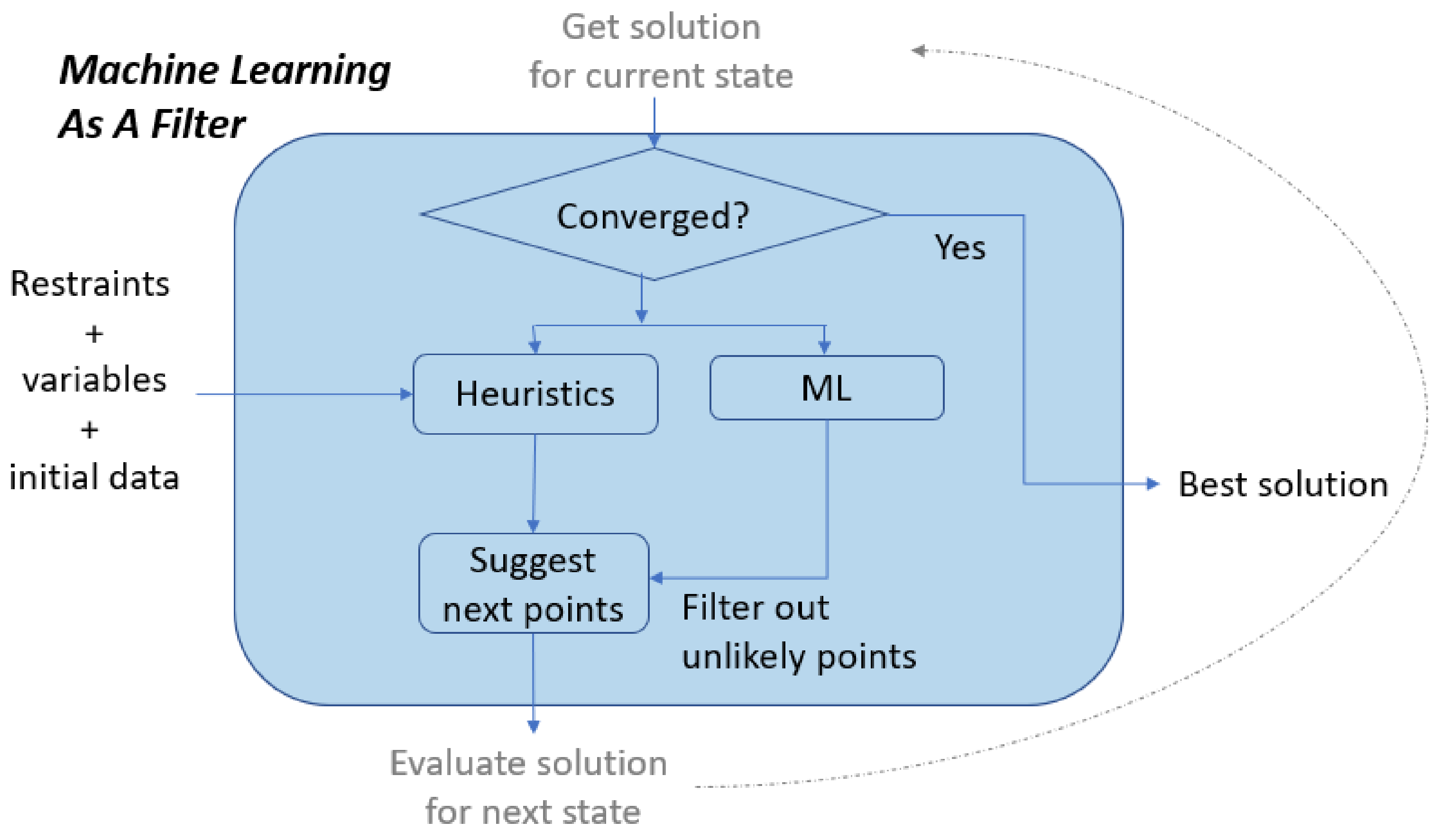
Heuristics

Best solution

Suggest next points

Evaluate solution for next state

Fig. 1: Framework 1 – Machine Learning and Heuristic Optimization as a Sequential Process



Machine Learning As A Filter

Get solution for current state

Converged?

Yes

Restraints + variables + initial data

Heuristics

ML

Best solution

Suggest next points

Filter out unlikely points

Evaluate solution for next state

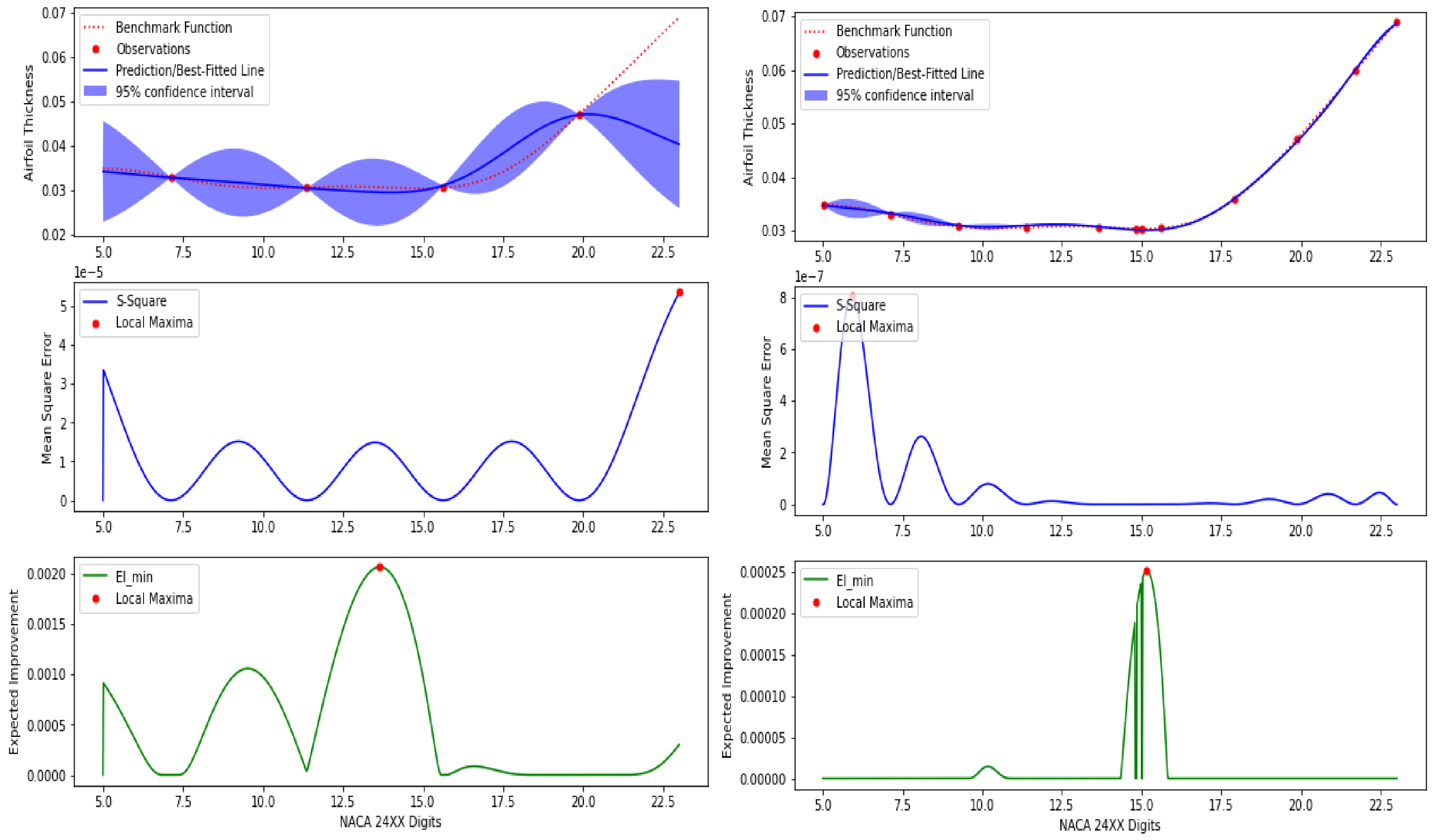
Fig. 2: Framework 2 – Machine Learning and Heuristic Optimization as a Parallel Process

Results and Discussion

- The Framework 1 model was successful established. The results showed convergence with an r^2 value > 0.99 and an explained variance value > 0.9999.
- Convergence occurred after only 5 iterations through the SVR, indicating that the model could work well with more complex data.

Table 1: Average and Optimum Airfoil Thickness after Each Generation (Framework 1)

Generation	Evaluations	Average Thickness	Optimum Thickness
1	10	0.032019677	0.029918626
2	20	0.030259716	0.029839363
3	30	0.03008729	0.029839363



Figs. 3 & 4: SVR Results for the First and Last Iteration respectively (Framework 1) - showing airfoil thickness, mean square error, and expected improvement

Conclusion

- The establishment of Framework 1 was successful with promising preliminary results. It is currently being refined to explore the possibility to include capacity of faster convergence to global optimum.
- Framework 2 is also being developed to investigate the benefits of using machine learning and heuristic algorithm in parallel to take advantage of their strength at the same time.