Supervisor Report for the MSc Thesis “Using ML to Model and Optimize Chip Geometry for Improved Lithography”

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Summary

The problem addressed in this thesis is how to choose a chip geometry that allows maximizing the number of chips produced from a given silicon wafer, while maintaining several manufacturing constraints. The proposed solution involves a number of machine learning and optimization techniques, with very promising results.

Evaluation of the Content

The solution presented here comes in two parts: first, developing a model that predicts the number of chips that can be obtained with a given geometry. Second, an optimizer uses that model to determine the best geometry.

The methods proposed are motivated by the features of the problem. Linear regression provides a standard baseline, against which more complex approaches must be measured. There is an inherent partitioning in the modelling, which can be understood by examining a related but massively simplified problem: fit the maximum number of squares of a given area L^2 on a disc, minimizing the non-covered part. Assume we have solved the problem for a given length L. Gradually decreasing L will, in the beginning, result not in more fitted squares, but in more “waste”. Only after a given point will we be able to make a gain in the number of squares we can fit on the disc (and a concomitant sudden decrease of the waste), after which decreasing L will again only produce more waste, and so on. This makes ensemble methods quite plausible, and Mr. Ahmad has focused on two of the currently more popular ones: random forests and XGBoost.

Somewhat surprisingly, a deep neural network (DNN) beats all of these approaches. It also does better than a hand-crafted analytic model based on the geometrical constraints. This has consequences for the optimization part. Since DNNs are essentially black boxes, the optimizer cannot rely on extra information such as gradient or Hessian of the objective function. This makes evolutionary approaches an attractive alternative, and Mr. Ahmad has judiciously opted for differential evolution, which is known to be competitive for problems described in terms of continuous (real-valued, as opposed to integer) variables.

The combination of DNN and differential evolution is shown to lead to very good results, offering a promising approach to the improvement of the lithography process and a starting point for further optimization.

Structure and Quality of Presentation

The introductory chapter situates the problem in the wider context of the semiconductor industry, and gives the reader an idea of the staggering costs involved, providing ample motivation for the thesis.

Chapter 2 gives the reader background information needed for a better understanding of the problem and the proposed solution. On the problem side, there is a clear presentation of the important steps in the process of lithography. On the solution side, there is a concise introduction to machine learning and optimization.

Chapter 3 is a brief review of existing approaches to the optimization of lithography processes. Chapter 4 presents the methods that were chosen to attack the problem, and Chapter 5 presents and discusses the results obtained. The thesis ends with Chapter 6, consisting of a summary of the work and a proposal for possible future directions of development.

Overall, the thesis has a clear and logical structure. The pictures and diagrams that accompany the text are well described and helpful in understanding the problem and the results. The thesis is readable and the quality of the English is very good. On the negative side, the reader is left with some unanswered questions, for example: how many layers does the DNN used for the modelling have? We are told that “[v]arious facets of the algorithm’s configuration, such as population size, mutation factor, and crossover strategy, were evaluated”, but the thesis lacks the results of this evaluation.

Collaboration with the Student

Mr. Ahmad was a pleasure to work with. He has worked largely on his own, developing the solutions in a methodical, reflective fashion. In our regular meetings, I have made a number of suggestions. Not all of them were followed, but they were all carefully considered and dispassionately discussed: I have probably learnt as much from him, as he from me.

Result

I recommend awarding the thesis the grade **1,3 (sehr gut)**.

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