

# Preface

Most applied optimization problems involve constraints: What is the maximum profit that a manufacturer can make given a limited number of machines and a limited labour force? What is the minimum amount of fuel that a fleet of trucks can consume while making a specified set of deliveries? What is the smallest amount of silicon needed to etch an electronic circuit while respecting limits on signal propagation time, inter-wire distance, etc.? Applications of constrained optimization are everywhere in industry, business, and government.

Of course, the solution returned by an optimization algorithm must also be feasible: we want the best possible value of the objective function that satisfies all constraints and variable bounds. Some optimization algorithms are not even able to proceed towards optimality until a feasible solution is available. In addition, the optimization question can be converted to a feasibility question, and vice versa. And what happens when an algorithm is unable to find a feasible solution? How do we know what went wrong? How do we repair the model? Questions of optimization, feasibility, and infeasibility are inextricably linked.

There has been a surge of important developments related to feasibility and infeasibility in optimization in the last two decades, a trend that continues to accelerate even today. New and more efficient methods for seeking feasibility in difficult optimization forms such as mixed-integer programs and nonlinear programs are emerging. The first effective algorithms for analyzing infeasible models have been discovered and implemented in commercial software. A community of researchers in constraint programming has begun to integrate their knowledge and approaches with the optimization community. Unanticipated spin-off applications of the new algorithms are being found. It's an exciting time.

The goal of this book is to summarize the state of the art in recent work at the interface of optimization and feasibility. It should serve as a useful reference for researchers, graduate students, and software developers working on optimization, feasibility, infeasibility, and related topics. Readers having a reasonable grounding in optimization (linear and nonlinear programming, mixed-integer programming, etc.) should have no difficulty following the material.

Lightweight coverage of topics in constraint programming, with an emphasis on constraint satisfaction problems, is included to illustrate the extensive overlap and convergence in the two literatures. An ideal version of the book would cover topics in constraint programming in the same depth as topics in optimization, but this is beyond the scope of this project: collecting and organizing the wealth of new developments relating to feasibility and infeasibility in optimization. I hope the resulting book is useful to both optimizers and constraint programmers, and

that it helps accelerate the ongoing merger of the two communities merge into a stronger hybrid.

## Acknowledgements

My graduate work was conducted during the late 1970s and early 1980s. Inspired by the energy crises of those times, I constructed network optimization models to minimize the use of energy in large industrial plants. Later I found the optimization modeling more interesting than the energy aspects of this work. I had noticed that some of the processing network models that I was using in the energy work suffered from an inability to carry flow in some of the arcs, a pathology later labeled *nonviability* (see Sec. 9.2). I developed algorithms to automatically identify and analyze this problem.

Enter Harvey Greenberg. At that time he was involved in a project to develop an *Intelligent Mathematical Programming System* (IMPS) (see e.g. Greenberg (1996b)), and consequently had an interest in algorithms for analyzing modeling errors of various types, such as nonviability. Harvey organized an extraordinary series of meetings on the IMPS topic for an eclectic group of researchers from academia and industry. Harvey invited me to one of these meetings and, as they say, the rest is history. Sitting in the bar one night after the IMPS meeting we had a discussion about whether or not you could isolate the cause of infeasibility in a linear program to an irreducible subset of the constraints defining the model. At the time, Harvey didn't think it could be done, but I did, so I bet him a beer that I could find a way to do so. As you will see in Part II of the book, I won that bet.

But there is a postscript to this story. I have now known Harvey for around twenty years, and we have gone on to make numerous one-beer bets on other issues in optimization. I have not won a single one of those subsequent bets, so I am currently several hundred beers in debt to him. But I have an even bigger debt than that. Harvey became my unofficial mentor, always ready to provide advice and suggestions and listen to my ideas. His influence on my work has been profound.

Harvey and Pascal Van Hentenryck both took the time to read an early draft of the book and provide advice and suggestions that greatly improved it. Both pointed out topics that should be greatly expanded upon, especially the material on constraint programming, but time is unfortunately limited, so a full treatment of that topic remains another project. And as clever as those two fellows are, I'm sure I've managed to hide a few errors in the manuscript that they did not find: those are mine alone.

Last but not least are the two incredible ladies in my life, my wife Linda and daughter Annie, who can finally look at this book and see what kept me glued to the computer for such long hours over the past year. Thanks for being there.

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