RECENT ADVANCES IN OPTIMIZATION TECHNIQUES

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Proceedings of the Symposium on
Recent Advances in Optimizations Techniques
Sponsored by the Systems Science and Cybernetics Group of the IEEE
and the
Optical Society of America
with the cooperation of
Carnegie Institute of Technology
and the
Research and Development Center, Westinghouse Electric Corporation
Held at Carnegie Institute of Technology
Pittsburgh, Pennsylvania
April 21–23, 1965

JOHN WILEY & SONS, INC.—New York London Sydney

SECOND PRINTING, APRIL, 1967

Printed in the United States of America

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OPTIMIZATION TECHNIQUES

Preface

This book is the proceedings of the Symposium on Recent Advances in Optimization Techniques held on the campus of Carnegie Institute of Technology, April 21-23, 1965. The symposium was sponsored jointly by the Systems Science and Cybernetics Group of the IEEE and the Optical Society of America.

The conference was intended to provide an opportunity to the practitioners in nonlinear optimization to exchange ideas and to gain familiarity with the concepts and methods of others in different technological areas. A principal aim of the symposium was the breaching of the nomenclature and notation barrier which tends to isolate those who are working on a specific class of problems in a specific field from their counterparts in other areas. The invited papers of Feder and Grey illustrate the terminology of optics as well as the size of the optimization problems encountered in this field. The distinctions between the terminology employed there and that of non-linear programming should be noted and not permitted to obscure the basic mathematical similarities.

In selecting the papers for the conference, priority was given to those works concerned with implementation and application to real-life problems rather than to analytical treatises. The invited papers of Howard and Luenberger are exceptions; the first illustrates a future challenge in decision-making for stochastic processes and the second the common underlying mathematical foundation for the optimization of various classes of systems using the Maximum Principle.

The proceedings includes all the papers presented and no editorial judgment should be presumed regarding the validity of the technical contents. All manuscripts were edited for reasonable consistency of style, although different notations were deliberately retained in order to familiarize the reader with the many varieties encountered in practice. This is necessary because there is no "standard" notation on which all authors could possibly agree. Finally, an index of names and subject matter was added for the benefit of the reader.

The contributed papers have been grouped into two broad categories irrespective of the order in which they were presented at the conference. The first group deals with the optimization of static systems, essentially nonlinear programming, integer programming and search techniques. The second deals with trajectory optimization, controller synthesis and performance optimization of dynamic systems with deterministic or stochastic inputs.

The editors express their gratitude to the members of the Program Committee of the symposium, Messrs. R. W. House, S. N. MacNeille, R. A. Mathias, and A. J. Perlis, who helped in formulating the program. Special thanks are due to A. K. Rigler for his efforts as Secretary-Treasurer and his other contributions before and after the conference. Thanks are also due to J. G. Brainard, A. Charnes, W. K. Linvill, H. Teager and C. Zener, the Chairmen of the Sessions, and to all the contributors and participants of the symposium who, in the last analysis, are primarily responsible for its success. Finally, our vote of thanks to Janice Ramage for her patience and diligence in typing the whole proceedings for photo-offset, making numerous corrections and finally proofreading.

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Contents

Welcome from the Optical Society of America

W. L. HYDE
Director, Institute of Optics, University of Rochester and Director at Large, American Optical Society

We are meeting in Pittsburgh today to discuss the problem of optimizing systems with many non-linear variables. I am here to greet you on behalf of the Optical Society of America, one of the sponsors of the meeting.

You may, with some justice, ask what the Optical Society has to do with this problem, and I would like to explain. To do so, let us go back to Vienna about 1840 when Josef Petzval designed the lens which still bears his name, and which was probably the first lens ever really "designed." As he laid it out in its final form, it was made of four pieces of glass. The first two were cemented together, the last two were close together but uncemented. In addition there was a diaphragm, or stop, part way between the two pairs.

From what we know today, we can tell that it was easy for him to rough out the lens so that it had certain elementary properties that he wanted: focal length, aperture, and size. But we can be sure that it also had substantial blur, and he set about reducing this blur by modifying the original design.

The design contains seven radii of curvature, eight thicknesses or spacings, and at least two kinds of glass. He probably let the lenses be "thin" and kept the last two practically in contact, thus deliberately making no use of five of his variables, and he probably had no real choice of glass, since it was only fourteen years since the death of Fraunhofer who (with Guinand) professionalized the making of crown and flint glasses. Even then he had at least ten variables at his disposal. Every time he changed one of them the focal length changed, so he had to learn to change them in pairs at least, and better yet, change several at once to make improvements. This seems to call for simultaneous equations.

One of the disadvantages of "thin" lenses, he quickly found out, was that they easily become too thin and either the center thickness vanishes, or the edge vanishes and there is nothing to get hold of, so when the solutions of the simultaneous equations finally appear, they are likely to be most unpalatable.

I suspect he solved his problem in a way which is still common today, if not exactly popular. He defined the "optimum solution" as the best one you have achieved when the money runs out.

I can picture the day the job ended. Petzval was Professor at the Military College and had probably arranged for some computational help and went to report to his boss how the job was going.

"I've got the boys organized now, and the cost per multiplication is down to 10^{-1} groschen," says Petzval.

"How many multiplications?" queries the boss.

"Well, errrrr, about 10^6," replies Professor Petzval.

"Mein Gott," says the boss, "That means you've spent 10^5 groschen or 10^3 schillings. How much was in the budget when we started?"

I will draw a curtain over the rest of this unpleasant interview, but ever since then, Austrians have said, "If you have a Hungarian friend, you don't need an enemy." I suspect that they are talking about Petzval, for he was an Hungarian, but more basic, he was a lens designer, a class of men who deserve our sympathy.

The lens that resulted from this exercise was produced by Voigtlander and was so successful that both the firm and the lens have survived until today, and so has the problem of the optimum lens.

Lens design has a big advantage (or disadvantage, depending on your point of view): you can calculate before manufacturing exactly how good the lens is going to be. The designer cannot blame his result on uncontrollable variables. This healthy fact means that lens designers have had to face their task with responsibility for more than a hundred years, searching to find the best answer possible. Maybe after this conference, they will be able to say, at least, that they know how. At the same time, they may have something to tell the rest of you.

It is for this reason that the Optical Society of America is supporting the meeting, and that I have the pleasure of bringing the greetings of the Society.

Lens Design Viewed as an Optimization Process

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I. EVALUATING A LENS DESIGN

The usual procedure for the numerical evaluation of a lens design is known as ray-tracing. A set of selected rays are traced from points on the object through the lens to the image plane. Each ray is traced individually by a set of recursion formulae shown below. In what follows, suppose that the lens consists of a set of spherical surfaces centered around a common optical axis. This will simplify the discussion without impairing the generality of the optimization procedure. See Fig. 1.

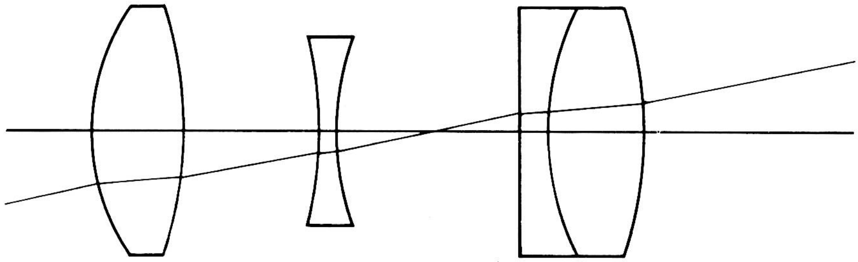

Fig. 1. Shows a typical lens and a sample ray traced from object plane to image plane. The path of the ray in each medium is a straight line.