EDGE DETECTION AND GEOMETRIC METHODS IN COMPUTER VISION (DIFFERENTIAL TOPOLOGY, PERCEPTION, ARTIFICIAL INTELLIGENCE, LOW-LEVEL)

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DEGREE DATE: 1984

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Blicher, Albert Peter

EDGE DETECTION AND GEOMETRIC METHODS IN COMPUTER VISION

University of California, Berkeley PH.D. 1984

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Edge Detection and Geometric Methods in Computer Vision

By

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DISSERTATION

Submitted in partial satisfaction of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

Mathematics

in the

GRADUATE DIVISION

OF THE

UNIVERSITY OF CALIFORNIA, BERKELEY

Approved: .... 11-12-84...
~~Co~~- Chairman Date
.... 11-12-84
co-Chairman
.... 11-12-84..
.... 11-13-84

DOCTORAL DEGREE CONFERRED
DECEMBER 18, 1984
....

Edge Detection and Geometric Methods in Computer Vision

by

A. Peter Blicher

Edge Detection and Geometric Methods in Computer Vision

A. Peter Blicher

Abstract

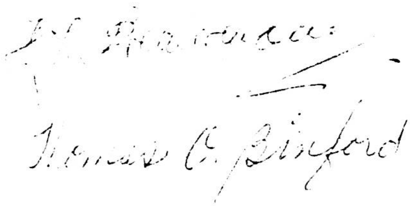
Basic problems of vision are studied from the viewpoint of modern differential topology and geometry; primarily: edge detection, stereo matching, picture representation at multiple scales, and motion. Some mathematical background is provided for the non-expert.

A comprehensive review of edge detection is presented, including analyses from a mathematical perspective as well as evaluations of practical performance and promise.

Some new edge detection techniques are introduced, including a nonlinear operator based on a symmetry principle, a variational approach to global edge finding, and a least-squares localization method. A theorem is proved which shows that localizing edge position and orientation requires at least 2 orientation dependent families of convolution operators.

A unifying mathematical structure is presented for vision, notably stereo, motion stereo, optic flow (apparent flow of visual space under motion), and matching. The general matching problem is analyzed, and it is proved that generically, general matching is highly degenerate for monochrome pictures, but has a unique solution for 2 or more color dimensions. The result is extended to pictures with unknown bias and gain. Smale diagrams and level set topology are introduced as invariants useful for matching, reducing the problem to graph or tree matching. The level set topology tree is also proposed as a method of multi-scale description of the picture, and shown to be an invariant generalization of the "scale space" technique.

The motion problem is analyzed using Lie group methods, and a theorem is proved establishing that generically 6 simultaneous values of time derivative of the monochrome picture function are necessary and sufficient to uniquely specify the 3-dimensional rigid motion of a generic given object. For 2 or more color dimensions, this is reduced to values at 3 points in the picture.



Acknowledgments

Through the period of this work, my parents have been my greatest asset, not only by their love and sacrifice, but in many, many ways.

I am grateful to my advisers, Prof. Tom Binford and Prof. Hans Bremermann, for their unflagging support and encouragement. Tom Binford generously provided the financial support and facilities which made this work possible. Hans Bremermann's kindness and helpfulness continued unabated throughout a long and rocky trek. Stephen Omohundro has helped immensely with many discussions. Lynn Hall patiently and selflessly made this effort possible for me. Dr. Harlyn Baker aided me in manifold ways. Dr. Anni Bruss, Dr. Dick Gabriel, David Marimont, Dr. David Lowe, Dr. Hans Moravec, Prof. Rod Brooks, Dr. Oussama Khatib, Allan Miller, Michael Lowry, and Sathya Narayanan have all been generous with their help, advice, and friendship. Dr. Eric Berger and Prof. Morris Hirsch gave me expert mathematical advice.

The Stanford computer science community, always generous, helpful, encouraging, and pleasant, far beyond the norm, have my heartfelt gratitude for magically transforming difficulties into pleasures. Betty Scott, Len Bosack, Ralph Gorin, Marty Frost, Marlie Yearwood, Amy Atkinson, Don Coates, Lynn Gotelli, Harry Llull, Richard Manuck, Les Earnest, and Patte Wood have all been kind far above the call of duty. Prof. John McCarthy is, if not the father, then the midwife of this environment I have enjoyed.

I am indebted to Dr. Lee Nackman of the IBM T.J. Watson Research Center for bringing the work of Koenderink and van Doorn of Utrecht to my attention.

This document was typeset using TEX, and therefore owes a debt to Prof. Donald Knuth, who with TEX has elevated the art of writing to the art of computer programming.

Arthur Keller, Dave Fuchs, and Prof. Knuth provided expert help with TEX in numerous times of need.

For leading me to this research, I must also thank the professors of engineering who taught me that the key to engineering is understanding physics; the professors of physics who taught me that the key to physics is understanding mathematics; and the professors of mathematics who taught me that mathematics has nothing to do with the material world.

This work was partially supported by ARPA contracts MDA903-80-C-0102 and N00039-82-C-0250.

Preface

I wrote this work for an audience of both vision workers and mathematicians. There are many people who could be counted in both groups, but the full intended audience has a wide spectrum of backgrounds. Among vision workers, I include students of biological vision, but it is artificial vision that I am directly addressing. It is widely appreciated that there are many common problems, but I haven't written about any specifically *biological* problems, such as explaining the function of some cell population. My hope is not only to communicate research results, but to convince readers in each of these fields that there is something of interest to them in the other. Many people have a bad taste from previous experience with touters of fancy mathematics in these concrete situations, with elixirs which turned out to be oversold or plain irrelevant. Mathematics is not magic; using it doesn't melt all impediments into triviality. It merely provides a structure for understanding, and an apparatus for resolving questions. *If* the questions are the right grist for the mill. Attracting these fields to each other isn't necessarily easy.

Also, it poses a problem in writing; since I have tried to keep the material accessible to the novice, some of it must necessarily be old hat to the expert, so I apologize to the expert whom I have subjected to the obvious. I have tried to make this work reasonably self-contained, including various standard definitions and results from differential topology and geometry. When these are not in the main line of thought, they have been relegated to fine print, so they can be easily skipped by those who already have the necessary background. Sometimes, standard terms are used before they are defined, and sometimes they are defined twice, partially from a lack of organization, but primarily to locate the mathematical digressions where they are most important, and avoid bogging things down where they are not. I haven't tried to be exhaustive in this, or I would have been obliged to include a complete introduction to differential topology and geometry, something which has already been accomplished with great skill by others. The chapter Geometric Methods in Vision makes the heaviest use of abstract mathematics; therefore I have put most mathematical background material into the fine print of that chapter. Since I have assumed some of that background material in earlier chapters, the reader may find it useful to glance through it to clarify the unfamiliar, such as the implicit function theorem, or functional notation.

The 3 major chapters (A Survey of Edge Detection, Contributions to Edge Detection, and Geometric Methods in Vision) are largely independent, and can be read in any order, or in isolation. The survey has many discussions which go beyond summarizing, and should be of interest to readers who are already familiar with the literature, as well as to newcomers. The contributions chapter is probably of most interest to specialists, while the geometry chapter is likely to appeal to the more mathematically inclined.

Stanford, California

October, 1984

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