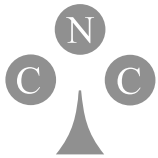
Natural Computing Series



Gustavo Olague

Evolutionary Computer Vision

The First Footprints

Springer

Gustavo Olague
EvoVisión Research Team
CICESE Research Center
Ensenada, Baja California, Mexico

ISSN 1619-7127
Natural Computing Series
ISBN 978-3-662-43692-9 ISBN 978-3-662-43693-6 (eBook)
DOI 10.1007/978-3-662-43693-6

Library of Congress Control Number: 2016954088

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer-Verlag GmbH Berlin Heidelberg
The registered company address is: Heidelberger Platz 3, 14197 Berlin, Germany

With my fondest devotion to my beloved and wonderful son, Matthieu, who is the light of my life.

Dear Carméla, you came into my life like a magical book full of surprises and joy. In this quest I discovered the ways of love, the sunflower faces the sun and the shadows fall behind it, letting me know the importance of always selecting the path towards enlightenment. One makes the possible and God makes the impossible. These two things, attitude and faith, are fundamental in the search for happiness. The book is meant to write down memories inside your heart. All sorts of thoughts can be selected to take you to a state of enjoyment. Well here is our book and there are already a lot of things in it and it is not yet full. Beyond these, you will find my gratitude and love that I have for you.

Foreword

Computer vision is to understand computational models of human perception. A mathematical building of vision is still daunting since an exact discourse about processing and representations of visual information in nature remains elusive. Evolutionary Computer Vision (ECV) has appeared as one of the methodologies that can challenge computer vision problems and has produced excellent results. This book by Gustavo Olague is a first attempt to unify computer vision and evolutionary computing.

Gustavo is a leading pioneer and outstanding researcher in computer vision and evolutionary computing. He first presents an historical account of computer vision as an introduction to understanding the relationship with evolutionary computing. Then, the mathematical foundations of optimization are provided together with key computational algorithms that are used in the book, as well as a comprehensible description of those commonly applied in the scientific literature. The introductory chapters explain fundamental concepts and prepare the reader for the journey from ideas to algorithms. More importantly, the book gives a detailed account of impressive results through actual working programs in the three major fields of low-, intermediate- and high-level computer vision. The success is due to the interdisciplinary efforts of Gustavo and his collaborators in the last decade. Multiple examples are given to outline an innovative methodology that combines mathematical optimization concepts under the general framework of adaptation to reach the goal of solving the task at hand.

Needless to say, the proposed methodology has been widely recognized at international forums of academic journals, conferences and competitions. The book is written in a concise and complete manner; readers will not only learn the state of the art of this new field of study, but also will discover the philosophy and theory advocated by Gustavo. It will guide you through a new interdisciplinary field where the 3D modeling of computer vision is achieved using theoretical methods with elegant mathematics to applications with exciting intellectual results.

Clear Water Bay, Hong Kong, May 2013 *Long Quan*

Foreword

Evolutionary Computer Vision (ECV) is considered nowadays as a new research methodology where the study of artificial vision meets evolutionary algorithms. The field of evolutionary computing deals with difficult continuous and combinatorial optimization problems where the usefulness of the Darwinian principles of variation and natural selection are of paramount importance as we attempt to apply them to solve challenging real-world problems, such as those that arise in computer vision.

This superb book written by Gustavo Olague, a leading researcher in evolutionary computing and computer vision, represents pioneering work where the principles of mathematical optimization are merged with the paradigm of artificial evolution in an original and productive way. Here, the reader will discover the history of this new research area, as well as the philosophies and theories described by biologists, mathematicians and engineers that have been useful in the achievement of great technological breakthroughs. Indeed, ECV represents a new interdisciplinary research area where analytical methods are combined with powerful stochastic optimization and meta-heuristic approaches. After two introductory chapters the reader will find numerous examples in the areas of low-, intermediate- and high-level vision, where the definition of the goals together with computational structures are the two necessary elements useful in the emergence of optimal solutions. According to Gustavo the ultimate goal of ECV is the creation of machines that exhibit the ability to observe the world around them. This may not be around the corner yet but the present work will certainly contribute toward this goal. In this way, the link between the two methodologies, analysis and synthesis, represents the key to finding the proper definition of the criteria that will be used at the time of solving a difficult visual task. Indeed, the methodology proposed includes strong epistemological and ontological arguments related to the definition of the goals that a robot vision system should confront in the search for truly autonomous behaviors. In this respect, the book goes well beyond a merely technical approach and offers wholly new perspectives on current and future computer vision work.

In summary, the methodology outlined in this book has achieved impressive results through actual working programs. In particular, this work will guide the reader through a new interdisciplinary field where he or she will learn not only to consider how to solve a given problem but also the implications of defining the aims in the context of truly intelligent agents. In other words, he or she will take a step towards the answer to the question: What is the visual task for?

Lausanne, Switzerland, May 2013 *Marco Tomassini*

Preface

The seeds for this book were first planted in 2008 during a conversation with Ronan Nugent, who invited me to publish a monograph about my research subject, which I had started to name Evolutionary Computer Vision together with my friends Stefano Cagnoni and Evelyne Lutton. At that time we had published two special issues on this subject in the *Pattern Recognition Letters* and *Evolutionary Computation* journals, as well as edited a book on a related subject. The goal of the book was to provide an introductory textbook for engineers and researchers on a challenging subject at the forefront of two great research domains.

Genetic and Evolutionary Computation (GEC) is a research field in computer science which deals with optimization techniques and adaptive systems inspired by the rules of natural evolution. One of its goals is to endow computers and robots with information processing abilities comparable to those found in nature. The general applicability of its methods makes it possible to use GEC to solve problems in a large number of application domains. In particular, GEC methods can be applied effectively to those research domains whose tasks require robust and flexible techniques in real-world scenarios. Among those domains, computer vision represents a very challenging problem for its complexity, which is still daunting to experienced researchers. Indeed, computer vision offers open problems such as identifying patterns, understanding sense data, taking appropriate actions, emulating human-like perception capabilities in a robot or computer, and learning from experience, to mention but a few.

This book takes the opportunity to review both challenging research areas with the aim of providing a reliable source for engineers and scientists, with detailed examples mainly developed within my research project in Ensenada. Computer vision is steadily gaining relevance within the evolutionary computation community since GEC techniques are capable of exploring huge search spaces effectively, searching for and often finding solutions that lie far away from the rather limited region spanned by more traditional, hand-coded ones, and providing top-notch results. This last point should be accomplished with a carefully designed evaluation function and problem representation. These two main aspects are in accordance with the long tradition of mathematical optimization, in which case, in our experience, bioinspired techniques can achieve the desired emergent visual behavior.

The application of evolutionary computing in computer vision tasks requires knowledge of the application domain and abstraction of the studied problem in terms of evolvable structures through the selection of appropriate representations. Therefore, the effective design of an evolutionary system needs to answer ques-

tions related to what is being evolved or the selection of a suitable representation, which in turn is related to the mechanisms by which evolution takes place, in other words, selection of a suitable evolutionary algorithm. Also, it needs to answer how an evolved structure can be evaluated through the definition of a fitness function. The solutions being evolved by GEC techniques should be compared with those currently embedded in well-known vision systems in order to substitute them or hybridize them with the original features that have emerged with artificial evolution. This approach to the design of vision systems seems to be on its way to being accepted as a standard technique in computer vision research. We hope and expect that this monograph can enhance and speed up this process, which is already leading to wider acceptance of Evolutionary Computer Vision techniques within the computer vision and evolutionary computing communities.

This book is suitable as an introductory course at the senior undergraduate and graduate levels in computer vision and evolutionary computing for students of computer science, electrical and electronics engineering, and applied mathematics. I recommend students to take either an image processing or a computer graphics course, as well as a mathematical optimization course as a prerequisite so that they can spend less time learning general background mathematics and more time studying the book. The first three chapters are especially important since they explain the relevant information for our approach to Evolutionary Computer Vision. The following chapters are divided into three main parts with the goals of providing examples for feature detection and recognition, planning for optimal 3D reconstruction, and visual learning with results of actual working programs.

In teaching my courses, I found it useful for students to encourage and promote the practice of the philosophy of science since our research subject is at the frontier of concepts that do not yet have a definite definition, in particular our two main subjects: vision and evolution. Also, I often ask students to work with real-world images and require them to practice with algorithms and mathematical models and challenge them to present a final project conducted in small groups. Since this is a new research area and the book is mainly about my own research project, I urge all interested readers (students, researchers and instructors) to practice the wonderful task of reading.

Ensenada, January 2016 *Gustavo Olague*

Acknowledgements

First of all, I would like to express my gratitude to all the people whose passion for research and inquiry as well as encouragement have helped me write this book.

Marco A. Clemente, my M.S. thesis advisor at Instituto Tecnológico de Chihuahua, taught me the essentials of writing and presentation. Moreover, he was truly a good friend who helped me at crucial moments of my life. Also, I would like to warmly acknowledge my family in México, USA and France for all their love and support during all these years.

Roger Mohr, my Ph.D. supervisor, first introduced me to computer vision at Institut National Polytechnique de Grenoble (INPG) in Felix Viallet, and later at Institut National de Recherche en Informatique et Automatique (INRIA) Grenoble Rhône-Alpes in Montbonnot Saint-Martin. He taught me the fundamentals of good research as well as to question and debate research results and techniques and encouraged me in my journey towards a rewarding graduate career in what became the subject of this book. The rich environment provided within the MOVI research team gave me new perspectives on innovative approaches to computer vision; since it was filled with some of the world's best researchers in computer vision. Thus, during all those years I enjoyed the company of excellent researchers like Long Quan, Radu Horaud, Patrick Gros, Richard Hartley, Hervé Mathieu, and many students who are now recognized researchers: Peter Sturm, Cordelia Schmid, Bill Triggs, Bart Lamiroy, Riad Hammoud, ZhongDan Lan, Sylvaine Picard, Maxime Lhuillier, Yves Dufournaud, Andreas Ruf, David Demirdjian, Adrien Bartoli, and Jérôme Blanc. They fired up my interest in photogrammetry and computer vision.

At the Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE) in Ensenada, Baja California, I founded a research project on Evolutionary Computer Vision on January 15, 1999. I was fortunate to start my research job in an environment where I felt free to direct my research goals. While working at CICESE I had the opportunity to apply for research grants that helped me collaborate with many European researchers, mainly in the evolutionary computation domain, such as Marc Schoenauer, who read my Ph.D. thesis, Francisco Fernández de Vega, Evelyne Lutton, and Stefano Cagnoni. Thus, during my first years at CICESE, my first publications were directly related to my work in France.

I had the fortune of being a recipient of the Talbert Abrams Award offered by the American Society for Photogrammetry and Remote Sensing in May 2003. I would like to express my sincere gratitude to Clive Fraser, Wolfgang Förstner and Scott Mason, who were inspirational during those research years.

Also, I would like to remember all the students I have had the privilege of advising, supervising and interacting with, including Leonardo Trujillo, Eddie Clemente, Cesar Puente, Enrique Dunn, León Dozal, Benjamín Hernández, Cynthia Pérez, Blanca Lorena Villareal, and Daniel Hernández.

I would like to extend thanks to my colleagues Jose Luis Gordillo, Juan-Manuel Ahuactzin, Humberto Sossa and Enrique Sucar, for their interest and help during all these research years.

A special debt of gratitude is owed to Ronan Nugent for his unflagging support as editor in computer science at Springer. He has been very patient during the years since this book was first planned.

Contents

Part IV 3D Computer Vision

Acronyms

Next you will find a list of abbreviations used within the book.

ACO	Ant Colony Optimization
Alife	Artificial Life
CA	Cellular Automata
CCD	Charge-coupled Device
CGP	Coevolutionary Genetic Programming
CUF	Corner Unit Function
CV	Computer Vision
DE	Differential Evolution
DoG	Difference of Gaussians
EC	Evolutionary Computing/Evolutionary Computation
E-CAD	Evolutionary Computer Aided Design
ECV	Evolutionary Computer Vision
EP	Evolutionary Programming
EPOCA	Evolving Positions of Cameras
ES	Evolution Strategies
FOD	First-order Design
IPGP	Interest Point operator with Genetic Programming
GA	Genetic Algorithm
GIN	Gaussian Intensity Neighborhood
GLCM	Gray Level Co-occurrence Matrix
GLOH	Gradient Location and Orientation Histogram
GP	Genetic Programming
GPLAB	Genetic Programming toolbox for MATLAB
HGA	Hierarchical Genetic Algorithms
LGP	Linear Genetic Programming
MCDM	Multicriteria Decision Making
MMIP	Man-made Interest Point
MOEA	Multi-objective Evolutionary Algorithm
MO-GP	Multi-objective Genetic Programming
MOP	Multi-objective Parameterized
MOPD	Multi-objective Problem Design
NSGA	Non-dominated Sorting Genetic Algorithm
PCA	Principal Component Analysis
PESA	Pareto Envelope-based Selection Algorithm

PHOG	Pyramid Histogram of Gradient Orientation
PND	Photogrammetric Network Design
PSO	Particle Swarm Optimization
RDGP	Region Descriptor operator with Genetic Programming
RIFT	Rotation Invariant Feature Transform
ROC	Receiver Operating Characteristic
ROI	Region of Interest
SBX	Simulated Binary Crossover
SIFT	Scale Invariant Feature Transform
SO-GP	Single Objective Genetic Programming
SOD	Second Order Design
SPEA	Strength Pareto Evolutionary Algorithm
SURF	Speed Up Robust Feature
SVM	Support Vector Machine
URTF	Unit Retro-reflective Target Function
USEF	Unit Step Edge Function
VXL	Vision-*Something*-Libraries
ZOD	Zero Order Design