



# Studies in Computational Intelligence, Volume 86

Editor-in-chief

Prof. Janusz Kacprzyk

Systems Research Institute

Polish Academy of Sciences

ul. Newelska 6

01-447 Warsaw

Poland

E-mail: kacprzyk@ibspan.waw.pl

---

Further volumes of this series can be found on our homepage: [springer.com](http://springer.com)

Vol. 62. Lakhmi C. Jain, Raymond A. Tedman and Debra K. Tedman (Eds.)  
*Evolution of Teaching and Learning Paradigms in Intelligent Environment*, 2007  
ISBN 978-3-540-71973-1

Vol. 63. Włodzisław Duch and Jacek Mańdziuk (Eds.)  
*Challenges for Computational Intelligence*, 2007  
ISBN 978-3-540-71983-0

Vol. 64. Lorenzo Magnani and Ping Li (Eds.)  
*Model-Based Reasoning in Science, Technology, and Medicine*, 2007  
ISBN 978-3-540-71985-4

Vol. 65. S. Vaidya, L.C. Jain and H. Yoshida (Eds.)  
*Advanced Computational Intelligence Paradigms in Healthcare-2*, 2007  
ISBN 978-3-540-72374-5

Vol. 66. Lakhmi C. Jain, Vasile Palade and Dipti Srinivasan (Eds.)  
*Advances in Evolutionary Computing for System Design*, 2007  
ISBN 978-3-540-72376-9

Vol. 67. Vassilis G. Kaburlasos and Gerhard X. Ritter (Eds.)  
*Computational Intelligence Based on Lattice Theory*, 2007  
ISBN 978-3-540-72686-9

Vol. 68. Cipriano Galindo, Juan-Antonio Fernández-Madrigal and Javier Gonzalez  
*A Multi-Hierarchical Symbolic Model of the Environment for Improving Mobile Robot Operation*, 2007  
ISBN 978-3-540-72688-3

Vol. 69. Falko Dressler and Iacopo Carreras (Eds.)  
*Advances in Biologically Inspired Information Systems: Models, Methods, and Tools*, 2007  
ISBN 978-3-540-72692-0

Vol. 70. Javaan Singh Chahl, Lakhmi C. Jain, Akiko Mizutani and Mika Sato-Ilic (Eds.)  
*Innovations in Intelligent Machines-1*, 2007  
ISBN 978-3-540-72695-1

Vol. 71. Norio Baba, Lakhmi C. Jain and Hisashi Handa (Eds.)  
*Advanced Intelligent Paradigms in Computer Games*, 2007  
ISBN 978-3-540-72704-0

Vol. 72. Raymond S.T. Lee and Vincenzo Loia (Eds.)  
*Computation Intelligence for Agent-based Systems*, 2007  
ISBN 978-3-540-73175-7

Vol. 73. Petra Perner (Ed.)  
*Case-Based Reasoning on Images and Signals*, 2008  
ISBN 978-3-540-73178-8

Vol. 74. Robert Schaefer  
*Foundation of Global Genetic Optimization*, 2007  
ISBN 978-3-540-73191-7

Vol. 75. Crina Grosan, Ajith Abraham and Hisao Ishibuchi (Eds.)  
*Hybrid Evolutionary Algorithms*, 2007  
ISBN 978-3-540-73296-9

Vol. 76. Subhas Chandra Mukhopadhyay and Gourab Sen Gupta (Eds.)  
*Autonomous Robots and Agents*, 2007  
ISBN 978-3-540-73423-9

Vol. 77. Barbara Hammer and Pascal Hitzler (Eds.)  
*Perspectives of Neural-Symbolic Integration*, 2007  
ISBN 978-3-540-73953-1

Vol. 78. Costin Badica and Marcin Paprzycki (Eds.)  
*Intelligent and Distributed Computing*, 2008  
ISBN 978-3-540-74929-5

Vol. 79. Xing Cai and T.-C. Jim Yeh (Eds.)  
*Quantitative Information Fusion for Hydrological Sciences*, 2008  
ISBN 978-3-540-75383-4

Vol. 80. Joachim Diederich  
*Rule Extraction from Support Vector Machines*, 2008  
ISBN 978-3-540-75389-6

Vol. 81. K. Sridharan  
*Robotic Exploration and Landmark Determination*, 2008  
ISBN 978-3-540-75393-3

Vol. 82. Ajith Abraham, Crina Grosan and Witold Pedrycz (Eds.)  
*Engineering Evolutionary Intelligent Systems*, 2008  
ISBN 978-3-540-75395-7

Vol. 83. Bhanu Prasad and S.R.M. Prasanna (Eds.)  
*Speech, Audio, Image and Biomedical Signal Processing using Neural Networks*, 2008  
ISBN 978-3-540-75397-1

Vol. 84. Marek R. Ogiera and Ryszard Tadeusiewicz  
*Modern Computational Intelligence Methods for the Interpretation of Medical Images*, 2008  
ISBN 978-3-540-75399-5

Vol. 85. Arpad Kelemen, Ajith Abraham and Yulan Liang (Eds.)  
*Computational Intelligence in Medical Informatics*, 2008  
ISBN 978-3-540-75766-5

Zbigniew Les  
Magdalena Les

# Shape Understanding System

The First Steps toward the Visual  
Thinking Machines

With 330 Figures

 Springer

Professor Zbigniew Les  
The Queen Jadwiga Research  
Institute of Understanding  
P.O. Box 654  
Toorak, Victoria 3142  
Australia  
zles@qjfpl.org

Magdalena Les  
The Queen Jadwiga Research  
Institute of Understanding  
P.O. Box 654  
Toorak, Victoria 3142  
Australia  
zles@qjfpl.org

ISBN 978-3-540-75768-9

e-ISBN 978-3-540-75769-6

Studies in Computational Intelligence ISSN 1860-949X

Library of Congress Control Number: 2007938883

© 2008 Springer-Verlag Berlin Heidelberg

This work is subject to copyright. All rights are reserved, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilm or in any other way, and storage in data banks. Duplication of this publication or parts thereof is permitted only under the provisions of the German Copyright Law of September 9, 1965, in its current version, and permission for use must always be obtained from Springer-Verlag. Violations are liable to prosecution under the German Copyright Law.

The use of general descriptive names, registered names, trademarks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

Cover design: Deblik, Berlin, Germany

Printed on acid-free paper

9 8 7 6 5 4 3 2 1

springer.com

This book is dedicated to our Patron St. Jadwiga Queen of Poland

# Contents

<b>Preface .....</b>	<b>xi</b>
<b>1. Thinking, Visual Thinking and Shape Understanding.....</b>	<b>1</b>
1.1. Introduction .....	1
1.2. Shape and Form .....	4
1.3. Understanding.....	9
1.3.1. Cognition .....	13
1.3.2. Visual Perception .....	14
1.3.3. Visual Intelligence .....	16
1.3.4. Knowledge .....	17
1.3.5. Learning .....	22
1.3.6. Reasoning.....	24
1.3.7. Recognition .....	26
1.4. Thinking.....	26
1.5. Shape Understanding System .....	34
<b>2. Shape Classes.....</b>	<b>47</b>
2.1. Possible Classes of Shape .....	47
2.1.1. General Classes: A Priori Classes .....	48
2.1.1.1. Convex Classes .....	50
2.1.1.1.1. Convex Polygon Class and Its Subclasses .....	50
2.1.1.1.2. Convex Curve-Polygon Class and Its Subclasses .....	52
2.1.1.1.3. Convex Curve Class and Its Subclasses .....	54
2.1.1.2. Concave Classes.....	57
2.1.1.2.1. Levels of Iterations.....	58
2.1.1.2.2. Concave Polygon Class.....	61
2.1.1.2.3. Concave Curve-Polygon Class.....	64
2.1.1.3. Thin Classes .....	66
2.1.1.4. Cyclic Class .....	72
2.1.1.5. Complex Cyclic Class.....	74

2.1.1.6. Cyclic Thin Class: The G-Class.....	75
2.1.1.6.1. Convex Cyclic Thin G-Class.....	77
2.1.1.6.2. Concave Cyclic Thin G-Class.....	78
2.1.1.7. Colored Classes.....	79
2.1.2. The a Posteriori Classes.....	80
2.1.2.1. The Star Class.....	81
2.1.2.2. The Spade Class.....	84
2.1.2.3. The Letter Class.....	89
2.1.3. String Form: Type of the Class.....	93
2.1.4. Generalization.....	96
<b>3. Digital Objects, Image Transformations, and Reasoning</b>	
<b>Process.....</b>	<b>101</b>
3.1. Digital Image Representation.....	101
3.2. Processing Methods: Image Transformations.....	102
3.2.1. Image Transformation and the Visibility Measure.....	103
3.3. Reasoning Process.....	105
3.3.1. Convex Object: Reasoning Process.....	107
3.3.2. Concave Polygon Object: Reasoning Process.....	121
3.3.3. Thin Object: Reasoning Processes.....	125
3.3.4. Cyclic Object: Reasoning Process.....	132
<b>4. Categories.....</b>	<b>135</b>
4.1. Introduction.....	135
4.2. Category of Visual Objects.....	139
4.2.1. Perceptual Categories.....	141
4.2.2. Structural Categories.....	143
4.2.2.1. Element Category.....	143
4.2.2.2. Pattern Category.....	146
4.2.2.3. Picture Category.....	149
4.2.2.4. Category of Animation.....	153
4.2.3. Ontological Categories.....	153
4.2.3.1. Interpretation of the Visual Object.....	154
4.2.3.2. Dependence Among Ontological Categories.....	157
4.2.3.3. Figure Category.....	163
4.2.3.3.1. Polygon Category.....	164
4.2.3.3.2. Category of Curves.....	166
4.2.3.3.3. Category of Curve-Polygon Figures.....	168
4.2.3.3.4. Category of Mathematical Objects.....	168
Category of 2D Mathematical Objects.....	168
Category of 3D Figures.....	175
Category of Mathematical Coordinate Systems.....	175

---

4.2.3.3.5. Category of Statistical Objects.....	177
4.2.3.3.6. Category of Visual Physical Models.....	180
4.2.3.4. Category of Signs.....	182
4.2.3.4.1. Category of Visual Symbols .....	183
Category of Mathematical Symbols .....	184
Category of Musical Symbols .....	186
Category of Engineering Symbols.....	187
4.2.3.4.2. Category of Symbolic Signs.....	190
4.2.3.5. Category of Letters .....	193
4.2.3.6. Category of Real-World Objects.....	196
4.2.3.6.1. Categories of Macro- and Micro-Objects.....	204
4.2.3.6.2. Category of Earthy-World Objects .....	205
Category of Non-Living Objects .....	206
Category of Living Objects .....	213
Category of Animals.....	214
Category of Plants .....	217
4.2.3.7. Category of Imaginary Objects .....	223
4.2.3.8. Category of Real-World Processes .....	224
4.2.3.9. Category of Visual Tests .....	228
4.3. Categorical Learning.....	234
<b>5. Visual Thinking: Understanding.....</b>	<b>241</b>
5.1. Understanding in the Context of Shape	
Understanding System .....	241
5.2. Thinking and Visual Thinking.....	245
5.3. Visual Thinking as a Problem Solving Process.....	247
5.4. Problem Solving .....	251
5.4.1. Problems Given in the Form of the Symbolic	
Representations .....	255
5.4.2. Problem Given in the Form of Both Symbolic	
and Visual Representations .....	258
5.4.3. Problem Given in the Form of the Visual	
Representation.....	260
5.4.3.1. Performing Task Given by the User .....	260
5.5. Visual Thinking as a Problem Solving .....	267
5.5.1. Perception: Problem Solving .....	267
5.5.2. Naming and Recognition of the Different	
Categories of Objects.....	278
5.5.2.1. Figure Naming: Assigning	
the Name to the Figure.....	280
5.5.2.1.1. Naming of the Figure Without Name.....	281
5.5.2.1.2. Naming of the Figure with Name.....	282



---

5.5.2.2. Naming of the Sign .....	284
5.5.2.2.1. Naming of Mathematical Symbols.....	285
5.5.2.2.2. Naming of Symbolic Signs.....	287
5.5.2.3. Letter Naming .....	292
5.5.2.3.1. Naming of the Different Fonts of the Letter..	292
5.5.2.3.2. Similarities of Different Letters .....	298
5.5.2.4. Naming and Recognition of Real-World Objects ..	304
5.5.2.5. Naming of the Mathematical Object .....	326
5.5.2.6. Identification of Statistical Visual Objects .....	329
5.5.2.6.1. Data Analysis.....	330
5.5.2.7. Category of Physical and Engineering Models.....	334
5.5.2.8. Visual Resemblance: Visual Analogy.....	336
5.5.2.9. Spatial Problems.....	342
5.5.2.10. Problem Solving – Categorical Knowledge.....	348
5.5.2.11. Visual Diagnosis .....	350
5.5.2.12. Assembling Tools .....	355
5.5.2.13. Moving Object Outside.....	371
5.5.2.14. Obstacle Detection and Motion Planning .....	372
5.5.2.15. Visual Intelligence Tests.....	375
5.5.2.15.1. Visual Discrimination Test.....	376
5.5.2.15.2. Visual Sequential Memory Test.....	378
5.5.2.15.3. Visual Form Constancy Test.....	379
5.5.2.15.4. Matrix Test.....	380
5.5.2.15.5. Category of Spatial Tests .....	394

## Preface

This book presents the results of the research in one of the most complex and difficult areas of research such as research in the areas of thinking and understanding. This research that is carried out in the newly founded Queen Jadwiga Research Institute of Understanding [www.qjfp.pl.org/QJRIU/Eng/Eng\\_QJRIU\\_PO\\_O.htm](http://www.qjfp.pl.org/QJRIU/Eng/Eng_QJRIU_PO_O.htm) is focused on research on the problem of visual understanding and visual thinking. Visual understanding is part of the general understanding problem and it is not possible to carry out the research in visual understanding without reference to the nonvisual understanding problems. Understanding appears as the result of the thinking processes, and doing research in the area of understanding there is a need to include thinking process as one of the research problems that should be solved in the context of understanding investigations. According to our knowledge, this book is the first attempt to investigate the complexity of the visual thinking problems in the context of building the thinking machine. The aim of our research is to build the machine that can have capabilities to solve visual problems during thinking process. We are aware how complex this problem is and we are aware that the results of our research are only the first steps in building the thinking machine being able to solve complex visual problems. However, we believe that the results of our research will pave the way into the new way of thinking about designing the thinking machines and, especially, will supply the new scientific arguments about our human nature.

Until now, the problem of understanding and thinking was the topic of research in the area of philosophy, psychology, or cognitive science. Philosophical investigations of many thinkers such as Plato, Aristotle, Locke, Berkeley, or contemporary thinkers contributed into progress of understanding and thinking processes. Although there are some research on this topic in the area of artificial intelligence (AI), researchers in AI do not pay sufficient attention into understanding/thinking problems. It was probably for that reason that they tried to tailor the problem of what they called “artificial intelligence” to the abilities of the existing computing machines.

Another reason was that until now, there was no proper representation that could capture visual aspects of the world and represent them in the form that could be compatible with other representations of the nonvisual knowledge.

When existing systems are built based on the results of the scientific discoveries in the domain of psychology, cognitive science, computer science, or AI, our approach is based on the results of philosophical investigations of such thinkers as Aristotle, Locke, or Berkeley. In Chap. 1 of this book, the brief description of the results of main philosophical investigations concerning thinking and understanding is presented. In this chapter, shape that is regarded as the main perceptual category of thinking process and the important visual feature of the perceived world is briefly described. In the following sections of this chapter, the different problems connected with understanding are briefly presented. The relation between understanding and thinking is discussed in the following sections of this chapter. The last section includes the short description of the shape understanding system (SUS). In this book, the problems connected with the implementation issues of the SUS are not presented. The reason for that is that the theoretical issues connected with thinking and understanding are very complex, and inclusion of the extended description of implementation issues could cause that the contents of this book would be less understandable. In Chap. 2, concepts of shape classes that are understood as the basic perceptual categories are explained. The classes are represented by their symbolic names. Each class is related to each other and based on these classes there is relatively easy to establish the “perceptual similarity” among perceived objects. In Chap. 3, the description of the reasoning process that leads to assigning the perceived object to one of the shape classes is given. Each class possesses its characteristic reasoning process. The result of the reasoning process is the assignment of the examined object to one of the shape classes represented by the symbolic names. The symbolic name is used to find the visual concept and next to assign the perceived object into one of the ontological categories. Ontological categories are part of the new hierarchical categorical structure of the SUS. The new hierarchical categorical structure is explained in Chap. 4. The categorical chains that represent the categories of visual objects and knowledge categories are applied to interpret the perceived object as the symbol, the letter, or the real world object. In Chap. 5, examples of the visual reasoning processes that can be considered as the thinking process are presented. The thinking process is regarded as the continuous computational activity that is triggered by perception of a new object, by perception of an “inner object,” or by the task given by the user. Thinking can lead to solving a problem where there is only one solution (e.g., the visual intelligence test) or solving a problem where there are many possible solutions

(e.g., designing the tools). In this book, the focus is on thinking that leads to solving a problem that has only one solution.

We are aware that this book could be written in a different way where some issues could be explained in more details or presented in the different ways. We would like to explain that this book was written in very “difficult” conditions. During the most crucial part of writing of this book, we were notoriously expelled from our own flat where most work connected with preparation of this book was carried out. We think that for most of the readers, it would be difficult to understand how it could happen that in twenty-first century someone could be expelled from his home. We believe that it could happen only in country such as Australia where for more than 15 years, we Polish scientists are subjected to psychological terror from some Australian people and institution. The details of our persecution in Australia are described on our Web site ([www.qjfp.org/Przesladowanie/Eng/](http://www.qjfp.org/Przesladowanie/Eng/)). We would like to take this opportunity and ask the Australian Government in Canberra to take responsibility for all damage that we suffered from Australian people and institutions.