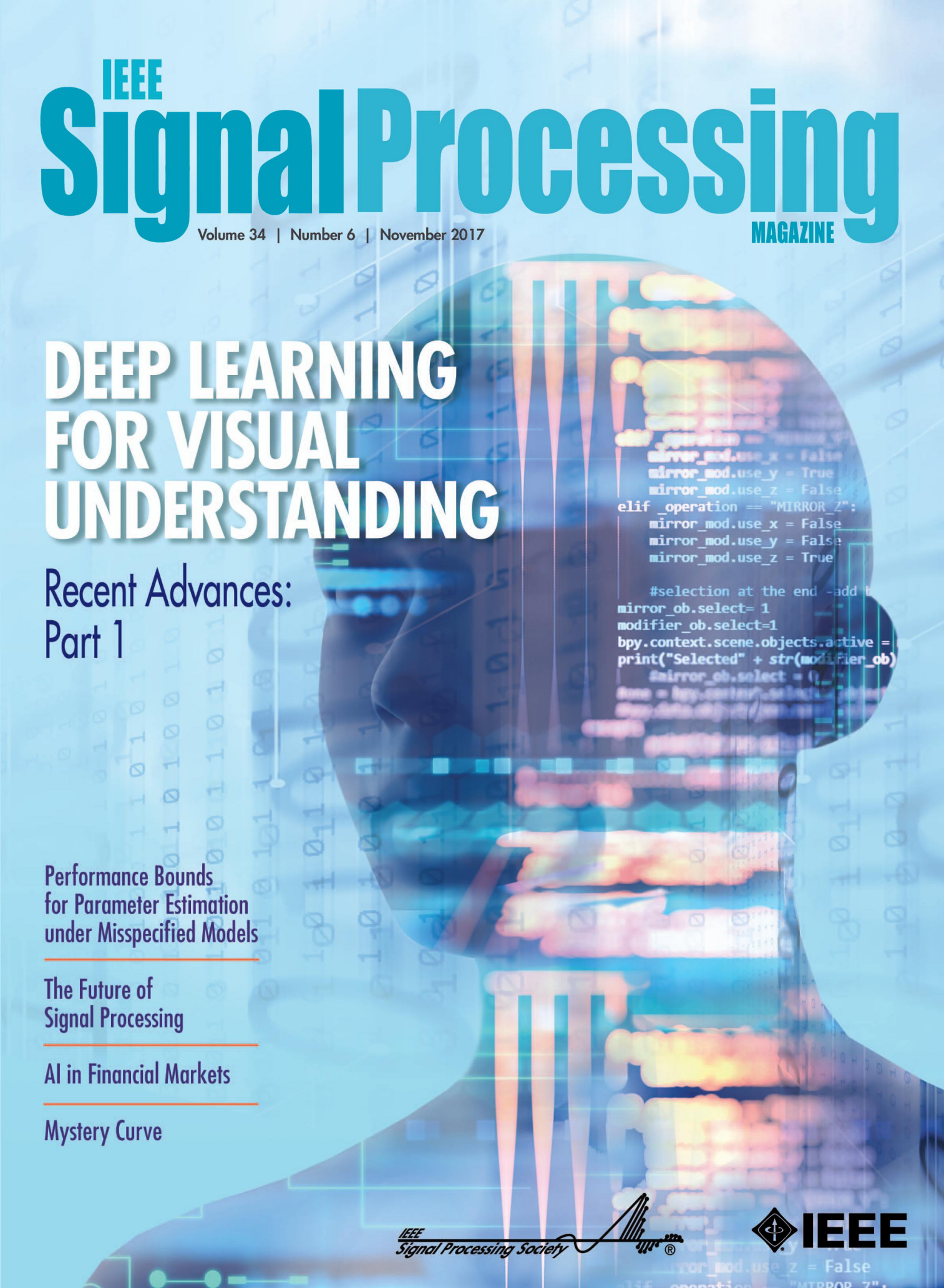
IEEE
Signal Processing MAGAZINE
Volume 34 | Number 6 | November 2017



DEEP LEARNING FOR VISUAL UNDERSTANDING

Recent Advances: Part 1

Performance Bounds for Parameter Estimation under Misspecified Models

The Future of Signal Processing

AI in Financial Markets

Mystery Curve

IEEE Signal Processing Society

IEEE

Contents

Volume 34 | Number 6 | November 2017

SPECIAL SECTION

DEEP LEARNING FOR VISUAL UNDERSTANDING: PART 1

24 **FROM THE GUEST EDITORS**
Fatih Porikli, Shiguang Shan, Cees Snoek, Rahul Sukthankar, and Xiaogang Wang

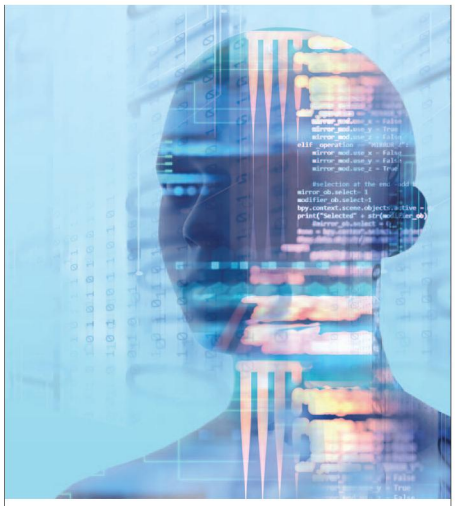
26 **DEEP REINFORCEMENT LEARNING**
Kai Arulkumaran, Marc Peter Deisenroth, Miles Brundage, and Anil Anthony Bharath

39 **WEAKLY SUPERVISED LEARNING WITH DEEP CONVOLUTIONAL NEURAL NETWORKS FOR SEMANTIC SEGMENTATION**
Seunghoon Hong, Suha Kwak, and Bohyung Han

50 **THE ROBUSTNESS OF DEEP NETWORKS**
Alhussein Fawzi, Seyed-Mohsen Moosavi-Dezfooli, and Pascal Frossard

©ISTOCKPHOTO.COM/MIAKIEVY

PG. 142



ON THE COVER

This special issue of *IEEE Signal Processing Magazine* provides survey articles on the latest advances in deep learning for visual understanding. Its objective is to encourage a diverse audience of researchers and enthusiasts toward an effective participation in the solution of analogous problems in other signal processing fields by inseminating similar ideas.

COVER IMAGE: ©ISTOCKPHOTO.COM/MONSITJ

63 **VISUAL QUESTION ANSWERING**
Damien Teney, Qi Wu, and Anton van den Hengel

76 **DEEP METRIC LEARNING FOR VISUAL UNDERSTANDING**
Jiwen Lu, Junlin Hu, and Jie Zhou

85 **CONVOLUTIONAL NEURAL NETWORKS FOR INVERSE PROBLEMS IN IMAGING**
Michael T. McCann, Kyong Hwan Jin, and Michael Unser

96 **DEEP MULTIMODAL LEARNING**
Dhanesh Ramachandram and Graham W. Taylor

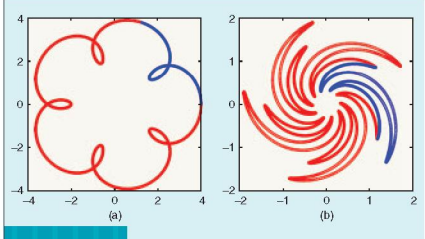
109 **DEEP LEARNING FOR IMAGE-TO-TEXT GENERATION**
Xiaodong He and Li Deng

117 **DEEP-LEARNING SYSTEMS FOR DOMAIN ADAPTATION IN COMPUTER VISION**
Hemanth Venkateswara, Shayok Chakraborty, and Sethuraman Panchanathan

130 **DEEP CONVOLUTIONAL NEURAL MODELS FOR PICTURE-QUALITY PREDICTION**
Jongyoo Kim, Hui Zeng, Deepti Ghadiyaram, Sanghoon Lee, Lei Zhang, and Alan C. Bovik

FEATURE

142 **PERFORMANCE BOUNDS FOR PARAMETER ESTIMATION UNDER MISSPECIFIED MODELS**
Stefano Fortunati, Fulvio Gini, Maria S. Greco, and Christ D. Richmond



PG. 158

IEEE SIGNAL PROCESSING MAGAZINE (ISSN 1053-5888) (ISPREG) is published bimonthly by the Institute of Electrical and Electronics Engineers, Inc., 3 Park Avenue, 17th Floor, New York, NY 10016-5997 USA (+1 212 419 7900). Responsibility for the contents rests upon the authors and not the IEEE, the Society, or its members. Annual member subscriptions included in Society fee. Nonmember subscriptions available upon request. **Individual copies:** IEEE Members US$20.00 (first copy only), nonmembers US$241.00 per copy. Copyright and Reprint Permissions: Abstracting is permitted with credit to the source. Libraries are permitted to photocopy beyond the limits of U.S. Copyright Law for private use of patrons: 1) those post-1977 articles that carry a code at the bottom of the first page, provided the per-copy fee indicated in the code is paid through the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923 USA; 2) pre-1978 articles without fee. Instructors are permitted to photocopy isolated articles for noncommercial classroom use without fee. **For all other copying, reprint, or republication permission,** write to IEEE Service Center, 445 Hoes Lane, Piscataway, NJ 08854 USA. Copyright © 2017 by the Institute of Electrical and Electronics Engineers, Inc. All rights reserved. Periodicals postage paid at New York, NY, and at additional mailing offices. **Postmaster:** Send address changes to IEEE Signal Processing Magazine, IEEE, 445 Hoes Lane, Piscataway, NJ 08854 USA. Canadian GST #125634188 **Printed in the U.S.A.**

Digital Object Identifier 10.1109/MSP.2017.2750304

COLUMNS

8 **Panel and Forum**
Challenges and Open Problems in Signal Processing: Panel Discussion Summary from ICASSP 2017
Yonina C. Eldar, Alfred O. Hero III, Li Deng, Jeff Fessler, Jelena Kovačević, H. Vincent Poor, and Steve Young

14 **Community Voices**
What Is the Future of Signal Processing?
Andres Kwasinski and Min Wu

17 **Special Reports**
Medical Optical Imaging
John Edwards

21 **Reader's Choice**
Top Downloads in IEEE *Xplore*

158 **Lecture Notes**
The Mystery Curve: A Signal Processing Point of View
Soo-Chang Pei and Kuo-Wei Chang

164 **Tips & Tricks**
Fast- and Low-Complexity atan2(*a*,*b*) Approximation
Vicente Torres, Javier Valls, and Richard Lyons

176 **Perspectives**
To the Victor Go the Spoils: AI in Financial Markets
Xiao-Ping (Steven) Zhang

DEPARTMENTS

4 **From the Editor**
Signals and Signal Processing: The Invisibles and the Everlastings
Min Wu

5 **President's Message**
Signal Processing Is More than Its Beloved Name
Rabab Ward

170 **Dates Ahead**

SUSTAINABLE FORESTRY INITIATIVE Certified Chain of Custody Promoting Sustainable Forestry www.sfiprogram.org SFI-01081

IEEE prohibits discrimination, harassment, and bullying. For more information, visit http://www.ieee.org/web/aboutus/whatis/policies/p9-26.html.

IEEE Signal Processing Magazine

EDITOR-IN-CHIEF
Min Wu—University of Maryland, College Park U.S.A.

AREA EDITORS
Feature Articles
Shuguang Robert Cui—University of California, Davis, U.S.A.
Special Issues
Douglas O'Shaughnessy—INRS, Canada
Columns and Forum
Kenneth Lam—Hong Kong Polytechnic University, Hong Kong SAR of China
e-Newsletter
Ervin Sejdic—University of Pittsburgh, U.S.A.
Social Media and Outreach
Andres Kwasinski—Rochester Institute of Technology, U.S.A.

EDITORIAL BOARD
Mrityunjoy Chakraborty – Indian Institute of Technology, Kharagpur, India
George Chrisikos – Qualcomm, Inc., U.S.A.
Alfonso Farina—Leonardo S.p.A., Italy
Mounir Ghogho—University of Leeds, U. K.
Lina Karam—Arizona State University, U.S.A.
C.-C. Jay Kuo—University of Southern California, U.S.A.
Sven Loncărić—University of Zagreb, Croatia
Brian Lovell—University of Queensland, Australia
Jian Lu—Qihoo 360, China
Henrique (Rico) Malvar—Microsoft Research, U.S.A.
Yi Ma—ShanghaiTech University, China
Stephen McLaughlin—Heriot-Watt University, Scotland
Athina Petropulu—Rutgers University, U.S.A.
Peter Ramadge—Princeton University, U.S.A.
Shigeki Sagayama—Meiji University, Japan
Erchin Serpedin—Texas A&M University, U.S.A.
Shihab Shamma—University of Maryland, U.S.A.
Vahid Tarokh—Harvard University, U.S.A.
Wade Trappe—Rutgers University, U.S.A.
Gregory Wornell—Massachusetts Institute of Technology, U.S.A.
Dapeng Wu—University of Florida, U.S.A.

ASSOCIATE EDITORS—COLUMNS AND FORUM
Ivan Bajic—Simon Fraser University, Canada
Rodrigo Capobianco Guido—São Paulo State University, Brazil
Ching-Te Chiu—National Tsing Hua University, Taiwan
Panayiotis (Panos) Georgiou—University of Southern California, U.S.A.
Hana Godrich—Rutgers University, U.S.A.
Xiaodong He—Microsoft Research
Danilo Mandic—Imperial College, U.K.
Aleksandra Mojsilovic—IBM T.J. Watson Research Center
Vishal Patel—Rutgers University, U.S.A.
Fatih Porikli—MERL
Shantanu Rane—PARC, U.S.A.
Saeid Sanei—University of Surrey, U.K.
Roberto Togneri—The University of Western Australia
Alessandro Vinciarelli—IDIAP–EPFL
Azadeh Vosoughi—University of Central Florida
Stefan Winkler—UIUC/ADSC, Singapore
Changshui Zhang—Tsinghua University, China

ASSOCIATE EDITORS—e-NEWSLETTER
Csaba Benedek—Hungarian Academy of Sciences, Hungary
Paolo Braca—NATO Science and Technology Organization, Italy
Quan Ding—University of California, San Francisco, U.S.A.
Pierluigi Failla—Compass Inc, New York, U.S.A.
Marco Guerriero—General Electric Research, U.S.A.
Yang Li—Harbin Institute of Technology, China
Yuhong Liu—Penn State University at Altoona, U.S.A.
Andreas Merentitis—University of Athens, Greece
Michael Muma—TU Darmstadt, Germany
Xiaorong Zhang—San Francisco State University, U.S.A.

ASSOCIATE EDITOR—SOCIAL MEDIA/OUTREACH
Guijin Wang—Tsinghua University, China

IEEE SIGNAL PROCESSING SOCIETY
Rabab Ward—President
Ali Sayed—President-Elect
Carlo S. Regazzoni—Vice President, Conferences
Nikos D. Sidiropoulos—Vice President, Membership
Thrasyvoulos (Thrasos) N. Pappas—Vice President, Publications
Walter Kellerman—Vice President, Technical Directions

IEEE SIGNAL PROCESSING SOCIETY STAFF
Rebecca Wollman—Publications Administrator

IEEE PERIODICALS MAGAZINES DEPARTMENT
Jessica Welsh, *Managing Editor*
Geraldine Krolin-Taylor, *Senior Managing Editor*
Janet Dudar, *Senior Art Director*
Gail A. Schnitzer, *Associate Art Director*
Theresa L. Smith, *Production Coordinator*
Mark David, *Director, Business Development - Media & Advertising*
Felicia Spagnoli, *Advertising Production Manager*
Dawn M. Melley, *Editorial Director*
Peter M. Tuohy, *Production Director*
Fran Zappulla, *Staff Director, Publishing Operations*

Digital Object Identifier 10.1109/MSP.2017.2750305

SCOPE: *IEEE Signal Processing Magazine* publishes tutorial-style articles on signal processing research and applications as well as columns and forums on issues of interest. Its coverage ranges from fundamental principles to practical implementation, reflecting the multidimensional facets of interests and concerns of the community. Its mission is to bring up-to-date, emerging and active technical developments, issues, and events to the research, educational, and professional communities. It is also the main Society communication platform addressing important issues concerning all members.