

# **Studies in Computational Intelligence**

Volume 943

## **Series Editor**

Janusz Kacprzyk, Polish Academy of Sciences, Warsaw, Poland

The series “Studies in Computational Intelligence” (SCI) publishes new developments and advances in the various areas of computational intelligence—quickly and with a high quality. The intent is to cover the theory, applications, and design methods of computational intelligence, as embedded in the fields of engineering, computer science, physics and life sciences, as well as the methodologies behind them. The series contains monographs, lecture notes and edited volumes in computational intelligence spanning the areas of neural networks, connectionist systems, genetic algorithms, evolutionary computation, artificial intelligence, cellular automata, self-organizing systems, soft computing, fuzzy systems, and hybrid intelligent systems. Of particular value to both the contributors and the readership are the short publication timeframe and the world-wide distribution, which enable both wide and rapid dissemination of research output.

Indexed by SCOPUS, DBLP, WTI Frankfurt eG, zbMATH, SCImago.

All books published in the series are submitted for consideration in Web of Science.

More information about this series at <http://www.springer.com/series/7092>

Rosa M. Benito · Chantal Cherifi ·  
Hocine Cherifi · Esteban Moro ·  
Luis Mateus Rocha · Marta Sales-Pardo  
Editors

# Complex Networks & Their Applications IX

Volume 1, Proceedings of the Ninth  
International Conference on Complex  
Networks and Their Applications  
COMPLEX NETWORKS 2020

### *Editors*

Rosa M. Benito  
Grupo de Sistemas Complejos  
Universidad Politécnica de Madrid  
Madrid, Madrid, Spain

Chantal Cherifi  
IUT Lumière  
University of Lyon  
Bron Cedex, France

Hocine Cherifi  
LIB, UFR Sciences et Techniques  
Université de Bourgogne  
Dijon, France

Esteban Moro  
Grupo Interdisciplinar de Sistemas  
Complejos, Departamento de Matematicas  
Universidad Carlos III de Madrid  
Leganés, Madrid, Spain

Luis Mateus Rocha  
Center for Social and Biomedical  
Complexity, Luddy School of Informatics,  
Computing, and Engineering  
Indiana University  
Bloomington, IN, USA

Marta Sales-Pardo  
Department of Chemical Engineering  
Universitat Rovira i Virgili  
Tarragona, Tarragona, Spain

ISSN 1860-949X

ISSN 1860-9503 (electronic)

Studies in Computational Intelligence

ISBN 978-3-030-65346-0

ISBN 978-3-030-65347-7 (eBook)

<https://doi.org/10.1007/978-3-030-65347-7>

© The Editor(s) (if applicable) and The Author(s), under exclusive license  
to Springer Nature Switzerland AG 2021

This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, 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.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG  
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

# Preface

This 2020 edition of the International Conference on Complex Networks & Their Applications is the ninth of a series that began in 2011. Over the years, this adventure has made the conference one of the major international events in network science.

Network science continues to trigger a tremendous interest among the scientific community of various fields such as finance and economy, medicine and neuroscience, biology and earth sciences, sociology and politics, computer science and physics. The variety of scientific topics ranges from network theory, network models, network geometry, community structure, network analysis and measure, link analysis and ranking, resilience and control, machine learning and networks, dynamics on/of networks, diffusion and epidemics, visualization. It is also worth mentioning some recent applications with high added value for current trend social concerns such as social and urban networks, human behavior, urban systems—mobility, or quantifying success. The conference brings together researchers that study the world through the lens of networks. Catalyzing the efforts of this scientific community, it drives network science to generate cross-fertilization between fundamental issues and innovative applications, review the current state of the field and promote future research directions.

Every year, researchers from all over the world gather in our host venue. This year's edition was initially to be hosted in Spain by Universidad Politécnica de Madrid. Unfortunately, the COVID-19 global health crisis forced us to organize the conference as a fully online event.

Nevertheless, this edition attracted numerous authors with 323 submissions from 51 countries. The papers selected for the volumes of proceedings clearly reflect the multiple aspects of complex network issues as well as the high quality of the contributions.

All the submissions were peer-reviewed by 3 independent reviewers from our strong international program committee. This ensured high-quality contributions as well as compliance to conference topics. After the review process, 112 papers were selected to be included in the proceedings.

Undoubtedly, the success of this edition relied on the authors who have produced high-quality papers, as well as the impressive list of keynote speakers who delivered fascinating plenary lectures:

- Leman Akoglu (Carnegie Mellon University, USA): “Graph-Based Anomaly Detection: Problems, Algorithms and Applications”
- Stefano Boccaletti (Florence University, Italy): “Synchronization in Complex Networks, Hypergraphs and Simplicial Complexes”
- Fosca Giannotti (KDD Lab, Pisa, Italy): “Explainable Machine Learning for Trustworthy AI”
- János Kertész (Central European University, Hungary): “Possibilities and Limitations of using mobile phone data in exploring human behavior”
- Vito Latora (Queen Mary University of London, UK): “Simplicial model of social contagion”
- Alex “Sandy” Pentland (MIT Media Lab, USA): “Human and Optimal Networked Decision Making in Long-Tailed and Non-stationary Environments”
- Nataša Pržulj (Barcelona Supercomputing Center, Spain): “Untangling biological complexity: From omics network data to new biomedical knowledge and Data-Integrated Medicine”

The topics addressed in the keynote talks allowed a broad coverage of the issues encountered in complex networks and their applications to complex systems.

For the traditional tutorial sessions prior to the conference, our two invited speakers delivered insightful talks. David Garcia (Complexity Science Hub Vienna, Austria) gave a lecture entitled “Analyzing complex social phenomena through social media data,” and Mikko Kivela (Aalto University, Finland) delivered a talk on “Multilayer Networks.”

Each edition of the conference represents a challenge that cannot be successfully achieved without the deep involvement of many people, institutions and sponsors.

First of all, we sincerely gratify our advisory board members, Jon Crowcroft (University of Cambridge), Raissa D’Souza (University of California, Davis, USA), Eugene Stanley (Boston University, USA) and Ben Y. Zhao (University of Chicago, USA), for inspiring the essence of the conference.

We record our thanks to our fellow members of the Organizing Committee. José Fernando Mendes (University of Aveiro, Portugal), Jesús Gomez Gardeñes (University of Zaragoza, Spain) and Huijuan Wang (TU Delft, Netherlands) chaired the lightning sessions. Manuel Marques-Pita (Universidade Lusófona, Portugal), José Javier Ramasco (IFISC, Spain) and Taha Yasseri (University of Oxford, UK) managed the poster sessions. Luca Maria Aiello (Nokia Bell Labs, UK) and Leto Peel (Université Catholique de Louvain, Belgium) were our tutorial chairs. Finally, Sabrina Gaito (University of Milan, Italy) and Javier Galeano (Universidad Politécnica de Madrid, Spain) were our satellite chairs.

We extend our thanks to Benjamin Renoust (Osaka University, Japan), Michael Schaub (MIT, USA), Andreia Sofia Teixeira (Indiana University Bloomington, USA), Xiangjie Kong (Dalian University of Technology, China), the publicity

chairs for advertising the conference in America, Asia and Europa, hence encouraging the participation.

We would like also to acknowledge Regino Criado (Universidad Rey Juan Carlos, Spain) as well as Roberto Interdonato (CIRAD - UMR TETIS, Montpellier, France) our sponsor chairs.

Our deep thanks go to Matteo Zignani (University of Milan, Italy), publication chair, for the tremendous work he has done at managing the submission system and the proceedings publication process.

Thanks to Stephany Rajeh (University of Burgundy, France), Web chair, in maintaining the Web site.

We would also like to record our appreciation for the work of the local committee chair, Juan Carlos Losada (Universidad Politécnica de Madrid, Spain) and all the local committee members, David Camacho (UPM, Spain), Fabio Revuelta (UPM, Spain), Juan Manuel Pastor (UPM, Spain), Francisco Prieto (UPM, Spain), Leticia Perez Sienes (UPM, Spain), Jacobo Aguirre (CSIC, Spain), Julia Martinez-Atienza (UPM, Spain), for their work in managing online sessions. They greatly participated in the success of this edition.

We are also indebted to our partners, Alessandro Fellegara and Alessandro Egro from Tribe Communication, for their passion and patience in designing the visual identity of the conference.

We would like to express our gratitude to our partner journals involved in the sponsoring of keynote talks: Applied Network Science, EPJ Data Science, Social Network Analysis and Mining, and Entropy.

Generally, we are thankful to all those who have helped us contributing to the success of this meeting. Sincere thanks to the contributors, and the success of the technical program would not be possible without their creativity.

Finally, we would like to express our most sincere thanks to the program committee members for their huge efforts in producing high-quality reviews in a very limited time.

These volumes make the most advanced contribution of the international community to the research issues surrounding the fascinating world of complex networks. Their breath, quality and novelty signal how profound is the role played by complex networks in our understanding of our world. We hope that you will enjoy reading the papers as much as we enjoyed organizing the conference and putting this collection of papers together.

Rosa M. Benito  
Hocine Cherifi  
Chantal Cherifi  
Esteban Moro  
Luis Mateus Rocha  
Marta Sales-Pardo

# Organization and Committees

## General Chairs

Rosa M. Benito  
Hocine Cherifi  
Esteban Moro

Universidad Politécnica de Madrid, Spain  
University of Burgundy, France  
Universidad Carlos III de Madrid, Spain

## Advisory Board

Jon Crowcroft  
Raissa D'Souza  
Eugene Stanley  
Ben Y. Zhao

University of Cambridge, UK  
University of California, Davis, USA  
Boston University, USA  
University of Chicago, USA

## Program Chairs

Chantal Cherifi  
Luis M. Rocha  
Marta Sales-Pardo

University of Lyon, France  
Indiana University Bloomington, USA  
Universitat Rovira i Virgili, Spain

## Satellite Chairs

Sabrina Gaito  
Javier Galeano

University of Milan, Italy  
Universidad Politécnica de Madrid, Spain

## Lightning Chairs

José Fernando Mendes  
Jesús Gomez Gardeñes  
Huijuan Wang

University of Aveiro, Portugal  
University of Zaragoza, Spain  
TU Delft, Netherlands



## Poster Chairs

Manuel Marques-Pita  
José Javier Ramasco  
Taha Yasseri

University Lusófona, Portugal  
IFISC, Spain  
University of Oxford, UK

## Publicity Chairs

Benjamin Renoust  
Andreia Sofia Teixeira  
Michael Schaub  
Xiangjie Kong

Osaka University, Japan  
University of Lisbon, Portugal  
MIT, USA  
Dalian University of Technology, China

## Tutorial Chairs

Luca Maria Aiello  
Leto Peel

Nokia Bell Labs, UK  
UCLouvain, Belgium

## Sponsor Chairs

Roberto Interdonato  
Regino Criado

CIRAD - UMR TETIS, France  
Universidad Rey Juan Carlos, Spain

## Local Committee Chair

Juan Carlos Losada

Universidad Politécnica de Madrid, Spain

## Local Committee

Jacobo Aguirre  
David Camacho  
Julia Martinez-Atienza  
Juan Manuel Pastor  
Leticia Perez Sienes  
Francisco Prieto  
Fabio Revuelta

CSIC, Spain  
UPM, Spain  
UPM, Spain  
UPM, Spain  
UPM, Spain  
UPM, Spain  
UPM, Spain

## Publication Chair

Matteo Zignani

University of Milan, Italy

## Web Chair

Stephany Rajeh

University of Burgundy, France

## Program Committee

Jacobo Aguirre	Centro Nacional de Biotecnología, Spain
Amreen Ahmad	Jamia Millia Islamia, India
Masaki Aida	Tokyo Metropolitan University, Japan
Luca Maria Aiello	Nokia Bell Labs, UK
Marco Aiello	University of Stuttgart, Germany
Esra Akbas	Oklahoma State University, USA
Mehmet Aktas	University of Central Oklahoma, USA
Tatsuya Akutsu	Kyoto University, Japan
Reka Albert	The Pennsylvania State University, USA
Aleksandra Aloric	Institute of Physics Belgrade, Serbia
Claudio Altafini	Linköping University, Sweden
Benjamin Althouse	New Mexico State University, USA
Lucila G. Alvarez-Zuzek	IFIMAR-UNMDP, Argentina
Luiz G. A. Alves	Northwestern University, USA
Enrico Amico	Swiss Federal Institute of Technology in Lausanne, Switzerland
Hamed Amini	Georgia State University, USA
Chuankai An	Dartmouth College, USA
Marco Tulio Angulo	National Autonomous University of Mexico (UNAM), Mexico
Demetris Antoniadis	RISE Research Center, Cyprus
Alberto Antonioni	Carlos III University of Madrid, Spain
Nino Antulov-Fantulin	ETH Zurich, Switzerland
Nuno Araujo	Universidade de Lisboa, Portugal
Elsa Arcaute	University College London, UK
Laura Arditti	Polytechnic of Turin, Italy
Samin Aref	Max Planck Institute for Demographic Research, Germany
Panos Argyrakis	Aristotle University of Thessaloniki, Greece
Malbor Asllani	University of Limerick, Ireland
Tomaso Aste	University College London, UK
Martin Atzmueller	Tilburg University, Netherlands
Konstantin Avrachenkov	Inria, France
Jean-Francois Baffier	National Institute of Informatics, Japan
Giacomo Baggio	University of Padova, Italy
Rodolfo Baggio	Bocconi University, Italy
Franco Bagnoli	University of Florence, Italy
Annalisa Barla	Università di Genova, Italy
Paolo Barucca	University College London, UK
Anastasia Baryshnikova	Calico Life Sciences, USA
Nikita Basov	St. Petersburg State University, Russia
Gareth Baxter	University of Aveiro, Portugal

Marya Bazzi	University of Oxford, UK
Mariano Beguerisse Diaz	University of Oxford, UK
Andras A. Benczur	Hungarian Academy of Sciences, Hungary
Rosa M. Benito	Universidad Politécnica de Madrid, Spain
Luis Bettencourt	University of Chicago, USA
Ginestra Bianconi	Queen Mary University of London, UK
Ofer Biham	The Hebrew University of Jerusalem, Israel
Livio Bioglio	University of Turin, Italy
Hanjo Boekhout	Leiden University, Netherlands
Johan Bollen	Indiana University Bloomington, USA
Christian Bongiorno	Università degli Studi di Palermo, Italy
Anton Borg	Blekinge Institute of Technology, Sweden
Stefan Bornholdt	Universität Bremen, Germany
Federico Botta	The University of Warwick, UK
Alexandre Bovet	Université Catholique de Louvain, Belgium
Dan Braha	NECSI, USA
Ulrik Brandes	ETH Zürich, Switzerland
Markus Brede	University of Southampton, UK
Marco Bressan	Sapienza University of Rome, Italy
Piotr Bródka	Wroclaw University of Science and Technology, Poland
Javier M. Buldu	Universidad Rey Juan Carlos, Spain
Raffaella Burioni	Università di Parma, Italy
Fabio Caccioli	University College London, UK
Rajmonda Caceres	Massachusetts Institute of Technology, USA
Carmela Calabrese	University of Naples Federico II, Italy
Paolo Campana	University of Cambridge, UK
M. Abdullah Canbaz	Indiana University Kokomo, USA
Carlo Vittorio Cannistraci	TU Dresden, Germany
Vincenza Carchiolo	Università di Catania, Italy
Giona Casiraghi	ETH Zurich, Switzerland
Douglas Castilho	Federal University of Minas Gerais, Brazil
Costanza Catalano	Gran Sasso Science Institute, Belgium
Remy Cazabet	Lyon University, France
David Chavalarias	CNRS, CAMS/ISC-PIF, France
Kwang-Cheng Chen	University of South Florida, USA
Po-An Chen	National Chiao Tung University, Taiwan
Xihui Chen	University of Luxembourg, Luxembourg
Xueqi Cheng	Institute of Computing Technology, China
Chantal Cherifi	Lyon 2 University, France
Hocine Cherifi	University of Burgundy, France
Peter Chin	Boston University, USA
Matteo Chinazzi	Northeastern University, USA
Matteo Cinelli	University of Rome “Tor Vergata”, Italy
Richard Clegg	Queen Mary University of London, UK

Reuven Cohen	Bar-Ilan University, Israel
Alessio Conte	University of Pisa, Italy
Marco Coraggio	University of Naples Federico II, Italy
Michele Coscia	IT University of Copenhagen, Denmark
Clementine Cottineau	CNRS, Centre Maurice Halbwachs, France
Regino Criado	Universidad Rey Juan Carlos, Spain
Mihai Cucuringu	University of Oxford and The Alan Turing Institute, USA
Marcelo Cunha	IFBA, Brazil
Giulio Valentino Dalla Riva	University of Canterbury, New Zealand
Kareem Darwish	Qatar Computing Research Institute, Qatar
Bhaskar Dasgupta	University of Illinois, Chicago, USA
Joern Davidsen	University of Calgary, Canada
Toby Davies	University College London, UK
Pasquale De Meo	Vrije Universiteit Amsterdam, Italy
Fabrizio De Vico Fallani	Inria - ICM, France
Charo I. del Genio	Coventry University, UK
Pietro Delellis	University of Naples Federico II, Italy
Jean-Charles Delvenne	University of Louvain, Belgium
Yong Deng	Xi'an Jiaotong University, China
Bruce Desmarais	The Pennsylvania State University, USA
Patrick Desrosiers	Université Laval, Canada
Riccardo Di Clemente	University of Exeter, UK
Matías Di Muro	Universidad Nacional de Mar del Plata-CONICET, Argentina
Jana Diesner	University of Illinois at Urbana-Champaign, USA
Shichang Ding	University of Goettingen, Germany
Linda Douw	Amsterdam UMC, Netherlands
Johan Dubbeldam	Delft University of Technology, Netherlands
Jordi Duch	Universitat Rovira i Virgili, Spain
Kathrin Eismann	University of Bamberg, Germany
Mohammed El Hassouni	Mohammed V University in Rabat, Morocco
Andrew Elliott	University of Oxford, UK
Michael T. M. Emmerich	Leiden University, Netherlands
Frank Emmert-Streib	Tampere University of Technology, Finland
Gunes Ercal	SIUE, USA
Alexandre Evsukoff	COPPE/UFRJ, Brazil
Mauro Faccin	Université Catholique de Louvain, Belgium
Sofia Fernandes	Laboratory of Artificial Intelligence and Decision Support, Portugal
Guilherme Ferraz de Arruda	ISI Foundation, Italy
Daniel Figueiredo	COPPE/UFRJ, Brazil
Jorge Finke	Pontificia Universidad Javeriana, Colombia
Marco Fiore	IMDEA Networks Institute, Spain
Alessandro Flammini	Indiana University Bloomington, USA

Manuel Foerster	Bielefeld University, Germany
Barbara Franci	Delft University of Technology, Netherlands
Diego Função	University of São Paulo, Brazil
Angelo Furno	University of Lyon and University Gustave Eiffel, France
Sabrina Gaito	University of Milan, Italy
Lazaros Gallos	Rutgers University, USA
José Manuel Galán	Universidad de Burgos, Spain
Joao Gama	University of Porto, Portugal
Yerali Gandica	Université Catholique de Louvain, Belgium
Jianxi Gao	Rensselaer Polytechnic Institute, USA
David Garcia	Medical University of Vienna and Complexity Science Hub Vienna, Austria
Federica Garin	Inria, France
Michael Gastner	Yale-NUS College, Singapore
Alexander Gates	Northeastern University, USA
Vincent Gauthier	Telecom SudParis/Institut Mines-Telecom, France
Raji Ghawi	Technical University of Munich, Germany
Tommaso Gili	IMT School for Advanced Studies Lucca, Italy
Silvia Giordano	SUPSI, Switzerland
Rosalba Giugno	University of Verona, Italy
David Gleich	Purdue University, USA
Antonia Godoy	Rovira i Virgili University, Spain
Kwang-Il Goh	Korea University, South Korea
Jaime Gomez	Universidad Politécnica de Madrid, Spain
Jesus Gomez-Gardenes	Universidad de Zaragoza, Spain
Antonio Gonzalez	Universidad Autónoma de Madrid, Spain
Bruno Gonçalves	New York University, USA
Joana Gonçalves-Sá	Nova School of Business and Economics, Portugal
Przemyslaw Grabowicz	University of Massachusetts, Amherst, USA
Carlos Gracia-Lázaro	BIFI, Spain
Justin Gross	UMass Amherst, USA
Jelena Grujic	Vrije Universiteit Brussel, Belgium
Jean-Loup Guillaume	L3i - Université de la Rochelle, France
Mehmet Gunes	Stevens Institute of Technology, USA
Sergio Gómez	Universitat Rovira i Virgili, Spain
Meesoon Ha	Chosun University, South Korea
Jürgen Hackl	University of Liverpool, Switzerland
Edwin Hancock	University of York, UK
Chris Hankin	Imperial College London, UK
Jin-Kao Hao	University of Angers, France
Heather Harrington	University of Oxford, UK

Yukio Hayashi	Japan Advanced Institute of Science and Technology, Japan
Mark Heimann	University of Michigan, USA
Torsten Heinrich	University of Oxford, Germany
Denis Helic	Graz University of Technology, Austria
Chittaranjan Hens	Indian Institute of Chemical Biology, India
Laura Hernandez	Université de Cergy-Pontoise, France
Samuel Heroy	University of Oxford, UK
Takayuki Hiraoka	Aalto University, Finland
Philipp Hoevel	University College Cork, Ireland
Petter Holme	Tokyo Institute of Technology, Japan
Seok-Hee Hong	University of Sydney, Australia
Ulrich Hoppe	University of Duisburg-Essen, Germany
Yanqing Hu	Sun Yat-sen University, China
Flavio Iannelli	Humboldt University, Germany
Yuichi Ikeda	Kyoto University, Japan
Roberto Interdonato	CIRAD - UMR TETIS, France
Giulia Iori	City, University of London, UK
Antonio Iovanella	University of Rome “Tor Vergata”, Italy
Gerardo Iñiguez	Central European University, Hungary
Sarika Jalan	IIT Indore, India
Mahdi Jalili	RMIT University, Australia
Jaroslav Jankowski	West Pomeranian University of Technology, Poland
Marco Alberto Javarone	Coventry University, UK
Hawoong Jeong	Korea Advanced Institute of Science and Technology, South Korea
Tao Jia	Southwest University, China
Chunheng Jiang	Rensselaer Polytechnic Institute, USA
Ming Jiang	University of Illinois at Urbana-Champaign, USA
Di Jin	Tianjin University, China
Di Jin	University of Michigan, USA
Ivan Jokić	Delft University of Technology, Netherlands
Bertrand Jouve	CNRS, France
Jason Jung	Chung-Ang University, South Korea
Marko Jusup	Tokyo Institute of Technology, Japan
Arkadiusz Jędrzejewski	Wrocław University of Science and Technology, Poland
Byungham Kahng	Seoul National University, South Korea
Rushed Kanawati	Université Paris 13, France
Rowland Kao	University of Edinburgh, UK
Márton Karsai	ENS de Lyon, France
Eytan Katzav	The Hebrew University of Jerusalem, Israel
Mehmet Kaya	Firat University, Turkey

Domokos Kelen	Institute for Computer Science and Control, Hungary
Dror Kenett	Johns Hopkins University, USA
Yoed Kenett	University of Pennsylvania, USA
Janos Kertesz	Central European University, Hungary
Mohammad Khansari	University of Tehran, Iran
Hamamache Kheddouci	Universite Claude Bernard, France
Hyoungshick Kim	Sungkyunkwan University, South Korea
Junseok Kim	University of Michigan, USA
Maksim Kitsak	Northeastern University, USA
Mikko Kivela	Aalto University, Finland
Konstantin Klemm	IFISC (CSIC-UIB), Spain
Peter Klimek	Medical University of Vienna, Austria
Daniel Kondor	SMART, Singapore
Xiangjie Kong	Dalian University of Technology, China
Ismo Koponen	University of Helsinki, Finland
Onerva Korhonen	Université de Lille, Finland
Jan Kralj	Jozef Stefan Institute, Slovenia
Reimer Kuehn	King's College London, UK
Prosenjit Kundu	National Institute of Technology Durgapur, India
Ryszard Kutner	University of Warsaw, Poland
Haewoon Kwak	Qatar Computing Research Institute, Qatar
Richard La	University of Maryland, USA
Hemank Lamba	Carnegie Mellon University, USA
Renaud Lambiotte	University of Oxford, UK
Aniello Lampo	UOC, Spain
Christine Largeron	Université de Lyon, France
Jennifer Larson	New York University, USA
Anna T. Lawniczak	University of Guelph, Ontario, Canada
Eric Leclercq	University of Burgundy, France
Deok-Sun Lee	Inha University, South Korea
Sune Lehmann	Technical University of Denmark, Denmark
Balazs Lengyel	Hungarian Academy of Sciences, Hungary
Juergen Lerner	University of Konstanz, Germany
Fabrizio Lillo	University of Bologna, Italy
Ji Liu	Stony Brook University, USA
Yang-Yu Liu	Harvard University, USA
Giacomo Livan	University College London, UK
Lorenzo Livi	University of Manitoba, Canada
Alessandro Longheu	University of Catania, Italy
Laura Lotero	Universidad Pontificia Bolivariana, Colombia
Meilian Lu	Beijing University of Posts and Telecommunications, China
John C. S. Lui	The Chinese University of Hong Kong, Hong Kong

Leonardo Maccari	Ca' Foscari University of Venice, Italy
Matteo Magnani	Uppsala University, Sweden
Cécile Mailler	UVSQ, France
Nishant Malik	Rochester Institute of Technology, USA
Fragkiskos Malliaros	University of Paris-Saclay, France
Noel Malod-Dognin	University College London, UK
Giuseppe Mangioni	University of Catania, Italy
Ed Manley	University of Leeds, UK
Rosario Nunzio Mantegna	Palermo University, Italy
Madhav Marathe	University of Virginia, USA
Manuel Sebastian Mariani	University of Zurich, Switzerland
Radek Marik	Czech Technical University, Czechia
Andrea Marino	University of Florence, Italy
Antonio Marques	Universidad Rey Juan Carlos, Spain
Manuel Marques-Pita	Universidade Lusofona, Portugal
Christoph Martin	Leuphana University of Lüneburg, Germany
Cristina Masoller	Universitat Politècnica de Catalunya, Spain
Emanuele Massaro	Ecole Polytechnique Fédérale de Lausanne, Switzerland
Rossana Mastrandrea	IMT Institute of Advanced Studies, Italy
John Matta	SIUE, USA
Arya McCarthy	Johns Hopkins University, USA
Fintan Mcgee	Gabriel Lippmann Public Research Centre, Ireland
Matúš Medo	University of Electronic Science and Technology of China, China
Jörg Menche	CeMM of the Austrian Academy of Sciences, Austria
Jose Fernando Mendes	University of Aveiro, Portugal
Ronaldo Menezes	University of Exeter, UK
Humphrey Mensah	Syracuse University, USA
Anke Meyer-Baese	FSU, USA
Radosław Michalski	Wrocław University of Science and Technology, Poland
Tijana Milenkovic	University of Notre Dame, USA
Letizia Milli	University of Pisa, Italy
Andreea Minca	Cornell University, USA
Shubhanshu Mishra	University of Illinois at Urbana-Champaign, USA
Bivas Mitra	Indian Institute of Technology Kharagpur, India
Marija Mitrovic	Institute of physics Belgrade, Serbia
Andrzej Mizera	University of Luxembourg, Luxembourg
Osnat Mokryn	University of Haifa, Israel
Roland Molontay	Budapest University of Technology and Economics, Hungary
Raul Mondragon	Queen Mary University of London, UK



Misael Mongiovi	Consiglio Nazionale delle Ricerche, Italy
Andres Moreira	Universidad Tecnica Federico Santa Maria, Chile
Paolo Moretti	Friedrich-Alexander-University Erlangen-Nurnberg, Germany
Esteban Moro	Universidad Carlos III de Madrid, Spain
Greg Morrison	University of Houston, USA
Sotiris Moschoyiannis	University of Surrey, UK
Elisha Moses	The Weizmann Institute of Science, Israel
Igor Mozetič	Jozef Stefan Institute, Slovenia
Animesh Mukherjee	Indian Institute of Technology, India
Masayuki Murata	Osaka University, Japan
Tsuyoshi Murata	Tokyo Institute of Technology, Japan
Alessandro Muscoloni	TU Dresden, Germany
Matthieu Nadini	New York University, Italy
Zachary Neal	Michigan State University, USA
Muaz Niazi	COMSATS Institute of IT, Pakistan
Rolf Niedermeier	TU Berlin, Germany
Peter Niemeyer	Leuphana Universität Lüneburg, Germany
Jordi Nin	Universitat Ramon Llull, Spain
Rogier Noldus	Ericsson, Netherlands
El Faouzi Nour-Eddin	IFSTTAR, France
Neave O'Clery	University College London, UK
Masaki Ogura	Nara Institute of Science and Technology, Japan
Marcos Oliveira	Leibniz Institute for the Social Sciences, USA
Andrea Omicini	Università degli Studi di Bologna, Italy
Luis Ospina-Forero	University of Manchester, UK
Gergely Palla	Statistical and Biological Physics Research Group of HAS, Hungary
Pietro Panzarasa	Queen Mary University of London, UK
Fragkiskos Papadopoulos	Cyprus University of Technology, Cyprus
Symeon Papadopoulos	Information Technologies Institute, Greece
Michela Papandrea	SUPSI, Switzerland
Francesca Parise	MIT, USA
Han Woo Park	Yeungnam University, South Korea
Juyong Park	KAIST, South Korea
Fabio Pasqualetti	UC Riverside, USA
Leto Peel	Universite Catholique de Louvain, Belgium
Tiago Peixoto	Central European University and ISI Foundation, Germany
Matjaz Perc	University of Maribor, Slovenia
Hernane Pereira	UEFS and SENAI CIMATEC, Brazil
Lilia Perfeito	Nova SBE, Portugal
Chiara Perillo	University of Zurich, Switzerland
Giovanni Petri	ISI Foundation, Italy
Jürgen Pfeffer	Technical University of Munich, Germany

Carlo Piccardi	Politecnico di Milano, Italy
Flavio Pinheiro	Universidade NOVA de Lisboa, USA
Clara Pizzuti	CNR-ICAR, Italy
Chiara Poletto	Sorbonne University, France
Maurizio Porfiri	New York University Tandon School of Engineering, USA
Pawel Pralat	Ryerson University, Canada
Victor Preciado	University of Pennsylvania, USA
Natasa Przulj	University College London, Spain
Oriol Pujol	University of Barcelona, Spain
Rami Puzis	Ben Gurion University of the Negev, Israel
Christian Quadri	University of Milan, Italy
Marco Quaggiotto	ISI Foundation, Italy
Filippo Radicchi	Northwestern University, USA
Tomasz Raducha	Faculty of Physics, University of Warsaw, Poland
Jose J. Ramasco	IFISC (CSIC-UIB), Spain
Felix Reed-Tsochas	University of Oxford, UK
Gesine Reinert	University of Oxford, UK
Benjamin Renoust	Osaka University, Japan
Daniel Rhoads	Universitat Oberta de Catalunya, Spain
Pedro Ribeiro	University of Porto, Portugal
Massimo Riccaboni	IMT Institute for Advanced Studies Lucca, Italy
Laura Ricci	University of Pisa, Italy
Alessandro Rizzo	Politecnico di Torino, Italy
Celine Robardet	INSA Lyon, France
Luis E. C. Rocha	Ghent University, Belgium
Luis M. Rocha	Indiana University Bloomington, USA
Francisco Rodrigues	University of São Paulo, Brazil
Fernando Rosas	Imperial College London, UK
Giulio Rossetti	KDD Lab ISTI-CNR, Italy
Camille Roth	CNRS, Germany
Celine Rozenblat	University of Lausanne, Institut de Géographie, Switzerland
Giancarlo Ruffo	Università di Torino, Italy
Meead Saberi	UNSW, Australia
Ali Safari	Friedrich-Alexander Universität Erlangen-Nürnberg, Germany
Marta Sales-Pardo	Universitat Rovira i Virgili, Spain
Arnaud Sallaberry	Université Paul Valéry Montpellier 3, France
Iraj Saniee	Bell Labs, Alcatel-Lucent, USA
Francisco C. Santos	Universidade de Lisboa, Portugal
Jari Saramäki	Aalto University, Finland
Koya Sato	University of Tsukuba, Japan
Hiroki Sayama	Binghamton University, USA
Antonio Scala	Italian National Research Council, Italy

Michael Schaub	University of Oxford, UK
Maximilian Schich	The University of Texas at Dallas, USA
Frank Schweitzer	ETH Zurich, Switzerland
Santiago Segarra	Rice University, USA
Irene Sendiña-Nadal	Rey Juan Carlos University, Spain
M. Ángeles Serrano	Universitat de Barcelona, Spain
Saray Shai	Wesleyan University, USA
Aneesh Sharma	Google, USA
Rajesh Sharma	University of Tartu, Estonia
Julian Sienkiewicz	Warsaw University of Technology, Poland
Anurag Singh	NIT Delhi, India
Lisa Singh	Georgetown University, USA
Rishabh Singhal	Dayalbagh Educational Institute, India
Sudeshna Sinha	Indian Institutes of Science Education and Research, India
Per Sebastian Skardal	Trinity College, USA
Oskar Skibski	University of Warsaw, Poland
Michael Small	The University of Western Australia, Australia
Keith Smith	University of Edinburgh, UK
Igor Smolyarenko	Brunel University London, UK
Zbigniew Smoreda	Orange Labs, France
Tom Snijders	University of Groningen, Netherlands
Annalisa Socievole	National Research Council of Italy, Italy
Igor M. Sokolov	Humboldt University of Berlin, Germany
Albert Sole	Universitat Rovira i Virgili, Spain
Sucheta Soundarajan	Syracuse University, USA
Jaya Sreevalsan-Nair	IIIT Bangalore, India
Massimo Stella	Institute for Complex Systems Simulation, UK
Arkadiusz Stopczynski	Technical University of Denmark, Denmark
Blair D. Sullivan	University of Utah, USA
Xiaoqian Sun	Beihang University, China
Xiaoqian Sun	Chinese Academy of Sciences, China
Pål Sundsøy	NBIM, Norway
Samir Suweis	University of Padua, Italy
Boleslaw Szymanski	Rensselaer Polytechnic Institute, USA
Bosiljka Tadic	Jozef Stefan Institute, Slovenia
Andrea Tagarelli	DIMES, University of Calabria, Italy
Kazuhiro Takemoto	Kyushu Institute of Technology, Japan
Frank Takes	Leiden University and University of Amsterdam, Netherlands
Fabien Tarissan	ENS Paris-Saclay (ISP), France
Dane Taylor	University at Buffalo, SUNY, USA
Claudio Juan Tessone	Universität Zürich, Switzerland
François Théberge	Tutte Institute for Mathematics and Computing, Canada

Olivier Togni	Burgundy University, France
Ljiljana Trajkovic	Simon Fraser University, Canada
Jan Treur	Vrije Universiteit Amsterdam, Netherlands
Milena Tsvetkova	London School of Economics and Political Science, UK
Liubov Tupikina	Ecole Polytechnique, France
Janos Török	Budapest University of Technology and Economics, Hungary
Stephen Uzzo	New York Hall of Science, USA
Lucas D. Valdez	FAMAF-UNC, Argentina
Pim van der Hoorn	Eindhoven University of Technology, Netherlands
Piet Van Mieghem	Delft University of Technology, Netherlands
Michalis Vazirgiannis	AUEB, Greece
Balazs Vedres	University of Oxford, UK
Wouter Vermeer	Northwestern University, USA
Christian Lyngby Vestergaard	CNRS and Institut Pasteur, France
Anil Kumar Vullikanti	University of Virginia, USA
Johannes Wachs	Central European University, Hungary
Huijuan Wang	Delft University of Technology, Netherlands
Lei Wang	Beihang University, China
Ingmar Weber	Qatar Computing Research Institute, Qatar
Guanghui Wen	Southeast University, China
Gordon Wilfong	Bell Labs, USA
Mateusz Wilinski	Scuola Normale Superiore di Pisa, Italy
Richard Wilson	University of York, UK
Dirk Witthaut	Forschungszentrum Jülich, Germany
Bin Wu	Beijing University of Posts and Telecommunications, China
Jinshan Wu	Beijing Normal University, China
Feng Xia	Federation University Australia, Australia
Haoxiang Xia	Dalian University of Technology, China
Xiaoke Xu	Dalian Minzu University, China
Gitanjali Yadav	University of Cambridge, UK
Gang Yan	Tongji University, China
Xiaoran Yan	Indiana University Bloomington, USA
Taha Yasseri	University of Oxford, UK
Ying Ye	Nanjing University, China
Qingpeng Zhang	City University of Hong Kong, USA
Zi-Ke Zhang	Hangzhou Normal University, China
Junfei Zhao	Columbia University, USA
Matteo Zignani	University of Milan, Italy
Eugenio Zimeo	University of Sannio, Italy
Lorenzo Zino	University of Groningen, Netherlands
Antonio Zippo	Consiglio Nazionale delle Ricerche, Italy

Fabiana Zollo  
Arkaitz Zubiaga  
Claudia Zucca

Ca' Foscari University of Venice, Italy  
Queen Mary University of London, UK  
University of Glasgow, UK

# Contents

## Community Structure

<b>A Method for Community Detection in Networks with Mixed Scale Features at Its Nodes</b> .....	3
Soroosh Shalileh and Boris Mirkin	
<b>Efficient Community Detection by Exploiting Structural Properties of Real-World User-Item Graphs</b> .....	15
Larry Yueli Zhang and Peter Marbach	
<b>Measuring Proximity in Attributed Networks for Community Detection</b> .....	27
Rinat Aynulin and Pavel Chebotarev	
<b>Core Method for Community Detection</b> .....	38
A. A. Chepovskiy, S. P. Khaykova, and D. A. Leshchev	
<b>Effects of Community Structure in Social Networks on Speed of Information Diffusion</b> .....	51
Nako Tsuda and Sho Tsugawa	
<b>Closure Coefficient in Complex Directed Networks</b> .....	62
Mingshan Jia, Bogdan Gabrys, and Katarzyna Musial	
<b>Nondiagonal Mixture of Dirichlet Network Distributions for Analyzing a Stock Ownership Network</b> .....	75
Wenning Zhang , Ryohei Hisano, Takaaki Ohnishi, and Takayuki Mizuno	
<b>Spectral Clustering for Directed Networks</b> .....	87
William R. Palmer and Tian Zheng	
<b>Composite Modularity and Parameter Tuning in the Weight-Based Fusion Model for Community Detection in Node-Attributed Social Networks</b> .....	100
Petr Chunaev, Timofey Gradov, and Klavdiya Bochenina	

<b>Maximal Labeled-Cliques for Structural-Functional Communities . . . . .</b>	<b>112</b>
Debajyoti Bera	
<b>Community Detection in a Multi-layer Network Over Social Media . . . .</b>	<b>124</b>
Maham Mobin Sheikh and Rauf Ahmed Shams Malick	
<b>Using Preference Intensity for Detecting Network Communities . . . . .</b>	<b>137</b>
József Dombi and Sakshi Dhama	
<b>Community Detection Algorithm Using Hypergraph Modularity . . . . .</b>	<b>152</b>
Bogumił Kamiński, Paweł Prałat, and François Théberge	
<b>Towards Causal Explanations of Community Detection in Networks . . .</b>	<b>164</b>
Georgia Baltso, Anastasios Gounaris, Apostolos N. Papadopoulos, and Konstantinos Tsichlas	
<b>A Pledged Community? Using Community Detection to Analyze Autocratic Cooperation in UN Co-sponsorship Networks . . . . .</b>	<b>177</b>
Cosima Meyer and Dennis Hammerschmidt	
<b>Distances on a Graph . . . . .</b>	<b>189</b>
Pierre Miasnikof, Alexander Y. Shestopaloff, Leonidas Pitsoulis, Alexander Ponomarenko, and Yuri Lawryshyn	
<b>Local Community Detection Algorithm with Self-defining Source Nodes . . . . .</b>	<b>200</b>
Saharnaz Dilmaghani, Matthias R. Brust, Gregoire Danoy, and Pascal Bouvry	
<b>Investigating Centrality Measures in Social Networks with Community Structure . . . . .</b>	<b>211</b>
Stephany Rajeh, Marinette Savonnet, Eric Leclercq, and Hocine Cherifi	
<b>Network Analysis</b>	
<b>Complex Network Analysis of North American Institutions of Higher Education on Twitter . . . . .</b>	<b>225</b>
Dmitry Zinoviev, Shana Cote, and Robert Díaz	
<b>Connectivity-Based Spectral Sampling for Big Complex Network Visualization . . . . .</b>	<b>237</b>
Jingming Hu, Seok-Hee Hong, Jialu Chen, Marnijati Torkel, Peter Eades, and Kwan-Liu Ma	
<b>Graph Signal Processing on Complex Networks for Structural Health Monitoring . . . . .</b>	<b>249</b>
Stefan Bloemheувel, Jurgen van den Hoogen, and Martin Atzmueller	
<b>An Analysis of Four Academic Department Collaboration Networks with Respect to Gender . . . . .</b>	<b>262</b>
Lauren Nakamichi, Theresa Migler, and Zoë Wood	

<b>Uncovering the Image Structure of Japanese TV Commercials Through a Co-occurrence Network Representation . . . . .</b>	<b>273</b>
Mariko I. Ito and Takaaki Ohnishi	
<b>Movie Script Similarity Using Multilayer Network Portrait Divergence . . . . .</b>	<b>284</b>
Majda Lafhel, Hocine Cherifi, Benjamin Renoust, Mohammed El Hassouni, and Youssef Mourchid	
<b>Interaction of Structure and Information on Tor . . . . .</b>	<b>296</b>
Mahdiah Zabihiyayvan, Reza Sadeghi, Dipesh Kadariya, and Derek Doran	
<b>Classifying Sleeping Beauties and Princes Using Citation Rarity . . . . .</b>	<b>308</b>
Takahiro Miura, Kimitaka Asatani, and Ichiro Sakata	
<b>Finding High-Degree Vertices with Inclusive Random Sampling . . . . .</b>	<b>319</b>
Yitzchak Novick and Amotz BarNoy	
<b>Concept-Centered Comparison of Semantic Networks . . . . .</b>	<b>330</b>
Darkhan Medeuov, Camille Roth, Ksenia Puzyreva, and Nikita Basov	
<b>Diffusion and Epidemics</b>	
<b>Analyzing the Impact of Geo-Spatial Organization of Real-World Communities on Epidemic Spreading Dynamics . . . . .</b>	<b>345</b>
Alexandru Topîrceanu	
<b>Identifying Biomarkers for Important Nodes in Networks of Sexual and Drug Activity . . . . .</b>	<b>357</b>
Jacob Grubb, Derek Lopez, Bhuvaneshwar Mohan, and John Matta	
<b>Opinion Dynamic Modeling of Fake News Perception . . . . .</b>	<b>370</b>
Cecilia Toccaceli, Letizia Milli, and Giulio Rossetti	
<b>Influence Maximization for Dynamic Allocation in Voter Dynamics . . .</b>	<b>382</b>
Zhongqi Cai, Markus Brede, and Enrico Gerding	
<b>Effect of Interaction Mechanisms on Facebook Dynamics Using a Common Knowledge Model . . . . .</b>	<b>395</b>
Chris J. Kuhlman, Gizem Korkmaz, S. S. Ravi, and Fernando Vega-Redondo	
<b>Using Link Clustering to Detect Influential Spreaders . . . . .</b>	<b>408</b>
Simon Krukowski and Tobias Hecking	
<b>Prediction of the Effects of Epidemic Spreading with Graph Neural Networks . . . . .</b>	<b>420</b>
Sebastian Mežnar, Nada Lavrač, and Blaž Škrlić	



<b>Learning Vaccine Allocation from Simulations</b> . . . . .	432
Gerrit Großmann, Michael Backenköhler, Jonas Klesen, and Verena Wolf	
<b>Suppressing Epidemic Spreading via Contact Blocking in Temporal Networks</b> . . . . .	444
Xunyi Zhao and Huijuan Wang	
<b>Blocking the Propagation of Two Simultaneous Contagions over Networks</b> . . . . .	455
Henry L. Carscadden, Chris J. Kuhlman, Madhav V. Marathe, S. S. Ravi, and Daniel J. Rosenkrantz	
<b>Stimulation Index of Cascading Transmission in Information Diffusion over Social Networks</b> . . . . .	469
Kazufumi Inafuku, Takayasu Fushimi, and Tetsuji Satoh	
<b>Diffusion Dynamics Prediction on Networks Using Sub-graph Motif Distribution</b> . . . . .	482
Alexey L. Zaykov, Danila A. Vaganov, and Valentina Y. Guleva	
<b>Using Distributed Risk Maps by Consensus as a Complement to Contact Tracing Apps</b> . . . . .	494
Miguel Rebollo, Rosa M. Benito, Juan C. Losada, and Javier Galeano	
<b>Dynamics on/of Networks</b>	
<b>Distributed Algorithm for Link Removal in Directed Networks</b> . . . . .	509
Azwirman Gusrialdi	
<b>Data Compression to Choose a Proper Dynamic Network Representation</b> . . . . .	522
Remy Cazabet	
<b>Effect of Nonisochronicity on the Chimera States in Coupled Nonlinear Oscillators</b> . . . . .	533
K. Premalatha, V. K. Chandrasekar, M. Senthilvelan, R. Amuda, and M. Lakshmanan	
<b>Evolution of Similar Configurations in Graph Dynamical Systems</b> . . . . .	544
Joshua D. Priest, Madhav V. Marathe, S. S. Ravi, Daniel J. Rosenkrantz, and Richard E. Stearns	
<b>Congestion Due to Random Walk Routing</b> . . . . .	556
Onuttom Narayan, Iraj Saniee, and Vladimir Marbukh	
<b>Strongly Connected Components in Stream Graphs: Computation and Experimentations</b> . . . . .	568
Léo Rannou, Clémence Magnien, and Matthieu Latapy	

<b>The Effect of Cryptocurrency Price on a Blockchain-Based Social Network</b> . . . . .	581
Cheick Tidiane Ba, Matteo Zignani, Sabrina Gaito, and Gian Paolo Rossi	
<b>Multivariate Information in Random Boolean Networks</b> . . . . .	593
Sebastián Orellana and Andrés Moreira	
<b>Earth Sciences Applications</b>	
<b>Complexity of the Vegetation-Climate System Through Data Analysis</b> . . . . .	609
Andrés F. Almeida-Ñañay, Rosa M. Benito, Miguel Quemada, Juan C. Losada, and Ana M. Tarquis	
<b>Towards Understanding Complex Interactions of Normalized Difference Vegetation Index Measurements Network and Precipitation Gauges of Cereal Growth System</b> . . . . .	620
David Rivas-Tabares and Ana M. Tarquis	
<b>Spatio-Temporal Clustering of Earthquakes Based on Average Magnitudes</b> . . . . .	627
Yuki Yamagishi, Kazumi Saito, Kazuro Hirahara, and Naonori Ueda	
<b>Information Spreading in Social Media</b>	
<b>Analyzing the Robustness of a Comprehensive Trust-Based Model for Online Social Networks Against Privacy Attacks</b> . . . . .	641
Nadav Voloch, Ehud Gudes, and Nurit Gal-Oz	
<b>Media Partisanship During Election: Indonesian Cases</b> . . . . .	651
Ardian Maulana and Hokky Situngkir	
<b>Media Polarization on Twitter During 2019 Indonesian Election</b> . . . . .	660
Ardian Maulana and Hokky Situngkir	
<b>Influence of Retweeting on the Behaviors of Social Networking Service Users</b> . . . . .	671
Yizhou Yan, Fujio Toriumi, and Toshiharu Sugawara	
<b>Author Index</b> . . . . .	683