

## Editor-in-Chief

*Kai Rannenberg, Goethe University Frankfurt, Germany*

## Editorial Board

TC 1 – Foundations of Computer Science

*Jacques Sakarovitch, Télécom ParisTech, France*

TC 2 – Software: Theory and Practice

*Michael Goedicke, University of Duisburg-Essen, Germany*

TC 3 – Education

*Arthur Tatnall, Victoria University, Melbourne, Australia*

TC 5 – Information Technology Applications

*Erich J. Neuhold, University of Vienna, Austria*

TC 6 – Communication Systems

*Aiko Pras, University of Twente, Enschede, The Netherlands*

TC 7 – System Modeling and Optimization

*Fredi Tröltzsch, TU Berlin, Germany*

TC 8 – Information Systems

*Jan Pries-Heje, Roskilde University, Denmark*

TC 9 – ICT and Society

*Diane Whitehouse, The Castlegate Consultancy, Malton, UK*

TC 10 – Computer Systems Technology

*Ricardo Reis, Federal University of Rio Grande do Sul, Porto Alegre, Brazil*

TC 11 – Security and Privacy Protection in Information Processing Systems

*Steven Furnell, Plymouth University, UK*

TC 12 – Artificial Intelligence

*Ulrich Furbach, University of Koblenz-Landau, Germany*

TC 13 – Human-Computer Interaction

*Marco Winckler, University Paul Sabatier, Toulouse, France*

TC 14 – Entertainment Computing

*Matthias Rauterberg, Eindhoven University of Technology, The Netherlands*

## **IFIP – The International Federation for Information Processing**

IFIP was founded in 1960 under the auspices of UNESCO, following the first World Computer Congress held in Paris the previous year. A federation for societies working in information processing, IFIP's aim is two-fold: to support information processing in the countries of its members and to encourage technology transfer to developing nations. As its mission statement clearly states:

*IFIP is the global non-profit federation of societies of ICT professionals that aims at achieving a worldwide professional and socially responsible development and application of information and communication technologies.*

IFIP is a non-profit-making organization, run almost solely by 2500 volunteers. It operates through a number of technical committees and working groups, which organize events and publications. IFIP's events range from large international open conferences to working conferences and local seminars.

The flagship event is the IFIP World Computer Congress, at which both invited and contributed papers are presented. Contributed papers are rigorously refereed and the rejection rate is high.

As with the Congress, participation in the open conferences is open to all and papers may be invited or submitted. Again, submitted papers are stringently refereed.

The working conferences are structured differently. They are usually run by a working group and attendance is generally smaller and occasionally by invitation only. Their purpose is to create an atmosphere conducive to innovation and development. Refereeing is also rigorous and papers are subjected to extensive group discussion.

Publications arising from IFIP events vary. The papers presented at the IFIP World Computer Congress and at open conferences are published as conference proceedings, while the results of the working conferences are often published as collections of selected and edited papers.

IFIP distinguishes three types of institutional membership: Country Representative Members, Members at Large, and Associate Members. The type of organization that can apply for membership is a wide variety and includes national or international societies of individual computer scientists/ICT professionals, associations or federations of such societies, government institutions/government related organizations, national or international research institutes or consortia, universities, academies of sciences, companies, national or international associations or federations of companies.

More information about this series at <http://www.springer.com/series/6102>

Gilbert Peterson · Sujeet Shenoj (Eds.)

# Advances in Digital Forensics XIV

14th IFIP WG 11.9 International Conference  
New Delhi, India, January 3–5, 2018  
Revised Selected Papers

*Editors*

Gilbert Peterson  
Department of Electrical and Computer  
Engineering  
Air Force Institute of Technology  
Wright-Patterson AFB, OH  
USA

Sujeet Shenoj  
Tandy School of Computer Science  
University of Tulsa  
Tulsa, OK  
USA

ISSN 1868-4238 ISSN 1868-422X (electronic)  
IFIP Advances in Information and Communication Technology  
ISBN 978-3-319-99276-1 ISBN 978-3-319-99277-8 (eBook)  
<https://doi.org/10.1007/978-3-319-99277-8>

Library of Congress Control Number: 2018951631

© IFIP International Federation for Information Processing 2018

This work is subject to copyright. All rights are reserved 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, express 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

# Contents

Contributing Authors	ix
Preface	xvii
PART I THEMES AND ISSUES	
1	
Measuring Evidential Weight in Digital Forensic Investigations	3
<i>Richard Overill and Kam-Pui Chow</i>	
2	
Challenges, Opportunities and a Framework for Web Environment Forensics	11
<i>Mike Mabey, Adam Doupé, Ziming Zhao and Gail-Joon Ahn</i>	
3	
Internet of Things Forensics – Challenges and a Case Study	35
<i>Saad Alabdulsalam, Kevin Schaefer, Tahar Kechadi and Nhien-An Le-Khac</i>	
PART II FORENSIC TECHNIQUES	
4	
Recovery of Forensic Artifacts from Deleted Jump Lists	51
<i>Bhupendra Singh, Upasna Singh, Pankaj Sharma and Rajender Nath</i>	
5	
Obtaining Precision-Recall Trade-Offs in Fuzzy Searches of Large Email Corpora	67
<i>Kyle Porter and Slobodan Petrovic</i>	
6	
Anti-Forensic Capacity and Detection Rating of Hidden Data in the Ext4 Filesystem	87
<i>Thomas Göbel and Harald Baier</i>	

7

- Detecting Data Leakage from Hard Copy Documents 111  
*Jijnasa Nayak, Shweta Singh, Saheb Chhabra, Gaurav Gupta, Monika Gupta and Garima Gupta*

## PART III NETWORK FORENSICS

8

- Information-Entropy-Based DNS Tunnel Prediction 127  
*Irvin Homem, Panagiotis Papapetrou and Spyridon Dosis*

9

- Collecting Network Evidence Using Constrained Approximate Search Algorithms 141  
*Ambika Shrestha Chitrakar and Slobodan Petrovic*

10

- Traffic Classification and Application Identification in Network Forensics 161  
*Jan Pluska, Ondrej Lichtner and Ondrej Rysavy*

11

- Enabling Non-Expert Analysis of Large Volumes of Intercepted Network Traffic 183  
*Erwin van de Wiel, Mark Scanlon and Nhien-An Le-Khac*

12

- Hashing Incomplete and Unordered Network Streams 199  
*Chao Zheng, Xiang Li, Qingyun Liu, Yong Sun and Binxing Fang*

13

- A Network Forensic Scheme Using Correntropy-Variation for Attack Detection 225  
*Nour Moustafa and Jill Slay*

## PART IV CLOUD FORENSICS

14

- A Taxonomy of Cloud Endpoint Forensic Tools 243  
*Anand Kumar Mishra, Emmanuel Pilli and Mahesh Govil*

15

- A Layered Graphical Model for Cloud Forensic Mission Attack Impact Analysis 263  
*Changwei Liu, Anoop Singhal and Duminda Wijesekera*

## PART V MOBILE AND EMBEDDED DEVICE FORENSICS

16

Forensic Analysis of Android Steganography Apps 293  
*Wenhao Chen, Yangxiao Wang, Yong Guan, Jennifer Newman, Li Lin and Stephanie Reinders*

17

Automated Vulnerability Detection in Embedded Devices 313  
*Danjun Liu, Yong Tang, Baosheng Wang, Wei Xie and Bo Yu*

18

A Forensic Logging System for Siemens Programmable Logic Controllers 331  
*Ken Yau, Kam-Pui Chow and Siu-Ming Yiu*

19

Enhancing the Security and Forensic Capabilities of Programmable  
Logic Controllers 351  
*Chun-Fai Chan, Kam-Pui Chow, Siu-Ming Yiu and Ken Yau*

# Contributing Authors

**Gail-Joon Ahn** is a Professor of Computer Science and Engineering, and Director of the Center for Cybersecurity and Digital Forensics at Arizona State University, Tempe, Arizona. His research interests include security analytics and big-data-driven security intelligence, vulnerability and risk management, access control and security architectures for distributed systems, identity and privacy management, cyber crime analysis, security-enhanced computing platforms and formal models for computer security devices.

**Saad Alabdulsalam** is a Ph.D. student in Computer Science at University College Dublin, Dublin, Ireland. His research interests include Internet of Things security and forensics.

**Harald Baier** is a Professor of Internet Security at Darmstadt University of Applied Sciences, Darmstadt, Germany; and a Principal Investigator at the Center for Research in Security and Privacy, Darmstadt, Germany. His research interests include digital forensics, network-based anomaly detection and security protocols.

**Chun-Fai Chan** is a Ph.D. student in Computer Science at the University of Hong Kong, Hong Kong, China. His research interests include penetration testing, digital forensics and Internet of Things security.

**Wenhao Chen** is a Ph.D. student in Computer Engineering at Iowa State University, Ames, Iowa. His research interests include program analysis and digital forensics.



**Saheb Chhabra** is a Ph.D. student in Computer Science and Engineering at Indraprastha Institute of Information Technology, New Delhi, India. His research interests include image processing and computer vision, and their applications to document fraud detection.

**Kam-Pui Chow** is an Associate Professor of Computer Science at the University of Hong Kong, Hong Kong, China. His research interests include information security, digital forensics, live system forensics and digital surveillance.

**Spyridon Dosis** is a Security Engineer at NetEnt, Stockholm, Sweden. His research interests include network security, digital forensics, cloud computing and semantic web technologies.

**Adam Doupé** is an Assistant Professor of Computer Science and Engineering, and Associate Director of the Center for Cybersecurity and Digital Forensics at Arizona State University, Tempe, Arizona. His research interests include vulnerability analysis, web security, mobile security, network security and ethical hacking.

**Binxing Fang** is a Member of the Chinese Academy of Engineering, Beijing, China; and a Professor of Information Engineering at the University of Electronic Science and Technology, Guangdong, China. His research interests are in the area of cyber security.

**Thomas Göbel** is a Ph.D. student in Computer Science at Darmstadt University of Applied Sciences, Darmstadt, Germany; and a Researcher at the Center for Research in Security and Privacy, Darmstadt, Germany. His research interests include digital forensics, anti-forensics and network forensics.

**Mahesh Govil** is a Professor of Computer Science and Engineering at Malaviya National Institute of Technology, Jaipur, India; and Director of National Institute of Technology Sikkim, Ravangla, India. His research interests include real-time systems, parallel and distributed systems, fault-tolerant systems and cloud computing.

**Yong Guan** is a Professor of Electrical and Computer Engineering at Iowa State University, Ames, Iowa. His research interests include digital forensics and information security.

**Garima Gupta** is a Postdoctoral Researcher in Computer Science and Engineering at Indraprastha Institute of Information Technology, New Delhi, India. Her research interests include image processing and computer vision, and their applications to document fraud detection.

**Gaurav Gupta** is a Scientist D in the Ministry of Information Technology, New Delhi, India. His research interests include mobile device security, digital forensics, web application security, Internet of Things security and security in emerging technologies.

**Monika Gupta** recently received her Ph.D. degree in Physics from National Institute of Technology Kurukshetra, Kurukshetra, India. Her research interests include image processing and computer vision, and their applications to document fraud detection.

**Irvin Homem** is a Ph.D. student in Computer and Systems Sciences at Stockholm University, Stockholm, Sweden; and a Threat Intelligence Analyst with IBM, Stockholm, Sweden. His research interests include network security, digital forensics, mobile forensics, machine learning, virtualization and cloud computing.

**Tahar Kechadi** is a Professor of Computer Science at University College Dublin, Dublin, Ireland. His research interests include data extraction and analysis, and data mining in digital forensics and cyber crime investigations.

**Nhien-An Le-Khac** is a Lecturer of Computer Science, and Director of the Forensic Computing and Cybercrime Investigation Program at University College Dublin, Dublin, Ireland. His research interests include digital forensics, cyber security and big data analytics.

**Xiang Li** is a Researcher at the Bank of China, Beijing, China. Her research interests include web application security and digital forensics.

**Ondrej Lichtner** is a Ph.D. student in Information Technology at Brno University of Technology, Brno, Czech Republic. His research interests include network architecture design and secure network architectures.

**Li Lin** is a Ph.D. student in Applied Mathematics at Iowa State University, Ames, Iowa. His research interests include digital image forensics and statistical machine learning.

**Changwei Liu** is a Postdoctoral Researcher in the Department of Computer Science at George Mason University, Fairfax, Virginia. Her research interests include network security, cloud security and digital forensics.

**Danjun Liu** is an M.S. student in Computer Science and Technology at the National University of Defense Technology, Changsha, China. His research interests include cyber security and software reliability.

**Qingyun Liu** is a Professor of Information Engineering at the Institute of Information Engineering, Chinese Academy of Sciences, Beijing, China. His research interests include information security and network security.

**Mike Mabey** recently received his Ph.D. in Computer Science from Arizona State University, Tempe, Arizona. His research interests include digital forensics, threat intelligence sharing and security in emerging technologies.

**Anand Kumar Mishra** is a Ph.D. student in Computer Science and Engineering at Malaviya National Institute of Technology, Jaipur, India; and a Guest Researcher in the Information Technology Laboratory at the National Institute of Standards and Technology, Gaithersburg, Maryland. His research interests include digital forensics and cyber security, especially related to cloud computing and container technology.

**Nour Moustafa** is a Postdoctoral Research Fellow at the Australian Centre for Cyber Security, University of New South Wales, Canberra, Australia. His research interests include cyber security, intrusion detection and machine learning.

**Rajender Nath** is a Professor of Computer Science and Engineering at Kurukshetra University, Kurukshetra, India. His research interests include computer architecture, parallel processing, object-oriented modeling and aspect-oriented programming.

**Jijnasa Nayak** is a B.Tech. student in Computer Science and Engineering at National Institute of Technology Rourkela, Rourkela, India. Her research interests include computer vision, image processing, natural language processing and their applications to document fraud detection.

**Jennifer Newman** is an Associate Professor of Mathematics at Iowa State University, Ames, Iowa. Her research interests include digital image forensics and image processing.

**Richard Overill** is a Senior Lecturer of Computer Science at King's College London, London, United Kingdom. His research interests include digital forensics and cyber crime analysis.

**Panagiotis Papapetrou** is a Professor of Computer and Systems Sciences at Stockholm University, Stockholm, Sweden; and an Adjunct Professor of Computer Science at Aalto University, Helsinki, Finland. His research interests include algorithmic data mining with a focus on mining and indexing sequential data, complex metric and non-metric spaces, biological sequences, time series and sequences of temporal intervals.

**Slobodan Petrovic** is a Professor of Information Security at the Norwegian University of Science and Technology, Gjøvik, Norway. His research interests include cryptography, intrusion detection and digital forensics.

**Emmanuel Pilli** is an Associate Professor of Computer Science and Engineering at Malaviya National Institute of Technology, Jaipur, India. His research interests include cyber security, privacy and forensics, computer networks, cloud computing, big data and the Internet of Things.

**Jan Pluskal** is a Ph.D. student in Information Technology at Brno University of Technology, Brno, Czech Republic. His research interests include network forensics, machine learning and distributed computing.

**Kyle Porter** is a Ph.D. student in Information Security and Communications Technology at the Norwegian University of Science and Technology, Gjøvik, Norway. His research interests include approximate string matching algorithms, and applications of machine learning and data reduction mechanisms in digital forensics.

**Stephanie Reinders** is a Ph.D. student in Applied Mathematics at Iowa State University, Ames, Iowa. Her research interests include steganalysis and machine learning.

**Ondrej Rysavy** is an Associate Professor of Information Systems at Brno University of Technology, Brno, Czech Republic. His research interests are in the area of computer networks, especially, network monitoring, network security, network forensics and network architectures.

**Mark Scanlon** is an Assistant Professor of Computer Science, and Co-Director of the Forensic Computing and Cybercrime Investigation Program at University College Dublin, Dublin, Ireland. His research interests include artificial-intelligence-based digital evidence processing, digital forensics as a service and remote evidence processing.

**Kevin Schaefer** is an Information Technology and Forensics Investigator at the Land Office of Criminal Investigation Baden-Wuerttemberg in Stuttgart, Germany. His research interests include mobile phone and smartwatch forensics.

**Pankaj Sharma** is an Assistant Professor of Computer Science and Engineering at Chitkara University, Punjab, India. His research interests include digital forensics, security and privacy.

**Ambika Shrestha Chitrakar** is a Ph.D. student in Information Security and Communications Technology at the Norwegian University of Science and Technology, Gjøvik, Norway. Her research interests include approximate search algorithms, intrusion detection and prevention, big data, machine learning and digital forensics.

**Bhupendra Singh** is a Ph.D. student in Computer Science and Engineering at the Defence Institute of Advanced Technology, Pune, India. His research interests include digital forensics, filesystem analysis and user activity analysis in Windows and Linux systems.

**Shweta Singh** is a B.Tech. student in Computer Science at Maharsihi Dayanand University, Rohtak, India. Her research interests include machine learning and their applications to digitized document fraud.

**Upasna Singh** is an Assistant Professor of Computer Science and Engineering at the Defence Institute of Advanced Technology, Pune, India. Her research interests include data mining and knowledge discovery, machine intelligence, soft computing, digital forensics, social network analysis and big data analytics.

**Anoop Singhal** is a Senior Computer Scientist, and Program Manager in the Computer Security Division at the National Institute of Standards and Technology, Gaithersburg, Maryland. His research interests include network security, network forensics, cloud security and data mining.

**Jill Slay** is the La Trobe Optus Chair of Cyber Security at La Trobe University, Melbourne, Australia. Her research interests include digital forensics, cyber intelligence and cyber skilling.

**Yong Sun** is a Professor of Information Engineering at the Institute of Information Engineering, Chinese Academy of Sciences, Beijing, China. His research interests include information security and network security.

**Yong Tang** is an Associate Researcher in the Network Research Institute at the National University of Defense Technology, Changsha, China. His research interests include cyber security and software reliability.

**Erwin van de Wiel** is a Digital Forensic Investigator with the Dutch Police in Breda, The Netherlands. His research interests are in the area of digital forensics.

**Baosheng Wang** is a Researcher in the Network Research Institute at the National University of Defense Technology, Changsha, China. His research interests include computer networks and software reliability.

**Yangxiao Wang** recently received his B.S. degree in Computer Engineering from Iowa State University, Ames, Iowa. His research interests include digital forensics and information security.

**Duminda Wijesekera** is a Professor of Computer Science at George Mason University, Fairfax, Virginia. His research interests include systems security, digital forensics and transportation systems.

**Wei Xie** is an Assistant Researcher in the Network Research Institute at the National University of Defense Technology, Changsha, China. His research interests include cyber security and software reliability.

**Ken Yau** is a Ph.D. student in Computer Science at the University of Hong Kong, Hong Kong, China. His research interests are in the area of digital forensics, with an emphasis on industrial control system forensics.

**Siu-Ming Yiu** is an Associate Professor of Computer Science at the University of Hong Kong, Hong Kong, China. His research interests include security, cryptography, digital forensics and bioinformatics.

**Bo Yu** is an Assistant Researcher in the Network Research Institute at the National University of Defense Technology, Changsha, China. His research interests include cyber security and software reliability.

**Ziming Zhao** is an Assistant Research Professor in the School of Computing, Informatics and Decision Systems Engineering at Arizona State University, Tempe, Arizona. His research interests include system and network security.

**Chao Zheng** is an Associate Professor of Information Engineering at the Institute of Information Engineering, Chinese Academy of Sciences, Beijing, China. His research interests include deep packet inspection, digital forensics, protocols and network security.

# Preface

Digital forensics deals with the acquisition, preservation, examination, analysis and presentation of electronic evidence. Computer networks, cloud computing, smartphones, embedded devices and the Internet of Things have expanded the role of digital forensics beyond traditional computer crime investigations. Practically every crime now involves some aspect of digital evidence; digital forensics provides the techniques and tools to articulate this evidence in legal proceedings. Digital forensics also has myriad intelligence applications; furthermore, it has a vital role in information assurance – investigations of security breaches yield valuable information that can be used to design more secure and resilient systems.

This book, *Advances in Digital Forensics XIV*, is the fourteenth volume in the annual series produced by the IFIP Working Group 11.9 on Digital Forensics, an international community of scientists, engineers and practitioners dedicated to advancing the state of the art of research and practice in digital forensics. The book presents original research results and innovative applications in digital forensics. Also, it highlights some of the major technical and legal issues related to digital evidence and electronic crime investigations.

This volume contains nineteen revised and edited chapters based on papers presented at the Fourteenth IFIP WG 11.9 International Conference on Digital Forensics, held in New Delhi, India on January 3-5, 2018. The papers were refereed by members of IFIP Working Group 11.9 and other internationally-recognized experts in digital forensics. The post-conference manuscripts submitted by the authors were rewritten to accommodate the suggestions provided by the conference attendees. They were subsequently revised by the editors to produce the final chapters published in this volume.

The chapters are organized into five sections: Themes and Issues, Forensic Techniques, Network Forensics, Cloud Forensics, and Mobile and Embedded Device Forensics. The coverage of topics highlights the



richness and vitality of the discipline, and offers promising avenues for future research in digital forensics.

This book is the result of the combined efforts of several individuals. In particular, we thank Gaurav Gupta and Robin Verma for their tireless work on behalf of IFIP Working Group 11.9 on Digital Forensics. We also acknowledge the conference sponsors, Cellebrite, Magnet Forensics and Lab Systems, as well as the support provided by the Department of Electronics and Information Technology (Ministry of Communications and Information Technology, Government of India), U.S. National Science Foundation, U.S. National Security Agency and U.S. Secret Service.

GILBERT PETERSON AND SUJEET SHENOI