ICIAM 2019 SEMA SIMAI Springer Series 1

Tomás Chacón Rebollo
Rosa Donat
Inmaculada Higueras *Editors*

Recent Advances in Industrial and Applied Mathematics

OPEN ACCESS

Springer

SEMA SIMAI Springer Series

ICIAM 2019 SEMA SIMAI Springer Series

Volume 1

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This sub-series of the SEMA SIMAI Springer Series aims to publish some of the most relevant results presented at the ICIAM 2019 conference held in Valencia in July 2019.

The sub-series is managed by an independent Editorial Board, and will include peer-reviewed content only, including the Invited Speakers volume as well as books resulting from mini-symposia and collateral workshops.

The series is aimed at providing useful reference material to academic and researchers at an international level.

More information about this subseries at https://link.springer.com/bookseries/16499

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ISSN 2199-3041 ISSN 2199-305X (electronic)
SEMA SIMAI Springer Series
ISSN 2662-7183 ISSN 2662-7191 (electronic)
ICIAM 2019 SEMA SIMAI Springer Series
ISBN 978-3-030-86235-0 ISBN 978-3-030-86236-7 (eBook)
https://doi.org/10.1007/978-3-030-86236-7

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The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Foreword

During the second week of July, the ICIAM 2019 Congress took place in Valencia with almost 4,000 participants, with 50 plenary talks, more than 300 mini-symposia, 550 contributed talks and 250 posters. A wide representation of world applied mathematics met in Valencia to present and discuss how mathematics was applied to the most diverse disciplines, such as applied mathematics for industry and engineering, biology, medicine and other natural sciences, control and systems theory, dynamical systems and nonlinear analysis, finance and management science, industrial mathematics, mathematics and computer science, numerical analysis, partial differential equations and simulation and modeling, to name some of them.

Within the organizing committee, the idea arose that these presentations and discussions should be reflected in some way for the future. And the offer from Springer came up to launch a series of volumes that would record the most notable advances that took place in it.

This offer crystallized in the *ICIAM 2019 SEMA SIMAI Springer Series*, which includes the present volume, dedicated to the conferences of the invited speakers, which occupies a very central and special place, since it is offered in open access mode, thanks to the support of Sociedad Española de Matemática Aplicada (SeMA).

The selection of the 336 mini symposia of the ICIAM 2019 was made by its academic committee. In a very direct relationship with it, the editorial committee of this series was formed by F. Arándiga Llaudes, M. Gómez Mármol, F. Guillén-González, F. Ortegón Gallego, C. Parés, P. Quintela, C. Vázquez-Cendón, S. Xambó-Descamps and myself. The members of this committee were in charge of selecting the proposals, many of them derived from mini-congress symposia, and also to act as the editors in charge for some of the 14 volumes that make up this series:

1. *Recent Advances in Industrial and Applied Mathematics*, edited by Tomás Chacón Rebollo, Rosa Donat and Inmaculada Higueras.
2. *Stabilization of Distributed Parameter Systems: Design Methods and Applications*, edited by Grigory Sklyar and Alexander Zuyev.
3. *Cartesian CFD Methods for Complex Applications*, edited by Ralf Deiterding, Margarete Oliveira and Kai Schneider.

4. *Applications of Wavelet Multiresolution Analysis*, edited by Juan Pablo Muszkats, Silvia Alejandra Seminara and María Inés Troparevsky.
5. *Progress in Industrial Mathematics: Success Stories*, edited by Manuel Cruz, Carlos Parés and Peregrina Quintela.
6. *Applied Mathematics for Environmental Problems*, edited by María Isabel Asensio, Albert Oliver and José Sarrate.
7. *Improving Applied Mathematics Education*, edited by Ron Buckmire and Jessica M. Libertini.
8. *Fractals in Engineering: Theoretical Aspects and Numerical Approximations*, edited by Maria Rosaria Lancia and Anna Rozanova-Pierrat.
9. *Recent Advances in Differential Equations and Control Theory*, edited by Concepción Muriel and Carmen Pérez-Martínez.
10. *Emerging Problems in the Homogenization of Partial Differential Equations*, edited by Patrizia Donato and Manuel Luna-Laynez.
11. *Multidisciplinary Mathematical Modeling*, edited by Francesc Font and Tim Myers.
12. *Mathematical Descriptions of Traffic Flow: Micro, Macro and Kinetic Models*, edited by Gabriella Puppo and Andrea Tosin.
13. *Systems, Patterns and Data Engineering with Geometric Calculi*, edited by Sebastià Xambó-Descamps.
14. *Modeling, Simulation and Optimization in the Health and Energy Sector*, edited by Rene Pinnau, Nicolas R. Gauger and Axel Klar.

As can be easily seen, the application of mathematics spreads through the most diverse areas, such as industry, health and energy, engineering data science, environmental problems, geometric calculi, numerical approximation, traffic flow, education, etc.

Now is the time for the reader to delve into the volumes of this series and learn, reflect, incorporate new ideas and generally enjoy their content, hoping that the volumes of this series can serve as a reference for even more innovative applications of mathematics in the future.

Finally, it is time of acknowledgements. Starting with the ICIAM 2019 Congress, especially its executive committee led by Tomás Chacón and Rosa Donat as living forces of the event, as well as the scientific committee led by Alfio Quarterioni and the multiple organizers of mini-symposia, speakers and attendees. Continuing with Francesca Bonadei as the promotor within Springer of the need for the existence of this series, and with the members of the editorial board of this series, and ending with the editors in charge and authors of each volume, which with its excellent work, are the real creators of the message of this series.

Barcelona, Spain Amadeu Delshams

Preface

The papers appearing in this volume are authored by some of the invited speakers of the **9th International Congress of Industrial and Applied Mathematics**, held in València from July 15 to 19, 2019. This volume is part of a series dedicated to ICIAM 2019-Valencia.

The congress, hosted by the Spanish Society for Applied Mathematics (SeMA), was organized at the Universitat de València (Spain), on behalf of the International Council for Industrial and Applied Mathematics (ICIAM). With 3983 participants from 99 different countries, more than 3400 lectures delivered and nearly 250 poster presentations, ICIAM 2019 has been a great success. These data represent a net increase in participation, with respect to an already rising trend in previous editions of this series of events, which can be considered a sound proof of the growing interest of the applied and industrial mathematics community in ICIAM congresses.

The industrial aspect of the congress was further enriched by organizing a specific mathematical technology transfer oriented activity: '*The Industry Day'*. Fourteen speakers, selected from a broad representation of different sectors, presented the results of ongoing collaborations with academy and the benefits derived from it, such as better products and services, optimization of processes, organization and accounting, and growth and innovation. In addition, 19 industrial mini-symposia were scheduled during the congress, and 48 'industry-related' posters were on display during '*The Industry Day*.'

Thirty-five satellite events took place during 2018 and 2019 covering a broad range of topics within industrial and applied mathematics. These events included two CIMPA schools (Kenitra, Morocco and Tunis, Tunisia, 2019), devoted to initiate young students from developing countries into research. Also, several Spanish towns/regions were appointed sub-venues of ICIAM-2019-Valencia (Bilbao, Galicia, Málaga, Seville and Zaragoza) and, as such, organized 12 satellite events. We are deeply thankful to the organizers of all satellite events.

The preparation of the candidacy in 2012 started the long process involved in the planning of this complex event. Our deepest gratitude and heartiest thanks go to all the people who helped with their abilities to create ICIAM 2019-Valencia. A list of all the committees and people involved in this task is given in this book.

The congress could not have been possible without the support of a large set of sponsors. A special mention is due to our main sponsors: Banco Santander, who financed over 70% of the Grant Program of the congress, and the Universitat de València, for its generous offer to make available their facilities to hold the conference. Thanks are also due to the Spanish universities that contributed to fund over 20% of the Grant Program and to the individual donors who contributed to the remaining 5%.

A thankful recognition is also due to our four institutional sponsors: Ministry of Science, Innovation and Universities, Generalitat Valenciana, Diputació de València and Ajuntament de València.

On behalf of ICIAM 2019, we would like to express our most sincere gratitude to the invited speakers that have contributed to this volume for taking the time to provide their valuable contributions, helping us to make this the reference publication of the congress.

Sevilla, Spain — Tomás Chacón Rebollo
Valencia, Spain — Rosa Donat
Pamplona, Spain — Inmaculada Higueras

ICIAM Congresses

1987	Paris
1991	Washington, D.C.
1995	Hamburg
1999	Edinburgh
2003	Sydney
2007	Zurich
2011	Vancouver
2015	Beijing

2019-Valencia

Opening ceremony

Traditional valencian dances and Muixeranga (human towers)

Plenary talk

Closing ceremony and transfer of ICIAM flag

ICIAM Prize Winners

ICIAM Collatz Prize

1999 Stefan Müller, Max Planck Institut für Mathematik Leipzig, Germany.
2003 Weinan E, Princeton University, USA.
2007 Felix Otto, Universität Bonn, Germany.
2011 Emmanuel J. Candès, Stanford University and CALTECH, USA
2015 Annalisa Buffa, CNR-IMATI, Italy.
2019 Siddharta Mishra, ETH Zürich, Switzerland.

ICIAM Lagrange Prize

1999 Jacques-L. Lions, Collège de France and Académie des Sciences de Paris, France.
2003 Enrico Magenes, Università di Pavia, Italy.
2007 Joseph Keller, Stanford University, USA.
2011 Alexandre J. Chorin, U.C. Berkeley and LBNL, USA.
2015 Andrew J. Majda, New York University, USA.
2019 George Papanicolaou, Stanford University, USA.

ICIAM Maxwell Prize

1999 Grigory I. Barenblatt, UC Berkeley, USA, and University of Cambridge, UK.
2003 Martin D. Kruskal, Rutgers University, USA.
2007 Peter Deuflhard, Zuse Institute Berlin, Germany.
2011 Vladimir Rokhlin, Yale University, USA.

2015 Jean-Michel Coron, Université Pierre et Marie Curie, France.
2019 Claude Bardos, Université Paris Diderot (Paris VII), France.

ICIAM Pioneer Prize

1999 Ronald R. Coifman, Yale University, USA,
Helmut Neunzert, University of Kaiserslautern, Germany.
2003 Stanley Osher, University of California, Los Angeles, USA.
2007 Ingrid Daubechies, Princeton University, USA,
Heinz Engl, Johannes Kepler University, and Austrian Academy of Sciences, Austria.
2011 James Albert Sethian, UC Berkeley and LBNL, USA.
2015 Björn Engquist, The University of Texas at Austin, USA.
2019 Yvon Maday, Sorbonne University, Paris, France.

ICIAM Su Buchin Prize

2007 Gilbert Strang, Massachusetts Institute of Technology, USA.
2011 Edward Lungu, University of Botswana, Botswana.
2015 Li Tatsien, Fudan University, P.R. China.
2019 Giulia Di Nunno, University of Oslo, Norway.

2019 ICIAM Prize Ceremony. From left to right: Joan Ribó (Major of Valencia), Ximo Puig (President of the Generalitat Valenciana), Y. Maday, G. Di Nunno, His Majesty Felipe VI, G. Papanicolaou, C. Bardos, S. Mishra, M. Esteban and Pedro Duque (Minister for Science, Innovation and Universities)

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Acronyms of Spanish Universities

UC3M	Carlos III University, Madrid
UDC	University of A Coruña
UA	University of Alicante
UCA	University of Cadiz
UC	University of Cantabria
UCLM	University of Castilla La Mancha
ULL	University of La Laguna
UMA	University of Malaga
UNAV	University of Navarra
UNIOVI	University of Oviedo
USC	University of Santiago de Compostela
US	University of Seville
UVA	University of Valladolid

UVIGO	University of Vigo
UNIZAR	University of Zaragoza
UPV/EHU	University of the Basque Country
UMH	Miguel Hernández University
UPM	Technical University of Madrid
UPNA	Public University of Navarra
UIB	University of the Balearic Islands
UV	Universitat de València
UJI	Universitat Jaume I
UPC	Universitat Politècnica de Catalunya
UPV	Universitat Politècnica de València

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Opening Ceremony

Tomás Chacón Rebollo, Congress Director

Your Majesty, President of the Region of Valencia, Minister of Science, Innovation and Universities, Major of Valencia, President of ICIAM, respected guests and delegates, on behalf of the Spanish Society for Applied Mathematics and the organizing committee, it is for me a pleasure to convey you our warmest welcome to ICIAM-2019-Valencia Congress.

Mathematics is silently shaping the present technological world. It provides a deep insight in numberless processes and systems, thereby advancing scientific knowledge. It also generates added value in virtually all economic sectors. On top of that, the last years have witnessed a change in paradigm, as mathematics directly provide the technological basis of emerging sectors related with data analysis.

The research and transfer in mathematics have experienced a fast development in Spain; besides all sciences, since the last decades of the twentieth century, Spain occupies today the 7th world position in mathematical research by citations. The mathematics play a relevant role in the Spanish economy; in fact, 10% of the national gross income and 6% of the employment are directly due to its use in the economic activity.

ICIAM 2019 Congress features 27 invited talks, the 5 ICIAM prices, the Olga Taussky-Todd Lecture and the Public Lecture. It will count on nearly 2000 talks as well as 250 posters. It also includes three special panels of great interest to understand the social framework in which our job as mathematicians takes place. This is industry talking about mathematics, instead of mathematicians talking about their collaborations with industry. ICIAM 2019 also includes an Industry Day, where 14 technological companies have agreed to present how mathematics helps to improve their production processes.

Thanks to four different funding programs, we have been able to offer over 230 scholarships to young researchers as well as to researchers coming from developing countries. In addition, we have implemented a volunteers program with over 170 young students that will greatly help the organization of the congress.

All this has been possible thanks to the collaborative work of the scientific panel committee, chaired by Prof. Alfio Quarteroni, and an enthusiastic organizing committee. I convey my deepest thanks to all of them. Special thanks are addressed to the Spanish Society for Applied Mathematics, and its president, Prof. Rosa Donat, who also chairs the local organizing committee. Let me also acknowledge the role of our families, for their support all along the organization of the congress.

We are indebted to ICIAM for trusting us to organize this congress and especially to her past and present presidents, Profs. Barbara Keyfitz and Maria Esteban, for their help and advice in the organization process. We also address our deepest thanks to the many organizations that have sponsored the congress: the Spanish Government, the Region of Valencia, the Diputació de València, the City Council and the University of Valencia, Spanish centers, departments and institutes of mathematics, Springer Publishing House, Santander Bank and the many individual donors. We are also indebted to SIAM for embedding their annual meeting in this ICIAM Congress and also to all you for organizing and participating in the many activities that take place within it.

You find yourself at the perfect time and place to learn about new mathematical tools, exchange ideas and move ahead in the thrilling challenge of shaping the world with mathematics.

Welcome to ICIAM 2019-Valencia Congress!!

Maria J. Esteban, President of ICIAM

His Majesty the King, President of the Generalitat of Valencia, Major of Valencia, Minister of Science, Innovation and Universities, Congress Director, ladies and gentlemen, dear colleagues,

It is my great honor and pleasure, to welcome you all to ICIAM 2019, the ninth International Congress on Industrial and Applied Mathematics.

The ICIAM congresses are the main event organized by our international organization, a network of more than 50 learned societies. The global ICIAM community covers many countries and all topics that are related to the applications of mathematics to the real world, to industry, to health, to economy, to climate, to artificial

intelligence and so on. Mathematics is unavoidable in the development of new technologies and in the advancement of our societies. As the recent report on the impact of mathematics on the Spanish economy shows, investing in mathematics is a very good idea, because the economic returns are high. This was also apparent in similar impact studies carried out previously in the UK, the Netherlands and France.

This congress is the occasion when worldwide applied and industrial mathematicians show to each other what they have done in the past years and what they plan to do next. During these days, we will prepare the future.

Spain was chosen six years ago to organize this big congress, the main event in our community, taking place only every four years. In 2015, we were in Beijing, and in 2023, we will be in Tokyo. Here today in the beautiful city of Valencia, we host more than 4000 mathematicians from all over the world, junior, senior, students, professors, researchers and engineers. During these six years, our Spanish colleagues have worked nonstop to make this congress a big success. In the name of the whole ICIAM community, let me thank the organizers for their huge effort. Thank you very much to the Spanish Society of Applied Mathematics (SEMA) and to the whole Spanish applied mathematics community. Thanks also to all official Spanish institutions that have offered their support.

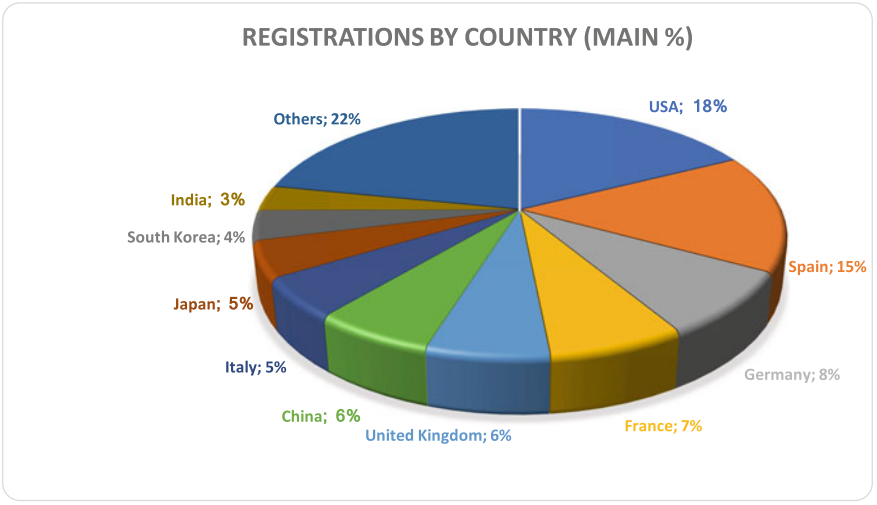
And now, to all of you who are eager to see how the congress will develop, I wish you a productive week. Just be patient and courageous, because the program of the congress is very heavy, but this is the only way to show the whole span of our community's work in only five days. I thank you all for being here, and I wish you a great congress and a very pleasant week!

ICIAM 2019 in Numbers

Scope

- 37 Distinguished Lectures (27 Invited, 5 ICIAM Prize, 3 SIAM Prize, Olga Taussky-Todd, Public Lecture)
- Industry Day (14 invited, industry-driven lectures)
- 2148 scientific contributions from participants (336 mini-symposia: 1344 talks, 555 contributed talks, 249 posters displayed). 90 simultaneous sessions.
- 234 scholarships awarded, 176 volunteers.
- 35 satellite meetings
- Outreach activities: Math-Work for children. Arquímedes: A Planetarium Opera.
- Public lecture by Víctor M. Pérez-García (UCLM) (Can mathematics help in the war against cancer?)

3983 Registered Delegates (Geographical Distribution)



Percentage of participants per country

Number of Talks and Posters by Topic

Number of mini-symposia talks, contributed talks and posters by topic

Topics	Mini-symposia talks	Contributed	Talks posters
1. Applied Mathematics for Industry and Engineering	148	64	35
2. Astronomy, Astrophysics and Geophysics	4	8	2
3. Biology, Medicine and other natural sciences	68	41	15
4. Chemistry, Chemical Engineering	0	2	2
5. Computational Geometry	4	3	2
6. Computer Science	8	3	3
7. Control and Systems Theory	40	29	5
8. Discrete Mathematics	4	3	3
9. Dynamical Systems and Nonlinear Analysis	72	30	15

(continued)

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Topics	Mini-symposia talks	Contributed	Talks posters
10. Education	16	4	3
11. Finance and Management Science	32	7	3
12. Fluids Physics and Statistical Mechanics	32	19	6
13. Information, Communication, Signals	12	2	5
14. Linear Algebra and Geometry	16	19	1
15. Materials Science and Solid Mechanics	28	11	2
16. Mathematics and Computer Science	92	15	13
17. Numerical Analysis	316	102	39
18. Optimization and Operations Research	28	23	14
19. Ordinary Differential Equations	0	9	4
20. Partial Differential Equations	144	57	22
21. Probability and Statistics	20	12	2
22. Real and Complex Analysis	0	2	2
23. Simulation and Modeling	144	46	27
24. Social Science	0	1	0
25. Other Mathematical Topics and their Applications	40	16	11
26. General	0	1	0
MIA.1. Industrial mathematics success stories	40	11	3
MIA.2. Industrial mathematics case studies	12	8	7
MIA.3. Industrial mathematics education	4	2	3
MIA.4. Industrial mathematics infrastructures to promote industry—academia collaborations	20	5	0
Total	**1344**	**555**	**249**

Satellite Meetings

Bilbao

- 5thWorkshop on Quantitative Biomedicine for Health and Disease (QBIO2019), February 13–14, 2019.
- 150 European Study Group with Industry (150 ESGi), October 21–25, 2019,
- FCPNLO 2018—6th Workshop on Fractional Calculus, Probability and Nonlocal Operators: Applications and Recent Development, September 26–28, 2018.
- BiDAS 3—Third Bilbao Data Science Workshop, November 8–9, 2018.

Galicia

- 147 European Study Group With Industry (147 ESGI), April 8–12, 2019, Santiago de Compostela.
- ICCF 2019—International Conference on Computational Finance, July 8–12, 2019, A Coruña.
- I Conference on Transfer between Mathematics and Industry, July 22–24, 2019, Santiago de Compostela.

Sevilla

- Workshop on PDEs for Biology Systems, April 8–10, 2019.
- ECMI Postgraduate Modeling Week/VI Iberian Modeling Week, July 8–13, 2019.

Málaga

- NumHyp 2019—Numerical Approximation of Hyperbolic Systems with Source Terms and Applications, June 17–21, 2019.

Zaragoza

- Tecnologías en la Divulgación Matemática, DI-MA, May 10–11, 2018.
- Fifteenth International Conference Zaragoza-Pau on Mathematics and its Applications, September 10–12, 2018.
- International Conference on Adaptive Modeling and Simulation 2019 (ADMOS 2019), May 27–29, 2019, Alicante, Spain.
- CSAI—ECCOMAS Thematic Conference Computational Sciences and AI in Industry: new digital technologies for solving future societal and economical challenges, June 12–14, 2019, Jyväskylä, Finland.
- Patterns in Life and Social Sciences, June 13–20, 2019, Granada, Spain.
- 5th ALAMA Workshop: Numerical Linear Algebra (NLA 2019), June 17–18, 2019, Valencia, Spain.
- 17th School on Interactions between Dynamical Systems and Partial Differential Equations (JISD2019), June 17–21, 2019, Barcelona, Spain.
- MEGA 2019—Effective Methods in Algebraic Geometry, June 17–21, 2019, Madrid, Spain.
- ICASQF 2019—Third International Congress on Actuarial Science and Quantitative Finance, June 19–22, 2019, Manizales, Colombia.
- CIMPA Research School 'Data Science for Engineering and Technology,' June 25–July, 2019, Tunis, Tunisia.
- 30 Years of SIMAI: status and perspectives of applied and industrial mathematics in Italy and in Europe (SIMAI30th), July 1–2, 2019, Milan, Italy.
- École de Recherche CIMPA 'Modélisation, analyze mathématique et calcul scientifique dans la gestion des déchets ménagers,' July 3–13, 2019, Kenitra, Marocco.
- AIP 2019—Applied Inverse Problems, July 8–12, 2019, Grenoble, France.

- Tutorial Workshop within the program 'Geometry, compatibility and structure preservation in computational differential equations,' July 8, 2019, Cambridge, UK.
- SIAM Conference on Applied Algebraic Geometry 2019, July 9–13, 2019, Bern, Switzerland.
- Mathematical Modeling in Engineering and Human Behavior 2019, July 10–12, 2019, Valencia, Spain.
- CCMA2019 Madrid—International Conference Challenges in Mathematical Architecture: theory, modeling and applications, July 11–13, 2019, Madrid, Spain.
- SciCADE 2019—International Conference on Scientific Computation and Differential Equations, July 22–26, 2019, Innsbruck, Austria.
- Summer School and Workshop Wisla 19, August 19–29, 2019, Wisla, Poland.
- 8th International Conference on Matrix Analysis and its Applications (MAT TRIAD 2019), September 8–13, 2019, Liblice, Czech Republic.
- 2019 Rouen Probability Meeting: Stochastic geometry, Analysis of algorithms, Particle systems, September 23–27, 2019, Rouen, France.
- EHF2018—XVIII Jacques-Louis Lions Spanish-French School on Numerical Simulation in Physics and Engineering, June 25–29, 2018, Las Palmas de Gran Canaria, Spain.
- AGACSE 2018—7th Conference on Applied Geometric Algebras in Computer Science and Engineering, July 23–27, 2018, Campinas, Brazil.
- Second Spain–Brazil Joint Meeting of Mathematical Societies, December 11–14, 2018, Cádiz, Spain.

Other Satellite Meetings

- European Workshop on High Order Numerical Methods for Evolutionary PDEs: Theory and Applications (HONOM 2019), April 1–5, 2019, Madrid, Spain.

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