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Preface

The 5th International Congress on Mathematical Software (ICMS 2016) was held during July 11–14, 2016, at the Zuse Institute in Berlin, Germany. There were four invited plenary talks and 139 contributed talks. From the submitted extended abstracts, 68 were accepted for the present proceedings.

The scope of mathematics is as broad as human thought. With the ever-increasing power and pervasiveness of technology, computation has emerged as a tool of mathematics rivaling (and many would say surpassing) proof. Many problems and models of wide interest in engineering and science are too complicated for step-by-step human solution in any reasonable time frame, but require solution immediately (although often not completely certain). We agree with the following statement in the preface to the ICMS 2014 volume:

> We in the International Conference of Mathematical Software believe that the appearance of mathematical software is one of the most important modern developments in mathematics, and this phenomenon should be studied as a coherent whole. Our vision for ICMS is to serve as the major forum for mathematicians, scientists, programmers, and developers who are interested in software. Software is not static: Anyone who uses software knows that its typical "halflife" is frustratingly short: But it compiled properly just last year! There is constant renewal, development, and disruptive changes. It is partly caused by new mathematical advances, but often the pressure is from technological changes, e.g., the appearance of graphics processing units (GPUs).

Jack Dongarra in his invited paper discusses the major (and disruptive) changes that moving to "extreme scale" computing will cause. Exoscale computing and the importance of locality are leading to a new generation of algorithms and software.

Computation is a tool not only for applications to other subjects, but also for the modern development of mathematics. As in the wider world of engineering and science, computation that forms a proof as well as computation that constructs objects and reaches conclusions that are not completely certain have important roles. In his plenary talk, Wolfram Decker discusses the challenges to and progress in the integration of a number of powerful open source computer algebra software packages into a next-generation computer algebra system.

The knowledge base of mathematics, including theorems, precise definitions of objects, and a huge constellation of examples, is the bedrock for the development of new algorithms and software. Stephen Watt described in his plenary talk the progress toward the goal of an international mathematical knowledge base useable by individuals and software systems alike.

But computational mathematics and software goes even deeper, right down to the roots of the logical and constructive foundations of mathematics. In 2009 Vladimir Voevodsky added the concept of h-level (homotopy level) and the "univalence axiom" to homotopy type theory, where the basic objects are homotopy types and which replaces set-theoretic formalizations of mathematics. This so-called univalent foundation had far-reaching consequences. It can be regarded as a new foundation for mathematics in general but it also allows mathematical proofs to be formalized, i.e., translated into the formal language that can be processed by a computer proof assistant, much more easily than before. In his plenary talk, Voevodsky explained how "univalent models" of type theories allow for the direct formalization of constructive mathematics and the formalization of classical mathematics by adding the axiom of excluded middle and the axiom of choice for types of certain h-levels. A considerable amount of mathematics has been formalized in the Coq library UniMath using the univalent point of view.

We are thankful to all the individuals whose effort and support made ICMS 2016 possible: the plenary speakers, all the contributors of abstracts and extended abstracts, the special session organizers, and the LNCS team at Springer under the leadership of Alfred Hofmann. We benefited from the experience of the ICMS Advisory Board chaired by Professor Nobuki Takayama and from Professors Chee Yap, Hoon Hong, and Deok-Soo Kim. Last but not least, we acknowledge the work of the local chair, Professor Thorsten Koch, and his committee at the Zuse Institute.

May 2016

Gert-Martin Greuel
Thorsten Koch
Peter Paule
Andrew Sommese

Bylaws of ICMS

The motivation for these bylaws is to guide the future directions and governance of the International Congress of Mathematical Software (ICMS). Ultimately, we hope to build a community of researchers and practitioners centered around the aims of the previous ICMSs, namely "mathematical software" viewed as a scientific activity. Such a community is closely allied with areas such as algorithms and complexity, software engineering, computational sciences, and of course all of constructive mathematics including computer algebra and numerical computation. But mathematical software has unique (evolving) characteristics, which ICMS aims to foster and support. To build such a community, we need continuity and some rules governing the central activity of any research community, namely, the ICMS conference. The following proposal is based on, and consistent with, the historical patterns observed in the first four ICMSs (2002, 2006, 2010, 2014). The proposal is deliberately minimal and under-specified. Therefore, their interpretations should be guided by historical patterns.

Bylaw 1: Composition of Organizers

Each ICMS Conference shall have the following organizational positions:

1. Advisory Board
2. General Chair
3. Program Chair
4. Local Chair
5. Secretary
6. Program Committee
7. Local Committee

Chair could also mean Co-chairs.

Bylaw 2: Appointments

1. The Advisory Board shall consist of the General Chair, Program Chair, and Local Chair of the previous two conferences, and any other members that they shall appoint. The General Chair of the last-but-one ICMS shall serve as the chair for the current Advisory Board. All appointments to the Advisory Board last two ICMS conferences.
2. The Advisory Board appoints the Secretary.
3. The Advisory Board appoints the General Chair for the next conference.
4. The General Chair, in consultation with the Advisory Board, appoints the Program Chair and Local Chair.

5. The Program Chair, in consultation with the General Chair and the Advisory Board, appoints the Program Committee members.
6. The Local Chair, in consultation with the General Chair, appoints the Local Committee members.

Bylaw 3: Duties

1. The Advisory Board Chair will hold an ICMS business meeting during each conference.
2. The Secretary shall maintain a permanent ICMS website for past activities, and also a list of names and e-mails of attendees of past ICMS conferences.

Bylaw 4: Amendments

1. The bylaws can be amended by ballot, either at the ICMS business meeting or by email.
2. Persons who have registered for at least one of the three preceding ICMS Conferences are eligible to vote.

Appendix: Remarks on the Bylaws

1. The bylaw is self-described as minimal and under-specified; both are viewed as positive qualities. This appendix will comment on the bylaws using their historical (nonbinding) interpretations. It will also motivate the exclusion of certain items in the bylaw.
2. Historically, ICMS was organized as a satellite of ICM. Like ICM, ICMS is held every 4 years. But even in our short history, there was a break in this pattern in 2010. Looking forward, there are good arguments to have biennial meetings (e.g., this is better for community building).
3. We do not specify the format of ICMS, believing it to be the prerogative of the General Chair and the Program Chair to shape it to best serve the community. Historically, the program has centered around plenary speakers and special sessions organized by experts in the area of interest.
4. The term "software" is a unique characteristic of ICMS that distinguishes it from the allied areas mentioned in the bylaw. We are not only interested in "paper algorithms" but also in their implementation and in their software environment. We want to foster software development as a scientific activity, to promote the publication of software like paper publications, and to establish standards for such activities. Past ICMSs have an important component of software tutorial and demonstrations and distribution of free software (e.g., Knoppix CD).
5. The ICMS positions listed in the bylaw do not exclude additional positions: the positions of a treasurer and a "documentation chair" for software have been suggested. But we refrain from mandating such positions in the bylaw.

6. Term limit for appointments to ICMS posts is generally a good thing. Again, we do not encode this into the bylaw, as we recognize many good reasons to take exceptions, e.g., a competent "document chair" should probably be given a life appointment.
7. The idea of a permanent repository for ICMS is assumed in the bylaw. Nobuki Takayama has a website that might be considered as the starting point. The General Chair and Program Chair should each deposit a report for the activities of their particular ICMS in this repository.
8. The database swMATH is a freely accessible information service for mathematical software, currently maintained by the research campus MODAL, Zuse Institute Berlin (ZIB), and FIZ Karlsruhe. With its philosophy to provide access to an extensive database of information on mathematical software together with a systematic linking of software packages with relevant mathematical publications, it meets the needs of the mathematical software community.

Organization

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Topical Session Organizers

1. Univalent Foundations and Proof Assistants
   (Vladimir Voevodsky)
2. Software for Mathematical Reasoning and Applications
   (Bruno Buchberger, Tudor Jebelean, Temur Kutsia, and Wolfgang Windsteiger)
3. Computational Number Theory Meets Computational Algebraic Geometry
   (Wolfram Decker and Claus Fieker)
4. Algebraic Geometry in Applications
   (Gerhard Pfister)
5. Computational Aspects of Homological Algebra, Group, and Representation Theory
   (Mohamed Barakat and Max Horn)
6. Software of Polynomial Systems
   (Chenqi Mou and Dongming Wang)
7. Software for the Symbolic Study of Functional Equations
   (Moulay A. Barkatou, Thomas Cluzeau, and Suzy S. Maddah)
8. Symbolic Integration
   (Christoph Koutschan)
9. Symbolic Computation and Elementary Particle Physics
   (Carsten Schneider and Johannes Bluemlein)
10. Software for Numerically Solving Polynomial Systems
    (Daniel Bates, Jonathan Hauenstein, and Daniel Brake)
11. High-Precision Arithmetic, Effective Analysis, and Special Functions
    (Fredrik Johansson)
12. Mathematical Optimization
    (Ambros M. Gleixner, Christian Kirches, John Mitchell, and Ted Ralphs)
13. Interactive Operation to Scientific Artwork and Mathematical Reasoning
    (Setsuo Takato, Mastaka Kaneko, and Ulrich Kortenkamp)

14. Information Services for Mathematics: Software, Services, Models, and Data (Wolfram Sperber and Michael Kohlhase)
15. SemDML: Towards a Semantic Layer of a World Digital Mathematical Library (Michael Kohlhase, Olaf Teschke, and Stephen Watt)
16. Polyhedral Methods in Geometry and Optimization (Michael Joswig and Marc Pfetsch)
17. General Session (Gert-Martin Greuel, Peter Paule, and Andrew Sommese)

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Abstracts of the Invited Talks

Invited Plenary Speakers and Talks

Invited Plenary Speakers

Wolfram Decker	University of Kaiserslautern, Germany
Jack Dongarra	University of Tennessee, USA
Vladimir Voevodsky	IAS Princeton, USA
Stephen Watt	University of Waterloo, Canada

Abstracts of Invited Plenary Talks

1. *Current Challenges in the Development of Open Source Computer Algebra Software*
   Wolfram Decker (University of Kaiserslautern)

   Computer algebra is facing new challenges as more and more of the abstract concepts of pure mathematics are made constructive, with interdisciplinary methods playing a significant role. On the mathematical side, while we wish to provide cutting-edge techniques for applications in various areas, the implementation of an advanced and more abstract computational machinery often depends on a long chain of more specialized algorithms and efficient data structures at various levels. On the software development side, for cross-border approaches to solving mathematical problems, the efficient interaction of systems specializing in different areas is indispensable. In this talk, I will report on ongoing collaboration between groups of developers of several well-established open source computer algebra system specializing in commutative algebra and algebraic geometry, group and representation theory, convex and polyhedral geometry, and number theory. The ultimate goal of this collaboration is to integrate the systems, together with other packages and libraries, into a next generation computer algebra system surpassing the combined mathematical capabilities of the underlying systems.

2. *With Extreme Scale Computing the Rules Have Changed*
   Jack Dongarra (University of Tennessee)

   In this talk we will look at the current state of high performance computing and look at the next stage of extreme computing. With extreme computing there will be fundamental changes in the character of floating point arithmetic and data movement. In this talk we will look at how extreme scale computing has caused algorithm and software developers to changed their way of thinking on how to implement and program certain applications.

3. *UniMath - a library of mathematics formalized in the univalent style*
   Vladimir Voevodsky (IAS Princeton)

   The univalent style of formalization of mathematics in the type theories such as the ones used in Coq, Agda or Lean is based on the discovery in 2009 of a new class of models of such type theories. These "univalent models" led to the new intuition that resulted in the introduction into the type theory of the concept of h-level (homotopy level). This most important concept implies in particular that to obtain good intuitive behavior one should define propositions as types of h-level 1 and sets as types of h-level 2. Instead of syntactic Prop one then *defines* a type hProp(U) - the type of types of h-level 1 in the universe U and the type hSet(U) - the type of types of h-level 2 in U. With types of h-level 1 and 2 one can efficiently formalize all of the set-theoretic mathematics. With types of h-level 3 one can efficiently formalize mathematics at the level of categories etc. Univalent style allows to directly formalize constructive mathematics and to formalize classical mathematics by adding the excluded middle axiom for types of h-level 1 and the axiom of choice for types of h-level 2. UniMath is a growing library of constructive mathematics formalized in the univalent style using a small subset of Coq language.

4. *Toward an International Mathematical Knowledge Base*
   Stephen Watt (University of Waterloo)

   The notion of a comprehensive digital mathematics library has been a dream for some decades. More than in many other areas, results in mathematics have lasting value – once proven, always true. It is not uncommon for a research article to have primary references to work decades earlier. Another quality of mathematics is its precision; there is a clarity to mathematical definitions and results. This makes mathematics an ideal subject for mechanized treatment of knowledge. This talk shall outline the challenges and opportunities in transforming the complete mathematical literature into a knowledge base to be used by mathematicians and software systems alike.

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