2023 REPORT OF THE ICM STRUCTURE COMMITTEE

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1. Introduction

The second term of the Structure Committee of the International Congress of Mathematicians (ICM) started on 1 January 2023, with the committee membership comprising the authors of this report. This committee is tasked with deciding the structure of the Scientific Program of the ICM, in particular,

- the number of plenary lectures,
- the sections and their precise definition,
- the target number of talks in each section,
- other kinds of lectures, and
- the arrangement of sections.

The committee is also authorized to propose more radical changes to the structure of the ICM to the Executive Committee (EC), who will then decide in the matter.

Our work built upon several actions taken by the Structure Committee in its previous term, including

- Collecting feedback from the Program Committee panels for the 2022 ICM, as well as from ICM participants via an exit survey, an appeal from the personal blog of the SC chair and from the EC;
- Collecting the recollections of recent plenary speakers at the ICM and compiling them into a document to advise future plenary speakers;
- Creating a guidance document describing the factors the committee should take into account when deciding how to adjust the allocation of speaker slots to each section. For instance, panels could request an increase in slots by supplying a detailed justification for that increase to the SC as part of their feedback.

Our first action of this term was to have a broad philosophical discussion (on an internal IMU blog) about what the purpose of the modern ICM should be. This was very helpful in framing our subsequent deliberations, and we recommend that future terms of the Structure Committee also begin in this fashion. Our committee then discussed (mostly via the blog) the state of the ICM in view of feedback collected, and proposals to help the Congress achieve the purposes identified in our previous discussion. We presented a preliminary report on these proposals to the EC on 11 March, 2023. One of our proposals presented at that meeting, namely a proposal for the Program Committee (PC) to designate, for each section, a PC member as an additional liason to that section panel beyond the PC chair (in particular waiving the secret nature of that committee membership for this specific purpose), was adopted by the EC at that time.

Our commitee then turned attention to discussion (again on the internal blog) of individual sections. On July 21-22, 2023, our committee met in Lausanne, Switzerland to finalize our main recommendations and section allocations, with two of us (Buffa and Hairer) handling the local arrangements. Due to a large number of conflicting travel commitments, the meeting was conducted in a hybrid fashion, with just five of us participating in person; nevertheless, the meeting proceeded smoothly. The updates to the description and justification for each section were then finalized shortly afterwards by subcommittees comprised of one to four committee members for each section.

The SC chair and PC chair met online on several occasions to update each other on their work. While we did not do so in this cycle, we suggest that future SC chairs consider inviting the PC chair (perhaps in a virtual fashion) to their final meeting in order to benefit from their input.

The exceptional circumstances surrounding the 2022 virtual ICM made it difficult to use that congress as a reliable indicator of changes that needed to be implemented for future congresses. As such, our main structural proposals are relatively modest in nature, and largely consist of small technical adjustments to existing initiatives.

Similarly, our committee ended up making relatively minor changes to the section structure for this term, with three sections gaining one slot and three sections losing one slot, and with a number of small adjustments to the description and justification. Additionally Section 17 has been renamed from “Statistics and Data Analysis” to “Statistics, Machine Learning, Image and Signal Processing” to more accurately reflect the intended purpose of this section.

2. Current state of the Congress

The International Congress of Mathematicians continues to be viewed as one of the leading gatherings of mathematicians in the world. Historically, the Congress was a crucial venue in which to disseminate the most recent mathematical research, and to facilitate interactions between individual mathematicians. Nowadays, these functions can often be performed equally as well, if not better, in other venues, both physical and online. Nevertheless, the Congress is still uniquely well suited to perform several valuable services to the mathematical community. For instance, through the expositional quality of its lectures and proceedings, the Congress can highlight and synthesize exciting new developments in each of the subfields of mathematics, and influence their future direction. Through its prizes and prestigious lecture invitations, the Congress also recognizes mathematicians who are actively advancing the field, and also serves as a high-profile event in which to promote mathematics to the general public as well as government representatives. As the participants of the Congress range broadly over all areas of mathematics, the ICM also offers an opportunity to bring different communities of mathematics together, creating interactions between fields that might not have been possible otherwise. Many of the recommendations in this report were guided by a desire to further enhance these very positive aspects of the Congress.

Among mathematicians in traditionally "pure" fields, the ICM is undisputedly the premier such meeting, and fulfills to a substantial extent the objectives described above. However, in traditionally "applied" fields, the ICM is not as dominant, with other major conferences such as the meetings of the International Council for Industrial and Applied Mathematics (ICIAM) also being of comparable importance. Perhaps as a result of this, the previous Program Committee reported some difficulties in recruiting panel chairs and panel members in such fields, and also received a number of declines from invited speakers in these areas. We have made some modest proposals in this report to help address these issues, but the situation remains challenging, and will need to be closely monitored by future instantiations of this committee.

The scientific program of the ICM consists of twenty plenary lectures of an hour in length, together with approximately 180 sectional lectures of forty-five minutes in length held in parallel sessions, and distributed across 20 different sections representing different subfields of mathematics. As stated in the current guidelines, "plenary lectures should be broad surveys of recent major developments, aimed at the entire mathematical community. Plenary speakers should be outstanding mathematicians and good lecturers.". More generally, "Every ICM should reflect the current activity of mathematics in the world, present the best work being carried out in all mathematical subfields and different regions of the world, and thus, point to the future of mathematics.".

In the most recent Congress, a distinction was introduced between "traditional" sectional and plenary lectures, and "special" sectional and plenary lectures, following the recommendations of the previous term of the Structure Committee. Each section receives a certain number of "base slots" to be allocated towards traditional sectional lectures, which typically involve presentations of recent research in that section by one or more authors of that research. The panels for each section make recommendations for speakers for such lectures (sometimes jointly with other section panels), as well as nominations for traditional plenary lectures, with the Program Committee having the final say in these assignments. In addition, each section panel may make an unlimited number of "bids" for special sectional and plenary lectures, which are intended to be of broader interest to multiple sections.

The PC has 20 sectional slots, and one or two plenary slots, that it decides to assign to such special lectures. The previous PC reported that this program largely worked as intended, although with some section panels there was some confusion as to the precise mechanics of the special lecture program, as well as frictions with the PC regarding the final selection of speakers. Several of our proposals below are intended to address these concerns.

Due to the invasion of Ukraine in early 2022, the Congress had to be moved on short notice to a largely virtual format, with only the prize ceremony and laureate lectures being retained in a scaled-down in-person event. Despite this significant disruption and substantial logistical challenges, the resulting virtual ICM (as well as some grassroots efforts at in-person satellite events to support the virtual ICM) ended up being relatively well received, particularly among mathematicians from developing countries, who ended up having substantially greater access to the lectures of the Congress than in previous in-person events. These positive experiences have inspired some proposals that we describe in the next section to continue broadening the impact and reach of future Congresses beyond their in-person participants.

3. Main structural proposals

3.1. **Plenary lectures.** To maximize the effectiveness of the plenary lectures, the PC has in recent years implemented a "helper" program, in which each plenary speaker is assigned one or two experts in the general field of the speaker to assist them with preparing the lecture and offering feedback. The SC has also compiled advice and recollections from plenary lecturers from recent Congresses into a living document that is provided to invited plenary speakers at each subsequent Congress.

In view of the increasing importance of communication between the different subfields of mathematics, and the role that ICM plenary lectures can play in that communication, we would like to strengthen these guidelines and practices in the following three respects.

- We recommend that the guidance on plenary speakers be updated to "Plenary speakers should be outstanding mathematicians and must be able to communicate with exceptional clarity to those outside their field.".
- We propose to continue the helper program for plenary lectures, with the additional recommendation that the PC attempt to assign at least one helper that is not in exactly the same field as the plenary speaker. This is so that the plenary speaker can gain feedback on how accessible their lecture will be to an audience member in another field, and also as a reminder of the breadth of the target audience.
- Due to the need to maintain confidentiality regarding prize winners, it does not appear feasible to assign helpers to prize laudatio speakers. However, we recommend that such speakers be provided the advice document from past plenary speakers compiled by the SC.

Outside of these recommendations, we do not propose any changes to the total number, format, or length of the plenary lectures.

3.2. **Sectional lectures.** We do not propose any changes to the total number or length of the sectional lectures. The only adjustment we propose is to add the following sentence to current PC guidelines on sectional lectures for clarification, after "Sectional lectures are invited 45-minute lectures": "Individual lectures most commonly reflect recent research, but other models should also be used as appropriate, for example, recognizing older work whose significance has grown over time." This change is in response to some confusion expressed by some section panels regarding the extent to which older research could be recognized with a traitional sectional lecture. On the other hand, the traditional sectional lectures are not intended as a recognition of lifetime achievement; in such cases, a special sectional lecture could be an appropriate option instead.

We have noted that an increasing number of sectional lectures are awarded jointly to more than one mathematician. We believe that this is a healthy development that reflects the increasingly collaborative nature of the discipline, and do not feel that action needs to be taken in this regard, except to note that talks given by multiple speakers may require some additional planning on the part of the speakers to ensure that they are communicated effectively.

3.3. **Special lectures.** Special lectures are sectional or plenary lectures that deviate from the traditional format of contemporary research presented by one or more authors of that research, and are selected by a separate bidding process from these lectures that is not subject to the section allocation quotas. As described in the previous SC report, examples of such special lectures include

1. A talk that creates new connections between different areas of mathematics and its applications, and in particular has the potential to bring communities from both fields closer to each other.
2. A talk that does not fit neatly within existing section structures, for instance due to a highly interdisciplinary nature, or because it represents an emerging mathematical area not adequately covered by existing section descriptions.
3. A timely survey of a subfield of a section, given by an expert who may not necessarily be directly involved in the most recent developments.
4. A talk that involves an unusual but promising methodology or format that would not often be seen in standard sectional lectures.

Based on the feedback received, the experimental special lecture program for both plenary and sectional lectures appears to have been modestly successful and popular, despite the exceptional circumstances of the 2022 virtual ICM. We propose to continue this program at its current size of up to 20 special sectional lectures, as well as one to two special plenary lectures. Only the following minor modifications to the program are proposed:

- In the 2022 virtual ICM, several high quality bids for sectional lectures were submitted that were broadly in one of the first three categories listed above, but almost none were in the fourth category (unusual methodology or format). This may have been due to a lack of guiding examples for this latter category. We propose to refine the guidance by adding the following more specific examples to illustrate this category:
  - 4.1. A panel discussion by multiple experts on a recent mathematical development.
  - 4.2. A presentation by multiple junior researchers on an important recent collaboration.
  - 4.3. A "flipped" lecture in which an online presentation is provided to participants beforehand, and the allotted time is instead devoted to questions and answers.
  - 4.4. A live demonstration of some emerging technology of relevance to future mathematical research directions.
- In order to help broaden the range of topics covered by the ICM, we propose to replace the second example of a special lecture with
  2. A talk that does not fit neatly within existing section structures, for instance due to a highly interdisciplinary nature (either between mathematical fields, or between mathematics and the sciences), or because it represents an emerging mathematical area not adequately covered by existing section descriptions. In particular, it could be appropriate in some cases to invite a speaker who works primarily in a discipline other than mathematics.
- After the list of examples of special lectures, add "Bids for special lectures that connect pure and applied mathematics are particularly encouraged.".
- More generally, the PC is encouraged to view the special lecture mechanism as a laboratory for trialing experimental types of talks that might be more broadly adopted in future Congresses.
- Some panel chairs expressed a reluctance to nominate special lecturers on the grounds that this would constrain the freedom of the lecturer to specify the topic and format of the lecture. The PC chair may need to clarify that the invitation to such lecturers would explain the nature of the special lecture program, and work with those lecturers to find a suitable way to realize the intention of the special lecture in a manner that is acceptable to all parties.
- In the program for the 2022 virtual ICM, each special lecture was assigned to one or more sections that were considered relevant to the lecture. This created some confusion amongst some panel chairs of these assigned sections that were not involved in the bidding process for that lecture. In future congresses, any such assignment of sections to special lectures should

be carefully worded to avoid the impression that the special lecture necessarily originated from the corresponding section panels, for instance by also separately specifying the section(s) that nominated the special lecture.
- The SC recommends that special sectional lectures be incorporated into the schedules of the sections relevant to that lecture, rather than in a completely separate portion of the program. This will help reduce clashes, and help integrate the special lectures with the rest of the ICM.
- The EC is encouraged to mention the special lecture program when inviting Adhering Organizations and other interested parties to submit nominations for sectional and plenary speakers. (For instance, the International Commission for the History of Mathematics (ICHM) would be a natural source of nominations for special lectures relating to Section 20.)

The SC will increase efforts to monitor the effectiveness of the special lecture program, for instance by surveying the moderators of the special sessions after the conclusion of the Congress.

3.4. **Livestreaming the ICM.** During the 2022 virtual ICM, a number of *ad hoc* grassroots efforts were initiated by the mathematical community to create "overlay" in-person events in which some of the virtual ICM speakers would be physically hosted at the location of the event, and other virtual lectures would be streamed at these events, either live or with a short delay depending on time zone differences and technical capabilities. These events proved highly popular, and enhanced the impact and accessibility of the virtual ICM lectures across the globe, while mitigating some of the shortcomings of the virtual format that is present at our current level of technology.

Now that the Congresses are returning to a primarily in-person format, such "overlay" events are no longer as essential. Nevertheless, we recommend that the ICM Organizing Committee be open to efforts by interested mathematics institutions to livestream (or stream with a short delay) some or all portions of the ICM at their location as a "non-traditional satellite event", provided of course that the technical capability to do so is available and some reasonable cost-sharing arrangement can be agreed upon. If it is technologically feasible and all parties are willing to invest the effort in implementing this option, some form of two-way communication could also be considered.

The SC will follow up with organizers of such streaming events after the Congress to gauge their effectiveness.

Independently of such streaming efforts, we strongly endorse the existing practice of the IMU to archive the plenary and sectional lectures of recent Congresses in outlets such as the IMU Youtube channel.

3.5. **Interactions between PC and panels.** Several of the sectional panels reported some difficulties in communicating effectively with the Program Committee, as well as with other section panels for the purpose of negotiating joint nominations. Issues included lack of clarity regarding Conflict of Interest rules, diversity targets, and the special lecture program, as well as a perceived lack of transparency in the final selection of speakers by the PC. Another operational difficulty was that different panels sometimes ran on different timelines, so that one section panel might be ready to discuss a potential joint nomination with another section panel that was much further behind in the nomination process.

We expect the recently approved initiative to assign a PC liason to each section panel to be helpful towards alleviating some of these issues, particularly with regards to sections that are distant from the field of the PC chair. We also recommend the following further steps.

- We recommend that the PC chair schedule an online meeting with all panel chairs at an early stage of the process, in order to brief these chairs on such topics as conflict of interest guidelines, expectations for geographic and demographic diversity, the special lecture program, the procedure for generating joint nominations, and timelines for panel work. This would also be an opportunity for panel chairs to become acquainted with each other and ask questions of the PC. The PC chair may also consider scheduling further followup meetings with panel chairs if this is deemed helpful, or if scheduling or time zone conflicts prevent all chairs from attending the initial meeting.
- Once the PC finalizes the list of invited speakers to the Congress, individual panel chairs should be informed (for instance by the PC liason assigned to that chair) of the speakers selected in their section, prior to the issuance of the formal invitations. However, outside of exceptional circumstances (for instance due to a serious issue with a potential speaker that was not known to the PC), the decision of the PC should remain final.
- Section panels should be encouraged to be as detailed as possible in their justification for nominated speakers, as opposed to merely providing a ranked or unranked list without further information. For instance, a discussion of which subfields of the section are covered by each nominated speaker would help the PC in the event that adjustments to the list need to be made.
- It should be clarified, both in the invitation letter to panel chairs and members, and in the ICM program, that the program committee (rather than the section panel) makes the final decisions on selection of ICM speakers, taking into account the recommendations of the section panels, nominations from the local Organizing Committee, and declinations from invitees. (In the letter to panel chairs, it may also be mentioned that the PC will take into account additional factors such as geographic and demographic balance.) This is in response to complaints from several section panel chairs, who reported the widespread (but mistaken) impression that they

were solely responsible for the inclusion or omission of speakers from the final list of invitees.

3.6. **Data collection.** In the course of our deliberations, our committee found that it sometimes lacked data which would have been helpful to make informed recommendations. To assist future SC work, we therefore make the following recommendations.

- In addition to polling ICM participants with an exit survey, the SC should also survey the moderators of plenary and sectional sessions for feedback on the effectiveness of the lectures, as well as audience attendance. We will work on creating such a survey in time for the next Congress.
- The EC should collect PC and SC reports, aggregate statistics, templates of invitation letters, etc. that recent committee chairs have available, and store them in a secure online repository for long-term future use by subsequent Program and Structure committees. (Currently, such data is transferred from one committee to the next on an *ad hoc* basis, but a more formal repository would strengthen institutional memory.) Of course, only general resources containing no sensitive information involving individual invitees or panel members should be included in this repository.
- The EC can consider creating a standard form for each PC chair to record demographic data of speakers at the time of their final report, to be placed in the above repository. Subsequent PC chairs can use this data to help set demographic targets for their own committee, which can then be communicated to panel chairs. As part of this form, the PC can also record, for each plenary or special lecture, which sections are related to that lecture, in order to guide future PC work to avoid severe imbalances of representation of sections in these lectures.

3.7. **Invitations to speakers.** We have observed a high declination rate in invitations to speak at the ICM in some of the more applied sections of the Congress. One possible explanation for this is that several potential speakers in these areas are not fully aware of the purpose of the ICM and its connection to these applied areas. We recommend that the IMU president write a separate letter explaining the significance of the congress, to be sent concurrently with the invitation letter which would focus on logistical details. In the next two years, the SC will craft some proposed language for such letters, including paragraphs specific to particular sections (with particular attention to sections in applied math) for consideration by the president.

3.8. **Future bids for the ICM.** After the exceptional virtual Congress in 2022, the ICM is returning to a primarily in-person event in 2026. At present levels of remote conference technology, such in-person events will create more value for congress participants, but will also incur additional expenses; and with the current size of the congress, such events can only be hosted in large convention centers, in contrast to the early Congresses which were small enough to take place in a single university. We received some calls to reduce the size of the congress to more closely resemble its earlier incarnations, but we did not find a feasible way to do so while retaining all the benefits of the modern ICM. However, it is conceivable that in 2030 and beyond, the technology would have improved to the point where virtual or hybrid participation gives a comparable experience to in-person participation, and that a conference as large as the ICM could be viably hosted at two or more smaller locations, either simultaneously or with a slight delay in transmission between locations if there is a significant timezone difference.

In order to maximize the number of viable bids for future congresses, we therefore endorse the recent proposal by the EC to explicitly state in the next ICM bidding guidelines that the IMU is open to bids that plan to have a significant virtual component, and recommend that bids not be required to be hosted at a single physical location if there is a sound justification for selecting an alternative structure. While we still expect the majority of bids in the near future to follow the traditional model of an in-person event at a single large convention center, we would like to encourage innovative bids that reflect the advancing technology, and also potential future cultural changes in attitudes and preferences regarding remote participation. Examples of such innovation could include

- Systematically integrating virtual chats, social media, or other online participation with in-person sectional and plenary lectures.
- Having a single lecture delivered simultaneously to several physical locations, using cutting-edge technology to allow full audience participation at each location.
- Experimentally introducing new technologies, such as virtual reality, robot avatars, or artificial intelligence, in some selected talks.

Needless to say, innovation should not be pursued primarily for its own sake, but should be viewed as a potential means to achieve more fundamental objectives for a congress, such as reduced financial and environmental costs, increased participation, enhanced congress experience, or resilience to disruption by external events.

4. Recommended section descriptions and base allocations

The Structure Committee unanimously recommends the following revision of the section structure, and the number of base lecture slots allocated to each section (excluding the 20 discretionary slots retained by the Program Committee). After each description and justification, we give a brief commentary on the changes made in each section in comparison to the preceding Congress.

In allocating slots, there is an evident tension between the need for the ICM to evolve to reflect new developments, and the constraint of a fixed total number of slots. We have attempted to make minimal changes subject to these requirements.

In previous congresses, each section description was accompanied with a list of other sections that had a connection to that section. In recent years there has been a substantial increase in interdisciplinary research between sections, to the point that virtually every pair of sections has become connected in some fashion. As such, we no longer feel it useful to explicitly single out other sections for connections in the descriptions given below. Instead, all types of connections between two or more sections are permitted (and encouraged).

Following past practice, the slots allocated to most sections are given as a numerical range in this report. However, in recent years, the PC has ended up assigning close to the maximum number of slots in each section. While we did not do so for the current report, the next SC may consider formalizing this practice by eliminating the minimum slot allocation and instead providing a single numerical target number of slots.

Section 1. Logic (4–6 base lecture slots).

Description: *Model theory. Proof theory and Computability. Set theory. Applications.*

Justification: Mathematical Logic grew out of the quest for sound foundations in the mathematical enterprise, but now finds significant application to nonfoundational issues within the thriving modern field and across mathematics. The main streams took shape in the nineteenth century with Cantor's set theory and Frege's logic, through the foundational program of Hilbert, and culminating in the work of Gentzen, Gödel, Skolem, Tarski, and Turing in the first half of the twentieth century. Major current themes include: definability, stability, minimality notions, continuous model theory; strength of logical systems, recursion theory, complexity of proof systems, proof mining; descriptive set theory, combinatorial set theory, independence questions, large cardinals. The subject is a rich symbiosis of foundational questions, internal development, and applications, including to algebra, number theory, algebraic and complex geometry, topology, analysis, operator algebras, dynamical systems, combinatorics, computer science, and optimization.

Commentary: The panel reported some operational difficulties securing joint nominations, despite the increasing connections of logic with other sections. Partly as a consequence of this, the SC approved their request to add a base slot to the section. Following the panel recommendations, proof theory and computability theory have been combined in the description, and minor rewordings have also been made to the justification.

Section 2. Algebra (4–7 base lecture slots).

Description: *Rings (both commutative and non-commutative), fields and modules. Groups (finite, infinite, algebraic), their structure and representations. General algebraic structures, algebraic K-theory, category theory. Computational aspects of algebra and applications.*

Justification: Algebra is a fundamental subject in mathematics, and has especially close connections with algebraic geometry, topology, combinatorics, Lie theory and number theory. Many of its traditional subjects are very active (e.g. finite groups and their representations, algebraic K-theory, field arithmetic, etc.) and in other topics interactions with other areas have been very important (e.g. algebraic groups, Lie theory, algebraic geometry, category theory, combinatorial group theory, tensor categories, etc). The panel should pay especially close attention to a proper balance between these two aspects of the field.

Commentary: The panel made the case that the slots allocated to this section did not fully reflect the current breadth and level of activity in this section. After looking into this matter, the SC agreed with this assessment, and enlarged this section by an additional slot. Minor modifications were made to the description and justification, adding mention of tensor categories, and slightly de-emphasizing the role of representation theory.

Section 3. Number Theory (8–10 base lecture slots).

Description: *Algebraic number theory. Galois groups of local and global fields and their representations. Arithmetic of algebraic varieties and Diophantine equations. Geometry of numbers, Diophantine approximation, and transcendental numbers. P-adic analysis. Modular and automorphic forms, modular curves, and Shimura varieties. Langlands program. Zeta and L-functions. Analytic, additive and probabilistic number theory. Computational number theory and applications. Relations with logic and with physics.*

Justification: Number theory is one of the oldest branches in mathematics, and has stimulated the development of many other branches including complex and p-adic analysis, algebra and algebraic geometry, while continuing to thrive in its own right. Research in algebraic number theory has focussed on fundamental properties of Galois representations and L-functions, with deep connections on the one hand to algebraic geometry, as envisioned by Grothendieck's conjectures on motives, and on the other hand to representations of Lie groups and automorphic representations, as stipulated by the Langlands conjectures. Analytic number theory, with traditional focus on distribution of primes, has undergone a great revival in recent years, achieving solutions of longstanding problems, with new inputs from and connection to combinatorics and probability. Because many number theoretic problems often have a concrete nature, computational number theory is a very active field with connections to theoretical computer science.

Commentary: The upper allocation of slots was reduced from 11 to 10. Although some reductions of this type are, as noted, inevitable, the SC recognizes the continued centrality and importance of the topic, and the change will be reviewed by this committee after the 2026 ICM. No changes were made to the description, and only minor stylistic edits were made to the justification.

Section 4. Algebraic and Complex Geometry (8–11 base lecture slots).

Description: *Algebraic varieties, their cycles, cohomologies, and motives. Schemes, stacks and their derived versions. Geometric aspects of commutative algebra. Arithmetic geometry. Rational points. Low-dimensional and special varieties. Singularities. Birational geometry and minimal models. Moduli spaces and enumerative geometry. Transcendental methods and topology of algebraic varieties. Complex differential geometry, Kähler manifolds and Hodge theory. Relations with mathematical physics and representation theory. Computational methods. Real algebraic and analytic sets. p-adic geometry. D-modules and (iso)crystals. Tropical geometry. Derived categories and non-commutative geometry.*

Justification: Algebraic, arithmetic and analytic geometry lie at the crossroads of many developments in mathematics. It has especially close connections with Algebra, Number Theory, Topology, Differential Geometry and Mathematical Physics. Many of the modern developments in this area are deeply influenced by these related fields, and influence them in turn. The tools required to work in this area are diverse, ranging from complex analysis to finite field and p-adic techniques. Some fundamental ideas in the subject are profound, such as motives, moduli, or the way to go from the complex numbers to finite fields and back. In recent years, there have been a number of spectacular advances in birational geometry, moduli theory, D-modules and isocrystal theory, diophantine geometry, in the geometric study of derived categories, enumerative geometry and in motivic questions.

Commentary: Few problems were reported with this session, and no changes were made to the number of slots. No significant changes were made to the description and justification, other than to make explicit that the topic of schemes and stacks also encompasses their derived versions.

Section 5. Geometry (8–11 base lecture slots).

Description: *Local and global differential geometry. Geometric partial differential equations and geometric flows. Geometric structures on manifolds. Riemannian and metric geometry. Kähler geometry. Geometric aspects of group theory. Symplectic and contact manifolds. Convex geometry. Discrete geometry.*

Justification: Geometry plays a central role in the development of mathematics, especially in the late 20th century and the early 21st century. Applications of nonlinear PDEs to geometry were started in the last century, and still continue to expand (e.g., pseudo-holomorphic curves in symplectic and contact geometry yield new invariants). Riemannian and metric geometry are traditionally a central theme in geometry, and also have applications to other areas (e.g., group theory, topology, rigidity, probability, etc). Geometric structures on manifolds that are not necessarily metric (e.g projective, affine, and pseudo-Riemannian structures) have seen important recent developments, and geometric approaches became prominent in the study of both discrete groups as well as locally compact groups.

Commentary: Few problems were reported with this session. In the previous Congress, a large number of speakers in this section were joint with other sections, but we did not view this as sufficient justification to modify the allocation of slots. The description and justification has been retained from previous years with only minor changes.

Section 6. Topology (7–10 base lecture slots).

Description: *Algebraic, differential and geometric topology. Surgery and diffeomorphism groups of manifolds. Homotopy theory, including motivic homotopy and K-theory. Operads and higher categories. Floer and gauge theories. Low dimensional manifolds including knot theory. Moduli spaces. Symplectic and contact manifolds. Aspects of quantum field theory.*

Justification: Depending on the methods used, the subject is divided into Algebraic Topology, Differential Topology, and Geometric Topology. In its various forms it is essential to many core areas of mathematics including Geometry, Arithmetic, Analysis, Algebraic Geometry, Dynamical Systems and Mathematical Physics, and its methods are widely used in an increasing number of applied areas of mathematics. Recent years have seen major advances on some classical problems in 3- and 4-manifold theory, equivariant stable homotopy theory (Kervaire invariant), and the study of moduli spaces. At the same time newer subject areas such as geometric group theory, topological quantum field theory, and derived algebraic geometry have seen important developments which have shaped the topological landscape.

Commentary: Few problems were reported with this session, and no changes were made to the number of slots, description, or justification, other than to remove some redundancy in the latter.

Section 7. Lie Theory and Generalizations (6–9 base lecture slots).

Description: *Structure, geometry, and representations of Lie groups, algebraic groups, and their generalizations. Related geometric and algebraic objects, e.g., symmetric spaces, flag varieties, buildings, and other Lie theoretic varieties, vertex operator algebras, quantum groups. Discrete subgroups of Lie groups, and their actions on geometric objects. Non-commutative harmonic analysis. Geometric methods in representation theory.*

Justification: Lie groups and Lie algebras are one of the major axes of mathematics, capturing the concept of a continuous symmetry. They are extended and generalized in various directions, such as infinite dimensional Lie algebras, Hecke algebras, quantum groups, or vertex operator algebras. Their structure and representations (both analytic and algebraic) are often related to each other in deep ways. These find a multitude of applications in algebraic geometry, mathematical physics, harmonic analysis, number theory, combinatorics, and other areas. Structural results for Lie groups are also extended to locally compact groups. Another important direction is the study of discrete subgroups of Lie groups and their actions on geometric objects. Besides its intrinsic interest, this area has found connections and applications to mathematical physics, geometry, number theory, ergodic theory, dynamics, and even computer science.

Commentary: In the previous term of the SC, a proposal was considered (and rejected) to disband this section and redistribute it to Sections 2, 3, 4, and 9. The current panel gave convincing arguments to keep this section largely as is, and so we have made no significant changes to this section or its allocation, except to make small modifications to the description and justification, such as the explicit mention of flag varieties, to not isolate lattices as a special type of discrete subgroup, and to clarify that both analytic and algebraic representations of Lie groups and Lie algebras are in scope.

Section 8. Analysis (9–12 base lecture slots).

Description: *Classical analysis. Real and Complex analysis in one and several variables, potential theory, quasiconformal mappings. Harmonic, Fourier, and time-frequency analysis. Linear and non-linear functional analysis, operator algebras, Banach algebras, Banach spaces. Non-commutative geometry, free probability, analysis of random matrices. High-dimensional and asymptotic geometric analysis. Metric geometry and applications. Geometric measure theory.*

Justification: Analysis in the broad sense plays a central role in mathematics. It covers a large diversity of directions of research, while at the same time the tools it has developed are now being used to solve problems in a large number of other areas. This section includes complex analysis, harmonic analysis (both real-variable and abstract), functional analysis, operator algebras, geometric measure theory, and high-dimensional geometry. The subject combines quantitative estimates with qualitative results, and can be applied in both continuous and discrete settings. The classification and analysis of operator algebras such as von Neumann algebras and C^* algebras, as well as many other areas of analysis, have deep connections with such diverse areas of mathematics as geometric group theory, descriptive set theory, and ergodic theory. The analysis of integral operators (singular, oscillatory, potential, Fourier, etc.), and related objects such as pseudodifferential operators, has many applications to partial differential equations, index theory, geometry, mathematical physics, and number theory. There have been many further fruitful interactions between analysis and other areas, such as dynamical systems, probability, combinatorics, signal processing, and theoretical computer science.

Commentary: Few problems were reported with this section; in particular, the interaction between the operator algebra component of this section with the other subfields of analysis was smoother than in previous congresses. The number of slots in this (already quite large) section remain unchanged, however we encourage increased use of the special lecture mechanism, which was under-utilized by this section in the previous congress, in part due to a reluctance to prescribe topics to speakers. The description has remained unchanged; the panel proposed minor changes to the justification which we have incorporated.

Section 9. Dynamics (8–10 base lecture slots).

Description: *Topological and symbolic dynamics. Smooth dynamical systems, including those derived from ordinary differential equations. Hamiltonian systems and dynamical systems of geometric origin. One-dimensional, holomorphic and arithmetic dynamics. Dynamics on moduli spaces. Ergodic theory, including applications to combinatorics and number theory. Actions of discrete groups and rigidity theory. Homogenous dynamics, including applications to number theory. Infinite dimensional dynamical systems and partial differential equations.*

Justification: The study of dynamical systems originated in the study of motions, in particular of the planetary system and in the qualitative theory of ordinary differential equations. It now encompasses both qualitative and quantitative aspects of group actions with complicated orbits on various types of spaces whose structure is assumed to be preserved by the action (measure spaces, topological spaces, smooth manifolds, Riemannian or symplectic manifolds, or Borel spaces). The theory of dynamical systems examines questions such as: statistical properties of trajectories, asymptotic behaviour in large time, perturbation theory, generic properties of dynamical systems, etc..

While it retains an important connection with mathematical physics, dynamical systems have developed connections to many other branches of mathematics, for instance in number theory and in geometry. Dynamical ideas, e.g. entropy like invariants, had impact on the theory of C^* algebras (and vice versa). The theory of complex dynamics has in recent years been increasingly intertwined with arithmetic dynamics. Dynamical tools and concepts from random matrix products, in particular Lyapunov exponents, are ubiquitous in many disciplines.

Commentary: Aside from some difficulties in arranging for joint nominations, few problems were reported in this section. One of the slots allocated to this section was redistributed to another section. The upper allocation of slots was reduced from 11 to 10. While such reductions are, as noted, inevitable, the SC recognizes the continued centrality and importance of the topic, and the change will be reviewed by this committee after the 2026 ICM. The description is essentially unchanged from previous years, but the justification has been substantially revised following input from the panel chair.

Section 10. Partial Differential Equations (8–11 base lecture slots).

Description: *Solvability, regularity, stability and other qualitative and quantitative properties of linear and non-linear equations and systems. Asymptotics. Spectral theory, scattering, inverse problems, deterministic and stochastic control* *theory, stochastic differential equations. Nonlocal equations, free boundary problems, calculus of variations. Optimal transportation. Homogenization and multiscale problems. Approximate solutions and perturbation problems. Relations to many other fields.*

Justification: Partial differential equations (PDEs) are ubiquitous in science and engineering, including physical sciences, biology, economics and social sciences. The pivotal role of PDEs within mathematics is realized through fruitful interaction with other areas, including analysis, geometry, mathematical physics, probability, control, numerical analysis, scientific computation and modeling. Important new tools were developed in recent years to enable better understanding of non-linear PDEs. There are still many challenging open problems that drive current research in deterministic or stochastic settings, including theories for global behavior of compressible and incompressible Euler and Navier–Stokes equations, the Yang–Mills equations and the Einstein equations, multi-scale analysis of singular perturbation problems, variational problems, and control and inverse problems.

Commentary: Few problems were reported in this section, with the joint speaker mechanism working particularly well in this case. However, there were some difficulties in ensuring that the field of mathematical relativity was adequately represented by both this section and the Geometry section, and the PC may wish to pay particular attention to this issue. The allocation of slots remains unchanged. Some formulations in the justification were modified. In particular, the sentence "Partial differential equations (PDEs) are used to model an extremely rich variety of physical, probabilistic, and geometric phenomena that are governed by wave propagation, reaction, diffusion, dispersion, equilibrium, conservation and more." was removed altogether for lack of clarity. In the description, "kinetic equations" was removed because no other equation is explicitly mentioned.

Section 11. Mathematical Physics (8–11 base lecture slots).

Description: *Equilibrium and non-equilibrium statistical mechanics, including interacting particle systems. Partial differential equations including fluid dynamics, wave equations, general relativity, kinetic equations, and material science. Dynamical systems, including integrable systems. Stochastic models and probabilistic methods including random matrices and stochastic (partial) differential equations. Algebraic methods, including operator algebras, representation theory and algebraic aspects of Quantum Field Theory. Quantum mechanics and spectral theory, including quantum chaos. Quantum information and computation. Quantum many-body theory and condensed matter physics. Quantum field theory including gauge theories and conformal field theory. Geometry and topology in physics including string theory and quantum gravity.*

Justification: Mathematical physics is situated at the interface between mathematics and physics. Ideas and questions from physics continue to have an enormous impact in many mathematical fields, like geometry, operator algebras, topology, probability theory, and PDEs, to name only a few. Mathematical physics is extremely broad, both by the mathematics it uses and contributes to and by the physical systems that it deals with.

Commentary: Few problems were reported with this section, and we have made no changes to the section allocation or justification, and only minor rewordings to the description.

Section 12. Probability (7–10 base lecture slots).

Description: *All areas of discrete and continuous probability. Stochastic analysis, stochastic PDEs, Markov processes, jump processes. Interacting particle systems, random media, large deviations. Random matrices, free probability, quantum probability. Conformally invariant models, random growth models, exactly solvable models. Mathematical statistics. Branching processes, random graphs, random networks, percolation theory, stochastic geometry. Rough paths, regularity structures, rigorous RG techniques. Applications in statistics, data science, computer science, physics, and life sciences.*

Justification: The impact and influence of probability theory on the rest of mathematics, as well as on important aspects of our society, have been steadily growing over the last few decades.

The connections with mathematical and statistical physics have always been very close, and fruitful for both sides. Within mathematics, the relations with PDEs and functional analysis have always been important. More recently, close interactions have grown with geometry (through geometric analysis and geometric group theory), with conformal field theory and complex analysis (through conformally invariant models), with representation theory (through integrable probability), and with number theory (through random matrix theory). Probabilistic techniques are also playing an important role in modern combinatorics.

Its applications have also been expanding very rapidly, including in machine learning, statistics, and mathematical biology.

Commentary: Few problems were reported with this section; in particular, the separation of this section from Statistics appears to have caused little difficulty, and interactions with other section panels were mostly smooth. The description has been broadened to explicitly mention several additional subfields and applications of probability.

Section 13. Combinatorics (7–10 base lecture slots).

Description: *Combinatorial structures. Enumeration: exact and asymptotic. Graph theory. Probabilistic and extremal combinatorics. Designs and finite geometries. Algebraic combinatorics. Topological and analytical techniques in combinatorics. Combinatorial geometry. Combinatorial number theory. Additive combinatorics. Polyhedral combinatorics and combinatorial optimization.*

Justification: Discrete structures (such as graphs, set systems, matroids, or other diagrams and configurations) that exhibit a high degree of combinatorial complexity occur throughout mathematics, either as objects of interest in their own right, or as models for objects of importance in algebra, geometry, analysis, or theoretical computer science. The subject of combinatorics addresses many questions concerning these structures, ranging from enumerative questions such as counting how many objects of a certain size exist, to extremal questions such as the maximal and minimal values of various statistics associated to these objects, to structural questions concerning the nature of general objects in a given class of combinatorial structures, to more algebraic questions such as how such objects can be used in such areas of mathematics as representation theory, commutative algebra, or algebraic geometry. Modern combinatorics uses techniques from across mathematics (probability, analysis, topology, algebra, etc.) and conversely is becoming an increasingly important component of new advances in many different disciplines (computer science, number theory, representation theory, logic, etc.).

Commentary: This section has broadened in recent years; in particular the algebraic areas of combinatorics have become rather distinct from the probabilistic and extremal areas of the field. This caused some operational strains within the panel in this cycle. However, we believe it continues to make sense to consider this subject as a unified field at present, and have kept the section allocation, as well as the description and justification, unchanged. The SC may wish to consider more significant changes to this section in subsequent years.

Section 14. Mathematics of Computer Science (5–7 base lecture slots).

Description: *Computational complexity theory. Design and analysis of algorithms. Automata and Formal languages. Cryptography. Randomness and pseudorandomness. Computational learning theory. Optimization. Algorithmic game theory. Distributed systems and networks. Coding and Information theory. Semantics and verification of programs. Symbolic and numeric computation. Quantum computing and information. Algorithmic and computational aspects in mathematics. Computational models and problems in the natural and social sciences.*

Justification: The theory of computation lays the mathematical foundations of all computing systems. It continues to develop the theories supporting the exponential expansion of computer science and technology, including the necessary modeling, algorithm design, and analytic tools. This has created a web of interactions with many mathematical areas. The fundamental meta-problem of making mathematics and the sciences algorithmic, for instance by replacing existence theorems by procedures to find these objects, or by studying physical processes as information processes using the computational complexity methodology, has led to collaborations with practically every area of mathematics and many natural and social sciences, greatly enriching many fields, unraveling finer structures, solving important problems, providing insights (e.g., taking into account intractability results into modeling) and suggesting new challenges.

Commentary: Several operational issues with this section were reported, but we hope that the various recommendations made in this report regarding interactions between the PC and panels will help alleviate these issues. No changes were made to section allocation. Aside from stylistic edits, no substantive changes have been made to the description or justification.

Section 15. Numerical Analysis and Scientific Computing (6–8 base lecture slots).

Description: *Design of numerical algorithms and analysis of their accuracy, stability, convergence and complexity for problems with interests in applications. Numerical methods for high dimensional problems. Multiscale modelling. Probabilistic algorithms. Approximation theory and computational aspects of harmonic analysis. Numerical solution of algebraic, functional, stochastic, differential, and integro-differential equations. Algorithmic aspects of machine learning. Representative problems in computational science. Model reduction and uncertainty quantification.*

Justification: Numerical algorithms serve as the bridge between mathematical models and practical applications. Computation has now become one of the most dominant tools in science and technology. The design of effective numerical methods requires the use of sophisticated mathematical concepts and tools, together with a deep understanding of the problem at hand and of the many practical aspects involved in computing. Note also that machine learning techniques are having a notable impact on scientific computing and computational science. This section should showcase the most important work in these fields. Importance should come from the impact and insight the approach generates inside and also outside mathematics.

Commentary: Few problems were reported in this section. It was noted that in the past, many of the topics in this section were also represented by the previous Section 17 (Mathematics in Science and Technology), and was now somewhat underrepresented. We agreed, and transferred a slot from Section 16 to this section. The description and justification has also been updated.

Section 16. Control Theory and Optimization (4–6 base lecture slots).

Description: *Optimization problems. Theoretical and algorithmic aspects of deterministic and stochastic control problems. Robotics, drones and other automated systems. Optimal design and optimization-based approach to inverse problems. Linear, non-linear, integer, and stochastic programming. Optimization problems in machine learning and beyond, Mathematical and numerical aspects of reinforcement learning.*

Justification: Control and optimization have a strong mathematical foundation and play an important role in science, technology and society.

Optimization has always provided motivation for many branches of mathematics, and nowadays, it plays a key role in the success of machine learning. Control theory and the related reinforcement learning provide the foundation for optimal decision-making. They are also ubiquitous in fundamental science as they are a major tool for the simulation and the design of complex (cyber-)physical systems at all scales, from, e.g., protein folding to large-scale fusion reactors. This section aims to showcase contributions with strong mathematical or algorithmic content, as well as to present problems that demand a better mathematical understanding or numerical treatment.

Commentary: Aside from some operational concerns, few problems were reported in this section. Optimisation and control theory is a very large community that seats across disciplines. Numerically, the number of papers in this area is large compared to that of other sections, but this does not necessarily represent the size of the mathematics-related activity. As most of the work in this field happens at the interfaces of mathematics with other sciences, this section is among the ones which should propose special lectures, and special plenary lectures, as they would provide a tremendous contribution to the ICM. After comparing the sizes of the two mathematical communities working in Section 15 (numerical analysis/computing) and Section 16 (control/optimization), we found that the former section was underrepresented, and so have transferred a slot from this section to Section 15. The description and justification have also been updated.

Section 17. Statistics, Machine Learning, Image and Signal Processing (8–11 base lecture slots).

Description: *All areas of statistics, machine learning, signal and image processing. Relevant mathematical and/or algorithmic contributions in these three fields, as well as applications that have a significant impact for mathematics.*

Justification: Statistics, machine learning, signal and image processing are an important part of modern technology. Much of the work is driven by specific applications and by experimentation. However, the pursuit of underlying mathematical and statistical principles, new algorithms, new models and new oracles have proven to be fundamental in these developments. They are essential for ensuring that the enormous amounts of data being collected today are used in a principled and trustworthy manner, and for pushing forward the new frontier for data science. This section serves as a platform for exchanging ideas and new developments in these areas.

Commentary: This section, under the name of "Statistics and Data Analysis" had been significantly restructured in the preceding congress, being a merger of the "Statistics" portion of a previous "Probability and Statistics" section and data-oriented components of a previous "Mathematics in Science and Technology" section, which were both experiencing stresses. This new section was intended to encompass three related, but distinct areas: statistics, machine learning, and signal and image processing. Unfortunately, the section panel reported significant difficulties in striking the appropriate balance and coordination between the three communities, which, while oriented towards similar applications, have somewhat different history and culture. Nevertheless, our committee feels that the ICM offers a valuable opportunity to have experts from these fields communicate with each other and with other mathematicians, and have decided to continue this section, but with significant changes to the description, justification, and title in order to emphasize the envisioned synergy between these increasingly important areas of mathematics. The section may require some further adjustments in future congresses to reach an optimal state of equilibrium, and we recommend that subsequent Structure Committees continue to monitor the progress of this section carefully.

Section 18. Stochastic and Differential Modelling (4–6 base lecture slots).

Description: *All aspects of stochastic modelling and differential modelling, as well as their applications to such fields as biology, genetics, chemistry, medicine, artificial intelligence, material science, fluid mechanics, finance, and social network modelling. Deterministic and stochastic systems of any (possibly high) dimension, and at several scales (multiscale modelling), as well as their approximations. Discrete and continuous models. Tools for model reduction, Bayesian inference, asymptotics, uncertainty quantification and data assimilation.*

Justification: Throughout history, mathematics has been extraordinarily successful at modelling various aspects of reality, be it with differential equations (stochastic or not, partial or not) or discrete stochastic models. The technical richness and diversity of this space continues to progress at a considerable pace as does its importance to our society. Moreover, important areas of science that have mostly evolved without a rigorous mathematical approach, such as biology and medicine, are today experiencing a tremendous demand for mathematical understanding and provide a major source of mathematical challenges for differential systems.

This section aims to showcase the most important works in this field. Importance should come from the impact and insight the approach generates inside and also outside mathematics. The section will cover the modelling aspects, their mathematical foundations, and their numerical approximations.

Commentary: Apart from some operational concerns which we hope can be addressed in future with the recommendations in this report, few problems were reported in this section, and no change in allocation was made. The description was expanded to include additional applications and types of models, and the justification has been revised to be more focused.

Section 19. Mathematical Education and Popularization of Mathematics (2 base lecture slots + 3 panels).

Description: *Range of research and key issues in mathematics education, from elementary school to higher education. Modern developments in effective popularization of mathematics, from publications, to museums, to online communication. Connections with research mathematics, the arts and sciences, and to issues of broad public interest.*

Justification: Mathematics Education and Popularization of Mathematics are domains of interest and responsibility for all mathematicians, and are influenced by both the history of mathematics and cutting edge developments in technology; many departments of mathematics play a key role in preservice or inservice teacher training, and relations have been forged between mathematicians and museums, cultural festivals, and other outreach events. This section aims to present key issues and research in mathematics education, and new developments in the popularization of mathematics, building bridges between these two communities, to other mathematicians, and to society in general. The two themes are both complementary and supplementary. The range of domains of study in mathematics education are visible across topic study groups in the International Congresses on Mathematical Education (ICME).

Commentary: The 2022 section panel experienced an unusual amount of tension between the education and popularization components of this section, to the extent that they proposed splitting this section into two very small sections. After studying the issue, we resolved to continue the section as currently constituted, but recommend that one speaker slot and one panel discussion be reserved for math education, one speaker slot and one panel discussion be reserved for popularization, and the remaining panel discussion be organized by the entire section panel to be of broad interest to both communities. We note that the special lecture mechanism can also be used to bid for additional panels, for instance a panel that would build connections with the mathematical research community. The description and justification have been updated to more strongly emphasize connections both between these two communities in this section, as well to other disciplines (both mathematical and non-mathematical).

Section 20. History of Mathematics (3 base lecture slots).

Description: *Historical studies of all of the mathematical sciences in all periods and all cultural settings.*

Justification: Mathematics has a history that extends back more than 4000 years and reaches into every culture and civilization. Research in its history can be done on various methodological, biographical and contextual levels and can draw on diverse mathematical, philological and cultural sources. Treating those sources effectively requires not only broad general knowledge of historical, political, sociological, and even anthropological currents but also specialized technical mathematical knowledge. In recent years the digitization of texts has created significant new opportunities for research. In particular, the increased availability and accessibility of sources has helped to broaden the history of mathematics beyond the traditional historiography of the nineteenth and early twentieth centuries and towards the study of all mathematical sciences across all periods and cultural settings. In an age of rapid growth and specialization of mathematics, and in light of the increasing societal importance of mathematics, history can provide tools for reflection and inspiration to practitioners, as well as a means for understanding to the general public.

Commentary: Few problems were reported with this section, though the panel expressed a desire for additional speakers. The SC acknowledges the value of the study of mathematical history for practitioners, as is noted in the justification of this section. Although the tight limits on the total number of sectional slots did not permit enlargement of this section, we warmly encourage proposals from ICHM or other organizations for special sectional lectures in the history of mathematics.

5. Future committee plans

The SC plans to perform the following actions for the remainder of its 2023-2026 term.

- The SC chair and PC chair will remain in contact as needed, for instance to clarify any points in this report.
- The SC chair will brief the EC and General Assembly as required.
- Prior to the next ICM, the SC will update the exit survey for participants of the congress. We also plan a separate survey for moderators of the congress sessions, to obtain further insight as to how effective the ICM lectures are. As mentioned previously, we will also recommend language for a letter from the IMU president to invited lectures to explain the significance of the congress.
- At the conclusion of the ICM, we will survey plenary speakers for feedback and advice to future speakers, and use this to update our guidance document for those speakers. We will also once again send out a general call for feedback on the SC chair's personal blog.

We anticipate that most of these actions can be performed online, without the need for a further in-person meeting.