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Control Challenges for Social Systems Milestone Survey: Current Status and Future Vision

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Abstract: Control and automation technologies are playing a critical role in the trajectory of human civilisation and its impact upon living systems. Interactions between *advances in automation and control* and *society* in it's broadest sense are addressed by IFAC's '*Social Systems'* Coordinating Committee (CC9) and its five Technical Committees (TCs). CC9 is at the crossroads of several disciplines including business and commerce, pedagogy, international development, urban planning, digital culture amongst many others. This paper reports the results of an envisioning of CC9 and its TCs. It begins with an overview of CC9 and it's TCs. Following a strategic review of CC9 TCs, a qualitative analysis of TC reports is outlined. The findings offer a basis for a strategic agenda for social systems (CC9) in its relationship to other technical areas of IFAC. The analysis highlights potential for cooperation between CC9 communities and thirteen non-CC9 TCs, suggesting ways this might be accomplished.

Keywords: Social Systems, Finance, Business, Economics, Cyber Physical and Human Systems, Control Education, Ethics and Control, Cost Oriented Automation, Systemic and Structural Effects of Technologies, Diversity and Inclusion, International Stability, Culture.

1. HISTORICAL BACKGROUND OF CC9

This paper opens the milestone session at the World Congress in Yokohama and provides a framework for the discussion at the world congress. The outcome of the milestone session is to frame the agenda for social systems effects into the future. The Coordinating Committee for Social Systems comprises one of the largest, most diverse and multi-disciplinary communities in IFAC. CC9 activities lie at the very heart of the life of IFAC as a global research and praxis federation since the beginning. In his opening address at the 1960 World Congress, Conference Chair Academician Trapeznikov asked "*what [is] the overall goal of automation?*", answering this question by reflecting upon social and societal impacts (for good and ill) of automation. At the same 1960 World Congress our first President, Harold Chestnut remarked:

"All of our countries and the other countries in the world are looking for new and better ways of improving the standard of living and improving the lot of mankind. Automatic control is one of the more important methods of making this possible and relieving man of drudgery and hardship."

Hal Chestnut went on to co-found the fifth technical committee in CC9 some years later: TC9-5 which actively explores the international context of IFACs work. One of the most dramatic changes in more recent times was the closing of the "Developing Countries" TC (DECOM: TC9-3) in 2010. Much of the scope of this TC was merged into the work of other CC9 communities, especially TC 9-5. Recent years have also seen the emergence a new TC: *Control for Smart Cities* (the new TC9-3). A more recent development was a review of the core purpose and scope of TC9-2. Arising from this effort TC9-2 was renamed and reoriented. TC9-1 and TC 9-4 are also active and vibrant communities. TC 9-1 closely coordinates with efforts in other federations, such as IEEE. Meanwhile the immense contribution of TC 9-4 in pedagogy, control education and diversity and inclusion are well known across IFAC. TC9-5 looks outwards into the international context, exploring the implications and impact of control and automation technology proliferation on human civilisation. The next sections introduce each CC9 TC. This is followed by an analysis of TC activities and how these map to the wider IFAC technical areas in other CCs.

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2. ECONOMIC, BUSINESS & FINANCIAL SYSTEMS (TC 9.1)

TC 9.1 focuses on all aspects of modelling, analysis, synthesis, control, and management in Economic, Business, and Financial Systems. It brings together scientists, engineers, business professionals and other stakeholders to explore cutting edge theoretical developments at the interface between economics, business administration and financial engineering and comprising econometrics, statistics, control science, computer sciences, operations research and management science. The spectrum of activities includes theoretical and computational methods and tools for decision and control in the above areas. TC9-1 has formally expressed a desire to launch a new IFAC journal entitled "IFAC Journal of Cyber Physical Social Systems (IFAC-J-CPSS)". The core proposed journal offers a route to publication for leading high-quality, inter-disciplinary papers that address novel issues in CPSS research which exists at the intersection between engineering complexity and social complexity. At the time of writing the proposal is open and TC 9-1 are hopeful for a launch the journal in the next triennium.

3. SYSTEMS & CONTROL FOR SOCIETAL IMPACT (TC 9-2)

TC 9-2 has long been one of the most active communities in CC9. It's traditional scope was in the impact of automation and control sciences on society and the environment and especially human centred systems, automation based on human skill and related areas. A central challenge for TC 9.2 consisted in developing topics related to an Human-centred systems engineering for a socio-technical equilibrium. New behaviours of both humans and machines that involve new balances of the mutual influence between technologies and society led to a sense that the scope and name of the TC need to be revisited. Formerly called "Social Impact of Automation" this TC has been re-envisioned as part of a long strategic process. In the last triennium TC 9-2 revisited is core purpose and developed a new roadmap for community.

4. CONTROL FOR SMART CITIES (TC 9-3)

This TC was approved in October 2015 and, compared to other IFAC TCs, it is a young community within the IFAC family. The topics can be classified according to the application domains such as buildings, transportation systems, water systems, micro grids, healthcare systems, cybersecurity systems, just to name a few. TC 9-3 also addresses, opportunities, challenges and methodologies in the field of smart cities. The complex nature of smart cities provides a platform for the application of various existing control methodologies such as model-based predictive control, Markov decision processes and simulation-based optimization. Large scale and hierarchical dynamics of smart cities provide opportunities for new research topics. For example, networked control methods may address uncertainties in sensor and actuator communications across a smart city. Game theory helps us understand bottlenecks in a transportation system and provide a basis for the design of high-performing systems through the applications of distributed and decentralized control actions. The theory of the "system of systems" analyzes interactions among the various subsystems in an urban landscape. Like other CC9 TCs, "smart cities" is a bridge between control theory scholarship and real-life applications of automation.

5. CONTROL EDUCATION (TC9-4)

TC9-4 develops new methodologies and tools for teaching control topics effectively at all levels (K-12, high school, undergraduate, postgraduate, continuous learning). The covid-19 pandemic revolutionized teaching modalities all over the world. Traditional didactic modes of teaching and learning can be, if not completely substituted, substantially enriched. TC 9-4 examines ways to deliver solid theoretical knowledge combined with the soft skills (e.g. problem solving, team working, adaptivity, learning capabilities, communication, etc.) that are fundamental to professional and academic engagement with increasingly complex engineering systems. A major activity of the TC is to work the IEEE Control Systems Society to collect, organise and make centrally available a repository of control and automation teaching resources. The purpose of this activity is to provide access to instructors and students to teaching tools and exercises for their courses, yielding a significantly increased flexibility and opening up new possibilities for teaching and learning strategy. Resources include videos, remote and virtual laboratories, interactives, exercises, gamification tools amongst many others. Once the repository is well advanced, the aim is to provide support for the design and delivery of personalized control courses everywhere and to anyone. This will help address IFAC's diversity and inclusion goals by creating the basis for the development of low-cost equipment for hands-on laboratory experiences to be delivered in poor regions where such resources are difficult to access. The task is not trivial and involves an examination of:

1) Outdated educational practices and content
2) Taxonomies for Control and Automation Education

TC 9-4 also developes educational benchmarks for use at all academic levels, including continuing professional education. These might be used, for example, to apply fundamental concepts in practical applications or to verify the effectiveness of curriculum design procedures. TC 9.4 works closely with the IFAC Industry Committee as it collects and curates open access resources and benchmarks. TC9-4 cosponsors a variety of IFAC events. It's flagship event is the triennial IFAC Symposium on Advances in Control Education (ACE) which incprorates interactive sessions for young researchers to study automation and control topics.

6. TECHNOLOGY, CULTURE & INTERNATIONAL STABILITY (TC9-5)

Automation and control technology proliferation leads to dramatic changes in international stability and shapes, and is shaped by, culture and human values. Systemic and structural effects in the international and regional context in areas such as digital infrasucture, climate, finance, energy, conflict and migration, amongst others, have immense consequences for human civilisation. In recent years international and national systems of control, especially in the social and political spheres, have proven inadequate and prone to fundamental instability. Many basic assumptions are no longer certain and

are under question. IFAC, as a control systems and automation engineering community, recognises the need for radical new approaches by which to address these challenges. TC 9-5 (TECIS) is an almost unique community in that it draws together strands of thought and practice, as well as technological applications and solutions, from across a range of disciplines which share a common concern with the role of science and engineering in systems of international stability and the ways in which technology and culture interplay with each other. TECIS systematically examines these topics and explores the contribution of control science and automation engineering to solutions in this space. Members include visionary contributors from the commercial sector and non-governmental organisations and agencies as well as academia. As well as co-sponsoring a variety of events, TECIS organizes an annual IFAC International Stability, Technology and Culture (TECIS) Conferences. In the past 3 triennia TC9-5 members have published four special issues of the international journal "Artificial Intelligence and Society". TC9-5 contributions are as diverse as equality, diversity and inclusion; blockchain applications in energy; digital cultural heritage; migration; control of financial systems risk; enhancement of international cooperative measures; conflict and post-conflict; telemedicine; smart data and many others.

The future activities of TC 9-5 are increasingly important for IFAC. Perhaps this is not good news: it may reflect the uncertain times in which the human species finds itself.

7. COOPERATION BETWEEN CC9 TCS

CC9 encourages scholars to be actively engaged in a wide range of technical activities o bring value to IFAC scholarship and professional praxis. Engagement across CC9 TCs is especially encouraged. A good example of this has been the development of cyber-physical-social systems (CPSS) research. CPSS lies at the interstices of automatic control an other engineering sciences as well as important subjects in social sciences. TC 9-1 has worked closely with TC 9-2 to develop this field. This has resulted in TC9-1 and TC9-2 co-hosting IFACs new "Cyber-Physical & Human Systems" symposia. In the past triennium TC9-1 and TC9-2 successfully organised two CPHS symposia. The success of CPHS exemplifies the potential for more interactions across CC9 TCs. For example, TC 9-5 in cooperation with TC 9-2 and 9-3 and other IFAC TCs (e.g. transportation, logistics and enterprise networks – see later section in this report) might examine international institutional systems and their regulation. Cooperation with national safety agencies in advanced engineering contexts (cross- border transportation networks for example) could explore and highlight ways in which IFAC contributions deepen our understanding and provide insights into practical solutions for better control of risk and improvement of safety measures. This is in line with "risk philosophy" and "safety culture" which is a driving force in the emergence of new, advanced thinking about how to control for complex safety and risk factors, especially in high hazard, international, domains (ECAST (2017; EUROCONTROL (2017)). Equality, Diversity and Inclusion, especially in relation to the digital paradigm, is another important focus of CC9. The TC9-5 D&I Working Group now coordinates with the Diversity and Inclusion committee at council level and this will provide new opportunties for inter-disciplinary, future-oriented CC9 work.

8. CC9 IN IFAC: QUALITATIVE ANALYSIS

The CC9 chairperson engaged with the TCs in a strategic review of each technical committee. This resulted in a revised set of keyword phrases which were reported to the World Congress 2023 organising committee. These were organised into a text database for analysis. Working Group names were added to the database. Using adapted content analysis the data was then passed through a series of analyses using standard open-, axial- and selective- coding techniques using word clouds to provide substantive insights (Robson (2003) p. 194; Gray (2009) pp. 502-6; Kealy & Stapleton (2014). Word clouds were formed to draw out key underlying themes. Moderating filters were applied in some clouds top drill into the data. Wordclouds are common in meta-analyses of literatures (Arnaboldi, Cho and Sternberg (2021)). The next section presents thematics findings using word clouds.

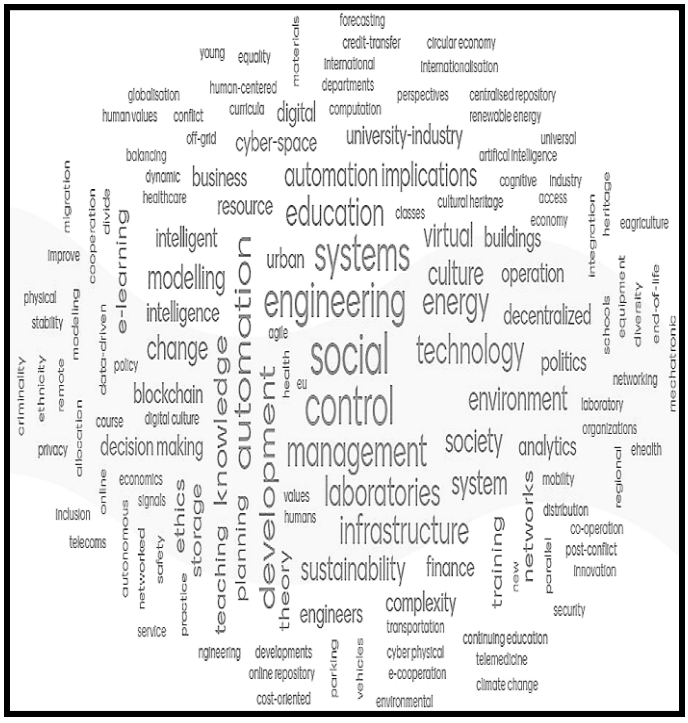

Figure 1. CC9 WordCloud: Frequency of Keywords (n=272)

Results

The initial analysis resulted in 272 keyword phrases. Their relative frequencies are visualised in figure 1. Whilst figure 1 revealed important CC9 activities it did not draw out the underlying key themes. The list was further revised using content analysis and moderation features of the workdcloud software to produce higher level themes. Figure 2 shows the wide range of activities and domains in which CC9 TCs. Figures 3 and 4 present the results of filters designed to draw out important results that are contained in figure 2 but that are difficult to isolate in the busy-ness of the word cloud.

Discussion and Interpretation

Technical reports and presentations submitted to the IFAC Technical Board describe CC9 as "multidisciplinary". This

suggests that the CC is an important space for translating theory into praxis and for focusing upon context. However no recent publications have attempted to understand the precise nature of the multi-disciplinary activity or the forms of output that result from the activity i.e. what aspects of human social existence CC9 attempts to improve. By screening out the subject areas using moderator functions, it was possible to produce a wordcloud which focussed upon the kinds of cross-disciplinary insights that CC9 seeks to learn and apply and which are designed to improve conditions in human society. This lens is presented in figure 3.

Figure 2. CC9 Main Themes Following Axial Coding.

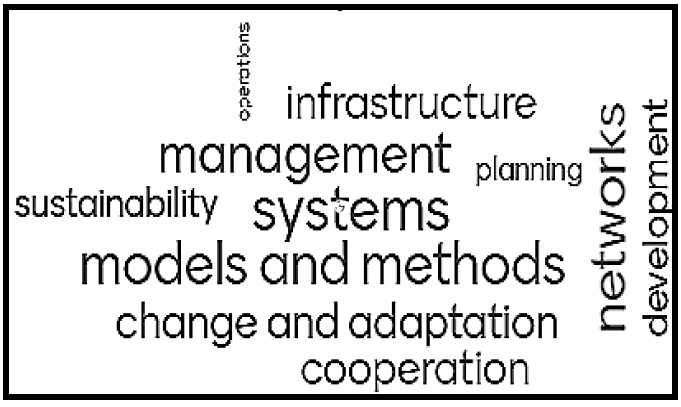

Figure 3. CC9 WordCloud: What CC9 Seeks to Improve

Figure 3 shows that CC9 gathers insights about *Models and Methods* and how these can be applied to various forms of *Systems, Networks, Infrastructures and Operations*.

In addition to theoretical contributions (*theory* is screened out of the figure 3 wordcloud), CC9 provides *planning, management and operation insights*, as well as insights about how to *improve cooperation*, *how to develop systems* and, most importantly, how to *build systemic sustainability*.

Figure 4. CC9 WordCloud: CC9 Domains of Activity

In addition to providing theoretical insights into social effects of automation and control, this meta-analysis suggests that CC9 can make major contributions to other CCs and their TCs. For example, ten possible contributions which go beyond social effects theory and applications are:

1) Regulatory frameworks e.g. analyses of potential Risk and Hazard arising from background conditions.
2) Ethical Frameworks
3) Contextual information for complex settings (e.g. Holons, Emergent phenomena).
4) Translation (from control sceince into/from other disciplines).
5) Tools and Methods identified in other disciplines and adapted for use in control and automation.
6) Experimental Data: Real-life use-cases for testing experimental designs and test data.
7) Development Frameworks including social policy frameworks.
8) Technologies emerging outside traditoinal control and automation engineering (e.g. blockchain).
9) Governance and Policy including sustainability, diversity and inclusion metrics, design thinking.
10) Management: Success and Failure Factors for large-scale complex systems in complex contexts, Transformation Frameworks (including implications of automation).

This list is by no means exhaustive and it should be noted that CC members have published contributions in all eleven categories. The next section identifies specific technical communities with whom CC9 TCs could readily collaborate.

Collaboration with other CCs

CC9 coordinated with CC8 during rescoping of TC9-2. This resulted in involvement (including a plenary session) in a CC8 event, IAMES 2022. CC9 brought industry and D&I participation to the TC 8-3 event. This example highlights that there are opportunities for greater involvement of CC9 in

the work of other CCs to support and engage with major debates and activities across IFAC.

What other potential for collaboration exists across IFAC?

In order to systematically highlight potential areas of collaboration with other CCs and TCs, a meta-analysis of the thematic text data was mapped to high level descriptions of IFAC TCs. This helped identify technical areas which might have the most potential for CC9 collaborations.

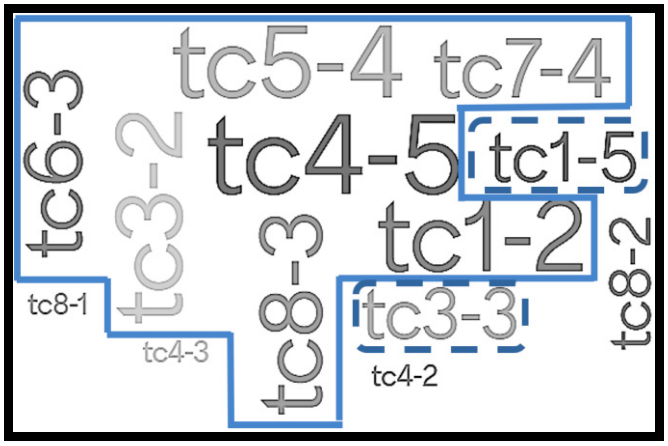

Figure 5. WordCloud of CC9 Themes Mapped Across IFAC

The visualisation (figure 4) revealed key-word based thematic groupings which were tentatively ranked (see table 1). The results suggested a strong potential for collaboration with 7 of the 8 other CCs and 13 TCs in those 7 CCs.

Collaboration Potential	TC	Name/Activity
Highest	4-5	Human Machine Systems
Very High	1-2	Adaptive and Learning Systems
	3-2	Computational Intelligence in Control
	5-4	Large Scale Complex Systems
Quite High	6-3	Power and Energy Systems
	7-4	Transportation Systems
	8-3	Modelling & Control of Environmental Systems
Less High	1-5	Networked Systems
	3-3	Telematics
Lower	8-2	Biological and Medical Systems
Others	4-2	Mechatronic Systems
	4-3	Robotics
	8-1	Control in Agriculture

Table 1. Ranking of CC9-to-IFAC Potential Collaborations

In this short paper it is not possible to provide a survey of all the potential areas of cooperation between the TC's listed in table 1 and CC9. Instead, in order to open up a potential discourse between CC9 and other CC's, we will very briefly review the four highest-ranking TCs in table 1 in light of the ac tivities of CC9.

TC4-5 addresses Human Factors, Human-Machine Symbiosis, Human-Automation Interaction, Human-Machine Hybrid Intelligence, Intelligent and Autonomous Systems, and Decision-Support Systems, all of which are domains of interest to CC9 (see figure 1 and 2). The context for the work of TC4-5 includes a wide range of application domains of real interest to all CC9 TCs. TC3-2 focusses upon knowledge-based systems, fuzzy, neural and evolutionary systems. The members explore both artificial and biologically plausible systems and provide deep insights into theory and applications. Figure 4 places human and machine intelligence at the centre of CC9 contributions to IFAC. For example, CC9 TCs might identify and design applications test beds for TC3-2. TC1-2 members work at with systemic uncertainty. Social systems are inherently open systems and highly uncertain spaces. There is a long tradition in social and management sciences of theories which address uncertainty. Human decision making in highly uncertain contexts, such as during a crisis or disaster, is an important theoretical domain for organisational-decision-making research (c.f. (Weick (1995), Furr and Eisenhardt (2021)). TC1-2 recognises the impossibility of perfectly describing mathematically the dynamics of real-life systems (including social systems). Indeed, this point raises very important philosophical questions, which have been explored in CC9 (e.g. Groumpos (2021)). It is evident that the theoretical work of TC1-2, especially in relation to problems associated with uncertainty in real-life contexts, is relevant to all CC9 TCs, especially TC9-5. We note that TC1-2 works in many applications contexts which are active in CC9, including power and energy, manufacturing, transportation, various networked systems, robotics and mechatronics (see figures 2 and 4). TC 5-4 takes special interest in the features of large-scale complex systems and notes the highly networked environment which involves the integration of a range of technologies with implications for economic and social life, as well as the environment. TC 5-4 grapples with the opportunitities and challenges associated with advances in computer and communication technologies and how these might support decision making in large-scale complex system contexts. It is evident from both figure 3 and figure 4 that these are also topics of great interest to CC9.

Each of the TCs named above sponsor regular IFAC events. For example, one of the most established IFAC symposia is "Large Scale Systems: Theory and Applications" (LSS) which was first held in Udine, Italy in 1976. It was last held in China in 2022. We note that CC9 TCs did not cosponsor this event yet contributions at LSS had implications for CC9. Applications contexts that were addressed in LSS 2022, with the relevant CC TCs shown in brackets, included urban traffic systems (TC9-3), water and environmental systems (TC9-5), power systems (TC9-3 and TC9-5) (Wang (2022)). Cooperation could begin with a CC9 TC Chair plenary LSS, and a TC 5-4 chair plenary at a CC9 event. The plenaries (followed by a special invited session) could be a basis for mapping out potential areas of collaboration of mutual interest from which an action plan for further cooperation be

established. This might result in journal special issue in which ideas could be exchanged in a written discourse. This is just one example of how new collarborations might be formed in IFAC which could leverage the work of CC9 across the global community and make new and significant contributions to science, engineering and society.

Collaboration beyond IFAC

CC9 has a long track record of cooperation with organisations outside IFAC. For example, TC9-1 has organised IEEE/IFAC events during the past two triennia and its members actively reach out to other federations. Likewise, TC 9-3 co-sponsors and jointly organises events with the IEEE Control Systems Society, IEEE Robotics and Automation Society and IEEE Power and Energy Society. CC9 has also deepened its coordination with the IEEE's new SSIT/UAT (Universal Access to Technology) initiative. The UAT community specialises in increasing access to advanced technologies across marginalised groups and communities. The TC9-5 working group on Ethics has published with "Scientists for Global Responsibility" including contributions to special journal issues and book chapters. International agencies also engage with CC9. For example, the United Nations Development Programme (UNDP) participated in a special panel session at the recent IFAC TECIS 2022 conference, contributing to a paper subsequently published in IFAC (Stapleton *et al* (2022)). The session highlighted implications of automation and control for human rights and freedoms. Digital diversity and inclusion challenges are a major issue for European regulators, impacting upon ethnic minorities, economically disadvantaged groups, people with special needs, LGBTQ+ communities and others. EU AI regulations respond to these challenges with major implications for IFAC (Donnelly & Stapleton (2022)).

9. FINAL REMARKS

This survey paper summarises the strategic review of CC9 TCs which culminated in revised scopes across all TCS and new keywords and key phrases describing the contribution of CC9 to IFAC. CC9 communities are working in a critical area where the opportunities and challenges of advanced control and automation systems and technologies are explored. There is a solid platform for further CC9 engagement with communities both inside and outside IFAC. CC9 is multidisciplinary, working with cutting edge technical advances to improve living conditions on the planet. It provides important thought-leadership for IFAC in areas critical for the sustainability of human civilisation in an increasingly digitised, interconnected and complex global society. The societal impact of emerging technologies such as AI, blockchain, CPHS, smart cities etc. offer important opportunities for high impact research and praxis. In addition to technical challenges, there are also many social challenges which CC9 addresses. As IFAC tries to show leadership in science and engineering by embodying a high inclusive and diverse community, both vertically and horizontally, the importance of the Diversity and Inclusion Working Group in TC 9-5 cannot be overstated as a means by whichy D&I challenges can be uncovered, voiced and addressed. The contribution of TC9-4 to a more inclusive education is also of critical importance here. Scholars and practitioners alike are currently revisiting ethics frameworks as we try to appreciate the complex implications of emerging systems for life on our fragile planet.

The evidence of this survey paper is that CC9 is in a very healthy state and well positioned into the next triennium. There is busy agenda ahead as IFAC maximises the opportunity that CC9 offers and address the challenges for human civilisation with which CC9 grapples.

ACKNOWLEDGEMENTS

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