IEEE Information Theory Society Newsletter

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President's Column

Andrea Goldsmith

I write this column en route back from the Information Theory Workshop in Taormina, Sicily, with memories of that magical city's dramatic cliffs, deep blue ocean, and views of the majestic and ominous Mt. Etna still lingering. Taormina hosted the Society's final Board of Governors (BoG) meeting and final technical meeting of the year. The close of that workshop marks the final phase of my presidency. In this last column I will reflect on the current state of the society, some challenges and open issues that will be left in the hands of my successors, as well as my own strategic view of how we might plan for the future in order to remain a vibrant and successful society many decades into the future.

Our society ends the year in excellent shape. We have weathered the financial storm and plummeting reserves well; for the year we have a budget surplus of about $100,000, an anticipated recovery in our reserves loss, and surplus income from our symposium and workshops. The financial outlook for next year is similar with an expected surplus of the same order, which can be used for new initiatives. However, we should not be complacent on the financial front, since the annual surplus will evaporate over the next 3 years as the new IEEE Xplore income formula for conference papers is phased in. A gradual loss of income as libraries move away from print subscriptions is also anticipated, and this trend has already begun. Thus, in order to keep our budget in the black while maintaining and perhaps growing our activities, we will need to find ways to cut costs and/or bring in new revenue. The easy solution is to increase fees, either membership fees, conference and workshop fees, or the fees we charge members for print copies of the Transactions (which the society currently subsidizes by about $65 per year per member). But this is not the only solution, and certainly not the desired one. Other mechanisms to generate more income being discussed include increasing Xplore income (by reducing sub-to-pub time and publishing more tutorial and survey papers that are widely accessed by people inside and outside our field), using our website to generate revenue via commercial advertising and sponsorship, and endowing some of our activities such as the Student School and the Distinguished Lecture Program.

In reflecting on our main accomplishments this year, they have come about mostly from our newest committees. The Student Committee under the leadership of Aylin Yener held its second Student School, with 40% higher enrollment than last year. Moreover, the school receives the 2nd highest number of hits on our website, after the main page, which indicates the tremendous value of its archived material. Plans are already in the works for schools in 2010 and 2011. Our website has received approximately 60,000 hits since its February launch, with 255 visits per day. Under the expert leadership of Nick Laneman, it has become the go-to-site for information about the society, and is better integrated with the newsletter with the help of Editor Tracey Ho. Our revamped Chapters and Membership Committee under Giuseppe Caire has launched a Distinguished Lecture Program for our chapters, with five lecturers to be in place next year. They also sponsored the first Padovani Lecture at the 2009 North American Student School and worked with the Online Committee to create a showcase for chapter activities. Other important developments are the mentoring activities of the Outreach Committee, a best practices document for editors generated by the Publication Committee, getting BoG members more involved in society committees, and our work to reestablish the IEEE Baker Prize recognizing fundamental papers across all IEEE publications, which looks to obtain final IEEE approval in November.

A few important items remain under discussion regarding society activities. The Conference Committee has put forth a document for discussing policy guidelines on the nature, venues, and costs of our conferences and workshops. Some questions posed include: Should we proactively solicit targeted and/or interdisciplinary workshop proposals or should our workshops generally remain broad? Should our workshops have more time for discussion and "work" rather than conference-like presentations? Should the locales and sites of our symposia and workshops be chosen to maximize appeal or to minimize cost, or should we

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From the Editor

Tracey Ho

Dear IT Society members,

In this year end issue of 2009, we have Andrea Goldsmith's last column as IT Society President. Please join me in thanking her for her vision and leadership over the past year, and in welcoming Frank Kschischang who will be Society President next year. My personal thanks also to Andrea and the other officers for their guidance and advice in my first year as newsletter editor.

I hope you will also enjoy the other articles in this issue, which include reflections on the 2009 IT Society Paper Award-winning article "Interference Alignment and the Degrees of Freedom of the K User Interference Channel" by Viveck Cadambe and Syed Jafar, as well as the summary by Noga Alon of his ISIT 2009 plenary talk on combinatorial reasoning in information theory.

In the coming year, the online editor Nick Laneman and I will be exploring ways to better integrate the newsletter and website, and to broaden the scope of content. We welcome any comments and suggestions that you might have.

As a reminder, announcements, news and events intended for both the printed newsletter and the website, such as award announcements, calls for nominations and upcoming conferences, can be submitted jointly at the IT Society website http://www.itsoc.org/, using the quick links "Share News" and "Announce an Event". Articles and columns intended only for the printed newsletter should be e-mailed to me at tho@caltech.edu. The deadlines for the next few issues are:

Issue	Deadline
March 2010	January 10, 2010
June 2010	April 10, 2010
September 2010	July 10, 2010

Please submit ASCII, LaTeX or Word source files; do not worry about fonts or layout as this will be taken care of by IEEE layout specialists. Electronic photos and graphics should be in high resolution and sent as separate files.

I look forward to your contributions and suggestions for future issues of the newsletter.

Tracey Ho

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alternate between these criteria? Should the cost be lower for local participants in disadvantaged locations? These issues will be discussed among the officers and in upcoming BoG meetings, with some policy guidelines developed around the conclusions. Another ongoing topic of discussion is how to solicit and publish tutorial papers along with non-technical content of interest to our members and the general technical community. We do not currently have good mechanisms or motivation for publishing either type of article within our society, as the Transactions rarely publishes tutorial papers and the newsletter lacks the prestige and citation value that motivates most authors. Hence many of our members publish articles of this type in the magazines and journals of other societies. Ways to publish such material "in-house", and enjoy their financial and intellectual benefits, will be a topic of ongoing discussion in the coming year.

The Transactions continue to be highly regarded and of excellent quality. Moreover, several important steps have been made to address our long sub-to-pub time, including a significant increase in the number of Associated Editors (AEs), from 26 to 46 over the last two years, a migration plan from Pareja to Manuscript Central, and a comprehensive document on Best Practices for Editors. However, despite the focus and effort on reducing our sub-to-pub time this year, it has actually increased since January, from an average of 97.2 weeks to 99 weeks. There has been ongoing discussion among the officers, the BoG, and the Publications Committee on how to address this vexing issue. It was concluded in Taormina that the only way to make significant progress on bringing our sub-to-pub time down to a reasonable level is to become more "businesslike" in our paper handling: developing an editorial policy for AEs, authors, and reviewers; creating and imposing firm deadlines; and better tracking the status of each paper along with statistics on AEs, reviewers, and authors. This dramatic change cannot be brought about singlehandedly by the Editor-in-Chief (EiC), no matter how determined. Thus, the officers anticipate hiring a half-time "managing editor" for the Transactions to help the EiC and AEs focus on their editor duties rather than on paper tracking and administration. The managing editor will help the EiC track overall statistics as well as the status of each paper to identify substantial delays, bottlenecks, and items falling through the cracks. We hope that this additional administrative help will streamline paper processing and make the EiC and AE jobs easier and more enjoyable, as well as serve as a resource for authors in tracking their papers. In addition, a Task Force will be formed with the specific charge of reducing sub-to-pub. This Sub-to-Pub Task Force, headed by the EiC, will help to determine the role of the managing editor, develop the new editorial policy, and address the main causes contributing to our publication delays. This Task Force may eventually become a standing Steering Committee for the Transactions to address broader issues. These changes obviously require support from the current as well as the next EiC, whose term will begin in June 2010 when our formidable EiC Ezio Biglieri ends his three-year tenure. The Nominations and Appointments Committee together with the officers are in the process of an EiC search. A top criteria in this search is to find someone who will embrace these changes and make reducing sub-to-pub a priority during his or her term. I would like to thank Ezio on behalf of the society for all his efforts to address this difficult problem, and for his vision and leadership in steering our Transactions. His successor will have a tough act to follow.

In terms of strategic thinking, we have enjoyed tremendous success as a field and as a society over the last decades. Information Theory has been at the heart of and benefitted much from the Information Technology (IT) revolution, with its core ideas enabled by the advances in analog and digital circuits as well as Moore's Law. While the decades following Shannon's 1948 paper were dominated by the IT industry and hence our relevance was secure, the IT industry has now matured, and the biggest technical challenges are no longer IT-centric. This will require us to embrace new areas and new ways of thinking; to figure out how to become more interdisciplinary and tackle large problems that may elude simple models and closed-form solutions. We must also continue to engage young members and students to participate in the society, as they bring new ideas and research areas that will keep us vibrant and relevant. We must work harder to demonstrate the impact of our work to the broader community, so that our research continues to be amply funded, and our members get good jobs where the importance and relevance of their work is easily recognized. We must embrace new technologies in our publishing and other activities, and keep our website a dynamic and exciting portal showcasing the society, its activities, and its members. Finally and most critically, we must maintain the warmth, openness, vibrancy, and flexibility so unique to our society that makes it such a desirable professional home for its members.

On New Year's Day 2010, Frank Kschischang will step into the president's role, with Giuseppe Caire and Muriel Médard serving as first and second Vice Presidents, respectively. The society will greatly benefit from their collective wisdom, dedication, and leadership. I will move into the role of Junior Past President, with G. David Forney as our Senior Past President. Aria Nostratinia will be the Society's Secretary and Nihar Jindal its Treasurer. Bixio Rimoldi will complete his five-year officer term this year. Bixio was President when I began my officer term, and I learned much from his leadership. It was a pleasure and privilege to work with him, and we will miss his steady hand and deep perspective in our officer deliberations. Seven members have been elected or re-elected to a three-year term on the BoG starting in January: Martin Bossert, Max H. M. Costa, Rolf Johannesson, Hans-Andrea Loeliger, Prakash Narayan, Muriel Médard, and Li Ping. We welcome the new BoG members and would like to thank the outgoing BoG members ending their terms, Ryuji Kohno, Tor Helleseth, and Alon Orlitsky, for their leadership and wisdom in helping to govern our society.

And finally, my adieu. It has been a pleasure and an honor to lead this great society over the past year. The Information Theory Society is truly unique within the IEEE, with an open and welcoming culture, few barriers to try new things, and an extremely vibrant and proactive membership. While I have not accomplished all I wanted to this year, I have set a few important wheels in motion, and hope that in general I have left the society better off than one year ago. I have especially enjoyed working with the BoG and Committee Chairs on the many new and ongoing initiatives, which have greatly benefitted our members. Their vision, thoughtfulness, and dedication are the reason for these successes. I am also deeply grateful to my fellow officers Bixio Rimoldi, Dave Forney, Frank Kschischang, and Giuseppe Caire. They have been extremely dedicated, thoughtful, energetic, and wise about all issues facing the society, which has made my job much easier as well as a lot of fun. I look forward to working with Frank, Giuseppe and Muriel over the next two years as Past President. I'm sure that our society will continue to prosper and thrive under their great leadership.

The Historian's Column

Anthony Ephremides

In my last column I commented about music and the members of our community. In it, there were some typos, one of which merits correction, and there was one major omission. The typo that needs correction concerns the spelling of Ezio Biglieri's name. The demon of the print shop (that remains alive and active even in the electronic era) converted his name to an unspeakably distorted version that reminded one the name of Dr. Caligari. Deep apologies to our Transactions Editor-in-Chief.

The omission, however, is a more serious affair. Although I paid tribute to my comrades-in-song (like Sergio Verdu and the "tenured tenors") who bellowed along with me on multiple occasions, I neglected a man whose raspy voice left an indelible mark on my ears, as he accompanied my efforts to sing operatic arias. He was the first member of our community whom I identified as an opera lover and who was a valued colleague for many years and who remains a close friend. His name is Lee Davisson. Many of you out there know him personally and others know of his pioneering work in universal data compression that won him the best paper award of our Society in the early seventies. Undoubtedly, there are many who do not know him.

Lee is a man of quiet demeanor and steel nerves who has a poker face and a hilarious sense of humor. And he likes opera. And he will sing. And he doesn't have a voice for singing. These traits synthesize a personality of unparalleled potential for fun. And fun we had.

In the decade of the '70's, the years of Richard Nixon, Jimmy Carter, and the first energy crisis that shot gasoline prices and car queue sizes at gas stations to the ceiling, the Metropolitan Opera had the custom of touring a number of cities in the country after the end of its regular season in New York. So, it would visit Washington in the early part of June for one week of performances. For obvious reasons of cost reduction it would seek local volunteers to act as supernumeraries in its performances. For the grand sum of $4.00 a head (ostensibly to help defray driving costs) it would assemble anywhere from a handful to a few dozen individuals who would agree (more accurately, love, if not give everything they had) to be on the stage as soldiers, loiterers, anonymous villagers, monks, warriors and other characters who are needed to give a performance the credibility it needs.

The thrill of being on stage was amplified by the proximity to the greatest singers of the world and the play-acting that formed the subject of their dreams. Supernumeraries are delightful opera lovers who are frustrated opera singers or aficionados who live out their dream for some fleeting moments on the stage.

So, Lee and I, (yes, it is time to publicly admit it) sought the coveted role of a supernumerary and succeeded getting it on some occasions. We actually appeared together in a memorable performance of Wagner's Lohengrin (among others).

The way it worked was as follows. After being notified by mail that our application was accepted, we were summoned to report at 5pm (for a curtain time of 8pm) for necessary preparations. These consisted, first of all, of a stern warning not to even think of opening our mouths in song while on stage. Then we were given the necessary garb and had the most rudimentary rehearsal of what we were supposed to do. This inadequate training produced hilarious results.

In particular, during that fateful performance of Lohengrin, what we were supposed to do was to march as spear-carrying medieval soldiers on stage in Act III and align ourselves in a V-formation that framed the main action on the stage. "Action" is a euphemism in Wagner operas. All we were supposed to do was stand there after deployment for about thirty minutes enjoying the singing and the music unfolding in our midst. Essentially no one moved anything except for the singers who moved their lips.

As it happened, Lee was the first one in the row of soldiers who were supposed to deploy on a straight line. During rehearsal, the exact location of the soldiers had not been fully specified. So, Lee walked all the way to the end of the stage stopping right over the orchestra pit. When he stopped, he made a 90°-degree turn to face the center of the stage, as instructed. To his horror, he realized that all the other soldiers had stopped significantly earlier, leaving him to stand along and separated from the rest of the pack.

As they say, the mettle of man manifests itself in crisis. Lee stayed cool, pretended that nothing was amiss and proceeded to start a painfully slow and long process of inching his way sideways towards the other soldiers. It may have taken him about ten minutes to cover a distance of about twenty feet, but in the end, there he was, properly positioned along everyone else, without anyone (except, perhaps, me) noticing!

This was just one of the many joint appearances most of which were, what we might call today, "virtual". Although we did not dare sing while serving the Muses with the Met, we did not hesitate to do so in many restaurants, parties, workshops, symposia, and gatherings at the homes of tolerant friends.

Lee is now retired, devoting much of his time to his other great love, sailing around the world with his wife. I, hereby, pay tribute to my first ever comrade-in-song.

P.S. : And that's not all; in my last column I made reference to a young Turkish lady with a beautiful voice who joined me in singing. I professed shamefully that I had forgotten her name. Well, thanks to Jim Massey my memory has been restarted; her name is Melek Yucel and she is at the Middle East Technical University in Turkey. My apologies, Melek!

Reflections on Interference Alignment and the Degrees of Freedom of the *K* User Interference Channel

2009 Information Theory Society Paper Award

Viveck R. Cadambe, Syed A. Jafar

This letter is comprised of four sections, which may be seen as answering four questions – (1) What is the main result of our work in [1]? (2) How did the idea of interference alignment evolve leading upto this work? (3) What is the main technical difficulty and how is it overcome? and, (4) What are some of the key ideas surrounding interference alignment that have emerged out of this line of research upto the present time?

1 The Result – Everyone gets Half the Cake

An interference channel is the canonical information theoretic model to capture the competition for limited resources that defines a wireless network. The resource of interest to us in this work is the number of interference-free signaling dimensions/ bandwidth/degrees of freedom, which essentially determines the pre-log factor of the sum-capacity of the network. Using time (and alternatively, a "cake") as a surrogate for generic signaling dimensions – e.g., time, frequency, space, signal levels – let us say that a single transmitter-receiver pair, in the absence of interference, is able to communicate *all the time*. In other words, since there is no competition, the single user is able to get all the cake. Now, what happens when a second transmitter-receiver pair also wishes to communicate independent information over the same wireless medium? If the users are not too far from each other, the broadcast nature of the medium creates interference between the two users (transmitter-receiver pairs) and classical results in information theory tell us that the best (fair) solution is for each user to communicate free from interference for half the time – everyone gets half the cake. Of course, since there are only two users competing for the network degrees of freedom, the result is not surprising. The natural question then, is to ask how this result extends to more than 2, say K, users. The conventional wisdom, as evident from widely prevalent orthogonal access schemes like TDMA, is that if interference is to be avoided, each user should communicate for a fraction $1/K$ of the time. This solution corresponds to a natural cake-cutting view of medium-access. The main result of this paper is to show that even with K users competing to access the same wireless medium, it is possible for each user to communicate, free from interference, for a fraction 1/2 of the time. Thus, regardless of the number of users, everyone gets half the cake.

At first sight, the conclusion that everyone gets half a cake seems to directly violate a basic conservation principle. However, the apparent contradiction is resolved by correctly accounting for the total number of signaling dimensions. As the number of users increases, the spatial bandwidth of the wireless medium – the number of cakes – increases as well. After all, it is well known that with joint processing of signals either across all K transmitters or across all K receivers, the resulting multiple input multiple output (MIMO) broadcast (BC) or multiple-access channel (MAC) has a bandwidth K times higher than the single transmitter-receiver pair. Thus, there are potentially K cakes in the K user interference channel. The natural question then, is to account for what is lost due to the *distributed* nature of the network. In this light, the main result of the paper shows that the cost of distributed processing is no more than half the total number of degrees of freedom. Since half the degrees of freedom are lost necessarily even in the two user interference channel, it is easy to see that this solution cannot be improved upon, thus establishing the exact degrees of freedom of the K user interference channel.

2 The Evolution of Interference Alignment Leading Up To [1]

The key to the result described above is the idea of interference alignment – the signals are designed in such a way that they cast overlapping shadows at the receivers where they constitute interference while remaining distinguishable at the receivers where they are desired. The enabling premise for interference alignment is the relativity of alignment, i.e. each receiver sees a different alignment of signal spaces. Before [1] introduced the idea of interference alignment to the interference channel, there were three available bodies of work on interference alignment that addressed the 2 user X channel and the compound MISO BC. The degrees of freedom benefits of overlapping interference spaces were first reported by Maddah-Ali et. al. in their ISIT 2006 paper [2] and in a report [3] published in July 2006, for the 2 user X channel, where an iterative algorithm was formulated for optimizing the transmitters and receivers in conjunction with dirty paper coding and/or successive decoding. With M antennas at each node the surprising conclusion was that $\lfloor 4M/3 \rfloor$ DoF are achievable. This was unlike the 2 user interference channel [4] where no more than M DoF are achievable. This work was followed by a report by Jafar [5] that appeared on arXiv in September 2006, where the idea of interference alignment was crystallized in the form of the first closed-form solution for a beamforming scheme that achieved perfect interference alignment with only linear processing (beamforming and zero forcing). The direct (non-iterative) approach taken by Jafar [5] was also adopted by Maddah Ali et. al. in their second report [6] published in December 2006. In parallel with the work on the X channel, there was the work by Weingarten, Shamai and Kramer [7] (ITA at UCSD, January 2007) that independently discovered interference alignment in the context of the compound MISO BC. The report [5] developed into the journal paper by Jafar and Shamai [8] (IT Trans. Jan 2008) where the achievable DoF of the 2 user X channel were improved from $\lfloor 4M/3 \rfloor$ to $4M/3$. Maddah Ali et. al.'s second report [6] lead to their journal paper [9] (IT Trans. Aug. 2008). Incidentally, it was in [8] that the terminology "*interference alignment*" was used for the first time to describe this idea.

The feasibility of interference alignment in all the cases considered prior to [1], could also be intuitively verified by counting the number of equations and variables in the signal space interference alignment problem formulation. However, using the same argument for a K user interference channel would indicate at first that interference alignment should be infeasible (i.e. number of equations exceeds the number of variables) for $K > 3$ users. How to solve this seemingly over-constrained problem, was indeed the main difficulty encountered in arriving at the results of [1]. In the next section we provide an intuitive understanding of the source of this difficulty and the solution proposed in [1] that circumvents it.

3 The Difficulty and the Solution

3.1 The Difficulty: An Over-Constrained Problem

The interference alignment problem for the K user interference channel can be understood as follows. Consider transmitters 1 and 2 that transmit their signals using signaling vectors in V_1 and V_2, respectively. In other words V_1, V_2 are matrices whose columns indicate the signaling vectors used by the transmitters 1 and 2 respectively. Now at receivers 3 and 4, where both these signals are undesired, interference alignment requires that they should align. This is expressed as the constraint:

$$\text{span}(H_{31}V_1) = \text{span}(H_{32}V_2)$$
$$\text{span}(H_{41}V_1) = \text{span}(H_{42}V_2)$$

Here H_{rt} is a linear transformation representing the channel between receiver r and transmitter t, and span (A) refers to the vector subspace spanned by the columns of A. With equal number of dimensions at all nodes (i.e. equal number of antennas), the channels are invertible and the above relationship can be expressed as:

$$\text{span}(V_1) = \text{span}(\underbrace{H_{31}^{-1}H_{32}H_{42}^{-1}H_{41}}_{T_1}\, V_1) = \text{span}(T_1V_1)$$
$$\Rightarrow V_1 = \text{inv-subsp}(T_1) \tag{1}$$

Thus, the signaling space used by transmitter 1, V_1 should be an *invariant subspace* of the linear transformation T_1 which is determined by the channel coefficients alone. Similarly, the signals from transmitter 1 and 2 should align at receivers $5, 6, \ldots, K$. Moreover, signals from transmitter 1 and 3 should align at receivers $2, 4, 5, \ldots, K$. Proceeding similarly, it is easy to see that each such alignment constraint implies, among other things, a new constraint on V_1 of the form of (1). Thus, we need to *simultaneously* satisfy

$$V_1 = \text{inv-subsp}(T_1) = \text{inv-subsp}(T_2) = \cdots = \text{inv-subsp}(T_N) \tag{2}$$

for arbitrarily large N, as the number of users K becomes large. Essentially, the main difficulty in solving this problem is that we need a non-trivial common invariant subspace of all the T_i. In general, this is easily seen to be infeasible as follows. (1) The T_i are determined by the channel coefficients, so we have no control over them. (2) It is well known that generic linear transformations do not have non-trivial common invariant subspaces.

3.2 The Solution: Channel Structure and Common Almost-Invariant Subspaces

The solution proposed in [1] relies on the assumption that channel matrices T_i are commutative with respect to multiplication. While this is not true for generic channel matrices, it is true for channel matrices that have a diagonal structure, such as those that are obtained by time extensions e.g. over time-varying channels. Even with this assumption, it is easily seen that the trivial common invariant subspaces of diagonal matrices do not solve the interference alignment problem (mainly because the desired signals must not align with the interference at any receiver).

The main insight of [1], which makes the problem feasible, is to look for an *approximate* solution. Instead of requiring that V_1 should be a non-trivial and exactly invariant sub-space of so many effective channel matrices, we look for signal spaces V_1 that are non-trivial and *almost* invariant sub-spaces of $T_1, \ldots, T_N$. In other words, we want a large (but not necessarily complete) overlap between the spaces spanned by V_1 and by T_iV_1, for all $i = 1, 2, \ldots, N$.

To see the thought process used to arrive at the solution, let us start with V_1 equal to some generic signaling vector w. Now, $V_1 = w$ and $T_iV_1 = T_iw$ and there is no overlap. We need V_1 to overlap (or align) with T_iV_1. Therefore, to increase overlap between V_1 and T_iV_1, we now expand our beamforming space V to include the vectors T_iw so that $V_1 = \{w, T_1w, T_2w, \ldots, T_Nw\}$. Now, $T_iV_1 = \{T_iw, T_iT_jw, \forall j \in \{1, 2, 3, \ \ldots, N\}\}$. At this point there is an overlap of 1 signaling vector T_iw which is present in both V_1 and T_iV_1 for all $i = 1, \ldots, N$.

Repeating the procedure thus n times, each time expanding V_1 to include the vectors of T_iV_1 from the previous time, we get V_1 to contain all the n^N vectors of the form $T_1^{\alpha_1}T_2^{\alpha_2} \ldots T_N^{\alpha_N}\, w$ where $\alpha_i \in \{0, 1, \ldots, n-1\}$. With this choice for V_1, the space T_iV_1 contains all vectors of the form $T_1^{\alpha_1}T_2^{\alpha_2} \ldots T_i^{(\alpha_i+1)}T_{i+1}^{\alpha_{i+1}} \ldots T_N^{\alpha_N}\, w$ where $\alpha_i \in \{0, 1, 2, \ldots, n-1\}$. Note that we have used the fact that the matrices T_i being diagonal, commute. Also note each time we expand V_1, the extent of overlap between V_1 and T_iV_1 increases. On carefully examining the extent of overlap between V_1 and T_iV_1, it is found that, for large n, the dimension of $\text{span}(V_1) \cap \text{span}(T_iV_1)$ is approximately equal to the dimension of $\text{span}(V_1)$. Thus, asymptotically in n, V_1 aligns perfectly with $T_1V_1, T_2V_1, \ldots, T_NV_1$ and we have found a non-trivial common *almost*-invariant sub-space for $T_1, T_2, \ldots, T_N$.

There are, of course, several other issues to be dealt with – e.g. the size (dimensionality) of V_1 should be roughly half the size of the overall signal space so that everyone gets half the cake, the desired signals at receiver 1 should be linearly independent of the interference, and similar considerations are needed for all transmit signal spaces $V_2, V_3, \ldots, V_K$ and for all receivers. For these, we refer the reader to the full paper [1]. However, the construction intuitively described above, is in our opinion the most far-reaching contribution of this paper. Indeed, the same ideas were used to show the achievability of the DoF for X networks with more than 2 users, and for asymmetric MIMO K user interference channels [10]. Morever, recent work by Motahari et. al. [11] shows that even for constant channels and with no symbol extensions, the alignment scheme described above can be applied in essentially the same form to achieve the outer bounds on DoF of various constant-channel networks. While the notion of linear independence is replaced with algebraic independence over rationals, the key to interference alignment in [11], as in [1], is the commutative multiplication property which is obviously satisifed by scalar channel coefficients. In its re-interpreted form introduced by Motahari et. al. [11] for constant channels, the alignment scheme described above has also been used by Gou et. al. [12] to settle a conjecture made by Weingarten et. al. for the finite state compound MISO BC in [7].

4 The Key Ideas Surrounding Interference Alignment

In this section we enumerate some of the recent conceptual advances in our understanding of the capacity limits of wireless networks following the connecting thread of interference alignment.

1) *Iterative Interference Alignment:* Iterative algorithms for interference alignment were introduced for the 2 user MIMO X channel in [2] and for MIMO interference networks in [13]. These algorithms are useful not only to achieve interference alignment at high SNR but also to provide good performance at intermediate SNR values. They also allow distributed mechanisms to align interference with only local channel knowledge at each node.

2) *Explicit Beamforming:* The first closed-form interference alignment solution was proposed for the 2 user MIMO X channel in the report [5] leading to the journal paper [8]. The alignment scheme perfectly aligns interference without the need for iterative optimization or non-linear schemes like dirty paper coding and successive decoding used previously in [2, 3]. In general, explicit beamforming solutions are not known in many cases even when signal space interference alignment solutions are known to be feasible [14].

3) *Symbol Extensions:* The idea of using symbol extensions – i.e., beamforming over multiple channel uses – for interference alignment was introduced in [7] for the 2 user compound MISO BC. It was later used in [8] for the 2 user X channel with constant channel coefficients. Before these works, it was not known whether fractional DoF values could be achieved. It is noteworthy that the MIMO MAC, BC and 2 user MIMO Interference channel with perfect channel knowledge at all nodes allow only integer values for maximum DoF.

4) *Channel Variations:* The idea of exploiting channel variations to accomplish signal space interference alignment when it is not feasible with constant channels, was introduced in [8] for the 2 user SISO X channel. The main problem was that constant channels lead to scaled identity matrices which, because they do not rotate the signal vectors, do not provide the relativity of alignment needed for signal space interference alignment. Symbol extensions over varying channels create diagonal – but not scaled identity – channel matrices which rotate the signal spaces differently between each transmitter-receiver pair, thus providing the relativity of alignment that could be exploited to achieve interference alignment.

5) *Asymptotic Interference Alignment:* The idea that interference can be aligned over a large number of dimensions by exploiting the commutative property of diagonal channel matrices even when the unstructured (i.e. with non-diagonal generic channel matrices) problem is over-constrained, was introduced in [1]. This result showed that with enough bandwidth expansion, any number of simultaneous alignment requirements could be satisfied. An important consequence of this result is the robustness of the degrees of freedom characterizations of finite state compound networks for a finite number of channel states [12].

6) *Inseparability of Parallel Interference Channels:* While joint coding over symbol extensions in time-varying channels was exploited for interference alignment as mentioned above, it was not known whether this was a fundamental necessity or merely a matter of convenience. [15] established that this was the case by showing that parallel interference channels with 3 or more users were inseparable, i.e. the capacity of parallel channels was strictly higher than the sum of the individual capacities of the sub-channels. The result was extended to 2 user interference channels in [16].

7) *Asymmetric Complex Signaling:* Even as increasingly sophisticated interference alignment schemes were found for time-varying channels, the DoF of various networks with constant channels remained open for the reason mentioned above. A new idea, called *asymmetric complex signaling* was introduced through an example in [1] and later crystallized in [17] to move past this hurdle for some networks. It was found that by translating the complex signal space into a real signal space the scaled identity channel matrices were translated to rotation matrices (corresponding to phase rotations) which again provided the relativity of alignment needed for interference alignment in signal vector space.

8) *Signal Level and Lattice Alignment:* A novel idea for interference alignment – in signal scale and through lattice codes – emerged out of the deterministic layered erasure channel model of [18] and was crystallized in [19] for the many-to-one interference channel and in [20, 21] for fully connected interference networks. The main insight was that with lattice codes it is possible to decode the sum of interference codewords – since the sum of lattice points from the same lattice is again a lattice point – even when the interferers could not be individually decoded. This is in contrast to random coding constructions where decoding the total interference is equivalent to decoding each interferer individually. The idea was further advanced through a sophisticated scaled lattice alignment scheme in [22, 11]. Their main insight was that integer lattices scaled by rationally independent factors are separable, almost surely, at high SNR. Since scalar channels satisfy the commutative property, with this new insight the asymptotic alignment solutions of [1] were easily extended to constant channels.

9) *Ergodic Interference Alignment:* A key concern with nearly all interference alignment schemes was that they may only be effective at very high SNR values. This concern was alleviated by a new idea introduced in [23], called ergodic interference alignment. This surprisingly simple idea showed that by carefully coding over pairs of complementary channel matrices not only could perfect interference alignment be accomplished but also the optimal performance at any

SNR value could be achieved in many meaningful settings. In a nutshell this result that in an ergodic fading K user interference network with independent and uniform phase variations everyone gets half the cake not only at high SNR but at any SNR value.

10) *Exploiting Propagation Delays:* While all the schemes mentioned above relied on the knowledge of channel coefficient values at the transmitters, a novel alignment scheme that exploits only the signal propagation delays was proposed in [1] as a toy example. This scheme was generalized and explored further in [24] and [25] and was found to have interesting similarities with the asymptotic alignment schemes in its reliance on bandwidth expansion to achieve interference alignment.

11) *Exploiting Channel Correlations:* A novel interference alignment scheme was introduced in [26] where, like the propagation delay based scheme, interference alignment is achieved without any knowledge of the channel coefficient values at the transmitters. The key is to exploit the channel temporal correlation structure captured in a staggered block fading model. While both schemes do not require the knowledge of channel coefficient values at the transmitters, the staggered block fading model appears much more natural than the propagation delay based model. A difference in channel coherence times of different users naturally leads to a staggered block fading model. However, the staggered block fading model can also be imposed on a channel by e.g., switching among antenna configurations with reconfigurable antennas or by switching among antennas in the manner of commonly used antenna selection schemes where the number of antennas exceeds the number of RF chains.

5 Conclusion

We summarize here the answers to the questions highlighted in the introduction. The main result of [1] is that in a time-varying interference network with perfect channel knowledge at all nodes, regardless of the number of transmitter-receiver pairs competing for medium access, each user is able to access half the channel degrees of freedom, free from interference. The key concept involved is the idea of interference alignment that evolved out of prior work on the 2 user X channel in [8, 9] and on the compound MISO BC in [7]. The main challenge in arriving at this result is the apparent difficulty in trying to align signals perfectly *everywhere* they are not desired while keeping them distinct *everywhere* they are desired, especially as the number of users grows. This seemingly over-constrained problem is solved in an asymptotic and approximate sense in [1] by exploiting the commutative property of diagonal channel matrices obtained from symbol extensions over time varying channels. In closing, while the exact capacity of most wireless networks may never be found, an increasing body of work on interference alignment continues to develop new and often surprising insights that may bring us closer to this holy grail of network information theory.

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Combinatorial Reasoning in Information Theory

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Abstract

Combinatorial techniques play a crucial role in the investigation of problems in Information Theory. We describe a few representative examples, focusing on the tools applied, and mentioning several open problems.

1 Introduction

Combinatorial ideas play a prominent role in the study of problems in Information theory. Indeed, the whole theory can be developed using a combinatorial approach, as done, for example, in [12]. In this brief survey we discuss several examples in which tools from Combinatorics and Graph Theory are applied in the investigation of problems in Information Theory. The combinatorial approach seems especially powerful for tackling problems in zero-error information theory which deals with scenarios in which no positive probability of error is tolerated. Problems of this type are discussed in a significant number of papers starting with [23], and are also the focus of the present short paper. This is not meant to be a comprehensive treatment of the subject, but hopefully provides an interesting description of several intriguing information theoretic results obtained by combinatorial reasoning.

2 The Shannon Capacity of graphs

For an undirected graph $G = (V, E)$, let $G^{\wedge n}$ denote the graph whose vertex set is V^n in which two distinct vertices $(u_1, u_2, \ldots, u_n)$ and $(v_1, v_2, \ldots, v_n)$ are adjacent iff for all i between 1 and n either $u_i = v_i$ or $u_i v_i \in E$. The *Shannon capacity* $c(G)$ of G is the limit $\lim_{n\to\infty}(\alpha(G^{\wedge n}))^{1/n}$, where $\alpha(G^{\wedge n})$ is the maximum size of an independent set of vertices in $G^{\wedge n}$. This limit exists, by super-multiplicativity, and it is always at least $\alpha(G)$. (It is worth noting that it is sometimes customary to call $\log c(G)$ the Shannon capacity of G, but we prefer to use here the above definition, following Lovász [19].)

The study of this parameter was introduced by Shannon in [23], motivated by a question in Information Theory. Indeed, if V is the set of all possible letters a channel can transmit in one use, and two letters are adjacent if they may be confused, then $\alpha(G^n)$ is the maximum number of messages that can be transmitted in n uses of the channel with no danger of confusion. Thus $c(G)$ represents the number of distinct messages *per use* the channel can communicate with no error while used many times.

There are several known upper bounds for the Shannon capacity of a graph. The most effective one is a geometric bound proved in [19], which is called the Lovász θ-function. Other bounds appear in [23], [16], [1].

The (*disjoint*) *union* of two graphs G and H, denoted $G + H$, is the graph whose vertex set is the disjoint union of the vertex sets of G and of H and whose edge set is the (disjoint) union of the edge sets of G and H. If G and H are graphs of two channels, then their union represents the *sum* of the channels corresponding to the situation where either one of the two channels may be used, a new choice being made for each transmitted letter.

Shannon [23] proved that for every G and H, $c(G + H) \geq c(G) + c(H)$ and that equality holds if the vertex set of one of the graphs, say G, can be covered by $\alpha(G)$ cliques. He conjectured that in fact equality always holds. In [1] it is proved that this is false in the following strong sense.

Theorem 2.1. *For every k there is a graph G so that the Shannon capacity of the graph and that of its complement $\overline{G}$ satisfy $c(G) \leq k$, $c(\overline{G}) \leq k$, whereas $c(G + \overline{G}) \geq k^{(1+o(1))\log k/(8 \log\log k)}$ and the $o(1)$-term tends to zero as k tends to infinity.*

The proof, which contains an explicit description of G, is based on some of the ideas of Frankl and Wilson [14], together with the basic approach of [16] and [2]. The main idea is to prove an algebraic upper bound for the Shannon capacity of a graph in terms of the dimension of an appropriately defined space of multivariate polynomials, and use this bound with polynomials over a field of one characteristic for the graph, and over a field of another characteristic for its complement. As shown in [1], the idea of using different fields is crucial here, and one cannot deduce the result using other known bounds like the θ-function.

The above counter-intuitive example is extended in [7], where it is shown that for every $\mathcal{F}$, a family of subsets of $[t]$, it is possible to assign a channel $\mathcal{C}_i$ to each sender $i \in [t]$, such that the capacity of a group of senders $X \subset [t]$ is high iff X contains some $F \in \mathcal{F}$. This corresponds to a case where only privileged subsets of senders are allowed to transmit in a high rate. The basic approach in the proof is similar to the algebraic one in [1], but requires some additional combinatorial arguments.

The behavior of the Shannon capacity of graphs in general is far from being well understood. Even the capacity of small, simple graphs, like the cycle of length 7, is not known (see [11] and some of its references for the known estimates on the capacity of odd cycles of length exceeding 5). As shown in [6], the sequence $(\alpha(G^{\wedge n}))^{1/n}$, whose limit is the Shannon capacity $c(G)$, can be very complicated, exhibiting a large number of jumps. It is not known if the maximum possible value of the Shannon capacity of a graph whose independence number is 2 is bounded by an absolute constant. This is equivalent to a well studied Ramsey-theoretic question about the asymptotic behavior of the maximum possible

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number of vertices in a complete graph whose edges can be colored by k colors with no monochromatic triangle (see [13], [3]).

Another interesting open problem is whether for every $\varepsilon > 0$ and every $n > n_0(\varepsilon)$ there exists a graph G on n vertices satisfying $\alpha(G) < n^{\varepsilon}$ and $c(G) > n^{1-\varepsilon}$. The asymptotic behavior of the expected value of the Shannon capacity of the random graph $G(n, 0.5)$, which is known to be at most $O(\sqrt{n})$, as shown in [17], and at least $\Omega(\log n)$, as this is the typical independence number, is also open, and it seems plausible to conjecture that it is $\Theta(\log n)$. The maximum possible value of the Shannon capacity of the disjoint union of two graphs, each of capacity k is also unknown. This maximum is at least $k^{\Omega(\log k/\log\log k)}$, by the results of [1] mentioned above, but it is not even known that it is bounded by any function of k. Finally, it is not known if the problem of deciding whether the Shannon capacity of a given input graph exceeds a given value is decidable.

3 Multiple Instances

There are several examples of communication problems in which the number of bits that have to be transmitted per instance for multiple independent instances decreases dramatically as the number of instances increases. Several examples of this type are given in [3], based on properties of the so-called Witsenhausen rate of a graph, introduced in [25]. Here we describe a few more recent examples.

3.1 Mail Order and Multiple Product Lines

In this short subsection we describe a simple yet intriguing result from [22], where the author applies the existence of expanders, which are sparse pseudo-random graphs, to describe an interesting result in which communication can be saved when several independent tasks are combined. For simplicity we describe only a very special case which captures the essence of the argument.

The problem was first considered in [24], its worst case version is analyzed in [22]. Consider a mail-order firm that sells m-different shirts. Assume, further, that each potential customer is interested in ℓ of the m shirts, and wants to get one of them, having no preference between those ℓ. The firm is interested in the minimum number of bits it should get from a customer, in order to be able to mail him one of the shirts he likes. We assume here that every subset of ℓ of the shirts may be the desired set of some customer. It is not difficult to see that there is a valid protocol enabling the customer to transmit only $\lceil \log_2(m - \ell + 1)\rceil$ bits. Indeed, he simply sends the number of the first shirt among the first $m - \ell + 1$ ones that appears in his set of desired shirts. Moreover, this is optimal. This is because if there are at most $m - \ell$ distinct transmissions that the company may get from any customer, then there are at most $m - \ell$ shirts that it can mail in response. Thus, a customer interested only in ℓ of the shirts that are not being sent in any of these responses will not get a shirt from his desired list, which is impossible, establishing the required lower bound.

Suppose, now, that the mail order firm expands into two product lines, and starts to sell pants as well. There are m kinds of pants, and each customer likes ℓ of them, and wants to get one of those he likes. Thus, each customer now wants to get one of his favorite ℓ shirts, and one of his favorite ℓ pants, where we assume no relation between the two sets. How many bits should the customer send? To be specific, consider only one representative case, when, say, $\ell = n/4$. Obviously one can use the same protocol separately for each product, sending a total of $2\lceil \log_2(m - \ell + 1)\rceil$ bits. It is also clear that $\lceil \log_2(m - \ell + 1)\rceil$ is a lower bound, as the communication problem for one of the products requires that many bits. Which of these two bounds is closer to the best possible solution? Somewhat surprisingly it turns out that there is a protocol whose performance is close to the lower bound. The crucial observation here is to use expanders. In the particular example given here, we need a sparse bipartite graph with m vertices in each of its two color classes S, P, where $|S| = |P| = m$, so that between any two subsets $X \subset S$ and $Y \subset P$, with $|X| = |Y| = \ell$ $(=n/4)$, there is at least one edge. It is known (c.f., e.g., [5], Chapter 9) that there are such graphs with less than $64m$ edges. Fix such a graph, and view S as the set of shirts and P as the set of pants. If the preferred set of ℓ shirts of a customer is X and the preferred set of pants is Y, with $|X| = |Y| = \ell$, then he can simply transmit the label of an edge connecting X and Y. The number of bits required is thus less than $\lceil \log_2(64m)\rceil$, which is only the number required for one product plus a small constant number of bits.

3.2 Broadcasting with Side Information

The following variant of source coding, called Informed Source Coding On Demand was proposed by Birk and Kol [10]. A sender S wishes to broadcast a word $x = x_1x_2 \ldots x_n$, where $x_i \in \{0, 1\}^t$ for all i, to m receivers $R_1, \ldots, R_m$. Each R_j has some prior side information, consisting of some of the blocks x_i, and is interested in a single block $x_{f(j)}$. The sender wishes to transmit a codeword that will enable each and every receiver R_j to reconstruct its missing block $x_{f(j)}$ from its prior information. Let β_t denote the minimum possible length of such a binary code. The objective is to study the possible behavior of the numbers β_t for various scenarios. For simplicity we consider here only the case $t = 1$, although the case of bigger values of t, treated in [4], is also interesting.

The motivation for informed source coding is in applications such as Video on Demand. In such applications, a network, or a satellite, has to broadcast information to a set of clients. During the first transmission, each receiver misses a part of the data. Hence, each client is now interested in a different (small) part of the data, and has a prior side information, consisting of the part of the data he received [26]. Note that the assumption that each receiver is interested only in a single block is not necessary. Indeed, one can simulate a receiver interested in r blocks by r receivers, each interested in one of these blocks, and all having the same side information.

The problem above generalizes the problem of Index Coding, which was first presented in [10], and later studied in [8] and [20]. Index Coding is equivalent to a special case of the problem above in which $m = n$, $f(j) = j$ for all $j \in [m] = \{1, \ldots, m\}$ and the size of the data blocks is $t = 1$.

It is natural to describe the above source coding problems in terms of a certain hypergraph. Define a *directed hypergraph* $H = (V, E)$ on the set of vertices $V = [n]$. Each vertex i of H corresponds to an input block x_i. The set E of m edges corresponds to the receivers $R_1, \ldots, R_m$. For the receiver R_j, E contains a directed edge $e_j = (f(j), N(j))$, where $N(j) \subset [n]$ denotes the set of blocks which are known to receiver R_j. Clearly the structure of H captures the definition of the broadcast setting. Let $\beta_1(H)$ denote the minimal number of bits required to broadcast the information to all the receivers when the block length is $t = 1$.

We are interested in the asymptotic behavior of the number of bits that have to be transmitted when we consider parallel instances. Let $k \cdot H$ denote the disjoint union of k copies of H. Define $\beta_t^*(H) := \beta_1(t \cdot H)$. In words, β_t^* represents the minimal number of bits required if the network topology is replicated t independent times. Such a scenario can occur when the topology is standard (resulting, for example, from using a common application or operation system). Therefore it is identical across networks, albeit with different data. A simple sub-additivity argument shows that the limit

$$\beta^*(H) := \lim_{t\to\infty} \frac{\beta_t^*(H)}{t} = \inf_t \frac{\beta_t^*(H)}{t}$$

exists.

Let $H = ([n], E)$ be a directed hypergraph for a broadcast network, and set $t = 1$. It is convenient to address the more precise notion of the *number of codewords* in a broadcast code which satisfies H. We say that $\mathcal{C}$, a broadcast code for H, is *optimal*, if it contains the minimum possible number of codewords (in which case, $\beta_1(H) = \lceil \log_2 |\mathcal{C}| \rceil$). We say that two input-strings $x, y \in \{0,1\}^n$ are confusable if there exists a receiver $e = (i, J) \in E$ such that $x_i \neq y_i$ but $x_j = y_j$ for all $j \in J$. This implies that the input-strings x, y can not be encoded with the same codeword. Let γ denote the maximal cardinality of a set of input-strings which is pairwise unconfusable. The following result, proved in [4], relates β^* and γ.

Theorem 3.1. *Let H and γ be defined as above. The following holds for any integer k:*

$$\left(\frac{2^n}{\gamma}\right)^k \leq |\mathcal{C}| \leq \left\lceil \left(\frac{2^n}{\gamma}\right)^k kn \log 2 \right\rceil$$

where $\mathcal{C}$ is an optimal code for $k \cdot H$. In particular, $\beta^*(H) = \lim_{k\to\infty} \frac{\beta_1(k \cdot H)}{k} = n - \log_2 \gamma$.

A surprising corollary of the above theorem is that β^* may be strictly smaller (and in fact even much smaller) than β_1. Indeed, as β^* deals with the case of disjoint instances, it is not intuitively clear that this should be the case: one would think that there can be no room for improving upon $\beta_1(H)$ when replicating H into t disjoint copies, given the total independence between these copies (no knowledge on blocks from other copies, independently chosen inputs). Note that even in the somewhat related Information Theoretic notion of the Shannon capacity of graphs (corresponding to channel coding rather than source coding), though, as described in the previous section, the capacity of a disjoint union may exceed the sum of the individual capacities, it is easy to verify that disjoint unions of the *same graph* can never achieve this. The following theorem demonstrates that the possible gap between $\beta_1(t \cdot H)/t$ and $\beta_1(H)$ can be very large: in fact, β^* may be bounded while β_1 is arbitrarily large:

Theorem 3.2. *There exists an explicit infinite family of broadcast networks for which $\beta^*(H) < 3$ is bounded and yet $\beta_1(H)$ is unbounded.*

The proofs combine properties of graph powers (specifically, the results of [21] and [9] on the chromatic numbers of the so called OR powers of a graph) with results about integral and fractional colorings of Cayley graphs, and about the chromatic numbers of Kneser graphs (see [18], [15]). More details can be found in [4].

4 Conclusions

Combinatorics is a powerful tool for tackling problems in Information theory. We have seen a few examples that illustrate this phenomenon; the study of the Shannon capacity of a graph, the investigation of a broadcasting problem with side information, and that of the potential merits of encoding multiple independent messages in certain scenarios.

Tools and techniques from Discrete Mathematics appear in the study of numerous additional problems in Information theory, and in particular play a crucial role in the theory of Error Correcting Codes.

The reverse direction, that is, that of applying information theoretic tools in the derivation of combinatorial results, is also a fruitful, active direction, which is not discussed here, and can be the topic of a similar article.

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IT Society Members Honored

Vijay Bhargava, Professor in the Department of Electrical and Computer Engineering at the University of British Columbia in Vancouver, Canada has been elected a Foreign Fellow of the Indian National Academy of Engineering (INAE). Founded in 1987, INAE is a member of the International Council of Academics of Engineering and Technological Sciences (CAETS). Earlier this year Prof. Bhargava was awarded a Distinguished Visiting Fellowship by the Royal Academy of Engineering of United Kingdom. He served as President of the Society in 2000 and is currently Editor-in-Chief of the IEEE Transactions on Wireless Communications.

John M. Cioffi and H. Vincent Poor have been elected International Fellows of the Royal Academy of Engineering of the United Kingdom, two of only three engineers worldwide to be so elected this year. They were inducted into the Academy at its New Fellows Dinner on November 9, 2009, in London.

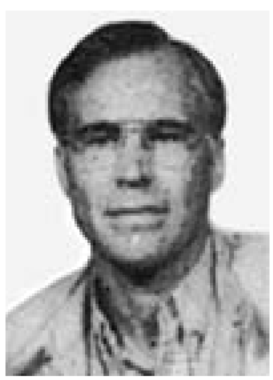
John Cioffi is Chairman and CEO of ASSIA, Inc., in Redwood City, CA, and Hitachi America Professor of Engineering, Emeritus, at Stanford University, where he received his PhD in 1984. Also an IEEE Fellow and a member of the U. S. National Academy of Engineering (NAE), Cioffi received the International Marconi Prize in 2006 for his pioneering work in DSL and was a recipient of the UK's IEE JJ Thomson Medal in 2000 as well as the IEEE's Kobayashi Award in 2001, and the 1999 University of Illinois Outstanding Alumni award. Cioffi founded Amati Corporation in 1991 and was its CTO and a board member through its 1995 IPO and until it was acquired by Texas Instruments in 1998. Cioffi has served on numerous public and private boards of directors, including Marvell (1999—2006) and currently Teranetics (2003-present), ClariPhy (2003-present) and AltoBeam (2008-present), as well as the board of trustees of the Marconi Society. Cioffi has published several hundred technical papers and is the inventor named on over 100 patents, many of which are heavily licensed in the communication industry.

Vince Poor is the Michael Henry Strater University Professor of Electrical Engineering, and Dean of the School of Engineering and Applied Science, at Princeton University, where he received his Ph.D. in 1977. He is an IEEE Fellow, an NAE member, and a Fellow of the American Academy of Arts & Sciences. He served as President of the IEEE Information Theory Society in 1990, as Editor-in-Chief of the *IEEE Transactions on Information Theory* in 2004–07, and as General Co-Chair of the 2009 IEEE International Symposium on Information Theory, held earlier this year in Seoul. Recognition of his work includes a Guggenheim Fellowship in 2002, the IEEE Education Medal in 2005, the Aaron D. Wyner Award of the IT Society in 2008 and the Edwin Howard Amstrong Award of the IEEE Communications Society in 2009. His publications include the recent books *Quickest Detection* (Cambridge University Press, 2009) and *Information Theoretic Security* (Now Publishers, 2009).

In Memoriam, Gerry Seguin

Vijay Bhargava

Gerald Edourard Seguin was born in Glengarry County, Ontario, Canada on 14 December 1943. He passed away on 16 July 2009 in Kingston, Ontario of complications arising from Parkinson disease. He is survived by four children.



Gerry Seguin

Gerry received his Ph.D. degree from the University of Notre Dame, Notre Dame, Indiana in 1971 under the supervision of Professor James L. Massey. Soon after that he joined the Electrical Engineering Department at the Royal Military College of Canada/College militaire royal du Canada where he was one of the few professors to teach courses in both English and French. A popular teacher, he was legendary for teaching a difficult course on Error-Correcting Codes without notes or external aids. Just, "chalk, talk and walk" was his style during the lectures.

An avid traveller and research collaborator, Gerry spent his sabbatical leaves at Concordia University, Montreal; Technische Universiteit Eindhoven, Universite Laval, Ville de Quebec; Ecole Polytechnique de Montreal and Universite du Sud-Toulon, Var, France.

Gerry's research interest was primarily in algebraic coding theory but he also published research papers on arithmetic codes and convolutional codes. While it was known from the work of Chen, Peterson and Weldon (via the Normal Basis Theorem) as to when a cyclic code can be put in quasi-cyclic form, Gerry answered the more difficult question of under what conditions quasi-cyclic codes can be put in cyclic form. By examining the mappings of cyclic codes over an extension field into binary codes he was able to construct a large number of very good quasi-cyclic codes. Gerry discovered a class of linear codes especially designed to provide additional error protection for data consisting of bytes all having even (or odd) parity and provided a practical decoding algorithm for them.

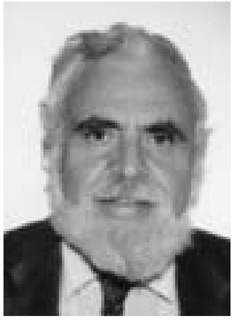
Gerry was Vice Chair of the 1983 IEEE International Symposium on Information Theory held in St. Jovite, Quebec, Canada. At the Symposium, among other things, he helped in what was perhaps the first Information Theory Tennis Tournament!

Gerry was a humble person who helped many younger colleagues in their career. We will cherish his memory as friend and mentor.

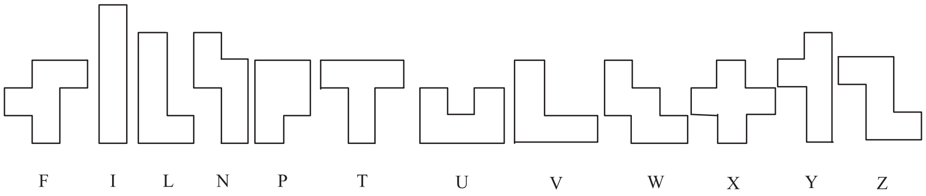
GOLOMB'S PUZZLE COLUMN™

More Pentomino Exclusion

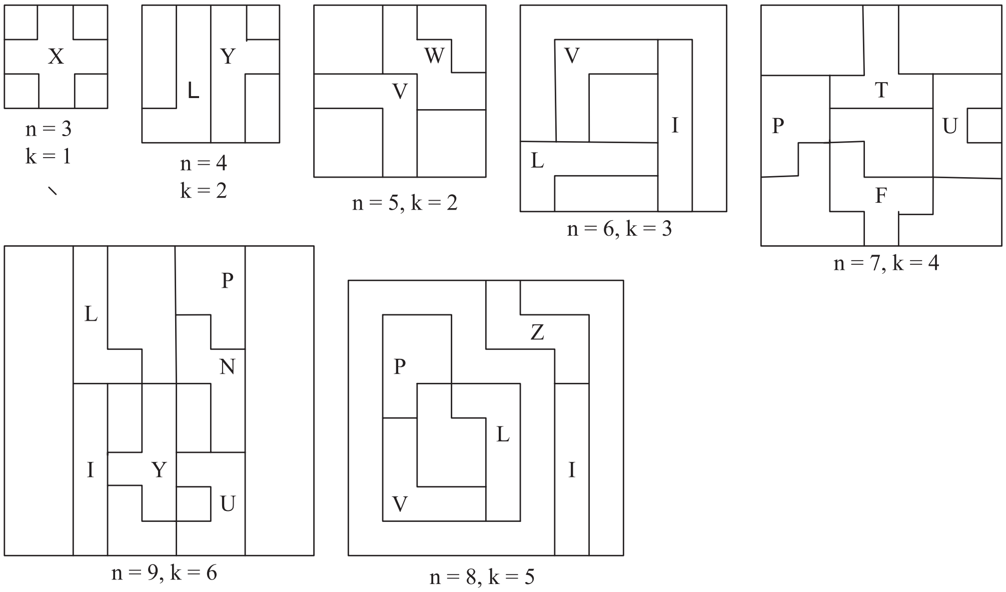
Solomon W. Golomb



In this Column, in December, 2007, I asked readers to find patterns on $n \times n$ boards where the smallest number, k, of pentominoes on the board would prevent any of the remaining $12 - k$ pentominoes from being placed on the board. Recall that the 12 pentominoes are:



Examples of solutions (given in the March, 2008, issue) included



The solution for $n = 5$ is unique. The solution for $n = 8$ is the only one that does not use U or Y. The solution for $n = 7$ is the only one that uses none of I, L, or V.

1. There is also a unique solution for $n = 6$ that uses none of I, L, or V, with $k = 3$. Can you find it?

Note that for $5 \leq n \leq 9$, the best value of k is $k = n - 3$. This can be extended to $n = 10$ and $n = 11$. (In the previous Column, an extra "monomino", i.e. a single square, had to be placed on the $n \times n$ board, in addition to $n - 3$ pentominoes, to keep the other $12 - k = 15 - n$ pentominoes off the board, for $n = 10$ and $n = 11$.)

2. Place 7 pentominoes on the 10×10 board in such a way that none of the other 5 will fit.

3. Place 8 pentominoes on the 11×11 board in such a way that none of the other 4 will fit.

   (It is required that pentominoes be placed on boards in accordance with the grid lines of the board, as in all the examples given above.)

In the previous Column, for the 12×12 board, I allowed 10 pentominoes on the board to keep off the other 2. Here are two more challenging tasks.

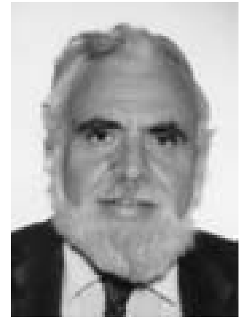
4. Place only 8 pentominoes, plus 5 monominoes (individual squares) on the 12×12 board in such a way that none of the other 4 pentominoes will fit.

5. Place 9 pentominoes, plus 2 monominoes, on the 12×12 board, in such a way that none of the other 3 pentominoes will fit. (This is the best I've been able to do thus far, and it was not easy. But let me know if you find a solution requiring only one monomino, or none at all!)

GOLOMB'S PUZZLE COLUMN™

Finding Sums Solutions

Solomon W. Golomb



ANSWERS.

1. $\sum_{n=1}^{\infty} \frac{(-1)^{n+1}}{n} = \ln 2$.
2. $\sum_{n=1}^{\infty} \frac{(-1)^{n+1}}{2n-1} = \frac{\pi}{4}$.
3. $\sum_{n=1}^{\infty} \frac{n}{2^n} = 2$.
4. $\sum_{n=1}^{\infty} \frac{n^2}{2^n} = 6$.
5. $\sum_{n=1}^{\infty} \frac{1}{n^2+n} = 1$.
6. $\sum_{n=2}^{\infty} \frac{1}{n^2-1} = \frac{3}{4}$.
7. $\sum_{n=2}^{\infty} \frac{n}{n^4+n^2+1} = \frac{1}{6}$.
8. $\sum_{n=1}^{\infty} \frac{1}{n^2} = \frac{\pi^2}{6}$.

DERIVATIONS (Not Unique)

1. $$\sum_{n=1}^{\infty} \frac{(-1)^{n+1}}{n} = \left(\sum_{n=1}^{\infty} \frac{(-1)^{n+1} z^n}{n}\right)_0^1 = \sum_{n=1}^{\infty} (-1)^{n+1} \int_0^1 z^{n-1} dz$$
$$= \int_0^1 \left(\sum_{n=1}^{\infty} (-1)^{n+1} z^{n-1}\right) dz = \int_0^1 \frac{dz}{1+z} = \ln(1+z)\Big|_0^1 = \ln 2.$$

2. $$\sum_{n=1}^{\infty} \frac{(-1)^{n+1}}{2n-1} = \left(\sum_{n=1}^{\infty} \frac{(-1)^{n+1} z^{2n-1}}{2n-1}\right)_0^1 = \sum_{n=1}^{\infty} (-1)^{n+1} \int_0^1 z^{2n-2} dz$$
$$= \int_0^1 \left(\sum_{n=1}^{\infty} (-1)^{n+1} z^{2n-2}\right) dz = \int_0^1 \frac{dz}{1+z^2} = \int_0^{\frac{\pi}{4}} \frac{d(\tan\theta)}{1+\tan^2\theta}$$
$$= \int_0^{\frac{\pi}{4}} \frac{\sec^2\theta}{\sec^2\theta} d\theta = \int_0^{\frac{\pi}{4}} d\theta = \frac{\pi}{4}.$$

3. $$\sum_{n=1}^{\infty} n z^n = z \sum_{n=1}^{\infty} n z^{n-1} = z \frac{d}{dz} \sum_{n=1}^{\infty} z^n = z \frac{d}{dz}\left(\frac{z}{1-z}\right)$$
$$= \frac{z}{(1-z)^2}. \text{ At } z = \tfrac{1}{2},\ \sum_{n=1}^{\infty} \frac{n}{2^n} = \frac{\frac{1}{2}}{\frac{1}{4}} = 2.$$

4. $$\sum_{n=1}^{\infty} n^2 z^n = z \sum_{n=1}^{\infty} n^2 z^{n-1} = z \sum_{n=1}^{\infty} \frac{d}{dz} n z^n$$
$$= z \frac{d}{dz} \sum_{n=1}^{\infty} n z^n = z \frac{d}{dz}\left(\frac{z}{(1-z)^2}\right) = z \cdot \frac{(1+z)}{(1-z)^3} .$$
$$\text{At } z = \tfrac{1}{2},\ \sum_{n=1}^{\infty} \frac{n^2}{2^n} = \frac{1}{2} \cdot \frac{(1+\frac{1}{2})}{\frac{1}{8}} = 6.$$

5. $\sum_{n=1}^{\infty} \frac{1}{n(n+1)} = \sum_{n=1}^{\infty} \left(\frac{1}{n} - \frac{1}{n+1}\right) = \left(1 - \frac{1}{2}\right) + \left(\frac{1}{2} - \frac{1}{3}\right) + \left(\frac{1}{3} - \frac{1}{4}\right) + ... = 1.$

6. $\sum_{n=2}^{\infty} \frac{1}{n^2-1} = \frac{1}{2} \sum_{n=2}^{\infty} \left(\frac{1}{n-1} - \frac{1}{n+1}\right) = \frac{1}{2}\{\left(1 - \frac{1}{3}\right) + \left(\frac{1}{2} - \frac{1}{4}\right) + \left(\frac{1}{3} - \frac{1}{5}\right) + \left(\frac{1}{4} - \frac{1}{6}\right)$ $+ ...\} = \frac{1}{2}\left(1 + \frac{1}{2}\right) = \frac{3}{4}.$

7. $\sum_{n=2}^{\infty} \frac{n}{n^4+n^2+1} = \frac{1}{2} \sum_{n=2}^{\infty} \left(\frac{1}{n^2-n+1} - \frac{1}{n^2+n+1}\right) = \frac{1}{2}\{\left(\frac{1}{3} - \frac{1}{7}\right) + \left(\frac{1}{7} - \frac{1}{13}\right) + \left(\frac{1}{13} - \frac{1}{21}\right) + ...\} =$ $\frac{1}{2} \cdot \frac{1}{3} = \frac{1}{6}.$

8. We start with the Fourier expansion of $y = |x|$ on $(-\pi, \pi)$. (Since $|x|$ is an even function, no sine terms occur.)
   $a_0 = \frac{1}{2\pi} \int_{-\pi}^{\pi} |x| dx = \frac{2}{2\pi} \int_0^{\pi} x dx = \frac{1}{\pi} \cdot \frac{\pi^2}{2} = \frac{\pi}{2}.$
   For $n \geq 1$, $a_n = \frac{1}{\pi} \int_{-\pi}^{\pi} |x| \cos nx \ dx = \frac{2}{\pi} \int_0^{\pi} x \cos nx \ dx = \frac{2}{\pi} \left\{ \frac{x \sin nx}{n} \Big|_0^{\pi} - \int_0^{\pi} \frac{\sin nx \ dx}{n} \right\} =$ $\frac{2}{\pi} \left\{0 + \frac{\cos nx}{n^2}\right\}_0^{\pi} = \frac{2}{\pi} \left(\frac{(-1)^n}{n^2} - \frac{1}{n^2}\right) = \left\{ \begin{array}{ll} \frac{-4}{\pi n^2}, & n \text{ odd} \\ 0, & n \text{ even} \end{array} \right\}.$
   Then, on $-\pi < x < \pi$, $|x| = \frac{\pi}{2} - \frac{4}{\pi} \sum_{odd\ n=1}^{\infty} \frac{\cos nx}{n^2}.$
   At $x = 0$, $\frac{\pi}{2} = \frac{4}{\pi} \sum_{odd\ n=1}^{\infty} \frac{1}{n^2}$, and $\sum_{odd\ n=1}^{\infty} \frac{1}{n^2} = \frac{\pi^2}{8}.$
   To get $S = \sum_{n=1}^{\infty} \frac{1}{n^2}$, observe that $S - \frac{1}{4}S = \sum_{n=1}^{\infty} \frac{1}{n^2} - \sum_{n=1}^{\infty} \frac{1}{(2n)^2} = \sum_{odd\ n=1}^{\infty} \frac{1}{n^2} = \frac{\pi^2}{8}$, and $\sum_{n=1}^{\infty} \frac{1}{n^2} = S = \frac{4}{3}\left(\frac{\pi^2}{8}\right) = \frac{\pi^2}{6}.$
   (This sum had stumped Leibniz and the Bernouillis, and was finally solved by Euler. This derivation by Fourier series was not one of the four methods of solution given in Euler's collected works.)

   -

   Rigorous justifications of the summation techniques used above are not difficult to provide.

Report on the Second Annual North American School of Information Theory

Aylin Yener and Gerhard Kramer

The Second Annual School of Information Theory was held during August 10–13, 2009, on the beautiful campus of Northwestern University in Evanston, IL. We are happy to report that the school was a great success.

As for last year's school at Penn State University, the goal was to offer graduate students and postdoctoral researchers an opportunity to interact with each other and with leading researchers and teachers of the field. We reported on the preparations for the event in the 2009 March and June Newsletters. The school experienced a 40% growth in student attendees from 101 in 2008 to 141 students this year. If we include our 4 speakers, 7 co-organizers, and 10 guests, the total number of attendees was over 160.

The school featured lectures by four of our favorite teachers. Dan Costello from the University of Notre Dame gave three lectures on Coding Theory; Bruce Hajek of UI Urbana-Champaign presented three lectures on Network Theory; Abbas El Gamal of Stanford University delivered the inaugural Padovani lecture with three talks on Multi-user Information Theory; and Bob Gallager of MIT gave the keynote lecture on The Early Development of Information Theory and What It Means for Today. As Dan, Bruce, and Abbas can attest, delivering 4.5 hours of lectures in one day is no mean feat! A picnic with a campfire was held on the evening of August 11 and a speaker & organizer dinner was held on the evening of August 12.

Student participation was a requirement for attendance: every student introduced his or her work in the form of a short (1-minute) talk as well as a poster presentation. The students took their presentations seriously and individuals could be seen explaining their work well after the poster sessions were officially over. The instructors participated actively in the poster sessions to the delight of the students.

An effort of this magnitude would not be possible without the enthusiastic assistance of many individuals. In particular, we are grateful to Randall Berry and Dongning Guo for their outstanding local organization; Daniela Tuninetti, Natasha Devroye, and Yalin Sagduyu for putting together a splendid program; Matthieu Bloch for his responsiveness and expert web programming (we couldn't have had anyone better). Maurice Parris provided assistance in accounting; Stephano Rini proved to be a talented photographer. The following student volunteers deserve our thanks for making the school a success: Jieying Chen, Hang Zhou, Jun Luo, Suvarup Saha, Ka Hung Hui, Lei Zheng, Changxin Shi, Echo Yang, Songqing Zhao, and Yang Weng.

Students enjoying Dan Costello's lectures on coding theory.

Group photo before the picnic with Lake Michigan in the background.

Students surrounding and gleaning wisdom from Bob Gallager.

The organization team (from right to left): Randall Berry, Dongning Guo, Yalin Sagduyu, Aylin Yener, Natasha Devroye, Daniela Tuninetti, Gerhard Kramer. Matthieu Bloch was unable to attend.

The school was made possible by financial support from the IEEE Information Theory Society, the DARPA ITMANET program, ARO, NSF, the Northwestern University Master of Science in Information Technology Program, and funds provided by the University of Notre Dame, USC, and Roberto Padovani.

We now again arrive at the stage where we look forward to next year's school, and we will communicate the details on the 2010 organization as it proceeds. In the meantime, we invite you to browse the 2009 School website that has the lecture slides, video recordings of the lectures, and the student posters: please see http://www.itsoc.org/people/committees/student/2009-school-of-it

Two DIMACS Meetings on Compressive Sensing

October 16, 2009

Emina Soljanin

In March 2009, two DIMACS meetings on compressive sensing were held back to back. The exact title of the meetings was "DIMACS Working Group and Workshop on Streaming, Coding, and Compressive Sensing: Unifying Theory and Common Applications to Sparse Signal/Data Analysis and Processing". The participants were coding theorists, statisticians, and computer scientists.

As one of the co-organizers of the meetings who had the least of the technical knowledge on the subject but nevertheless initiated the activities, I will only briefly describe the workshop, and provide links to webpages from which more information can be obtained. I hope that the organizing committee will soon be able to provide a more technical document about what we learned during these meetings, and how relevant that is for information theorists. The purpose of this report is also to make a contribution towards resolving some issues raised in the society's Board of Governors recent discussions on the purpose and accessibility of our standard meetings (ISIT and ITW), and possibilities of organizing conferences that do not simply mimic the standard.

Proposal for the DIMACS meetings was written almost a full year before the meetings took place, and funding was obtained shortly after the proposal submission from ARO through DIMACS. The idea to organize such meetings was conceived much earlier. In the Spring of 2006, I was assigned to work on a projet dealing with heavy hitters detection together with two brilliant Bell Labs statisticians Jin Cao and Aiyou Chen. At about the same time, seminal work on compressive sensing was beginning to appear in print. The approach that my colleagues took to solve our problem reminded me of the techniques described in than emerging compressive sensing literature. By using very simple information theoretic reasoning, I was able to comment on the efficiency of the scheme the two statisticians proposed for heavy hitters detection, in a way that they did not previously know. It was then that I realized that bringing together researchers from different areas may, in this particular case, be truly beneficial.

Because of the significant role that computer science plays in this subject, DIMACS (dimacs.rutgers.edu) seemed the most natural institution to ask for support of a workshop. Other possibilities that the members of our society may consider are math institutes such as BIRS (http://www.birs.ca), IMA (http://www.ima.umn.edu), MSRI (http://www.msri.org), and the one in Oberwolfach (http://www.mfo.de). As an organizer or a workshop participant or both, I have seen that these institutions are run very differently, but they all support interdisciplinary interactions and provide extremely stimulating conditions for research.

The meetings' organizers were Aiyou Chen, Bell Labs, Graham Cormode, AT&T Labs, Andrew McGregor, UCSD, Olgica Milenkovic, UIUC, S. Muthukrishnan, Rutgers University, and Emina Soljanin, Bell Labs. The working group part of the meeting included 10 tutorial/survey one-hour talks. The talks were presented over two days and there was lot of time for discussions.

The workshop part of the meeting was held on the third day, and 11 talks were given in a conventional conference format, presenting new results. The detailed program with abstracts, and slides of most of the talks are available online at

dimacs.rutgers.edu/Workshops/WGUnifyingTheory

dimacs.rutgers.edu/Workshops/UnifyingTheory

Andrea Goldsmith, our society president, recently noted that the existence and success of non-standard workshops mostly rests on the vision and efforts of the organizers. I will warn potential organizers that such efforts may not be directly and obviously important for their careers and even scientific benefits may not be immediate and may never be realized. But then again, let us remember the following words addressed by R. P. Feynman to a meeting of NSF Postdoctoral fellows in Washington: "If you give more money to theoretical physics, it doesn't do any good if it just increases the number of guys following the comet ahead. So it is necessary to increase the amount of variety . . ."

Now the reader may be wandering what happened to our Bell Labs project. Oh, well, let me just quote a sentence from the New York Times article about the latest Nobel prize in physics: "The technology was intended for a picture phone but the project was canceled, and Dr. Boyle and Dr. Smith moved on to other research topics even as CCDs began to spread around the planet."

10th International Symposium on Communication Theory and Applications

13–17 July, 2009, University of Cumbria, Ambleside, UK

This is a Report on the 10th International Symposium on Communication Theory and Applications (ISCTA'09), which took place, as previously, in the beautiful surroundings of Ambleside in the English Lake District. The Symposium was sponsored by the IEEE Information Theory and Communications Societies, Rinicom Ltd, HW Communications, and the Department of Communication Systems, Lancaster University, UK. A total of 70 papers were presented in sessions on Error-Control Coding, Communications Systems and Networks, Source Coding and Security, Signal Processing, LDPC Codes, and two Poster Sessions. Invited talks were given by Bob McEliece (Caltech, USA), Ian Blake (University of British Columbia, Canada), Mario Blaum (Complutense University, Madrid, Spain), Juergen Lindner (Ulm University, Germany), Mike Pursley (Clemson University, USA), Jim Massey (JLM Consulting, Copenhagen, Denmark), Ernst Gabidulin (Moscow Institute of Physics and Technology, Russia), Dick Blahut (University of Illinois, USA), Valdemar da Rocha (Federal University of Pernambuco, Recife, Brasil), Erdal Arikan (Bilkent University, Turkey), Peter Farkas (Slovak University of Technology, Bratislava, Slovakia), Shu Lin (University of California, Davis, USA), Rolando Carrasco (University of Newcastle, UK), Dan Costello (University of Notre Dame, USA), Jossy Sayir (University of Cambridge, UK), Paddy Farrell (Lancaster University, UK), Yuichi Kaji (Nara Institute of Science and Technology, Japan) Han Vinck (University of Duisburg-Essen, Germany), Thomas Mittelholzer, IBM Research, Zurich, Switzerland), and Mike Darnell (HW Communications and Newcastle University, UK). Shu Lin gave a nice speech dedicating his talk to the memory of Wesley Peterson, who died this year, and Tadao Kasami, who died in 2006, both of whom greatly influenced Shu's interest in coding theory and practice. He also hinted that he was contemplating retirement, but we all found this hard to believe!

There was a Welcome Reception on the Monday evening, and on Tuesday evening Garik Markarian (Lancaster University, UK) gave an interesting and forward looking after-dinner talk on "Assisted Living: From Quality of Service to Quality of Life". As usual, the

Wednesday afternoon was free for participants to enjoy the Lake District fells, and as the weather was good, several hiking parties scaled the heights! All this exercise worked up a good appetite for the evening barbecue. A splendid Symposium Banquet took place on the Thursday evening, much enjoyed by all the participants. The after-dinner speeches and jokes were as good as ever!

The closing session on the Friday was sadder than usual, because it was announced that we had attended the final Symposium in the biennial series, which began in 1991. As the organisers (Bahram Honary, Mike Darnell and Paddy Farrell) pointed out, we were all increasing in years, and it was best to finish on a high note. Certainly the quality and interest of this last Symposium was as good as ever, thanks to the dedication and hard work of all the participants.

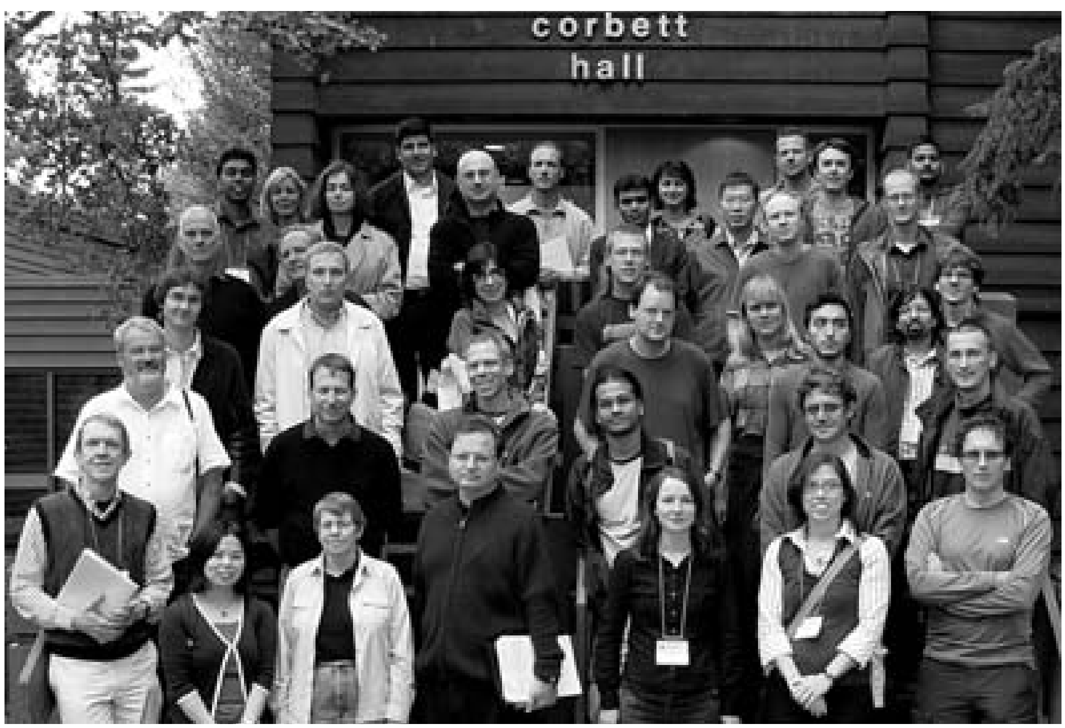
The Proceedings can be obtained from www.lancs.ac.uk or www.hwcomms.com.

Workshop Report: Applications of Matroid Theory and Combinatorial Optimization to Information and Coding Theory

August 2–7, 2009, Banff, Alberta, Canada

Navin Kashyap (Queen's University),
Emina Soljanin (Alcatel-Lucent Bell Labs), and
Pascal O. Vontobel (Hewlett-Packard Laboratories)
Workshop organizers

In the first week of August 2009, a group of forty-one researchers met at the Banff International Research Station (BIRS) to discuss applications of matroid theory and combinatorial optimization within the fields of information and coding theory. Besides the organizers, the group included invited experts and students from diverse but related fields. The workshop was the completion of nearly two years of consistent effort to make a productive gathering of participants from many different backgrounds, who, we believed, could greatly benefit from interacting with each other.



BIRS <http://www.birs.ca> is a joint Canada-US-Mexico initiative that provides an environment for creative interaction and the exchange of ideas, knowledge, and methods within the Mathematical Sciences, and with related sciences and industry. BIRS is located on the site of the world-renowned Banff Centre in Alberta.

The aim of this workshop was to bring together researchers from pure and applied mathematics, computer science, and engineering, who are working on related problems in the areas of matroid theory, combinatorial optimization, coding theory, secret sharing, network coding, information inequalities, and similar fields. The goal was to allow for the exchange of mathematical ideas and tools that can help tackle some of the open problems of central importance in coding theory, secret sharing, and network coding, and at the same time, to get pure mathematicians and computer scientists to be interested in the kind of problems that arise in these applied fields.

Matroids are structures that abstract certain fundamental properties of dependence common to graphs and vector spaces. The theory of matroids has its origins in graph theory and linear algebra, and its most successful applications in the past have been in the areas of combinatorial optimization and network theory. Recently, however, there has been a flurry of new applications of this theory in the fields of information and coding theory.

It is only natural to expect matroid theory to have an influence on the theory of error-correcting codes, as matrices over finite fields are objects of fundamental importance in both these areas of mathematics. Indeed, as far back as 1976, Greene (re-)derived the MacWilliams identities – which relate the Hamming weight enumerators of a linear code and its dual – as special cases of an identity for the Tutte polynomial of a matroid. However, aside from such use of tools from matroid theory to re-derive results in coding theory that had already been proved by other means, each field has had surprisingly little impact on the other, until very recently.

Matroid-theoretic methods are now starting to play an important role in coding theory. They are being used to gain insight into the performance and complexity of graph-based iterative decoding algorithms and linear programming decoding algorithms. In a parallel and largely unrelated development, ideas from matroid theory are also finding other novel applications within the broader realm of information theory.

Specifically, they are being applied to explore the fundamental limits of secret-sharing schemes and network coding. But perhaps the most remarkable and unexpected application of matroid methods is in the context of information inequalities, where they are being used to find a set of linear inequalities sufficient to characterize the Shannon entropy function.

Program

Our workshop covered four major areas within the realm of information theory – coding theory, secret sharing, network coding, and information inequalities – which have seen a recent influx of ideas from matroid theory and combinatorial optimization. Time was also allocated for talks purely on matroid theory, in particular, to an exposition of the Matroid Minors Project that drives much of current research in matroid theory.

The workshop program was composed of hour-long talks, and shorter, half-hour talks. The long talks were mainly of an expository or tutorial nature, and were grouped together into "themed" sessions covering the major areas of emphasis listed above. The short talks were primarily devoted to newer research results in areas related to the workshop themes.

We provide below a listing of the talks from the workshop, grouped into five categories. The detailed program with abstracts, and slides of most of the talks are available online at http://www.birs.ca/birspages.php?task=displayevent&event_id=09w5103.

Matroids

James Oxley, "An introduction to matroid theory"

Bert Gerards, "Binary matroid minors I"

Jim Geelen, "Binary matroid minors II"

Dillon Mayhew, "Excluded minors for real-representable matroids"

Coding theory and combinatorial optimization

Navin Kashyap, "Applications of matroid methods to coding theory"

Martin Wainwright, "Linear and other conic programming relaxations in combinatorial optimization: graph structure and message-passing"

Pascal Vontobel, "Pseudo-codewords: fractional vectors in coding theory"

Thomas Britz, "From codes to matroids and back"

Alex Grant, "Quasi-uniform codes and their applications"

Eimear Byrne, "Upper bounds for error-correcting network codes"

Olgica Milenkovic, "Sub-linear compressive sensing and support weight enumerators of codes: a matroid theory approach"

Alexander Barg, "Linear codes in the ordered Hamming space"

Secret sharing schemes

Carles Padro, "On the optimization of secret sharing schemes for general access structures"

Amos Beimel, "Secret sharing schemes, matroids, and non-Shannon information inequalities"

Pradeep Kiran Sarvepalli, "Matroids in quantum computing and quantum cryptography"

Network coding

Emina Soljanin, "Basics of network coding"

Chandra Chekuri, "Combinatorial optimization in routing vs. network coding"

Alex Sprintson, "Applications of matroid theory to network coding"

Randall Dougherty, "Is network coding undecidable?"

Serap Savari, "A combinatorial study of linear deterministic relay networks"

Michael Langberg, "Algorithmic complexity of network coding"

Information inequalities

Raymond Yeung, "Facets of entropy"

Frantisek Matus, “Entropy functions, information inequalities, and polymatroids”

Andreas Winter, “A new inequality for the von Neumann entropy”

Randall Dougherty, “Non-Shannon entropy inequalities and linear rank inequalities”

Conclusions drawn

The workshop achieved its goal of encouraging interactions between researchers from several different disciplines, for whom there is currently no other forum (conference or workshop) that could serve as a natural meeting point. The workshop was extremely well received by all the participants, making it a runaway success. The fact that the workshop succeeded in all that it attempted to achieve, despite the conventional wisdom that workshops that try to bring together multiple research communities run the risk of failing all of them, is a testament to the quality of the talks, and to the relevance of the topics covered to a broad audience.

We would like to take this opportunity to say a few words about our experience of organizing the workshop. BIRS decides on its workshop schedule for a given year two years in advance – for example, the workshop program for 2009 was decided in late 2007. This means that our planning for the workshop, starting from the stage of submitting a workshop proposal to BIRS, had to begin well in advance of the actual workshop. But once the workshop proposal was written (and the workshop approved by BIRS), organizing the actual workshop was just a matter of putting the program together, as BIRS handles all the administrative details.

What makes BIRS workshops especially attractive, aside from their spectacular setting in the Canadian Rockies, is the fact that BIRS provides room and board free of charge to all participants. The Banff Centre, within which BIRS is located, offers excellent facilities – wireless internet, meeting rooms, gyms, swimming pool – all of which are again made available free of charge to BIRS workshop participants. Furthermore, the BIRS policy of requiring that workshops be small (there is an absolute upper limit of 42 participants) ensures a friendly atmosphere within which researchers can interact with each other.

Overall, we genuinely enjoyed our experience of organizing and participating in a BIRS multi-disciplinary workshop. For the benefit of our field and indeed science in general, we would urge members of the Information Theory Society and community to take advantage of the wonderful, low-cost facilities offered by BIRS for holding small meetings and workshops. Step-by-step instructions for how to organize workshops at BIRS can be found at http://www.birs.ca/organizers/

Positions Available

Positions of Postdoctoral Fellows, Research Associates, and Research Assistant Professor are open at the *Institute of Network Coding* (INC) of *The Chinese University of Hong Kong* (CUHK). Initial appointments are typically for two years, and the commencing date is flexible.

Applicants should have a strong research record in network coding related areas, including theory, applications, or implementation.

For further information please visit the INC home page at http://inc.ie.cuhk.edu.hk/ or contact Raymond Yeung at whyeung@ie.cuhk.edu.hk

Call for Nominations

IEEE Information Theory Society Claude E. Shannon Award

The IEEE Information Theory Society Claude E. Shannon Award is given annually for consistent and profound contributions to the field of information theory.

Award winners are expected to deliver the Shannon Lecture at the annual IEEE International Symposium on Information Theory held in the year of the award.

NOMINATION PROCEDURE: Nominations and letters of endorsement must be submitted by March 1 to the current President of the IEEE Information Theory Society. (In 2010 the President will be Prof. Frank Kschischang <frank@comm.utoronto.ca>.) Please include:

Nominee:

1) Full name
2) Address, e-mail and telephone
3) Professional affiliation
4) Academic degrees (awarding institutions and dates)
5) Employment history
6) Principal publications (not more than ten).
7) Principal honors and awards
8) Optional. The nominee's CV may be submitted as an addendum to the nomination.

Nominator:

1) Full name
2) Address, Email and telephone
3) Optional. Endorser(s), names and addresses, e-mail addresses. (Letters of endorsement are not required. At most three may be submitted.)

Rationale:

Discussion of how the nominee has made consistent and profound contributions to the field of information theory (not more than two pages).

IEEE Information Theory Society 2010 Aaron Wyner Distinguished Service Award

The IT Society Aaron D. Wyner Award honors individuals who have shown outstanding leadership in, and provided long standing exceptional service to, the Information Theory community. This award was formerly known as the IT Society Distinguished Service Award. Nominations for the Award can be submitted by anyone and are made by sending a letter of nomination to the President of the IT Society. The individual or individuals making the nomination have the primary responsibility for justifying why the nominee should receive this award.

NOMINATION PROCEDURE: Letters of nomination should

- Identify the nominee's areas of leadership and exceptional service, detailing the activities for which the nominee is believed to deserve this award;
- Include the nominee's current vita;
- Include two letters of endorsement.

Current officers and members of the IT Society Board of Governors are ineligible. Please send all nominations by March 15, 2010 to IT Society President, Frank Kschischang <frank@comm.utoronto.ca>.

IEEE Information Theory Society 2010 Paper Award

The Information Theory Society Paper Award is given annually for an outstanding publication in the fields of interest to the Society appearing anywhere during the preceding two calendar years. The purpose of this Award is to recognize exceptional publications in the field and to stimulate interest in and encourage contributions to fields of interest of the Society. The Award consists of a certificate and an honorarium of US$1,000 for a paper with a single author, or US$2,000 equally split among multiple authors. The award will be given for a paper published in the two preceding years.

NOMINATION PROCEDURE: By March 1, 2010, please email the name of the paper you wish to nominate, along with a supporting statement explaining its contributions, to the Awards Committee chair Giuseppe Caire <caire@usc.edu>, not to the IT Transactions EiC as has been done in the past.

IEEE Joint Comsoc/IT 2010 Paper Award

The Joint Communications Society/Information Theory Society Paper Award recognizes outstanding papers that lie at the intersection of communications and information theory. Any paper appearing in a ComSoc or IT Society publication during the years 2007–2009 is eligible for the 2010 award. A Committee with members from both societies will make the selection. The award consists of a plaque and cash prize presented at the Comsoc or IT symposium of the authors' chosing.

NOMINATION PROCEDURE: By March 1, 2010, please email the name of the paper you wish to nominate, along with a supporting statement explaining its contributions to both communications and information theory, to Giuseppe Caire at <caire@usc.edu>.

IEEE Fellow Program

For (s)he's a jolly good (IEEE) Fellow! Do you have a friend or colleague who is a senior member of IEEE and is deserving of election to IEEE Fellow status? If so, consider submitting a nomination on his or her behalf to the IEEE Fellow Committee. The deadline for nominations is March 1st. IEEE Fellow status is granted to a person with an extraordinary record of accomplishments. The honor is conferred by the IEEE Board of Directors, and the total number of elected Fellows in any one year is limited to 0.1% of the IEEE voting membership. For further details on the nomination process please consult: http://www.ieee.org/web/membership/fellows/index.html

IEEE Awards

The IEEE Awards program has paid tribute to technical professionals whose exceptional achievements and outstanding contributions have made a lasting impact on technology, society and the engineering profession. Institute Awards presented by the IEEE Board of Directors fall into several categories:

Medal of Honor (Deadline: July 1)
Medals (Deadline: July 1)
Technical Field Awards (Deadline: January 31)
Corporate Recognitions (Deadline: July 1)
Service Awards (Deadline: July 1)
Prize Papers (Deadline: July 1)
Fellowship (Deadline: March 1)

The Awards program honors achievements in education, industry, research and service. Each award has a unique mission and criteria, and offers the opportunity to honor distinguished colleagues, inspiring teachers and corporate leaders. The annual IEEE Awards Booklet, distributed at the Honors Ceremony, highlights the accomplishments of each year's IEEE Award and Medal recipients.

For more detailed information on the Awards program, and for nomination procedure, please refer to http://www.ieee.org/portal/ pages/about/awards/index.html.

Call for Papers

IEEE Information Theory Society

CALL FOR PAPERS: Special Issue of the IEEE Transactions on Information Theory on Interference Networks

Interference is one of the defining features of a wireless network. How to optimally deal with interference is one of the most critical and least understood aspects of multiuser communication. With the exception of a few special cases, the capacity of even the two-user interference channel remains an open problem. After three decades of relatively little progress on this important problem, recent years have seen a burst of research activity leading to remarkable advances, particularly in terms of approximate capacity characterizations. The recent results have introduced valuable tools such as new deterministic models, defined new metrics such as the generalized degrees of freedom, inspired new techniques such as interference alignment, and given rise to many new and promising avenues for research – such as the need for structured codes, the existence of single letter capacity characterizations, the inseparability of parallel interference networks, the remarkable benefits of opportunistic scheduling schemes, distributed algorithms for interference management, understanding of cooperative/cognitive/competitive interaction, and the security and robustness of the emerging schemes.

The goals of the special issue are to provide the reader with a summary of the state of the art in this rapidly developing area, and to compile a collection of new research results on this subject. The special issue will consist of a mixture of invited and contributed papers. In the former case, leading experts will be invited to provide the interested reader with comprehensive, yet highly approachable introductions to the new ideas. In the latter case, possible topics for the special issue include, but are not limited to:

- Approximate Capacity Characterizations for Gaussian Interference Networks
- Deterministic Models for Interference Networks
- Interference management techniques (Avoidance, Structured Codes, Alignment etc.)
- Game theoretic view of Interference Networks
- Opportunistic Scheduling over Interference Networks
- Diversity Multiplexing Tradeoffs for Interference Networks
- Relaying, feedback, and bidirectional communication over Interference Networks
- Secrecy and Robustness to Jamming for Interference Networks

Within each topic, papers must focus primarily on the information & coding theoretic aspects of the research problem.

IMPORTANT DATES
Paper submission deadline: March 31st 2010
Completion of first round of reviews: June 30th 2010
Revised paper submission deadline: September 31st 2010
Final review and selection of papers: December 31st 2010
Final manuscripts to IEEE: January 2011
Publication of the Special Issue: March 2011

INSTRUCTIONS FOR MANUSCRIPT PREPARATION:
Detailed instructions including formatting and submission details can be found at http://interference-networks.org

GUEST EDITORS

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- **Sriram Vishwanath**, University of Texas, Austin

CONTACT
Sriram Vishwanath, 1 University Station C0806, Austin TX 78712. Email: sriram@ece.utexas.edu

Special issue of the IEEE Transactions on Information Theory Facets of Coding Theory: From Algorithms to Networks

Tribute to the Work of Ralf Koetter

A special issue of the IEEE Transactions on Information Theory, envisioned as a tribute to the scientific legacy of Ralf Koetter, will be published in early 2011. The scope of the special issue encompasses all aspects of coding theory (both algebraic and probabilistic), network coding, turbo equalization, as well as other topics in networks and signal processing. Ralf Koetter worked in all these areas and forged numerous ground-breaking connections among them. Further exploring these exciting connections is one of the goals of this special issue. Another goal is to highlight the many new facets of coding theory that emerged during the past decade, largely owing to the contributions of Ralf Koetter.

Original research papers, as well as expository and survey papers, are sought, both invited and contributed. Papers submitted to this special issue should relate in some way to the work of Ralf Koetter. Sample topics include, but are not limited to, the following:

- Algebraic theory of network coding and its applications
- Analysis of iterative algorithms in graphical models
- Codes on graphs: realization complexity and constructions
- Efficient decoding (especially list-decoding) of algebraic codes
- Error-correction in networks, both coherent and non-coherent
- Turbo equalization and related topics in signal processing

The deadline for submission of manuscripts is April 15, 2010, and early submission is encouraged. All submissions will undergo a rigorous peer review, handled by one of the Guest Editors.

A special Workshop titled *Facets of Coding Theory: from Algorithms to Networks* and dedicated to Ralf Koetter will take place at the Allerton House, Monticello, Illinois, from Sunday, September 26, until Tuesday, September 28, 2010, immediately prior to the Forty-Eighth Annual Allerton Conference. Authors of papers accepted for the special issue will be expected to present their work at this Workshop. However, presentation at the Workshop will not be a prerequisite for publication in the special issue. Conversely, inclusion of a paper in the Workshop program will not guarantee inclusion in the special issue.

Questions regarding the special issue should be directed to Alexander Vardy at <avardy@ucsd.edu>. Questions regarding the Workshop should be directed to Andrew Singer at <acsinger@illinois.edu>.

SUBMISSION PROCEDURE:
Prospective authors should submit their papers electronically at http://pareja.itsoc.org/initial_submission, and adhere to the regular guidelines of the IEEE Transactions on Information Theory, with the following exceptions. In the field labeled "Editorial Area or Special Issue," please select this special issue. All the papers will be deemed submitted *both* for publication in the special issue *and* for presentation at the Workshop, unless clearly indicated otherwise in the field labeled "Message to Editor-in-Chief." Authors may also indicate in the same field their preference for a Guest Editor to handle the submission.

SCHEDULE:

Manuscript submission deadline:	**April 15, 2010**
Notification of acceptance:	**August 31, 2010**
Final manuscripts due:	**September 28, 2010**
Tentative publication date:	**February 2011**

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Muriel Médard, Massachusetts Institute of Technology
Andrew C. Singer, University of Illinois at Urbana-Champaign
Alexander Vardy, University of California San Diego

Call for Papers

ISITA2010/ISSSTA2010
TAICHUNG

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2010 International Symposium on Information Theory and its Applications
and
2010 International Symposium on Spread Spectrum Techniques and Applications

The Splendor Hotel, Taichung, Taiwan
October 17-20, 2010

The 2010 International Symposium on Information Theory and its Applications (ISITA2010) and the 2010 International Symposium on Spread Spectrum Techniques and Applications (ISSSTA2010) will be jointly held in Taichung, Taiwan, from Sunday, October 17, through Wednesday, October 20, 2010.

Topics of interest include, but are not limited to:

- **Error Control Coding**
- **Coding Theory and Practice**
- **Coded Modulation**
- **Data Compression and Source Coding**
- **Pattern Recognition and Learning**
- **Speech/Image Coding**
- **Rate-Distortion Theory**
- **Shannon Theory**
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- **Data Networks**
- **Multi-User Information Theory**
- **Quantum Information Processing**
- **Mobile Communications**
- **Spread Spectrum Systems**
- **Detection and Estimation**
- **Signal Processing**
- **Sequence Design and Optimization**
- **Synchronization and Channel Estimation**
- **Multicarrier CDMA and OFDM**
- **UWB Communications**
- **MIMO & Diversity Techniques**
- **Wideband Channel Modeling**
- **Cognitive and Software Radios**
- **Cooperative Communications**
- **Optical Communications**

Papers will be selected on the basis of a full manuscript (not exceeding 6 pages). The deadline for submission is 23:59, March 7, 2010, GMT. Notification of decisions will be made by the end of May, 2010.

The accepted papers will appear in the Proceedings and IEEE Xplore. Detailed information on the technical program, special events, accommodation, and registration will be posted on the Symposium web site:

http://www.sita.gr.jp/ISITA2010/

Enquiries on matters related to the Symposium should be addressed to:

General matters:
isita-isssta2010@sita.gr.jp

Technical program matters:
isita-isssta2010tpc@ee.nthu.edu.tw

Deadline for paper submission	**March 7, 2010**
Notification of paper acceptance	**late May, 2010**
Deadline for final paper submission	**July 7, 2010**
Deadline for author registration	**July 7, 2010**

About Taichung: Taichung is located in the hub of central Taiwan and surrounded by many tourist attractions, such as Sun Moon Lake, Lushan Hot Spring and Shitou Forest Recreation Area. The pleasant climate, beautiful scenery, the rich history of art and culture, and the prosperous economy supply Taichung with the glamour of a world-class metropolis. Walking in the streets of Taichung, a visitor would discover a delicate mixture of modern and classic, of nature and technology, and of grandeur and simplicity.

Call for Papers

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2010 IEEE International Symposium on Information Theory

The *2010 IEEE International Symposium on Information Theory* (ISIT 2010) will take place *June 12 – 18, 2010* in Austin, Texas, the Live Music Capital of the World. Previously unpublished contributions from a broad range of topics in information theory are solicited, including (but not limited to) the following areas:

Channel coding theory and practice	Multi-terminal information theory
Communication theory	Pattern recognition and learning
Cryptography and data security	Quantum information theory
Detection and estimation	Sequences and complexity
Emerging applications of information theory	Shannon theory
Information theory and statistics	Signal processing
Information theory for networks	Source coding theory and practice

Researchers working in emerging fields of information theory especially are encouraged to submit original findings. Submitted papers should be of sufficient length and detail for review by experts in the field. Final papers will be limited to 5 pages in standard IEEE conference format. Detailed information on paper submission, technical program, accommodations, tutorials, travel and excursions will be posted on the symposium website: http://www.isit2010.org/

Key Dates:

Paper Submission Deadline: **January 7, 2010, 11:59pm, US Central Time**
Acceptance Notification: April 1, 2010

For more information about the symposium, please contact the General Co-Chairs, **Behnaam Aazhang** and **Costas N. Georghiades**.

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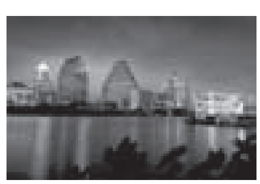

Call for Papers

SETA 2010
SEquences and Their Applications Conference

The sixth conference on **Sequences and their applications (SETA 2010)** will be held at Telecom ParisTech, Paris, France from **September 12 to 17, 2010**.

Contact
Patrick Solé
Département COMELEC
Télécom ParisTech
seta2010@telecom-paristech.fr

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Invited Speakers
- Robert Calderbank, Princeton University, USA
- James Massey, ETH Zurich, Switzerland (retired)
- Arne Winterhof, Österreichische Akademie der Wissenschaften (Austrian Academy of Sciences)

General Chair
- Patrick Solé, Telecom ParisTech

Local Arrangments
- Jean-Claude Belfiore, Telecom ParisTech

Proceedings
- Springer Lecture Notes in Computer Science

Important Dates
- April 1: Submission deadline
- Mid of May: Notification of acceptance
- Beginning of June: Final paper submission

TOPICS

Previously unpublished papers on all technical aspects of sequences and their applications in communications, cryptography, and combinatorics are solicited for submission to SETA'10. Topics include:
- Randomness of sequences
- Correlation (periodic and aperiodic types) and combinatorial aspects of sequences (difference sets)
- Sequences with applications in coding theory and cryptography
- Sequences over finite fields/rings/function fields
- Linear and nonlinear feedback shift register sequences
- Sequences for radar distance ranging, synchronization, identification, and hardware testing
- Sequences for wireless communication
- Pseudorandom sequence generators
- Boolean and vectorial functions for sequences, coding and/or cryptography
- Multidimensional sequences and their correlation properties
- Linear and nonlinear complexity of sequences

Contact seta2010@telecom-paristech.fr
http://www.telecom-paristech.fr, rubrique Agenda

Conference Calendar

DATE	CONFERENCE	LOCATION	WEB PAGE	DUE DATE
December 14–17, 2009	**Twelfth IMA International Conference on Cryptography and Coding**	Cirencester, UK	http://www.ii.uib.no/~matthew/Cirencester09/Cirencester09.html	Passed
January 6–8, 2010	**2010 IEEE Information Theory Workshop (ITW 2010)**	Cairo, Egypt	http://itw2010cairo.info/	Passed
January 18–21, 2010	**8th International ITG Conference on Source and Channel Coding (SCC'10)**	Siegen, Germany	http://www.scc2010.net	passed
January 31–February 5, 2010	**2010 Information Theory and Applications Workshop**	San Diego, CA	http://ita.calit2.net/workshop.php	by invitation
March 3–5, 2010	**2010 International Zurich Seminar on Communications**	Zurich, Switzerland	http://www.izs.ethz.ch/	passed
March 15–19, 2010	**2010 IEEE INFOCOM**	San Diego, CA	http://www.ieee-infocom.org/	passed
March 17–19, 2010	**44th Annual Conference on Information Sciences and Systems (CISS 2010)**	Princeton University, NJ	http://conf.ee.princeton.edu/ciss/	January 10, 2010
May 23–27, 2010	**IEEE International Conference on Communications (ICC 2010)**	Cape Town, South Africa	http://www.ieee-icc.org/2010/	Passed
June 12–18, 2010	**IEEE International Symposium on Information Theory**	Austin, Texas	http://www.isit2010.org/	January 7, 2010
September 12–17, 2010	**Sequences and Their Applications (SETA 2010)**	Paris, France	http://www.telecom-paristech.fr	April 1, 2010
Oct. 17–20, 2010	**2010 International Symposium on Information Theory and Its Applications and 2010 International Symposium on Spread Spectrum Techniques and Applications**	Taichung, Taiwan	http://www.sita.gr.jp/ISITA2010	March 7, 2010

Major COMSOC conferences: http://www.comsoc.org/confs/index.html