IEEE Information Theory Society Newsletter

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President's Column

Abbas El Gamal

I started writing this column while on vacation at the beautiful Kailua beach right after ISIT, the premier event of our society. Thanks to the excellent organization of the conference co-chairs Anders Madsen, Aleksandar Kavcic, Venugopal Veeravalli and their team, the conference was a great success. Some of the many highlights were the beautiful venue (a short walk away from Wikiki beach), the Shannon lecture by János Körner, and the other four plenary lectures. As usual, there were numerous award presentations and announcements. The first Cover Dissertation Award was presented to Hamed Hassani from EPFL, who unfortunately was not able to attend because his visa was not granted in time. IEEE President elect Howard Michel presented Balaji Prabhakar with the first IEEE Innovation in Societal Infrastructure Award "For his demonstration of the innovative use of information technology and distributed computing systems to solve long-standing societal problems, in areas ranging from transportation to healthcare and recycling." Then there were the surprise announcements of the winners of the 2014 IT Paper Award and the 2014 IEEE Jack Keil Wolf ISIT Student Paper Awards. Most importantly, the winner of the 2015 Shannon Award was announced to be Robert Calderbank, the Charles S. Sydnor Professor of Computer Science and Professor of Electrical and Computer Engineering and Mathematics at Duke University. Rob will give the Shannon lecture at next year's ISIT in Hong Kong.

There were also several popular mentoring and outreach events at ISIT. Osvaldo Simeone and Deniz Gunduz organized a "Meet the Shannon Awardee" lunch event with János Körner; Joerg Kliewer Bobak Nazer, and Daniela Tuninetti, planned the panel "How to survive tenure-track" in addition to the IT mentoring event; and Negar Kiyavash organized the "Climate change: What Conditions Help Women Thrive in STEM Areas?" event.

Speaking of mentorship and outreach activities, I would like to mention that the Women in Information Theory (WITHITS) program headed by Negar Kiyavash have developed individually produced videos highlighting the research conducted by some of our members. The videos are posted on our society's website at http://media.itsoc.org/withits.html.

As an affirmation of our exceptional educational, outreach and mentoring activities, I am happy to report that our society has won the 2014 IEEE Educational Activities Board Society/Council Professional Development Award with the citation: ***"for leadership in educating and mentoring the future generation of the information theory community."***

This award was established by the IEEE EAB to recognize IEEE Societies or Councils for major contributions to the professional development of its members through the provision of outstanding products, services and support in the areas of lifelong learning, continuing education, and professional development.

Winning this award is no small feat given the small size of our society relative to most of the other 37 IEEE societies. It is an acknowledgment of the exceptional efforts by many of our members. In particular, I would like to thank Muriel Medard, Aylin Yener, Andrea Goldsmith, Gerhard Kramer, Joerg Widmer, Alex Dimakis, and Alon Orlitsky for taking the time to provide the material for the nomination to this award and in general for their many significant contributions to the society.

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From the Editor

Tara Javidi

Dear IT Society members,

In the third issue of 2014, in addition to our popular and regular contribution by our historian Tony Ephremides and our puzzle master Solomon Golomb, we have an important contribution by Aylin Yener on the financial state of the society and two school/workshop reports. We are also featuring an article highlighting the mentoring activities and call for participation in the program. I thank Vitaly Skachek, Vincent Tan, Vijay Bhargava, and Jeorg Kliewer for their contributions. I would also like to thank Amos Lapidoth for providing our latest Teaching IT column. As most of our readers remember, the teaching IT column started a few years back with occasional (invited) and excellent contributions by some of the most distinguished members of IT Society.

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 also can be e-mailed to me at ITsocietynewsletter@ece.ucsd.edu with a subject line that includes the words "IT newsletter." The next few deadlines are:

Issue	Deadline
December 2013	October 10, 2014
March 2014	January 10, 2015
June 2014	April 10, 2015

Please submit plain text, 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 hear your suggestions (especially regarding the new column) and contributions.

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The Historian's Column

Anthony Ephremides

Information Theory is reaching the mature age of 66 this year. So, it is time to consider the human aspect of its historical thread. What about those men and women who have embraced the field and by their presence and devotion have actually imprinted their identity on the field itself?

The turnover in 66 years is substantial, if not transformational. Shannon's figure continues to loom large and unperturbed by the mere time-scale of less than a century. But how about all others who have helped sculpt the face of Information Theory? The pioneers clearly emerged from the epicenter of the revolution of 1948, namely MIT and Bell Labs. Fano, Elias, Slepian, Wyner, and then people like Gallager, Massey, Cover, Kailath, Sloane and so many others who populated the early years of the field and whose presence in the Transactions and Symposia were the staples of the Society's activities.

As time has gone by, the "faces" that dominate our field have also been evolving. Some passed away, others faded away for different reasons, and many newcomers and bright new stars have risen in the horizon. Has the texture of the human crowd in our field retained constancy? Sixty-six years is a long time. The old faces are becoming scarcer. Every year at the ISIT the silent absence of yet someone else is noted. Those who were thought to be irreplaceable are being replaced. The new faces are numerous. Is there a common thread? Does the collective image of our members retain some form of time-invariance? That is, do we believe in the same things as our "forefathers"? Do we behave the same way? Do we have the same values?

To answer this question it helps if we draw a composite sketch of the "classical" Information Theorist. Not obviously in terms of the work they do because that naturally keeps evolving. Rather, how is their attitude and style? The profile of an Information Theorist consists of some "core" elements. The legacy of the pioneers calls, first of all, for a devotion to the field. It calls for the earnest belief that this is a vibrant, challenging, and enduring field that has sprung from innovation in its purest and most fascinating form, namely simplicity and clarity. Secondly, it calls for a scientific attitude that transcends banality and over-eagerness. In other fields I often see overzealous researchers touting their work in almost childish ways. Like, "this is the first time anyone has done this", or "we are the first to have done so and so". By contrast, in our field I recall some unusual and contrasting scenes. I recall Slepian announcing just before his talk that the subject he would present "had no applications whatsoever"! Or others mentioning that the previous evening they discovered a mistake in their work, or admitting that because the last moment they had misgivings about their results they would change the content of their presentation. Self-effacing remarks have been the mark and the norm for most of the best contributions in our field. Not that our members do not have big egos. Some of them have…huge ones! I do not want to mention names but we all know some. It is that the style of presentation is more confident and detached and does not need defensiveness.

Another trait of the legacy of the early pioneers has been the intellectual depth of their work. The scientific aesthetics of Information Theory have established intellectual merit as the highest measure of a contribution. Is there scientific beauty in the work? Is there innovativeness, imagination, beauty? Yes, usefulness, utility, relevance are all important. But they come AFTER the fact. It is the fallout of the fundamental work. The main significance is not a 3 db improvement but how that improvement is obtained. It is the ideas that matter. And they should be fresh, interesting, attractive, and inspiring. If we cannot inspire the younger members, there is no future. And inspiration comes from these virtues of the legacy contributions.

Yet another trait of the "best" amongst us is a unique sense of humor that permeates even the most serious discourse. Board of Governors meetings are generally dreary affairs. Yet in the Information Theory Society they could be really entertaining events. The intellect and playfulness of most of our members would shine through the mundane agenda of these meetings. Nothing is (or should be) so serious that it causes melancholy. Just recall how that treasure of a movie (for those who were lucky to have seen it) called "Life is Beautiful" with Roberto Benigni found and displayed comedy amidst grave tragedy. I recall Aaron Wyner, after the very good financial picture reported by the Treasurer regarding the wealth of our Society in the '80's remarking that we were like Kuwait (small but rich!). Or when it was announced that we would have a workshop in New Zealand where the Lord of the Rings had been shot, someone propose to have a session on the Lord of the algebraic Rings. Or when there was a debate whether to have a workshop in Ireland or Scandinavia, a proposal was made (tongue-in-cheek) to hold the workshop, as a compromise, in Northern Ireland. And, on-and-on they went all kinds of nuggets of wit which would also surface in the presentations and the general atmosphere of jolliness that permeated our meetings. An apex has been reached in this regard with the hilarious ideas of the recognized genius of the form, Alon Orlitsky, with the ITA format. Here is a meeting that emerged shyly from nothing to earn the respect of our members through its content AND through the jolliness of its tone. There is probably no other meeting in the world that accepts without review the papers in its program and has, on average, one of the highest-quality technical programs.

So, coming back to our original question, are we carrying ably the values we inherited from our "founding fathers"? Are our younger members reflecting accurately the older ones? As we change, innovate, and evolve do we maintain the time-invariant uniqueness of our field?

I am not going to venture an answer. You be the judge. Whether we manage to perpetuate the Spirit born in 1948 or not, it is my belief that we should at least try. For the next sixty-six years.

Teaching IT Power Spectral Density of Communication Signals

Amos Lapidoth
ETH Zurich, Switzerland

Abstract

The transmitted waveforms in digital communications are rarely stationary, so they do not have a power spectral density (PSD) in the classical sense. To teach their PSD one needs a definition that is both general and useful. The traditional approach is to define the PSD via the average autocovariance function. Here I shall describe an alternative approach and offer some comparisons.

1 Introduction

The transmitted waveform in digital communications is usually modelled as a stochastic process (SP), because the data it conveys are viewed as random. But this SP is typically not wide-sense stationary (WSS), so the classical definition of the power spectral density (PSD) of a WSS SP as an integrable function whose Inverse Fourier Transform (IFT) is the SP's autocovariance function does not apply.

To overcome this difficulty, teachers often "stationarize" the signals in various ways. For example, in Pulse Amplitude Modulation (PAM), which is typically cyclostationary, they stationarize the random signal by introducing a random time offset. For Quadrature Amplitude Modulation (QAM) such an offset does not always suffice, and they thus also introduce a random phase. Once the process has been stationarized, they then apply the classical definition.

This approach has two shortcomings. The first is the lack of generality: different hacks are required to stationarize different transmission schemes. For example, in PAM the distribution of the time offset depends on whether or not forward error correction in the form of block coding is performed. And in QAM the need to introduce a random phase depends on whether or not the random sequence of complex symbols is proper. The second shortcoming is that this approach obscures the operational meaning of the PSD. Except for enabling them to calculate it on the exam, it is not clear to the students why knowing the PSD is useful. And saying that the Federal Communications Commission (FCC) places restrictions on it only begs the question as to why the FCC does so.

In the first part of this paper (Sections 1–4) I shall present a different approach, which I believe addresses these shortcomings. To avoid confusion with the classical PSD of WSS SPs, I shall refer to the PSD that I define as *Operational PSD* (OPSD). In the second part of the paper (Sections 5–6) I shall relate the OPSD to the *average autocovariance function*, which is often used to study nonstationary SPs [3, Ch. 4, Sec. 26.6]. The paper concludes with a discussion (Section 7) and some additional resources (Section 8).

To see the forest for the trees, I shall be somewhat informal and refer the interested readers to [2] for the technical details. In particular all the functions and SPs I consider are tacitly assumed measurable, and all the properties attributed to OPSD should be appended by the phrase "outside a set of frequencies of Lebesgue measure zero." Thus, when I write that the OPSD is "unique" I mean that two OPSDs of the same SP must be identical outside a set of frequencies of Lebesgue measure zero. A similar qualification applies when I say that the OPSD is "nonnegative." Also, to avoid unnecessary technical complications, we shall restrict attention to SPs of *bounded variance*, where a SP $\big(X(t)\big)$ is said to be of bounded variance if there exists some constant γ such that at every epoch $t \in \mathbb{R}$ the variance of the random variable (RV) $X(t)$ is bounded by γ:

$$\mathsf{Var}[X(t)] \le \gamma, \quad t \in \mathbb{R}. \tag{1}$$

Finally, we shall restrict ourselves to *centered stochastic processes*, i.e., to SPs of zero mean. The extensions to the general case are straightforward.

2 Power

We begin with the **power**, which is more intuitive and more fundamental.[1] The power in a SP $\big(X(t), t \in \mathbb{R}\big)$, or $\big(X(t)\big)$ or $\mathbf{X}$ for short, is P if

$$\mathsf{P} = \lim_{\mathsf{T}\to\infty} \frac{1}{2\mathsf{T}} \mathsf{E}\left[\int_{-\mathsf{T}}^{\mathsf{T}} X^2(t)\,\mathrm{d}t\right]. \tag{2}$$

For example, consider the PAM signal

$$X(t) = \mathsf{A} \sum_{\ell=-\infty}^{\infty} X_\ell\, g(t - \ell \mathsf{T}_\mathrm{s}), \quad t \in \mathbb{R}, \tag{3}$$

where $\mathsf{A}, \mathsf{T}_\mathrm{s} > 0$ are constants; the pulse-shape $\mathbf{g}$ is a deterministic real signal that decays sufficiently fast; and where the bi-infinite sequence $\ldots, X_{-1}, X_0, X_1, \ldots$ is bounded, centered, with

$$\mathsf{E}[X_\ell X_{\ell+m}] = \mathsf{K}_{XX}(m), \quad \ell, m \in \mathbb{Z}. \tag{4}$$

In this case a direct calculation [2, Section 14.5] shows that for any $\tau \in \mathbb{R}$,

$$\begin{aligned} &\mathsf{E}\left[\int_\tau^{\tau+\mathsf{T}_\mathrm{s}} X^2(t)\,\mathrm{d}t\right] \\ &\quad = \mathsf{A}^2 \sum_{m=-\infty}^{\infty} \mathsf{K}_{XX}(m) \int_{-\infty}^{\infty} g(t')\, g(t' - m\mathsf{T}_\mathrm{s})\,\mathrm{d}t' \\ &\quad = \mathsf{A}^2 \sum_{m=-\infty}^{\infty} \mathsf{K}_{XX}(m) \mathsf{R}_{\mathbf{gg}}(m\mathsf{T}_\mathrm{s}), \quad \tau \in \mathbb{R}, \end{aligned} \tag{5}$$

where $\mathsf{R}_{\mathbf{gg}}$ denotes the self-similarity function of $g(\cdot)$

$$\mathsf{R}_{\mathbf{gg}} : \tau \mapsto \int_{-\infty}^{\infty} g(t+\tau)\, g^*(t)\,\mathrm{d}t, \quad \tau \in \mathbb{R}. \tag{6}$$

From (5) we obtain

$$\begin{aligned} \left\lfloor \frac{2\mathsf{T}}{\mathsf{T}_\mathrm{s}} \right\rfloor \mathsf{E}\left[\int_\tau^{\tau+\mathsf{T}_\mathrm{s}} X^2(t)\,\mathrm{d}t\right] &\le \mathsf{E}\left[\int_{-\mathsf{T}}^{\mathsf{T}} X^2(t)\,\mathrm{d}t\right] \\ &\le \left\lceil \frac{2\mathsf{T}}{\mathsf{T}_\mathrm{s}} \right\rceil \mathsf{E}\left[\int_\tau^{\tau+\mathsf{T}_\mathrm{s}} X^2(t)\,\mathrm{d}t\right], \end{aligned} \tag{7}$$

[1] Teaching the power spectral density first and then integrating it to obtain the power is pedagogically unappealing and mathematically dubious; see Section 6.

and, thus, using the Sandwich Theorem,

$$\mathsf{P} = \frac{1}{\mathsf{T_s}}\,\mathsf{A}^2 \sum_{m=-\infty}^{\infty} \mathsf{K}_{XX}(m)\mathsf{R}_{\mathbf{gg}}(m\mathsf{T_s}) \tag{8}$$

$$= \frac{\mathsf{A}^2}{\mathsf{T_s}} \int_{-\infty}^{\infty} \sum_{m=-\infty}^{\infty} \mathsf{K}_{XX}(m)\, e^{i2\pi f m \mathsf{T_s}}\, |\hat{g}(f)|^2 \,\mathrm{d}f, \tag{9}$$

where $\hat{\mathbf{g}}$ denotes the Fourier Transform (FT) of $g(\cdot)$:

$$\hat{g}(f) = \int_{-\infty}^{\infty} g(t) e^{-i2\pi f t}\,\mathrm{d}t, \quad f \in \mathbb{R}. \tag{10}$$

Computing the power in QAM is a bit trickier: the key is to relate the power in the QAM signal to the power in its baseband representation (which is a complex PAM signal) [2, Chapter 18].

3 Defining the OPSD

Denoting by $\mathcal{L}_1$ the class of real-valued functions from the reals whose Lebesgue integral is finite, we propose the following definition for the OPSD.

Definition 1 (Operational PSD of a Real SP). *We say that the continuous-time real stochastic process $\big(X(t), t \in \mathbb{R}\big)$ is of* ***operational power spectral density*** S_{XX} *if $\big(X(t), t \in \mathbb{R}\big)$ is a measurable SP; the mapping $\mathsf{S}_{XX} : \mathbb{R} \to \mathbb{R}$ is integrable and symmetric; and for every stable real filter of impulse response $\mathbf{h} \in \mathcal{L}_1$ the power at the filter's output when it is fed $\big(X(t), t \in \mathbb{R}\big)$ is given by*

$$\text{Power in } \mathbf{X} \star \mathbf{h} = \int_{-\infty}^{\infty} \mathsf{S}_{XX}(f) |\hat{\mathrm{h}}(f)|^2 \,\mathrm{d}f.$$

This functional relationship can be motivated by thinking of the power as being the sum of the powers in the infinitesimal nonoverlapping (and hence orthogonal) frequency slivers that the signal occupies. The symmetry requirement is only needed if we do not allow for complex filters. (The OPSD for complex SPs has the same definition except that the symmetry requirement is dropped and the filters are allowed to be complex.)

To put the reader at ease we note that, when it exists, the OPSD is "unique" [2, Corollary 15.3.3], and it is "nonnegative" [2, Exercise 15.5]. Moreover, for WSS SPs this definition coincides with the standard definition of the PSD as an integrable function whose IFT is the autocovariance function [2, Theorem 25.14.3].

Our definition makes it clear that knowing the OPSD of the transmitted waveform can be useful. For example, it allows us to calculate the "adjacent channel interference," i.e., how much of the signal's power "spills over" into the front-end filter of a receiver operating at an adjacent channel. Alas, it tells us nothing about how to compute the OPSD. This is, of course, the price of a general definition that must be applicable to a wide-range of transmission schemes.

As we shall see in Section 5, the OPSD can often be calculated from the *average autocovariance function* when the latter exists. However, it turns out that, for some of the transmission schemes that are taught in a basic course on digital communications, the OPSD can easily be calculated from its definition. Consider, for example, the PAM signal (3). Passing $\big(X(t)\big)$ through a stable filter of impulse response $\mathbf{h} \in \mathcal{L}_1$ is tantamount to replacing its pulse-shape $\mathbf{g}$ by $\mathbf{g} \star \mathbf{h}$ [2, Section 15.4], so the power in $\mathbf{X} \star \mathbf{h}$ can be calculated from (9) by replacing the FT of $\mathbf{g}$ with the FT of $\mathbf{g} \star \mathbf{h}$ to yield

$$\text{Power in } \mathbf{X} \star \mathbf{h} = \int_{-\infty}^{\infty} \Big(\frac{\mathsf{A}^2}{\mathsf{T_s}} \sum_{m=-\infty}^{\infty} \mathsf{K}_{XX}(m) \cdot e^{i2\pi f m \mathsf{T_s}}\, |\hat{g}(f)|^2 \Big) |\hat{h}(f)|^2 \,\mathrm{d}f.$$

And since the term in parentheses is a symmetric function of f, it must coincide with the OPSD, so

$$\mathsf{S}_{XX}(f) = \frac{\mathsf{A}^2}{\mathsf{T_s}} \sum_{m=-\infty}^{\infty} \mathsf{K}_{XX}(m)\, e^{i2\pi f m \mathsf{T_s}}\, |\hat{g}(f)|^2 . \tag{11}$$

The calculation of the OPSD for QAM signals can be carried out in a similar, albeit a bit more complicated, way [2, Section 18.4]. The key is to study the baseband representation of $\mathbf{X} \star \mathbf{h}$; to show that it corresponds to the filtering of the baseband representation of $\mathbf{X}$ (which is a complex PAM signal) by a (different) filter; and to then use the relationship between the power in baseband and passband.

4 The OPSD of a Filtered SP

Starting from the definition of the OPSD, it is rather simple to show that feeding a SP $\big(X(t)\big)$ of a given OPSD S_{XX} to a stable filter of a given impulse response $\mathbf{r} \in \mathcal{L}_1$ results in a SP of OPSD

$$f \mapsto \mathsf{S}_{XX}(f)\; |\hat{r}(f)|^2. \tag{12}$$

To see this only requires the small leap of faith that the associativity of the convolution extends to stochastic processes. Indeed, to compute the OPSD of $\mathbf{X} \star \mathbf{r}$ we need to know the power in $(\mathbf{X} \star \mathbf{r}) \star \mathbf{h}$ for every $\mathbf{h} \in \mathcal{L}_1$. But, since convolution is (usually) associative, we expect that the SP $(\mathbf{X} \star \mathbf{r}) \star \mathbf{h}$ be (usually) identical to the SP $\mathbf{X} \star (\mathbf{r} \star \mathbf{h})$ and hence of equal power. The power in the latter is easily computed from S_{XX}: we view $\mathbf{r} \star \mathbf{h}$ as an impulse response of a filter; we view $\mathbf{X} \star (\mathbf{r} \star \mathbf{h})$ as the result of passing $\mathbf{X}$ through this filter; and we recall that $\mathbf{X}$ is of OPSD S_{XX} so the power in $\mathbf{X} \star (\mathbf{r} \star \mathbf{h})$—and hence also in $(\mathbf{X} \star \mathbf{r}) \star \mathbf{h}$—is

$$\int_{-\infty}^{\infty} \mathsf{S}_{XX}(f)\; \left|\hat{r}(f)\hat{h}(f)\right|^2 \,\mathrm{d}f.$$

Rewriting this as

$$\int_{-\infty}^{\infty} \Big(\mathsf{S}_{XX}(f)\; |\hat{r}(f)|^2\Big)\; \left|\hat{h}(f)\right|^2 \,\mathrm{d}f,$$

and noting that the term in parentheses is symmetric in f, we conclude that the operational PSD of $\mathbf{X} \star \mathbf{r}$ should be given by (12).

5 The OPSD and the Average Autocovariance Function

We next explore the relationship between the OPSD and the **average autocovariance function**, which is defined as follows [3, Chapter 4, Section 26.6]:

Definition 2 (Average Autocovariance Function). *We say that a SP $\big(X(t)\big)$ is of* ***average autocovariance function*** $\bar{\mathsf{K}}_{XX} : \mathbb{R} \to \mathbb{R}$ *if it is measurable, of bounded variance, and if for every $\tau \in \mathbb{R}$*

$$\lim_{\mathsf{T}\to\infty} \frac{1}{2\mathsf{T}} \int_{-\mathsf{T}}^{\mathsf{T}} \mathrm{Cov}[X(t), X(t+\tau)]\,\mathrm{d}t = \bar{\mathsf{K}}_{XX}(\tau). \tag{13}$$

By substituting 0 for τ in (13) and by recalling the definition of power (2), we obtain that if $\big(X(t)\big)$ is a centered SP of power P and of average autocovariance function $\bar{\mathsf{K}}_{XX}$, then

$$\mathsf{P} = \bar{\mathsf{K}}_{XX}(0). \tag{14}$$

An example of a SP that has an average autocovariance function is the PAM signal (3). In fact, the calculation of its average autocovariance function is very similar to the calculation of its power.

The following theorem provides an operational meaning to the average autocovariance function and shows that if it is integrable, then its FT is the OPSD. Thus, for stochastic processes having an integrable average autocovariance function, our definition of the OPSD and the definition in the literature of the operational PSD as the FT of $\bar{\mathsf{K}}_{XX}$ coincide.[2] It also provides a method for computing the operational PSD: compute $\bar{\mathsf{K}}_{XX}$ and take its FT.

Theorem 1 (The OPSD and the Average Autocovariance Function). *Let $\big(X(t)\big)$ be a centered SP of average autocovariance function $\bar{\mathsf{K}}_{XX}$.*

1) *If* $\mathbf{h}$ *is the impulse response of some stable filter, then*

$$\text{Power in } \mathbf{X} \star \mathbf{h} = \int_{-\infty}^{\infty} \bar{\mathsf{K}}_{XX}(\sigma)\, \mathsf{R}_{\mathbf{hh}}(\sigma)\, \mathrm{d}\sigma. \tag{15}$$

2) *If* $\bar{\mathsf{K}}_{XX}$ *is integrable, then its Fourier Transform is the OPSD of* $\big(X(t)\big)$:

$$\hat{\bar{\mathsf{K}}}_{XX} = \mathsf{S}_{XX}. \tag{16}$$

6 The OPSD and Power

Intuition suggests that the OPSD should integrate to the power. To see why, recall that if $\mathbf{X}$ is of OPSD S_{XX}, then

$$\text{Power in } \mathbf{X} \star \mathbf{h} = \int_{-\infty}^{\infty} \mathsf{S}_{XX}(f)\, \left|\hat{h}(f)\right|^2 \mathrm{d}f, \quad \mathbf{h} \in \mathcal{L}_1. \tag{17}$$

Suppose we now substitute for $\mathbf{h}$ the impulse response of a filter whose frequency response resembles that of an ideal unit-gain lowpass filter of very large cutoff frequency $\mathsf{W} \gg 1$. In this case the RHS of (17) would resemble the integral of $\mathsf{S}_{XX}(f)$ from –W to +W, which is approximately the integral from $-\infty$ to $+\infty$ when W is very large. And as to the LHS, if W is very large, then intuition suggests that $\mathbf{X}$ will hardly be altered by the filter, and the LHS would approximately equal the power in $\mathbf{X}$.

This intuition is excellent, and for most stochastic processes of interest the OPSD indeed integrates to the power. However, as our next example shows, there are some pathological counter-examples. In fact, in the absence of additional assumptions, we are only guaranteed that the integral of the OPSD cannot exceed the power.

Before presenting our example in detail, we begin with the big picture. In our example the SP $\mathbf{X}$ takes on the values ±1 only, so its power is 1. However, $\mathbf{X}$ changes between the values $+1$ and -1 progressively faster the further time is from the origin. As we next explain, this results in the power in $\mathbf{X} \star \mathbf{h}$ being zero for every stable filter $\mathbf{h}$, so $\mathbf{X}$ is of zero OPSD. The integral of the operational PSD is thus zero, while the power is one.

For some intuition as to why the power in $\mathbf{X} \star \mathbf{h}$ is zero, recall that when $\mathbf{h}$ is stable, its frequency response decays to zero. Consequently, above some cutoff frequency, the frequency response of the filter is nearly zero. Since our SP varies faster and faster the further we are from the origin of time, when we are sufficiently far from the origin of time the dynamics of our SP are much faster than the filter's cutoff frequency. Consequently, except for transients that result from the behavior of our SP near the origin of time, in steady state the response of $\mathbf{h}$ to $\mathbf{X}$ will be nearly zero. Since the transients do not influence the power in $\mathbf{X} \star \mathbf{h}$, the power in $\mathbf{X} \star \mathbf{h}$ is zero. We next present the example in greater detail.

Example 1. *Consider the SP $\big(X(t), t \in \mathbb{R}\big)$ whose value in the time interval $[\nu, \nu+1)$ is defined for every integer ν as follows: The interval is divided into $|\nu|+1$ nonoverlapping half-open subintervals of length $1/(|\nu|+1)$*

$$\left[\nu + \frac{\kappa}{|\nu|+1}, \nu + \frac{\kappa+1}{|\nu|+1}\right), \quad \kappa \in \{0, \ldots, |\nu|\},$$

and in each such subinterval the SP is constant and is equal to the RV $X_{\nu,\kappa}$, which takes on the values ±1 equiprobably with

$$\{X_{\nu,\kappa}\}, \quad \nu \in \mathbb{Z}, \kappa \in \{0, \ldots, |\nu|\}$$

being IID. Thus,

$$X(t) = \sum_{\nu=-\infty}^{\infty} \sum_{\kappa=0}^{|\nu|} X_{\nu,\kappa} \mathrm{I}\left\{\nu + \frac{\kappa}{|\nu|+1} \le t < \nu + \frac{\kappa+1}{|\nu|+1}\right\}, \tag{18a}$$

$$\big\{X_{\nu,\kappa}\big\} \sim \text{IID } \mathcal{U}(\{\pm 1\}). \tag{18b}$$

This SP is centered, of power $\mathsf{P} = 1$, and yet its operational PSD is zero at all frequencies. The integral of the OPSD of $\mathbf{X}$ is thus strictly smaller than the power in $\mathbf{X}$.

Proof. At every epoch t the RV $X(t)$ takes on the values ± 1 equiprobably and is thus centered. Moreover, $X^2(t)$ is deterministically 1, so the power in $\big(X(t)\big)$ is one. We next show that $\big(X(t)\big)$ is of average autocovariance function

$$\bar{\mathsf{K}}_{XX}(\tau) = \begin{cases} 1 & \text{if } \tau = 0, \\ 0 & \text{otherwise,} \end{cases} \quad \tau \in \mathbb{R}. \tag{19}$$

For τ equal to zero this follows immediately from our observation that $X^2(t)$ is deterministically equal to one. By symmetry, it suffices to establish (19) for positive τ. When τ is 1 or larger, the epochs t and $t + \tau$ fall—irrespective of t—in different intervals, so $X(t)$ and $X(t + \tau)$ are uncorrelated for all t. For such τ's $\bar{\mathsf{K}}_{XX}(\tau)$ is thus zero, in agreement with (19). It thus only remains to establish (19) for $0 < \tau < 1$. In this case t and $t + \tau$ are guaranteed to fall in different subintervals whenever

$$\tau \ge \frac{1}{|\lfloor t \rfloor|+1}, \tag{20}$$

where the RHS is the length of the subintervals to which the interval containing t—namely the interval $[\nu, \nu+1)$, where ν is $\lfloor t \rfloor$—is subdivided. (If this inequality is not satisfied, then $X(t)$ and $X(t + \tau)$ may or may not be in different subintervals.) For $\tau \in (0,1)$ Inequality (20) holds whenever $|\lfloor t \rfloor| \ge \tau^{-1} - 1$. Thus, when t is outside the finite interval

$$\big\{t' \in \mathbb{R} : |\lfloor t' \rfloor| < \tau^{-1} - 1\big\}$$

[2] The FT of the average autocovariance function is called "average spectral density" in [3].

the random variables $X(t)$ and $X(t+\tau)$ are uncorrelated. For t inside this finite interval the correlation between $X(t)$ and $X(t+\tau)$ is upper bounded by 1. Consequently, when we average $\mathsf{E}[X(t)X(t+\tau)]$ over t, the contribution of t's inside this interval washes out and the result is zero.

From (19) we conclude using Theorem 1 (ii) that the OPSD of $\big(X(t)\big)$ is zero. $\square$

In Example 1 the power is strictly larger than the integral of the OPSD, and the average autocovariance function is discontinuous at the origin. This is no coincidence: the integral of the OPSD never exceeds the power, and the two are the same whenever the SP has an average autocovariance function that is continuous at the origin:

Theorem 2 (The Power and the Integral of the OPSD). *Let $\big(X(t)\big)$ be a centered SP of OPSD S_{XX} and of power P.*

1) *The integral of the OPSD never exceeds the power*:

$$\mathsf{P} \geq \int_{-\infty}^{\infty} \mathsf{S}_{XX}(f)\,\mathrm{d}f. \tag{21}$$

2) *If, additionally, $\big(X(t)\big)$ is of some average autocovariance function $\bar{\mathsf{K}}_{XX}$, then equality in* (21) *holds if, and only if, $\bar{\mathsf{K}}_{XX}$ is continuous at the origin*.

7 Discussion

To teach the PSD we must provide the students with a general definition, an operational meaning, and some useful examples. Definition 1 provides the first two, and the class of PAM signals the third. PAM signals are particularly suitable for this purpose because filtering a PAM signal is tantamount to filtering its pulse shape, so—once we have taught the power in PAM—we can easily also calculate the power in filtered PAM. Another example is provided by QAM signals, but the analysis is a bit more difficult. Note, however, that this additional difficulty is already encountered in the calculation of the power, and, once we have taught the power, the OPSD is fairly straightforward.

A different viable approach is to define the PSD as the FT of the average autocovariance function. But if this approach is adopted, then one must also provide the students with an operational meaning such as that of Theorem 1(i). Once again, PAM signals can provide the desired example, but QAM might be a bit trickier.

The drawback of Definition 1 is that it is not immediately obvious from the definition that the OPSD is "unique" [2, Corollary 15.3.3]. But the added benefit is that it makes it almost obvious how the OPSD should behave when the SP is filtered (Section 4). At the end of the day it is up to the instructor to decide which definition is preferable. I prefer Definition 1 because providing the operational meaning to the FT of the average autocovariance function (Theorem 1(i)) requires a significant detour, and because Definition 1 is particularly suitable not only for PAM but also for QAM.

I am not very keen on teaching the OPSD by stationarizing the SP and by then using the classical definition for WSS SPs. This approach lacks generality and obscures the operational meaning. Moreover, in QAM it hides the beautiful result that the OPSD does not depend on the pseudo-covariance of the symbols. Indeed, this approach introduces a random phase that is tantamount to setting the pseudo-autocovariance function to zero and making the symbols proper.

Some readers who are familiar with the workings of a spectrum analyzer might contemplate using that as a pedagogical tool for teaching the OPSD. I suspect, however, that this might lead to confusion because in a spectrum analyzer time-averages and ensemble-averages are intertwined.[3] Moreover, different spectrum analyzers work in different ways and thus lead to different possible definitions. Some measure the power at the output of narrow bandpass filters centered around the different frequencies while others use the FFT. Moreover, the order in which the different limits are taken when analyzing a nonstationary SP using a spectrum analyzer is tricky. A related approach, which some teachers use to motivate the PSD of WSS SPs, is to study the limit

$$\lim_{\mathsf{T}\to\infty} \mathsf{E}\left[\left|\frac{1}{\sqrt{2\mathsf{T}}}\int_{-\mathsf{T}}^{\mathsf{T}} X(t)e^{-i2\pi ft}\,\mathrm{d}t\right|^2\right].$$

But relating this limit to the FT of the average autocovariance function can be tricky.

The OPSD is not only important in applications, but also a pleasure to teach. Whether you adopt Definition 1 is immaterial: what is important is that you go out and teach *it*.

8 Additional Resources

Most of the material on the OPSD can be found in the textbook [2] and in the videos of my lectures, which can be found at

`http://www.multimedia.ethz.ch/lectures/itet/2013/spring/227-0104-00L/`

Chapter 14, which is presented in Lecture 6, defines power and computes it for PAM; Chapter 15, which is presented in Lecture 7, defines the OPSD and computes it for PAM; and Chapter 18, which is presented in Lecture 9, computes the power and OPSD for QAM signals and also defines the OPSD for complex SPs. A shorter video on the OPSD of QAM can be found at

`http://www.afidc.ethz.ch/A_Foundation_in_Digital_Communication/QAMMovie.html`

The video emphasizes that the OPSD of QAM does not depend on the pseudo-covariance of the transmitted symbols.

An excellent starting point for the literature on the average autocovariance function is Note 174 in [4]. And for more on cyclostationarity see [1].

References

[1] W.A. Gardner, Ed., *Cyclostationarity in Communications and Signal Processing*, IEEE Press, 1994.

[2] A. Lapidoth, *A Foundation in Digital Communications*, Cambridge University Press, 2009.

[3] A.M. Yaglom, *Correlation Theory of Stationary and Related Random Functions I: Basic Results*, Springer-Verlag, 1986.

[4] A.M. Yaglom, *Correlation Theory of Stationary and Related Random Functions II: Supplementary Notes and References*, Springer-Verlag, 1986.

[5] A.M. Yaglom, "Einstein's 1914 paper on the theory of irregularly fluctuating series of observations," *IEEE ASSP Magazine*, pp. 7–11, Oct. 1987.

[3] For an excellent historical account of this issue, see [5]. (Thank you S. Verdu.)

Treasurer's Corner

Aylin Yener

As most of you know, I have served as the treasurer of our society since January 2012. In this column, I will try to give you a brief overview of the financial matters of our society since then and explain some recent developments that are undertaken by our society. My goal is to provide a short and high level overview for your information, so I promise there will be no boring accounting lingo, and hope that you will find the information interesting and useful.

First a bit of background: Just who or what is a treasurer? He/she is an officer of the society and a member of the Board of Governors who is the interface of the society governance with the IEEE Finance operations. He/she supervises the preparation of the yearly budget of the society with the goal of allocating sufficient funds for the activities to be undertaken by the society, and is responsible of executing and approval of the financial actions of the society. Our yearly operations include the conferences (ISIT and ITWs) we run; publications we have (the IEEE Transactions on Information Theory, and also this newsletter); various committee activities, meetings, the distinguished lecture program, annual awards and so on. Our major source of revenue is from the Transactions, in particular the allocation we receive from downloaded IEEEXplore papers of our Transaction papers. We also have surpluses from conferences, IEEExplore download revenue from conference papers, and a very modest income from the membership fees. IEEE is a huge non-profit organization with a large number of permanent staff and volunteers working together for its operations. The Information Theory Society is a relatively small society within IEEE, and all our society operations are solely run by volunteers including the treasurer. As you can imagine, there is a learning curve once the position starts (IEEE runs a workshop for treasurer's which in my case was three months after I took over), but one learns on the job rather quickly. Additionally, there are a number of wonderful employees at the IEEE headquarters in Piscataway, NJ who help me with the day to day operations related to the financial matters as well as policies, rules and regulations.

Our yearly budget is prepared approximately 5 months before the beginning of the year in a couple of iterations between the treasurer and the IEEE financial analyst designated for our society. The budget is for the calendar year only and at the end of the year, the books are closed which takes about three months to do, so we know the final numbers in March of the following year. It is important not to have a deficit at the end of the year, as having a deficit in consecutive years puts a society on what the IEEE calls the "watch list", scrutinizing its finances until the society gets back on the surplus side with cost cutting. This is clearly not a place to be since it puts serious limitations to society operations.

When I took over, it looked like the previous year was going to close with a (small) deficit, so that meant we had to be rather careful in 2012 with our spending. So, first we looked for places to cut cost, and to obtain our revenues in a timely manner. The latter involved ensuring closing the books from the conferences we ran within the same year, which was accomplished through my constant nagging of the organizers. I am happy to report the conference revenues are now being credited relatively soon after the end of each conference, despite the growing number of the meetings now that we have a number of schools running in addition to ISIT and ITW(s) each year. We also ensure various reimbursements are done in a timely manner so as to ensure not having surprise left over expenses for future years.

So in the end, we managed to get all our operations done and (thanks also to a new agreement IEEE had with a periodical subscription package with India), ended up with a surplus that was beyond our expectations in 2012. This outcome not only ensured we would not be on the watch list the next couple of years, but also allowed us for a new opportunity: IEEE allows new *initiatives*, i.e., spending for new activities that are not in the original budget in the current year that can cost up to 50% of the surplus of the previous year. This rule seemed like a good opportunity for us to have some new activities in 2013. As a result, the board approved and the society implemented the following new initiatives in 2013 thanks to the 2012 surplus funds:

1) The student committee added new initiatives including the now popular "Meet the Shannon Awardee" event;

2) The online committee got a good amount of additional support to improve the web pages infrastructure and provide media content (see for example http://media.itsoc.org/school.html and http://media.itsoc.org/isit.html) and more improvements to come;

3) WITHITS received funding for videos promoting information theory, see http://media.itsoc.org/withits.html .

Our 2013 budget also ended up with a surplus (a more modest one), which allowed us to undertake some new initiatives in 2014.These are the new information theory schools we are supporting in East Asia (Hong Kong), Australia and India, in addition to the North American and European schools that are annually supported.

From the perspective of our own operations, we have always been a conscientious society, run by tireless volunteers with minimal cost and maximum service. So, once we ironed out a couple of wrinkles, the finances were top-notch. This does not mean that everything is rosy though. We are bound by the operations and policies of IEEE and our revenue models are set by the IEEE. In fact, for long term sustainability of the IEEE at large, the revenue models for societies are changing with a model that is being phased in starting with the current 2014 budget year. This essentially means a reduction of our revenues, in particular from IEEEXplore downloads which is our major source of income. We knew this was going to happen, so the Board approved two very important proposals last year which not only had their own merit for our membership, but also ensured the financial health of the society for the next few years. The first one was that the editorial costs of the Transaction papers were reduced considerably by moving to the so called moderate electronic editing from the earlier full editing. The second one was to introduce a tiered registration model for our conferences, the result of which is that for the first time this year, your IEEE *Information Theory Society membership* will get you a better rate than simply being an IEEE member. Another welcome event that is also cost saving was that PAREJA was retired.

So, in closing, I am happy to report that the current financial state of our society is strong. We are supporting worthy activities such as schools, student events, outreach events and distinguished lectures, while simultaneously continuing to publish the Transactions with no fees or page limits imposed on the authors, a rather rare occurrence as compared to other IEEE societies. Our conferences are run with reasonable surpluses and again relatively reasonable registration fees. We are currently working on preparing the 2015 budget, and I expect a smooth-ride from the perspective of our operations.

I hope that you have found this overview useful, and I welcome any comments and questions; you can reach me at yener@ee.psu.edu.

Report on the 2014 European School of Information Theory (ESIT)

Vitaly Skachek

The 2014 European School of Information Theory (ESIT) took place on April 14–18th in Tallinn, Estonia. The school format was similar to that of the previous schools in Ohrid, Macedonia (2013) and Antalya, Turkey (2012). There were 70 participants, including 54 graduate students and early-stage researchers.

This year, the talks emphasized the topics of coding, security and networks. The school featured 3-hour lectures from six experienced researchers on a variety of topics within the field of information and communication theory. There were four poster sessions, in which the students presented their work and interacted with the senior scientists, as well as with the other students.

The participating students and young researchers came from sixteen different countries in Europe. The countries with the largest number of participants were Germany, France and Estonia. The participation of the students and young researchers was financially supported by the IEEE Information Theory Society and the EU program COST Action IC1104 on random network coding and designs over GF(q). In particular, the COST Action awarded travel grants to 24 students. Additional funding was also provided by EXCS—Estonian Center of Excellence in Computer Science.

The school had a number of guests. The list includes Marcus Greferath and Mario Pavcevic, the chair and co-chair of the COST Action IC1104. The school was attended also by Jasper Goseling and Frans Willems, who are organizing ESIT 2015 in the Netherlands.

The school started on Monday, April 14. The morning lecture was given by Bobak Nazer on topics related to physical-layer network coding. In the afternoon, there were two poster sessions, and around 10 student posters were presented at each session. The Tuesday morning lecture was given by Camilla Hollanti on lattices and their use in MIMO communication. In the afternoon, there were another two poster sessions. The morning lecture on Wednesday was given by Yingbin Liang, it covered the topics of information-theoretic security in wireless networks. Two lectures

were given on Thursday. In the morning, Ruediger Urbanke gave a talk on spatially-coupled LDPC codes. In the afternoon, Venkatesan Guruswami spoke about list decoding. The school was concluded on Friday by Yuval Ishai, who spoke about information-theoretically secure multi-party computations.

The social program created opportunities for networking and collaborations among the participants. Multiple events were included in the program, including three informal dinners, one official dinner and one dinner for invited speakers and organizers. A guided walking tour into Tallinn old town took place on Wednesday afternoon.

After the event, many attendants reported their satisfaction both with the organization and with the scientific contents. The team of organizers consisted of Vitaly Skachek, Helger Lipmaa, Dominique Unruh, Sven Laur and Juri Lember from the University of Tartu. The organization benefited from the advisory board that included Gerhard Kramer, Petar Popovski and Deniz Gunduz. The advisory board also included Marcus Greferath and Mario Pavcevic, who greatly helped with issues related to the COST Action support. The local organization in Tallinn was efficiently handled by Kerli Kangro from Tallinn University Conference Center. In Tartu, the project management was handled by Kairit Shor. Special thanks to Ivo Kubjas for taking care of video recording.

The preparations for ESIT 2015 in the Netherlands are under way. We are looking forward to next year's event.

Workshop Report

Beyond IID in information theory, 19–21 May 2014, National University of Singapore, Singapore

Organizers:

Marco Tomamichel (Center for Quantum Technologies, NUS)
Vincent Y. F. Tan (Dept of ECE and Dept of Math, NUS)
Stephanie Wehner (Center for Quantum Technologies, NUS)

A group of approximately 60 classical and quantum information theorists converged to the National University of Singapore on the sunny island of Singapore in mid-May 2014 for the second edition of the *Beyond IID in information theory* workshop. This workshop is a follow-up on the first edition held in Cambridge, U.K. on 8–11 Jan 2013.

Information theory has found a very large range of applications from communications to gambling systems and to physics. However, the use of established information-theoretic techniques such as typicality often relies on the i.i.d. assumption, which demands that certain processes (e.g., the use of a communication channel) can be repeated an arbitrary number of times identically and independently of the other invocations. In order to overcome this limitation, researchers have recently started to devise a more general theory of information--namely, non-asymptotic information theory, which enables the study of arbitrary, structureless settings. Recent topics of interest include explicit one-shot bounds on operational quantities, finite blocklength analysis, second-order coding rates (or dispersion analysis), the information spectrum method, and new techniques to derive strong converses in classical and quantum information theory.

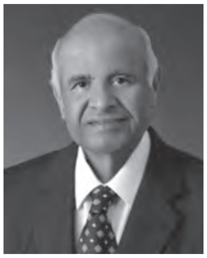
Although this generalized theory is still under development, it has already found a variety of applications, ranging from cryptography and communication theory to thermodynamics and statistical mechanics. The goal of the workshop is to bring together and foster interaction between researchers in the classical and quantum information theory communities who work on various approaches to this general theory of information and their applications. Even though similar results are continually discovered and re-discovered by these communities, the interaction between them has been limited. This workshop provided an ideal convivial setting for interactions.

The main themes that were covered in this workshop included novel achievability and converse techniques leading to good one-shot (finite blocklength) bounds for classical and quantum hypothesis testing and source and channel coding, information-theoretic security, the proper generalization of the Renyi divergence to the quantum setting and second- and higher-order asymptotics. We were pleased to have 26 invited speakers which include 6 distinguished plenary speakers Te Sun Han, Renato Renner, Yaoyun Shi, Sergio Verdu, Mark Wilde, and Andreas Winter.

We acknowledge kind support from the Center for Quantum Technologies, NUS, the Lee Foundation and Swissnex Singapore. The planning for the next edition of Beyond IID workshop is already underway and will be held in Banff in July 2015. We hope to see many attendees in the next edition!

InstaMag BeyondIId 2014, Singapore

IT Society Member Honored



Vijay Bhargava of the University of British Columbia, Vancouver, was this year's recipient of the Canadian Award for Telecommunications Research. This is a career award recognizing distinguished contributions made by an individual in Canada to research in the field of Telecommunications and was made at the 27th Queen's Biennial Symposium on Communications held in Kingston, Ontario during 1–3 June 2014. A long time member of the IT Society, Vijay's current research interest is spectrum and energy efficient design of wireless systems.

Vijay was on the organizing committee of ISIT'83 (St. Jovite, Quebec) and ISIT'95 (Whistler, British Columbia) and ITW 2002 (Bangalore, India). He has served as the President of the IT Society (2000) and of the IEEE Communications Society (2012, 2013). He is a recipient of the IEEE Haraden Pratt Medal "for meritorious service to the Institute, particularly in regional and section activities, and for his efforts to improve relationship with technical and professional organizations worldwide".

GOLOMB'S PUZZLE COLUMN™

Words With Repeated Letters

Solomon W. Golomb

Your challenge this time is more verbal than numerical. For each letter of the alphabet (from A to Z) and for each positive integer *k*, what is the shortest word you can find containing *k* copies of the given letter? (E.g., the word *unusual* contains the letter ***u*** three times.)

You may use any English word listed in a good collegiate dictionary, or, as second choice, familiar geographic names or brand names. Also, if no "normal" word can be found with *k* copies of the given letter, you may use a hyphenated near-reduplication term, like *hocus-pocus* or *wishy-washy*. Finally, if nothing else is available, you may use a familiar word from a foreign expression, such as either word from *sacre bleu* or from *guten Morgen.*

Only a very few letters (e.g. I and S) can be found as many as seven times in a single word. Your words may include endings (or prefixes) that can normally be attached to a given part of speech, e.g. lengthening the verb *vacate* to *vacationing*, or changing the adjective *happy* to *unhappiness.*

You are very likely to find improvements over your first attempts. Good hunting!

President's Column *continued from page 1*

The Annual Meeting of the Society took place on Sunday before ISIT. Among the highlights of this meeting was the presentation by Frank Kschischang of the report from the ad hoc committee on online supplements recommending allowing for peer-reviewed online-only supplementary material to be posted on Xplore together with each IT Transactions paper, entirely at the authors' discretion. Details will be posted in the *Information for Authors.* Muriel Medard presented the final report of the ad hoc committee on future directions. The full report will be published in the Newsletter.

Finally, the next important event of our society is the 2013 Information Theory Workshop, which will be held in Hobart, Tasmania, in November. I hope you enjoy the rest of the summer and please do not hesitate to email me your suggestions and comments at: abbas@ee.stanford.edu.

GOLOMB'S PUZZLE COLUMN™

Counting Necklaces Solutions

Solomon W. Golomb

1) The number of n-bead necklaces in c colors, distinct under cyclic rotation, is

$$\frac{1}{n}\sum_{d|n}\phi(d)\,c^{n/d}$$

where the summation is over all divisors d of n, and $\phi(\cdot)$ is Euler's phi-function.

2) The number of such necklaces which are also distinct relative to *reflection* ("flipping over") is given by

$$\frac{1}{2n}\left(\sum_{d|n}\phi(d)\,c^{n/d}+n\cdot c^{\frac{n+1}{2}}\right)\quad\text{if } n \text{ is odd,}$$

and

$$\frac{1}{2n}\left(\sum_{d|n}\phi(d)\,c^{n/d}+\frac{n}{2}c^{\frac{n}{2}}+\frac{n}{2}c^{\frac{(n+2)}{2}}\right)\quad\text{if } n \text{ is even.}$$

3) The number of necklaces distinct under cyclic rotation with no periodic substructure is

$$\frac{1}{n}\sum_{d|n}\mu(d)\,c^{n/d}$$

where $\mu(\cdot)$ is the Möbius mu-function.

4)

$n\backslash c$	2	3	4	5
4	6	24	70	165
5	8	51	208	629
6	14	130	700	2635
7	20	315	2344	11,165
8	36	834	8230	48,915

TABLE 1. Cyclically distinct n-bead necklaces in c colors.

$n\backslash c$	2	3	4	5
4	6	21	55	120
5	8	39	136	377
6	13	92	430	1505
7	18	198	1300	5895
8	30	498	4135	25,395

TABLE 2. Dihedrally distinct n-bead necklaces in c colors.

$n\backslash c$	2	3	4	5
4	3	18	60	150
5	6	48	204	624
6	9	116	670	2580
7	18	312	2340	11,160
8	30	810	8160	48,750

TABLE 3. Cyclically distinct primitive n-bead necklaces in c colors.

IT Society Mentoring Network: Call For Participation

Do you need advice whether you should postdoc for another year? Do you need someone to help with your first proposal? Do you need someone to talk about whether you should move to this new exciting research direction?

Then you should consider joining the IT Society Mentoring Network. A typical mentor/mentee pairing is a faculty member or professional in industry mentoring a graduate student or postdoc, or a senior faculty or industry researcher mentoring a junior faculty or researcher. We strongly encourage mentees to become also mentors currently or in the future.

A mentor/mentee relationship will be a priori a two year one. A mentor will agree to communicating with his/her mentee roughly a few times per year to provide professional advice and feedback, e.g., by helping the mentee with proposal writing or by introducing him to potential collaborators. The only requirement for our mentoring program is that a mentee should be part of the IEEE IT Society for the duration of the mentoring period. We are also having two mentor/mentee events each year at ITA and ISIT. For example, this year at ISIT 2014 in Honolulu, HI, we had a panel discussion on "How to survive tenure track", followed by our mentoring reception. Also, please check out the success stories below.

Anyone who is interested in joining the mentoring program (as a mentor/mentee or both) is invited to sign up by using the code below which will point to the IT Society website.

Panel discussion organized by the Outreach Subcommittee of the IT Society at ISIT 2014, Honolulu, HI: "How to survive tenure-track".

Jörg Kliewer
Chair IT Society Outreach Subcommittee
(Elza Erkip, Bobak Nazer,
Daniela Tuninetti)

http://goo.gl/kY9pGo

"Daniela's suggestions and support have been quite invaluable for me. How to advise and build rewarding relationships with graduate students, how to sustain a research fund cycle, and how to balance life and work are all universal problems related to academic life. It is very assuring to know that your mentor has also went through similar problems. Following Daniela's example and making use of her experience, it is easier to attack the problems I encounter."

"Melda and I officially became a mentee-mentor pair during the ISIT 2012 ITSoc Mentoring Event in Boston. I already knew Melda from before and was familiar with her PhD work; but what had caught my attention was her work on the interference channel with feedback, a topic very close to my research interests. Having plenty of technical problems to talk about—although not critical for an effective mentee-mentor duo—made it very easy for us establishing a truly personal relationship. We usually talk at technical conferences / workshops where we meet face-to-face, and occasionally via email, on our work and personal life."

Melda Yüksel, Mentee
Daniela Tuninetti, Mentor

"We meet regularly and discuss at conferences. While we do not have a formal mentoring plan, our feeling is that the arrangement is effective. In particular, the mentee feels free to ask questions to the mentor which otherwise he would not have asked had they not been connected via the mentoring program. The match is particularly relevant, given the diversity of academic and funding systems in Europe. The mentee appreciates the advice from his mentor, in particular since it is an independent view from a senior colleague who understands the processes of academia in Europe and our society. Thus, we believe that this program adds value and improves the support received by junior faculty members of the IT society."

Tobias Oechtering, Mentee
Albert Guillén i Fàbregas, Mentor

"The mentee and the mentor have been initially paired when the mentee was a senior grad student. The two have kept contact in person or by email whenever needed, the topics of conversation have appropriately changed over time as the careers have evolved. The meetings are not formal and this has allowed for an exchange that is friendly and cordial that is most beneficial for both parties."

Ayfer Özgür, Mentee
Aylin Yener, Mentor

ITW Jerusalem 2015

2015 IEEE Information Theory Workshop

Jerusalem, ISRAEL | April 26 – May 1

The 2015 IEEE Information Theory Workshop will take place from April 26th until May 1st in Jerusalem, Israel, at the Mishkenot Sha'ananim Conference Center. Jerusalem is one of the oldest cities in the world, a place where ancient history intertwines with the twenty-first century. Located in the Judean Mountains, between the Mediterranean and the Dead Sea, it offers a unique experience for the visitor with relics dating back as far as around 1000 BC, finest museums and breathtaking scenery.

Built over 150 years ago, Mishkenot Sha'ananim became the first Jewish residential area outside the Old City walls. Nowadays it is an alluring place with a conference center that serves as a center of academic inquiry and cultural value, a critical piece of Jerusalem's landscape that reframes the city as a vibrant, dynamic, cultural center of local, national and international appeal.

Call for Papers

Original technical contributions are solicited in all areas of Information Theory with emphasis on innovative and interdisciplinary research related to:

- Information theory and computer science
- Information theory and estimation
- Network information theory
- Codes for special applications

Schedule

Paper submission deadline: Oct. 24th 2014

Acceptance notification: Jan. 10th. 2015

Final paper submission: March 1st. 2015

Plenary Speakers

Plenary lectures will feature leading researchers in the workshop's emphasis areas

Paper Submission

Interested authors are invited to submit previously unpublished contributions. Papers for the contributed sessions, not exceeding five pages, should be submitted according to the directions which will appear on the conference website: **http://itw2015.eew.technion.ac.il**

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Conference Calendar

DATE	CONFERENCE	LOCATION	WEB PAGE	DUE DATE
September 14–17, 2014	**2014 80th Vehicular Technology Conference (VTC2014-Fall)**	Vancouver, Canada	http://www.ieeevtc.org/vtc2014fall/	Passed
October 1–3, 2014	**52nd Annual Allerton Conference on Communication, Control, and Computing**	Monticello, Illinois, USA	http://www.csl.uiuc.edu/allerton/	Passed
October 26–29, 2014	**2014 International Symposium on Information Theory and its Applications (ISITA 2014)**	Melbourne, Australia	http://www.isita.ieice.org/2014/	Passed
November 2–5, 2014	**Asilomar Conference on Signals, Systems, and Computers (ASILOMAR 2014)**	Pacific Grove, CA, USA	http://www.asilomarsscconf.org/	Passed
November 2–5, 2014	**IEEE Information Theory Workshop (ITW 2014)**	Hobart, Tasmania, Australia	http://itw2014.jaist.ac.jp/	Passed
December 3–5, 2014	**IEEE Global Conference on Signal and Information Processing (GlobalSIP 2014)**	Atlanta, Georgia, USA	http://www.ieeeglobalsip.org/	Passed
December 8–12, 2014	**2014 IEEE Global Communications Conference (GLOBECOM 2014)**	Austin, Texas, USA	http://www.ieee-globecom.org/	Passed
April 26–May 1, 2015	**34th IEEE International Conference on Computer Communications (INFOCOM 2015)**	Hong Kong	http://infocom2015.ieee-infocom.org/	Passed
June 8–12, 2015	**IEEE International Conference on Communications (ICC 2015)**	London, United Kingdom	http://icc2015.ieee-icc.org/	September 15, 2014
June 14–19, 2015	**2015 IEEE International Symposium on Information Theory (ISIT 2015)**	Hong Kong	http://www.isit2015.org/	TBA

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