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2001 Shannon Lecture
Constrained Sequences, Crossword Puzzles and Shannon

Jack Keil Wolf
University of California, San Diego and QUALCOMM Incorporated

One-dimensional constrained sequences play an important role in both communication and storage systems. Many interesting constraints exist, e.g., balanced codes, (d,k) codes, etc.

Jack Wolf presenting the 2001 Shannon Lecture in Washington D. C.

Initially we will concentrate on one-dimensional binary (d,k) sequences [1]. These sequences are described by two integers, d and k, 0 ≤ d < k, such that there are at least d and at most k 0's before and after every 1. As an example, … 01010001001010 … is a segment of an allowable (1,3) sequence while … 0110001000010 …is not, due to the violations that are underlined.

There is an abundance of literature on the applications of (d,k) sequences. Among these applications are their use in reducing intersymbol interference and aiding in timing recovery.

Binary (d,k) sequences are obtained from unconstrained binary sequences by encoding. For any valid encoding operation, it is assumed that a decoder will reproduce the original unconstrained binary sequence from an error-free version of the constrained sequence.

The *rate* of the encoder/decoder (i.e., the rate of the code) is defined as the ratio of the number of unconstrained binary digits to the number of constrained binary digits. As an example of a rate ½ code, consider the following encoding rule for a (1,3) code. Insert a 0 between every pair of unconstrained binary digits unless that pair of digits is both 0's in which case insert a 1. Using this rule the unconstrained sequence … 1 1 0 1 0 0 0 …becomes the constrained sequence … 1 0 1 0 0 0 1 0 0 1 0 1 0 … where the inserted binary digits are underlined. Decoding consists of removing the underlined binary digits. This is an example of a *fixed rate* code in that the number of constrained binary digits is always a constant times the number of unconstrained binary digits. It is also an example of a *systematic* code in that the unconstrained binary digits are present in the stream of constrained binary digits.

It is remarkable that Shannon's 1948 paper [2] provided the framework for much of our present understanding of (d,k) sequences even though interest in these sequences did not arise until several years after its publication. The basis for this understanding is the so-called *Shannon capacity*.

The following ideas all come from Shannon's 1948 paper. They apply to a much more general class of constraints than binary (d,k) sequences but here we will restrict our attention to just this special case.

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From the Editor

Lance C. Pérez

This issue of the *IEEE Information Theory Society Newsletter* contains a report on the 2001 International Symposium on Information Theory held in Washington D. C. We are also fortunate to have an article written by this year's Shannon Award winner, Jack Keil Wolf, recounting his Shannon Lecture.

Please help make the Newsletter as interesting and informative as possible by offering suggestions and contributing news. The deadlines for the next few issues are as follows:

Issue	Deadline
December 2001	October 15, 2001
March 2002	January 15, 2002
June 2002	April 15, 2002

Electronic submission, especially in ascii and MS Word formats, is encouraged.

I may be reached at the following address:

Lance C. Pérez
Department of Electrical Engineering
209N Walter Scott Engineering Center
University of Nebraska-Lincoln
Lincoln, NE 68588-0511
Phone: (402)472-6258
Fax: (402)472-4732
Email: lperez@unl.edu

Sincerely,

Lance C. Pérez

Lance C. Pérez

IEEE

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President's Column

President Joachim Hagenauer

Joachim Hagenauer

The first months of my Presidency of the Information Theory Society where overshadowed by the news that Claude Elwood Shannon had passed away on February 14th 2001 at the age of 84. I learned about it while reading the Herald Tribune on a flight back from Portugal. After consulting with Bob Gallager and Dave Forney, I learned that no official funeral procedures were planned, rather the funeral would take place privately within the family. On behalf of the Society I wrote a letter of condolence to Mrs. (Betty) Shannon. The Society received several letters of condolence, including one from the Popov Society and the Russian IEEE. They wrote: "We are sure that Prof. Claude Shannon's name will be written forever with gold letters in the history of modern science and technology." Several eulogies appeared, in the New York Times, CNN and in several European newspapers and magazines which I checked. Some articles oversimplified by calling Shannon "The father of the bit," others were more precise in assessing his achievements. A particularly appealing article was written by Bob Lucky in the IEEE Spectrum Magazine remembering Shannon under the title "When Giants Walked on Earth".

A Memorial was written in the US congressional record containing the words:

"Mr. President, I rise today in memory of Dr. Claude Shannon, a pioneer in the field of modern communications technology. His work provided a major part of the theoretical foundation leading to applications as diverse as digital cell phones, deep space communications and the compact disc… There are only a few authentic geniuses in this world. Dr. Shannon was one and today we remember him for his accomplishments."

Memorial Lectures were held at Bell Labs and I was invited to deliver a Memorial Lecture at the Technical University in Vienna in April. I further gave a report to the Technical Activities Board of the IEEE about our Society which included a eulogy of Shannon. I am sure that many more memorial events were held. The Shannon Statue commissioned by the IT Society under the guidance of David Neuhoff turned out to be a real success: In addition to Gaylord, Michigan, Shannon's home town, copies are or were about to be unveiled at places such as Bell Labs, Shannon Labs, UCSD and others. At the Board of Governors meeting in Baltimore and at the beginning of the Shannon Lecture at ISIT 2001 in Washington we observed a minute of silence in honor of the founder of Information Theory. On short notice the organizers of ISIT included a commemorative session at the beginning of our Symposium, during which Bob Gallager, Neil Sloane and Jim Massey remembered Shannon. I asked our historian Tony Ephremides to write a commemorative article in the ITSOC Newsletter. But the most vivid memory of Claude Shannon is that his ideas continue to inspire new research. This was evident in the Shannon Lecture delivered by the 2001 Shannon Award winner Jack Wolf and during sessions like "Channels with side information" chaired by Tom Cover. It is clear that Shannon's legacy is very much alive.

Another major event in 2000/2001 was a financial crisis for IEEE Corporate which had planned its budget counting on a substantial return from the stock market. Since this return did not materialize, the core unit's deficit had to be covered by 12% contributions from the reserves of all the IEEE societies. At the TAB meetings I attended and in the follow-up emails this resulted in several discussions and criticisms among the Presidents of the various societies. There was not much to do about it in 2000 and 2001 since the societies are bound to the parent organization IEEE. However, measures to cut expenses at the headquarters and central services were implemented to come up with a balanced budget in 2002 for the central IEEE and for the Societies. Unfortunately, our Society had to increase the IT membership fee, which had been kept stable for many years, to $30. The Board of Governors voted overwhelmingly to approve this measure particularly since we will now publish the IT Transactions with 12 issues instead of 6 plus 1.

We had to change on fairly short notice the newsletter editorship because the previous editor changed from her university to an industry position and could not continue as editor. This caused some delay in the preparation and mailing of the newsletter, as you surely noticed. Fortunately, Lance C. Pérez from the University of Nebraska stepped in as our new Newsletter editor. He is doing a great job and later this year the newsletter will be back on schedule.

Nevertheless, our Society is in good shape: Our membership grew by 4.7% last year, which is three times the average IEEE growth rate, several new Chapters have been formed, the frequency of the Transactions and of the Symposia has been increased and, as I said, "The legacy of Shannon is very much alive".

2001 Shannon Lecture
Constrained Sequences, Crossword Puzzles and Shannon

continued from page 1

Let N(n) denote the number of distinct binary (d,k) sequences of length n. Then for every d and k where $0 \le d < k$,

$$C_1 = \lim_{n \to \infty} \frac{\log[N(n)]}{n}$$

exists and is called the Shannon capacity of the constraint. Assuming that the logarithm is taken to the base 2, the Shannon capacity gives an achievable upper bound to the rate of any encoder that converts unconstrained binary digits to decodable (d,k) constrained binary digits. The assumption of base 2 logarithms will be made throughout this paper.

In his papefrom, Shannon gave two related methods for obtaining numerical values for C1. Applying the first method to (d,k) sequences, one writes a difference equation for N′(n), the number of (d,k) sequences of length n that end in a 1. N′(n) then is used in place of N(n) in the formula for C_1.

For k finite, this difference equation is:

$$N'(n)=N'(n-(d+1))+ N'(n-(d+2))+ \ldots +N'(n-(k+1)),$$

since all of the distinct sequences of length n ending in a 1 can be obtained by taking all of the distinct sequences of length (n-(j+1)), j = d, d+1, …k, that end in a 1 and appending a suffix made up of j 0's followed by a 1.

Shannon explained how to solve this difference equation to obtain the capacity, C_1. Applying Shannon's method to the above difference equation, one finds that C_1 is equal to the logarithm of the largest real root of the equation:

$$x^{k+2} - x^{k+1} - x^{k-d+1} + 1 = 0.$$

For the (1,2) constraint, the largest real root of this equation is approximately 1.3247 and its logarithm is approximately 0.4057.

The second method described by Shannon is to draw a lossless directed graph that generates the constrained sequences. Then C_1 is equal to the largest eigenvalue of the adjacency matrix of this graph. The graph for the (1,2) constraint is shown in Figure 1.

The adjacency matrix of this graph is:

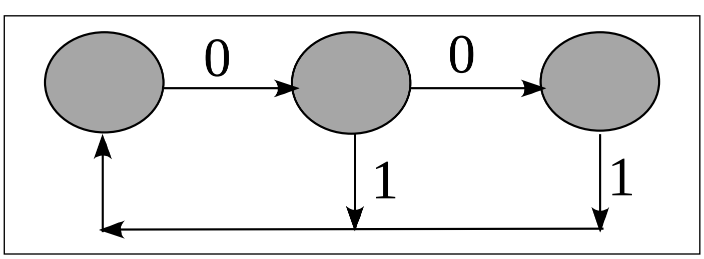

Figure 1 Directed graph for generating (1,2) sequences.

$$\begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 1 \\ 1 & 0 & 0 \end{bmatrix}.$$

The largest eigenvalue of this matrix is approximately 1.3247 and its logarithm is approximately 0.4057.

There exists a very simple encoding rule to convert i.i.d., equally probable, binary digits to (1,2) constrained binary digits with average rate 0.4. This average rate is 98.6% of the Shannon capacity. However, the code is a variable rate code in that the ratio of unconstrained binary digits to constrained binary digits depends upon the specific unconstrained binary sequence to be encoded. The encoding rule is: encode an unconstrained 0 as 01 and encode an unconstrained 1 as 001. Note that although the average rate of this encoder/decoder is 0.4, its minimum rate is 0.333, and its maximum rate is 0.5.

This completes our discussion of 1-dimensional constrained sequences.

Coding theorists have recently become interested in 2-dimensional constrained binary codes: i.e., constrained binary arrays where the binary digits are arranged in an array of rows and columns. Such codes might have application in page oriented storage systems. Although many interesting constraints can be envisioned, we will use as an example, a 2-dimensional (d,k) constraint where every row and every column satisfies a 1-dimensional (d,k) constraint.

A portion of a 2-dimensional (1,2) array is given below:

```
. . . 0 1 0 0 1 0 1 0 0 1 0 0 1 . . .
. . . 1 0 0 1 0 1 0 0 1 0 0 1 0 . . .
. . . 0 0 1 0 1 0 0 1 0 0 1 0 1 . . .
. . . 0 1 0 1 0 0 1 0 0 1 0 1 0 . . .
. . . 1 0 1 0 0 1 0 0 1 0 1 0 1 . . .
. . .
```

Note that the first row satisfies the (1,2) constraint and that the j-th row was obtained by sliding the (j-1)-st row one binary digit to the left for j=2, 3, …

To obtain the Shannon capacity for a 2-dimensional (d,k) array, C_2, we first count N(m,n), the number of arrays with m rows and n columns that satisfy the (d,k) row and column constraints. Then:

$$C_2 = \lim_{m,n \to \infty,\infty} \frac{\log[N(m,n)]}{mn}$$

It is known that C_2 exists for all values of (d,k) but the exact value of C_2 is unknown except for the cases where $C_2 = 0$ or $C_2 = 1$. Kato and Zeger [3] have shown that for all $0 \le d < k$, $C_2 = 0$ if, and only if, k=d+1 and d > 0.

Note that if $C_2 > 0$, N(m,n) grows exponentially in the product mn. Conversely if $C_2 = 0$, the growth in N(m,n) is slower than exponential in the product mn. However, C2 = 0 does not necessarily imply that N(m,n) = 0.

Although Shannon's 1948 paper does not give us a method for computing C_2, it does contain a brief discussion of 2-dimensional and higher-dimensional crossword puzzles which can be considered types of constrained arrays. In particular, the paper states in part:

> "The ratio of the entropy of a source to the maximum value it could have while still restricted to the same symbols will be called the *relative entropy*. One minus the relative entropy is the *redundancy*."
>
> "The redundancy of a language is related to the existence of crossword puzzles. If the redundancy is zero any sequence of letters is a reasonable text in the language and any two dimensional array of letters forms a crossword puzzle. If the redundancy is too high the language imposes too many constraints for large crossword puzzles to be possible. A more detailed analysis shows that if we assume the constraints imposed by the language are of a rather chaotic and random nature, large crossword puzzles are just possible when the redundancy is 50%. If the redundancy is 33%, three dimensional crossword puzzles should be possible, etc."

We next set about interpreting Shannon's statements and constructing a plausibility argument for his conclusions. It should be realized that these are just guesses as to what Shannon had in mind although they have been verified somewhat in a private correspondence from Edgar Gilbert [4] who reported that he discussed this matter with Shannon.

We first conjecture that what Shannon meant when he stated that large crossword puzzles were not "possible" was that the growth in the number of these puzzles was slower than exponential in the area or the volume. This is equivalent to the statement that the Shannon capacity is equal to 0 in those cases.

Next, we set about estimating the entropy of the language for crossword puzzles as they appear in American newspapers and magazines. To do this we need to describe a set of rules for allowable crossword puzzles. We realize that the following set of rules is not complete but we hope that they capture the essence of the constraints. The rules are based upon the fact that every row and every column consists of isolated words separated by one or more black squares and in American crossword puzzles every letter is contained in two words—a row word and a column word. In the following, we refer to a black square as a space.

Rule 1. A 2-dimensional crossword puzzle is a square array with n rows and n columns where each element in the array is from an alphabet of 27 symbols — 26 letters and a space.

Rule 2. Each row and each column consists of an arbitrary sequence of words from a dictionary of allowable words, adjacent words separated by one or more black spaces.

Now we attempt to estimate the redundancy of the language consistent with these rules. In a very interesting paper [5], Shannon estimated the per-letter entropy of English text. This is not the correct entropy to use in crossword puzzles since English text follows a much more complicated set of rules that involves interdependencies between words. However, in this paper Shannon estimated the per-letter entropy of isolated English words using a model of the relative frequency of words as they appear in English text called Zipf's law [6]. This estimate of the per-letter entropy corresponds to a redundancy of 55% which suggests that large 2-dimensional crossword puzzles are not possible.

However, there is no reason to believe that Zipf's law applies to the usage of words in crossword puzzles. Another frequency distribution could give a very different estimate for the redundancy.

To estimate the redundancy for crossword puzzles, we first write a difference equation for the number of sequences of length n that satisfy the row and column constraints. In a manner very similar to what was done for 1-dimensional (d,k) sequences, we denote by $N'(n)$, the number of such sequences that end in one or more spaces. Then the difference equation for $N'(n)$ is:

$$N'(n) = N'(n-1)+a_1 N'(n-2) +a_2 N'(n-3)+\ldots+a_L N'(n-(L+1)),$$

where a_j is the number of words of length j and L is the maximum length of an allowable word. The term $N'(n-1)$ is due to the fact that spaces can follow each other. The per-letter entropy of the language then is given as:

$$H = \lim_{n \to \infty} \frac{\log\left[N'(n)\right]}{n}.$$

Edgar Gilbert [3], many years ago, motivated by Shannon's assertions, estimated the entropy by counting the number of words of length j in two different dictionaries. Using the larger of these dictionaries, and eliminating words of length 1 and 2, Gilbert estimated the per-letter entropy as 2.78 bits. Dividing by $\log_2(27)$, one obtains the relative entropy as 0.585 which corresponds to a redundancy of 41.5%. Thus, according to Gilbert's calculations and Shannon's predictions, large 2-dimensional crossword puzzles would be possible but large 3-dimensional crossword puzzles would not be possible.

Paul Siegel and I [7] have previously given a plausibility argument for Shannon's assertions on the existence of large 2- and 3-dimensional crossword puzzles. Here a similar argument is presented to investigate the existence of a new type of 2-dimensional crossword puzzle. These puzzles have words and spaces in rows, columns <u>and</u> <u>diagonals</u>. The only diagonals considered go from left to right and start in the top row. To make all diagonals the same length, when a diagonal reaches the last column it wraps around and continues in the first column. A simple 3-by-3 example of such a puzzle with no spaces follows:

P	E	T
E	R	R
G	A	Y

The words used are:

Rows	Columns	Diagonals
PET	PEG	PRY
ERR	ERA	ERG
GAY	TRY	TEA

The plausibility argument as to the existence of large 2-dimensional crossword puzzles of this type goes as follows:

1. Begin with 27^{n^2} candidate puzzles.
2. There are N(n) acceptable sequences of length n.
3. The probability that any row, column or diagonal of a candidate puzzle is an acceptable sequence is $N(n)/(27)^n$.
4. Translating the assumption of "chaotic and random" into an assumption of statistical independence, the probability that all n rows, all n columns, and all n -45° (cyclic) diagonals satisfy the constraint is:
$$\left[\frac{N(n)}{27^n}\right]^{3n} = \frac{N(n)^{3n}}{27^{3n^2}}.$$
5. The expected number of puzzles satisfying the constraint is then:
$$\left(27^{n^2}\right)\left[\frac{N(n)^{3n}}{27^{3n^2}}\right] = \left[\frac{N(n)^{3n}}{27^{2n^2}}\right].$$
6. For large n, N(n) is approximately 2^{nH}. Also, $27=2^{\log(27)}$. Then, the expected number of puzzles satisfying the constraint is:
$$\frac{2^{3Hn^2}}{2^{2\log(27)n^2}} = 2^{(3H-2\log(27))n^2}.$$
7. Thus, for large n, the expected number of puzzles that satisfies the constraints grows exponentially with n^2 as n approaches infinity if
$$H/\log(27) > 2/3,$$
or equivalently if the redundancy is less than 33.3%.

The plausibility argument to verify Shannon's conclusions for ordinary 2-dimensional and 3-dimensional crossword puzzles (without constraints on diagonals) is very similar. The main changes are for the 2-dimensional case:

4. … the probability that all n rows and all n columns, satisfy the constraint is:
$$\left[\frac{N(n)}{27^n}\right]^{2n} = \frac{N(n)^{2n}}{27^{2n^2}}$$
6. … the expected number of puzzles … is:
$$H/\log(27) > 1/2,$$
7. … grows exponentially with n^2 as n approaches infinity if
$$H/\log(27) > 1/2,$$

or equivalently if the redundancy is less than 50%.

The main changes for the 3-dimensional case are:

1. Begin with 27^{n^3} candidate puzzles.
4. … the probability …is:
$$\left[\frac{N(n)}{27^n}\right]^{3n^2} = \frac{N(n)^{3n^2}}{27^{3n^3}}$$
6. … the expected number of puzzles … is:
$$\frac{2^{3Hn^3}}{2^{2\log(27)n^3}} = 2^{(3H-2\log(27))n^3}$$
7. … grows exponentially with n^3 as n approaches infinity if
$$H/\log(27) > 2/3,$$
or equivalently if the redundancy is less than 33.3%.

Note that the bound on the redundancy for 2-dimensional crossword puzzles with diagonals is the same as the bound for 3-dimensional crossword puzzles without diagonals. However, the assumption of statistical independence is probably on shakier grounds for the former.

We now return to 2-dimensional constraints on just rows and columns where the critical value of redundancy was 50% and ask the following:

Question. Does Shannon's result on 2-dimensional crossword puzzles predict the cases where the capacity of 2-dimensional (d,k) arrays is equal to or not equal to 0?

The answer to this question is both yes and no. It does predict all of the cases where the capacity is equal to 0 but it fails on some of the cases where the capacity is non-zero. First consider the case of the 2-dimensional (1,2) constraint on rows and columns. The relative entropy of the (1,2) constraints is .4057. Thus, the redundancy is 59.4%. Ignoring the fact that the (1,2) constraint may not be chaotic and random, Shannon's redundancy requirement predicts that $C_2=0$ for this constraint. And it is!

The only other cases where the 2-dimensional capacity is equal to 0 are: k=d+1, d>1. In each such case the redundancy is greater than 50% and Shannon's result predicts the correct answer.

However, the 1-dimensional (2,4) constraint has the same Shannon capacity as the 1-dimensional (1,2) constraint. This can be seen by noting that there exists a one-to-one relationship between the code words for the two constraints. For example, if one starts with a sequence that satisfies the (2,4) constraint, such as

… 1 0 0 <u>1 0 0 0</u> <u>1 0 0 0 0</u> 1 0 0 <u>1 0 0 0</u> 1 …

and if in every run of 3 or 4 0's one changes the second 0 to a 1, one obtains a sequence that satisfies the (1,2) constraint which for this example is:

… 1 0 0 <u>1 0 1 0</u> <u>1 0 1 0 0</u> 1 0 0 <u>1 0 1 0</u> 1 …

Furthermore, one can reverse the process and begin with sequences that satisfy the (1,2) constraint and convert them to sequences that satisfy the (2,4) constraint.

Thus, the redundancy of the (2,4) constraint is also 59.4% (the same as the (1,2) constraint) but the 2-dimensional capacity of the (2,4) constraint is strictly greater than 0. This follows from the result of Kato and Zeger or can be seen from the following construction.

Consider a binary 2-dimensional array of the form:

P1,1 P1,2 P1,3 P1,4 P1,5 P1,6 . . .
P2,1 P2,2 P2,3 P2,4 P2,5 P2,6 . . .
P3,1 P3,2 P3,3 P3,4 P3,5 P3,6 . . .
. . .

where each $P_{i,j}$ is one of the two 4-by-4 sub-matrices:

$$P_0 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad P_1 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix}.$$

Note that if either P_0 or P_1 is substituted for each $P_{i,j}$, the (2,4) constraint is satisfied for every row and every column. Such a construction shows that the 2-dimensional capacity is non-zero since each $P_{i,j}$ can represent 1 bit of information.

The non-applicability of Shannon's assertions to 2-dimensional (d,k) constrained arrays could be due to the fact that the constraints are not sufficiently random and chaotic. Other possibilities exist, but are beyond the scope of this discussion.

We now return to the discussion of crossword puzzles. We have found several constructions for 3- and higher-dimensional crossword puzzles that have non-zero rate. All of these constructions, however, violate the spirit of what would be considered an acceptable crossword puzzle.

One of these constructions follows. We begin with two 3-by-3-by-3, 3-dimensional crossword puzzles:

P O P	E R A	G E L
A L A	R A T	E R E
P E T	E Y E	T E A

and

S O P	A R E	W E D
A N A	G A Y	E Y E
P E T	O W E	T E N

each made up of 3-letter words in rows, columns and in the depth dimension. The words in the depth dimension should be read from left to right. All words in both 3-by-3-by-3 crossword puzzles are listed as acceptable words in an on-line scrabble dictionary of 3-letter words [8]. We then embed these 3-by- 3-by-3 crossword puzzles into 4-by-4-by-4 cubes with spaces filling the back, right and bottom face. Using a procedure very similar to the construction for 2-dimensional (2,4) codes, we can pack 3-dimensional space by using these two cubes in any order. Every row, column, and depth dimension will satisfy our specification for allowable crossword puzzles. The construction has non-zero rate since each cube can be used to carry one bit of information. Note that only a very small subset of allowable words is used and furthermore every 4^{th} row, column or depth dimension will be all spaces. Less interesting crossword puzzles (containing only 2 words) were used to construct higher-dimensional crossword puzzles of non-zero rate.

Jack Wolf being recognized as the 2001 Shannon Lecturer by the IT Society.

These constructions probably should not be allowed in that they do not produce puzzles that would be acceptable to even the most liberal crossword puzzle enthusiast. Furthermore, they do not reflect the redundancy estimated by Gilbert. Finally, they do not satisfy the random and chaotic assumption of Shannon. Thus, Shannon's assertions should not be applied to them.

The curious reader may be interested in a modified plausibility argument for Shannon's assertions which leads to a slightly different normalization for the relative entropy [7].

Acknowledgements

Most of this work was done jointly with my friend and colleague Paul Siegel. I am greatly indebted to him for his permission to report on it here. I am also indebted to my many other colleagues with whom I have collaborated during my career. Finally, I wish to thank all of my past and present students who have taught me most of what I know.

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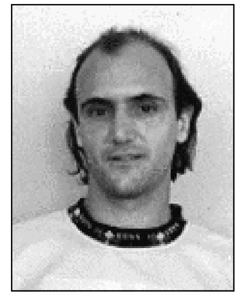
Information Theory Society Membership Fee Increased

Marc Fossorier, IT Society Treasurer

As anticipated in the treasurer report published in the December 2000 Information Theory Society Newsletter (ITSN), the poor status of the stock market during the year 2000 has had a catastrophic impact on the finance of the core IEEE (due to their too optimistic budget relying heavily on investment returns). Consequently, the core IEEE has had no other alternative than withdrawing money from all Societies reserves in order to cover this deficit. As a result, an amount of $164,900 was withdrawn from our Society reserves in 2000 and an additional amount of $250,000 has been budgeted for 2001 (so a total of about 28% of our end-of-year 2000 Society reserves). The main reason given by IEEE to justify this action was the important costs related to the upgrading and development of its infrastructure (especially web-related developments). While Societies directly benefit from these developments, their costs had been covered entirely by the core IEEE up to this year (mostly made possible by the investment returns higher than that budgeted by the core IEEE).

In addition to these withdrawals from Societies' reserves, IEEE also recommended that our Society raise its membership dues from $15 to $30 for members and from $445 to $520 for non-members (such as libraries). For the past few years, our Society has been discarding such recommendations from IEEE and was able to do so also mostly because of the returns on its long term investments (made by IEEE on behalf of our Society, since Societies decide in which ratio their assets are divided between cash available and long term investments, but have no input about the means of investing their money, which is entirely controlled by IEEE). However, our Society has also been very dynamic with many initiatives (see December 2000 ITSN), the most costly having been the development of its digital library (over $ 250,000) which can now be accessed freely by all members. Furthermore, starting in 2002, the number of regular issues of our Transactions will double (from six to twelve issues).



Marc Fossorier

Consequently, in June 2001, the Board of Governors voted overwhelmingly in favor to follow IEEE membership price recommendations for the year 2002.

2001 IEEE International Symposium on Information Theory

Omni Shoreham, Washington, DC, USA
24-29 June 2001

Thomas E. Fuja

The 2001 International Symposium on Information Theory (ISIT) was held June 24-29 at the Omni Shoreham Hotel in Washington, DC. In attendance were more than 650 registrants who took the opportunity to visit the American capital while enjoying a technical program that included almost 350 submitted papers, plenary talks spanning the breadth of information theory, and a delightful Shannon Lecture.

The 2001 ISIT began on a contemplative note Sunday afternoon with a one-hour commemorative session recalling the life of Claude E. Shannon, the founder of information theory who passed away February 24, 2001. Three invited speakers discussed Shannon's legacy; Robert Gallager (recently retired from MIT), Neil Sloan (of AT&T Shannon Lab), and Jim Massey (recently retired from ETH in Zurich) discussed the profound and fundamental contributions that Shannon made to the emerging information age, while at the same time sharing with the audience observations on the way Shannon worked and the way he encouraged and inspired those around him.

A traditional highlight of each Symposium is the Shannon Lecture, a talk given by that year's recipient of the Shannon Award, the Society's highest honor. The 2001 Shannon Award winner was Prof. Jack K. Wolf of the University of California at San Diego, and his Shannon Lecture was entitled "Constrained Sequences, Crossword Puzzles, and Shannon." In his lecture, Prof. Wolf referred to some cryptic statements made by Shannon regarding the existence of crossword puzzles and the redundancy of English – comments that Wolf and his colleagues fleshed out and that Wolf related to the problem of designing codes for constrained two-dimensional storage channels. Prof. Wolf's Shannon Lecture was a charming combination of remembrances – in particular, Wolf's encounter with Claude Shannon in the wee hours before Shannon gave the inaugural Shannon Lecture in 1973 in Ashkelon, Israel – together with an insightful exposition of a technical problem that could be appreciated by anyone who's ever attempted a NY Times crossword puzzle.

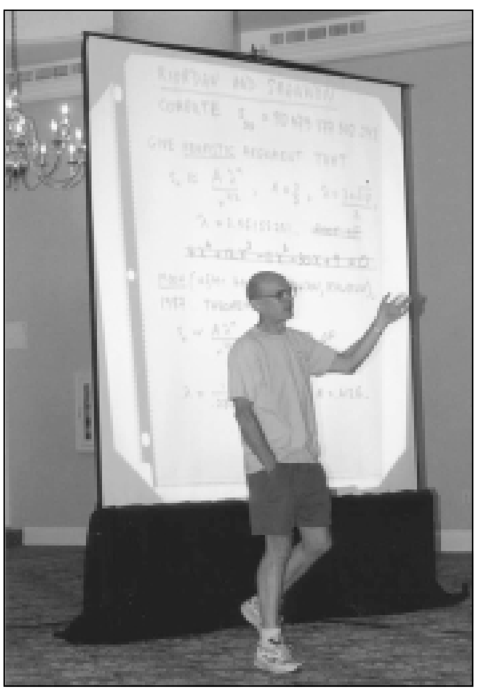
Professor Robert G. Gallager shares his memories of Claude E. Shannon during a special session at the 2001 ISIT

Also memorable were the four plenary lectures, one delivered each morning before the contributed sessions began:

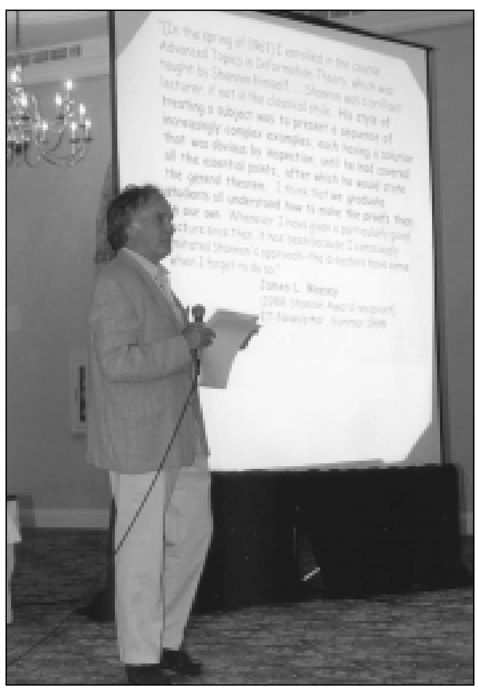
- On Monday, June 25, Prof. Bob McEliece of the California Institute of Technology spoke on "The Effectiveness of Turbo-like Codes on Non-Standard Channel Models."
- One Tuesday, June 26, Prof. Michael Rabin of Harvard University discussed recent work on "Information Theoretic Everlasting Encryption."

Professor Robert J. McEliece of the California Institute of Technology presents his plenary lecture at the 2001 ISIT.

- On Wednesday, June 27, Prof. Benjamin Weiss of Hebrew University regaled listeners about the state of "The Happy Marriage of Information and Ergodic Theory."
- And on Friday, June 29, Prof. Fred Jelinek of Johns Hopkins University reported on "Aspects of the Statistical Approach to Speech Recognition."



Neil J. A. Sloane, of the AT&T Shannon Lab, discusses the contributions of Claude E. Shannon.



James L. Massey entertains the 2001 ISIT audience with recollections of his interactions with Claude E. Shannon.

At the heart of any ISIT are the contributed technical sessions. ISIT 2001 had six parallel sessions every day; the 346 contributed papers were drawn from more than 560 submissions, and they covered the gamut of "wide sense" information theory, from channel coding in all its manifestations to compression, Shannon theory, cryptography, CDMA, estimation, computer networks, synchronization, and signal processing. Particularly well attended this year were the sessions on iterative decoding and related topics (e.g., turbo and low-density parity check codes) as well as space-time coding.

As is tradition, there were no sessions scheduled for Wednesday afternoon, giving the attendees a chance to see the sights of the host city. The ISIT organizers led all interested participants in a walk (and subway ride) to the national mall, the expanse of green stretching from the US Capitol to the White House and the Lincoln Memorial. Once there, ISIT participants spread

IT Society President Joachim Hagenauer presents Jack K. Wolf of the University of California, San Diego, with the 2001 Information Theory Society Shannon Award.

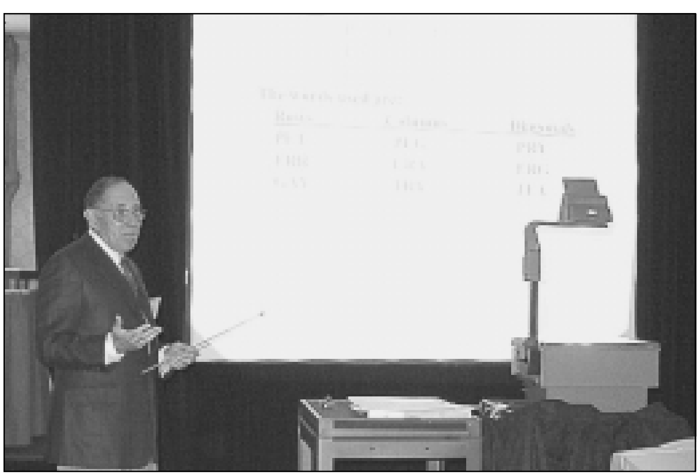
Prakash Narayan and Thomas E. Fuja, 2001 ISIT co-chairs, have a discussion with plenary speaker Benjamin Weiss of Hebrew University.

out in all directions – from the Smithsonian buildings to the National Holocaust Museum to the Washington Monument and beyond.

As part of the companions' program, bus tours of Washington DC as well as Alexandria and Mount Vernon (the home of George Washington) were arranged on Tuesday and Thursday.

The ISIT attendees came together as a group for two meals during the week.

- An Awards Luncheon was held on Tuesday, at which time the 2001 Shannon Award was given to Jack Wolf and the 2000 Prize Paper Award was given to Venkatesan Guruswami and Madhu Sudan for their paper "Improved Decoding of Reed-Solomon and Algebraic-Geometry Codes." In addition, numerous certificates of appreciation were given to outgoing volunteers, and Joel Snyder, President of the IEEE, was on hand to give IT Society member H. Vincent Poor the 2001 IEEE Graduate Teaching Award.
- The banquet was held Thursday evening in the Blue Room of the Omni Shoreham hotel. It was at that time that the organizers of the 2001 Symposium were recognized and the organizers of the 2002 Symposium (represented by co-chair Bixio Rimoldi) invited everyone to Lausanne, Switzerland for the next ISIT. Finally, it was at the end of the banquet that IT Society President Joachim Hagenauer announced the recipient of the 2002 Shannon Award – Prof. Toby Berger, of Cornell University.



Professor Jack K. Wolf presents his Shannon Lecture entitled "Constrained Sequences, Crossword Puzzles, and Shannon."

Venkatesan Guruswami receives the 2001 Information Theory Prize Paper Award for his paper "Improved Decoding of Reed-Solomon and Algebraic-Geometry Codes," co-authored with Madhu Sudan.

The 2001 ISIT concluded Friday afternoon with a luncheon reception that gave the attendees another chance to touch bases with their colleagues before dispersing throughout the world.

The co-chairs of the 2001 International Symposium on Information Theory were Prakash Narayan of the University of Maryland and Tom Fuja of the University of Notre Dame. Adrian Papamarcou of the University of Maryland was in charge of local arrangements. Chairing the technical program committee were Neri Merhav and Shlomo Shamai, both of the Technion.

Historian's Column

A. Ephremides

I have written before about the infamous Irwin Feerst. As many of you know (or recall), he was a feisty IEEE member who campaigned often for the Presidency of the Institute (and, once, came dangerously close to winning it). He was the ultimate populist whose main stance on almost everything was that IEEE should be an organization of (and for) "working" U.S. engineers and not of (or for) intellectuals, scientists, or ... "foreigners". Ordinarily he would command as much attention as a buffoon, but as he came close to rising to the top management position of the Institute, he posed enough of a threat to receive an inordinate amount of attention. The peak period of his activity was the 70s and the 80s.

Our Society was a frequent target of his. He singled us out as anathema to what he thought IEEE ought to be. The organizers of the 1977 ISIT in Ithaca had the bright idea to invite him for a debate with his opponent Ivan Getting (both were candidates for IEEE President) at the Symposium. I reported before briefly about that memorable event but my memory was refreshed recently as I was perusing old issues of our newsletter (that date from the era of Lalit Bahl's inimitable editorship).

A. Ephremides

So, during that debate, Irwin was challenged by several of our members who either asked him tough questions or reacted to his answers. Aaron Wyner was the first one to ask the following question: "Mr. Feerst, you have made some very disparaging remarks about the *IT Transactions* in your newsletter" (author's note: Feerst used to publish a notorious newsletter, more on which a bit later). I quote: 'Many of IEEE's publications have taken on the aspect of a modern sewage plant — a lot of crap hidden behind a pretentious exterior. These include *Spectrum*, the *Transaction on Information Theory*, *Transactions on Antennas and Propagation*, and *Transactions on Electronics in Medicine and Biology*. We must change the management of these periodicals and present papers written by working EEs for working EEs'. Would you care to comment?" The answer was: "The *IT Transactions* are indeed full of crap. Most of the papers are written by academics and foreigners (author's note: remarkable pairing of categories). There is nothing in there for working engineers like me". And he concluded with the famous quotation: "In fact, I can't even tell if I've got it right side up or upside down." There was pandemonium in the audience with catcalls and individual utterances like: "Maybe we should charge him double" or "If you think our Transactions are full of crap, you should read our newsletter."

As the reaction subsided, Lee Davisson followed up with: "Since the Transactions are self-supporting, if we want to publish crap, then we should publish crap." To which Feerst replied: "I am glad you brought that up, I have ...", at which point Fred Jelinek intervened with: "Could you speak a little softer or move the mike a little further away?" Feerst complied and continued: "I have here in my hand document S3437 (author's note: no clarification about what kind of document that may be) which shows that the average cost of printing a technical journal is about $131 per copy. So, your $8 (of dues) doesn't go a helluva long way towards paying for the Transactions." Amidst new catcalls the following was overheard: "I told you we should charge him double." Dave Forney politely remarked that the Transactions are supported by page charges and library subscriptions. Marty Hellman wondered aloud: "The IEEE has about 180,000 members. Assuming that the average member gets 9 issues of IEEE journals per year, the total cost exceeds 200 million dollars. Where on earth do we get this money?" And Jim Massey concluded with "The reason that the Transactions look the same upside down or right-side up to Irwin Feerst is because we use the binary system!"

The session went on pretty much in the same vein and, as is evident from the above sample, it achieved high levels of entertainment value.

To be fair, however, we must grant Mr. Feerst that he was not wrong on all counts. Among his targets were some truly objectionable practices by the top IEEE brass which unfortunately persist even today. Generally speaking, these have to

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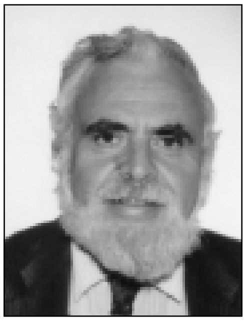
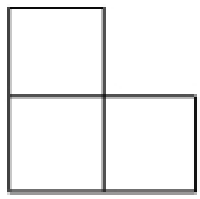
TILINGS WITH RIGHT TROMINOES

–Solomon W. Golomb



A "right tromino" is the shape formed by three quadrants of a 2×2 square:



1. Show that no matter where a single "monomino" (1×1square) is removed from a 2n×2n "board", the rest can be *tiled* (covered exactly, with no gaps and no overlaps) by right trominoes. (*Hint:* Try mathematical induction.)

2. Where can (and where cannot) a monomino be removed from a 5×5 "board" so that the rest can be tiled with right trominoes?

3. Where can (and where cannot) a "domino" (1×2 square) be removed from a 5×7 "board" so that the rest can be tiled with right trominoes?

4. Where can (and where cannot) a monomino be removed from a 7×7 "board" so that the rest can be tiled with right trominoes?

5. Suppose $m > 7$ and m is not a multiple of 3. Show that a monomino can be removed from anywhere on an $m \times m$ board and the rest can then be tiled with right trominoes.

6. What are the values of a and b (both positive integers) such that the entire $a \times b$ board can be tiled with right trominoes?

(Clearly the product ab must be divisible by 3, but this necessary condition is not sufficient.)

do with the use of IEEE funds for ventures by some individuals that are of dubious value and merit. For example, in the late seventies, the early years of the China-U.S. "rapprochement," there were many eager intrepid travelers from within the top ranks of IEEE management who wanted to visit China (in the name of cultivating bilateral technical contacts). In addition to the basic question of whether these ventures were planned properly, there were also questions of style and form. Take a look, for example, at a news release from *the Institute* entitled "IEEE delegation will visit mainland China." It started by saying (note the grammar and syntax): "There will be ten delegates from the Institute who will visit the People's Republic of China as well as their wives"(!!) A follow-up from that trip surfaced in Irwin Feerst's newsletter a few months later. It quoted from the publication Optical Spectra (p. 43 of the 12/77 issue) that was reporting on the trip headed by IEEE President Robert Saunders that read "The IEEE chief (sic), who is a Professor of Electrical Engineering at the University of California, Irvine, recently returned from a three-week visit to mainland China. A ten-member IEEE delegation found many technical areas lagging behind, but noted a rapid change in the rate of progress." Again, note the "quality" of the writing. In any event, Feerst's commentary was: "Naturally our curiosity was aroused as to who paid for this trip. We wrote to Robert Briskman, IEEE's perpetual Secretary-Treasurer to ask him. Briskman's straightforward reply was "I assumed you knew that the type of information requested is not normally furnished." Marvelous. Super. So, now, we ordinary working EEs are not permitted to know too much about IEEE's finances. But we are, of course, expected to pay our dues. Sounds as though Saunders and his entourage ate their two favorite dishes while in China –- "You Pay Dough and You know Zilch"!

Apart from the crass style and the offensive (to our Chinese colleagues) use of phonetics, there was a point in Feerst's fierce protest. And as recent financial woes of the IEEE demonstrate, the same type of misfeasance and malfeasance at the top of the Institute may very well persist and survive even today.

ISCTA'01: Sixth International Symposium on Communication Theory and Applications

St Martin's College, Ambleside, Lake District, UK
15-20 July 2001

Paddy Farrell

The sixth International Symposium on Communication Theory and Applications was held at St Martin's College, Ambleside, in the English Lake District, from Sunday 15th until Friday 20th July, 2001. The Symposium was supported by the Communication Systems Department of the University of Lancaster, the Institute of Integrated Information Systems of the University of Leeds, HW Communications Ltd and Advanced Hardware Architectures, Inc, and was sponsored by the IEE and the IEEE Communications and Information Theory Chapters (UKRI Section).

This was the fifth Symposium held at the College in Ambleside, a venue which, as before, both new and regular participants were very pleased to visit. As usual, the social programme played a key part in the event, and included a Drinks Reception and Jazz Quartet on the Monday, a non-technical Evening Talk on "Mountains Still to Climb" (radio aspects of Lake District mountain rescue) on the Tuesday, a Barbeque and Barn Dance on the Wednesday (information and communication theory was found to be essential for active participation in music and dancing!), and a Banquet on the Thursday. On the Wednesday afternoon everyone had the opportunity to enjoy the magnificent Lake District scenery on a variety of walks and trips. One intrepid trio completed the strenuous Fairfield Horseshoe, a hike of about 10 miles over six peaks, the highest reaching about 3000 feet. And by a miracle the weather was good throughout the week!

Han Vinck and others at the ISCTA'01 reception.

The technical programme was equally varied and interesting, with five days of sessions on a range of topics (see list below). Most sessions were plenary, and there was a very well attended Poster Session on the Tuesday. Ample time was provided for coffee, lunch and tea breaks, to foster informal discussions. 85 papers were presented, of which 11 were invited (see list below). 93 delegates attended, from 29 different countries, making about 120 participants in all when including relatives and friends.

Copies of the Proceedings of the Symposium (£ 50) can be obtained from Liz Hey (Hey@hwcomms.com). Photographs of the Symposium (with grateful thanks to the Official Photographer, Kees Immink) can be seen at http://www.hwcomms.com/photographs.htm

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Dr. J. Pereira, European Commission, Belgium
Prof. Dr. A.J.H. Vinck, University of Essen, Germany
Prof. Dr. S.B. Wicker, Cornell University, USA

Conference attendees enjoy the ISCTA'01 banquet at the Salutation hotel.

Sessions

Software Radio and Reconfigurability (Invited Session organised by J. Pereira)
Wireless Networks (Invited Session organised by S.B. Wicker)
Poster Session
Space-Time Coding
Information Security
DSP for Communications
Latest Applications of Turbo Codes (Tutorial Session organised by AHA, Ltd.)
Turbo and Product Codes
Shannon Session: Information Theory and Coding
Low Density Parity Check Codes
Modulation, Detection and Synchronisation
Aspects of Coding
Multiple Access Techniques

Invited Presentations

J. Pereira (European Community): Evolving perspectives of reconfigurable radio

B. Krishnamachari, R Bejar and S B Wicker (Cornell University): Distributed constraint satisfaction and the bounds on resource allocation in wireless networks

E.M. Gabidulin (Moscow Institute of Physics and Technology): Row scrambler, column scrambler, and distortion

V.C. da Rocha and C. Pimentel (Federal University of Pernambuco): Binary-constrained homophonic coding

A. Khandekar and R.J. McEliece (California Institute of Technology): Are turbo-like codes effective on non-standard channels?

G. Battail (ENST, Paris, retired): Is biological evolution relevant to information theory and coding?

R.M. Tanner (University of California, Santa Cruz), T E Fuja and D Shridhara (University of Notre Dame): A class of group-structured LDPC codes

Heng Tang, Yu Kou, Jun Xu, Shu Lin and K Abdel-Ghaffar (University of California, Davis): Codes on finite geometries: old, new, majority logic and iterative decodings

K.A. Schouhamer Immink (University of Essen): A survey of codes for optical disc recording

J. Ganz, A.P. Hiltgen (ETH-Zurich) and J.L. Massey (Emeritus): Fast acquisition sequences

A.J.H. Vinck (University of Essen): On permutation codes

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Sums and Products of Digits Solutions

Recall that for each positive integer n, $S(n)$ is the sum of the decimal digits of n, $P(n)$ is the product of the decimal digits of n, and $R(n) = n/S(n)$.

1. The known solutions to $S(n) \cdot P(n) = n$ are $n = 1$ (with $1 \cdot 1 = 1$), $n = 135$ (where $(1+3+5)(1 \cdot 3 \cdot 5) = 9 \cdot 15 = 135$), and $n = 144$ (where $(1+4+4)(1 \cdot 4 \cdot 4) = 9 \cdot 16 = 144$). These are the only solutions with $n < 10^7$. For all *very* large n (say $n > 10^{60}$), $S(n) \cdot P(n) < n$, so there are only finitely many solutions, but there may be more than the three just listed.

2. Not every positive integer m occurs in the form $R(n) = n/S(n)$. The values of $m \leq 100$ not of this form are (only) $m = 62$,63, 65, 75, 84, and 95.

If $m = R(n) = n/S(n)$, we have $n = mS(n)$, and n must be a multiple of m. We know that 9 divides n if and only if 9 divides $S(n)$, so if $S(9m) = 9$, then $R(9m) = (9m)/9 = m$. For $1 \leq m \leq 100$, $S(9m) = 9$ in 55 cases.The other 45 cases are the numbers from $10j+1$ to $10j+j$, for each j from 1 to 9. In 35 of these remaining 45 cases, $S(18m) = 18$, so in these cases $R(18m) = m$. The ten remaining values of m are: 62, 63, 64, 65, 73, 74, 75, 84, 85, and 95. Four of these occur as values of $R(n)$ as follows: $R(320) = 64$, $R(511) = 73$, $R(1998) = 74$, $R(1275) = 85$. (The case $m = 74$ corresponds to the situation where $S(27m) = 27$). It is easy to show that for any $x > 0$,we have $R(n) > x$ for all $n > N_x$, so it is a finite verification process to show that a given m never occurs as $R(n)$.

3. The k-digit number n for which $R(n)$ is a minimum, for all $k > 1$, has the following characteristics: It consists of a 1 followed by r 0 's followed by $k - r - 1$ 9 's. Since we are trying to minimize $R(n) = n/S(n)$ over all k-digit numbers, we are trying simultaneously to make n small and to make $S(n)$ large. The extremal value of n must clearly have the form $10\cdots099\cdots9$ to achieve this minimum, though the value of r (the number of consecutive 0's) requires a more careful argument. The cases with $2 \leq k \leq 16$ are as follows:

k	n	R(n)
2	19	1.90
3	199	10.47
4	1099	57.84
5	10999	392.82
6	109999	2972.95
7	1099999	23913.02
8	10999999	199999.98
9	109999999	1718749.98
10	1099999999	15068493.14
11	10999999999	134146341.45
12	109999999999	1208791208.78
13	1099999999999	10999999999.99
14	10999999999999	100917431192.65
15	100999999999999	926605504587.15
16	1009999999999999	8559322033898.30

Note that exponentially many more 9's are adjoined for each additional 0 inserted.The first 0 appears at $k = 4$, the second 0 at $k = 15$, the third 0 at $k = 116$, and in general, the r^{th} 0 (between the initial 1 and the left-most 9) appears at $k = \left(\frac{10^r - 1}{9}\right) + (r+2)$, for all $r \geq 0$.

4. Among all k-digit integers, $R(n)$ is an integer $I(k)$ times, with $I(1) = 9$, $I(2) = 23$, $I(3) = 180$, $I(4) = 1325$, $I(5) = 10334$, $I(6) = 83556$, and $I(7) = 710667$. Did you find further values of $I(k)$, or detect any patterns?

5. The k-digit numbers which give minimum *integer* values for $R(n)$ are as follows:

k	n	R(n)
1	any from 1 to 9	1
2	18	2
3	198	11
4	1098	61
5	10989	407
6	109888	3232
7	1078999	25093

Were you able to extend this table, or to detect any pattern?

CALL FOR PAPERS

2002 IEEE International Symposium on Information Theory

Palais de Beaulieu, Lausanne, Switzerland
June 30 – July 5, 2002

The 2002 IEEE International Symposium on Information Theory will be held at the Palais de Beaulieu in Lausanne, Switzerland, from Sunday, June 30, through Friday, July 5, 2002.

Previously unpublished contributions to the following areas are solicited:

- Coded modulation
- Coding theory and practice
- Communication complexity
- Communication systems
- Cryptology
- Data compression
- Data networks
- Detection and estimation
- Information theory and statistics
- Multiuser detection
- Multiuser information theory
- Pattern recognition and learning
- Quantum information processing
- Shannon theory
- Signal processing
- Source coding

Papers will be reviewed on the basis of an extended summary (not exceeding six pages) of sufficient detail to permit reasonable evaluation. The deadlines for submission are September 30, 2001 for paper copies and October 7, 2001 for electronic copies, with notification of decisions by February 8, 2002. In view of the large number of submissions expected, multiple submissions by the same author will receive especially stringent scrutiny. All accepted papers will be allowed twenty minutes for presentation, and one-page abstracts will be printed in the conference proceedings. Authors are strongly encouraged to submit electronic versions of their summaries by following the guidelines on the symposium web page. For those unable to submit electronically, *four copies* of the summary should be mailed to

Ms. Monique Borcard
ISIT 2002 Paper Submission
EPFL — DSC — LTHI
CH-1015 Lausanne
Switzerland

It is expected that a small number of grants for the partial reimbursement of travel costs may be available for the authors of accepted papers whose resources would not otherwise enable them to attend the symposium. Detailed information on the technical program, special events, accommodations, travel arrangements, excursions and applications for travel grants will be included in subsequent mailings, and will be posted at the symposium web site

`http://isit02.epfl.ch`

Inquiries on general matters related to the symposium should be addressed to

Prof. Bixio Rimoldi
Communication Systems Department
Swiss Federal Institute of Technology
CH-1015 Lausanne, Switzerland
E-mail: `isit02chair@epfl.ch`
Phone: +41 21 693 76 62
Fax: +41 21 693 43 12

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CONFERENCE ANNOUNCEMENT

2003 IEEE International Symposium on Information Theory

Pacifico Yokohama, Yokohama, Japan
June 29 – July 4 , 2003

The 2003 IEEE International Symposium on Information Theory will be held at Pacifico Yokohama, Yokohama, Japan, (http://www.pacifico.co.jp/) from Sunday, June 29, through Friday, July 4, 2003.

Previously unpublished contributions to the following areas are solicited

- Coded modulation
- Coding theory and practice
- Communication complexity
- Communication systems
- Cryptology and data security
- Data compression
- Data networks
- Detection and estimation
- Information theory and statistics
- Multiuser detection
- Multiuser information theory
- Pattern recognition and learning
- Quantum information processing
- Shannon theory
- Signal processing
- Source coding

The first call for papers will be published in January 2002.

Detailed information on the technical program, special events, accommodations, travel arrangements, excursions and applications for travel grants will be included in subsequent mailings, and will be posted at Symposium web site: http://www.kohnolab.dnj.ynu.ac.jp/~isit2003/

Inquiries on general matters related to the symposium should be addressed to

Ryuji Kohno, Professor, Division Head,
Yokohama National University, Graduate School of Engineering
Division of Physics, Electrical and Computer Engineering
79-5 Tokiwadai, Hodogaya-ku, Yokohama, Japan 240-8501
Email: isit2003@kohnolab.dnj.ynu.ac.jp
Tel:+81-45-339-4116, Fax(G4):+81-45-338-1157

Conference Calendar

DATE	CONFERENCE	LOCATION	CONTACT/INFORMATION	DUE DATE
September 2-7, 2001	**2001 IEEE Information Theory Workshop**	Cairns, Australia	Dr Lei Wei School of Elec., Comp. & Telecommun. Eng University of Wollongong NSW 2522, Australia L.Wei@elec.uow.edu.au Phone: +61 2 4221 3407 Fax: +61 2 4221 3236	March 31, 2001
October 3-5, 2001	**Mini-Workshop on Convolutional Codes**	Essen, Germany	Han Vinck IEM Ellernstrasse 29 45326 Essen, Germany Fax: +49 201 183 7663 E-mail: vinck@exp-math.uni-essen.de	August 7, 2001
June 30-	**2002 IEEE International Symposium on Information Theory**	Lausanne, Switerland	Palais de Beaulieu, Prof. Bixio Rimoldi Communication Systems Department Swiss Federal Institute of Technology CH-1015 Lausanne, Switzerland E-mail: isit02chair@epfl.ch Phone: +41 21 693 76 62 Fax: +41 21 693 43 12	July 5, 2002
March 17-21, 2002	**2002 IEEE Wireless Communications and Networking Conference (WCNC 2002)**	Orlando, Florida, USA	Dick Lynch Verizon Wireless, USA www.wcnc.org/2002	August 15, 2001
April 28- May 2, 2002	**2002 IEEE International Conference on Communications (ICC 2002)**	New York, New York, USA	Mark Karol Avaya Inc., USA mk@avaya.com www.icc2002.com	August 15, 2001
February 19-22, 2002	**2002 International Zurich Seminar on Broadband Communications**	ETH Zurich, Zurich, Switzerland	Prof. Dirk H. Dahlhaus Swiss Federal Inst. of Tech. Comm. Technology Laboratory Sternwartstr. 7 CH-8092 Zurich SWITZERLAND +41 1 63 22788 +41 1 63 21209 (Fax) dahlhaus@nari.ee.ethz.ch http://www.izs2002.ethz.ch	September 15, 2001

Conference Calendar

DATE	CONFERENCE	LOCATION	CONTACT/INFORMATION	DUE DATE
May 19-22, 2002	**2002 IEEE Communications Theory Workshop**	Naples Beach Hotel & Golf Club, Sanibel Island, FL	Mr. Gordon Stuber GCATT, Room 571 250 14th Street, NW Atlanta, GA 30318 +1 404 894 2923 +1 404 894 7883 (Fax) stuber@ece.gatech.edu	TBA
November 18-22, 2002	**GLOBECOM 2002 - 2002 IEEE Global Telecommunications Conference**	Taipei International Conventional Center, Taipei, Taiwan	Mr. Douglas S. J. Hsiao 12, Lane 551 Min-Tsu Road Sec. 5, Yang-Mei, Taoyuan 326 TAIWAN +886 3 424 5210 +886 3 424 4168 (Fax) sjhsiao@chttl.com.tw	TBA

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445 Hoes Lane, P.O. Box 1331
Piscataway, NJ 08855-1331 USA