Constrained sequences

at the occasion of the Eduard Rhein Prize for

Kees Schouhamer Immink

by

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University Duisburg-Essen
04.10.2014

UNIVERSITÄT DUISBURG ESSEN
Offen im Denken

The red thread

- What is a constrained sequence?

- The famous EFM code designed by Immink

8-Bit-Daten	14-Bit-Bitmuster (EFM)
00000000	01001000100000
00000001	10000100000000
00000010	10010000100000
00000011	10001000100000
00000100	01000100000000
00000101	00000100010000
00000110	00010000100000
00000111	00100100000000

History: From mechanical to optical recording to …

1885 Oscar Lochmann, Leipzig

the first disc-playing musical box.

Zink(Vinyl)-Schallplatte

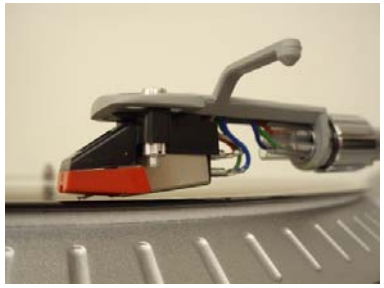
Emil Berliner mit der Urform seines Grammophons (1887)

CD/DvD

digital optical recording, was invented in the late 1960s by James T. Russell.

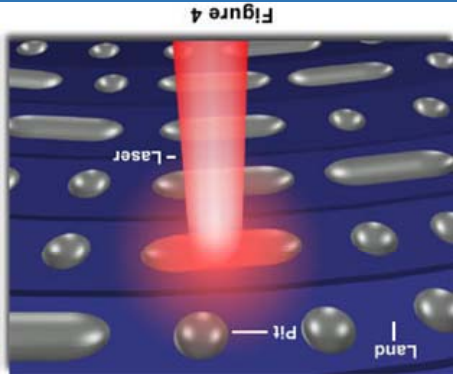
Sony and Philips (CD) made it a commercial and technical success (1983)

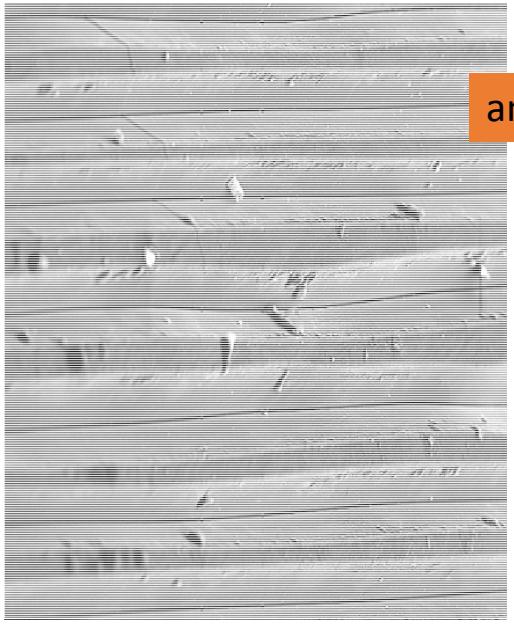
There are principle differences between a vinyl record and a CD



needle

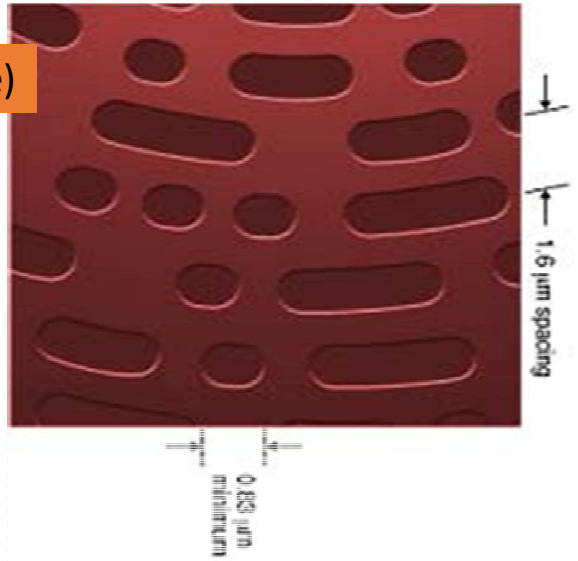
laser





analog (continuous)

digital (discrete)



Why digital (discrete) instead of analog?

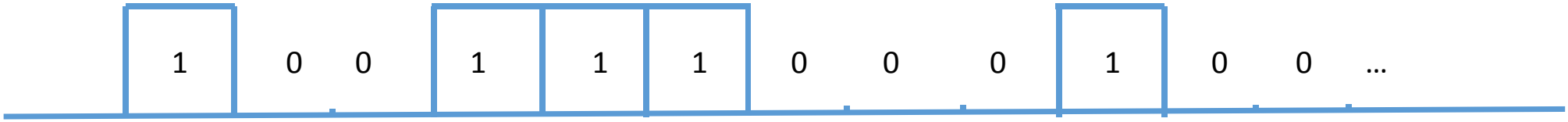
Easier to implement:

- error correction
- data reduction
- encryption
- synchronization
- formatting
- …

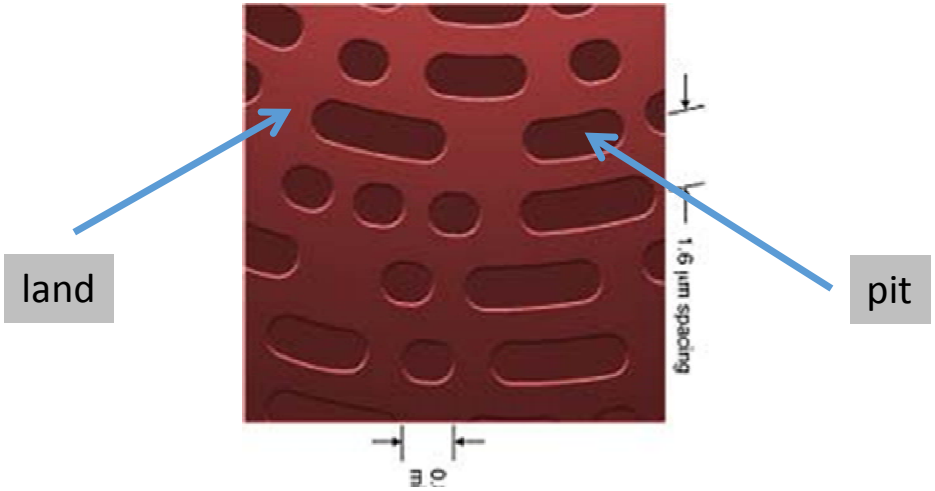
Higher Quality at lower Cost

What is the **writing** principle on CD ?

- Music is represented by a sequence of bits (0 and 1)

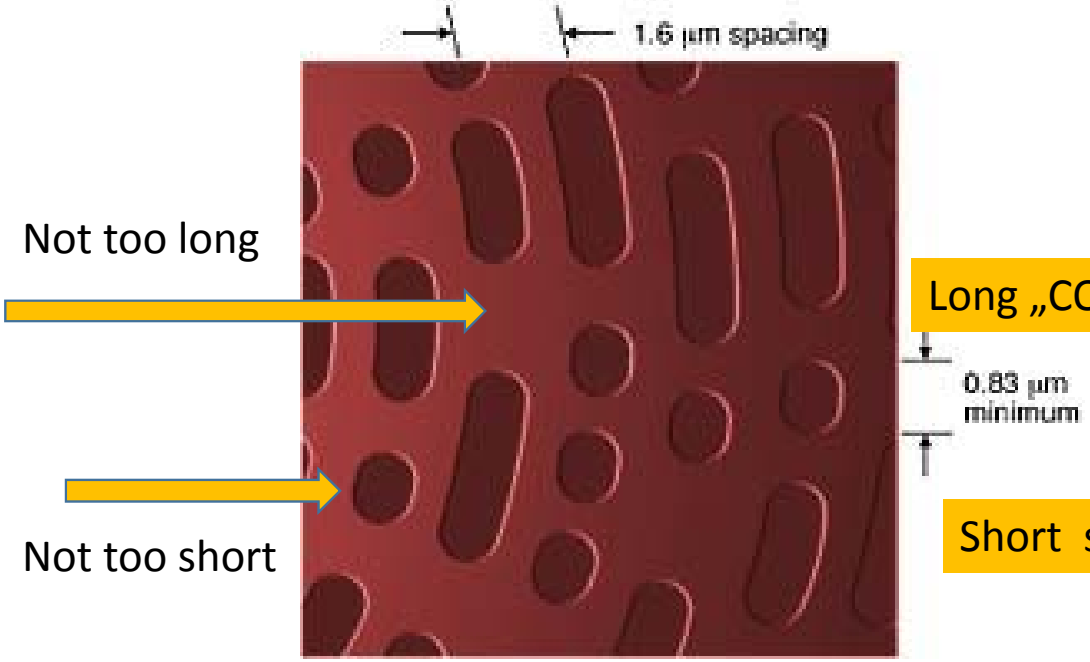


- Groups of 8 bits are converted into symbols suited for the medium CD (modulation)



What are the symbol constraints for writing on a CD ?

Symbol length has discrete values!



Not too long

Not too short

Long „CONSTANT“ sequences give synchronization problems

Short symbol duration gives detection problems

We also need to follow the correct tracks (control)!

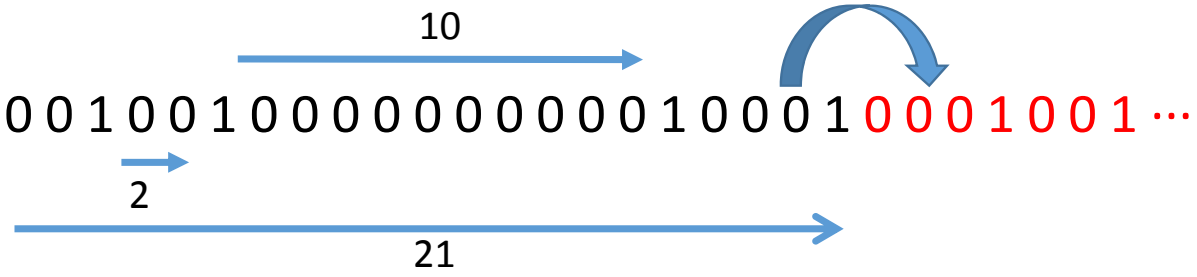
This requires a sequence with regular changes: the k-constraint!

Immink‘s design task: a binary puzzle

Convert 8 bits into binary words with the constraints:

- minimum two 0‘s between two 1‘s (d-constraint)
- maximum ten 0‘s after each other (k-constraint)
- minimize the length to have highest storage density
- constraints should also be valid after concatenation

EXAMPLE:



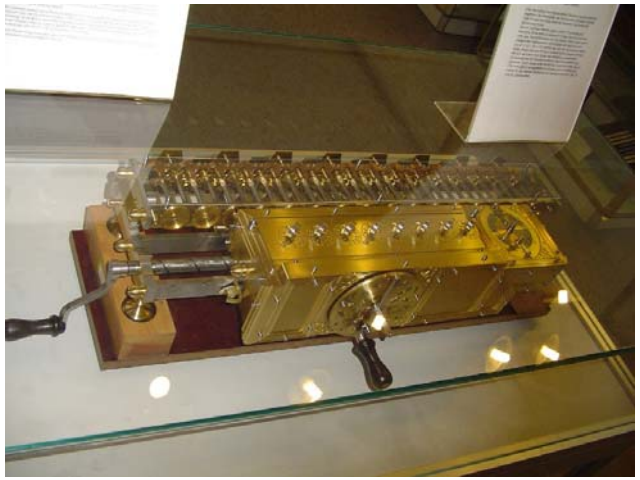
To do this, we need „binary mathematics“

Who is the inventor of the binary mathematics?

Leibniz (1646-1716)

Explanation of Binary Mathematics, 1703

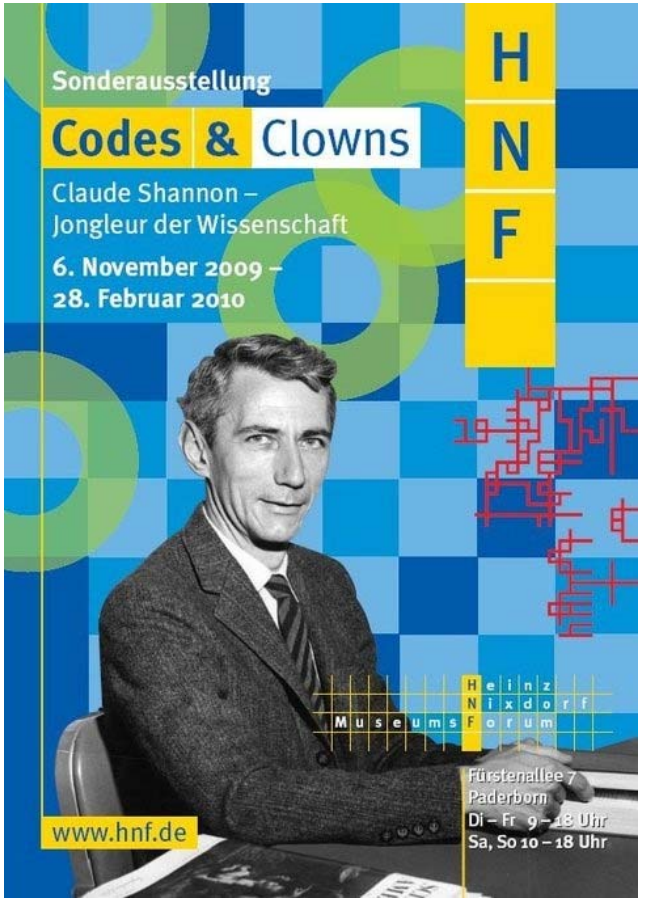
Explication de l'Arithmetique Binaire, 1703

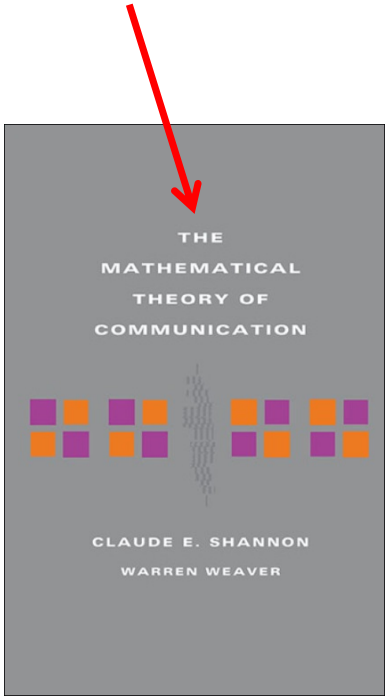


Die von Leibniz beschriebene Binär-Maschine kann als Vorläufer der binär rechnenden Computer angesehen werden, deren mechanische Ausführung 1936 vom Konrad Zuse gebaut wurde. Ein Modell dieser „Machina Arithmetica Dyadicae“ wurde vom Deutschen Museum in München konstruiert.

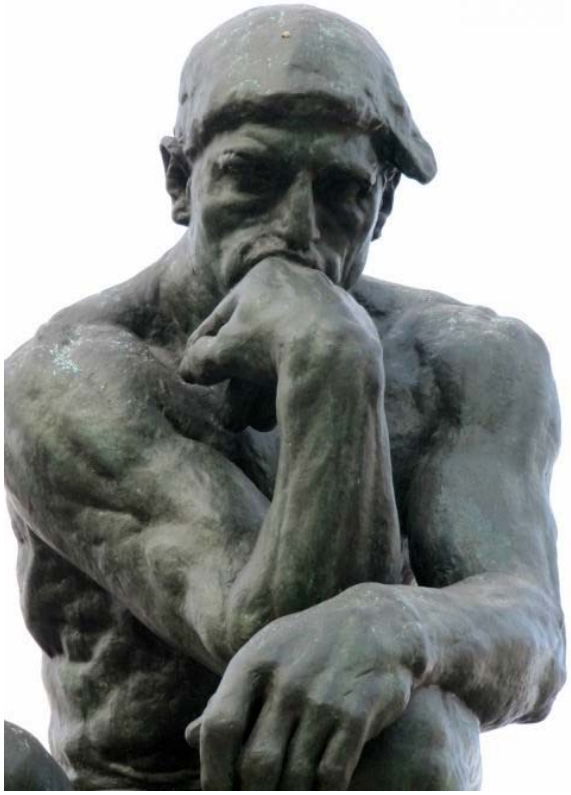
Claude Shannon showed how to do the calculations for the constrained sequences

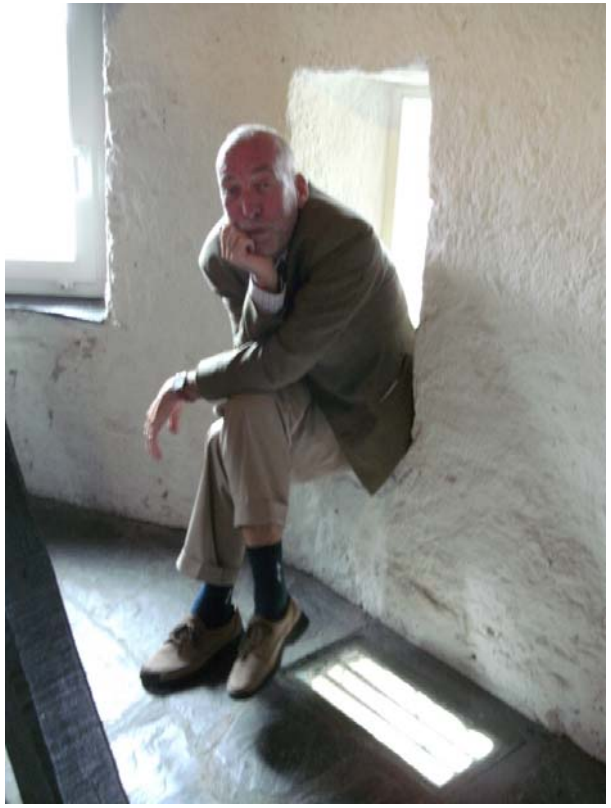
AES Convention, New York, 1985
Claude Shannon, and Kees Immink





But how does the theory work out in Practice ?





Immink modulates 8 bits (music) into constrained words of length 14

- constraints : at least two 0‘s between two 1‘s

8 bits → 14 bits

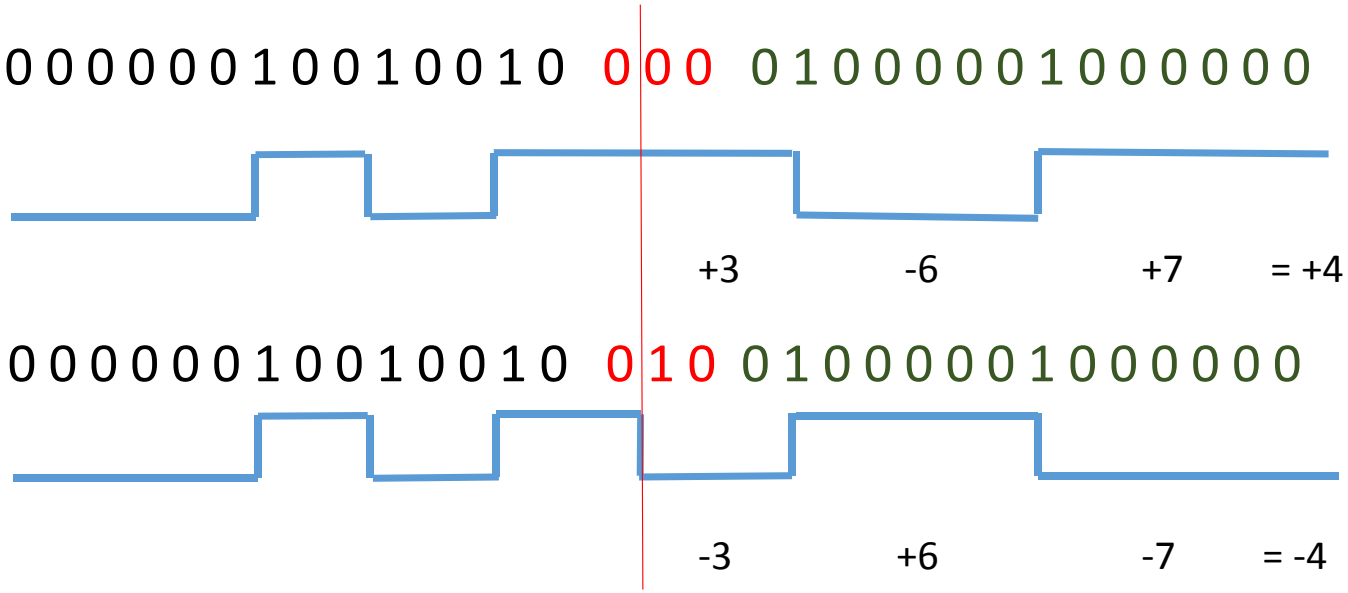
example: 0 1 0 1 1 0 0 1 => 1 0 0 0 0 0 1 0 0 1 0 0 0 0

- words are connected using 3 merging bits (to satisfy the constraint we need only 2!)

example: 0 0 0 0 0 0 1 0 0 1 0 0 1 0 [0 0 0 / 0 1 0] 0 1 0 0 0 0 0 0 0 0 1 0 0 0

what was Immink‘s idea?

Words are written as CD landscapes!

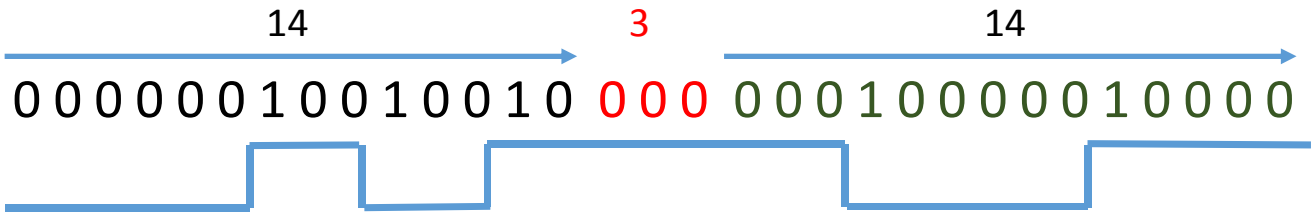


WE HAVE SOMETHING TO CHOSE!

This is what engineers like to do!

the **low frequency spectral properties can be improved** (Running Digital Sum) !

Core idea for the famous EFM (2,10) modulation code for CD (patent)
include the k constraint (max number of 0‘s) in the code design !



CONSTRUCTION: there are **277** words of length 14 with at least two 0‘s between two 1‘s

- remove all words with a segment of 11 or more 0‘s
- remove all words with 9 or 10 zeros at the beginning or end

Then,

*277 – 20 = 257 words left, JUST enough to store 8 bits ≡ **256 words***

Result 1: the concatenation of words has a **maximum of ten** 0‘s between two 1‘s

Result 2: the 3 merging bits can be used to **minimize the running digital sum** (RDS)

Sony and Philips cooperated (?)

Toshi Doi and ?

SONY(Toshi Doi, Ed. Rh.-1981): We take your code if you can implement it with less than 100 gates!

On an Apple !! Immink succeeded to beat Sony!

A famous PhD student from München contributed to the theory

Ernst Guillemin Ludwig-Maximilians-Universität München, 1926 PhD supervised by Arnold Sommerfeld

MIT Professor, Department of Electrical Engineering 1928-1963
(PhD supervisor of Robert Fano)

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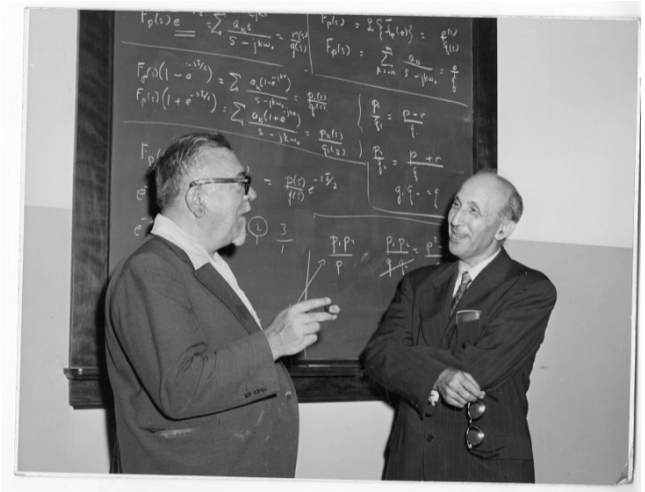
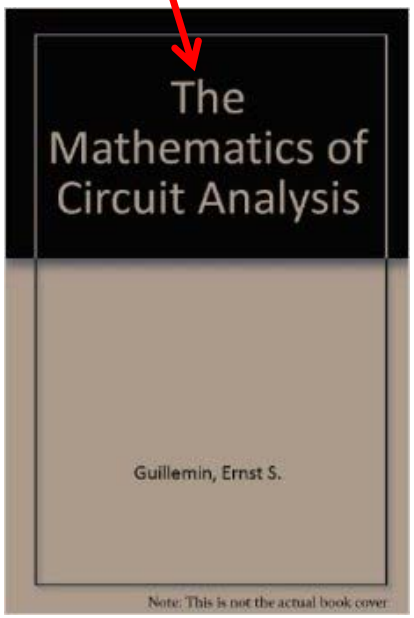
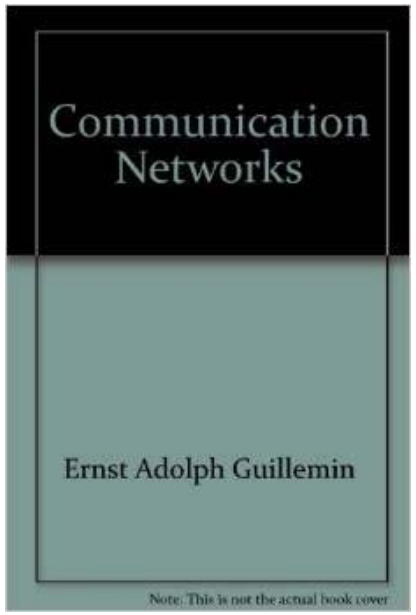






The …

This is the CD patent for the EFM code

United States Patent [19]

Immink et al.

[11] **Patent Number: 4,501,000**

[45] **Date of Patent: Feb. 19, 1985**

[54] **METHOD OF CODING BINARY DATA**

[75] Inventors: **Kornelis A. Immink; Jakob G. Nijboer,** both of Eindhoven, Netherlands; **Hiroshi Ogawa; Kentaro Odaka,** both of Tokyo, Japan

4

[73] Assignee: **Sony Corporation,** Tokyo, Japan

[21] Appl. No.: **286,982**

[22] Filed: **Jul. 27, 1981**

[51] **Int. Cl.**³ **H03K 13/02**

[52] **U.S. Cl.** ..... **375/25;** 375/106; 340/347 DD

[58] **Field of Search** ..... 375/18, 19, 25, 106, 375/112; 340/347 DD; 360/40, 48; 371/55, 57; 358/13

[56] **References Cited**

Assistant Examiner—Stephen Chin
Attorney, Agent, or Firm—Lewis H. Eslinger; Alvin Sinderbrand

[57] **ABSTRACT**

A system for block encoding words of a digital signal achieves a maximum of error compaction and ensures reliability of a self-clocking decoder, while minimizing any DC in the encoded signal. Data words of m bits are translated into information blocks of n_1 bits ($n_1 > m$) that satisfy a (d,k)-constraint in which at least d "0" bits, but no more than k "0" bits occur between successive "1" bits. The information blocks are catenated by inserting separation blocks of n_2 bits therebetween, selected so that the (d,k)-constraint is satisfied over the boundary between any two information words. For each information word, the separation block that will yield the lowest net digital sum value is selected. Then, the encoded

Takanawa Prince Hotel (Shinagawa), close to Sony headquarters

+

The patent for the DvD, EFM+ , has only one inventor

United States Patent [19]

Schouhamer Immink

[11] **Patent Number: 5,696,505**

[45] **Date of Patent: Dec. 9, 1997**

[54] **METHOD OF CONVERTING A SERIES OF M-BIT INFORMATION WORDS TO A MODULATED SIGNAL, METHOD OF PRODUCING A RECORD CARRIER, CODING DEVICE, DECODING DEVICE, RECORDING DEVICE, READING DEVICE, SIGNAL, AS WELL AS RECORD CARRIER**

[75] Inventor: **Kornelis A. Schouhamer Immink**, Eindhoven, Netherlands

[73] Assignee: **U.S. Philips Corporation**, Tarrytown, N.Y.

[21] Appl. No.: **385,533**

[22] Filed: **Feb. 8, 1995**

[30] **Foreign Application Priority Data**

Feb. 15, 1994 [EP] European Pat. Off. 94200387

[51] **Int. Cl.**[6] **H03M 7/00**

[52] **U.S. Cl.** **341/59**; 341/95

[58] **Field of Search** 341/95, 58, 59, 341/106

[56] **References Cited**

0392506A2 10/1991 European Pat. Off. G11B 20/14

Primary Examiner—Brian K. Young
Assistant Examiner—Peguy JeanPierre
Attorney, Agent, or Firm—Richard A. Weiss

[57] **ABSTRACT**

A a series of m-bit information words is converted to a modulated signal. For each information word from the series, an n-bit code word is delivered. The delivered code words are converted to the modulated signal. The code words are distributed over at least one group of a first type and at least one group of a second type. When a code word belonging to a group of the first type is delivered, its group establishes a coding state of a first type. When a code word belonging to an group of the second type is delivered, a coding state of a second type is established which is determined by the information word which is to be converted to the delivered code word. When one of the code words is assigned to the received information word, this code word is selected from a set of code words which depends on the coding state established. The sets of code words belonging to the coding states of the second type are disjunct. In this coding method, the number of unique bit combinations that may be established by the code words in the series are enlarged.

How rich could an inventor be?

Suppose she/he gets only 0.001 Euro per CD. Is that too much?

How many CDs are sold?

By 2007, 200 billion CDs have been sold worldwide

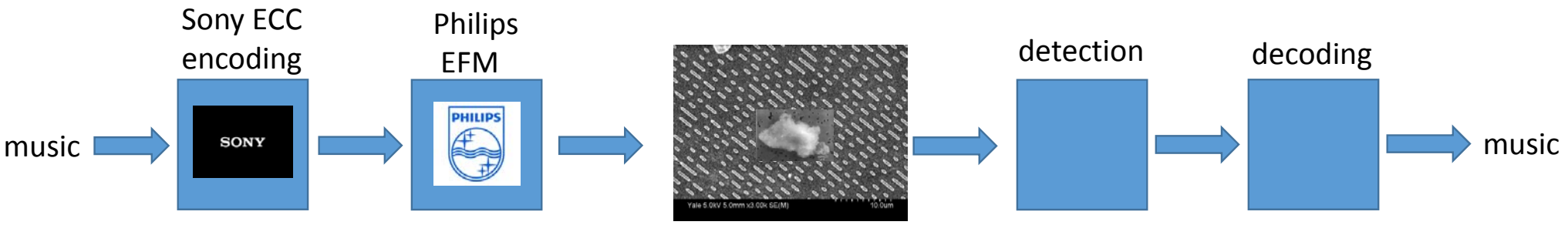
Unfortunately, the dutch patent law is not friedly for inventors

But …

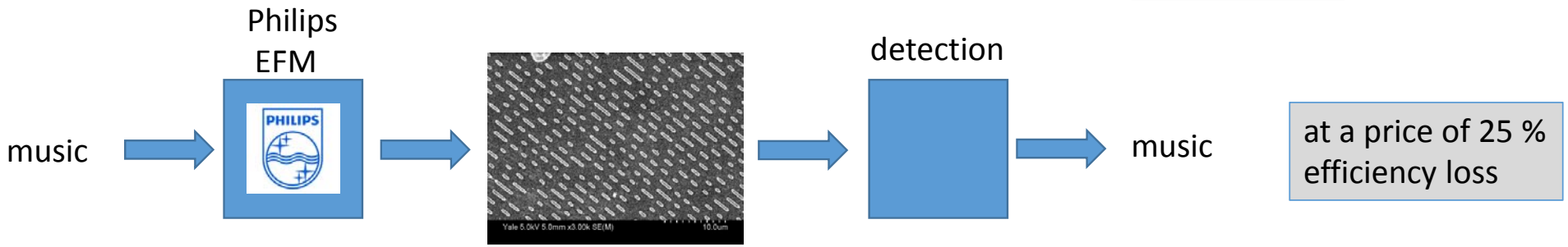
if the invention is made by an employee of a university or research institution, the employer is entitled to the patent, (*Art. 12 (1) Rijksoctrooiwet 1995*).

The CD is very noisy (dust, scratches, etc)

SONY contributed error correcting (Reed-Solomon) codes!



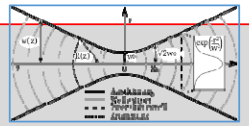
As a result: this situation is „equivalent“ to



at a price of 25 % efficiency loss

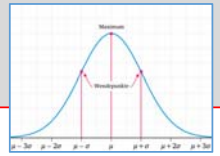
Even C.F. GAUSS contributed to the CD principles

- die gaußsche Optik, a mathematical description of laser light propagation



- the first **binary** wired communication link: 1833, Gauss, Wilhelm Weber and Carl August von Steinheil (München)

- description of Gaussian noise



Gauss and Weber (1833)

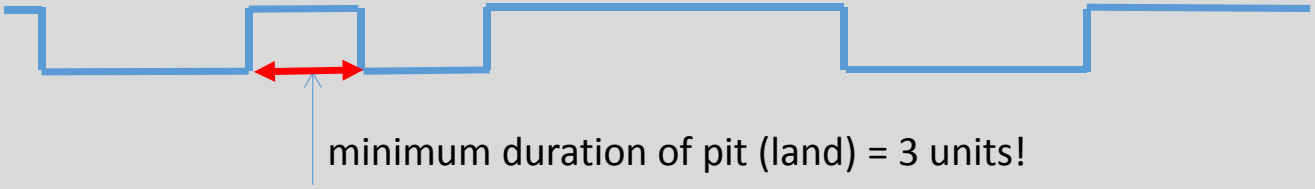
r	a	rrr	c,k	lrl	m	lrrr	w	llrr 4
l	e	rrl	d	rll	n	rrll	z	lllr 5
rr	i	rlr	v,v	rrrr	p	rlrl	0	llrl 6
rl	o	lrr	g	rrrl	r	rllr	1	lrll 7
lr	u	lll	h	rrlr	s	lrrl	2	rlll 8
ll	b	llr	l	rlrr	t	lrlr	3	llll 9

Without Gaussian noise,
no Information and Communication Theory

finally, a remarkable observation can be made

Constrained code: 0 1 0 0 0 0 1 0 0 1 0 0 1 0 0 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0

8 information bits
in 17(16) positions



Traditional coding: pits and lands must have the same duration

8 information bits
in 24 positions

DENSITY GAIN ≈ 40%

now we have a connection between Immink and Eduard Rhein

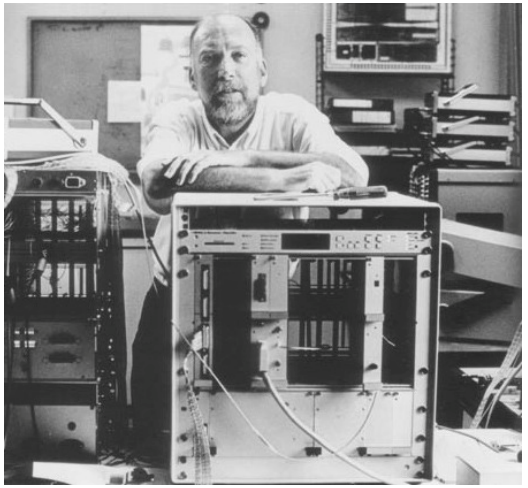
Das Füllschriftverfahren patentiert von **Eduard Rhein**

Statt wie bisher den Rillenabstand der Platten gleichmäßig nach dem größten Ausschlag einer Musikpassage zu gestalten, müssten die Rillen je **nach Lautstärke und Tonhöhe** ständig **variieren**.

Dadurch wäre Platz gewonnen, um mehr Musik auf einer Plattenseite unterzubringen.

Es brachte die Langspielplatten **von 46 Minuten auf 80 Minuten Spieldauer** und machte Rhein zum Multimillionär.

DENSITY GAIN ≈ 40%

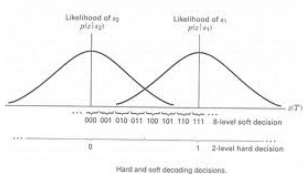


Scientific (PhD) Genealogy of Kees Schouhamer Immink (coincidence?)

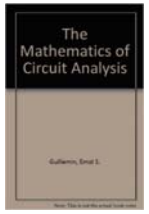
http://genealogy.math.ndsu.nodak.edu/

Friedrich Leibniz (1622, Leipzig)

Carl Friedrich Gauß (1799, Göttingen)



Ernst Guillemin (1926 München)



(via Fano, Kailath, Schalkwijk)

Kees Schouhamer Immink (1985, TU Eindhoven)

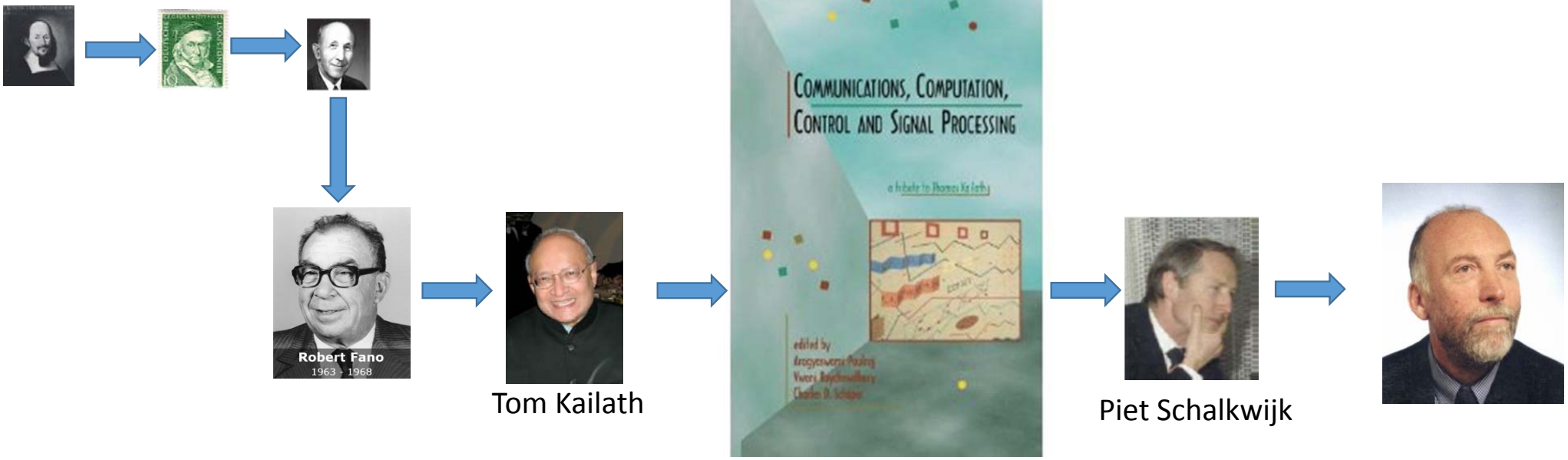
What to do after retirement at Philips ?

Not admitted in the army for the 2nd time

A better option:
Use the Eduard Rhein Prize

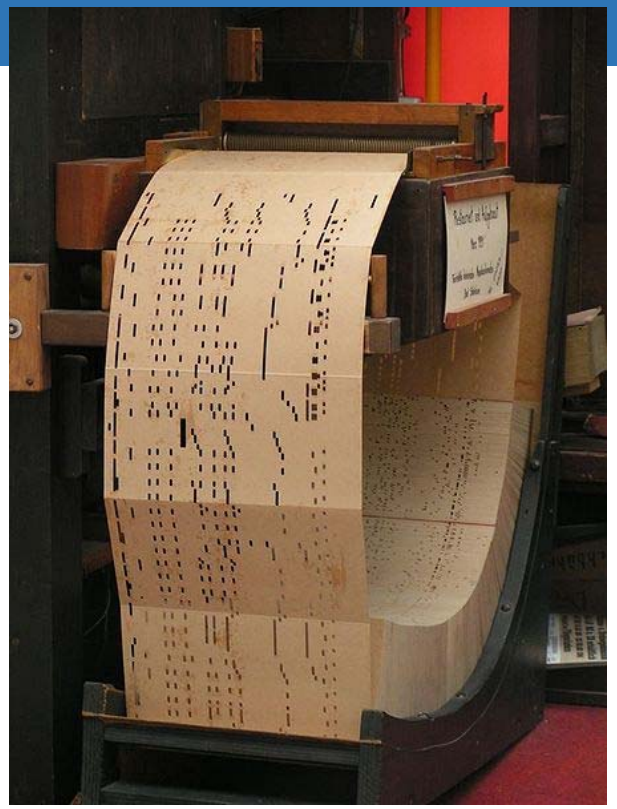
CONCLUSIONS

- We follow the scientific (genealogy) path leading to Kees Imminks work
  - Leibniz, Gauss, Guillemin



Immink combined: COMMUNICATION, COMPUTATION, CONTROL and SIGNAL PROCESSING

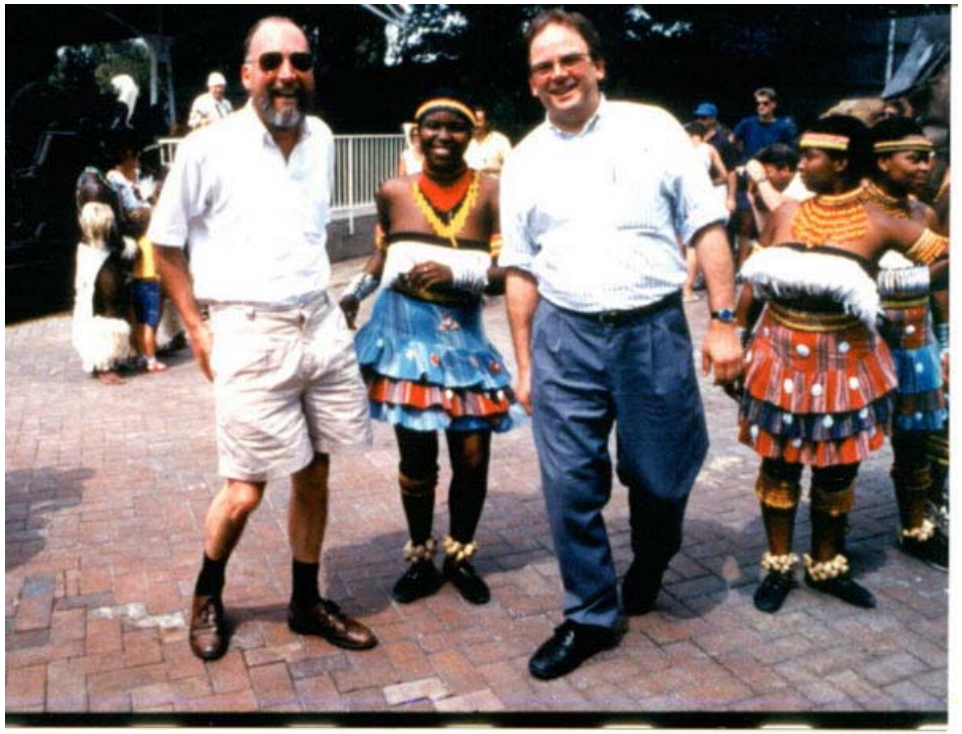
My favorite digital recording machine



Constrained writing (programming)!

Time for a demonstration!

Research can be exiting!



Johannesburg

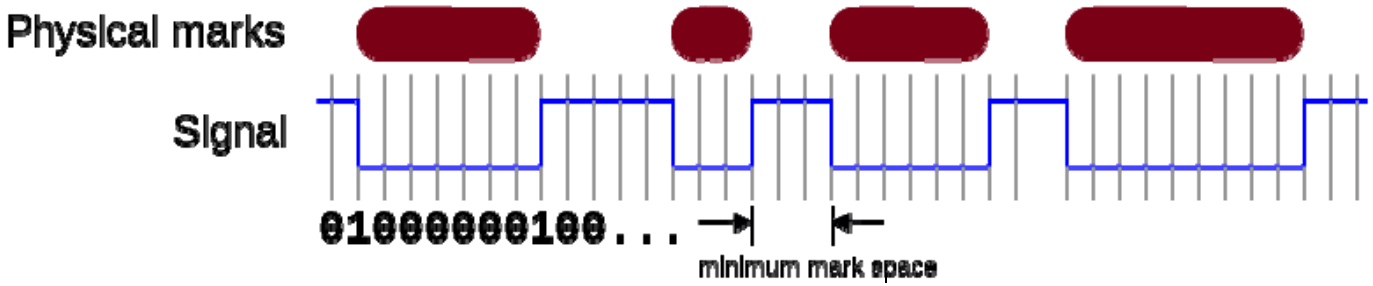
Ehime, Matsuyama

We enjoyed our research!

Dogo Matsuyama, Ehime University

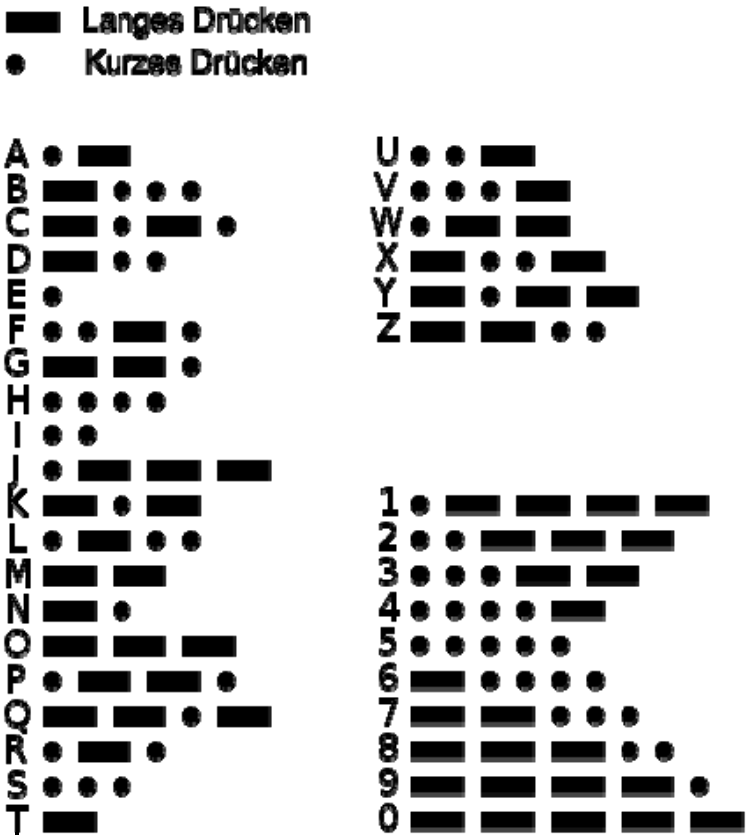
Code book CD (d,k) contrained sequence

the EFM code used in CDs and DVDs:



Between two transitions at least 3 symbols that are the same

A Morse code is a constrained sequence



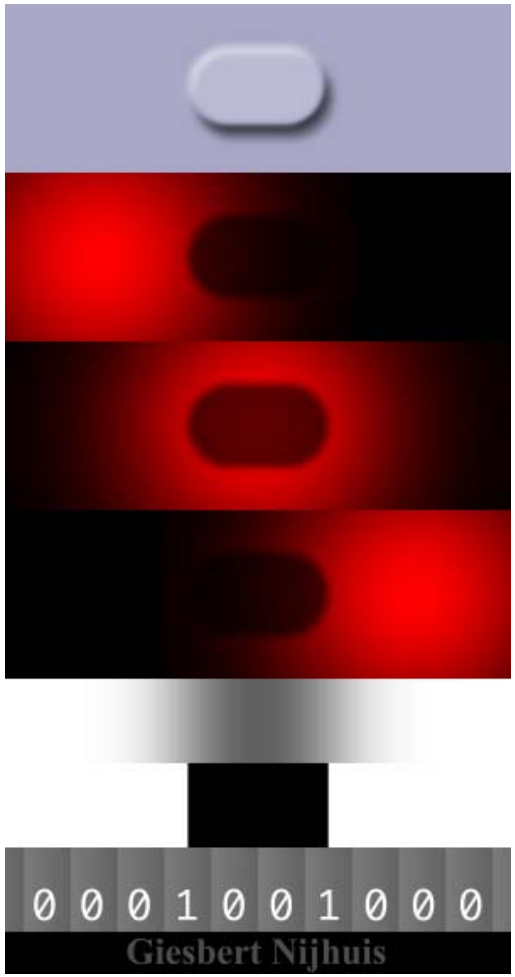
A = 1 0 1 1 1
B = 1 1 1 0 1 0 1 0 1
C = 1 1 1 0 1 0 1 1 1 0 1

Etc.

Only strings of length 3 and 1 are allowed

Between letters we have 0 0 0 (3)
Between words we have 0 0 0 0 0 0 0 (7)

How the smallest pit is read



- the smallest pit, as seen under normal daylight conditions.

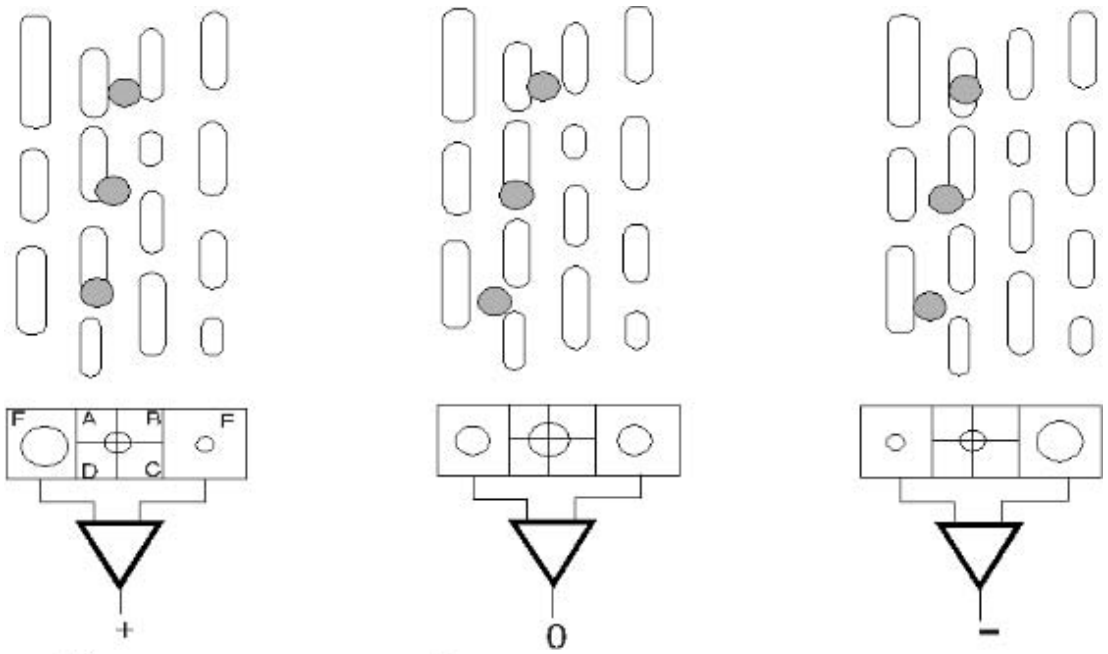
- the pit passing by the read-laser spot. the pit now looks dark because of diffusion and interference of the laser light.

- the intensity read-out of the reflected laser light.

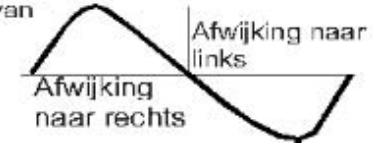
- threshold filter.

- extracted digital code.

Sporen volgen



Het genereren van een spoorvolgings correctiesignaal door middel van twee volgbundels.



United States Patent [19] [11] **4,286,318**

Immink et al. [45] **Aug. 25, 1981**

[54] **CONTROL LOOP**

[75] Inventors: **Kornelis A. Immink; Abraham Hoogendoorn,** both of Eindhoven, Netherlands

[73] Assignee: **U.S. Philips Corporation,** New York, N.Y.

[21] Appl. No.: **40,794**

4,012,634	3/1977	Bouton et al.	364/118 X
4,099,113	7/1978	Hayashi	364/118 X
4,141,065	2/1979	Sumi et al.	364/118 X

Primary Examiner—Joseph F. Ruggiero
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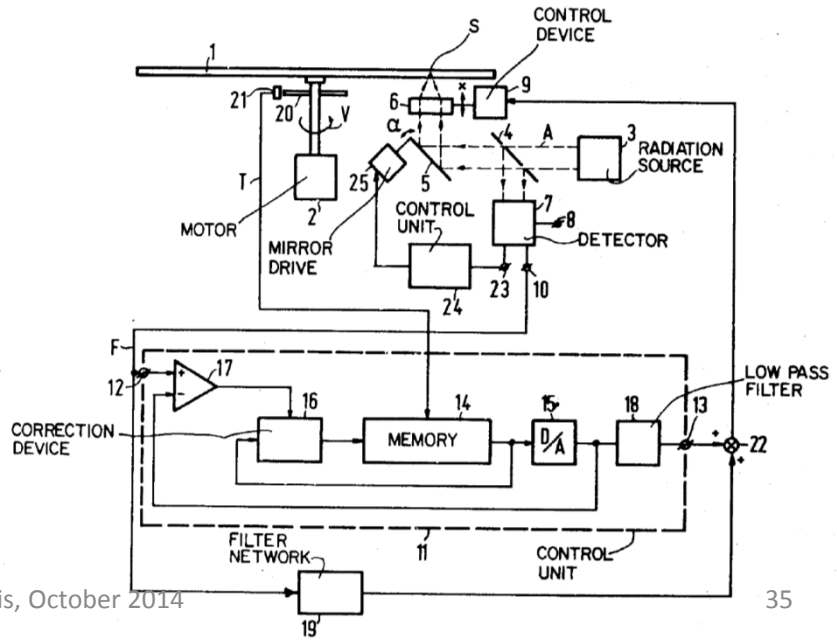
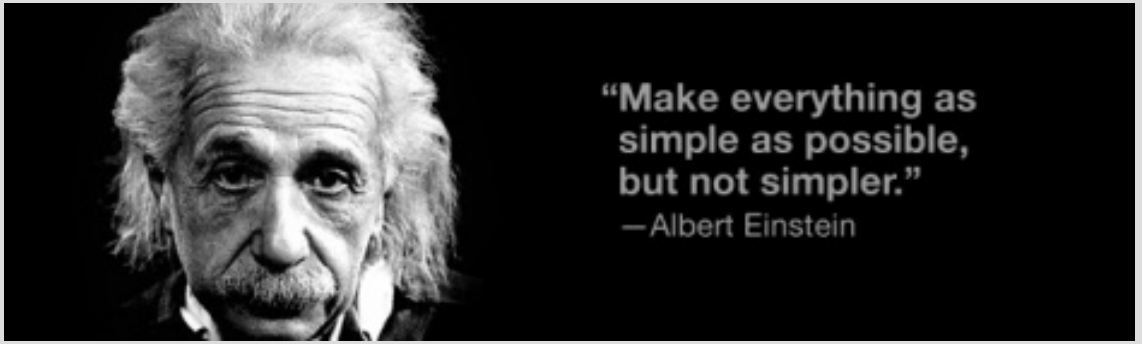
[57] **ABSTRACT**



Something to remember



A language is also a constrained sequence (Zwynge)

Words:

sh?

qu always followed by -a or e or i or o

Order of words:

grammar

Compact Disk of James Russel

he succeeded in inventing the first *digital-to-optical recording and playback system*

The earliest patent by Russell, US3501586, was filed in 1966, and granted in 1970.

- Sony launched its CDP-101—the first commercialized CD player in 1982.
- Sony and Philips paid royalties from CD player sales to Battelle and to Optical Recording Corporation.
- Time-Warner and other disc manufacturers settled with the Optical Recording Corporation in 1992, paying $30 million for patent infringement.
- *The court determined that Optical Recording had the sole rights over the technology mentioned in the patents. But because the patents properly belonged to Russell's employer, he never got a cent out of either deal.*

An example close to Immink‘s modulation code: the binary puzzle

0	1	0	1	1	0	1	0
0	1	1	0	0	1	0	1
1	0	0	1	0	1	0	1
1	0	1	0	1	0	1	0
0	1	0	0	1	1	0	1
1	1	0	1	0	0	1	0
0	0	1	1	0	1	1	0
1	0	1	0	1	0	0	1

RULES: Not more than two 0‘s and two 1‘s next to each other

Kees can do the last column

Remark: there is a solution!

Remark: The puzzle **can be solved**! But, the puzzle **has to be designed**!

To do this, we need „binary mathematics“