FRIEDRICH-ALEXANDER
UNIVERSITÄT
ERLANGEN-NÜRNBERG

TECHNISCHE FAKULTÄT

Image and Video Compression

SS 2021

Prof. Dr.-Ing. André Kaup

Chair of Multimedia Communications and Signal Processing

Friedrich-Alexander University Erlangen-Nürnberg

Remarks

Credits: L3 / E1 (4 SWS, 5 ECTS Credits)

Lecture: Recorded: Mo. 16:15 – 17:45 (H6), Wed. 10:15 – 11:45 (H6)
Live Q&A: Wed. 10:15 – 11:45 (Zoom)

Exercises: Recorded: Wed. 08:15 – 09:45 (H6)
Live Q&A: Wed. 08:15 – 09:45 (Zoom), Fabian Brand, M.Sc.

Master level course for

- *CME, IuK (Multimediasysteme) – required subject*
- *EEI (IT), WING (IKS), MT – restricted elective subject*

Lecture notes: can be downloaded as PDF from StudOn (admission required)

Written exam: 90 min, end of July (date to be set by examination office),
two-sided DIN A4 handwritten formulary and calculator allowed

Optional lab course: "Image and Video Compression", coder design in Matlab
Thursday 14:00 – 18:00 (06.021), Kristian Fischer, M.Sc.

Time Table Summer Term 2021

Mon. (H6) 16:15 – 17:45		Wed. (H6, Zoom) 08:15 – 09:45		Wed. (H6, Zoom) 10:15 – 11:45		Thu. (06.021) 14:00 – 18:00	
12.04.	Lecture 1	14.04.	–	14.04.	Lecture 2	15.04.	Lab Course
19.04.	Lecture 3	21.04.	Exercise 1	21.04.	Q&A Lec.	22.04.	Lab Course
26.04.	Lecture 4	28.04.	–	28.04.	Lecture 5	29.04.	Lab Course
03.05.	Lecture 6	05.05.	Exercise 2	05.05.	Q&A Lec.	06.05.	Lab Course
10.05.	Lecture 7	12.05.	Q&A Ex.	12.05.	Lecture 8	13.05.	–
17.05.	Lecture 9	19.05.	Exercise 3	19.05.	Q&A Lec.	20.05.	Lab Course
24.05.	–	26.05.	–	26.05.	Lecture 10	27.05.	Lab Course
31.05.	–	02.06.	Exercise 4	02.06.	–	03.06.	–
07.06.	Lecture 11	09.06.	Q&A Ex.	09.06.	Lecture 12	10.06.	Lab Course
14.06.	Lecture 13	16.06.	Exercise 5	16.06.	Q&A Lec.	17.06.	Lab Course
21.06.	Lecture 14	23.06.	Exercise 6	23.06.	Lecture 15	24.06.	Lab Course
28.06.	Lecture 16	30.06.	Q&A Ex.	30.06.	Q&A Lec.	01.07.	Lab Course
05.07.	Lecture 17	07.07.	Exercise 7	07.07.	Lecture 18	08.07.	Lab Course
12.07.	–	14.07.	Q&A Ex.	14.07.	Q&A Lec.	15.07.	Lab Course

Goals of this lecture

Basic understanding of

- Redundancy and lossless source coding
- Quantization and lossy source coding
- Decorrelation using Prediction, Transforms, Subbands
- Irrelevancy and human visual perception
- Motion compensation and hybrid coding

Basic knowledge of relevant standards

- Fax compression (T.4, T.6)
- Image compression (JPEG, JPEG-LS, JPEG2000)
- Video compression (MPEG-1, MPEG-2, H.264/AVC, H.265/HEVC)

References

Basic textbooks on image and video compression technology

J.-R. Ohm, "Multimedia Signal Coding and Transmission", Berlin: Springer-Verlag, 2015. *Covers image, video, and audio signal processing and coding, consistent mathematical treatment, very comprehensive.*

D. S. Taubman, M. W. Marcellin, "JPEG2000 Image Compression Fundamentals, Standards and Practice", Boston: Kluwer Academic Publisher, 2002. *Introduction into image source coding principles, followed by description of JPEG and JPEG2000 standards, extensive treatment.*

Y. Wang, J. Ostermann, Y.-Q. Zhang, "*Video Processing and Communications*", Upper Saddle River: Prentice Hall, 2002. *Covers recent developments in object-based coding, vector notation takes getting used to.*

T. Strutz, "Bilddatenkompression", Wiesbaden: Vieweg und Teubner, 4. Aufl. 2009. *Comprehensible reference book in German, contains numerous practical examples and also source code.*

References

Textbooks on video coding standards

M. Wien, "High Efficiency Video Coding", Berlin: Springer-Verlag, 2015. *Very illustrative textbook on most recent video compression standard HEVC, written by an active participant in standardization work.*

K. R. Rao, Do Nyeon Kim, Jae Jeong Hwang, "Video Coding Standards", Dordrech: Springer, 2014. *Comprehensive book on various recent video coding standards such as H.264, H.265, also includes AVS China and VP10.*

V. Sze, M. Budagavi, G. J. Sullivan, "High Efficiency Video Coding (HEVC)", Cham: Springer, 2014. *Companion to the formal text specification and reference software of most recent video coding standard HEVC.*

K. R. Rao, J. J. Hwang, "Techniques and Standards for Image, Video, and Audio Coding", Upper Saddle River: Prentice Hall, 1996. *Helpful reference book on earlier versions of MPEG and ITU standards, also covers audio*.

References

Background textbooks on digital image and video processing

J. W. Woods, "Multidimensional Signal, Image, and Video Processing", Amsterdam: Academic Press, 2nd edition, 2012.

R. C. Gonzalez, R. E. Woods, "Digital Image Processing", Upper Saddle River: Pearson Education, 3rd edition, 2008.

A. K. Jain, "Fundamentals of Digital Image Processing", Englewood Cliffs: Prentice Hall, 1989.

Mathematical background reading

T. Berger, "Rate Distortion Theory", Englewood Cliffs: Prentice Hall, 1971.

N.S. Jayant, P. Noll, "Digital Coding of Waveforms", Englewod Cliffs: Prentice Hall, 1984.

R. M. Gray, "Source Coding Theory", Dordrecht: Kluwer, 1990.

A. Gersho, R. M. Gray, "Vector Quantization and Signal Compression", Dordrecht: Kluwer, 1992.

Structure of the Course

1 Introduction
2 Multi-Dimensional Sampling
3 Entropy and Lossless Coding
4 Statistical Dependency (T.4, T.6)
5 Quantization
6 Predictive Coding (JPEG-LS)
7 Transform Coding
8 Subband Coding
9 Visual Perception and Color
10 Image Coding Standards (JPEG, JPEG2000)
11 Interframe Coding
12 Video Coding Standards (MPGE-x, H.26x)

1 Introduction

1.1 Application Examples

Action cam

Tablet PC

Smartphone

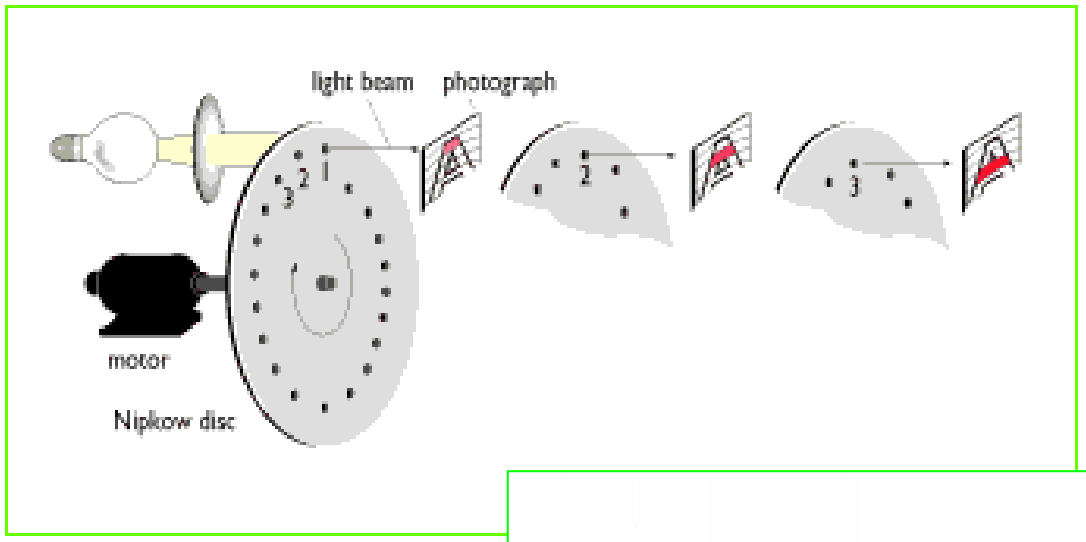
Laptop Computer

Home entertainment

Smartwatch

Digital camera

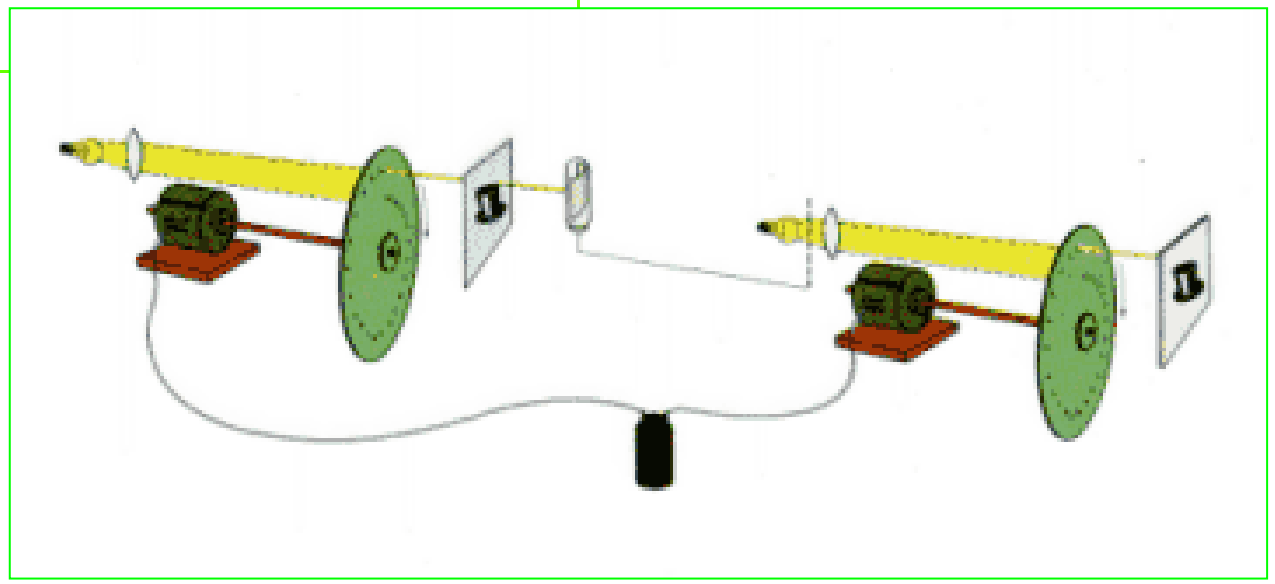
1.2 Historic Breakthroughs: Nipkow Disk



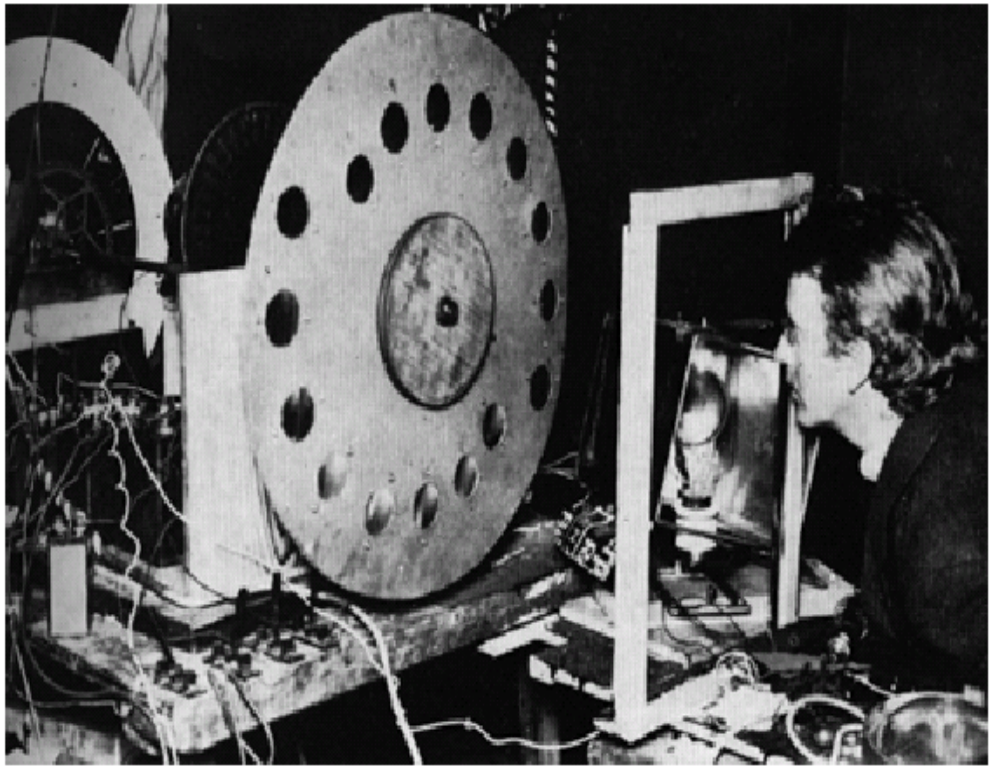
Line scanning through spirally located wholes

Invented by Paul Nipkow, 1883

Synchronously rotating disks at both ends



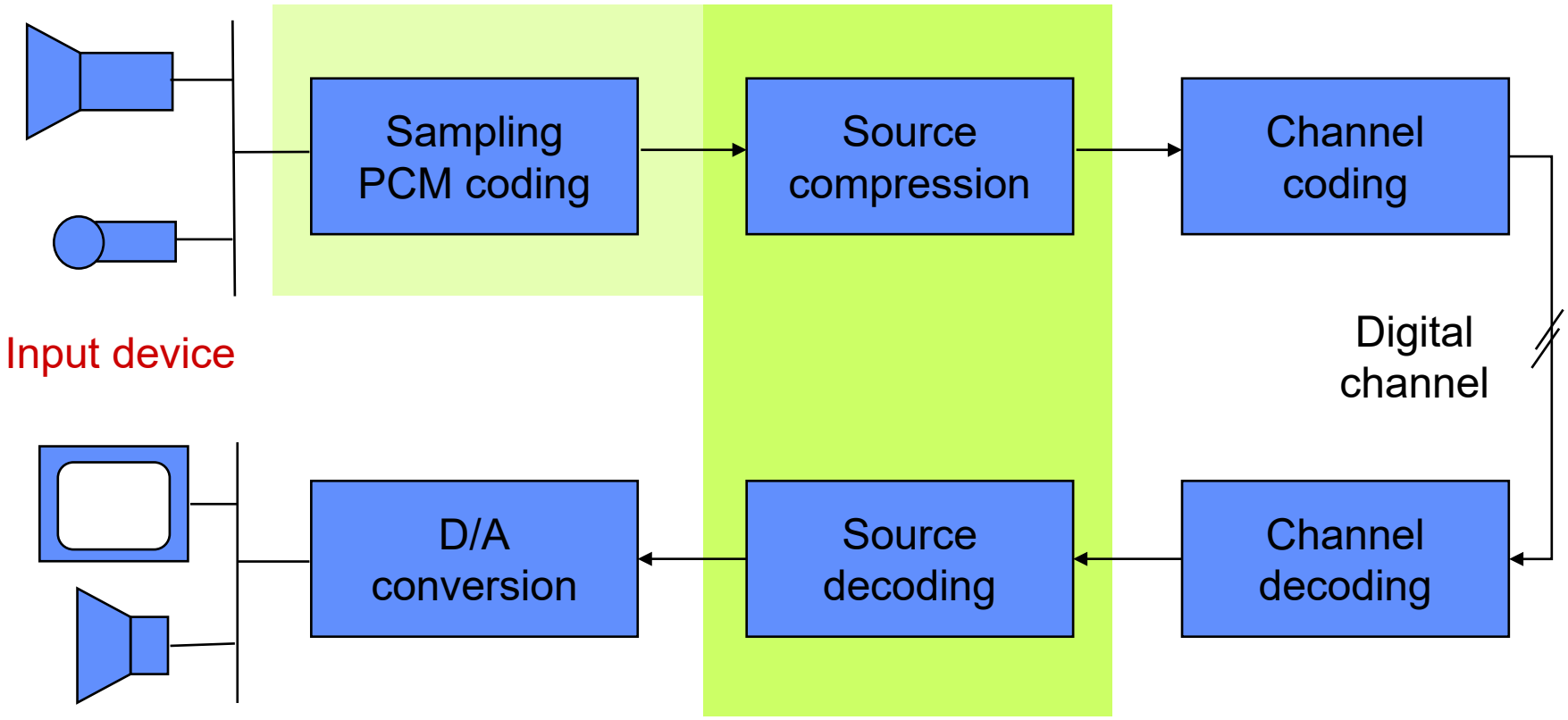
Nipkow Disk



Scottish TV pioneer John L. Baird
with Nipkow disk, around 1926

30 line television from
BBC public television
service, around 1930

1.3 Image / Video Transmission System



- Source coding compresses PCM coded input signal
- Channel coding adds data for error resilience

Digital Video Formats

	VGA	ITU-R BT.601 SDTV	ITU-R BT.709 HD	ITU-R BT.2020 UHD
Pixels / Line	640	720	1920	3840 / 7680
Lines	480	576	1080	2160 / 4320
Color sampling	4:2:0	4:2:2	4:2:2	4:2:0 - 4:4:4
Frame structure	P	I	P/I	P
Aspect ratio	4:3	4:3	16:9	16:9
Frame rate [Hz]	24-60	25	24-60	24-120
Bit depth [bit]	8	8	8-10	10-12
Raw data rate:				
Frame [kbyte]	450	810	4,050-5,063	$30{,}375\text{-}145 \cdot 10^3$
Seq. [Mbit/s]	88-297	166	796-2,488	$2{,}986\text{-}143 \cdot 10^3$

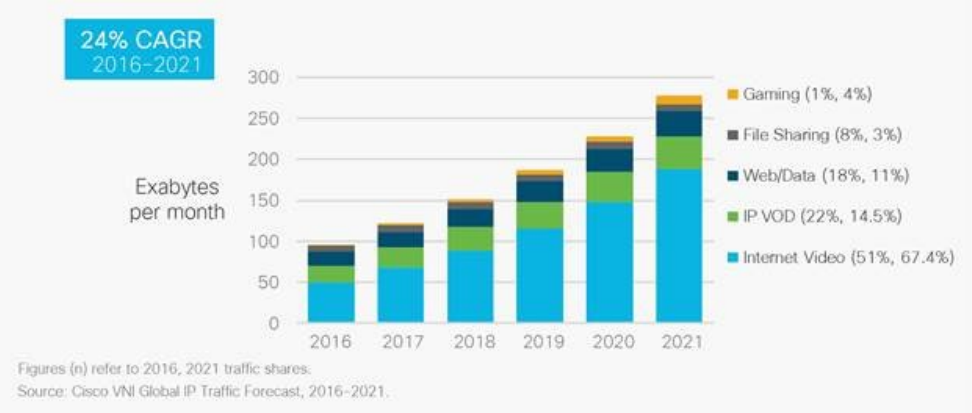
Examples of Storage Media

Media	Type	Capacity
Floppy Disk	Magnetic	1.44 MB
Zip Disk	Magnetic	100 MB
Jaz Disk	Magnetic	1 GB
CD-ROM	Optical	650 MB
DVD-120mm	Optical	4.7 GB
Blu-ray	Optical	27 GB
SD Memory Card	Solid State	~ 64 GB
Solid State Drive	Solid State	~ 512 GB

Examples of Transmission Media

Media	Typical data rate
Dial-Up Telephone	33.6-56 kbit/s
ISDN (Integrated Services Digital Network)	64 kbit/s
T1 (24xISDN)	1.544 Mbit/s
Ethernet	10 Mbit/s
Fast Ethernet	100 Mbit/s
Ultra-Fast Ethernet	1 - 10 Gbit/s
FDDI (Fiber Distributed Data Interchange)	100 Mbit/s
IR (Infra Red)	115 kbit/s - 16 Mbit/s
LTE (Long Term Evolution, Wireless)	100 - 800 Mbit/s

1.4 Motivation for Data Compression

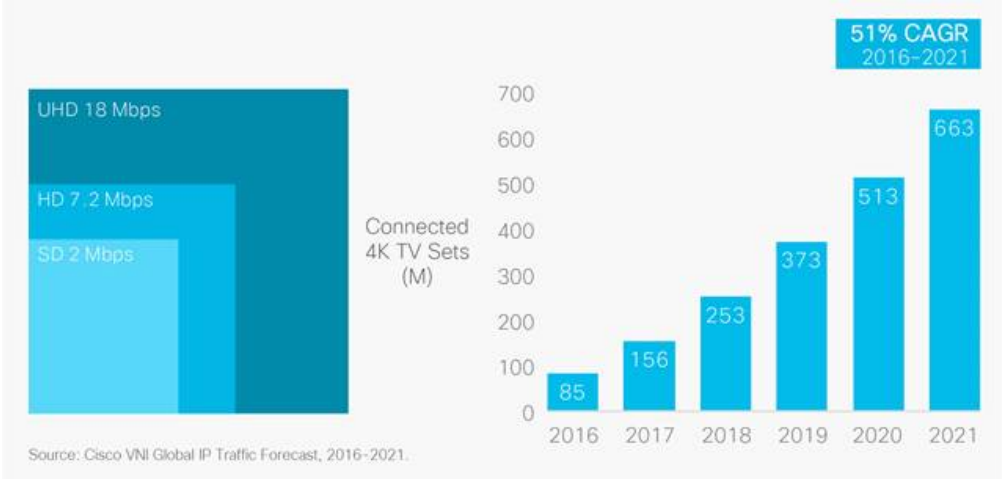


Global IP traffic by application category

IP video traffic accounts for 82 % of global traffic by 2021

Increasing video resolution

By 2021, 56 % of connected flat-panel TV sets are 4K



Motivation for Data Compression (Cont.)

Digital camera: 6000 x 4000 pixels (Full format 24 MP)
24 bit / pixel color
→ raw data 72 MB per image

Storage on SD card (32 GB)

Uncompressed: 444 pictures
Around the world trip with 5000 pictures → compression 1:11

Wireless transmission (LTE, 100 Mbit/s)

Uncompressed: 5,8 s
Transmission time of 0.5 s acceptable → compression 1:12

🗁 Demo 1 „JPEG Compression“

Motivation for Data Compression (Cont.)

Digital video: 3840 pixels / line x 2160 lines (UHD)
30 frames / s
24 bit / pixel color
→ data rate of 6 Gbit/s

Storage on media discs

One CD every second

One DVD every 6 seconds

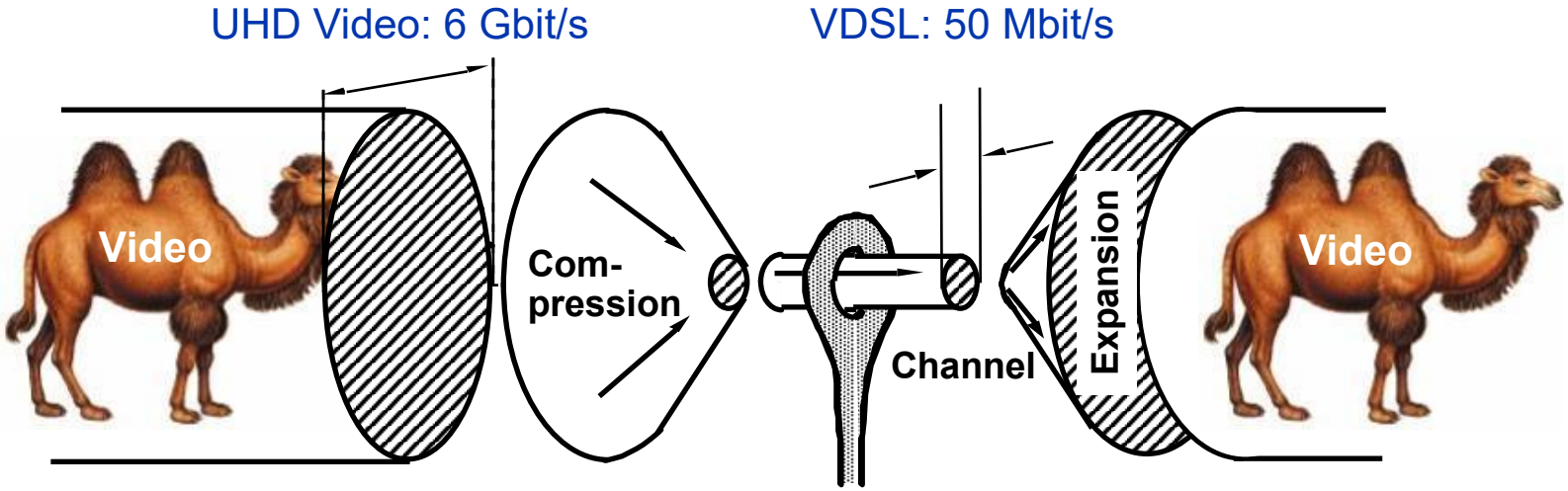
One Blu-ray disc every 36 seconds

Wired transmission (VDSL, 50 Mbit/s Downstream)

Requires 120 connections
Magenta M: 4.800 Euro / month

→ compression > 1:100

How does a camel go through the pinhole?



Goal: reduce amount of data

Constraint: maintain quality of image / video data

- Elimination of redundant information (signal)
- Reduction of irrelevant information (perception)

⇨ Irrelevancy depends on application area (e.g. medical vs. consumer area)

1.5 Principle of Image Compression

Original data

„Irrelevancy“

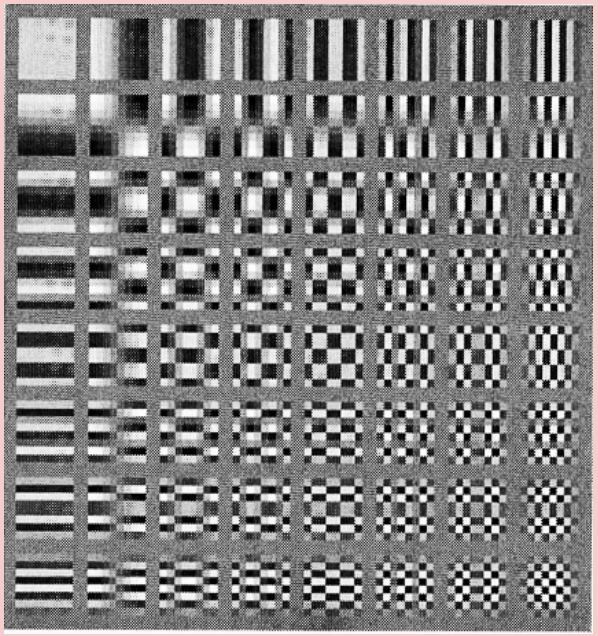
Coded data

Signal decomposition

Quantization

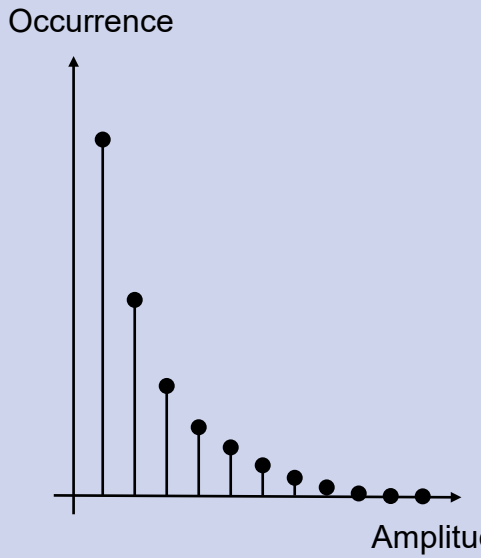
Lossless coding

Basis images for frequency analysis (DCT)



Adapted to signal statistics and perception

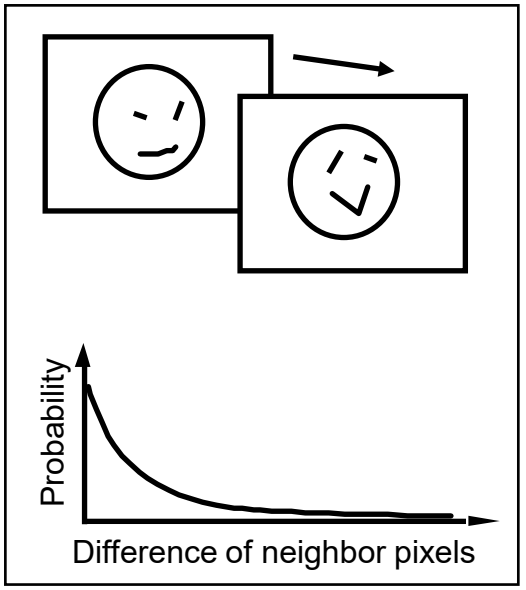
„Redundancy“



Redundancy Reduction

Principle: exploiting

- distribution redundancy of symbols
- spatial correlation
  "correlation of neighboring samples"
- temporal correlation
  "similarity of successive frames in a video"



Entropy coding
- Huffman coding
- Arithmetic coding
- Run-length coding

Predictive coding
- Spatial 2D prediction
- Temporal prediction
- Motion compensation

Decorrelation
- Transform coding
- Subband coding
- Wavelet coding

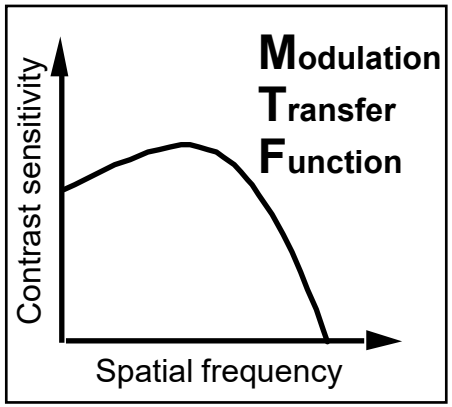
Irrelevancy Reduction

Principle

- Reducing data by information which is unimportant to receiver
- Exploiting limitations of human visual system

Methods

- Quantization
- Thresholding
- Temporal subsampling
- Color subsampling
- Vector quantization



Constraints for Image and Video Compression System

Application, transmission network, and terminals define the requirements for a coding system