Image Processing and Visual Communications

Overview II

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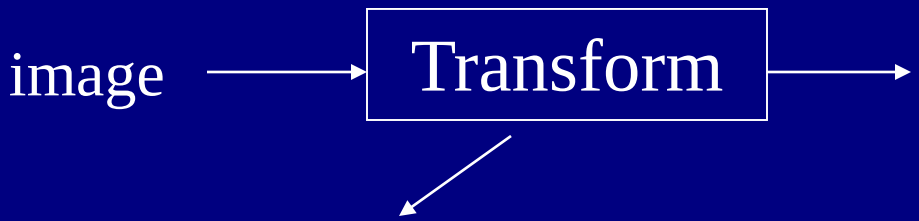
New Directions in Image Processing and Understanding

The Driving Forces

- **From Application Side**
  - Visual communications
  - Information retrieval applications
  - Medical/geology/astronomy/military/security applications ……
- **From Theory Side**
  - Image transforms
  - Image models (specifically statistical models)
  - Human visual system models
  - Knowledge-driven → data-driven approaches (machine learning, data mining ……)

Why Image Transforms?



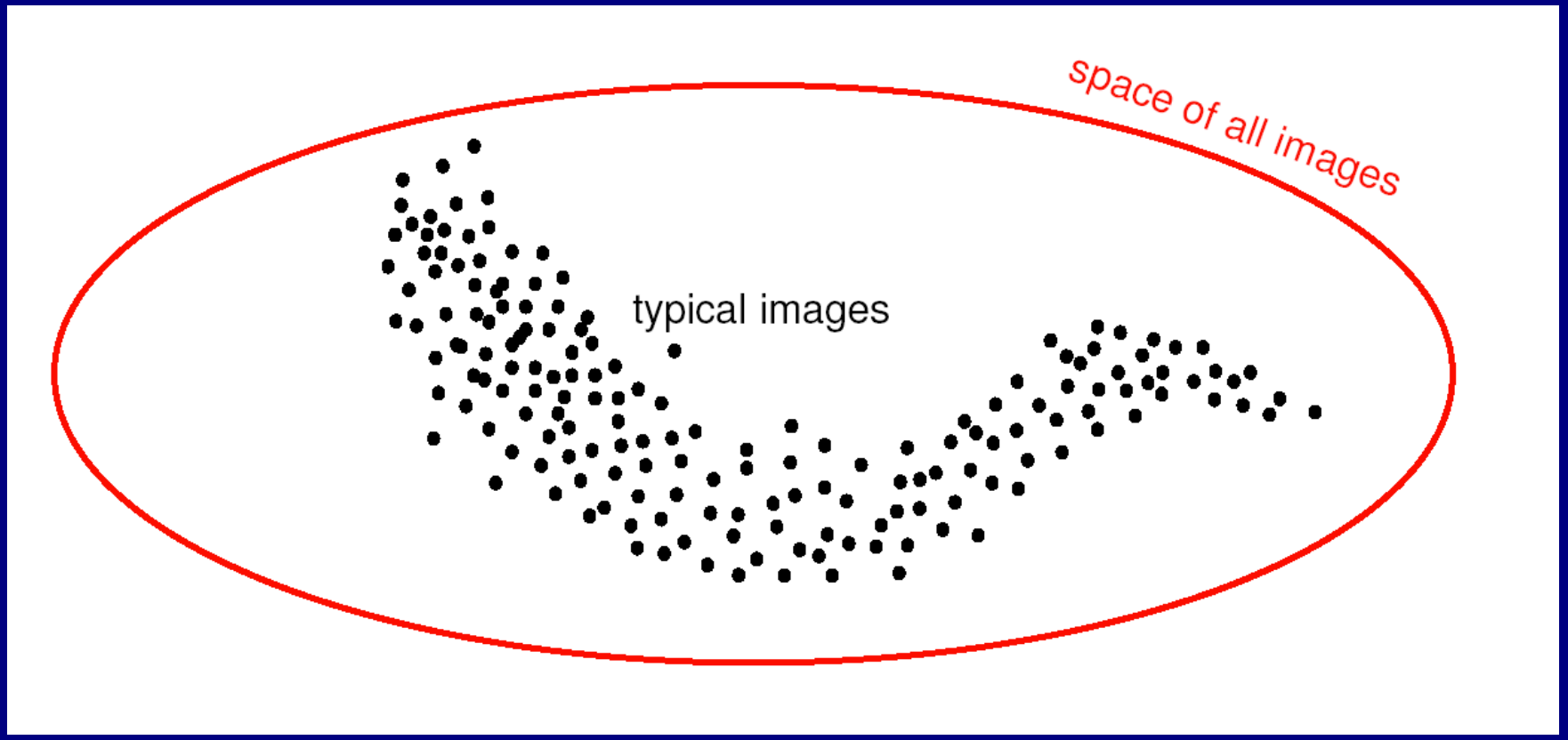
Desired properties:

- Invertible?
- Energy preserving?
- Linear phase?
- Compact support?
- ……

What's the gain?

- Energy compaction?
- Sparsity?
- Low entropy?
- Independence?
- ……

Why Statistical Image Models?



Strong PRIOR: typical (natural) images occupy an extremely tiny space in the space of all images. Why?

Courtesy: Dr. Eero P. Simoncelli

Why Human Visual System Models?

[Wang & Bovik '02]

Which distorted images have better quality?

Original Image

MSE=225

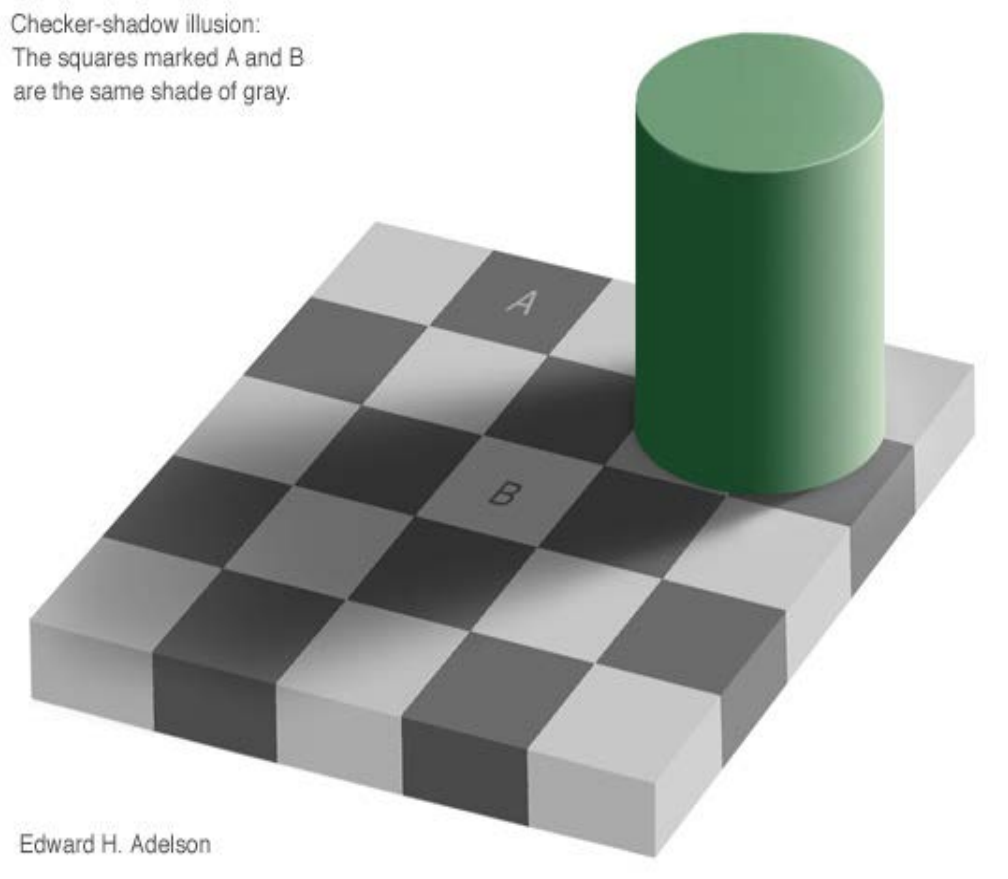
MSE = 225

MSE = 215

MSE=225

MSE = 225

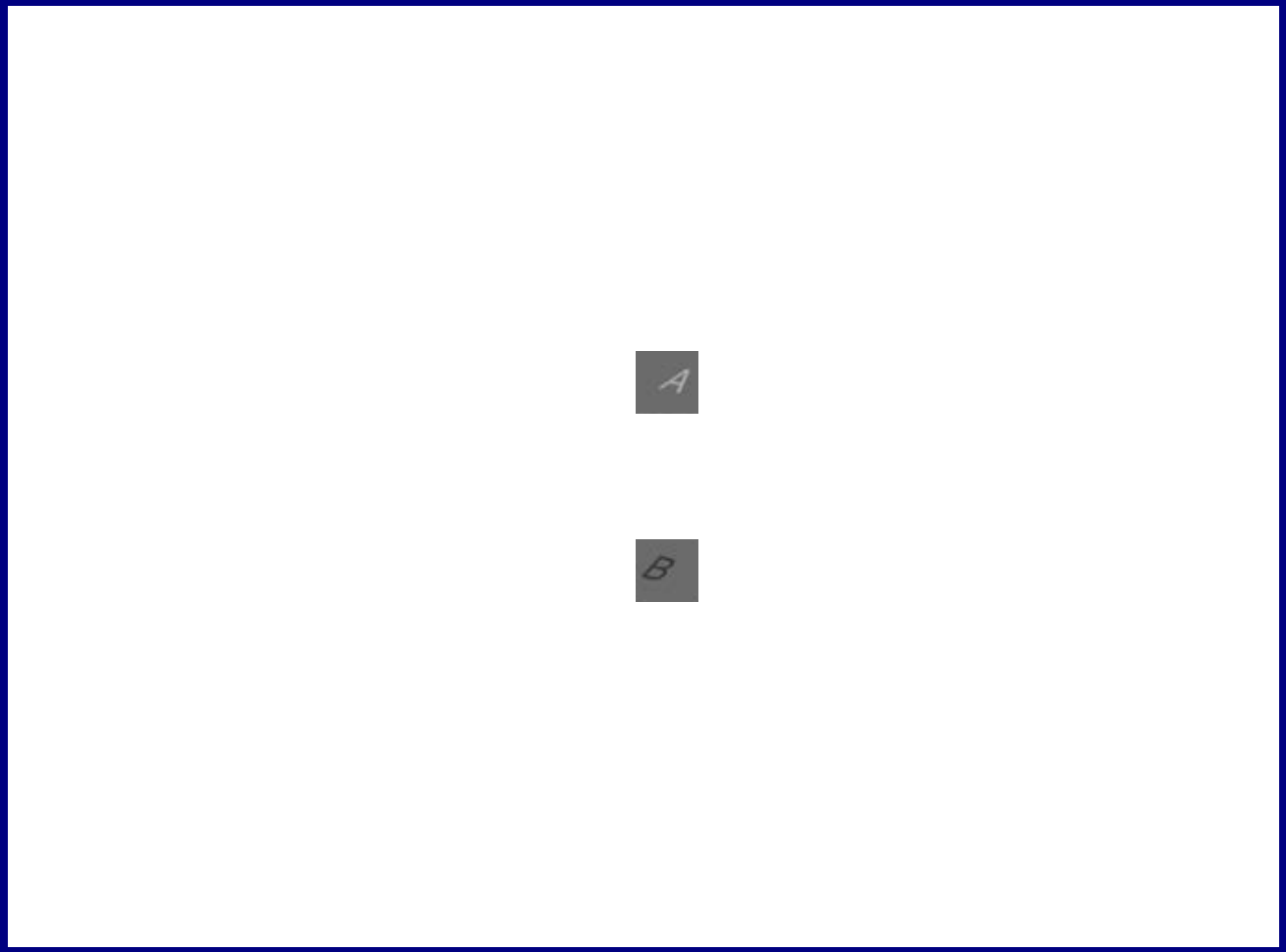
Visual Illusion



Visual Illusion

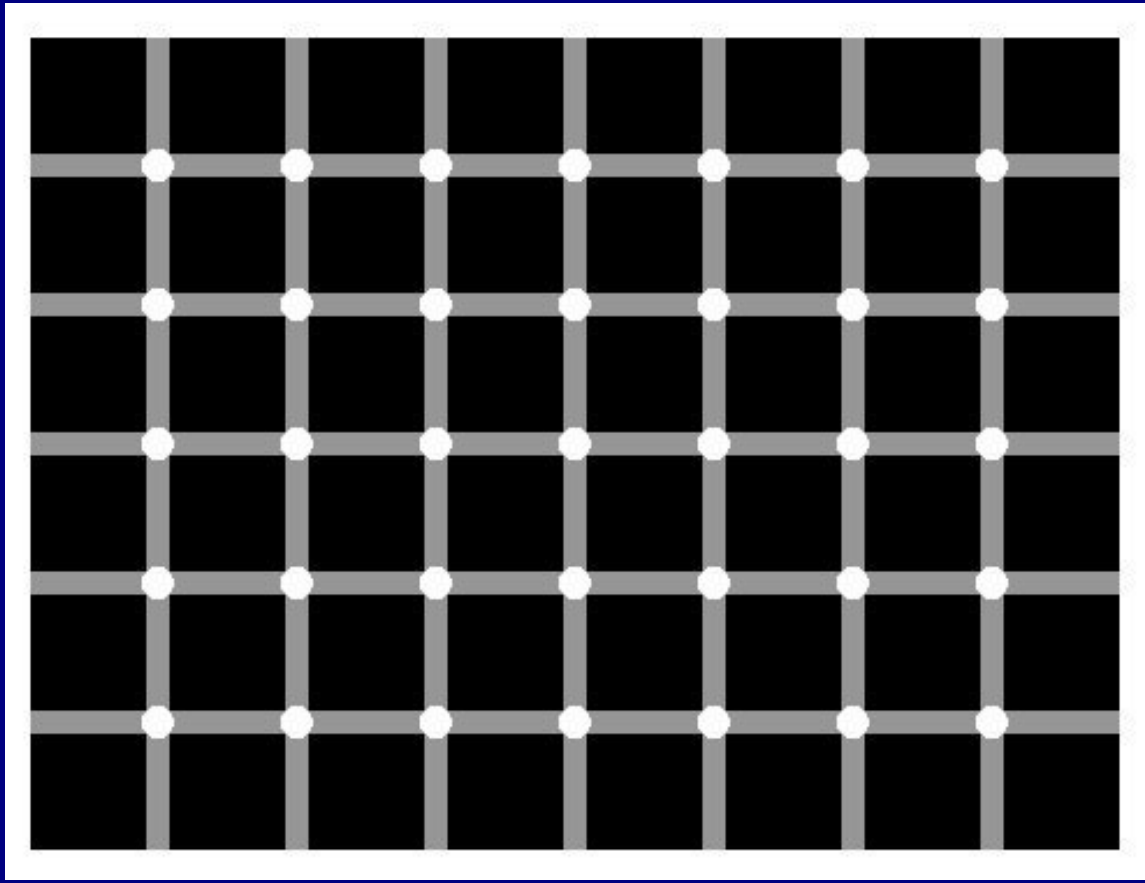
A and *B* – the same shade of gray

Visual Illusion



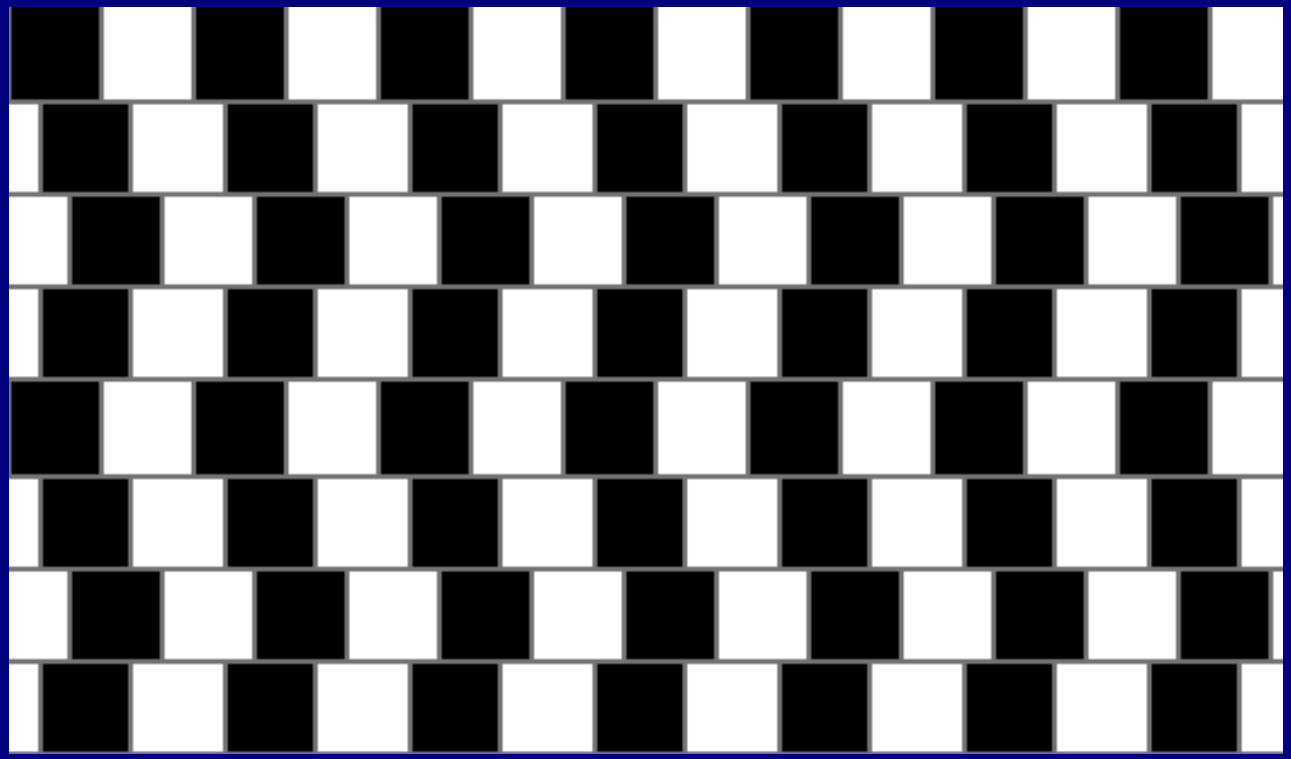
A and *B* – the same shade of gray

Visual Illusion



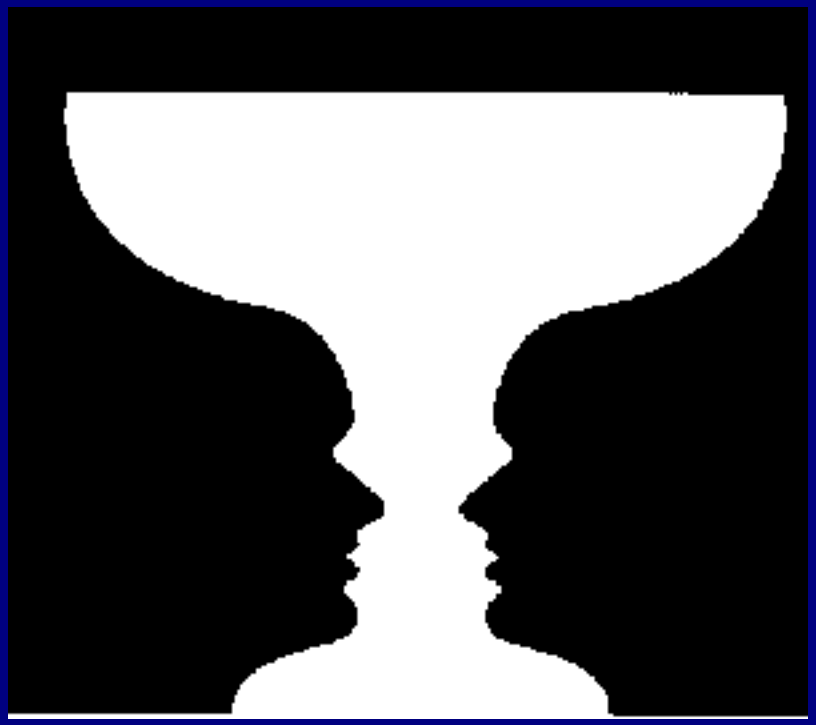
Find the black dot

Visual Illusion



Which horizontal lines are straight?

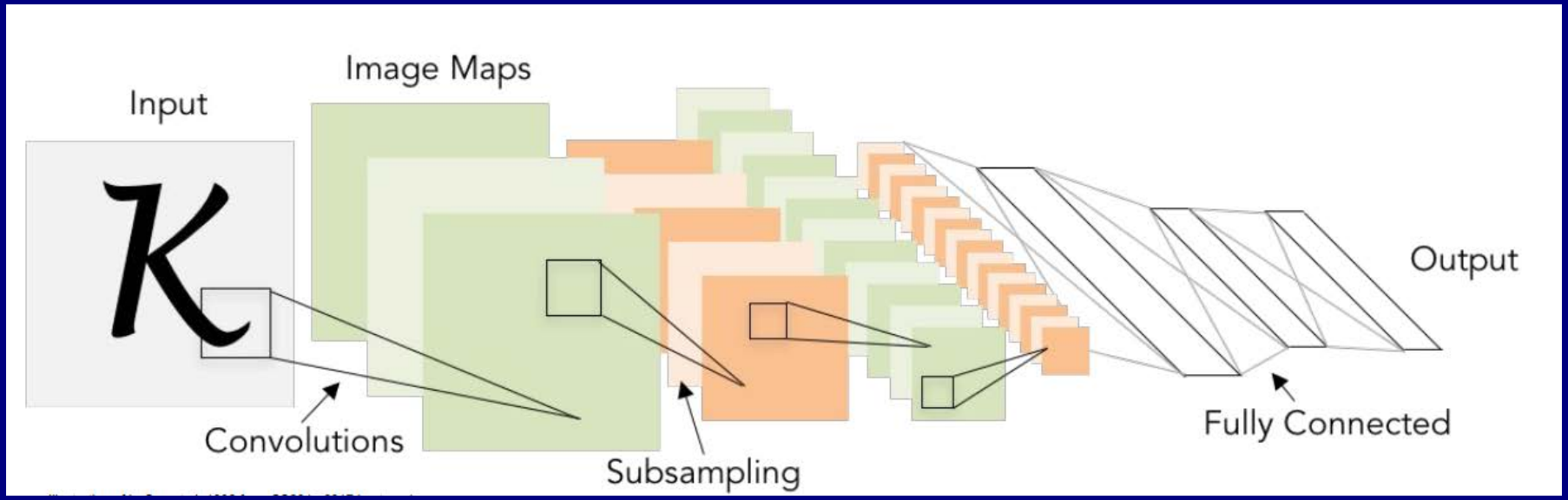
Visual Illusion



What is this?

Knowledge-Driven → Data-Driven Approaches

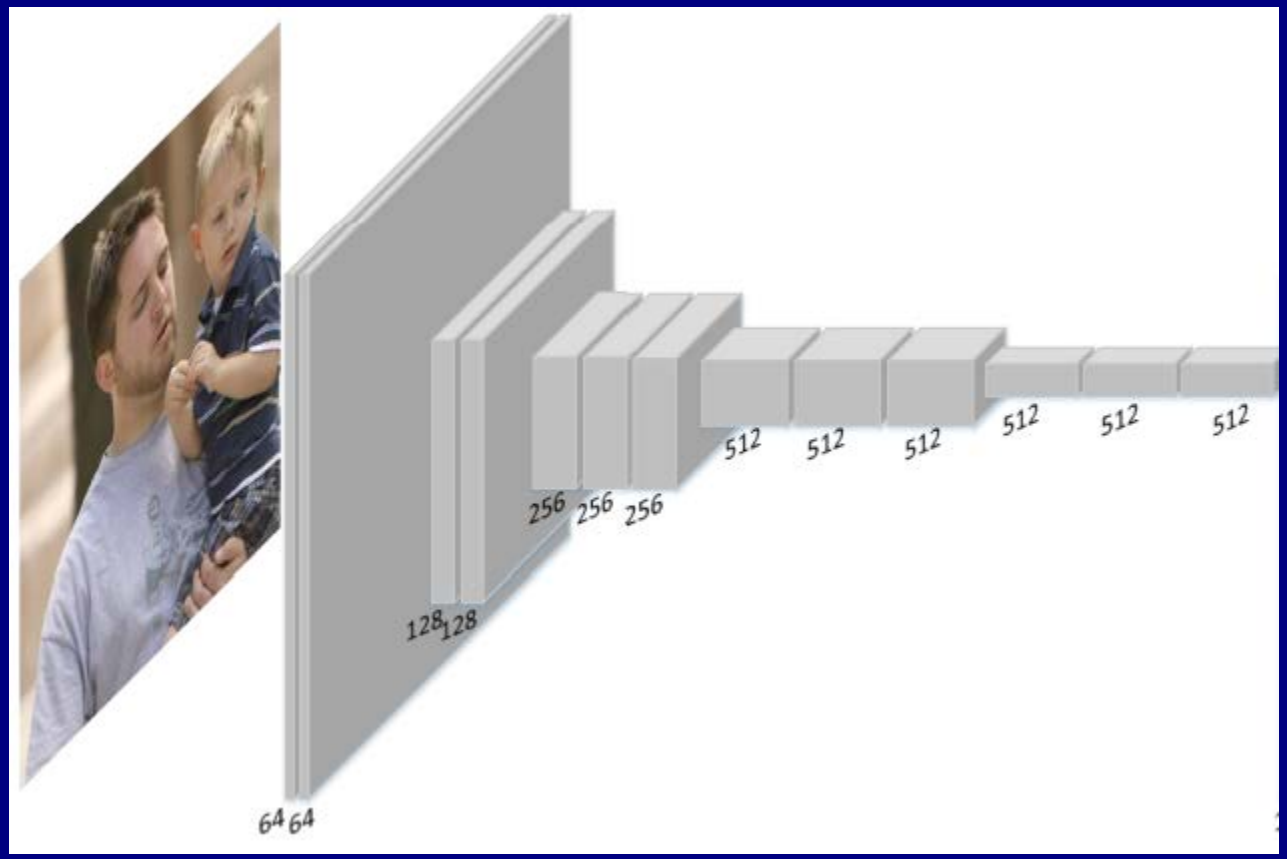
- **Disadvantages of knowledge-driven approaches**
  - Require deep domain knowledge
  - Too difficult for complex problems
- **Data-driven approaches**
  - Collect sufficient (big) data and learn rules from data



LeNet: Convolutional Neural Network (CNN) [LeCun '99]

Knowledge-Driven → Data-Driven Approaches

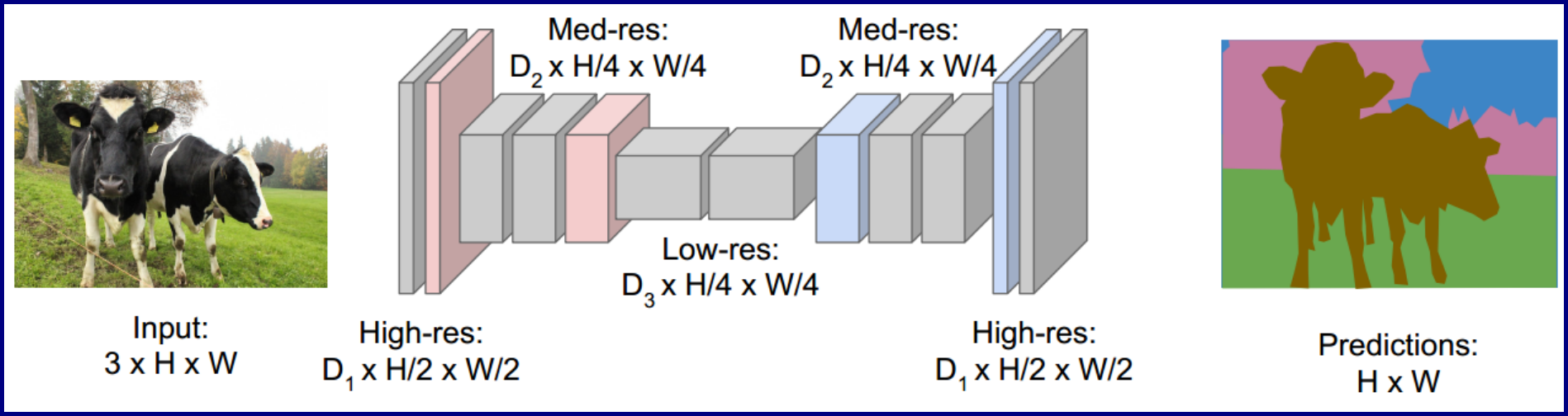
- **Deep neural networks (DNN)**
  - Rules learned and embedded in weights of networks



VGG network [Simonyan & Zisserman '14]

Knowledge-Driven → Data-Driven Approaches

- **DNN – applicable to different scenarios**
  - Image to feature mapping
    object detection, recognition, …
  - Image to image mapping
    segmentation, compression, …



Semantic segmentation [Long *et al.* '15] [Noh *et al.* '15]

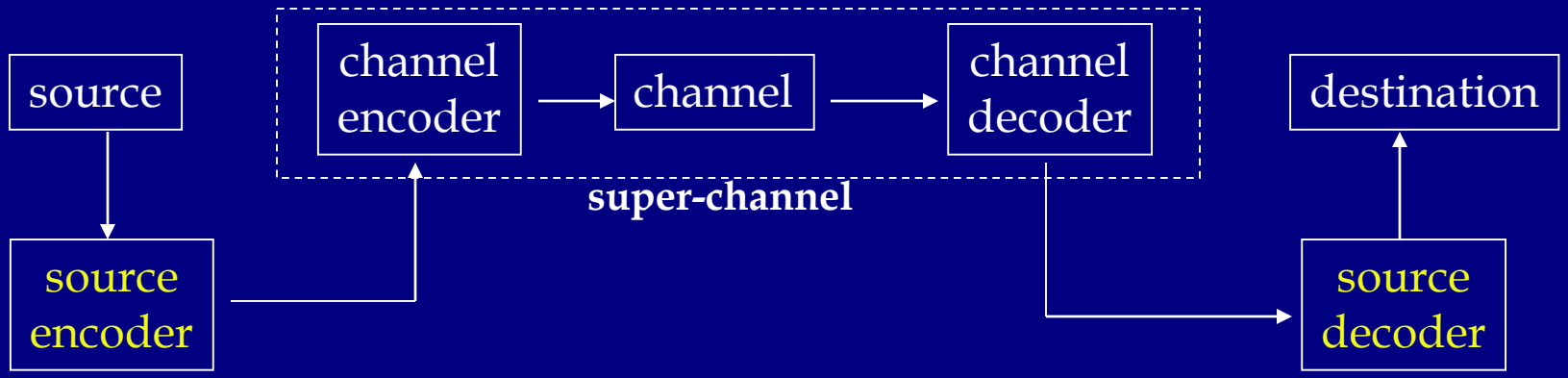
Knowledge-Driven → Data-Driven Approaches

- **Limitations of data-driven approaches**
  - Weak interpretability
  - Weak transferability
  - The data challenge
  - ……

How many dogs does an NN need to see before it is able to recognize a dog?

Visual Communications

Shannon's Picture of Communication (1948)



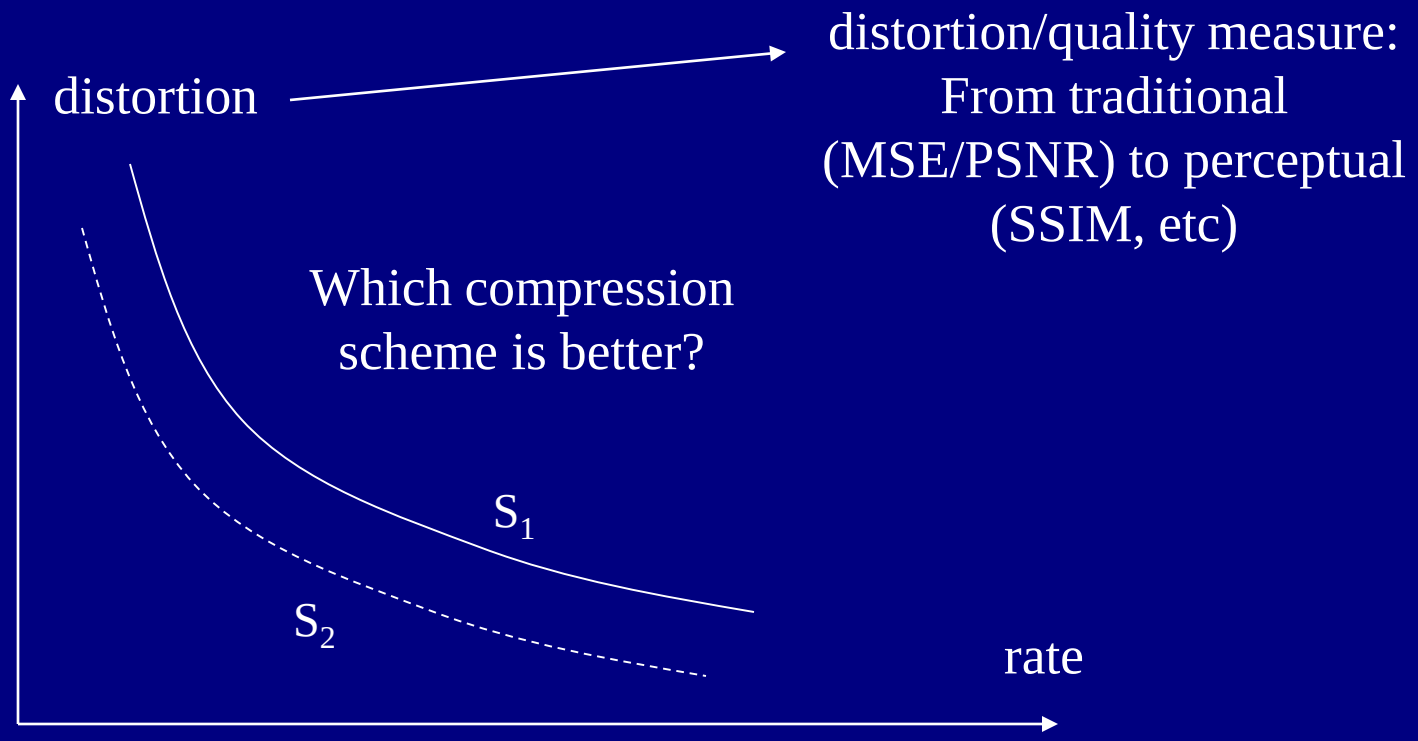
The goal of communication is to move information from here to there and from now to then

Examples of source:
Human speeches, photos, text messages, videos …

Examples of channel:
storage media, wired network cables, wireless transmission …

Traditional Problems in Visual Communication

- **Compression-Distortion Tradeoff**



- **Complexity/Cost**
  - Encoder/decoder speed and power consumption; memory requirement; software/hardware implementation complexity …

Image Compression

original image
262144 Bytes

From [Gonzalez & Woods]

From [Gonzalez & Woods]

image encoder

compressed bitstream
0011100001001101…
(2428 Bytes)

image decoder

compression ratio (CR) = 108:1

Image Compression

- **Lossless image compression**
  - Information preserving
    original image can be exactly recovered
  - Low compression ratio
  - JPEG-LS, JBIG …

- **Lossy image compression**
  - Lose information
    original image can be recovered, but not the same
  - High compression ratio
  - JPEG, JPEG2000 …

From JPEG to JPEG 2000

discrete cosine transform based

JPEG (CR=64)

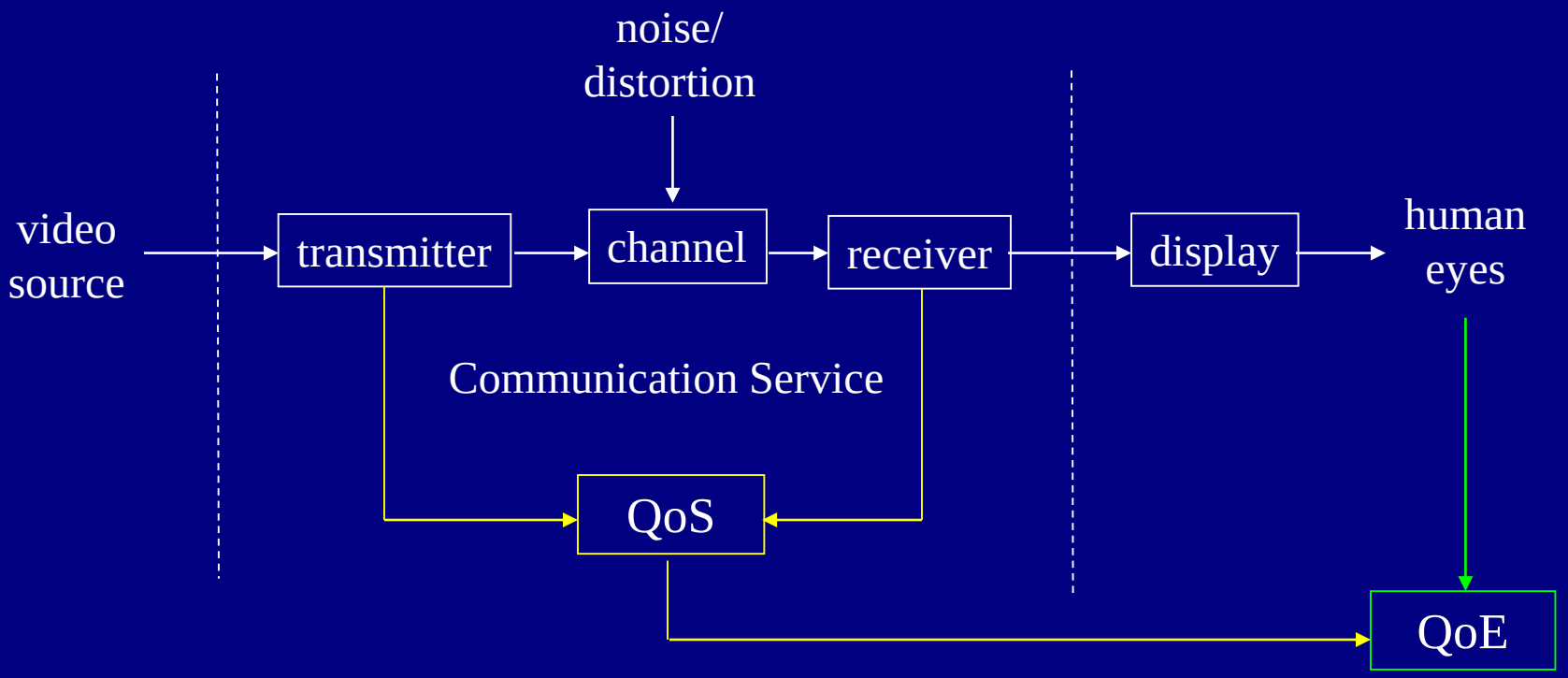
wavelet transform based

JPEG2000 (CR=64)

Courtesy: Dr. Xin Li

Advanced Problems

- **Quality**
  - Quality-of-Service (QoS) vs. Quality-of-Experience (QoE)

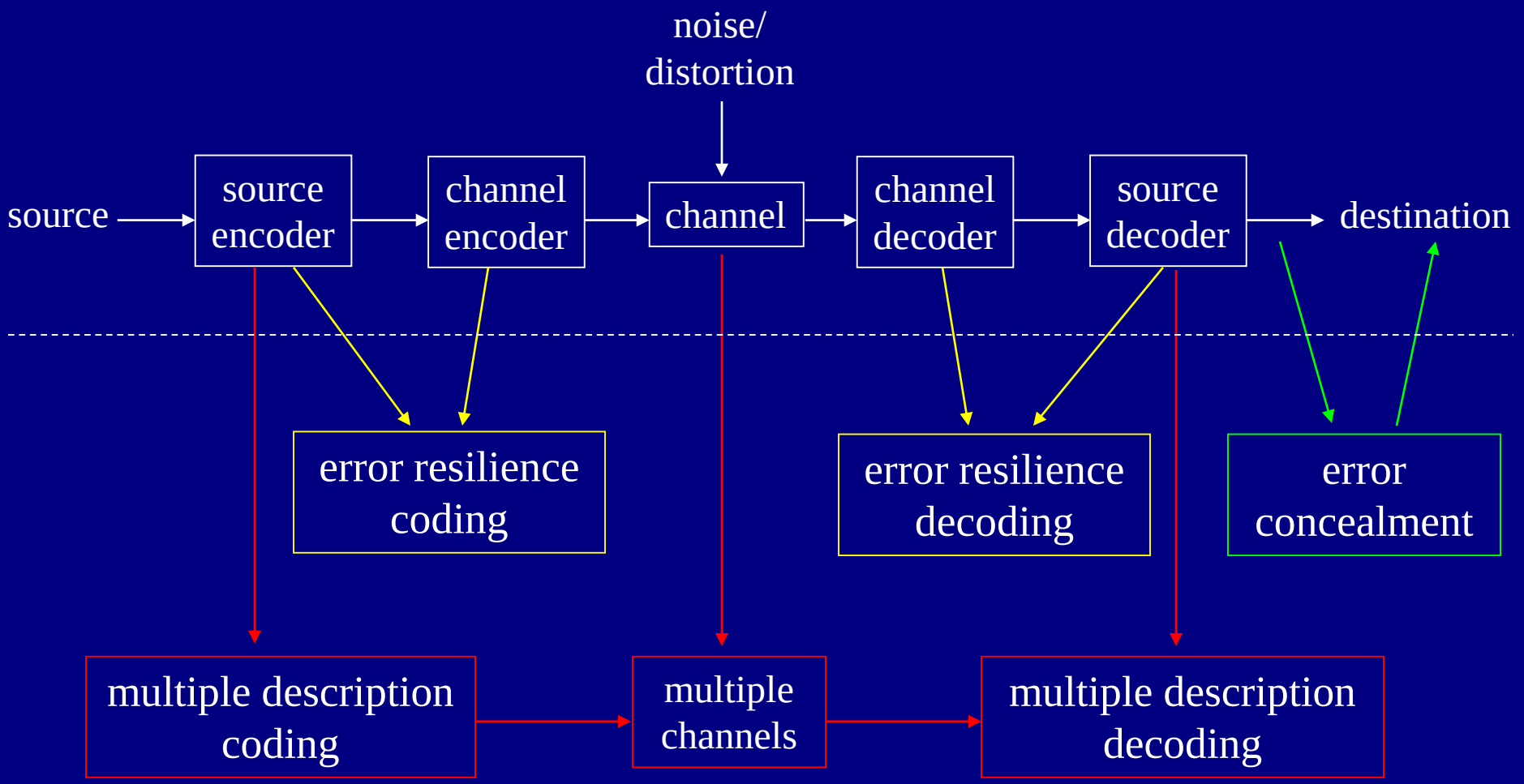


QoS factors: bitrate, error rate, package loss, delay, etc.

QoE factors: visual quality, freezing, display factor, etc.

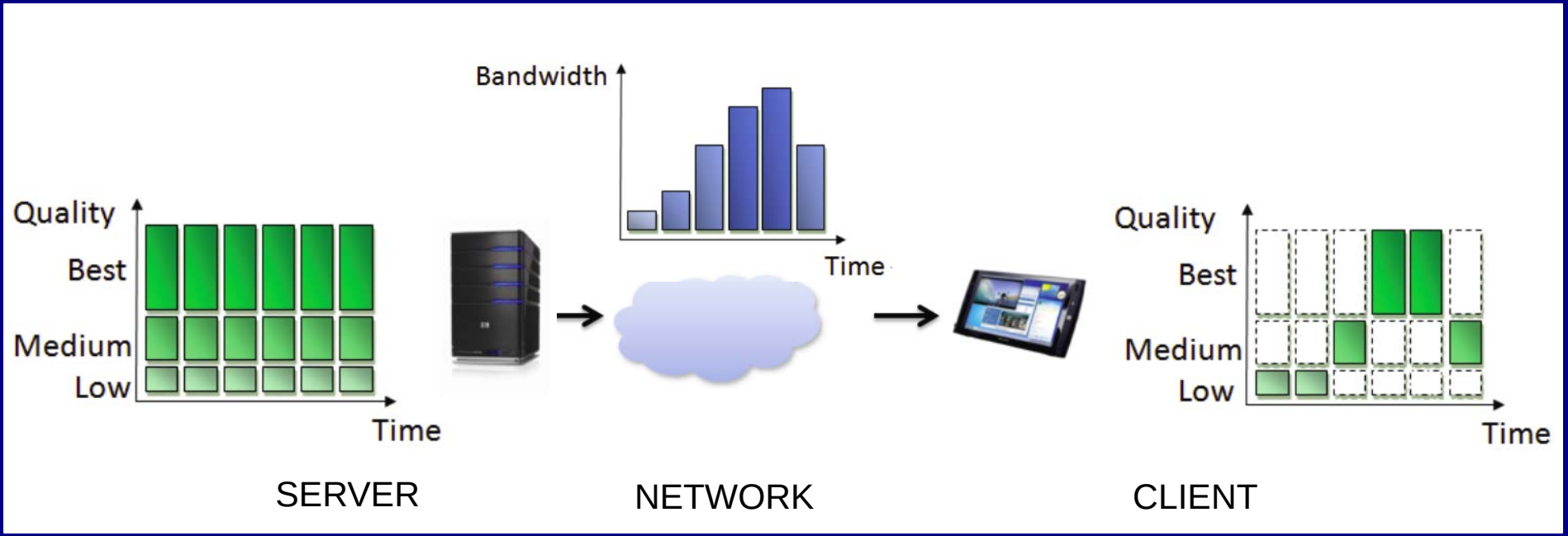
Advanced Problems

- **Robustness**



Advanced Problems

- **Robustness**
  - Error-resilient streaming
  - Adaptive bitrate (ABR) video steaming



Adapted from [Timmerer '16]

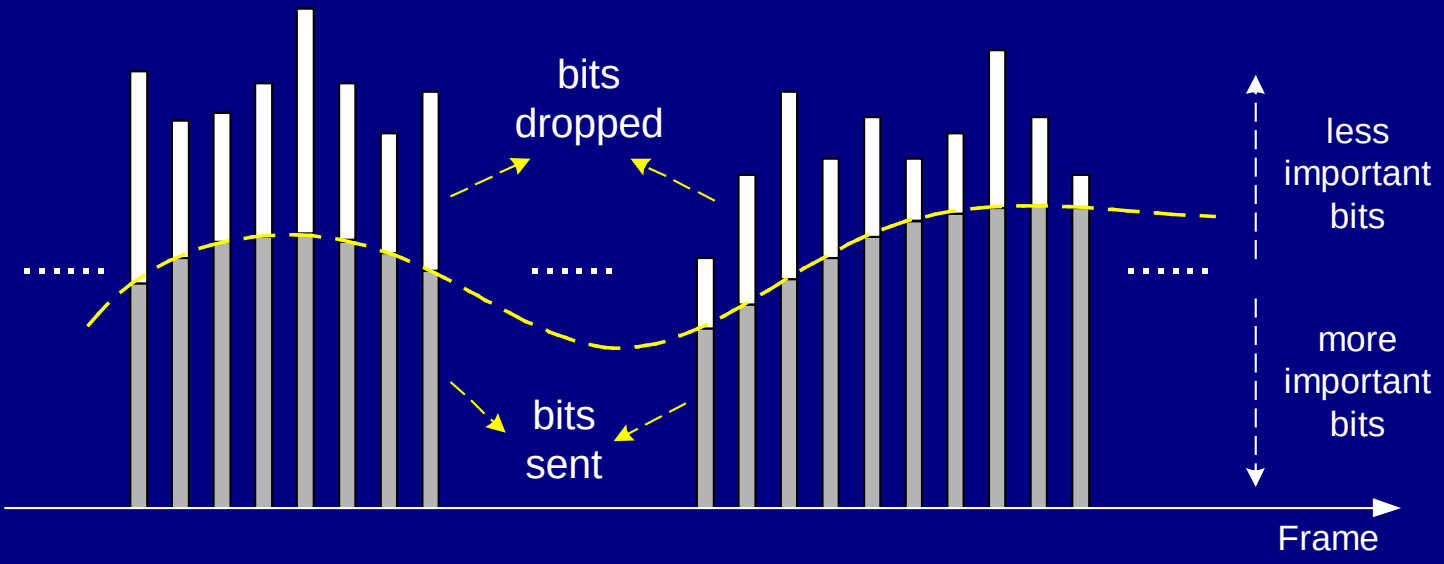
Advanced Problems

- **Scalability**
  - Goal: meet variable bandwidth requirement
  - Solutions:

    Repeated encoding

    Layered video

    Continuously scalable coding (research in progress)



Advanced Problems

- **Security**
  - Copyright protection
  - Data authentication

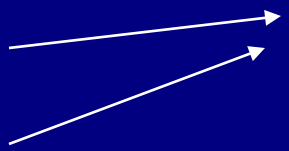


image watermarking
data hiding
cryptograph

- **Distributability**
  - Networking
- **Searchability**
  - Image annotation
  - Feature-based image/video retrieval/hashing
- **Editability**
  - Object-based coding
  - Image rendering