Distributed Source Coding:
A New Paradigm for Wireless Video ?

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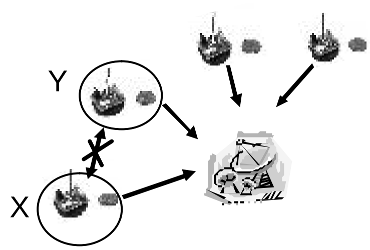
The distributed sensor network problem

- How to compress multiple correlated sensor outputs that do not communicate with each other?
  - capturing the redundancy in dense sensor networks

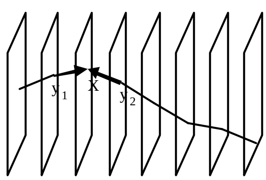


- Let us consider two sensors X, Y capturing correlated data:
  - **Can we exploit correlation between X & Y without communicating between the two sensor nodes?**
    - Communication between nodes consume energy and bandwidth

Video Compression so far …

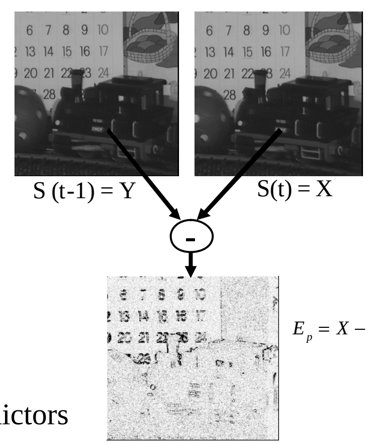
Applications

- Storage (CD, DVD)
- Broadcasting
- Streaming video-on-demand
- …



The answer today:

Motion-based predictive coding (MPEG-x, H.26x)



$$E_p = X - f(\hat{Y}_1, \ldots, \hat{Y}_M)$$

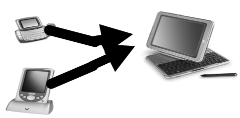
- Motion-based search of best predictor by coder
- Computes a prediction error
- Motion fields and prediction error transmitted
- Given the motion fields, the decoder can find the predictors

High compression efficiency, High encoding complexity
High sensitivity to transmission noise

The wireless video problem …
analogy with the sensor network problem

Wireless scenario

- Wireless digital cameras
- Mobile phones, PDA's
- Low-power video sensors
- Wireless video teleconferencing



Challenges:

- Narrow bandwidth
  - high compression efficiency
- Limited handheld battery power
  - low end-device (encoder) complexity
- Lossy & erroneous medium
  - Robustness to transmission impairments

Re-thinking the classical motion-based predictive coding paradigm !

-Adjacent frames as correlated 2D camera sensor data
- X, Y modelled as sequences of correlated Random Variables.

➢ Can the encoder compress X without knowing the realization of Y, but only the pmf(X|Y), with performances matching the classical predictive paradigm?

➢Separate coding => decreased encoder complexity, in-built resilience

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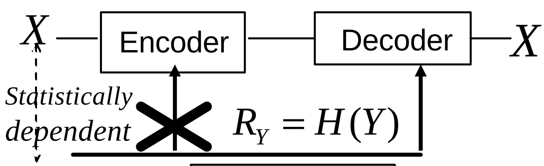
Outline

- Asymptotic answers from information theory
- Constructive solutions based on the analogy with the channel coding problem
- A range of applications
- Application to wireless video compression

Asymptotic answers

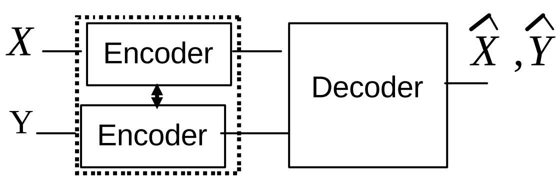
Lossless Case

Coding with side information



$$R_X \geq H(X \mid Y)$$

Slepian-Wolf theorem (1973)

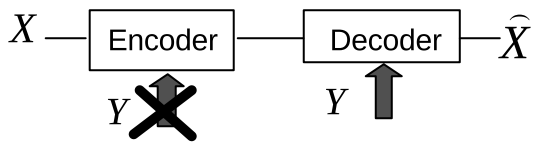


$$R_X + R_Y = H(X,Y)$$

with vanishing error probability if sequences Sufficiently long.

Lossy Case

Wyner-Ziv Theorem (1976)



$$R \geq R_X(D_X)$$

$$R \geq R_{X/Y}(D_X)$$

$$R_X \geq R^{WZ}_{X|Y}(D_X) \geq R_{X|Y}(D_X)$$

(Rate loss)

Equality under the Gaussianity assumption and with MSE as distortion measure

Don't forget: X and Y will be adjacent frames in the sequence!!

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Constructive solutions based on the analogy with the channel coding problem

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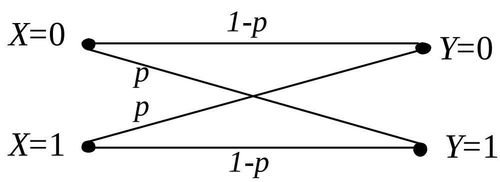
Analogy with the channel coding problem

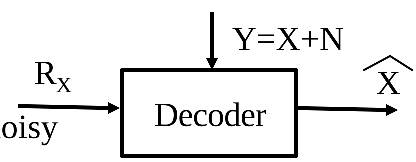
- The correlation between X and Y can be modeled as a *virtual channel*

Examples: **Binary Symmetric *virtual* Channel** | **AWGN *virtual* Channel**



$$H(Y \mid X) = -p.\log_2(p) - (1-p).\log_2(1-p)$$

Y= X + N ; P(Y/X)



- ➢ Side Information Y seen as a noisy observation of X
- ➢ Minimum number of bits R_X to estimate X from the noisy observation Y

- Near-capacity channel codes to approach the S-W limit

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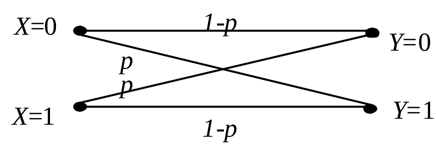
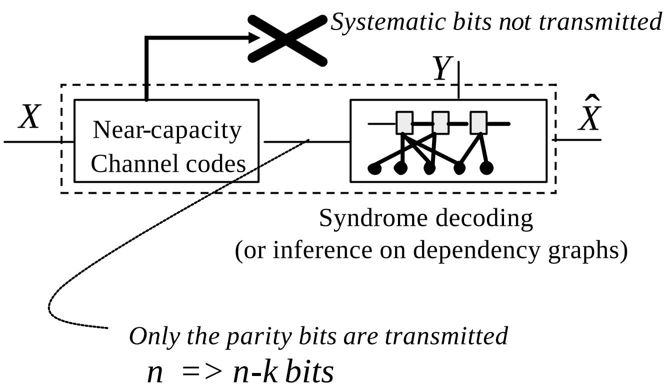
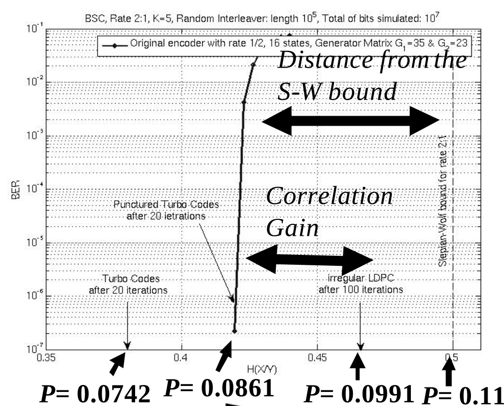
Slepian-Wolf Coder/Decoder Design

- Code adapted to the correlation virtual channel
  - How to compress?: extract from X the minimum information so that the decoder can estimate X given Y



For p=0.11, S-W bound: H(X/Y)=0.5

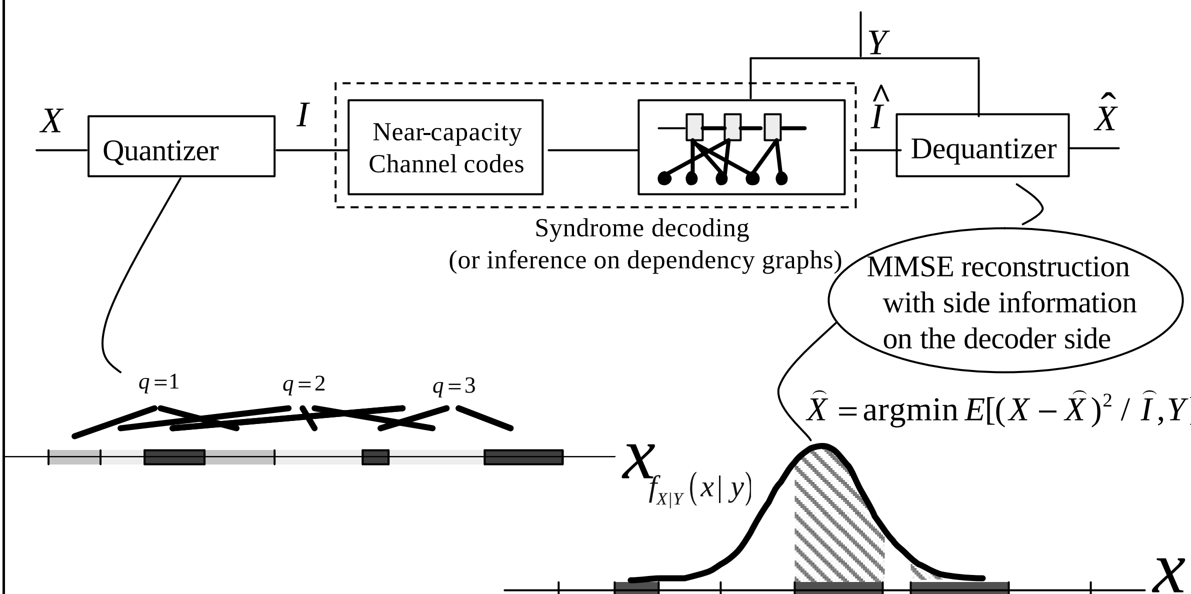




Compressing X at R_x=0.5
Measuring H(X/Y)
for vanishing error probabi
H(X/Y)= 0.4233 for p=0.08

Wyner-Ziv Coder/Decoder Design

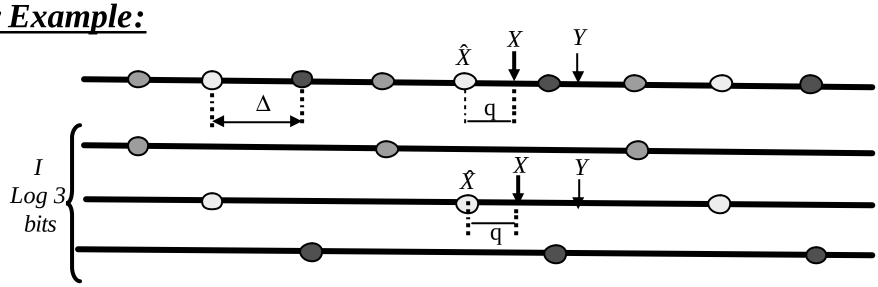
- Design a source codebook achieving the granular gain

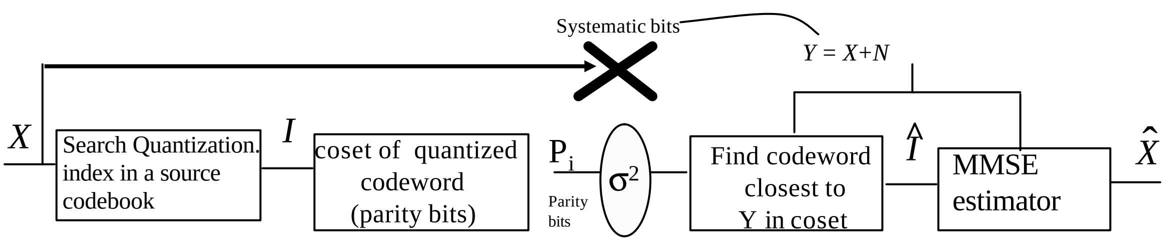


Optimum Design of W-Z Coder/Decoder: A Set Partitioning Problem

- Partitioning of the source codebook into a *good* channel code

Toy Example:





$$\hat{X} = \operatorname{argmin} E[(X - \hat{X})^2 / \hat{I}, Y]$$

A Few References …

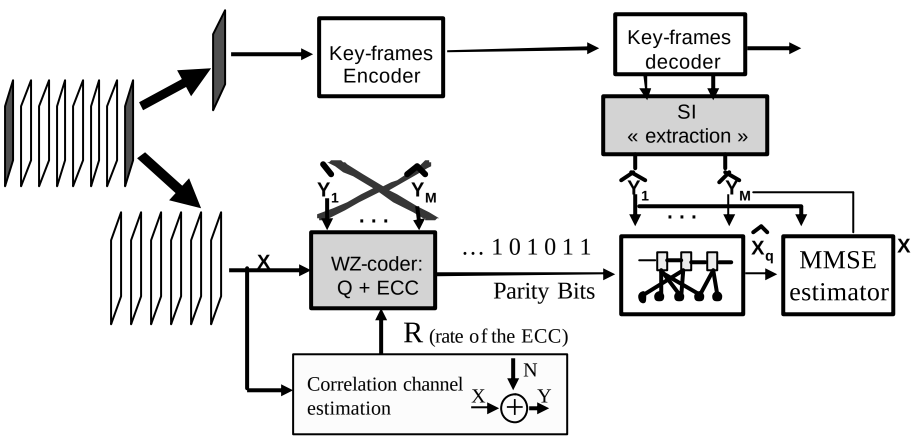
- With coset and multi-level coset codes
  - Ramchandran & Pradhan, DISCUS 99
  - Majumdar, Chou & Ramchandran 03, …
- With Turbo Codes (two or multiple binary and/or Gaussian sources)
  - Garcia-Frias & Zhao 01
  - Bajcsy & Mitran 01
  - Aaron & Girod 02
  - Liveris & Xiong 02
  - Lajnef, Guillemot & Siohan 04, …
- With Low Density Parity Check Codes
  - Liveris, Xiong & Georghiades 02,
  - Ramchandran & Pradhan 02,
  - Garcia-Frias & Zhong 03, …

Framework with a Range of Applications

- Distributed (dense) sensor networks
- Compression in embedded environments, e.g., hyperspectral compression for satellite imagery [Cheung, Wang, Ortega 05]
- **Wireless video**
- M-channel Multiple description coding [Puri et al. 04]
  - drift correction with low latency in video communication
- Multimedia security: data hiding, watermarking, steganography
  - duality between source coding and channel coding with side information
- Compression of encrypted data [Johnson et al. 04]

Distributed Coding for Wireless Video

- Low encoding complexity, No drift
  - Each frame is compressed independently (assuming only pmf (X,Y))
    - Motion-free, prediction-free transmission => no drift, error-resilience
  - Side-information Y is exploited at the decoder ONLY



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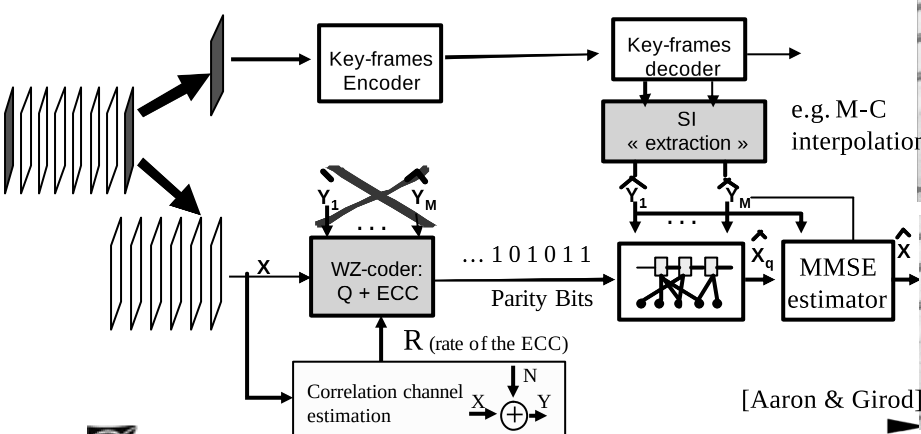
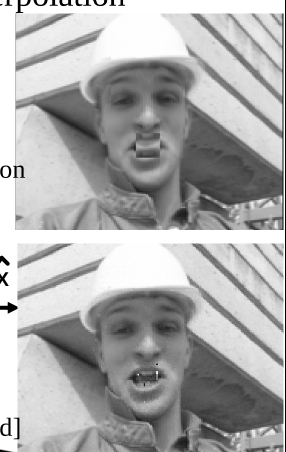
Distributed Coding for Wireless Video: …. A number of open issues

- No MSE performance loss over case when Y is available at both encoder and decoder **if the innovation of X w.r.t. Y is Gaussian**

ISSUE 1: Extraction of side information approaching at best this Gaussianity assumption AND with maximum correlation

One solution: A good motion model + Motion-compensated Interpolation





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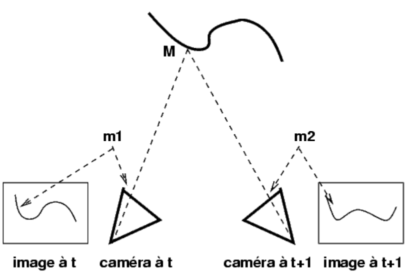
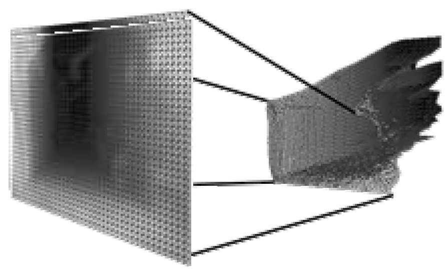
Side information extraction

- At the crossroad of information theory, signal processing and computer vision
  - Capturing the correlation via scene geometrical constraints
    - 3D reconstruction with epipolar constraints and 2D projection
  - Some sort of motion estimation at the decoder
    - In theory *joint typicality*, in practice extra information as a CRC, hash function, …



$$\min_{M_i, R_j, t_j} \sum_j \sum_i \left\| m_i^j - A.(R_j | t_j).M_i \right\|$$



Mesh-based dense motion field
Depth Map

3D model

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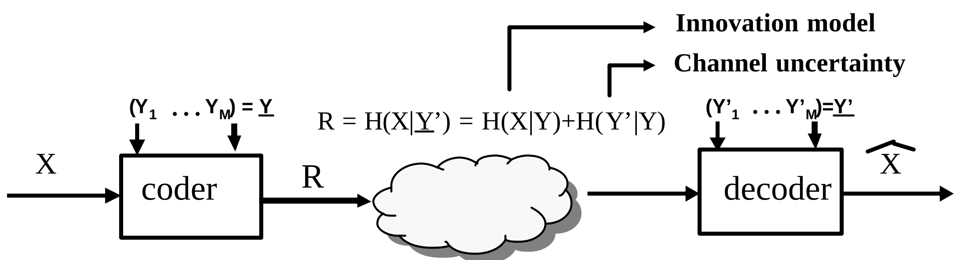
Distributed Coding for Wireless Video

- Codes depend on the ***virtual correlation channel*** between X and Y
  - **ISSUE 2: Correlation estimation/tracking with minimum information exchange**



- Feature points extraction and tracking for camera position estimation
- Improving the quality of the 2D projection

Feature points tracking
[Maitre, Morin, Guillemot]

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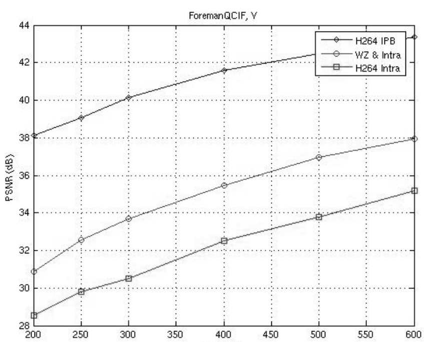
Performance illustrations

H.264 standard



H.264 Intra Mode (QP fixed)

W-Z coder/decoder

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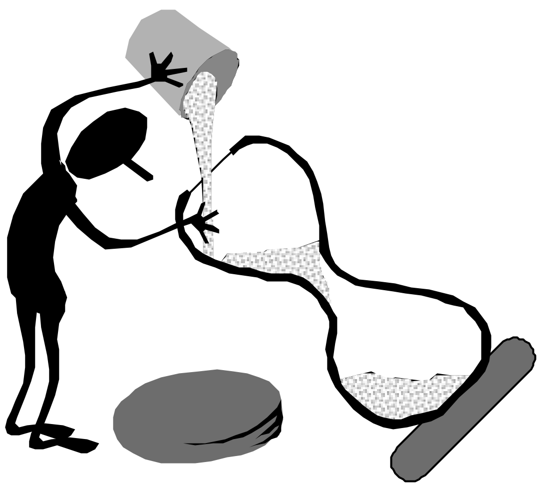
Concluding remarks

- Re-thinking the compression paradigm
  - Signal compression based on error correcting codes
  - A joint source-channel coding problem
- Features for wireless video (mobile video cameras, uplink wireless video)
  - Complexity balancing between coder and decoder
  - In-built resilience to channel impairments (e.g., « motion-free » video coding and transmission).
- A number of open issues for real systems

Thanks for listening!



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