Image Processing and Visual Communications

Robust Visual Communications

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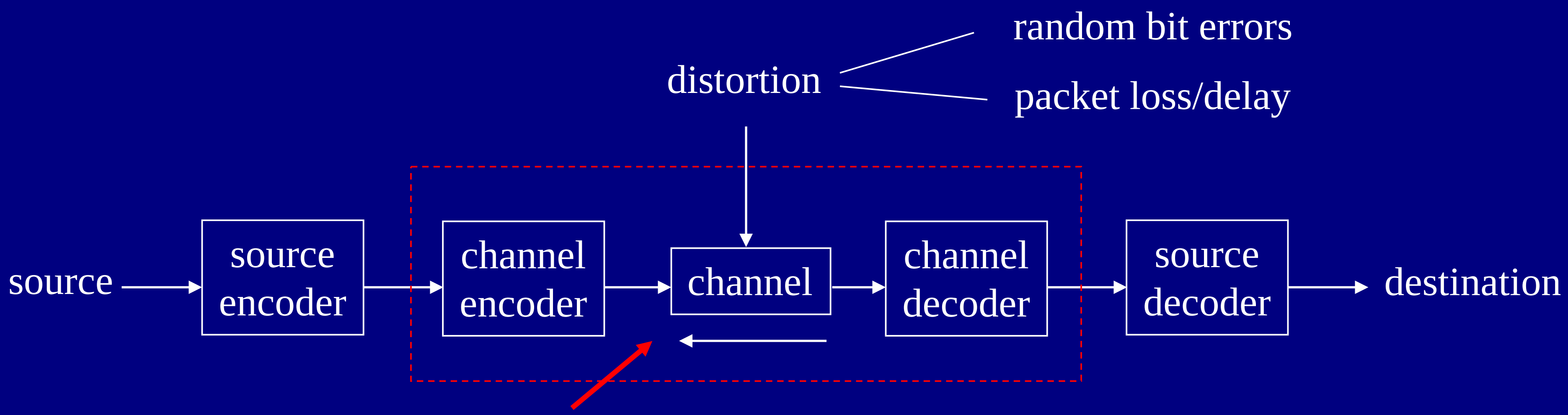
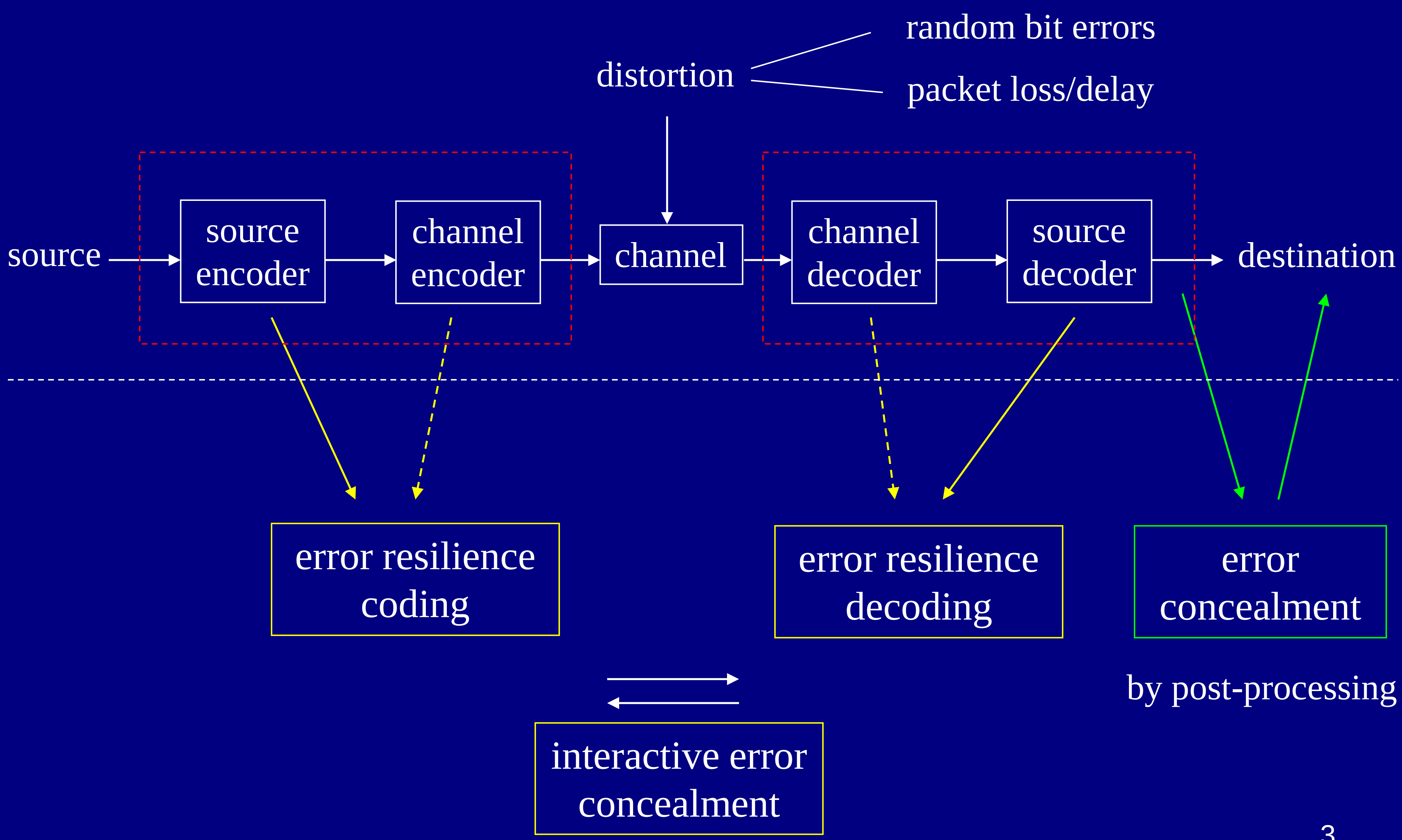
Robustness Issue in Visual Communications



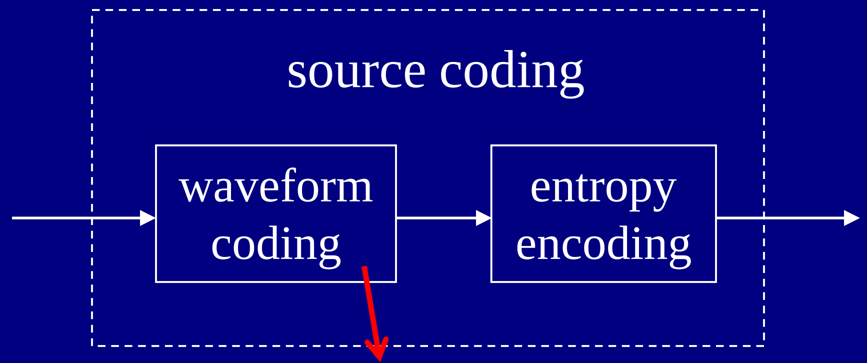
- **Conventional Solutions**
  - Error control code (ECC) by channel coding/decoding
  - Automatic retransmission request (ACQ) by network transport protocols, e.g. Transmission Control Protocol (TCP)
- **Potentials for Improvement**
  - Conventional solutions are independent of the nature of the source
  - Conventional solutions are independent of source coding/decoding and without pre/post-processing

Robust Coding in Visual Communications



Error Resilience: Source Coding

- **Idea: Adding redundant information**



transform (e.g., DCT) + quantization

- **Robust Waveform Coding**
  - Adding redundancy in waveform coder

    e.g., redundant transform
  - Restricting prediction domain

    e.g., group-of-picture (GoP) coding

    reduce error propagation
- **Robust Entropy Coding**
  - Self-synchronizing entropy coding: add synchronizing words
  - Error-resilient entropy coding: exploit varying bit importance

[Wang & Zhu, *Proceedings of the IEEE*, '98]

Error Resilience: Joint Source-Channel Coding

- **Idea: Joint optimal design of source-channel coder**

- **Methods**
  - Design quantizer and entropy coder to fit channel characteristics
  - Bit allocation according to bit importance and channel reliability

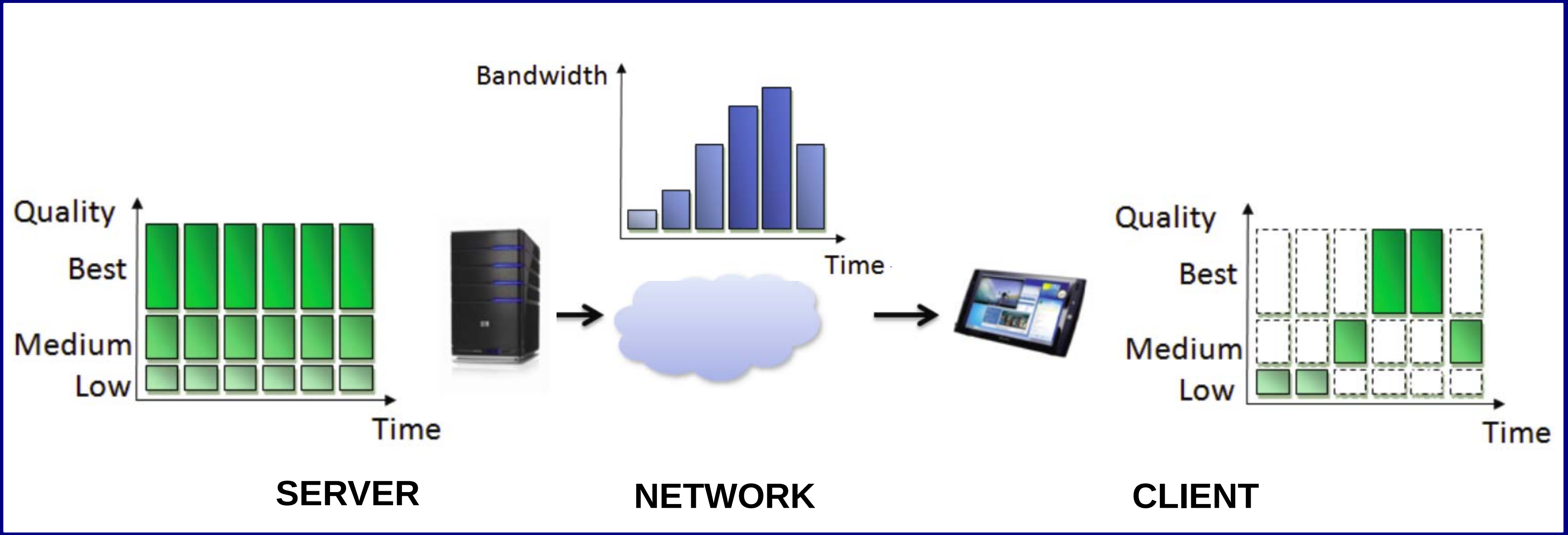
- **Keys to Success**
  - Understand the (statistical) nature of the source
  - Understand the (statistical) error characteristics of the channel
  - Unequal bit allocation for unequal error protection

- **Other Types of Joint Source-Channel Coding**
  - Multichannel transmission + layered coding
  - Multichannel transmission + multiple description coding

[Wang & Zhu, *Proceedings of the IEEE*, '98]

Error Resilience: Adaptive Streaming

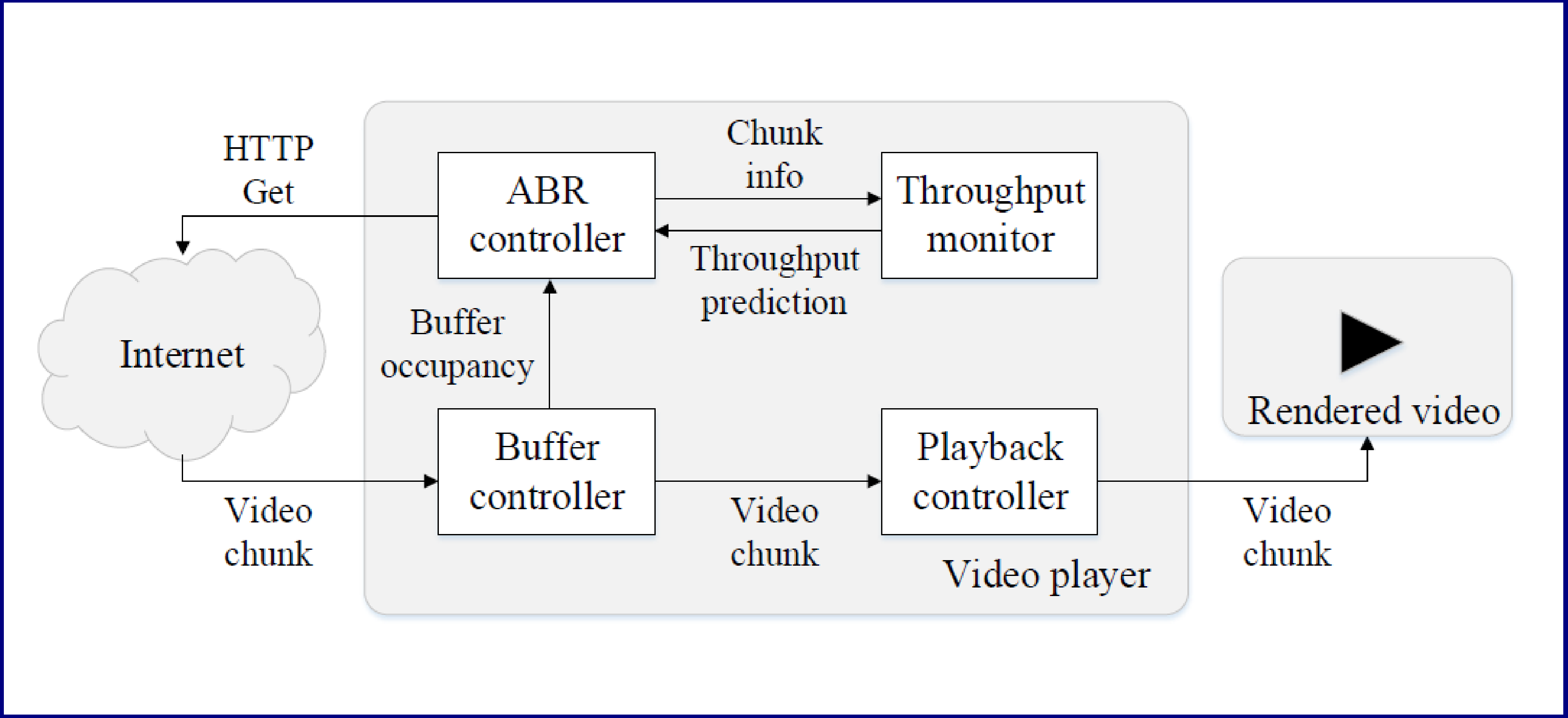
- **Idea: multi-encoding + instant selective transmission**
- **Application: Dynamic Adaptive Streaming over HTTP (DASH)**
  - Practically used in Internet Over-The-Top (OTT) transmission
    Youtube, Netflix, Hulu, …



Adapted from [Timmerer '16]

Error Resilience: Adaptive Streaming

- **The brain: Adaptive Bit Rate (ABR) controller at the player**

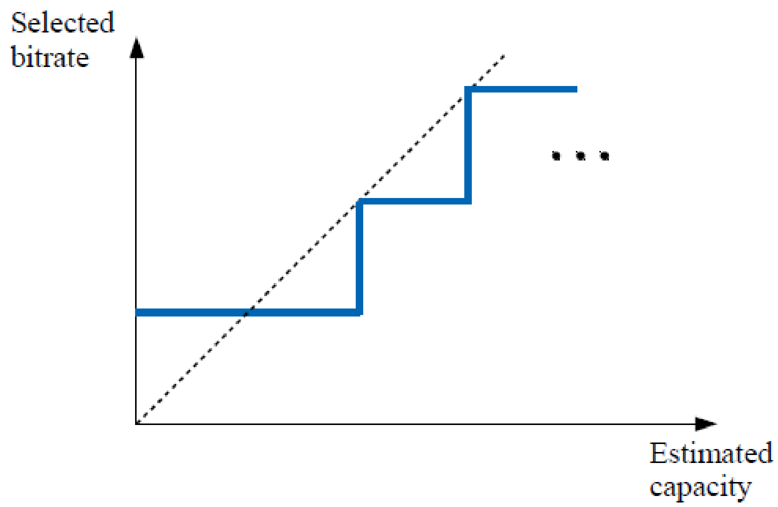


inside the video player

Adapted from [Timmerer '16]

Error Resilience: Adaptive Streaming

- **ABR controller: rate-based**



✔ De facto algorithm in DASH

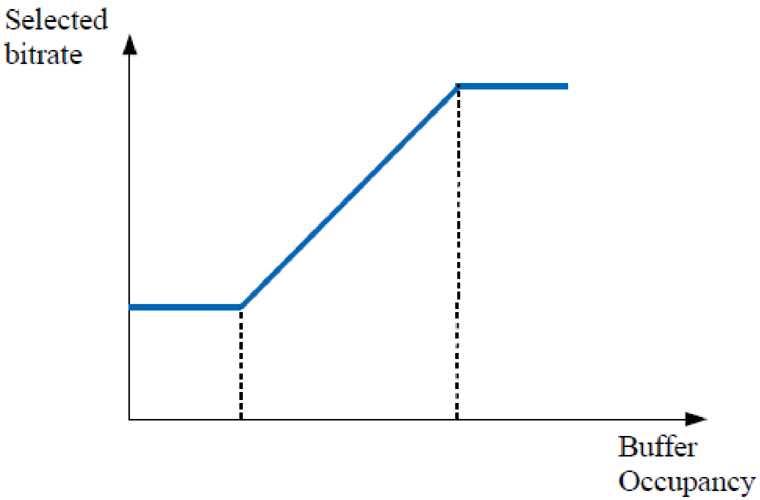
✔ Works well at start-up stage

✗ Inaccurate throughput estimation

Adapted from [Duanmu et. al. ‘19]

Error Resilience: Adaptive Streaming

- **ABR controller: buffer-based**



✔ Exact state variable

✔ Stable and reliable

✗ Performs poorly at start-up stage

Adapted from [Duanmu et. al. '19]

Error Resilience: Adaptive Streaming

- **ABR controller: rate-distortion optimization streaming (RDOS)**

Problem Formulation

$$\begin{aligned} \underset{\theta}{\text{maximize}} \quad & \mathbb{E}_{p_{\mathcal{E}}} \textstyle\sum_{t=1}^{T} \left[Q(a_t, \mathbf{x}_t, \mathbf{x}_{t+1}) - \lambda R_t(a_t) \right] \\ \text{subject to} \quad & a_t = \mathcal{G}_\theta(\mathbf{x}_{1:t}) \\ & \mathbf{x}_{t+1} = \mathcal{E}(a_t, \mathbf{x}_t) \end{aligned}$$

Notation

- $\mathcal{E}$: Environment
- T: Number of video segments
- Q: QoE
- R: Bitrate
- a: Selected bitrate level
- $\mathbf{x}$: State
- $\mathcal{G}$: Control policy

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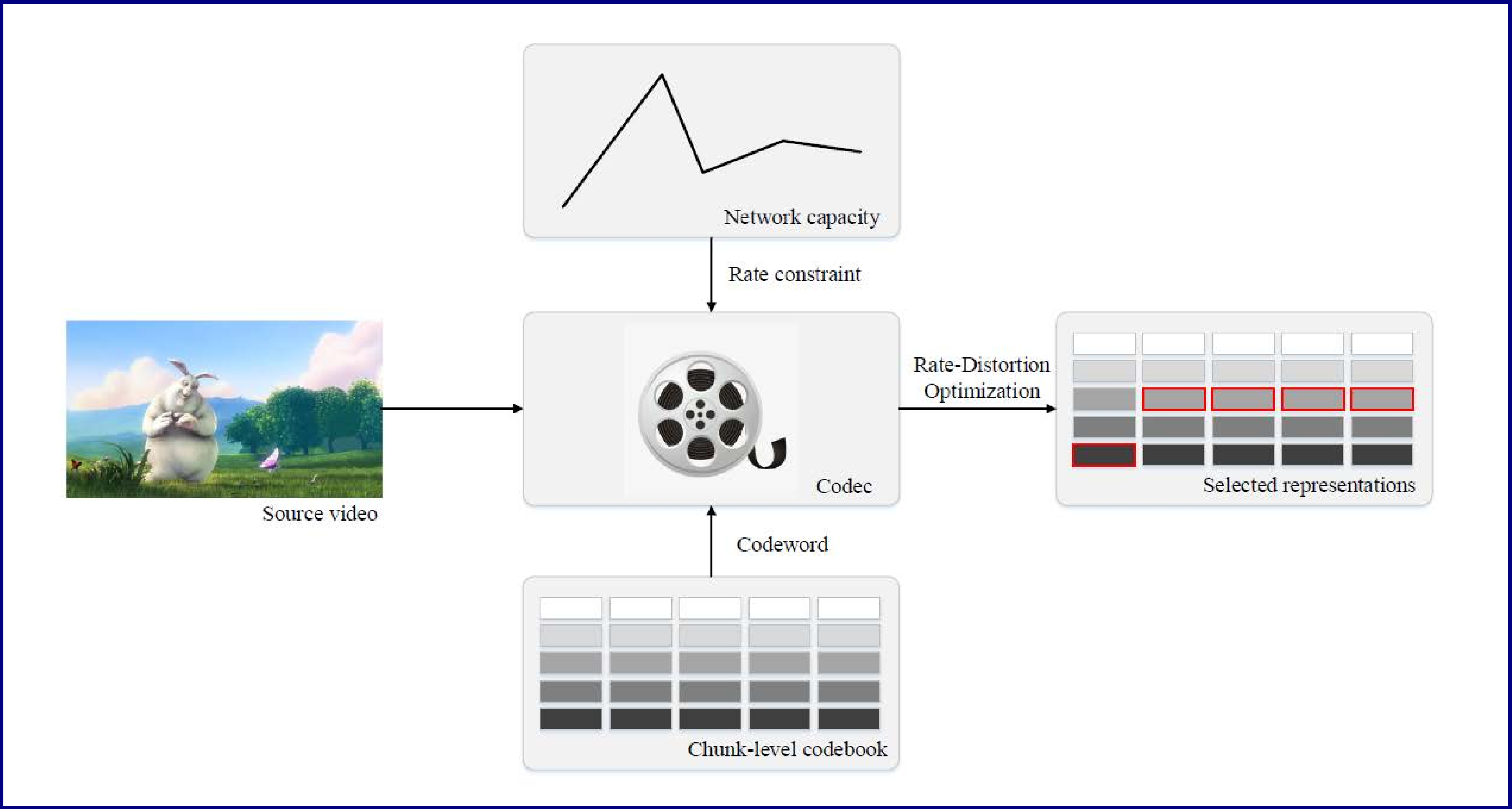
Adapted from [Duanmu et. al. '19]

Error Resilience: Adaptive Streaming

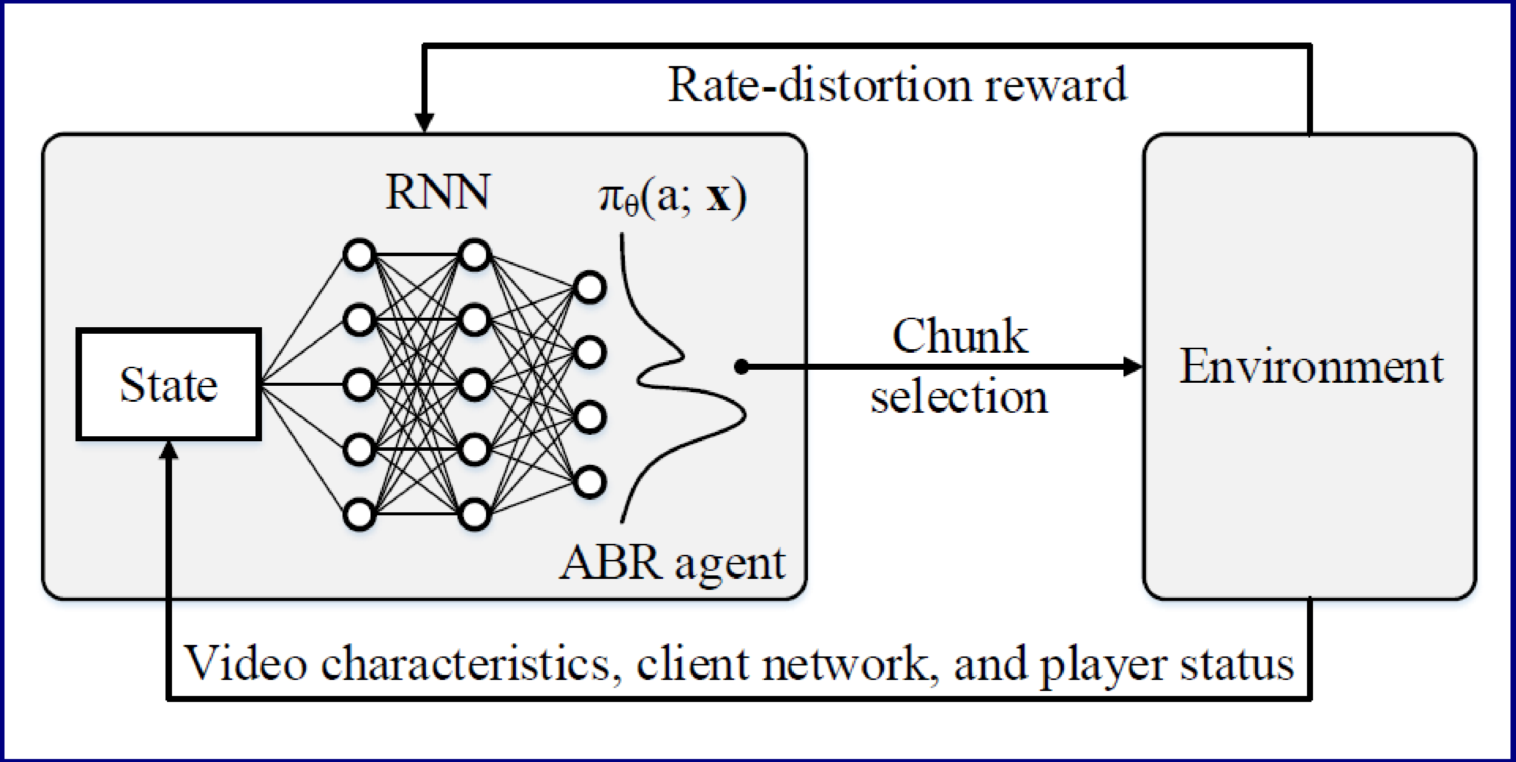
- ABR controller: rate-distortion optimization streaming (RDOS)



Adapted from [Duanmu et. al. '19]

Error Resilience: Adaptive Streaming

- **ABR controller: rate-distortion optimization streaming (RDOS)**



learning ABR algorithm: reinforcement learning

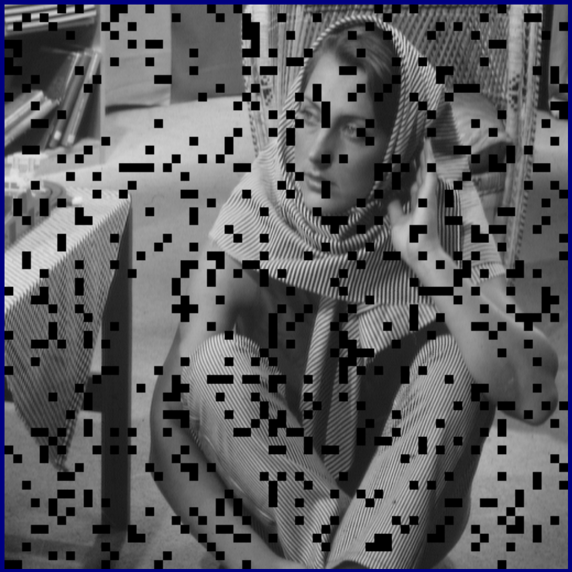
Adapted from [Duanmu et. al. '19]

Error Concealment

- **Error Concealment: A Post-processing Approach**
  - Pro: no change to existing visual communication systems
  - Con: recover signals purely by "*guessing*"

    Q: How can a guessing approach make sense at all?

- **Mostly Used: Recovery (Inpainting) of Lost Blocks**

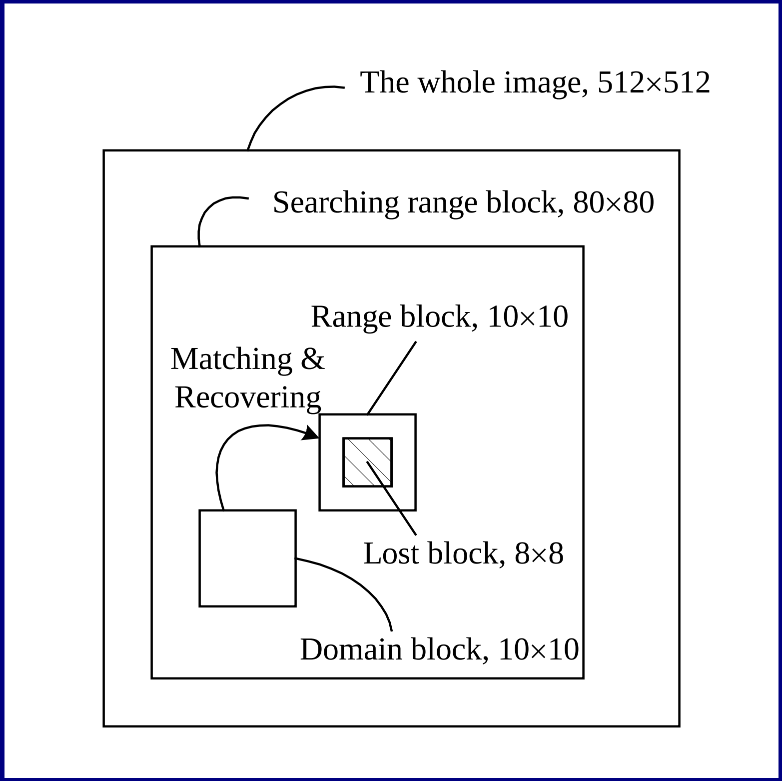


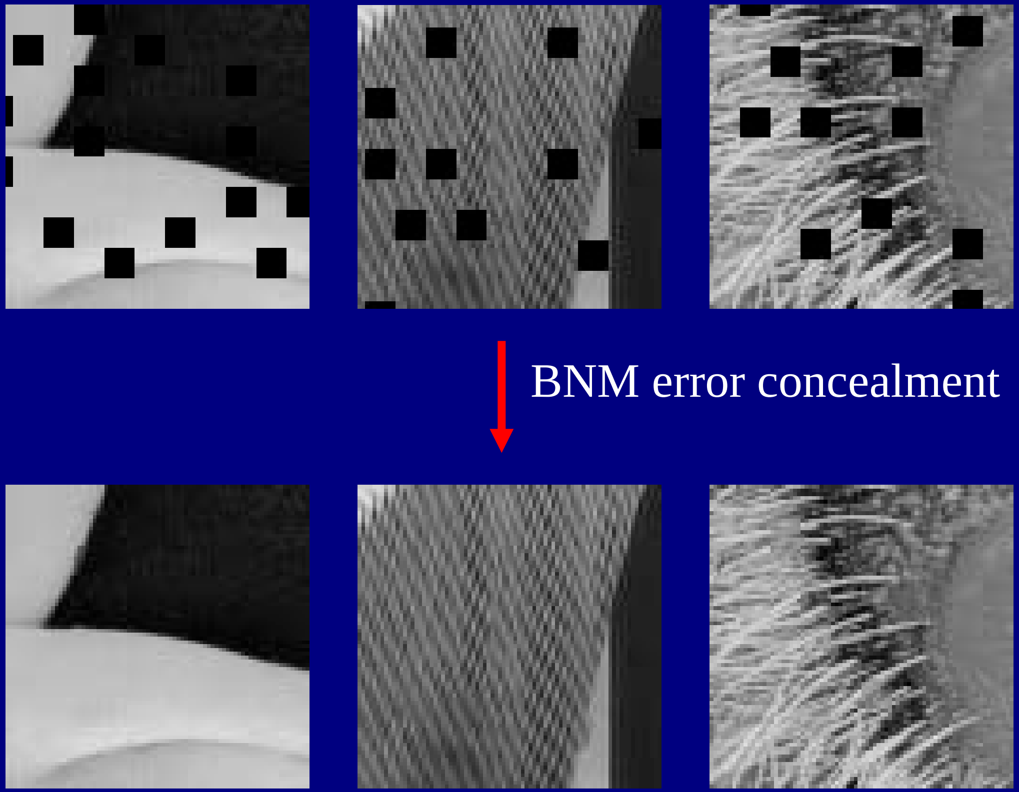
error concealment

[Wang *et al. IEEE Trans. IP* '98]

Error Concealment Methods

- **Still Image/Intra-frame Error Concealment**
  - (1) Methods based on smoothness constraints
  - (2) Best neighborhood matching (BNM) method

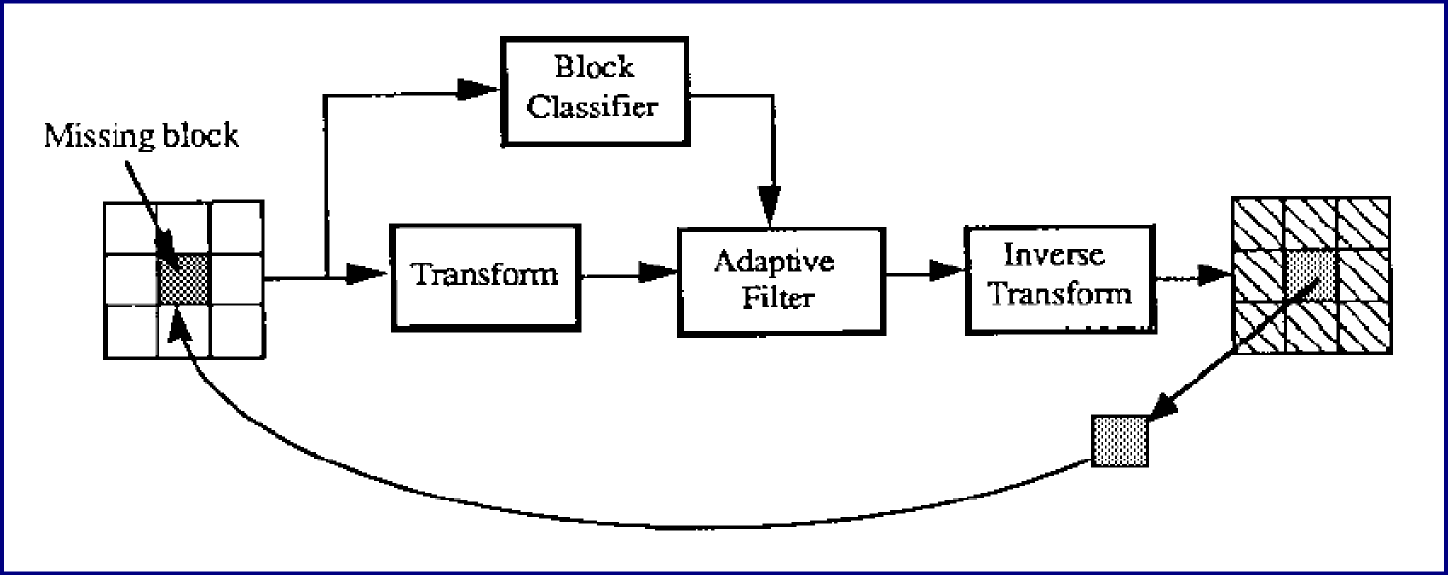




[Wang *et al*. *IEEE Trans. IP* ‘98]

Error Concealment Methods (con't)

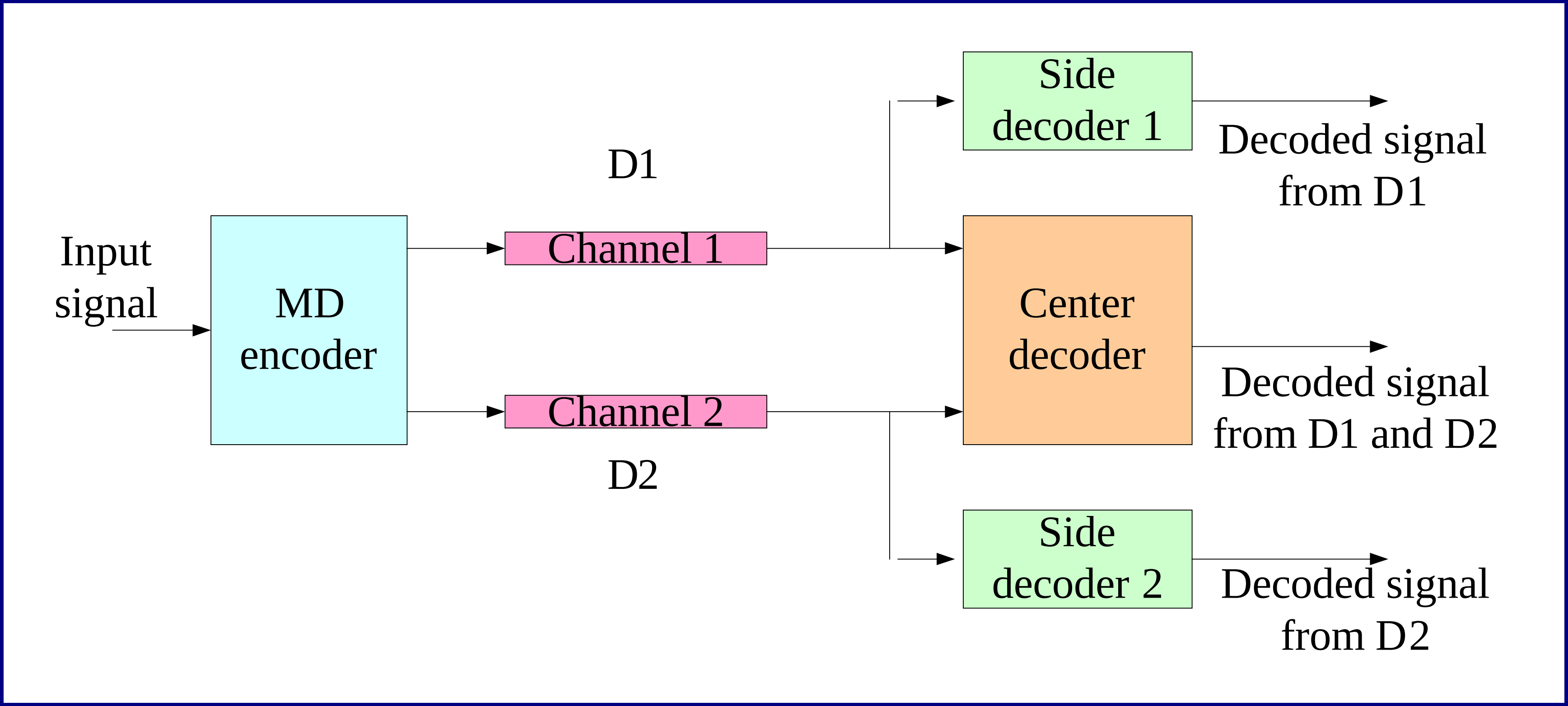
- **Still Image/Intra-frame Error Concealment**
  - (3) Iterative method: projection onto convex sets (POCS)



[Sun & Kwok. *IEEE Trans. IP* '95]

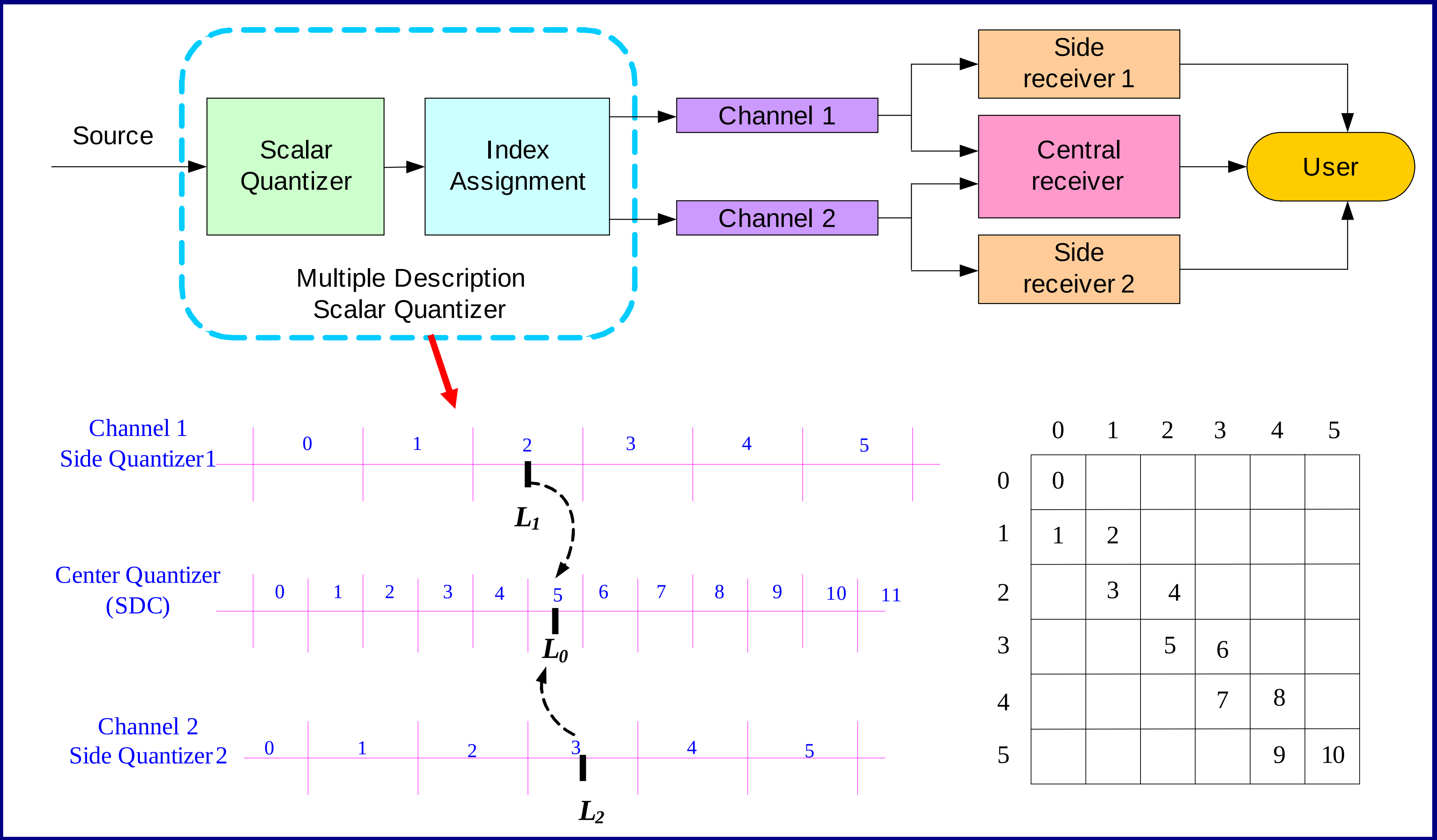
- **Video Error Concealment**
  - Recovering of motion vectors (smoothness constraints)

Multiple Description Coding System



[Y. Liu, '05]

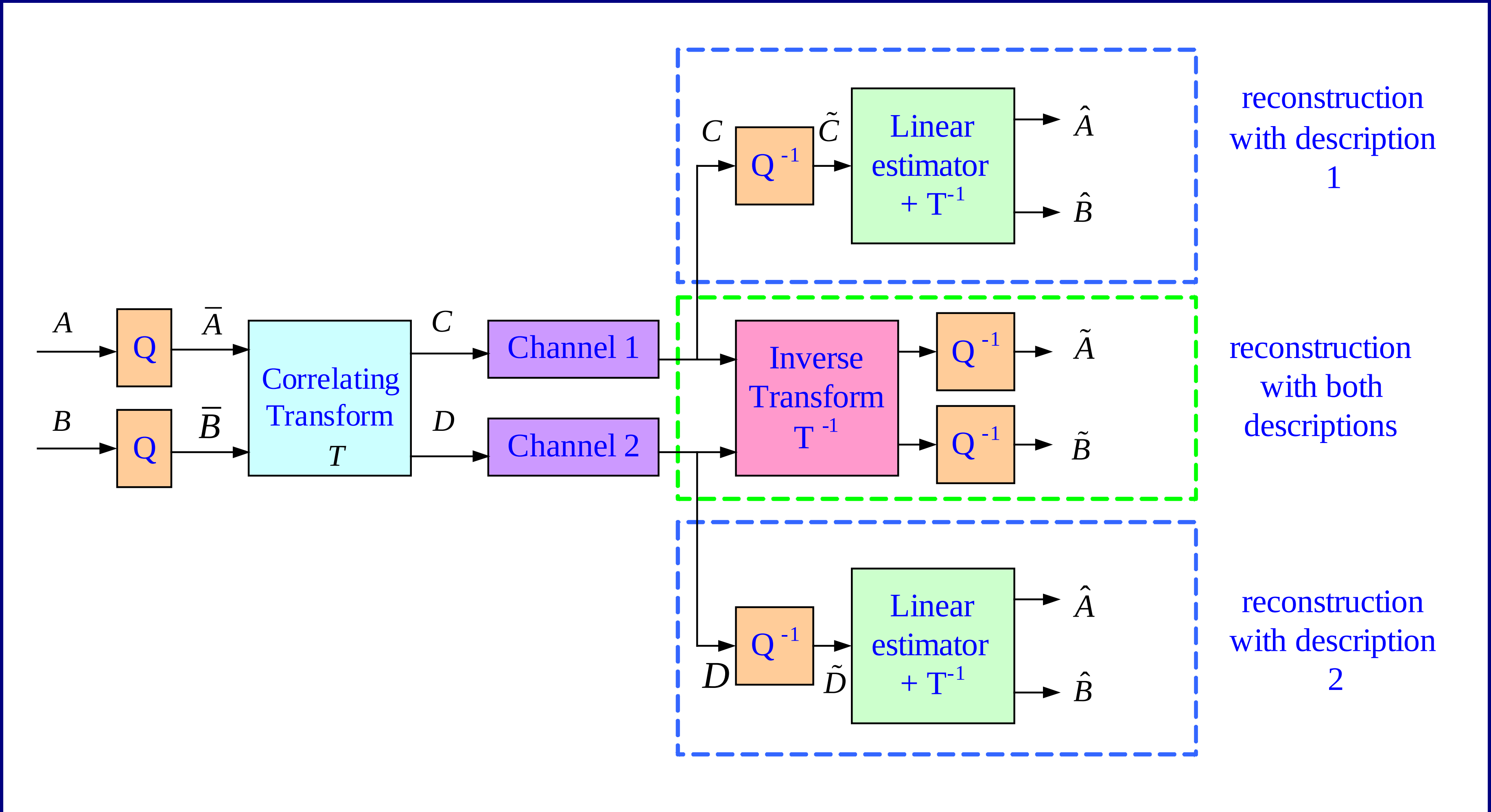
MDC Methods: MD Scalar Quantizer



[Vaishampayan ’93]

[Y. Liu, ‘05]

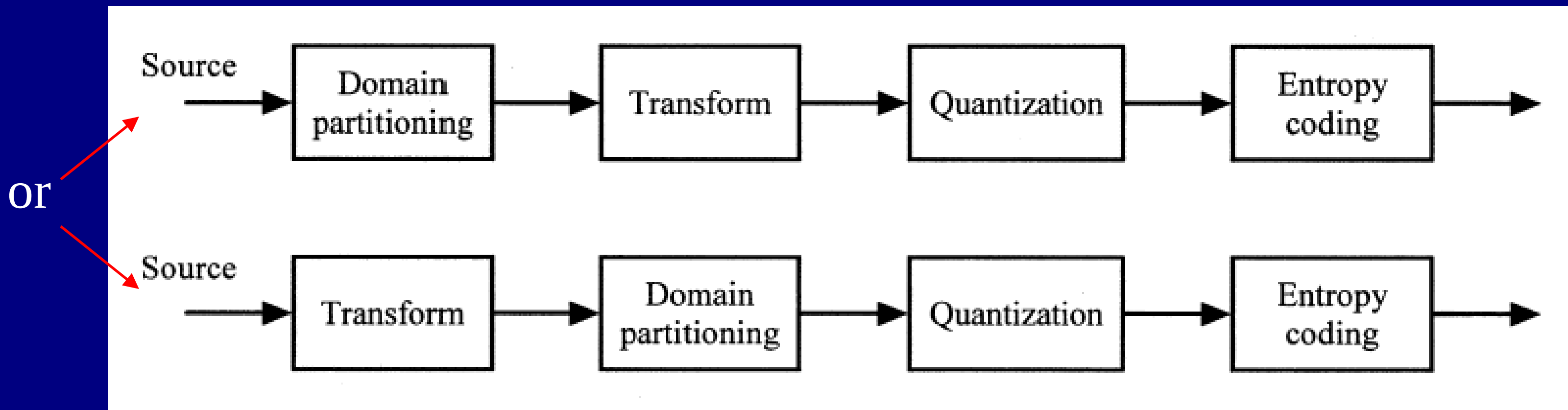
MDC Method: Pairwise Correlating Transform

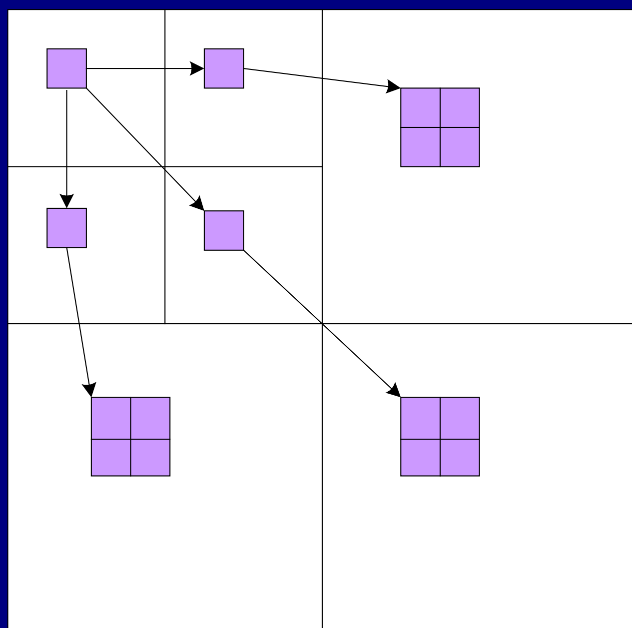


[Wang *et al.*, *IEEE Trans. IP*,'01]

[Y. Liu '05]

MDC Method: Domain Partitioning





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Example: Partition 7 wavelet subbands to 4 descriptions

[Bajic & Woods, *IEEE Trans. IP*,'03]