Distributed Video Coding Applications for Scalable and Flexible Decoding

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Content

This talk will cover two DSC applications:

- **Scalable video coding**
  - Error robust scalable coding
  - Low complexity encoding for multiple layers coding
- **Flexible video decoding**
  - Viewpoint switching in multiview video
  - Robust video transmission

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DSC Application to Scalable Video Coding

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Some Work on Scalable Coding Based on DSC

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- [Xu, Xiong; VCIP 04, IEEE Trans. IP 06]
  - Embedded enhancement layer similar to MPEG-4/H.26L FGS
  - Robust to error in base layer
  - Do not suffer performance loss due to layering
- [Tagliasacchi, Majumdar, Ramchandran, Tubaro; PCS 04, Eurasip SP 06]
  - Spatial/temporal/SNR scalability
  - Based on PRISM [Puri, Ramchandran; Allerton 02]
  - Robust to channel losses
  - Flexible distribution of complexity
- [Sehgal, Jagmohan, Ahuja; PCS 04]
  - Multiple Wyner-Ziv encoded versions for different possible predictors
  - Encoder streams an appropriate encoded version based on knowledge of predictors available at decoder
- [Wang, Cheung, Ortega; PCS 04, Eurasip JASP 06]
  - Improvement of MPEG4-FGS: Utilizing EL reconstruction for prediction
  - Low complexity overhead: Avoid replicating EL reconstruction at encoder

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Error Robust Scalable Coding

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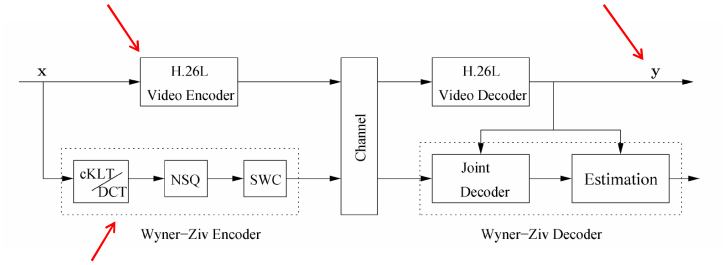
[Xu, Xiong; VCIP 04, IEEE Trans. IP 06]

Base layer (BL): Standard video codec

Side Information (SI): BL reconstruction



Enhancement layer (EL) based on bit-plane coding and DSC

Error corrupted base layer (SI) may still be used for DSC decoding

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Robust to Transmission Error

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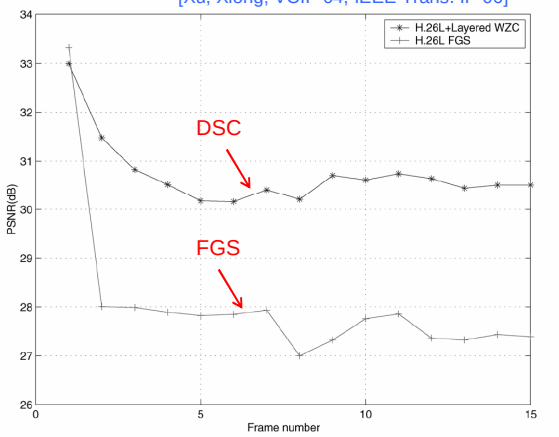
DSC-based system can achieve substantial improvement in situations with transmission error

[Xu, Xiong; VCIP 04, IEEE Trans. IP 06]

Football
1% macroblock loss at BL
BL: 1450 kbps
EL: 200 kbps



In addition, the system does not suffer performance loss due to layering, i.e., same performance as the monolithic WZ coding

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Spatial/Temporal/SNR Scalability

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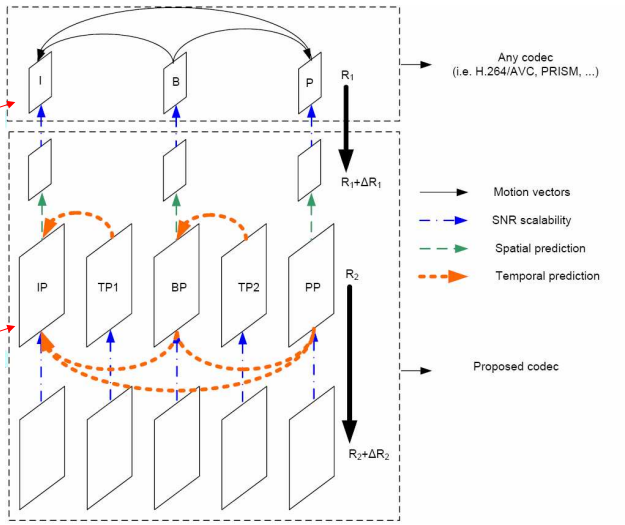
[Tagliasacchi, Majumdar, Ramchandran, Tubaro; PCS 04, Eurasip SP 06]

BL: Standard video codec/PRISM

Motion estimation (ME) at BL resolution: low complexity

EL: PRISM

Encoder does not perform ME at EL: Use BL motion information for correlation estimation



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Robust to Transmission Error

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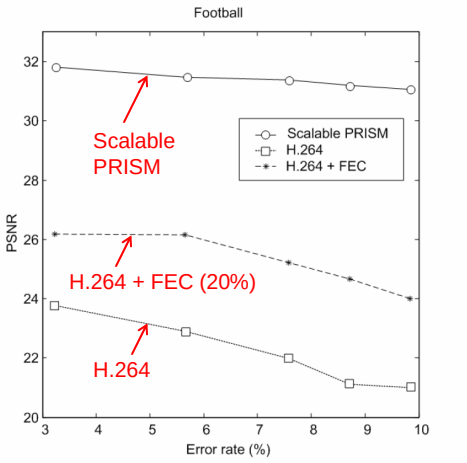
[Tagliasacchi, Majumdar, Ramchandran; PCS 04]

Football, CIF, 15fps, 1800 kbps
Packet dropped at both EL and BL



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Scalable Coding with Multiple Motion-Compensated Prediction (MCP) Loops

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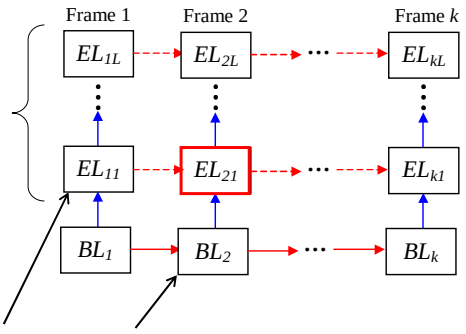
Multiple MCP loops approach
[Rose, Regunathan; IEEE Trans. IP 2001]

Encoder replicates all the EL reconstructions



Use both BL and EL for prediction: good coding efficiency

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Multiple MCP Loops Approach: Non-trivial Complexity

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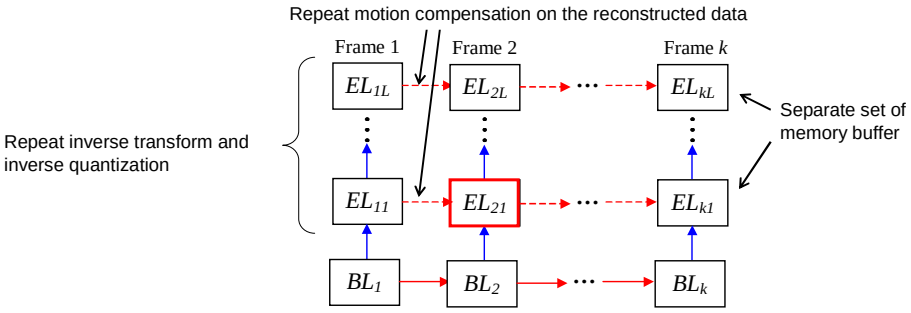
In multiple loops approach, the complexity of replicating all the EL reconstructions could be non-trivial in multiple layers coding



Our contribution: DSC counter-part to the multiple loops approach to achieve low complexity encoding

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Wyner-Ziv Scalable Video Coding (WZS) – Overview

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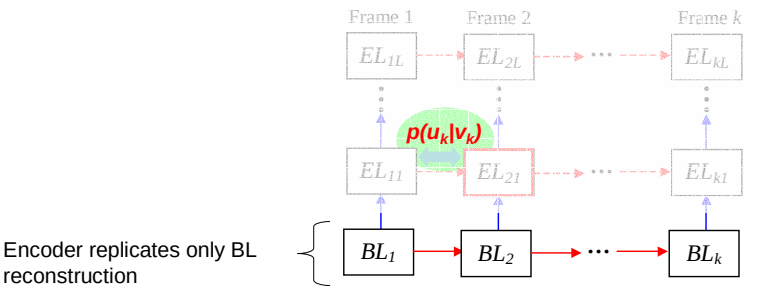
WZ scalable coding: Encoder does not replicate EL reconstruction
- EL predictor available only at decoder
- Side Information: EL predictor



Key point: DSC requires only the correlation information instead of the exact reconstructed data in encoding

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WZS: Encoder does not replicate EL reconstruction

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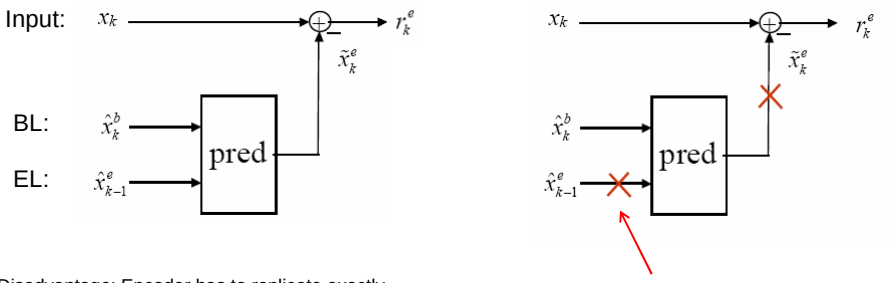
Multiple MCP loops

Wyner-Ziv Scalable



Disadvantage: Encoder has to replicate exactly all the possible EL reconstructions, so that the prediction residue can be computed

Encoder does not replicate EL reconstruction

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Cast scalable coding as a Wyner-Ziv problem

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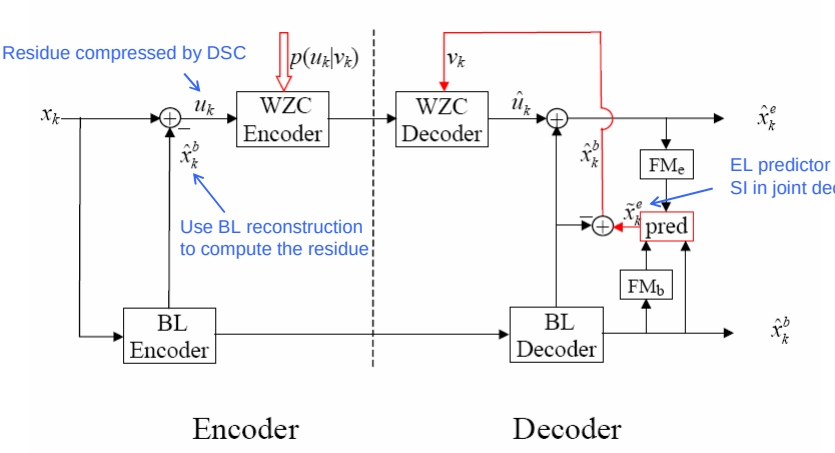

How to estimate $p(u_k|v_k)$?

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Correlation Estimation at Encoder

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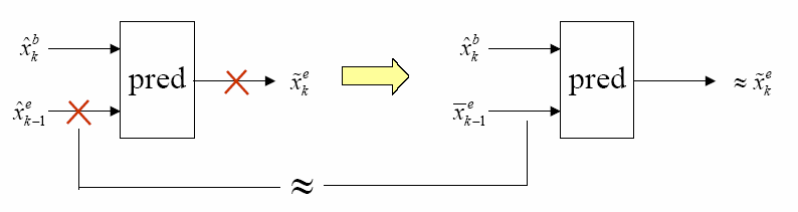
- Problem: How to estimate the correlation?
- Solution
  - Computing an approximation of the EL reconstruction at the encoder
  - Use approximation for correlation estimation

$$\overline{x}^e_{k-1} = Q_e(x_{k-1}) \approx \hat{x}^e_{k-1}$$

Compute the approximation by quantizing original frame to a quality level similar to EL



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Correlation information can be estimated with low complexity

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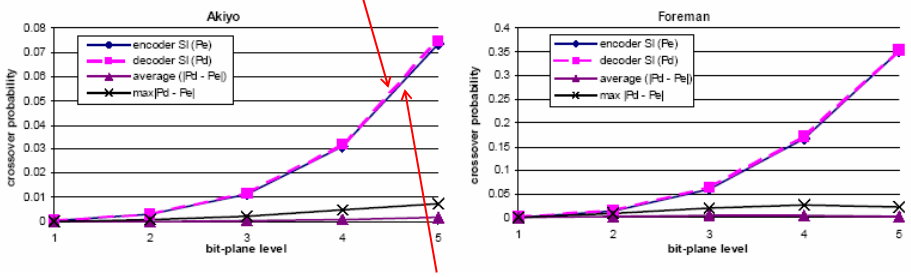
Our approximation can provide accurate statistics for DSC encoding

Correlation computed from EL reconstruction (available only at decoder)



Correlation estimated from the approximation (at encoder)

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WZS Encoder Block Diagram

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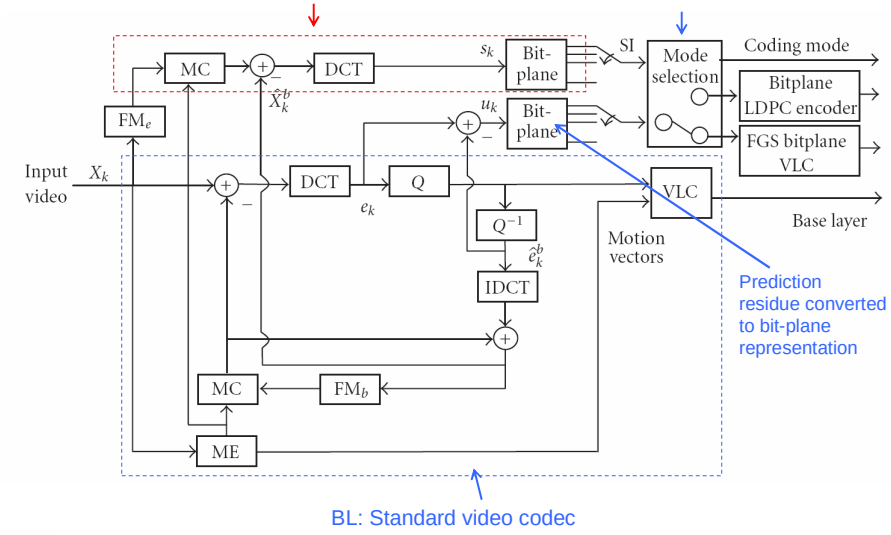
Process original frame to estimate the correlation
(Encoder has to only do this once, even for multiple layers)

Bit-plane compressed by DSC
or FGS bit-plane coding



BL: Standard video codec

Results

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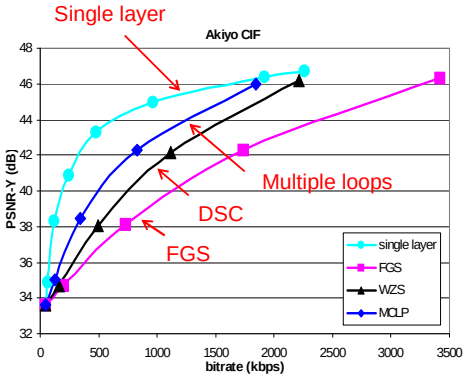
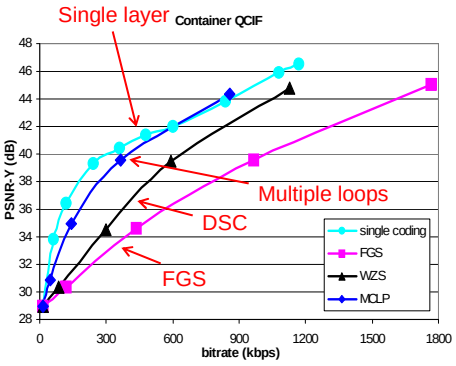
Our proposed algorithm out-performs MPEG-4 FGS





Summary: DSC Application to Scalable Coding

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- Robust to transmission errors
  - Corrupted SI (BL or spatial/temporal predictor) may still be used for DSC decoding
- Low complexity scalable encoding
  - Motion estimation at BL resolution (spatially down-sampled)
- Improvement to MPEG-4 FGS
  - Exploring temporal correlation at EL
  - Apply DSC techniques to reduce complexity overhead

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DSC Application to Flexible Video Decoding

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Flexible Video Decoding

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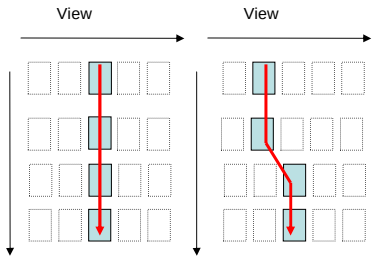
Apply DSC to generate a *single* bitstream that can be decoded in *several* different ways

- Free viewpoint switching in multiview video compression
- Forward and backward video playback
- Robust video transmission



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Flexible Decoding Example – Free Viewpoint Switching in Multiview Video

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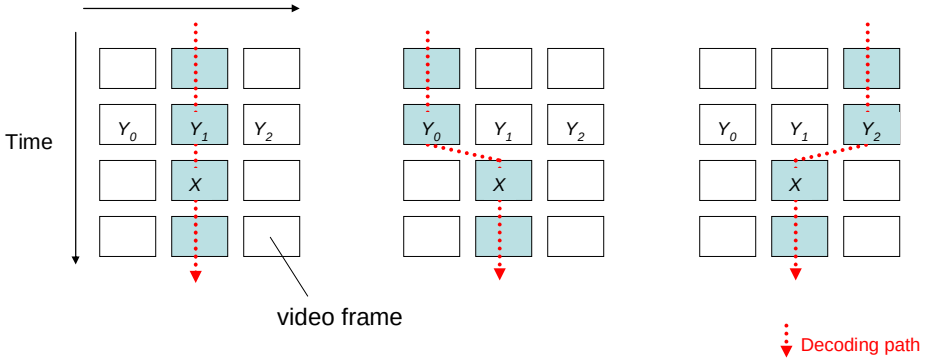
[Cheung, Ortega; PCS 07]

User selects a particular view: View

User switches between different views during playback:



In order to address viewpoint switching, compression schemes have to support **multiple decoding paths**

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Free viewpoint switching poses challenges to multiview compression

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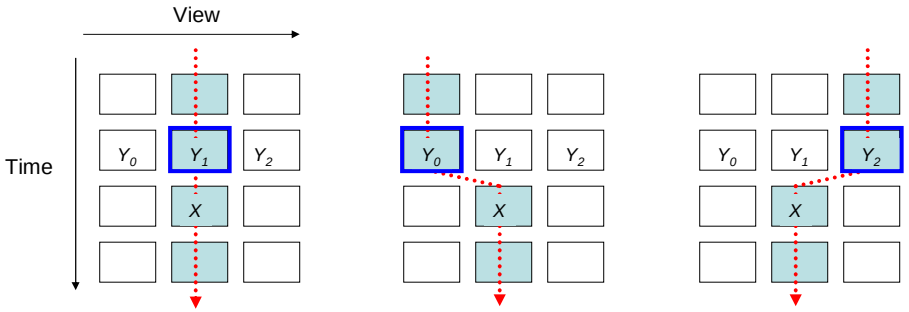
When users can choose among different decoding paths, it is not clear which previous reconstructed frame will be available to use in the decoding



Multiple decoding paths ⇒ Either Y_0 or Y_1 or Y_2 will be available at decoder ⇒ Uncertainty on predictor status at decoder!!!!

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Problem Formulation

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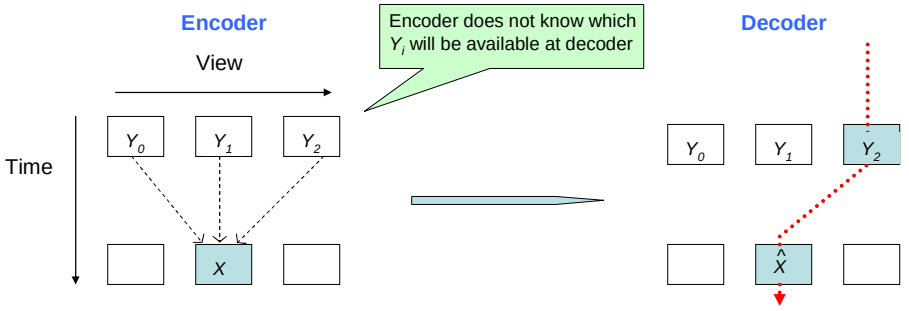
To support low-delay free viewpoint switching (flexible decoding), encoder needs to operate under uncertainty on decoder predictor

[Cheung, Ortega; MMSP 07]



- Assume feedback is not available
  - Low-delay, interactive application
  - Offline encoding of multiview data

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Other Flexible Decoding Examples – Forward/Backward Frame-by-frame Video Playback

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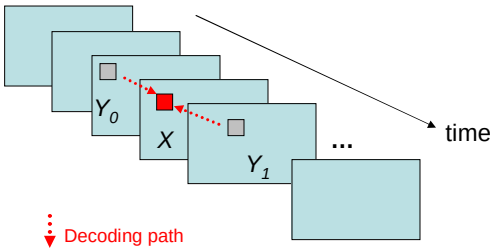
[Cheung, Wang, Ortega; VCIP 06]

User can choose to play back in either direction:
Either past **or** future reconstructed frame will be available at decoder



Y_0, Y_1: best motion-compensated predictor for X

- Not B-frame (as in video coding standards)
- Not multiple reference frames

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Other Flexible Decoding Examples – Robust Video Transmission

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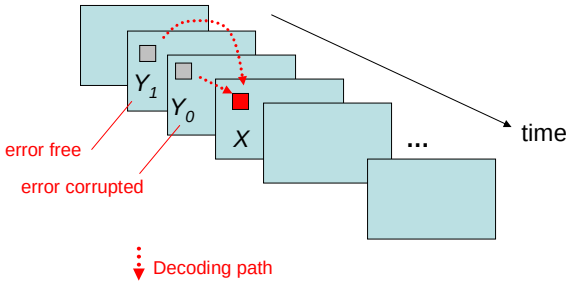
[Wang, Prabhakaran, Ramchandran; ICIP 06]



Some reference frames have error, but encoder does not know which one (assume feedback is not available)

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Address Viewpoint Switching/Flexible Decoding Within Closed-Loop Predictive (CLP) Coding Framework

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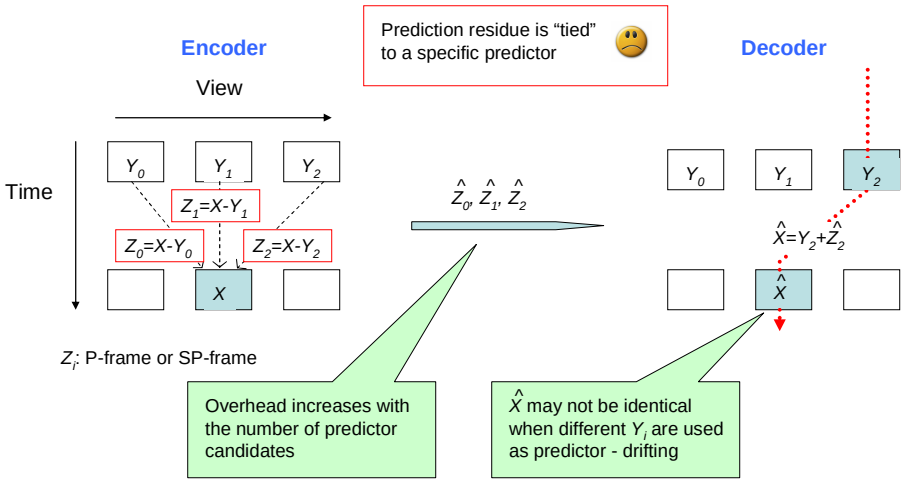
Encoder has to send **multiple** prediction residues to the decoder



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Our Contributions

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- Propose distributed source coding (DSC) based coding algorithm to address viewpoint switching (flexible decoding)
- **Apply DSC to generate a *single* bitstream that can be decoded in *several* different ways**
- Propose an efficient encoding algorithm
  - Macroblock mode
  - Significance coding
  - Correlation model
  - Minimum MSE dequantization

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Related Work

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Differences between our work on viewpoint switching and distributed multiview coding

(E.g., [Zhu, Aaron, Girod; SSP 03], [Toffetti, Tagliasacchi, Marcon, Sarti, Tubaro, Ramchandran; EUSIPCO 05])

	Distributed multiview image/video coding	**Free viewpoint switching**
Key objective	Distributed, independent encoding at spatially-separated sensors	Centralized encoding to generate a single bitstream to support multiple decoding paths
Encoder complexity	Low-complexity encoding	Not primary issue. Applications use off-line encoding
Encoder access to SI	SI not accessible	Encoder has access to all SI candidates

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Related Work

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- Provide random access in compression of image-based rendering data/multiview video
  - [Jagmohan, Sehgal, Ahuja; Asilomar 03]
  - [Aaron, Ramanathan, Girod; MMSP 04]
  - [Guo, Lu, Wu, Gao, Li; VCIP 06]
  - **All assume encoder has knowledge on predictor status, e.g., using feedback**
- Robust video transmission [Wang, Prabhakaran, Ramchandran; ICIP 06]
  - Specific algorithms used are different
- Improve decoding flexibility and accessibility [Naman, Taubman; ICIP 07]
  - Feedback and conditional replenishment
- Forward/backward video playback [Cheung, Wang, Ortega; VCIP 06]
  - Considerably different algorithm to achieve better coding performance

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Solution Based on Distributed Source Coding

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DSC - Virtual Communication Channel Perspective

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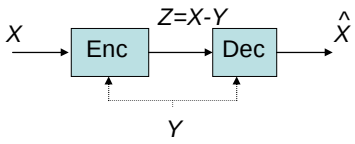
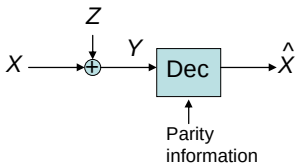
In DSC, encoder can communicate *X* by sending **parity information**
(E.g., [Girod, Aaron, Rane, Rebollo-Mondero; Proc. IEEE 04])

CLP:



DSC:



Parity information is **independent** of a specific predictor
- What matters is the **amount** of parity information

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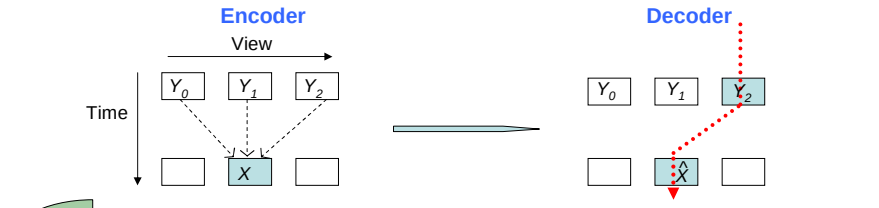
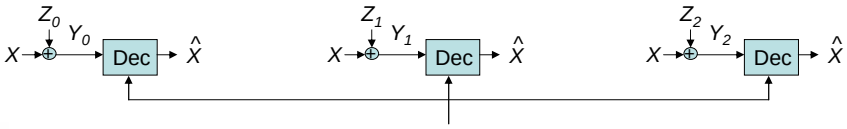
Address Viewpoint Switching (Flexible Decoding) Using DSC

Under predictor uncertainty, encoder can communicate X by sending an amount of parity corresponding to the **worst case correlation**



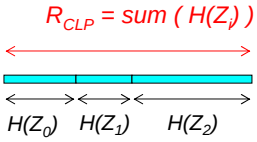
N virtual channels:

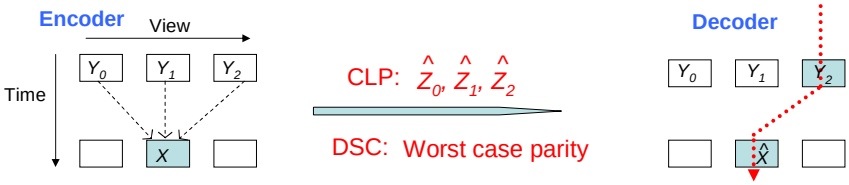


Parity corresponding to the worst case correlation noise

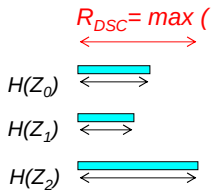
Viewpoint Switching (Flexible Decoding) – CLP vs. DSC

CLP





DSC



Bits required to communicate X with Y_i at decoder : $H(X \mid Y_i) = H(Z_i)$

Encoding Algorithm – Motion Estimation and Macroblock Classification

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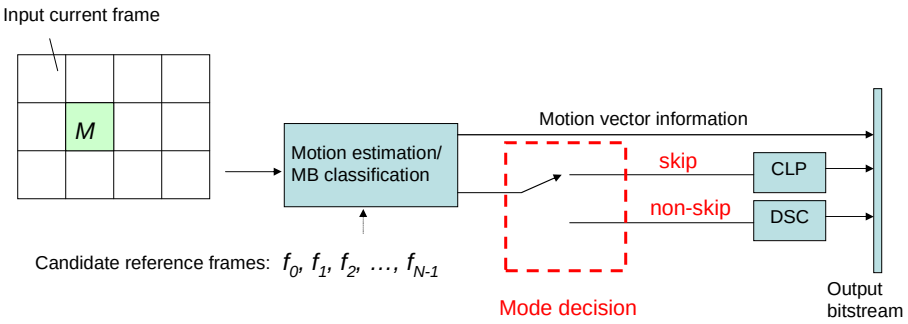
M may be classified to be in a *skip* mode if the difference between *M* and predictors from some f_i is small



Majority: using DSC

Encoding Algorithm – DSC Coded MB

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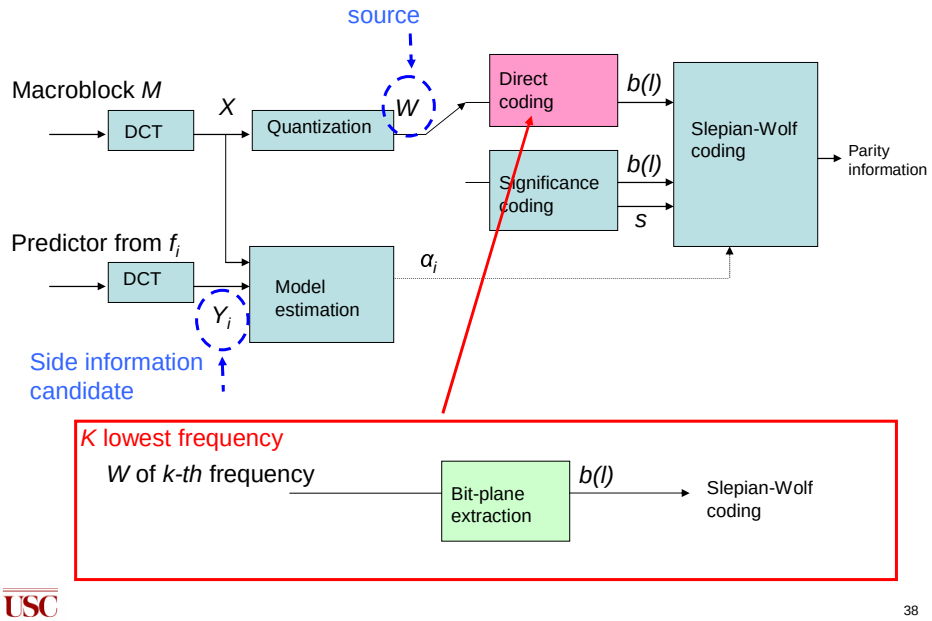
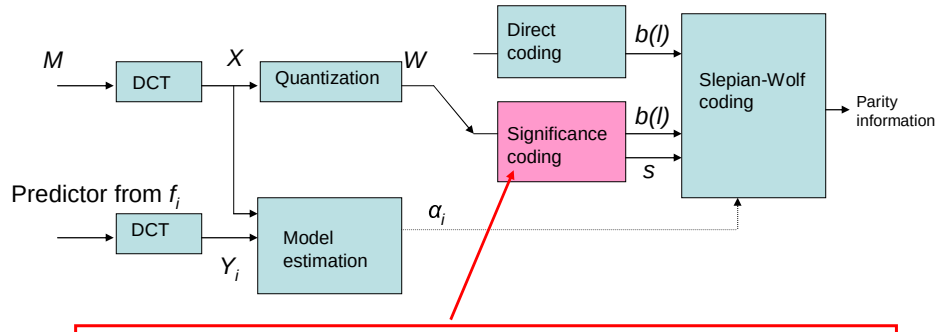
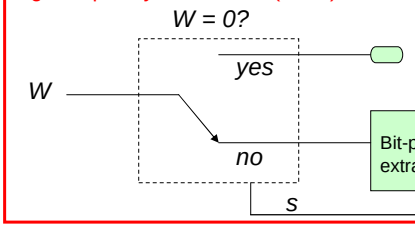


Encoding Algorithm – Significance Coding



High frequency coefficients ($k>=K$)

- Expected number of source bits = $1*p_k+(1+L_k)*(1-p_k)$
- Lead to source bits saving when $p_k>1/L_k$



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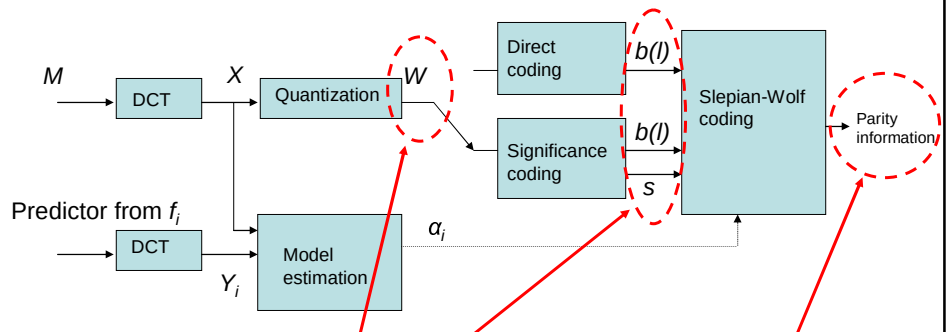
Drift-free: *W* in DSC coded MB are exactly recovered



Exactly recovered in decoding

Amount of output parity determined by the worst case correlation

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Models and Conditional Probability Estimation

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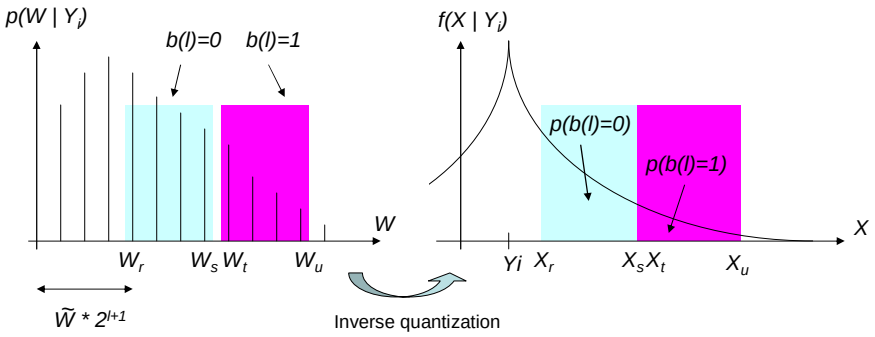
Estimate $p(b(l) \mid Y_i, b(l+1), b(l+2), \ldots)$ by integrating $f(X \mid Y_i)$ as follow:



Experimental Results - Multiview Video Coding

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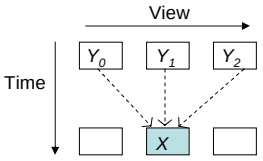
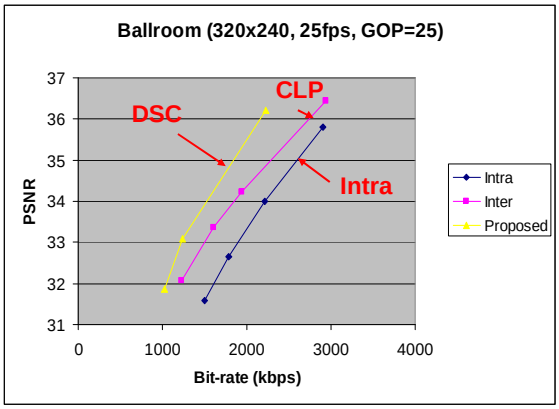
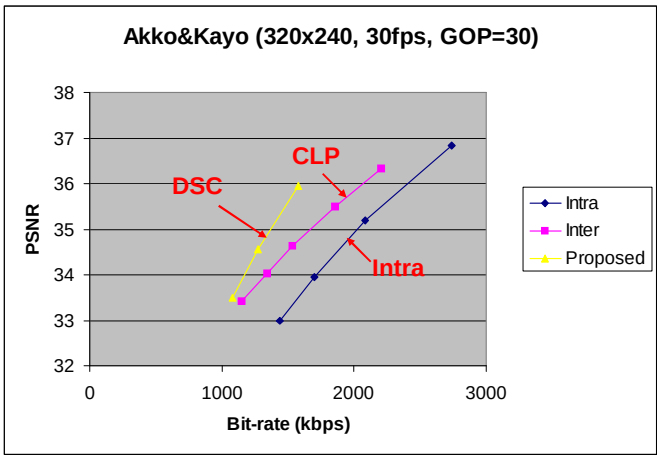
Allow switching from adjacent views: three predictor candidates





Our proposed algorithm out-performs CLP and intra coding

Experimental Results

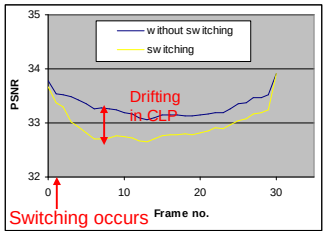


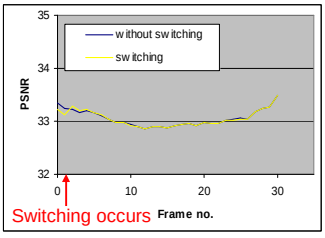
Drifting Experiments

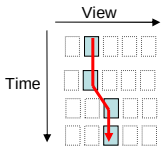
Our proposed algorithm is almost drift-free, since quantized coefficients in DSC coded MB are identically reconstructed

CLP DSC

Akko&Kayo (GOP=30)







View switching occurs at frame number 2

Scaling Experiments

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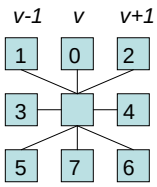
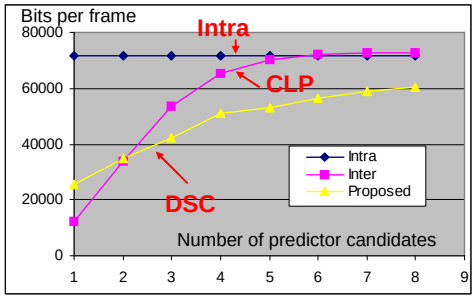
- Number of coded bits vs. number of predictor candidates





- Bit-rate of DSC-based approach increases at a slower rate compared with CLP
  - An additional candidate incurs more bits only if it has the worst correlation among all candidates

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Experimental Results – Forward/backward video playback

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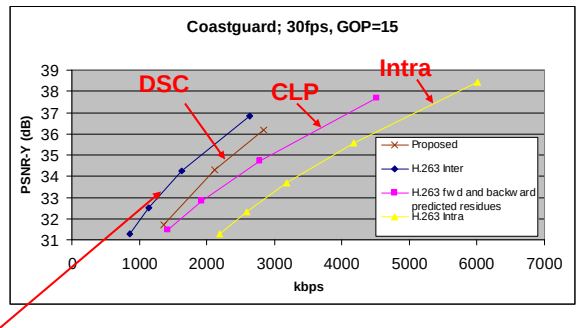
Forward/backward playback: **two** predictor candidates



Coastguard CIF

Inter-frame coding with one prediction residue: cannot support flexible decoding

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Summary: DSC Application to Viewpoint Switching/Flexible Decoding

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- DSC-based coding algorithm to address viewpoint switching/flexible decoding
  - **Single** bitstream to support **multiple** decoding paths
  - Parity information **independent** of a specific predictor
  - Overhead depends on the **worst correlation** rather than the number of decoding paths
  - Outperform CLP and intra coding in terms of coding performance
  - Our proposed system is almost drift-free

Comments or Questions?

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Parity information is independent of a specific predictor

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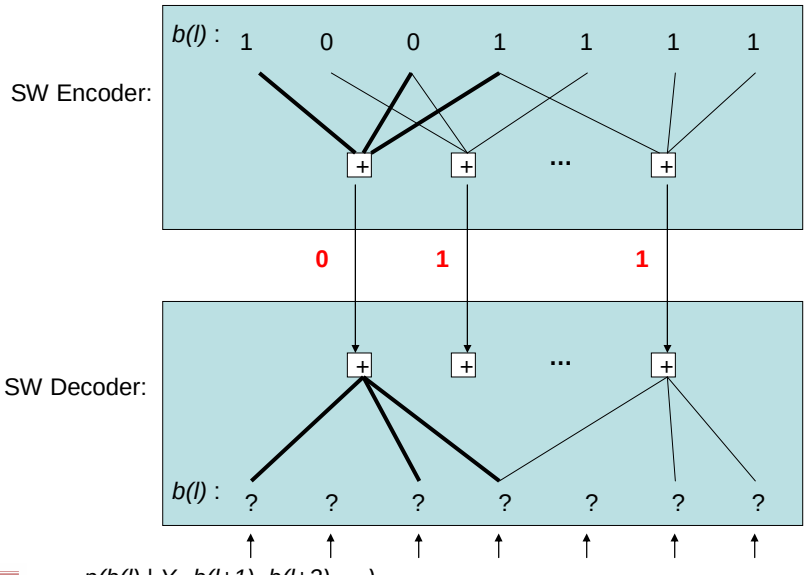

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$p(b(l) \mid Y_i, b(l+1), b(l+2), \ldots)$

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