Rectification-based View Interpolation and Extrapolation: R-D Analysis and Applications in Multiview Video/Image Coding

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Outline

- Introduction
- R-D analysis
- Applications
- Summary

Introduction

- Multiview video coding (MVC) is an important component of 3DAV applications
- Disparity-compensated prediction:
  - Used by H.264 MVC
  - Not always efficient [Schwarz'06]
- View interpolation/synthesis-based prediction:
  - Exploits geometric redundancy
  - Also useful for free viewpoint TV

Introduction

- **Existing view interpolation-based MVC methods:**
  - Require parallel cameras [Yamamoto'07]
  - Or need camera parameters or depth map [Martinian'06, Shimizu'07]

- **Recently at PCS'09 we apply the projective rectification-based view interpolation in [Hartley'99] to MVC**
  - Allow flexible camera setup
  - Camera parameters not needed
  - Also used for rendering in [Farin'06, Kauff'07]
  - R-D performance not studied yet

- **This talk:**
  - Theoretical model for rectification-based view interpolation and the corresponding R-D model for MVC [ICME'09]
  - View extrapolation-based MVC [ICME'09]
  - Multiple description coding (MDC) of multiview images [Asilomar'09]

Rectification based View Interpolation

[Hartley'99]

Left and right views

↓

Estimate the fundamental matrix F:
- Corner detection
- Random Sample Consensus (RANSAC)
(Calibration not needed)

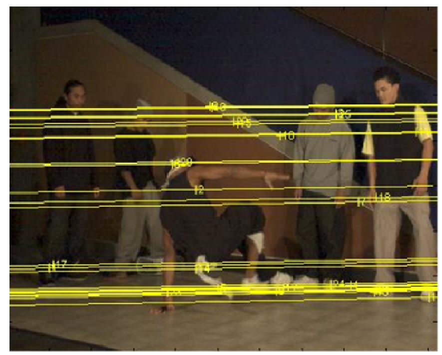
↓

Get projective rectification matrix:
- Find **epipoles** from F matrix
- Rotate the **epipoles** to infinity
(parallel cameras created)

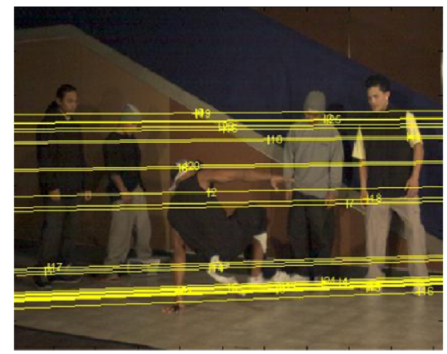
1-D disparity after rectification →

Left view

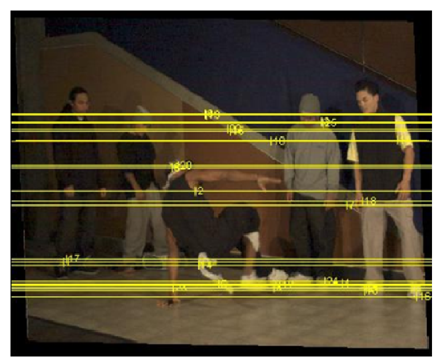
Right view



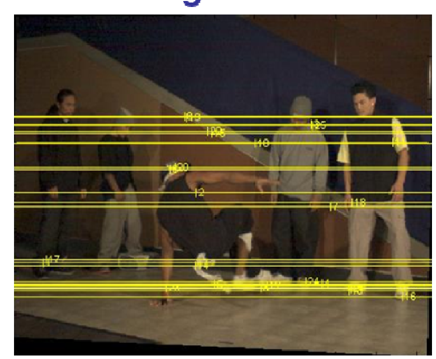
Left view



Right view



Rectified Left view



Rectified Right view

Rectification based View Interpolation

Rectified left & right views

↓

Perform disparity estimation

↓

Interpolate the middle view

↓

Un-rectify the interpolated view

Interpolated view

Unrectified interpolated view

- **Problem**: complexity

View Interpolation-based MVC

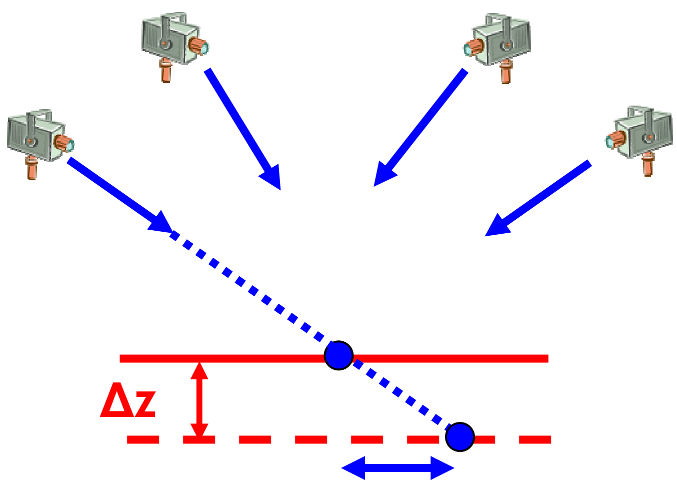
- **To use the view interpolation in H.264 based MVC, each frame can have 4 reference frames:**
  - The interpolated view (from rectification)
  - The temporal reference from the same view
  - The current frames in the left & right neighbouring views
- **Each block picks the best reference using R-D optimization.**

Existing Theoretical Models

- **Our R-D analysis is mainly based on the following papers:**
- [Girod *et al.*-'03,'06,'07]
- [Takahashi-ICIP'08]

- **1. MVC R-D Model in [Girod *et al.*-'03,'06,'07]:**
  - Object: 2D signal s(x,y) on a planar surface
  - Geometry error: an **offset Δz** from its true position

➔ Each view is a **shifted** version of s(x,y):



$$c_i(x,y) = s(x-\Delta_{x_i}, y-\Delta_{y_i}) + n_i(x,y)$$

- Other view-dependent effects are modeled as noise.
- The impact of Δz on MVC R-D performance can be derived from this.

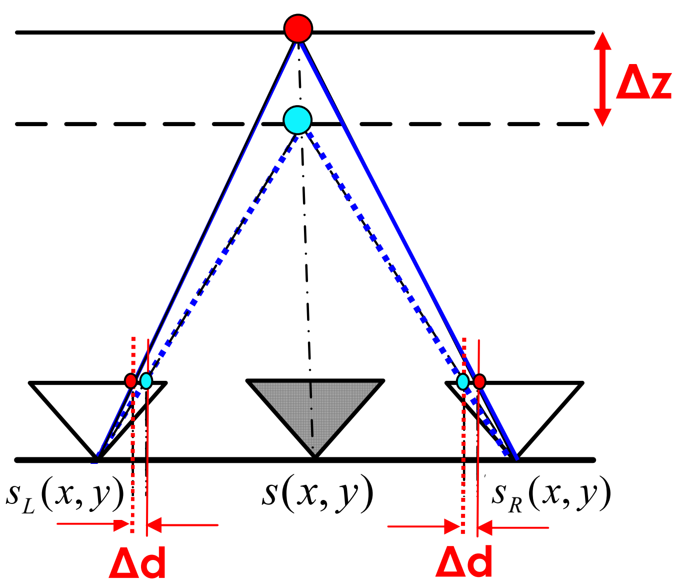
Existing Theoretical Models

- **2. View Interp. Model in [Takahashi-ICIP'08]:** s(x,y): middle view

$$s(x,y) = 1/2\{s_L(x+d,y) + s_R(x-d,y)\}$$

2d: disparity between left & right views

- **Assumption:** geometry error Δz causes some disparity error Δd



Interpolated view:

$$\hat{s}(x,y) = 1/2\{s_L(x+(d+\Delta d),y) + s_R(x-(d+\Delta d),y)\}$$
$$= 1/2\{s(x+\Delta d,y) + s(x-\Delta d,y)\}$$

Error: $$e(x,y) = s(x,y) - \hat{s}(x,y)$$

Power spectral density (PSD) of e(x,y):

$$\Phi_{ee}(\omega_x,\omega_y) = (1-\cos(\Delta d\cdot\omega_x))^2\Phi_{ss}(\omega_x,\omega_y).$$

The MSE of the interpolated view can be obtained.

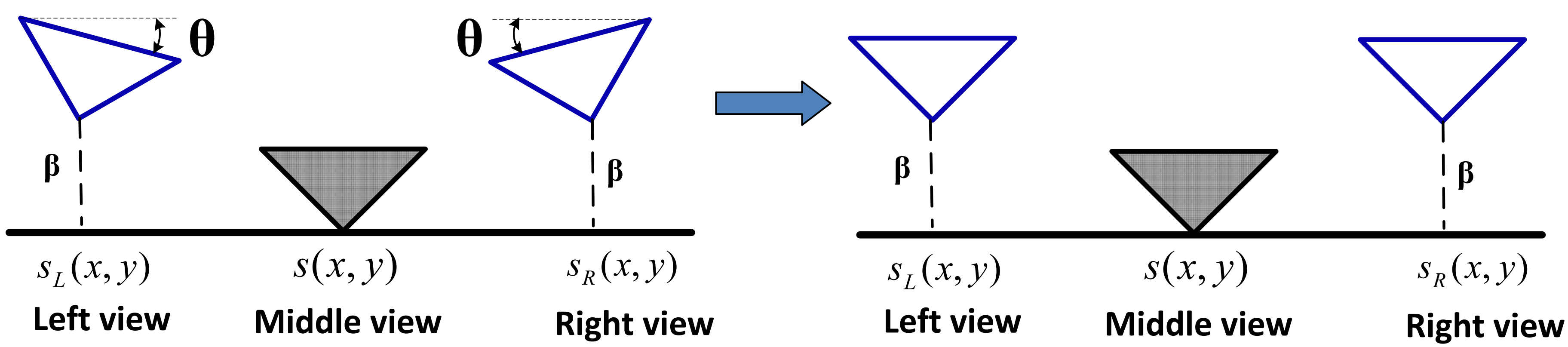
Limitations: 1. Parallel cameras; 2. R-D and MVC are not considered.

Proposed Model for Rectification-based View Interpolation

- **Our Goal: analyze the R-D performance of MVC when rectification-based view interpolation is used**
  - Assuming the orientations of the left & right views differ from the middle view by θ and are not in the same line as the middle view

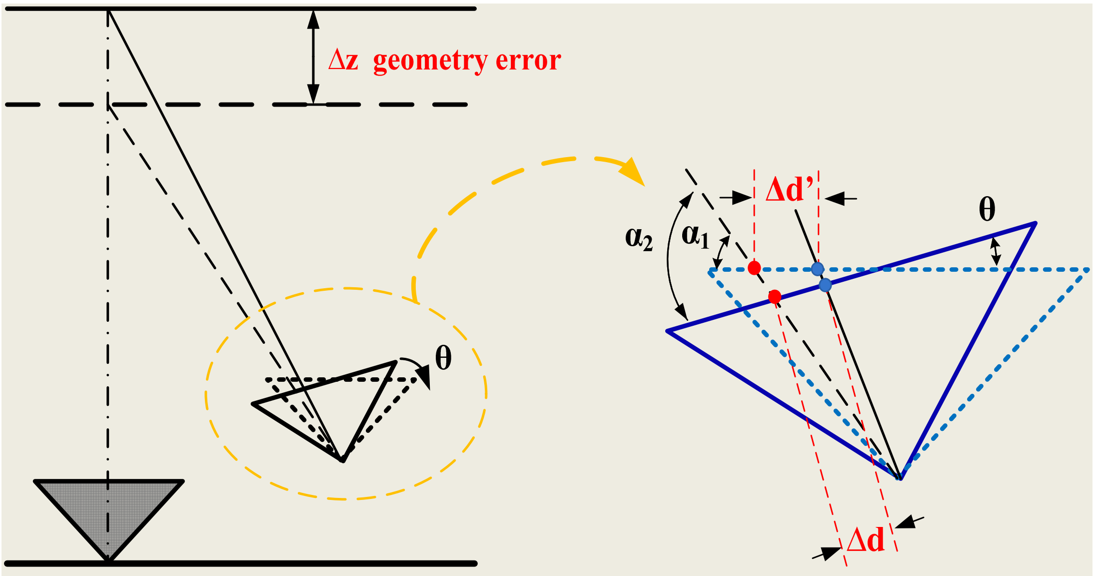
- **Rectification becomes:**

  1. Rotate left & right views to parallel positions.
  2. Shift them to the same line as the middle view.



Proposed Model for Rectification-based View Interpolation

- **Step 1:** After rotation, the disparity error **Δd** becomes **Δd'**:



$$\frac{\Delta d'}{\Delta d} \approx \cos\theta + \sin\theta \frac{\cos\alpha_1}{\sin\alpha_1}.$$

Avg. of Δd'/ Δd in the field of view:

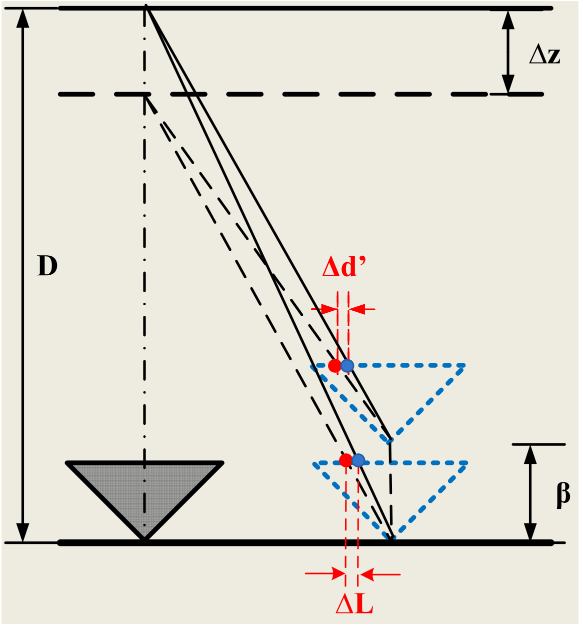
$$\frac{1}{\alpha_{FOV}} \int_{FOV} \left(\cos\theta + \sin\theta \cdot \frac{\cos\alpha_1}{\sin\alpha_1} \right) d\alpha_1 = \cos\theta.$$

➔ Rectification reduces the disparity error by a factor of cosθ on average.

Proposed Model for Rectification-based View Interpolation

- **Step 2:** If D>>β, the disparity error has little change after shifting by β ➔

$$\Delta L \approx \Delta d' \approx \Delta d \cdot \cos\theta.$$



Interpolated middle view after rectification:

$$\hat{s}(x,y) = 1/2\{s(x+\Delta d\cdot\cos\theta, y) + s(x-\Delta d\cdot\cos\theta, y)\}$$

Fourier Transform:

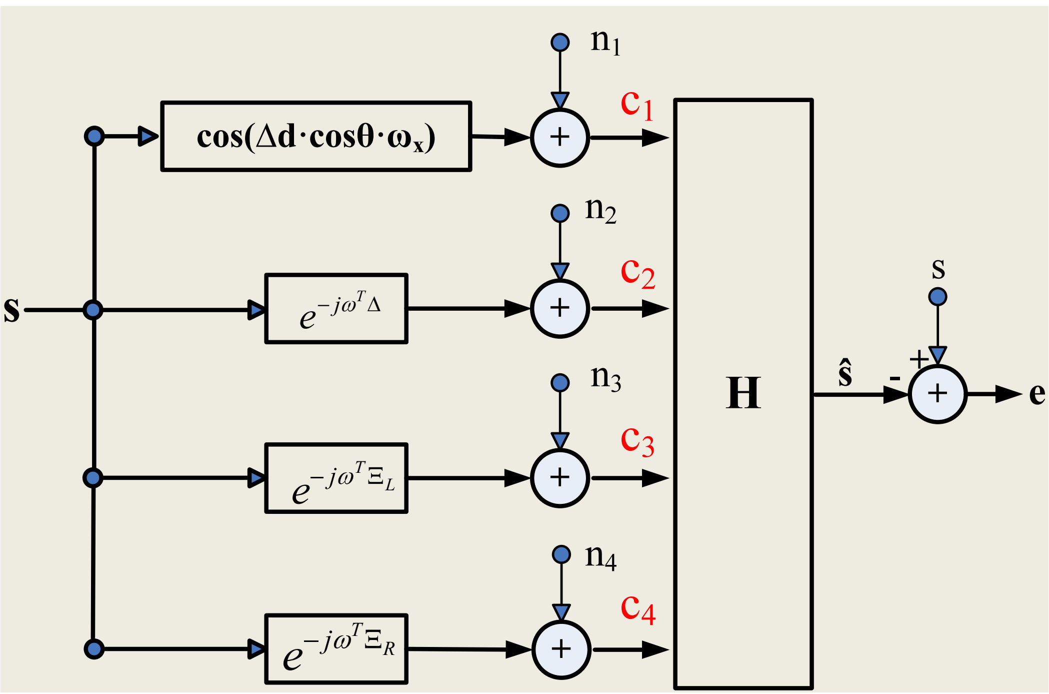
$$\hat{S}(\omega_x,\omega_y) = \cos(\Delta d\cdot\cos\theta\cdot\omega_x)\cdot S(\omega_x,\omega_y).$$

The model in [Takahashi-ICIP'08] is a special case of ours with θ = 0.

R-D Model for MVC with Rectification-based View Interpolation

- **To use view interp. In MVC, each frame has 4 reference frames:**
  - C_1: The interpolated view
  - C_2: The temporal reference with motion displacement Δ.
  - C_3, C_4: The references from left & right views, with disparity Ξ_L and Ξ_R.

- **The following model is obtained (based on [Girod *et al.*-'03,'06,'07]):**



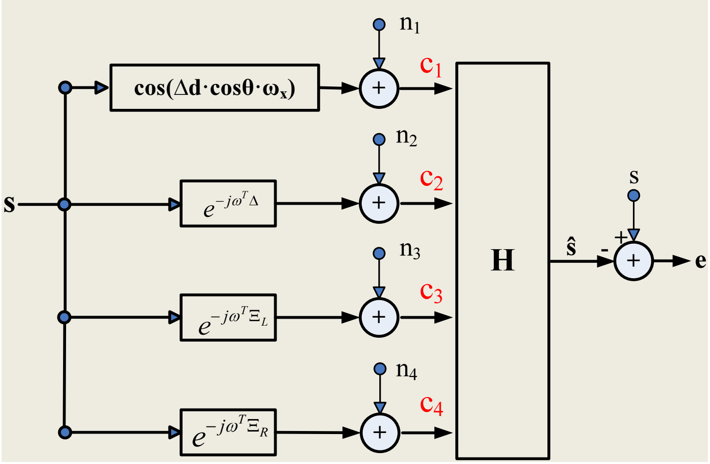
- The MVC can be modelled as a linear estimation problem.
- The prediction residual ***e*** is encoded.
- The RD performance can be obtained.
- **Another performance measure:** Rate difference w.r.t. direct coding.

R-D Model for MVC with Rectification-based View Interpolation

- **The LMMSE filter:** $$H = \Phi_{cs}^{*}\Phi_{cc}^{-1}$$

- **The PSD of the prediction residual:**

$$\Phi_{ee} = \Phi_{ss} - \Phi_{cs}^{*}\Phi_{cc}^{-1}\Phi_{cs}$$



$$\mathbf{c} = \begin{bmatrix} c_1 & c_2 & c_3 & c_4 \end{bmatrix}^T$$

- **R-D function of Gaussian signal x(x, y):**

$$R(\lambda) = \frac{1}{8\pi^2}\int_{\omega_x}\int_{\omega_y} \max\left(0, \log_2 \frac{\Phi_{xx}(\omega_x,\omega_y)}{\lambda}\right) d\omega_x d\omega_y$$

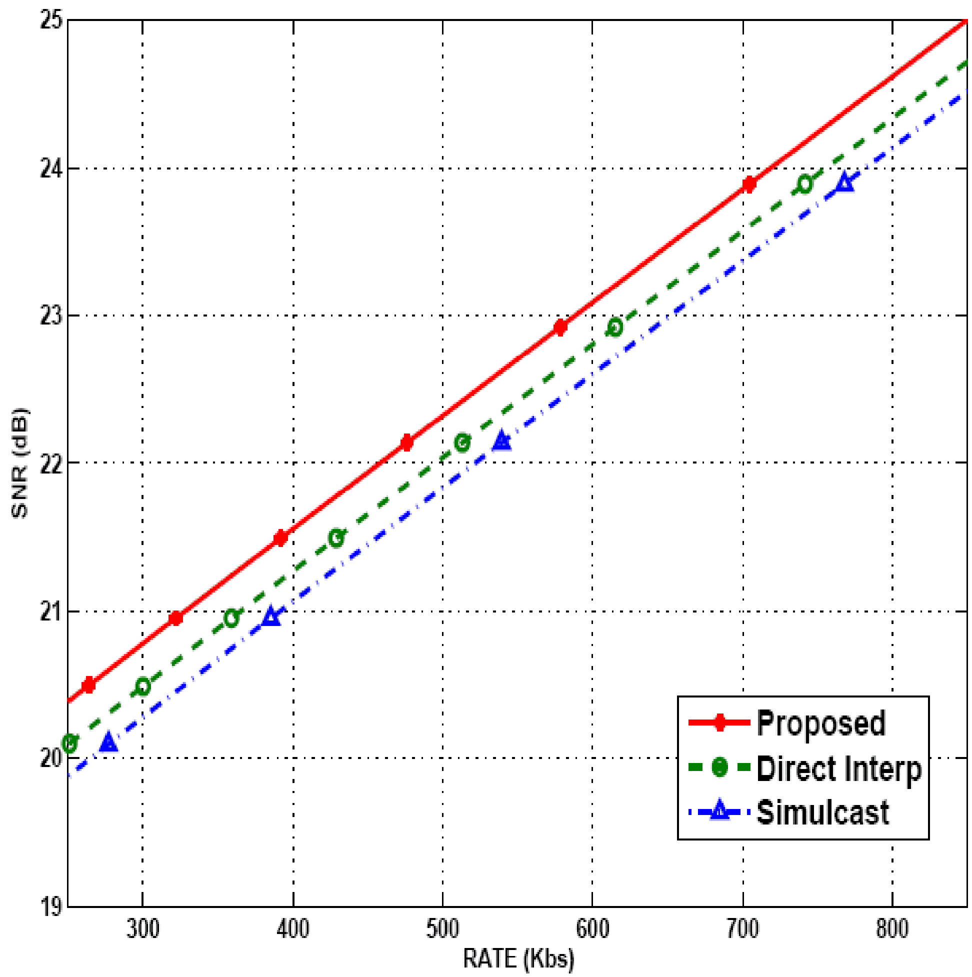
$$D(\lambda) = \frac{1}{4\pi^2}\int_{\omega_x}\int_{\omega_y} \min\left(\lambda, \Phi_{xx}(\omega_x,\omega_y)\right) d\omega_x d\omega_y$$

- **Rate difference between predictive coding and direct coding:**

$$\Delta R = R_e - R_s = \frac{1}{8\pi^2}\int_{\omega_x}\int_{\omega_y} \log_2 \frac{\Phi_{ee}(\omega_x,\omega_y)}{\Phi_{ss}(\omega_x,\omega_y)} d\omega_x d\omega_y$$

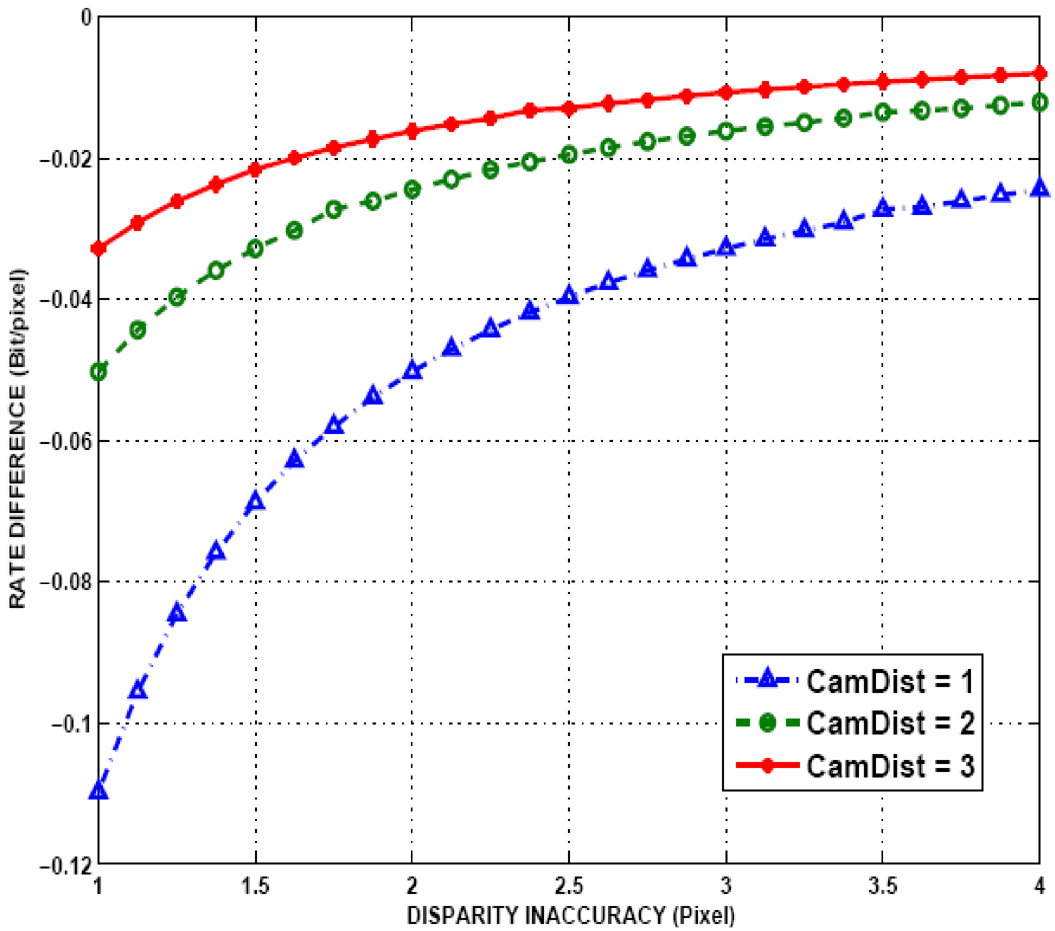
Simulation Results

- **R-D curves:** Gaussian source, $\theta = 30^{\circ}$
  (Direct interp.: view interp without rectification)



Simulation Results

- **Impact of disparity error Δd and camera distance on rate difference:**



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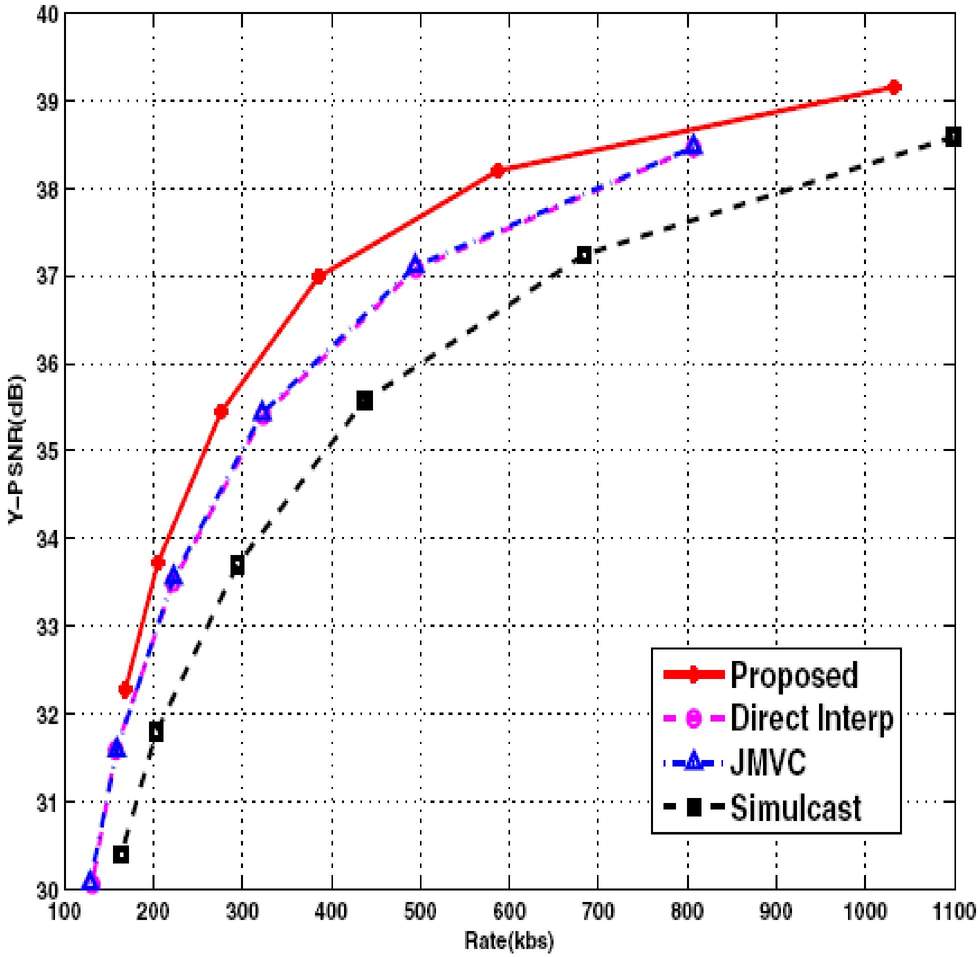
Interpolation-based MVC Results

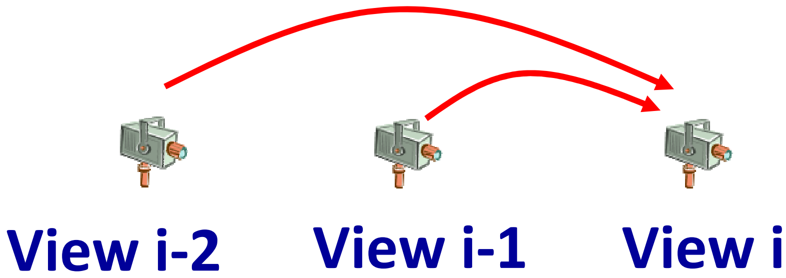
- **Coding Results: 2nd view of Breakdancers: up to 1 dB higher than JMVC**



- **Limitation: view interpolation can only be used in half of the views.**

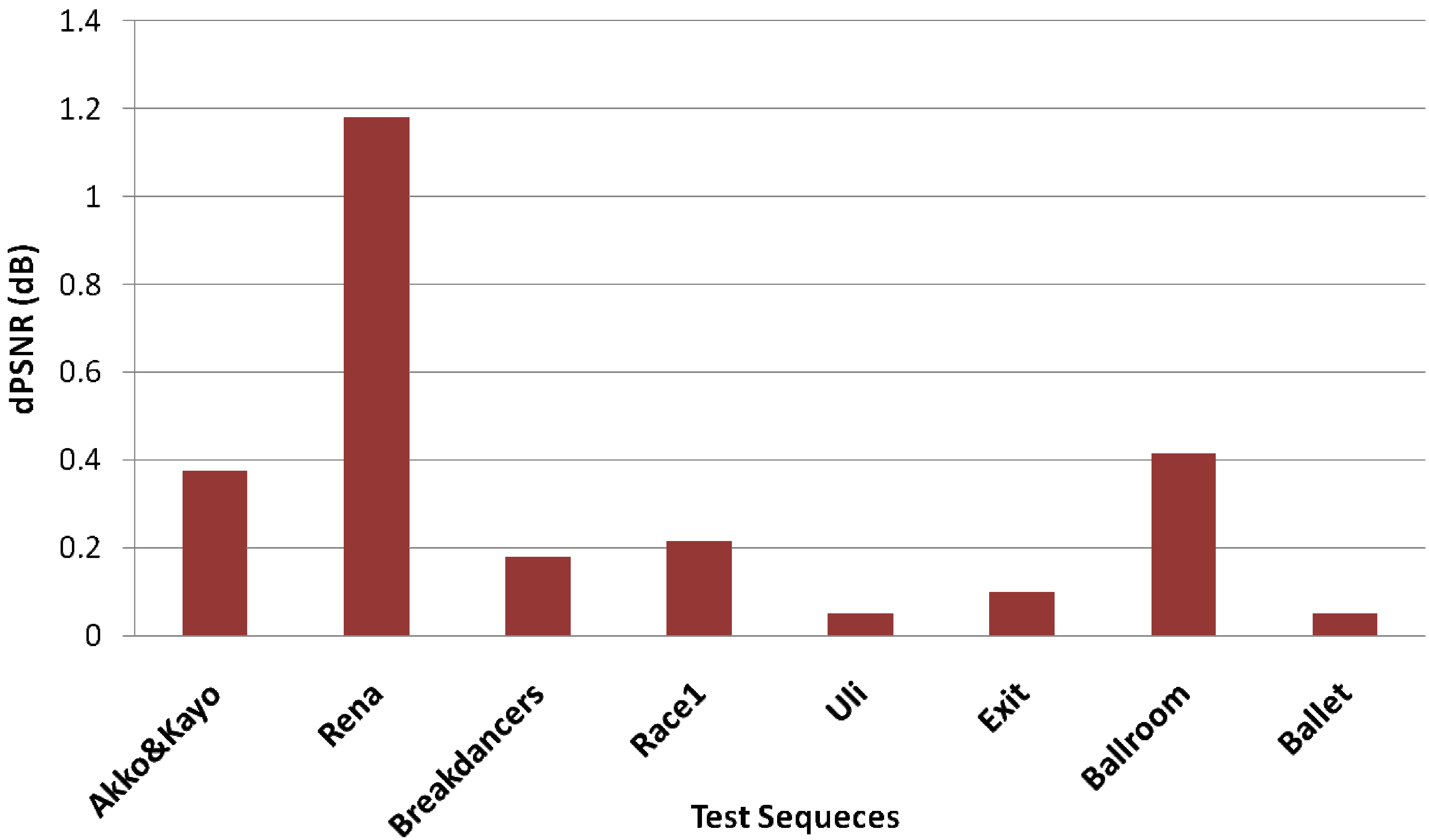
View Extrapolation

- **To apply view synthesis prediction to more views, we develop an rectification-based view extrapolation method:**
  - **Use two previous views**
  - Rectification → disparity estimation → view extrapolation → un-rectification

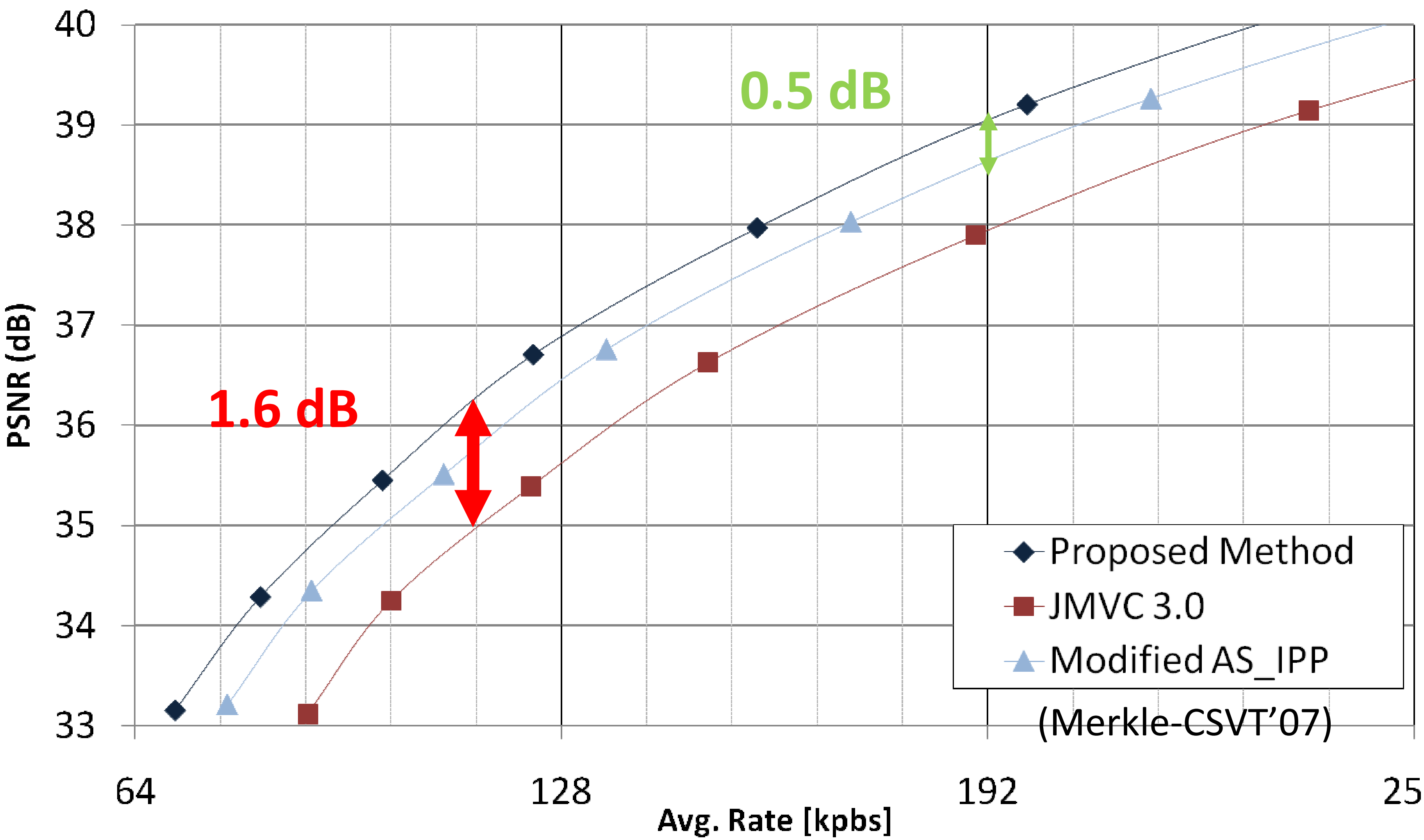


- **Extrapolation-based MVC:**
  - Encode the 1st and 2nd views using existing method
  - For other views, use the previous two views to extrapolate a synthesised view, which is used as an additional reference frame.

Average Gain of All Views Over JMVC



One View of Rena



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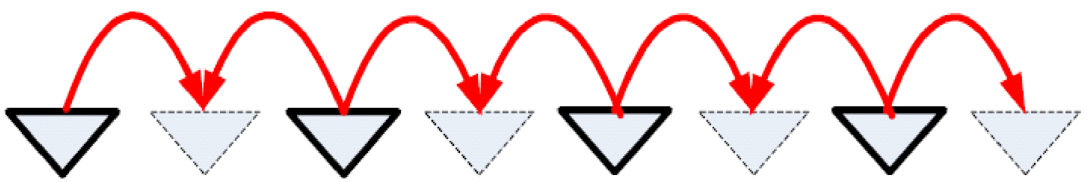
Multiple Description Coding of Multiview Images

- **Multiple description coding (MDC) of multiview images and videos have not been well studied.**

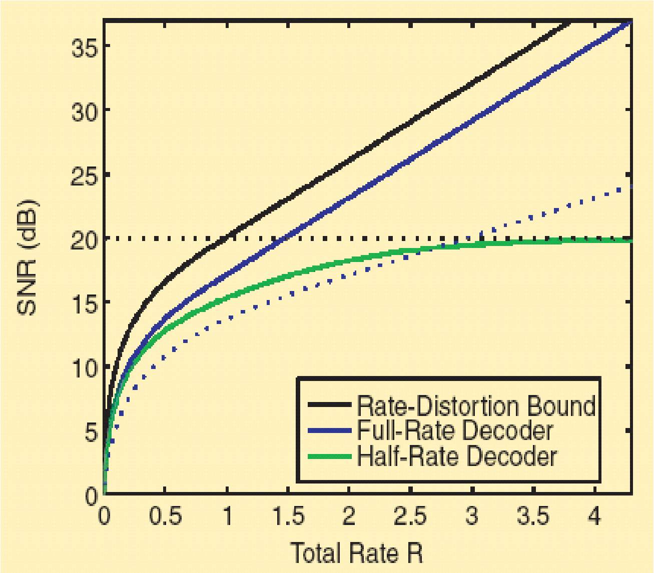
- **Related work: View subsampling [Ishii-ICIP08]:**
  - **Goal**: Reduce transmission bandwidth
  - **Approach**: Encode only half of the views (primary views).
  - **Decoder:** Missing (secondary) views are estimated from neighboring views using view interpolation.



- **Problem:**
  - The quality of the missing views cannot be improved even at high rates, due to prediction residual.

Multiple Description Coding of Multiview Images

- **This is equivalent to the even-odd spliting MDC scheme in** [Jayant'81]
- The problem of the half-rate decoder (side decoder) is also well known [Goyal'01]



[Goyal'01], pp. 78

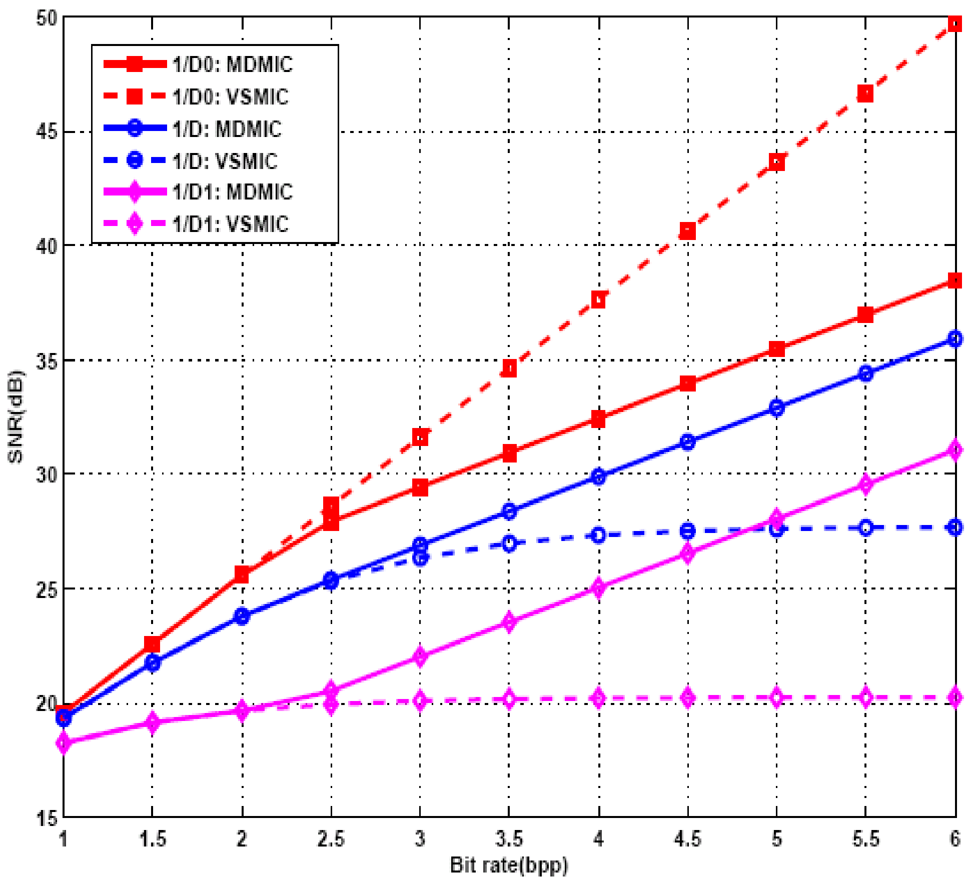
- **Possible solution: 2-layer coding [Wang'02], [Liang'07]:**
  - Base layer: primary views.
  - Enhancement layer: prediction residual of secondary views.

- **Rectification-based view interpolation is helpful here.**

Multiple Description Coding of Multiview Images

- **Theoretical R-D Analysis for MDC of multiview images:**

  Central/side/expected distortions vs bit rate



D0: **Central distortion** (two descriptions)

D1: **Side distortion** (one description)

D: **Expected distortion**

2-layer coding

View subsampling only

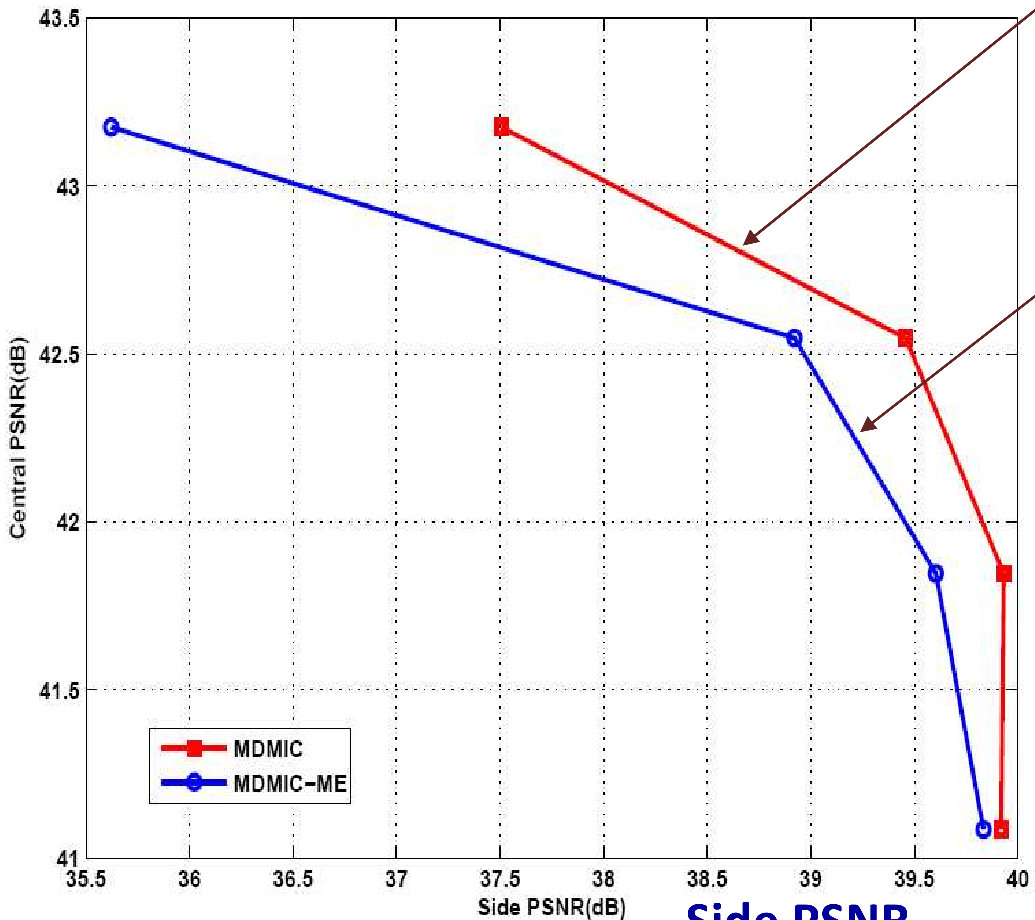
Multiple Description Coding of Multiview Images

- **MDC of multiview images with JMVC:**
  Ballroom sequence, 0.75 bpp per description

View interpolation
coded secondary views

JMVC inter frame coded
secondary views

Central PSNR



Side PSNR

Conclusions

- **Summary:**
  - Theoretical model for rectification-based view interpolation and the corresponding MVC
  - Performance in MVC with view interpolation and video extrapolation
  - Multiple description coding of multiview images

- **Current work:**
  - Refinement of the R-D model
  - Coding gain for all views

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  - Derek Pang

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