Statistical Methods for Inter-view Depth Enhancement

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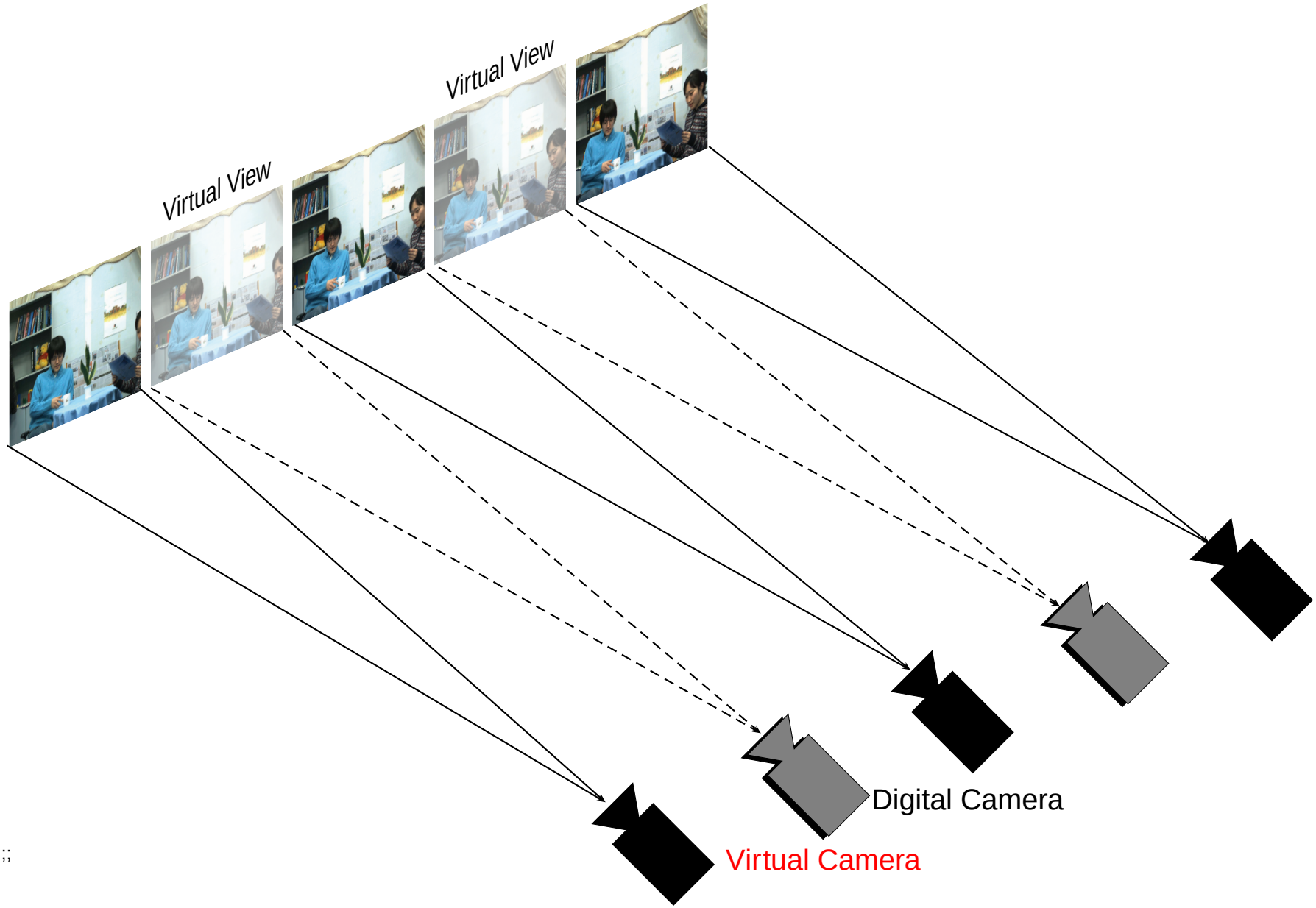
Outline

Outline

Free-viewpoint Television



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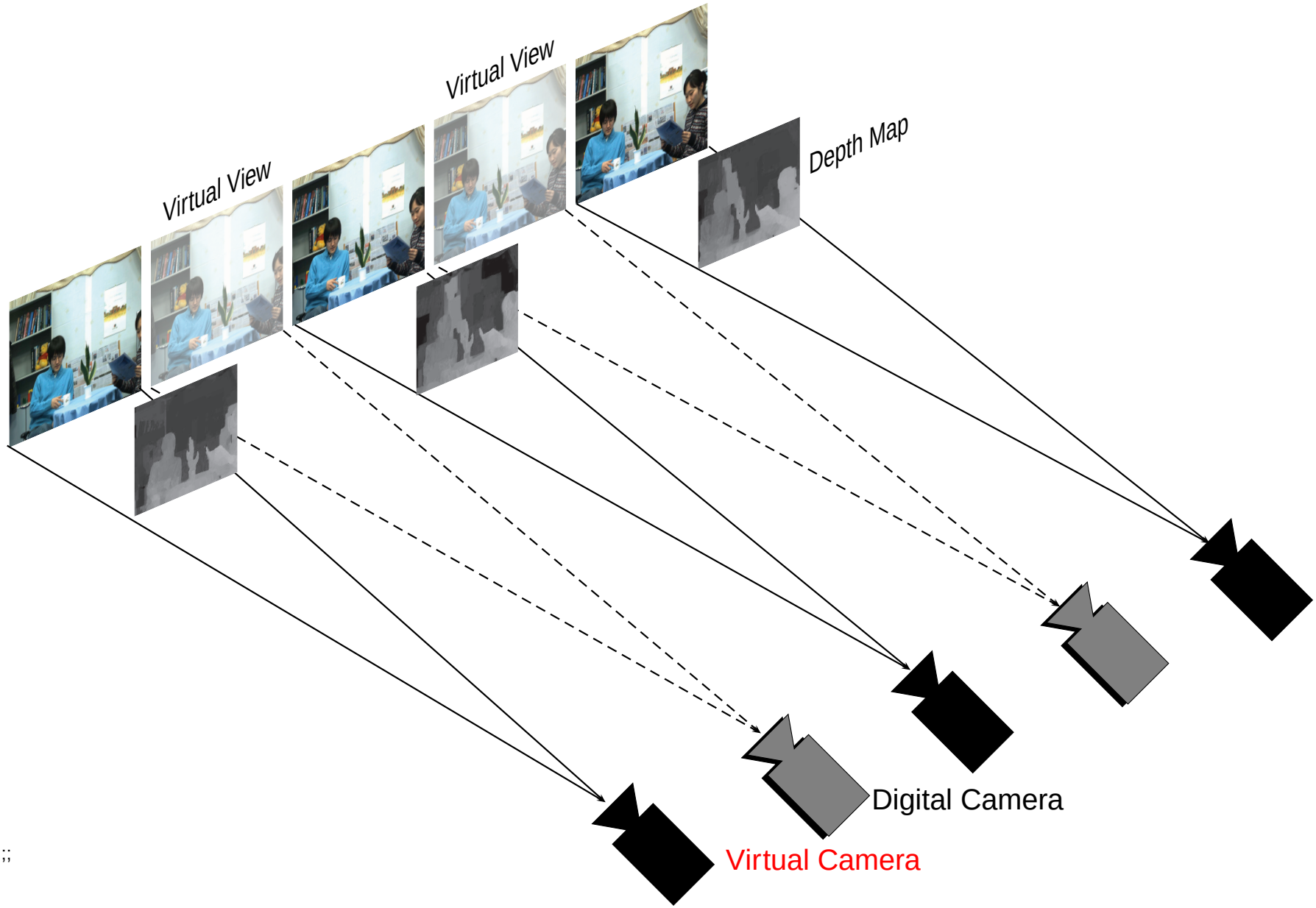
Free-viewpoint Television



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Depth Map Estimation

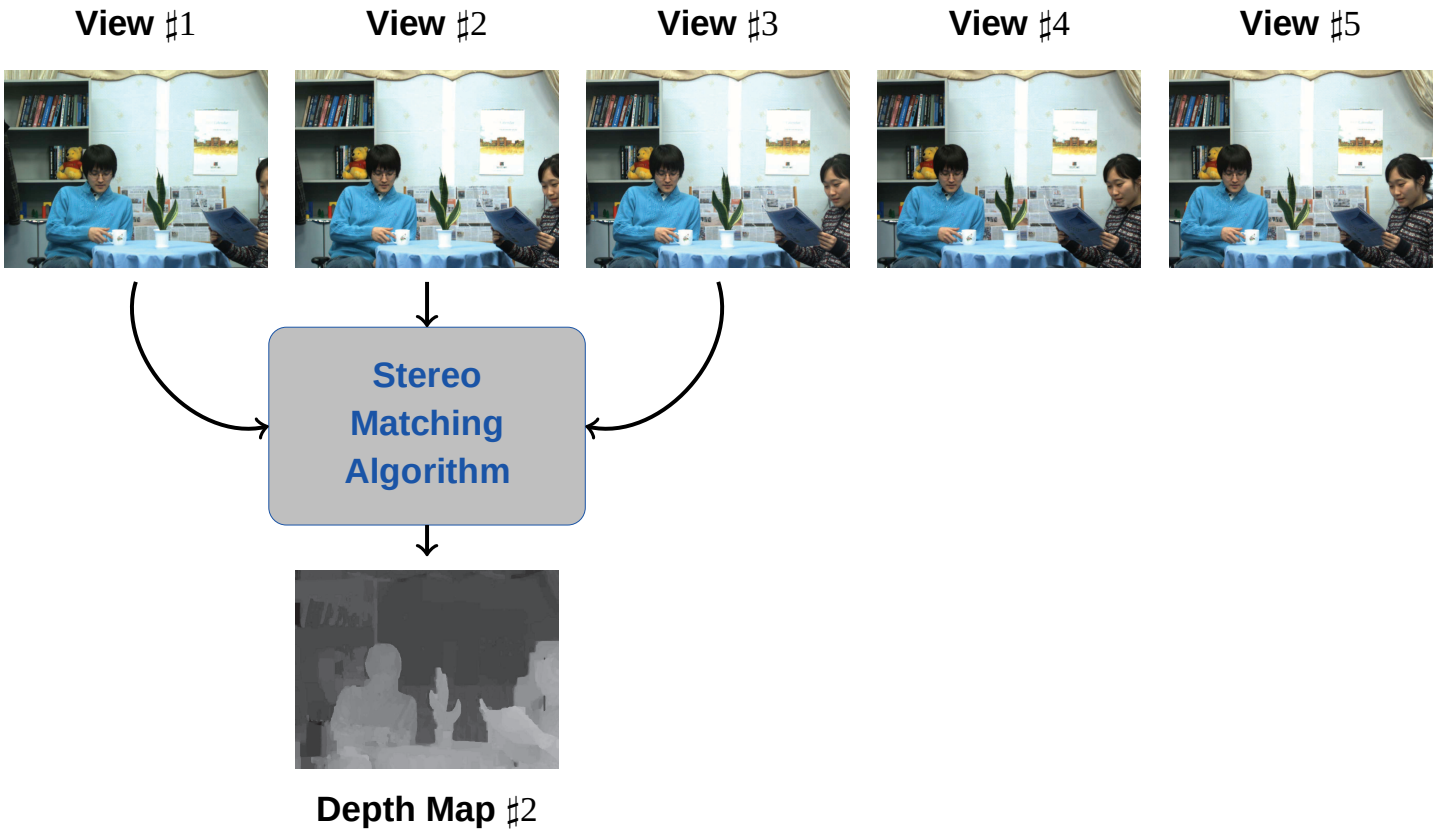
Example: MPEG Depth Estimation Reference Software[1]

View ♯1 **View ♯2** **View ♯3** **View ♯4** **View ♯5**

[1] M. Tanimoto, T. Fujii, K. Suzuki, N. Fukushima, and Y.Mori, "Reference softwares for depth estimation and view synthesis," ISO/IEC JTC1/SC29/WG11, Archamps, France, Tech. Rep. M15377, Apr. 2008.

Depth Map Estimation

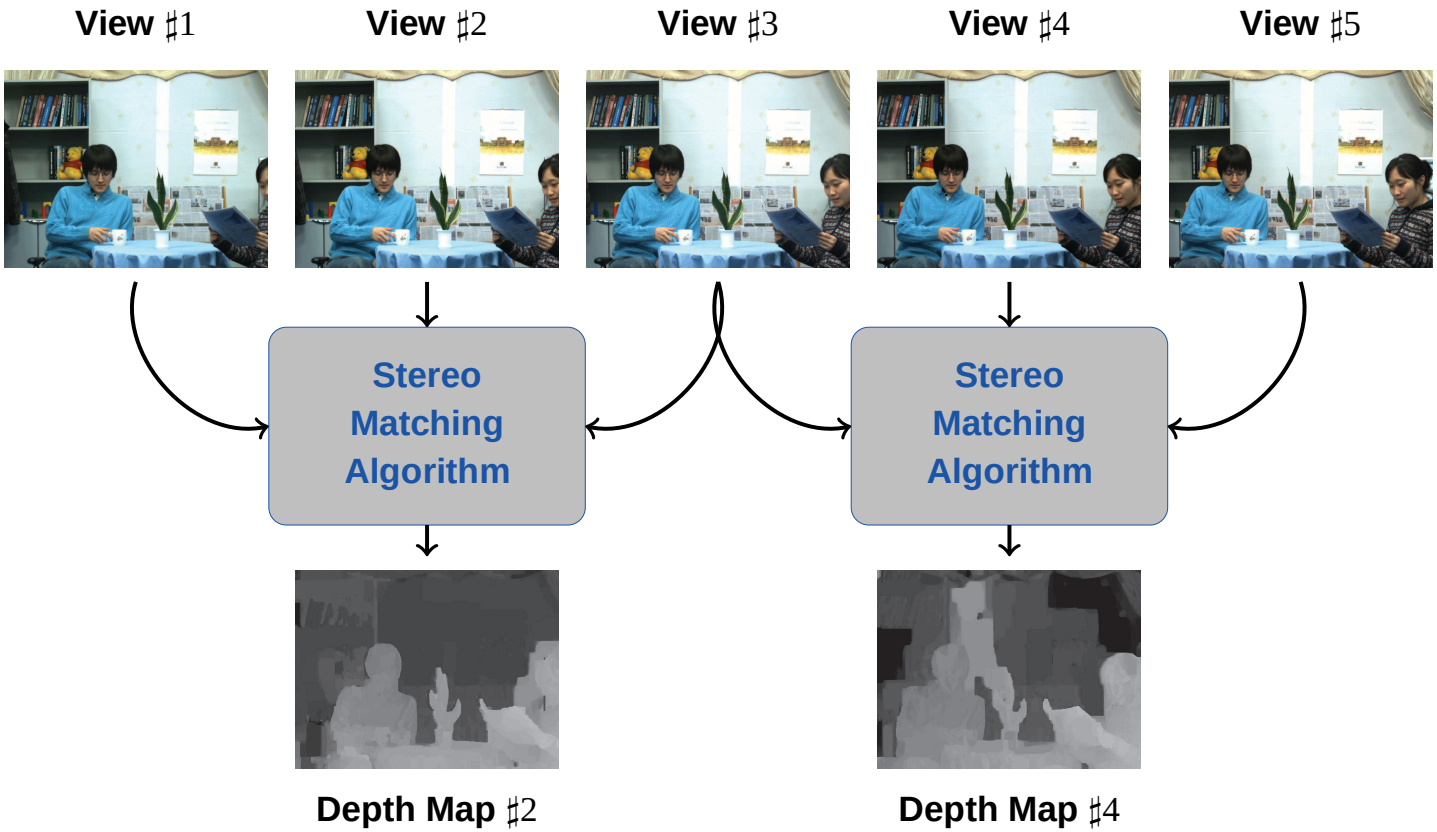
Example: MPEG Depth Estimation Reference Software[1]



[1] M. Tanimoto, T. Fujii, K. Suzuki, N. Fukushima, and Y.Mori, "Reference softwares for depth estimation and view synthesis," ISO/IEC JTC1/SC29/WG11, Archamps, France, Tech. Rep. M15377, Apr. 2008.

Depth Map Estimation

Example: MPEG Depth Estimation Reference Software[1]



[1]M. Tanimoto, T. Fujii, K. Suzuki, N. Fukushima, and Y.Mori, "Reference softwares for depth estimation and view synthesis," ISO/IEC JTC1/SC29/WG11, Archamps, France, Tech. Rep. M15377, Apr. 2008.

Example of Inter-view Depth Inconsistency

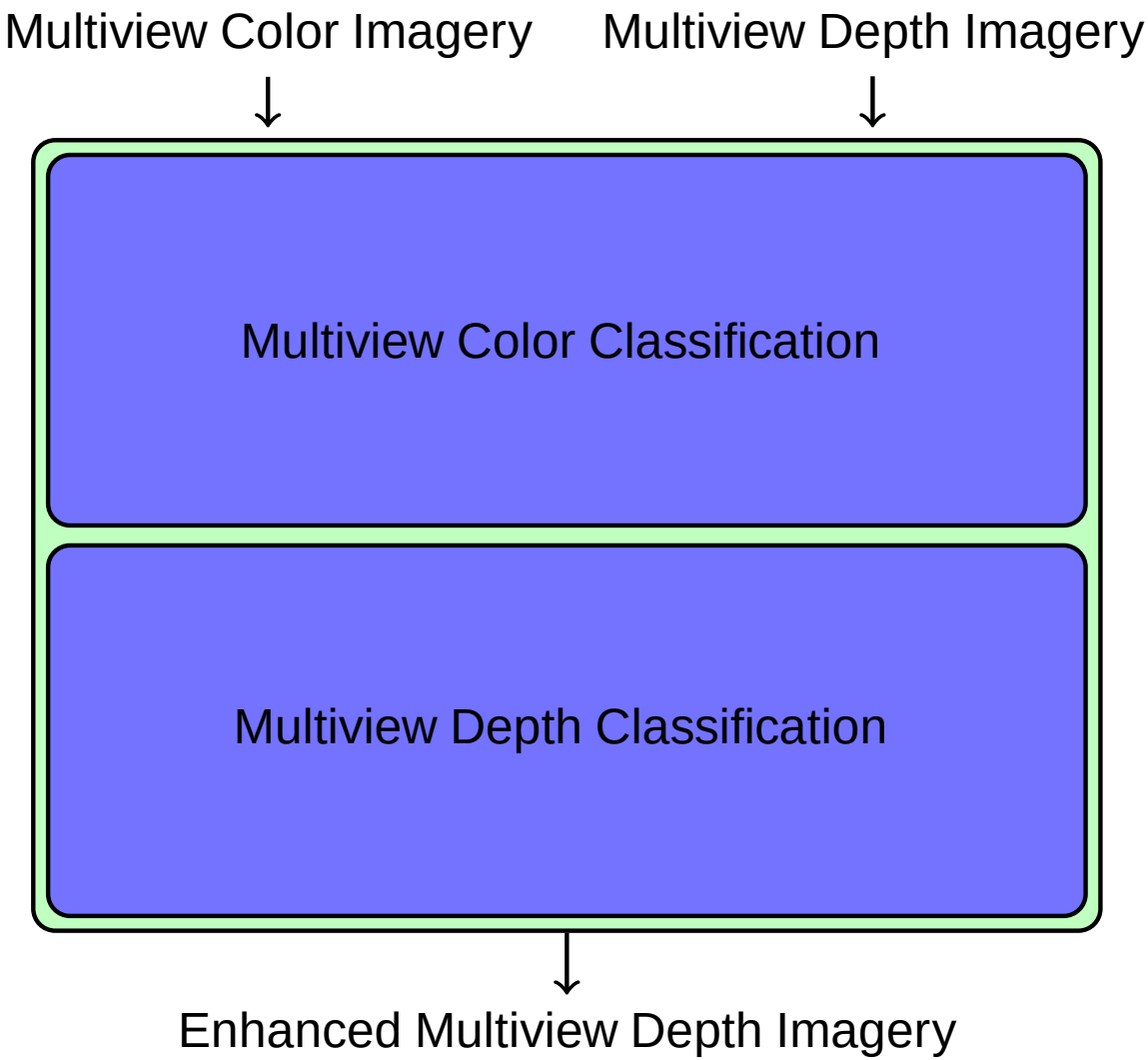
view ♯1 **view ♯2** **view ♯3**

Newspaper

Note: we assume a 1D-parallel camera arrangement

Outline

Overview: Probabilistic Depth Enhancement



Multiview Color Classification

Dirichlet mixture model with variational Bayes inference[2] [3]

- Variational Bayes inference automatically selects the number of cluster
- In image, the vector of chromaticity coefficients has non-negative elements and is bounded
- Use the Dirichlet mixture model with variational inference to capture the all underlying clusters in multiview imagery
- Use of superpixels helps to decrease the number of feature samples and hence, the computational complexity

[2] C. M. Bishop, "Pattern Recognition and Machine Learning", 1st ed. New York: Springer, 2006.

[3] Z. Ma, P.K. Rana, J. Taghia, M. Flierl, A. Leijon, "Bayesian estimation of Dirichlet mixture model with variational inference", Pattern Recognition, 2014.

Multiview Color Classification

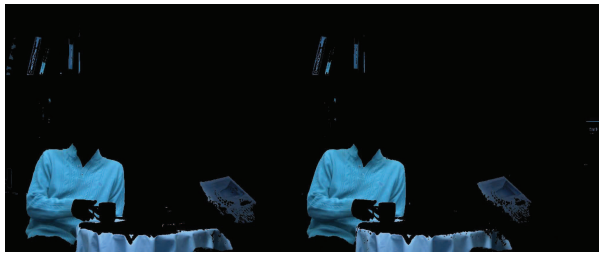
Example results

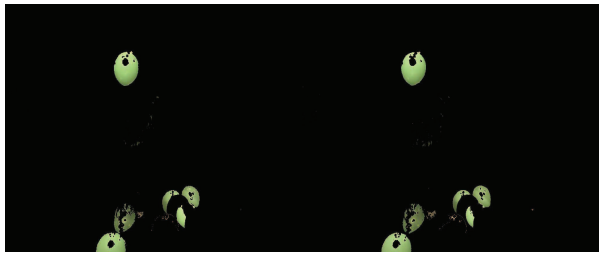
Newspaper

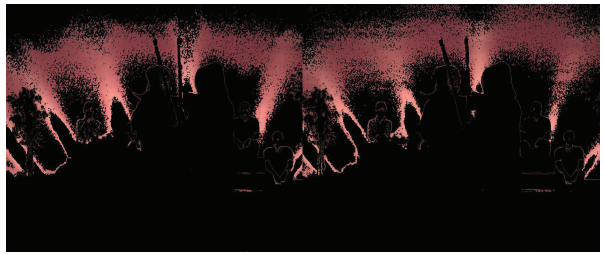
Balloons

Kendo

Input concatenated view imagery







Using Dirichlet mixture model with variational Bayes inference in xyz space

Multiview Color Classification

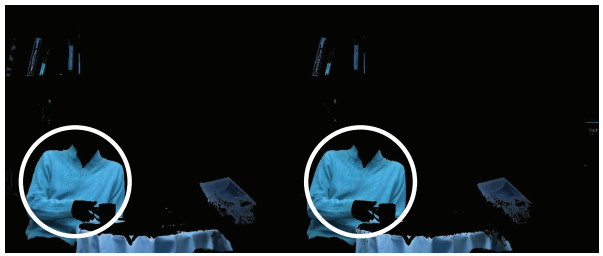
Example results

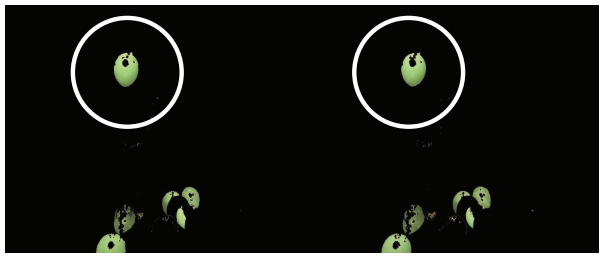
Newspaper

Balloons

Kendo

Input concatenated view imagery

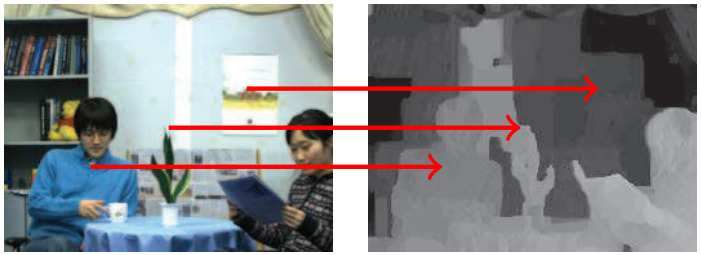




Using Dirichlet mixture model with variational Bayes inference in xyz space

Multiview Depth Classification

- Exploiting per-pixel association between color and depth pixels



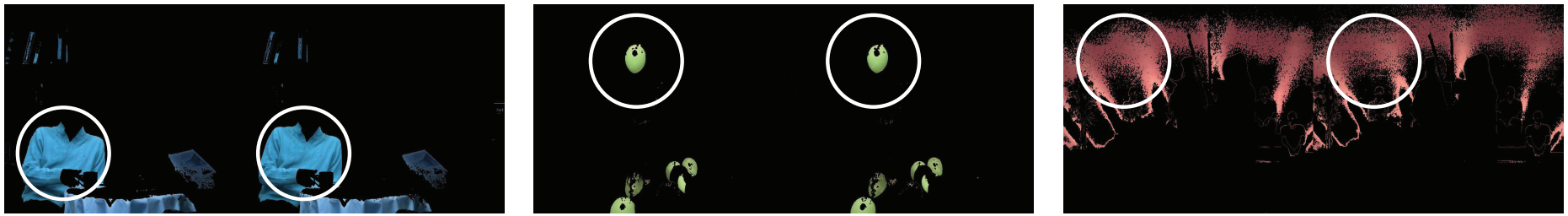
Color Image Depth Image

Multiview Depth Classification

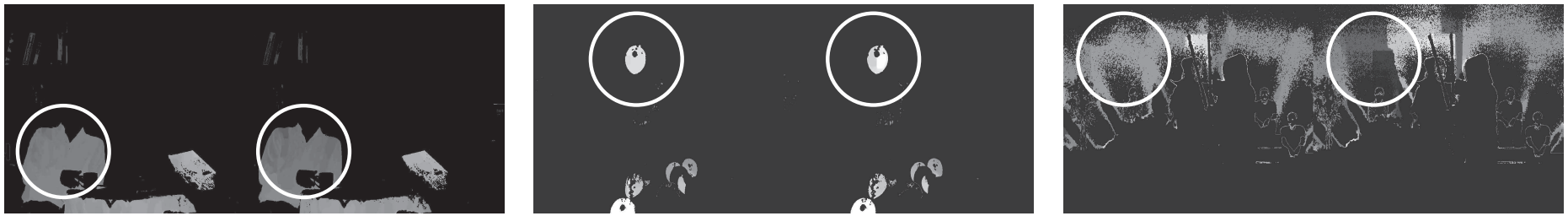
Example results

Newspaper | Balloons | Kendo

Input concatenated view imagery



Using Dirichlet mixture model with variational Bayes inference in xyz space



Multiview depth clusters

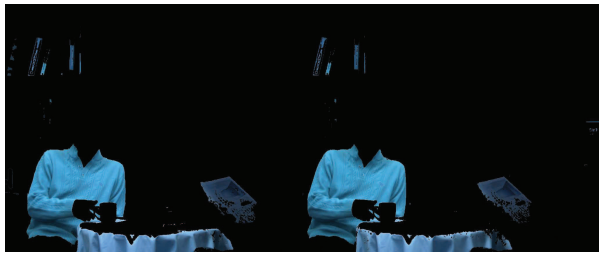
Multiview Depth Sub-classification

Difference between color and depth clusters

Newspaper

Input multiview data

Newspaper Color Cluster



Similar colors pixels

Newspaper Depth Cluster

May have different depth values

- Due to foreground and background depth difference, and inter-view inconsistency

Multiview Depth Sub-classification

To resolve depth cluster foreground and background ambiguity:

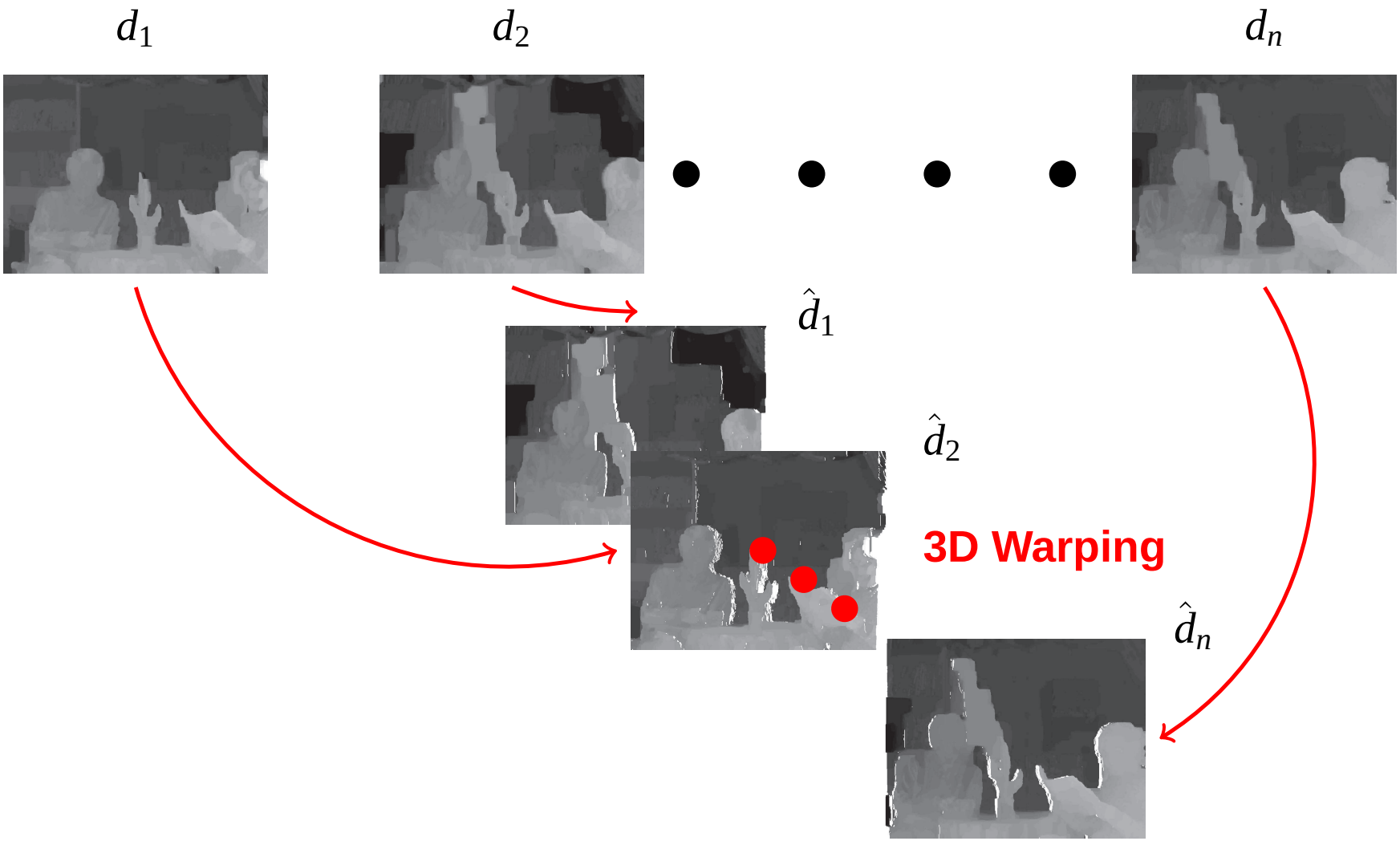
- Consider a feature vector that consists of depth pixel value and its location information with respect to the viewpoint it belongs
- Feature vectors are modeled by a mixture of multivariate Gaussian distributions using variational Bayesian inference
- The responsibilities play an important role in Bayesian classification, it express how responsible each mixture component is in explaining the data
- Replace the depth values in the depth sub-cluster by the responsibility-weighted mean. Here, the largest responsibility of the depth pixel is used for weighting.

Outline

Multiview Depth Imagery

d_1 d_2 d_n

3D Warping for Spatial Ailgnment



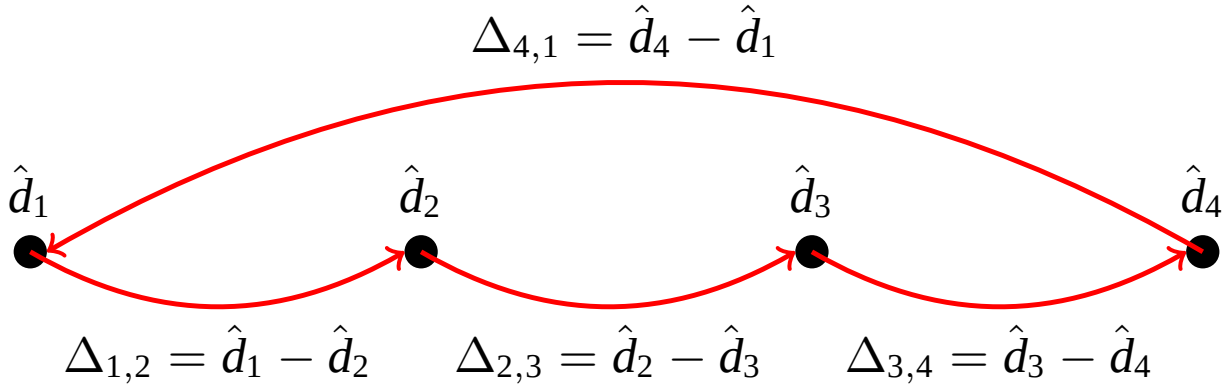
Co-located Warped Depth Hypotheses

Co-located Warped Depth Pixel Hypotheses

Example: Four Warped Depth Pixel Hypotheses

Inter-view Depth Inconsistency

Example: Four Warped Depth Pixel Hypotheses



Loop Depth Difference Vector

Loop Depth Difference Vector:

$$\Delta = \begin{bmatrix} \Delta_{1,2} & \Delta_{2,3} & \Delta_{3,4} & \Delta_{4,1} \end{bmatrix}^T$$

Energy of Loop Depth Difference Vector: It captures the individual inter-view depth differences

$$E_k(\Delta) = \Delta^T \Delta$$

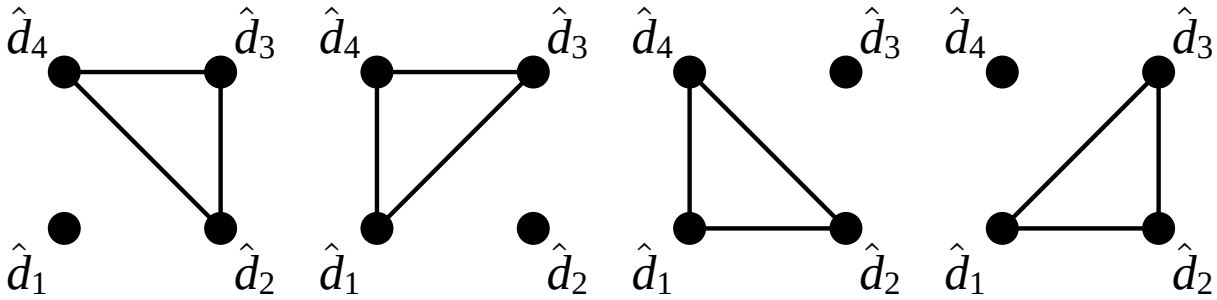
Inter-view Consistency Testing Rule:

$$E_k(\Delta) \begin{cases} \leq \theta & \text{accept all depth hypotheses and associated depth value as consistent} \\ = 0 & \text{all the depth hypotheses are assumed to be perfectly consistent} \\ > \theta & \text{reject all depth hypotheses and associated depth value} \end{cases}$$

where θ is the inter-view consistency threshold and directly proportional to the standard deviation of $\Delta_{i,j}$.

If Consistency Testing Fails

- Repeat the consistency testing with a reduced number of depth hypotheses until the desired consistency is achieved, $k \geq 2$
- For example: There are 4 unique ways to define the loop difference vectors with 3 out of 4 depth hypotheses and to perform the tests:

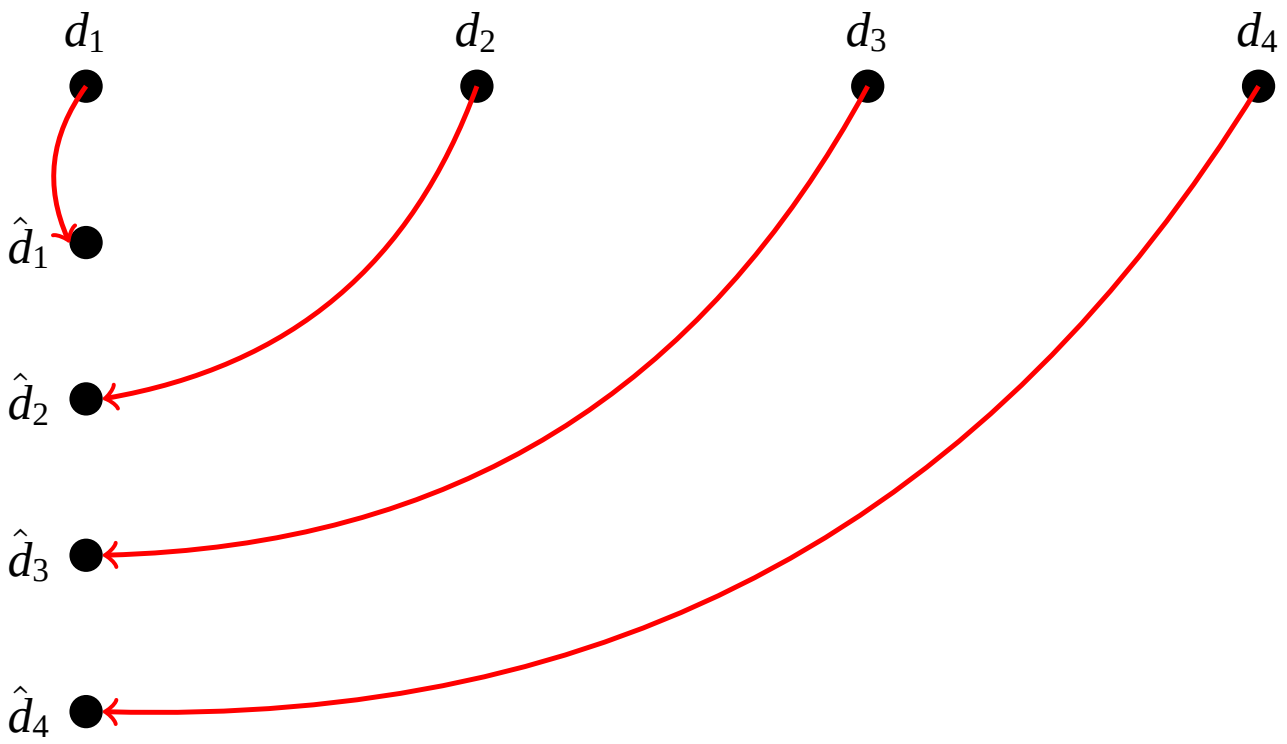


- If multiple tests are successful, we accept only the loop difference vector with the lowest energy.
- All tests fail, mark the pixel and use inpainting to decide the best depth value.
- Using this consistency information, the corresponding depth values can be used to determine an improved depth estimate

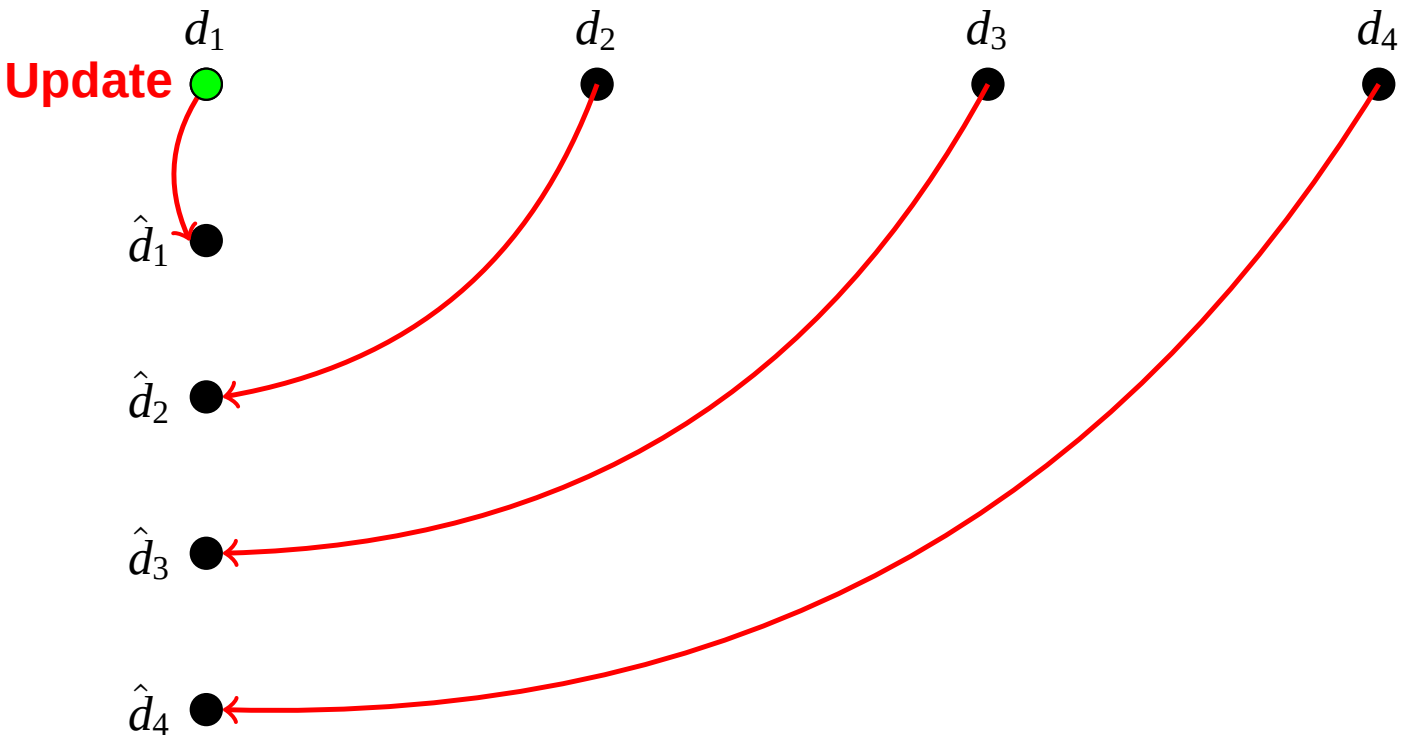
Iterative Depth Map Enhancement

d_1 d_2 d_3 d_4

Iterative Depth Map Enhancement

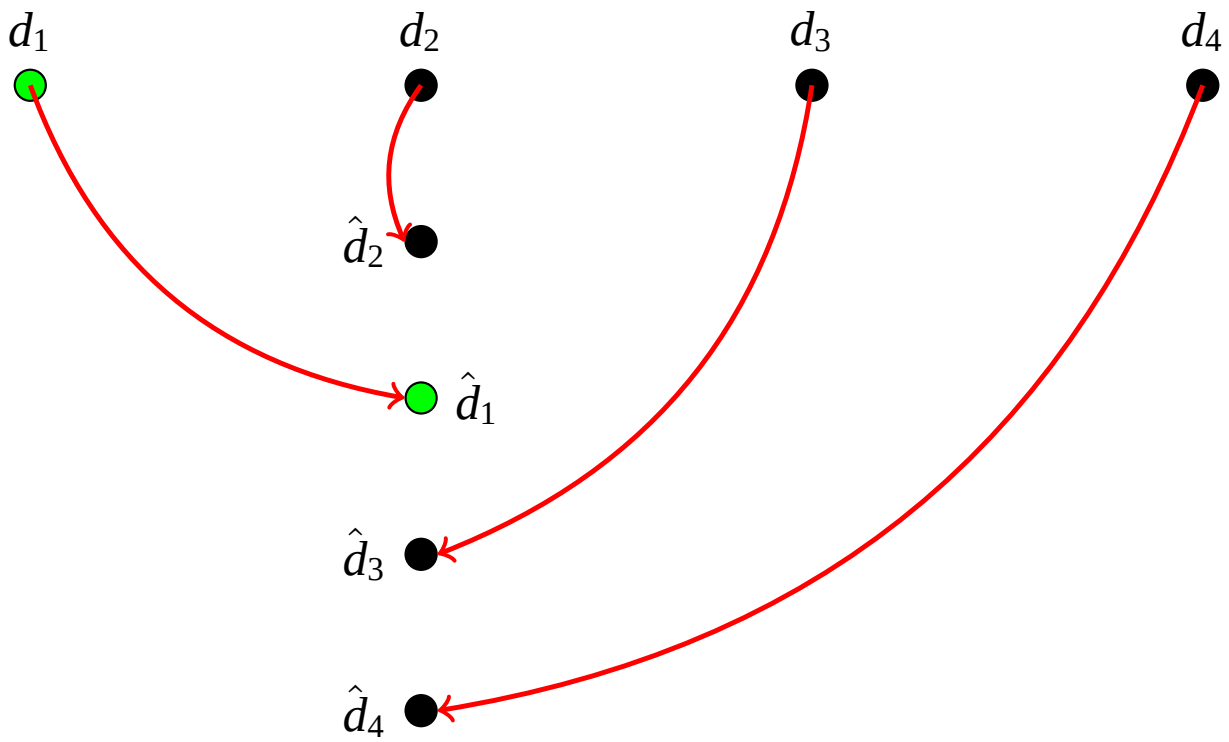


Iterative Depth Map Enhancement

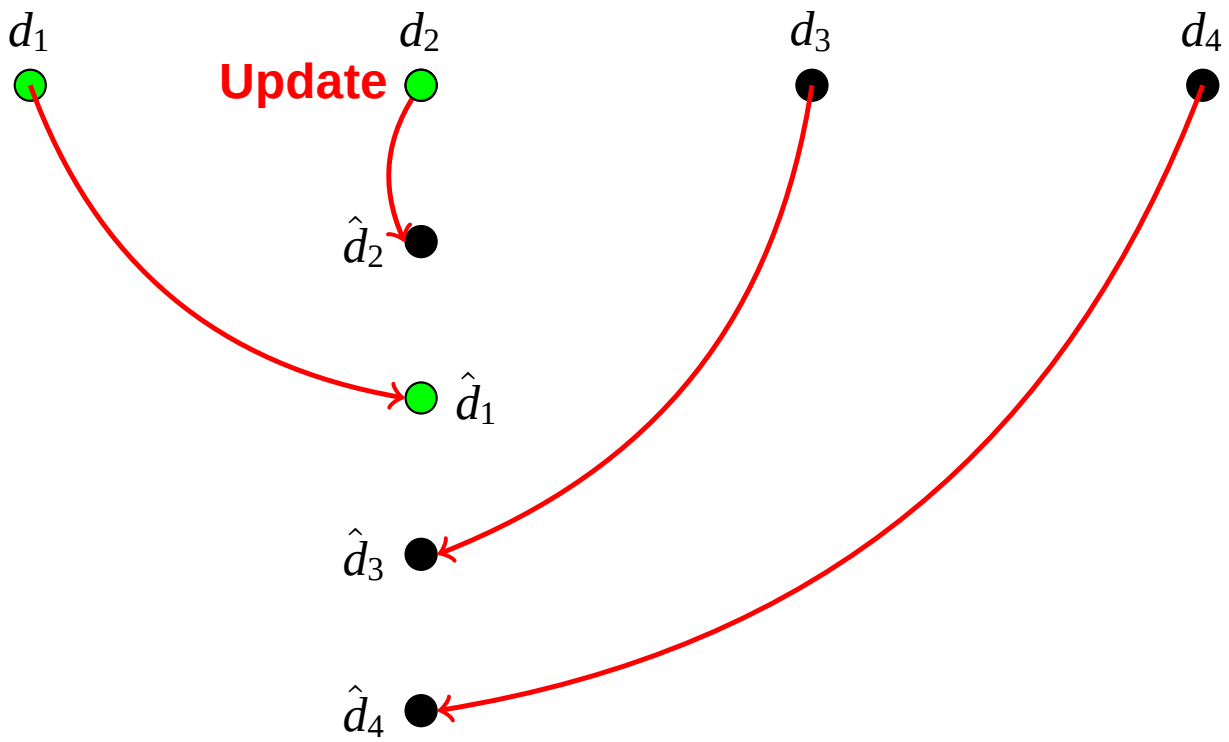


- Update Rule: The depth value is updated by weighted baseline averaging of the chosen depth hypotheses

Iterative Depth Map Enhancement



Iterative Depth Map Enhancement



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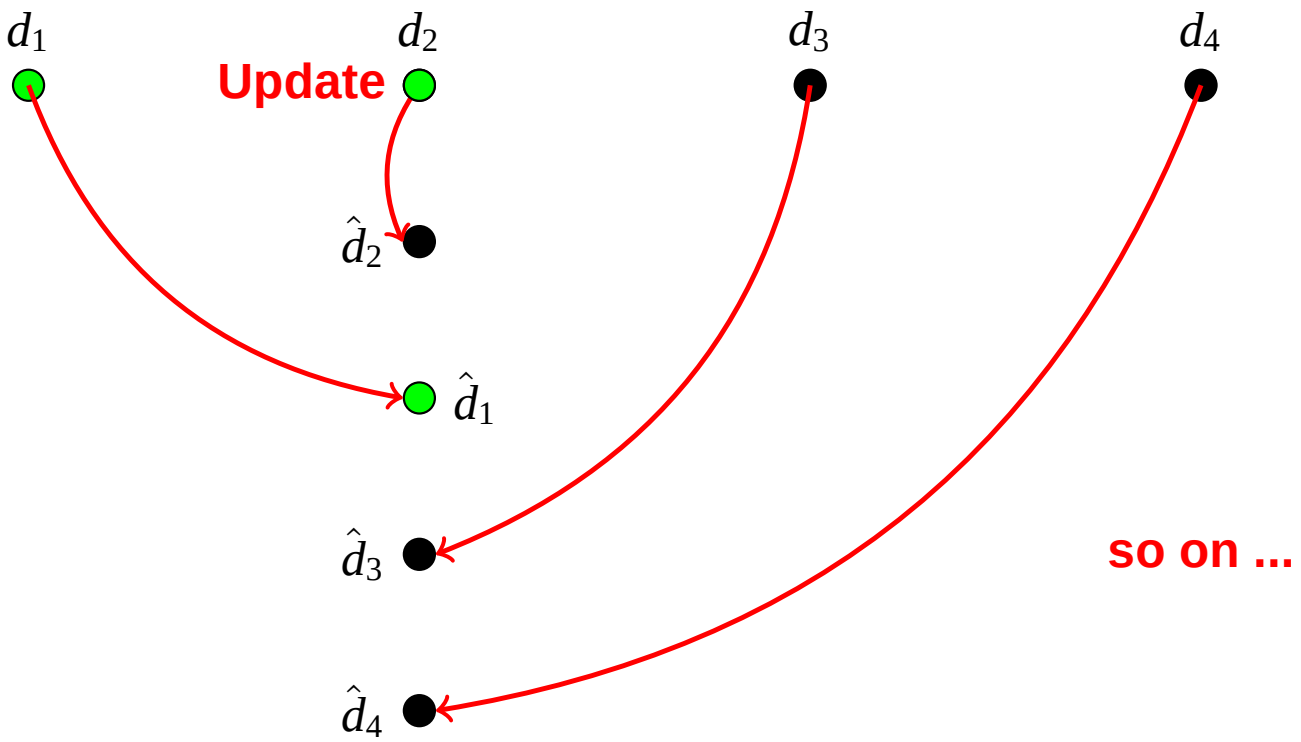
Iterative Depth Map Enhancement



- Update Rule: The depth value is updated by weighted baseline averaging of the chosen depth hypotheses
- Stopping Criterion: The loop energies from recent iterations does not change anymore

Outline

Experimental Test Set

MPEG 3DTV Multiview Data Set[4]

Newspaper (1024×768**)**

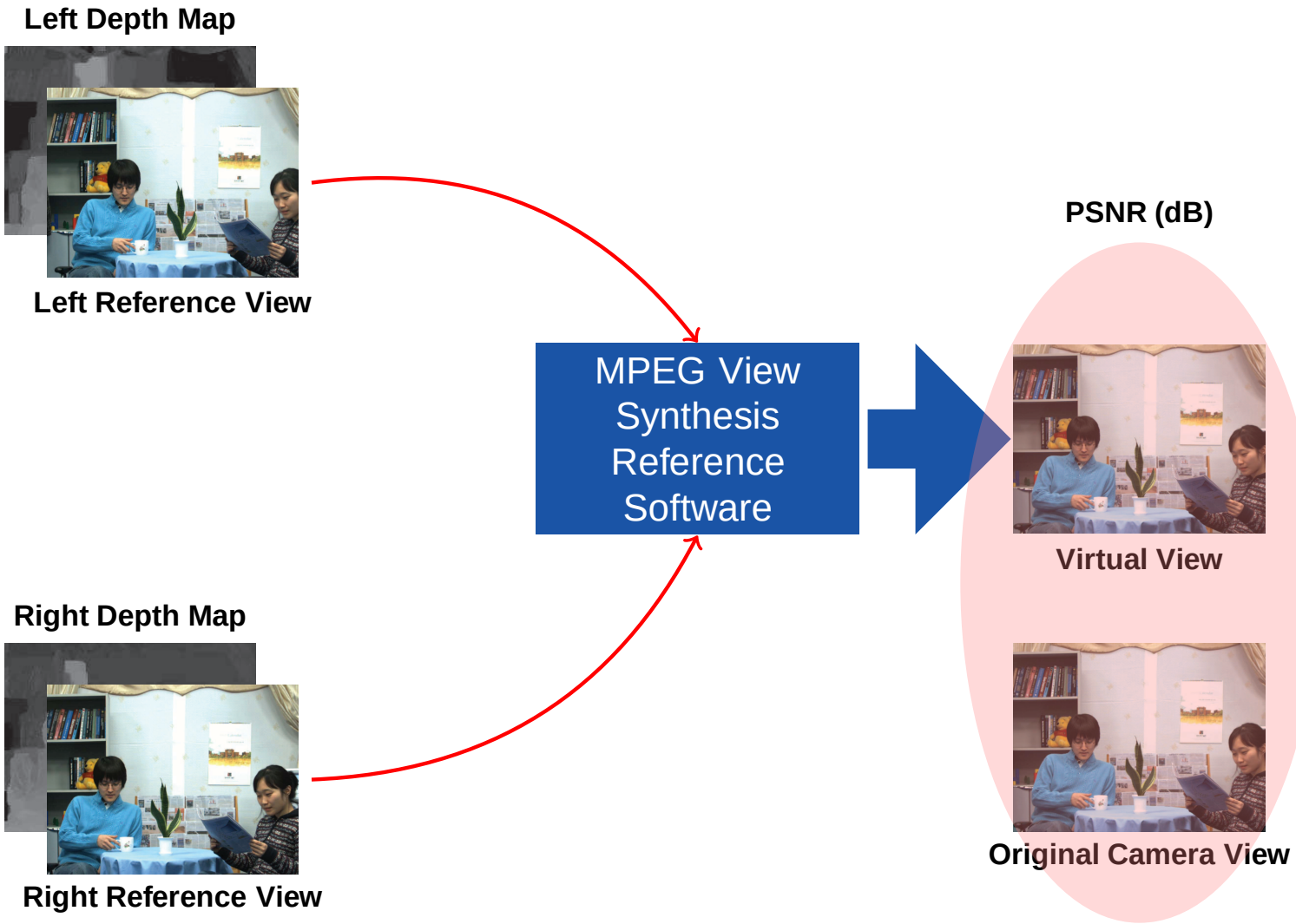
Lovebird1 (1024×768**)**

Kendo (1024×768**)**

Balloons (1024×768**)**

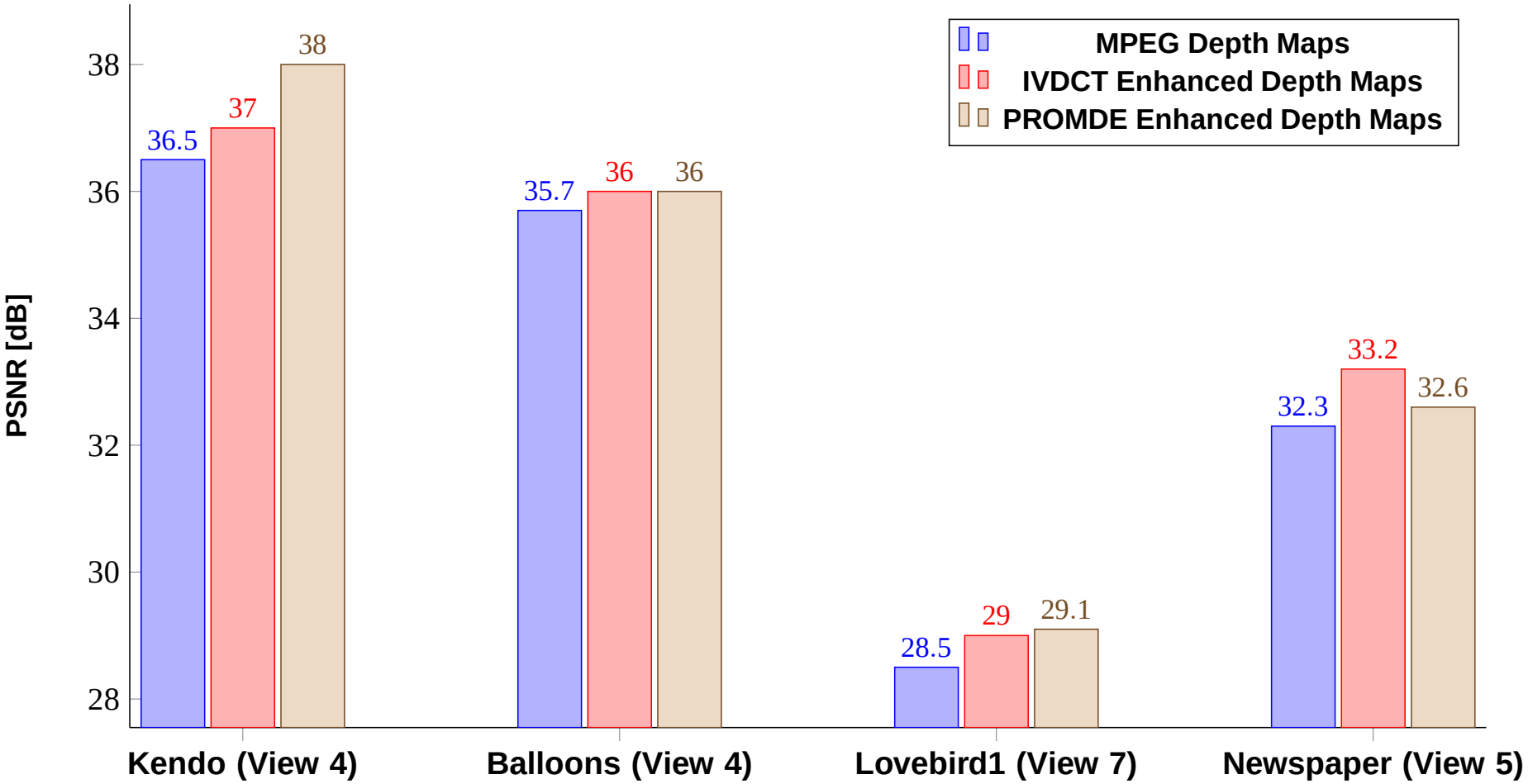
[4] MPEG, "Call for proposals on 3D video coding technology," ISO/IEC JTC1/SC29/WG11, Geneva, Switzerland, Tech. Rep. N12036, Mar. 2011.

MPEG View Synthesis Reference Software (VSRS) 3.5[5]



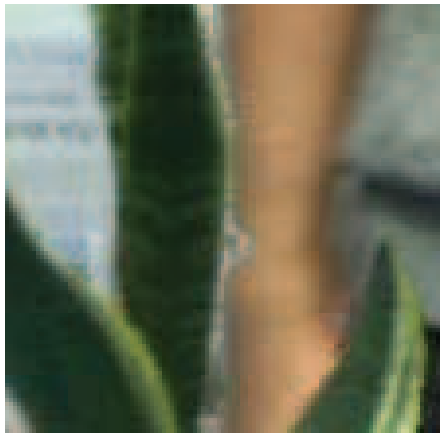
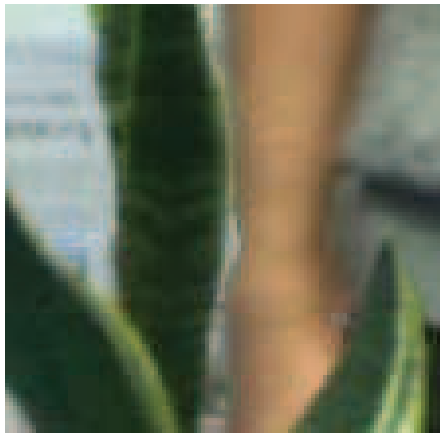
[5]M. Tanimoto, T. Fujii, K. Suzuki, N. Fukushima, and Y.Mori, "Reference softwares for depth estimation and view synthesis," ISO/IEC JTC1/SC29/WG11, Archamps, France, Tech. Rep. M15377, Apr. 2008.

Experimental Results

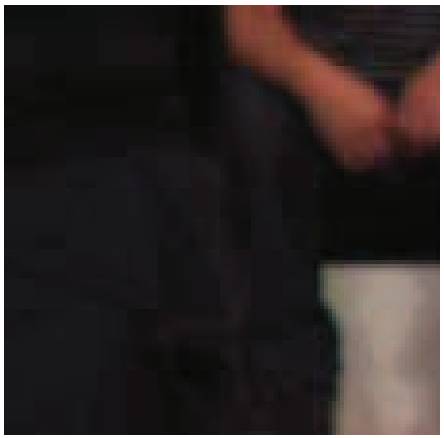
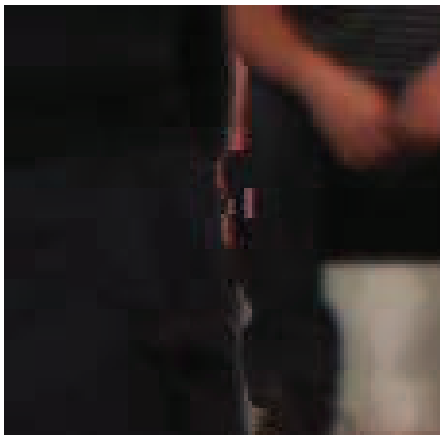
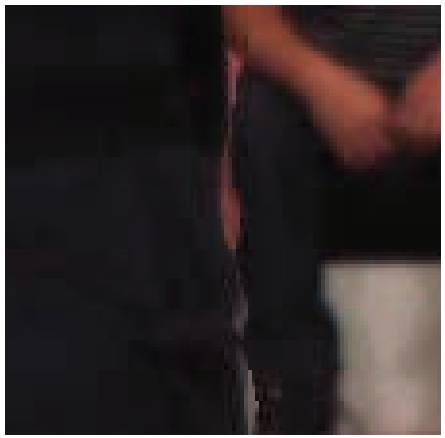


Selected Subjective Results

Newspaper

Kendo

Original **With MPEG Depth** **With PROMDE Depth**

Selected Subjective Results

Lovebird1

Original **With MPEG Depth** **With PROMDE Depth**

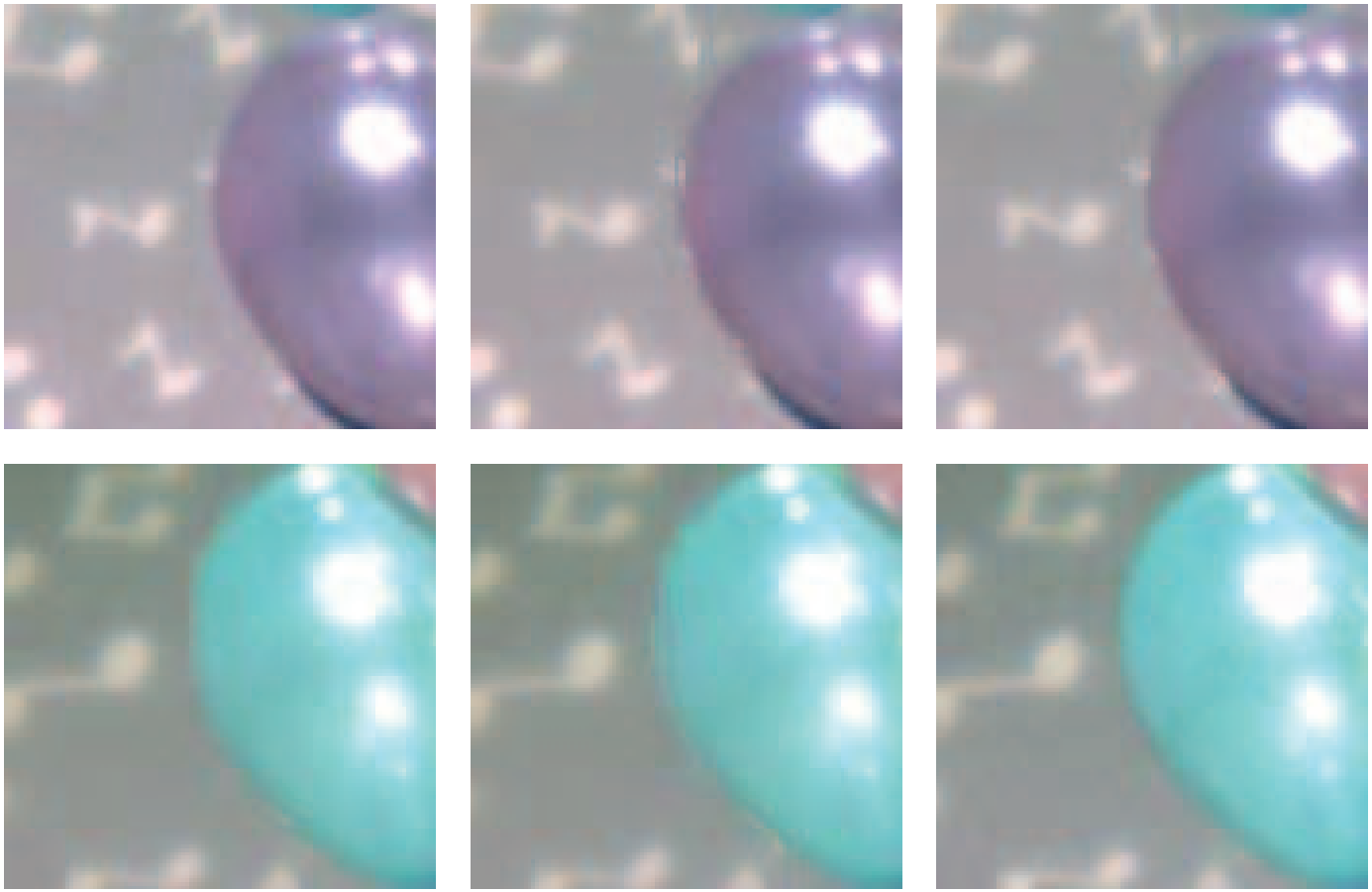
Conclusions

- The probabilistic approach exploits the inherent inter-view similarity in multiview imagery to repair the depth imagery.
- The testing exploits inherent inter-view depth consistency to enhance the visual experience of FTV.
- Experimental results demonstrate the effectiveness of both depth enhancement methods.
- Both depth enhancement methods are affected by the scene and the quality of the input depth imagery

Thank You

Selected Subjective Results

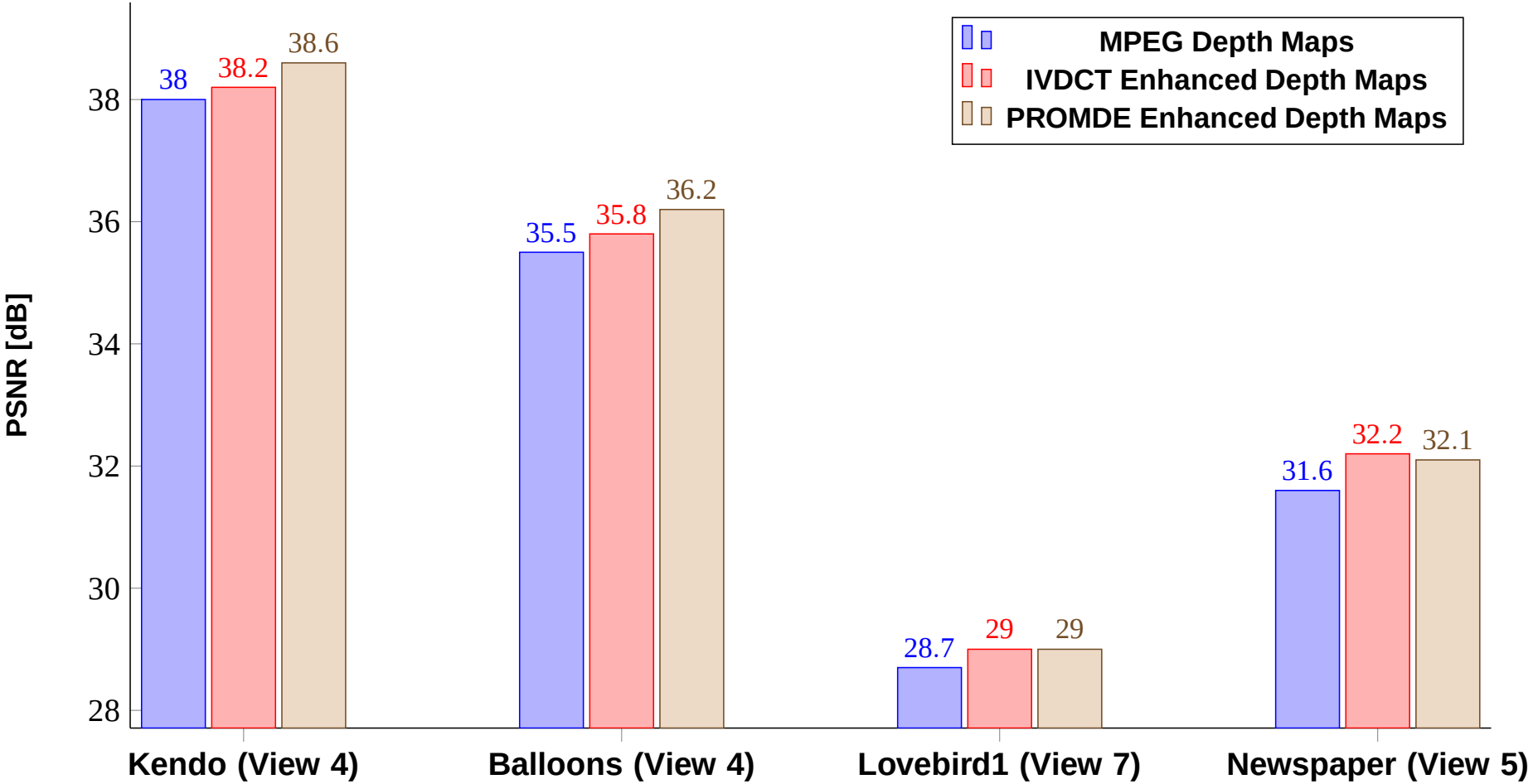
Balloons



Original | **With MPEG Depth** | **With Prob. Enhanced Depth**

Experimental Results

Probabilistic Reliability Based View Synthesis[6]



[6] L. Yang, T. Yendo, M. Panahpour Tehrani, T. Fujii, M. Tanimoto, "Probabilistic reliability based view synthesis for FTV," IEEE ICIP, 2010

Experimental Setup

- The virtual views are generated by using the 1D parallel synthesis mode of VSRS 3.5 with half-pel precision

Table: Experimental View Setting

Test Sequence	Input (Virtual) Views		
	VSRS	IVDCT	PROMDE
Kendo	3, (4), 5	1, 3, 5	1, 3, 5
Balloons	3, (4), 5	1, 3, 5	1, 3, 5
Lovebird1	6, (7), 8	4, 6, 8	4, 6, 8
Newspaper	4, (5), 6	2, 4, 6	2, 4, 6