Interactive Media Systems Group
Software Technology & Interactive Systems
Vienna University of Technology

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A Stereo Approach that Handles the Matting Problem via Image Warping

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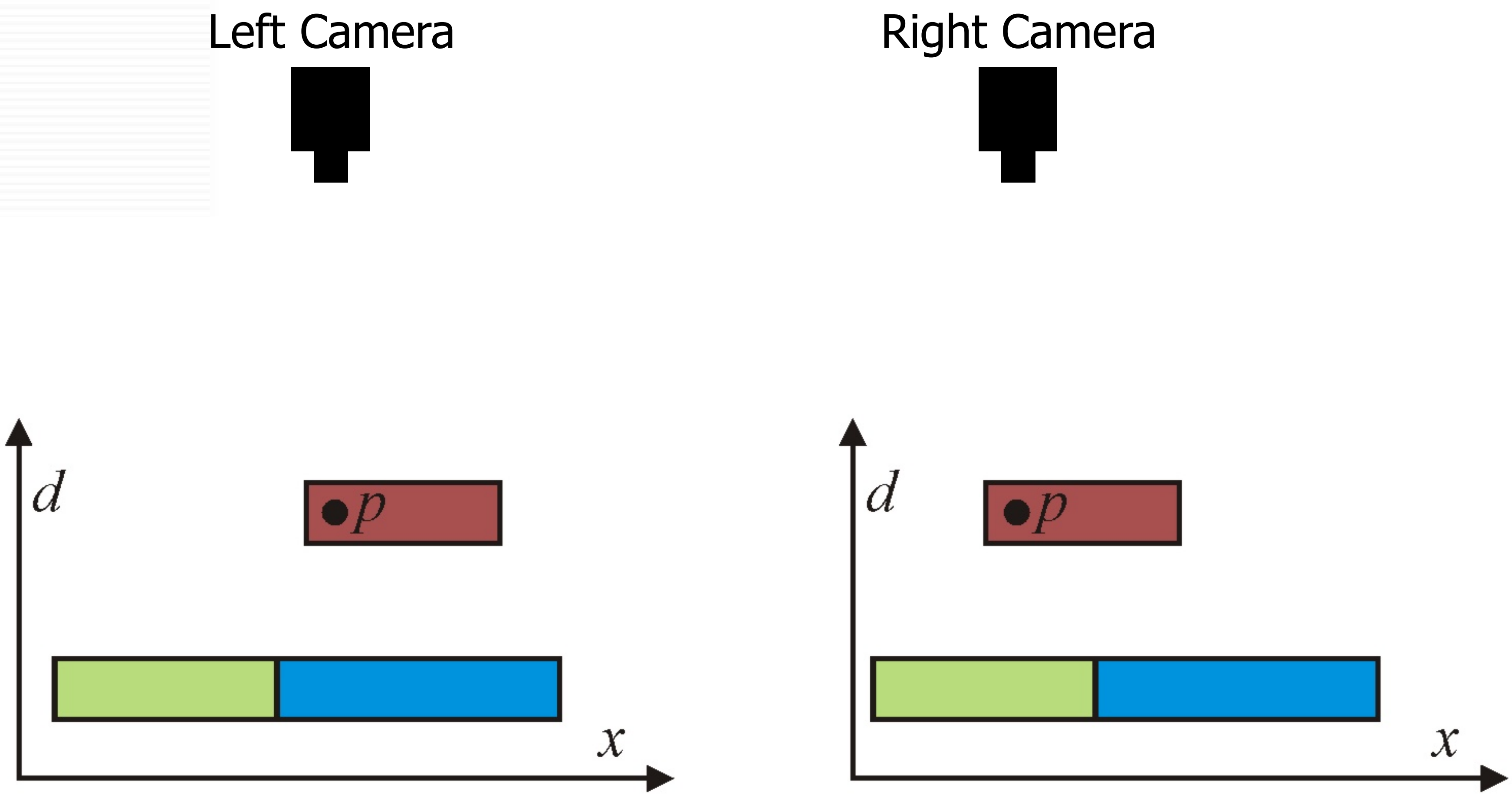
IEEE Conference on Computer Vision and Pattern Recognition (CVPR) 2009

Synergies between Stereo and Matting



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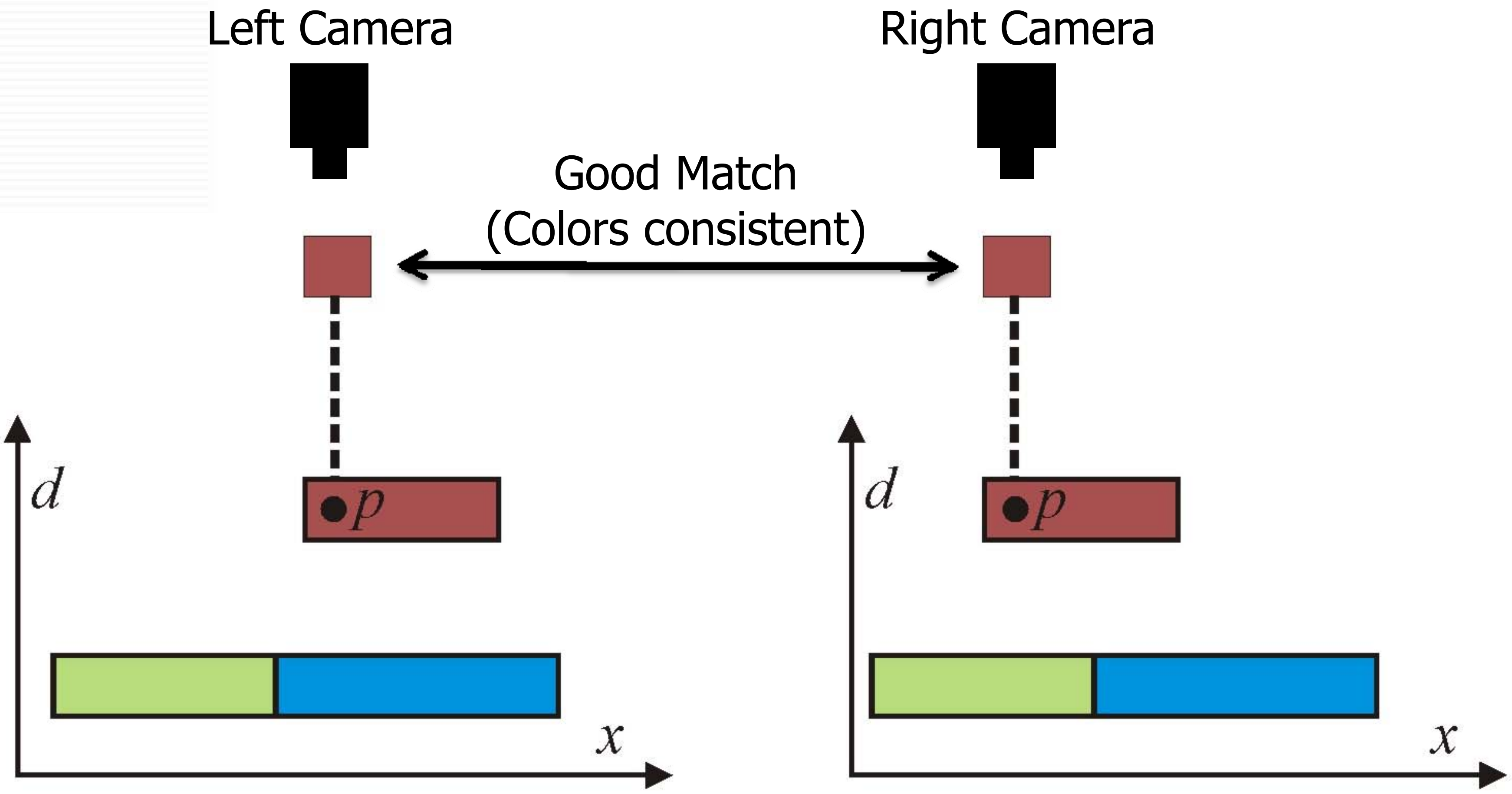

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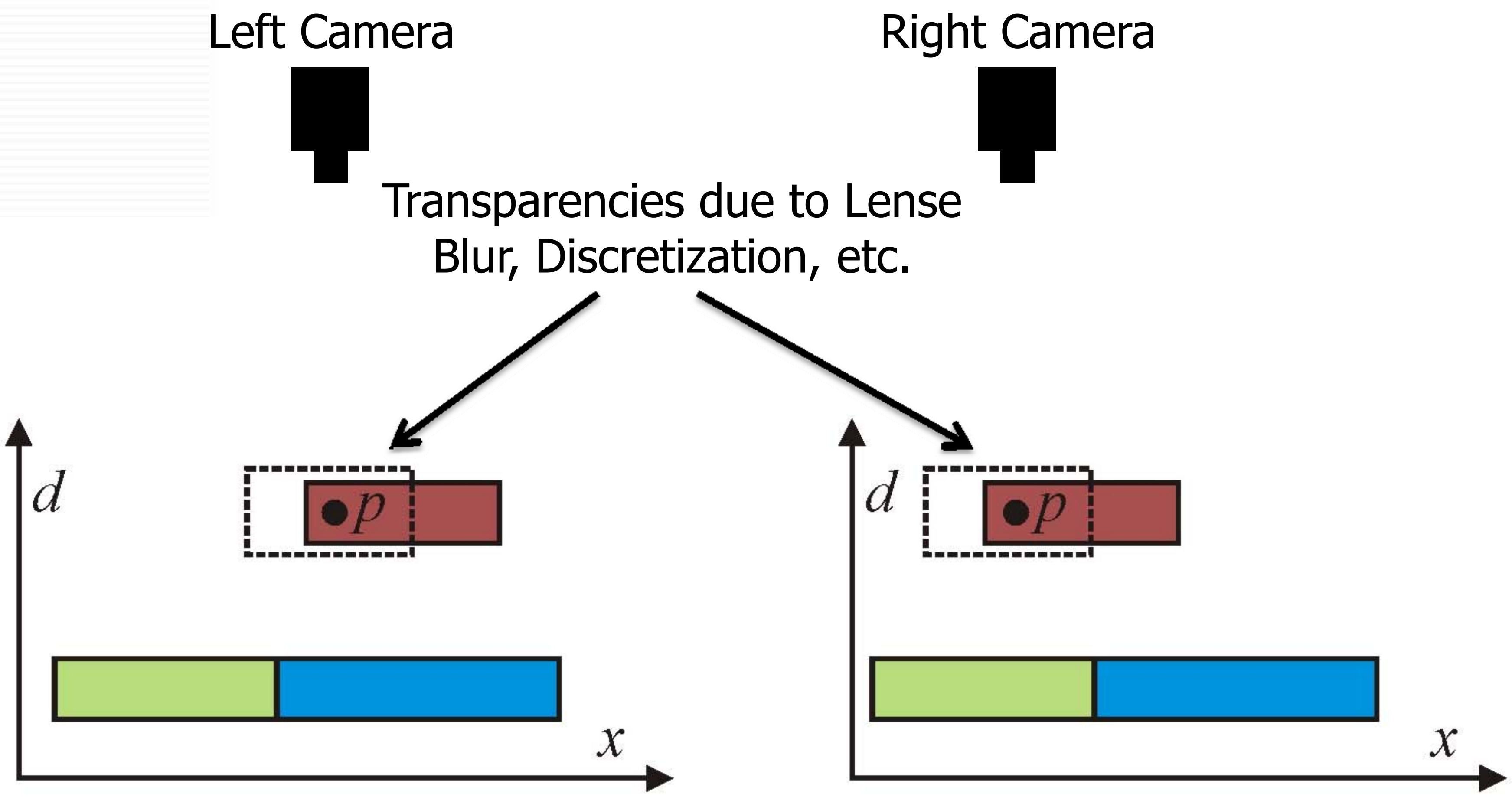

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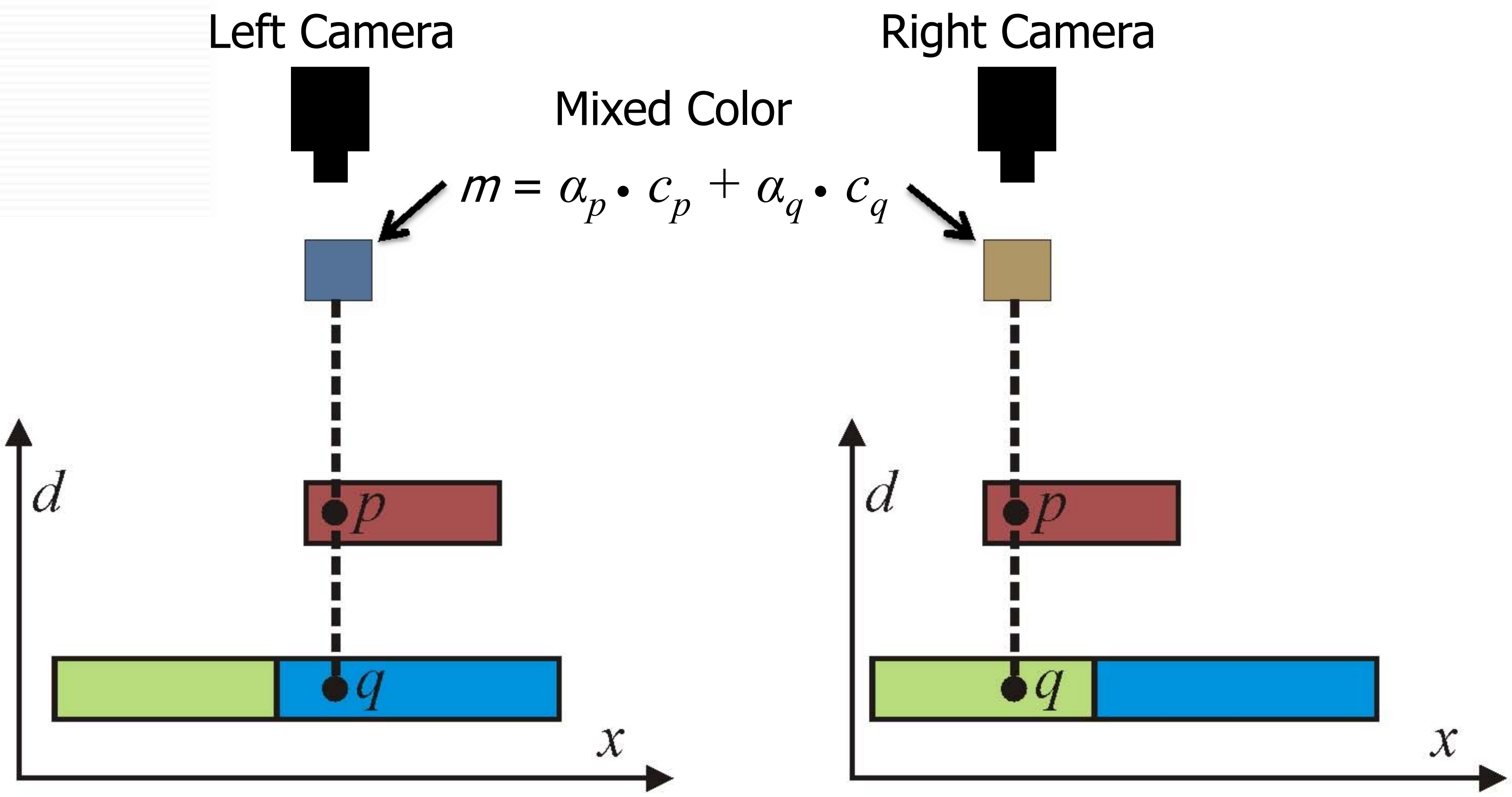

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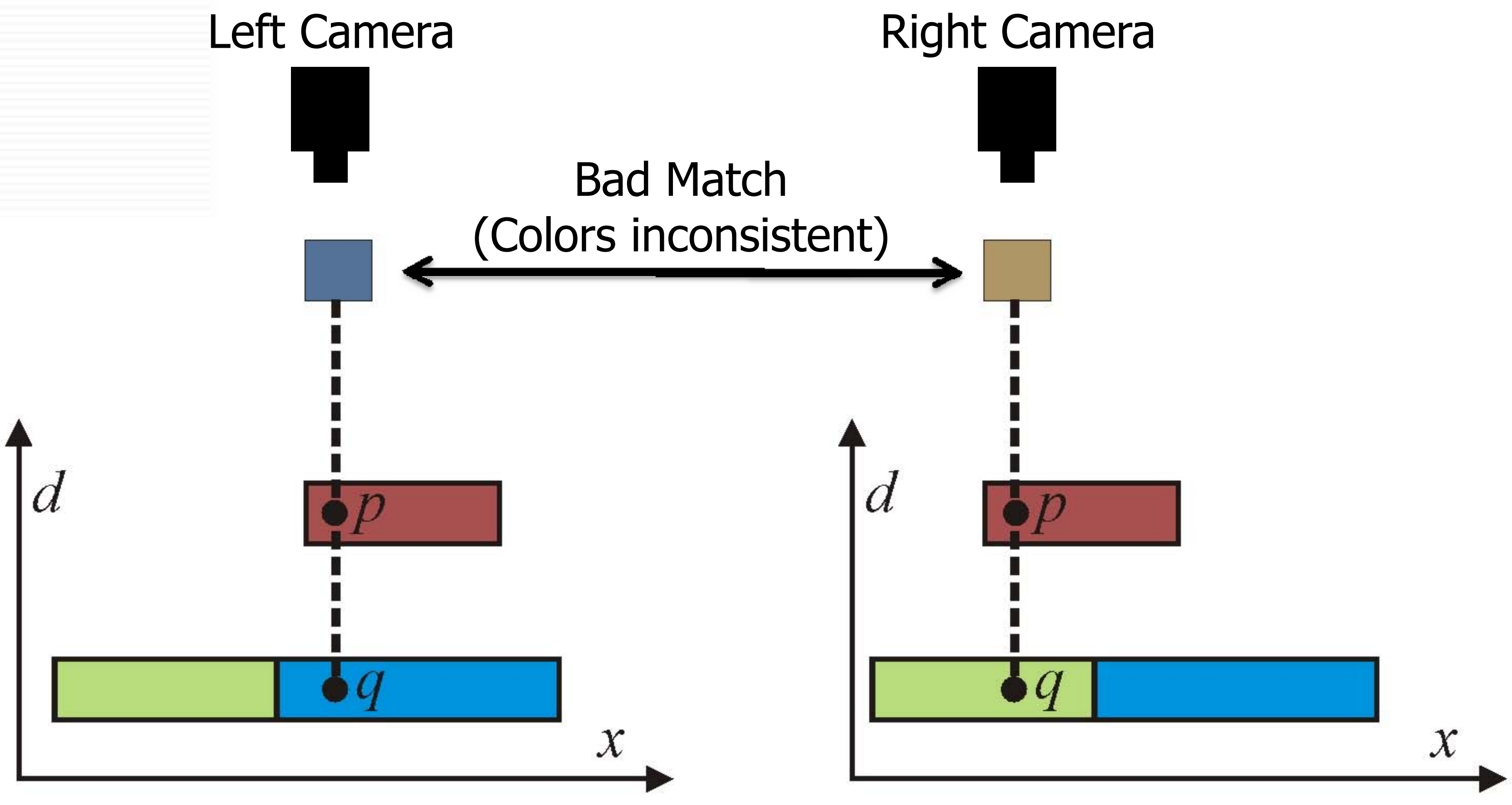


Synergies between Stereo and Matting

- Pixel mattes lead to color inconsistencies near disparity borders
- Overcome this problem:
  - Solve stereo and matting problems simultaneously
- Disparity information provides two instead of one mixed colors for computing alpha
  => Less ambiguity

Previous Work on Stereo Matting

- [Baker et al., CVPR98], [Szeliski and Golland, ICCV98]
  - Early work on stereo matting
- [Zitnick et al., SIGRAPH04]
  - Matting in postprocessing step
- [Hasinoff et al., CVIU06]
  - 3D curve fitting to precomputed disparity borders
- [Xiong and Jia, CVPR07]
  - Exploits synergies
  - Does not work for more than two depth layers
- [Taguchi et al., CVPR08]
  - Works for multiple depth layers
  - Does not exploit problem synergies

Contributions

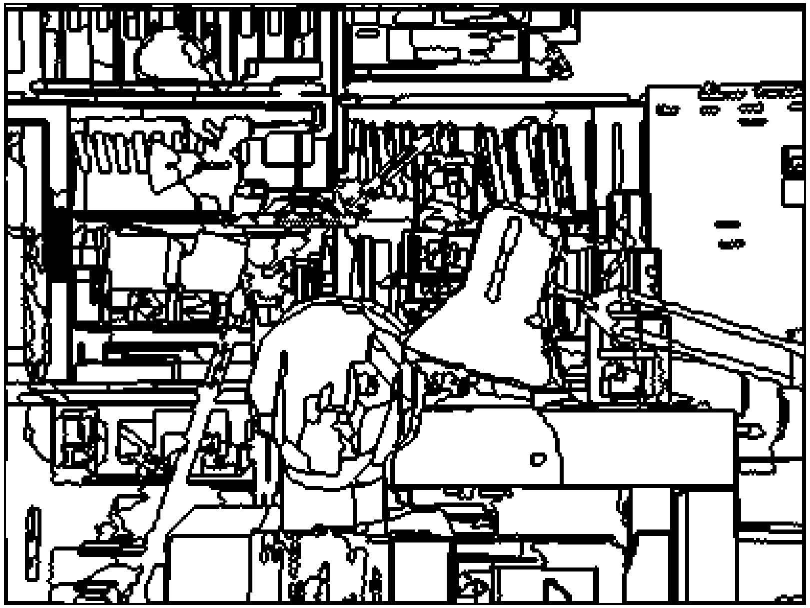
- Combined stereo and matting approach
  - Can handle multiple disparity layers
  - Still exploits problem synergies
- New assumption of constant solidity

Combined Stereo and Matting Approach

Overlapping segments

- Color segmentation of left image (oversegmentation)

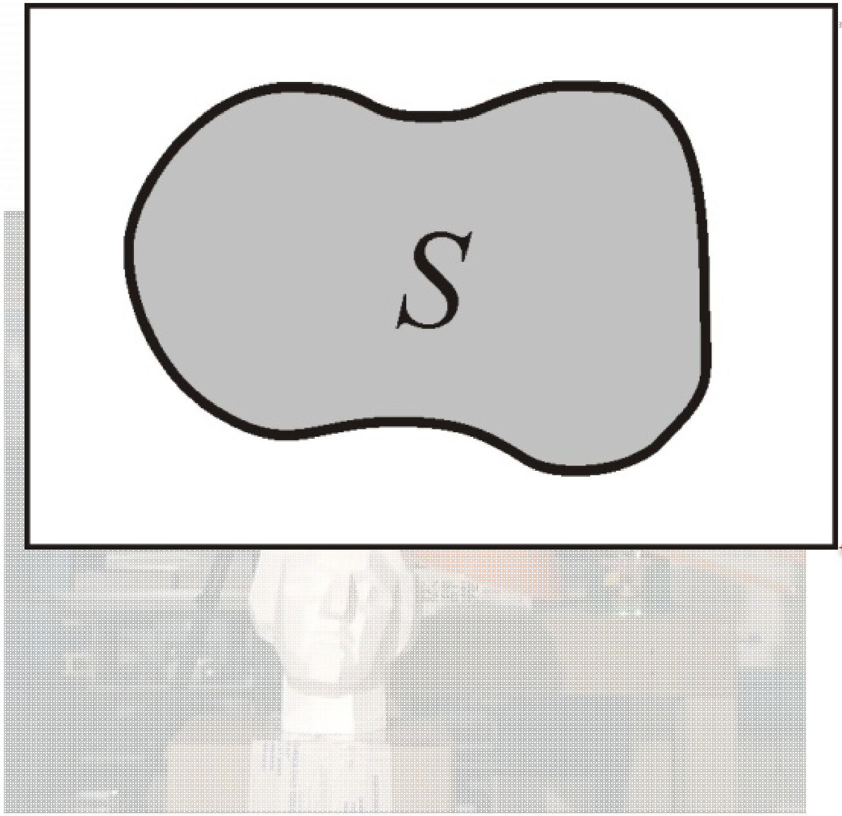
(Left Image)



(Segment Boundaries)

Overlapping segments

- ...ft image



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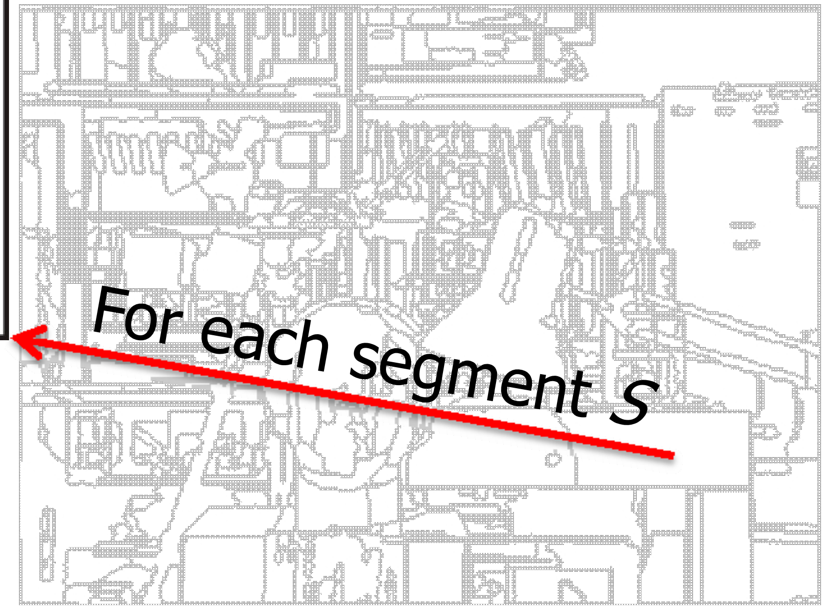
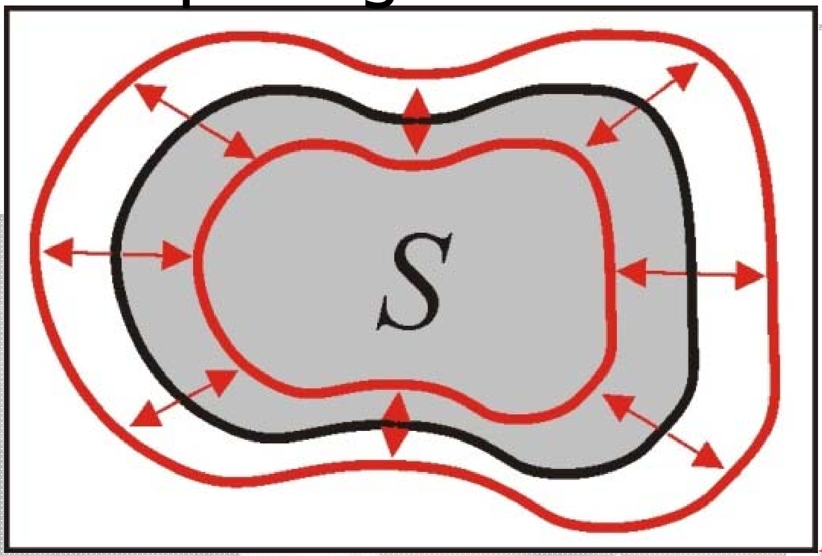


(Segment Boundaries)

Overlapping segments

Morphological Dilation



- ...ft image

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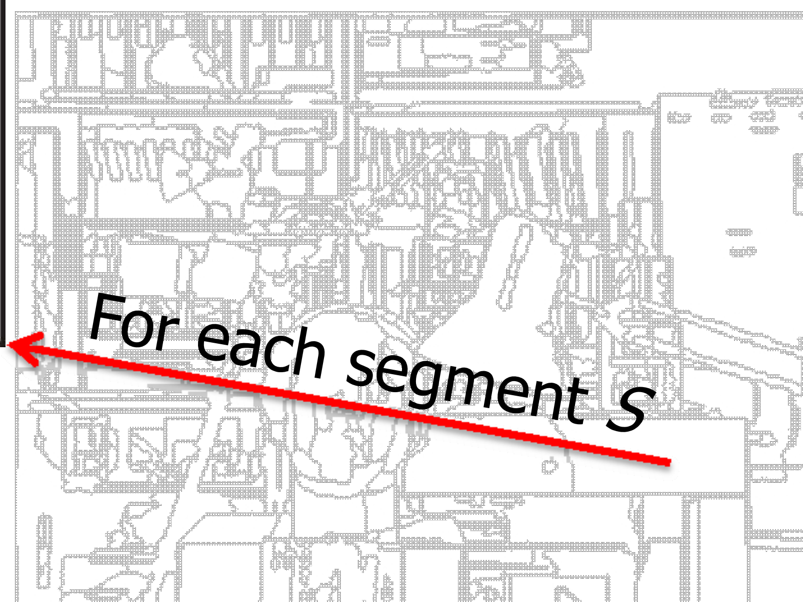
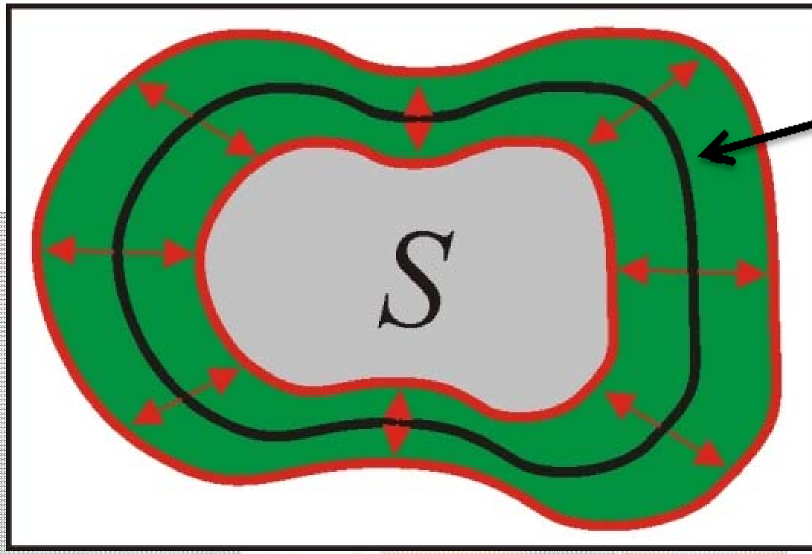


(Segment Boundaries)

Overlapping segments

- ...ft image



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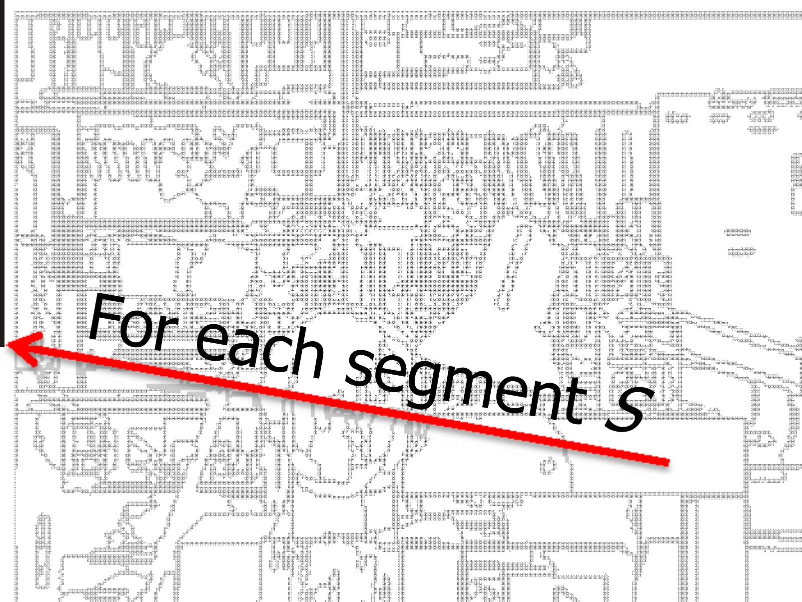
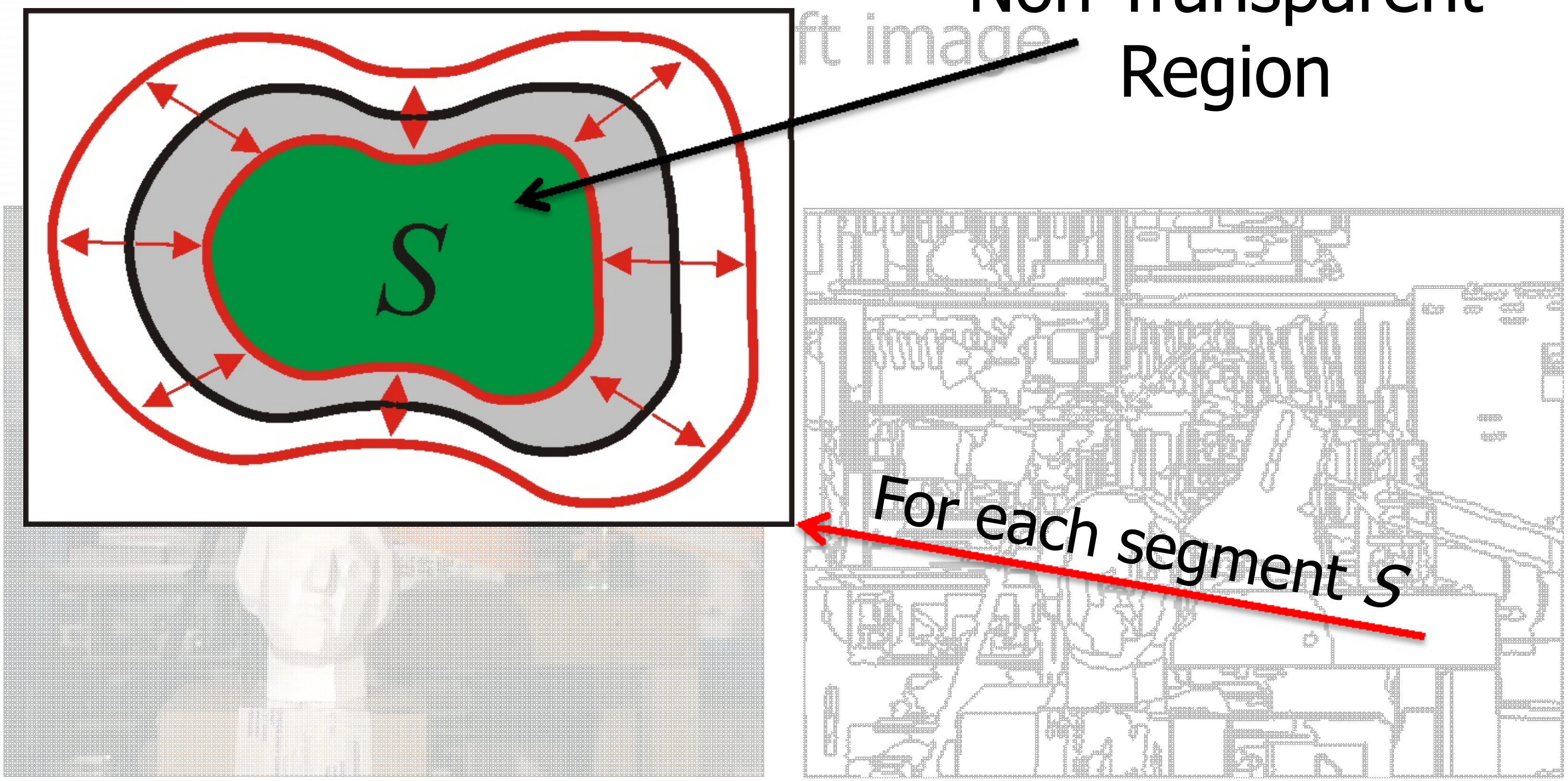


(Segment Boundaries)

Overlapping segments

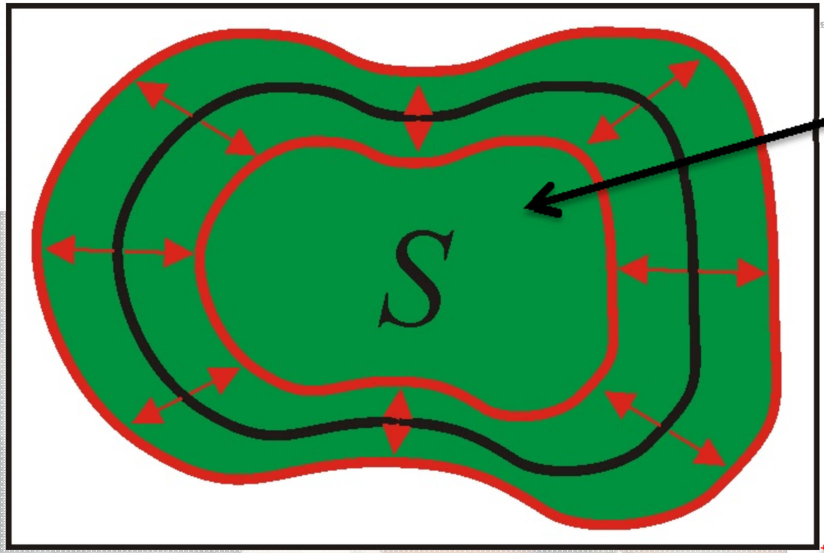
- ...ft image



(Left Image) (Segment Boundaries)

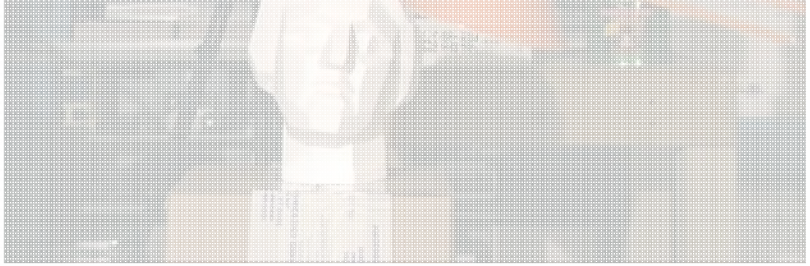
Overlapping segments

- ...ft image



Overlapping Segment

For each segment S



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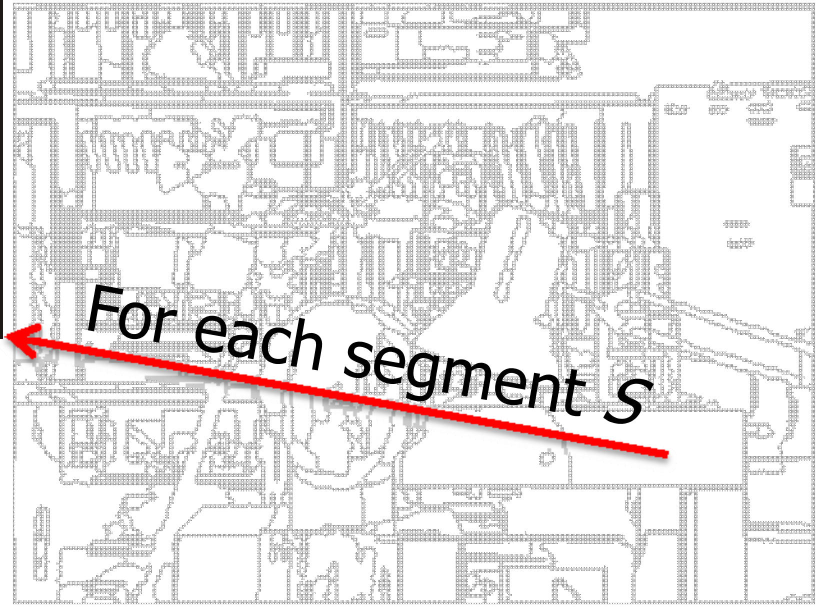


(Segment Boundaries)

Overlapping segments

Overlapping

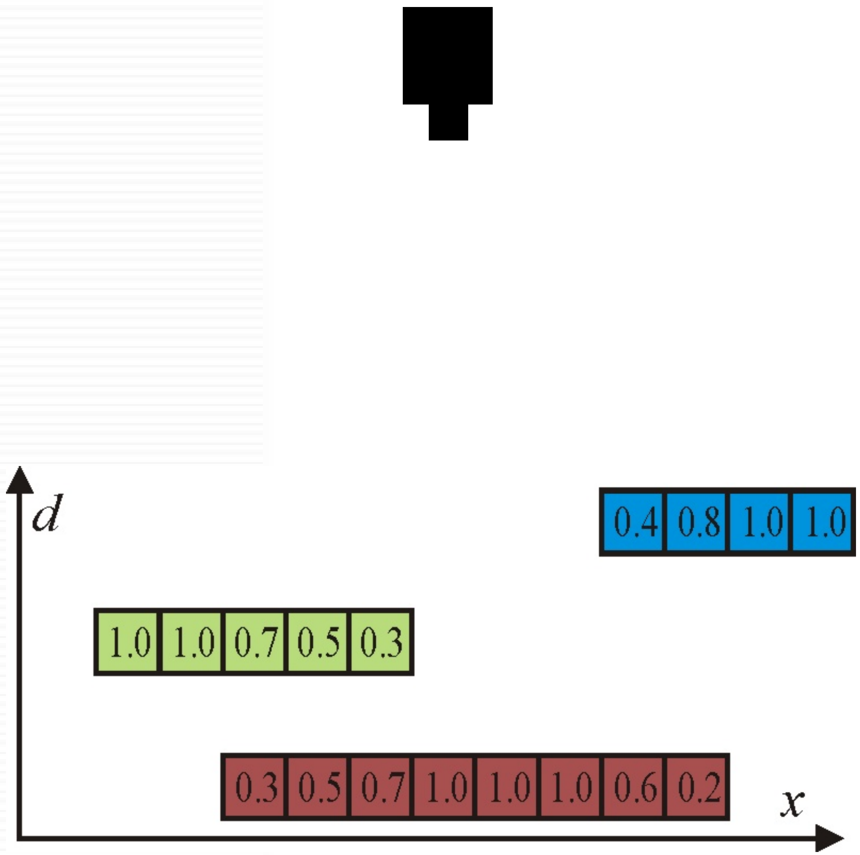
Find the following parameters via energy minimization:

- Disparity plane (for each overlapping segment)
- Alpha value (for each pixel)
- True Color (for each pixel)

(Left Image)

(Segment Boundaries)

How to measure the Goodness of Alphas, True Colors and Disparities?



(Left Buffer)

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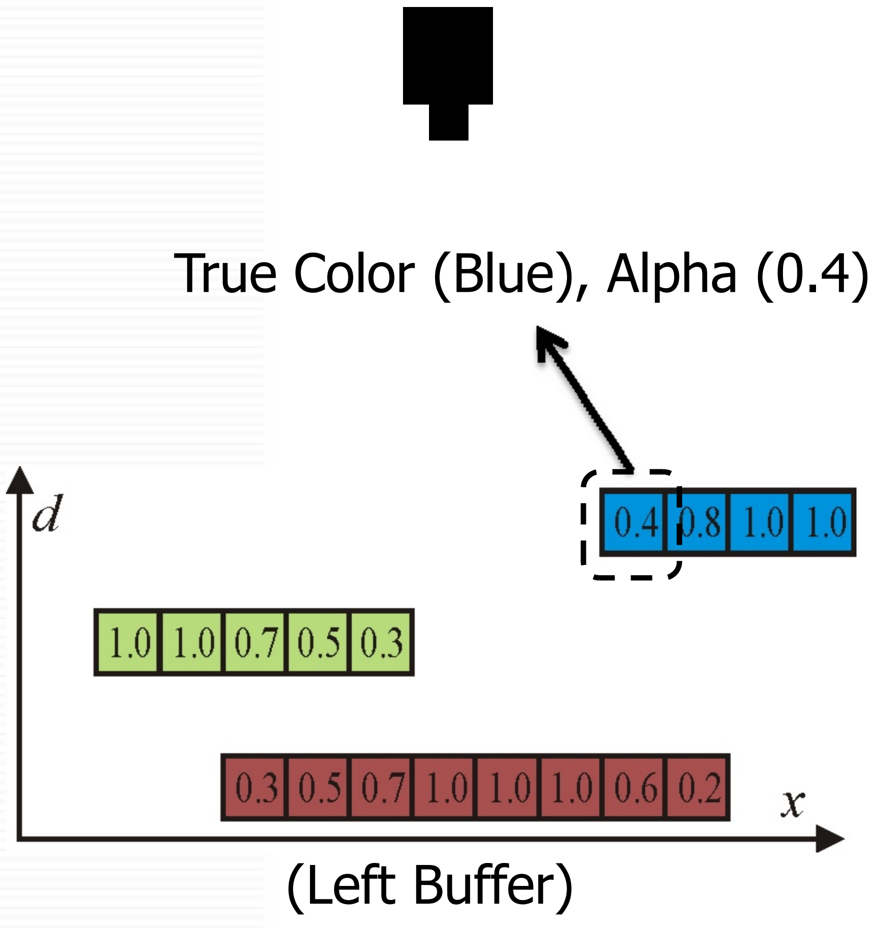

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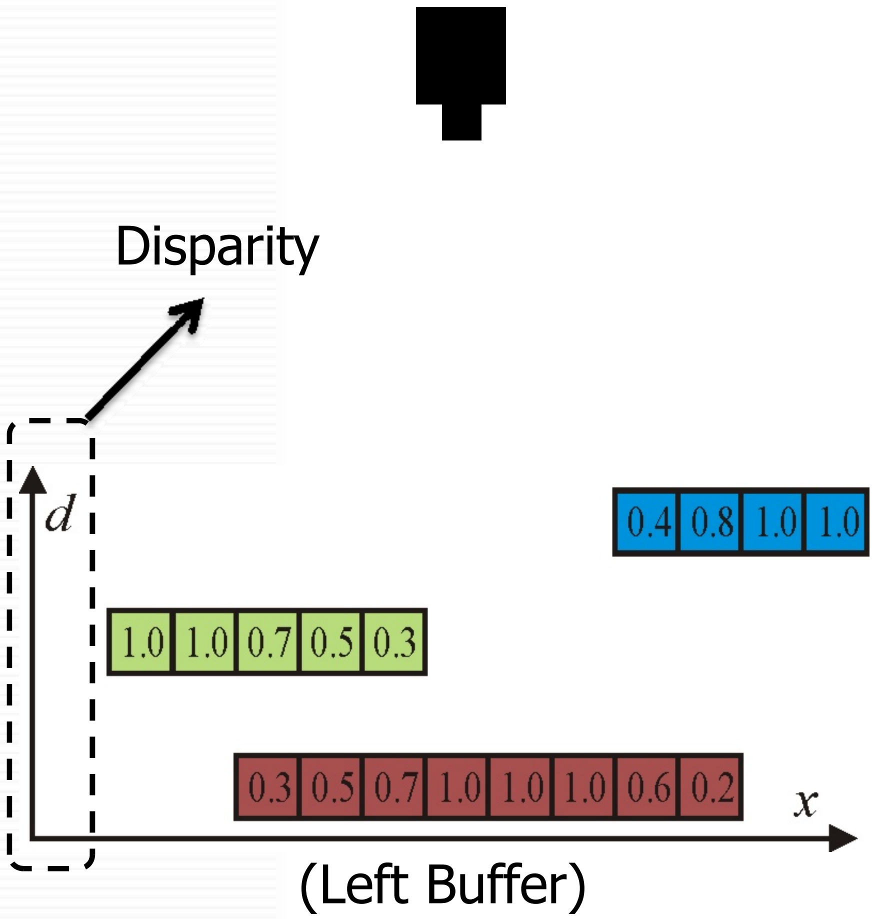

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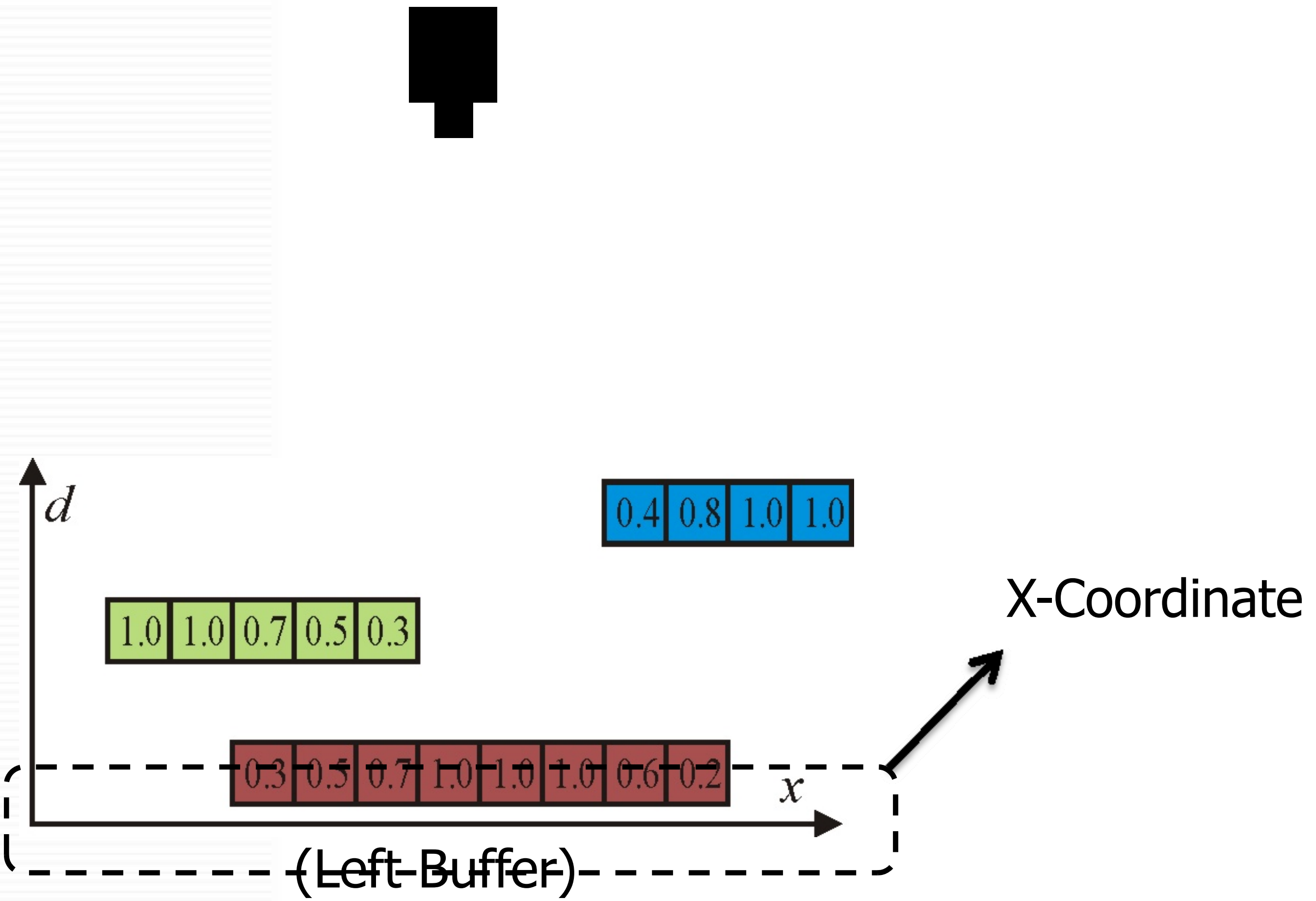

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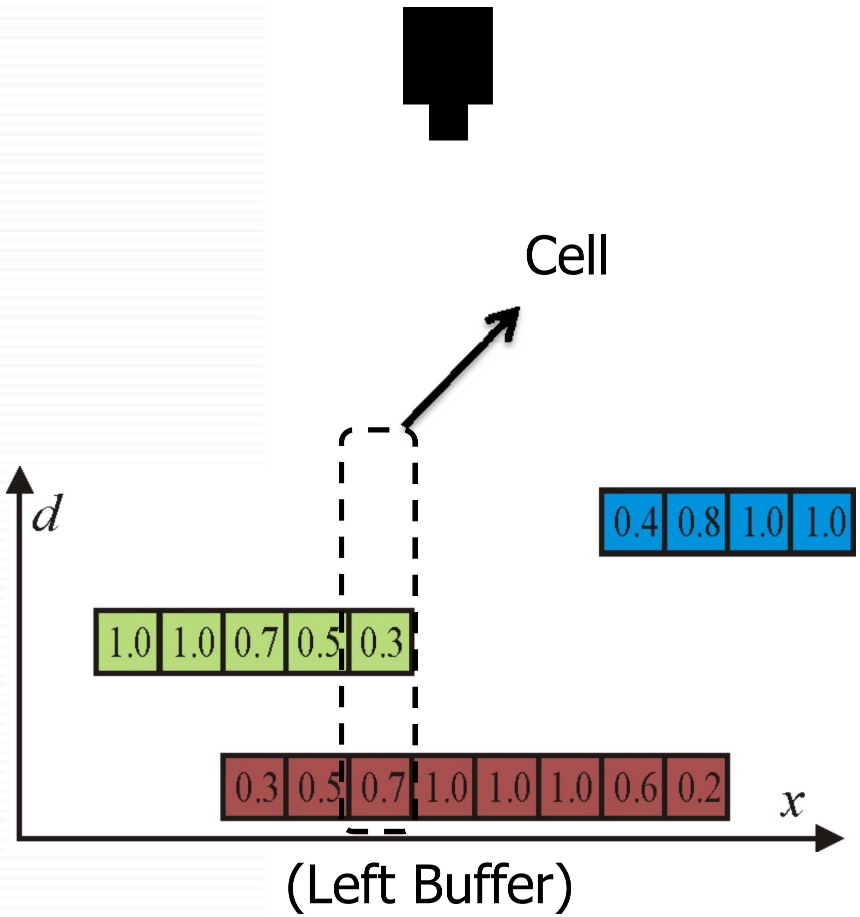

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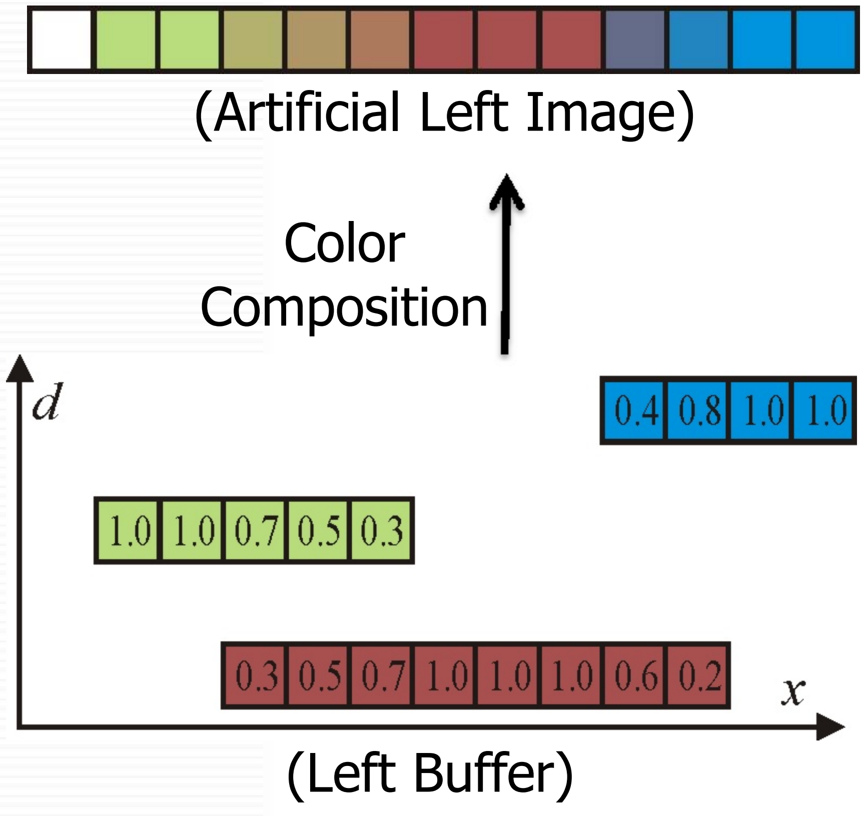

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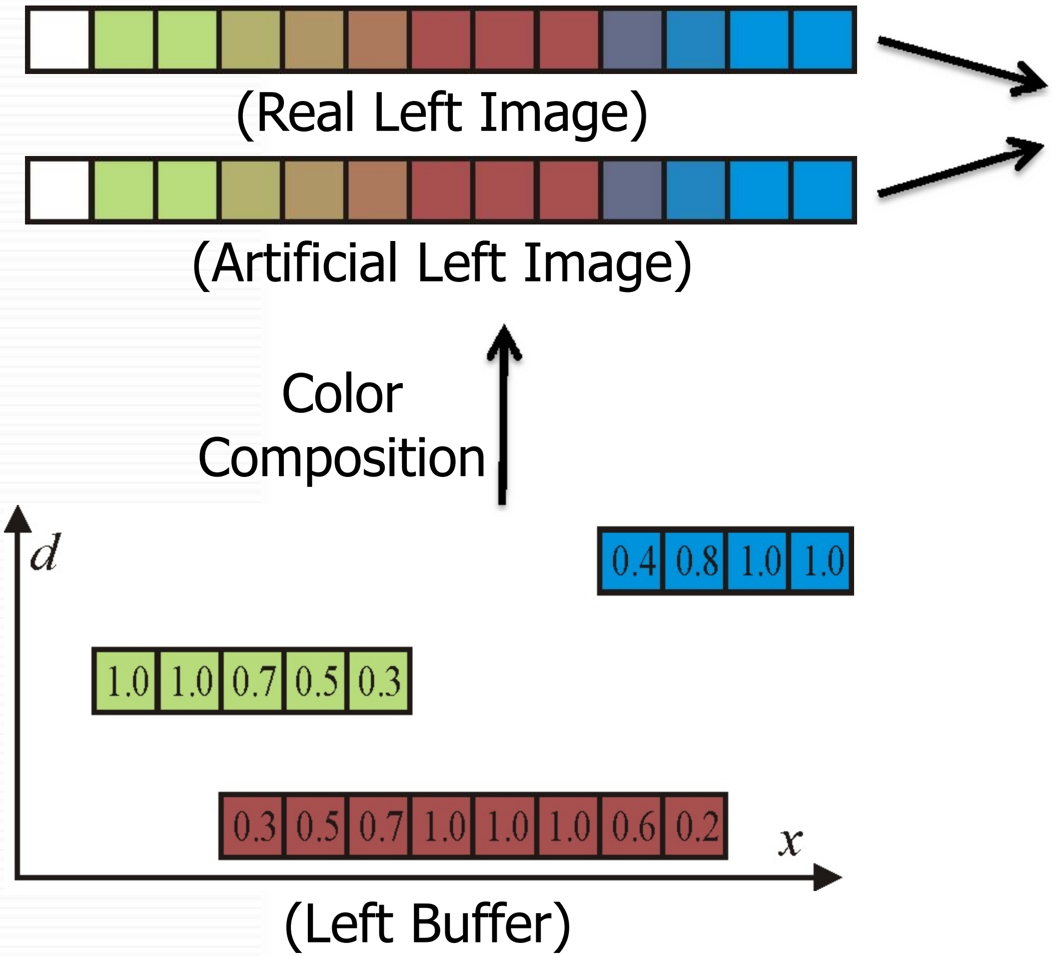

Very similar if Alphas and True Colors are correct

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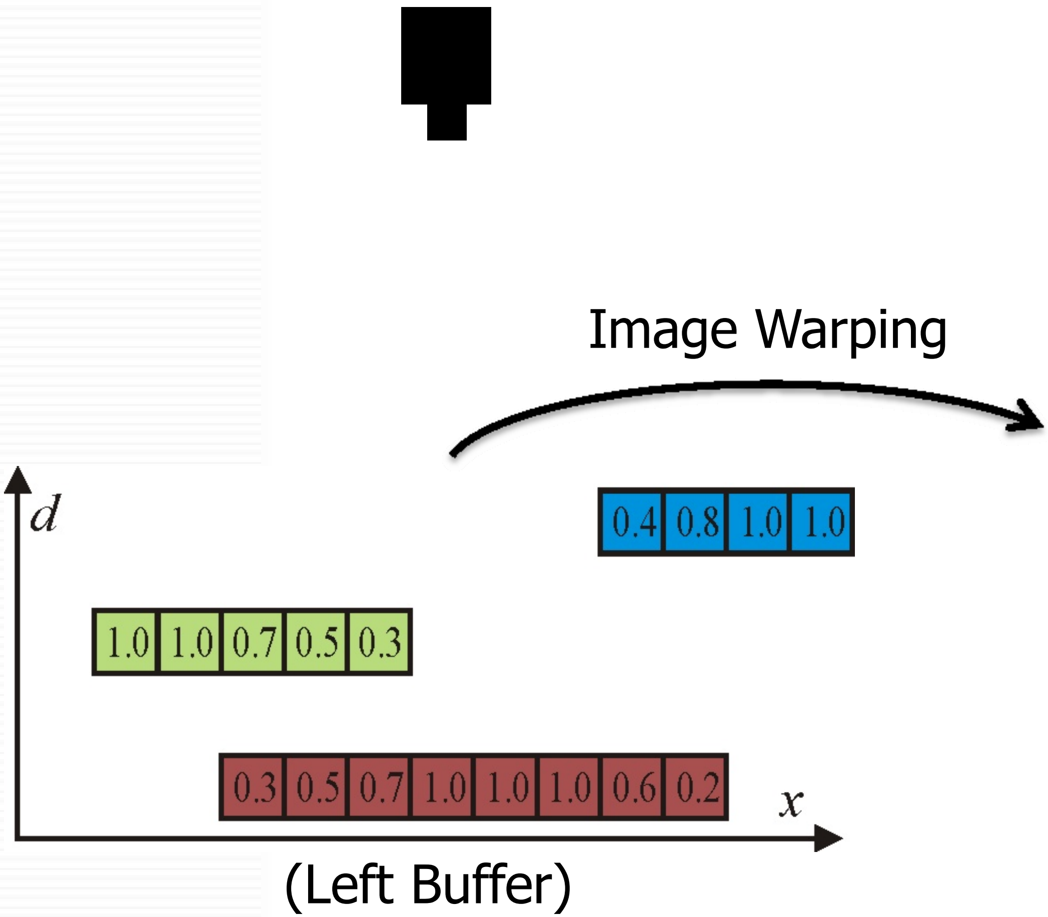

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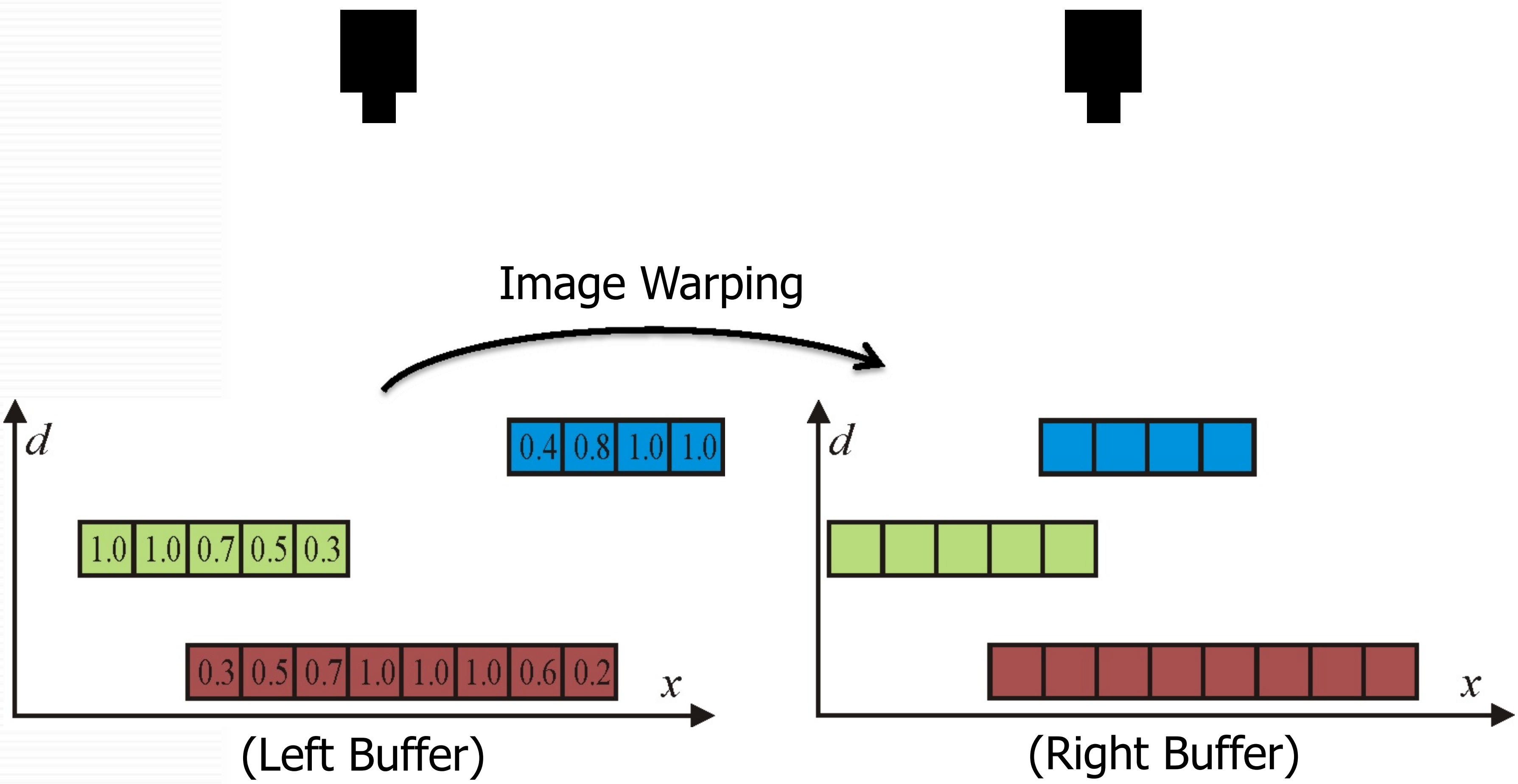

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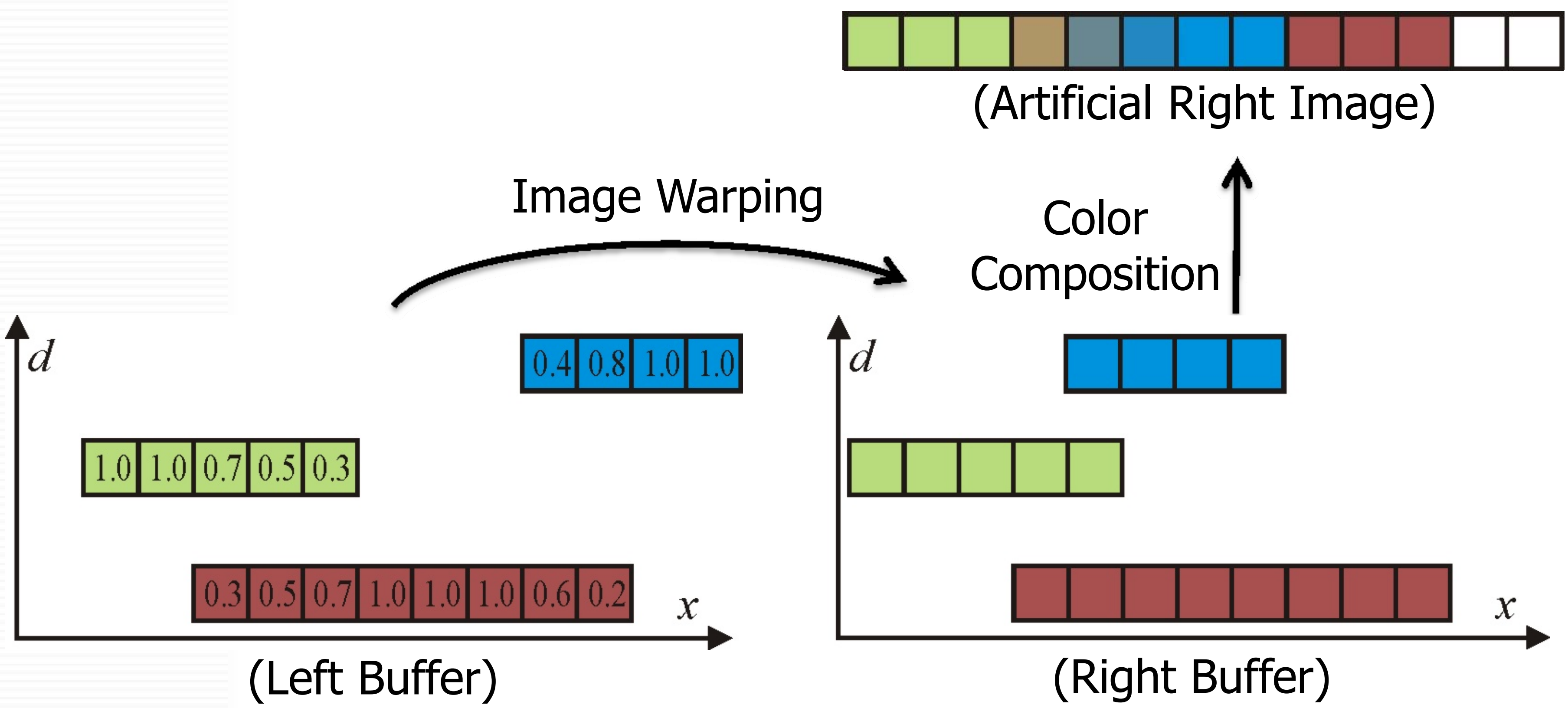

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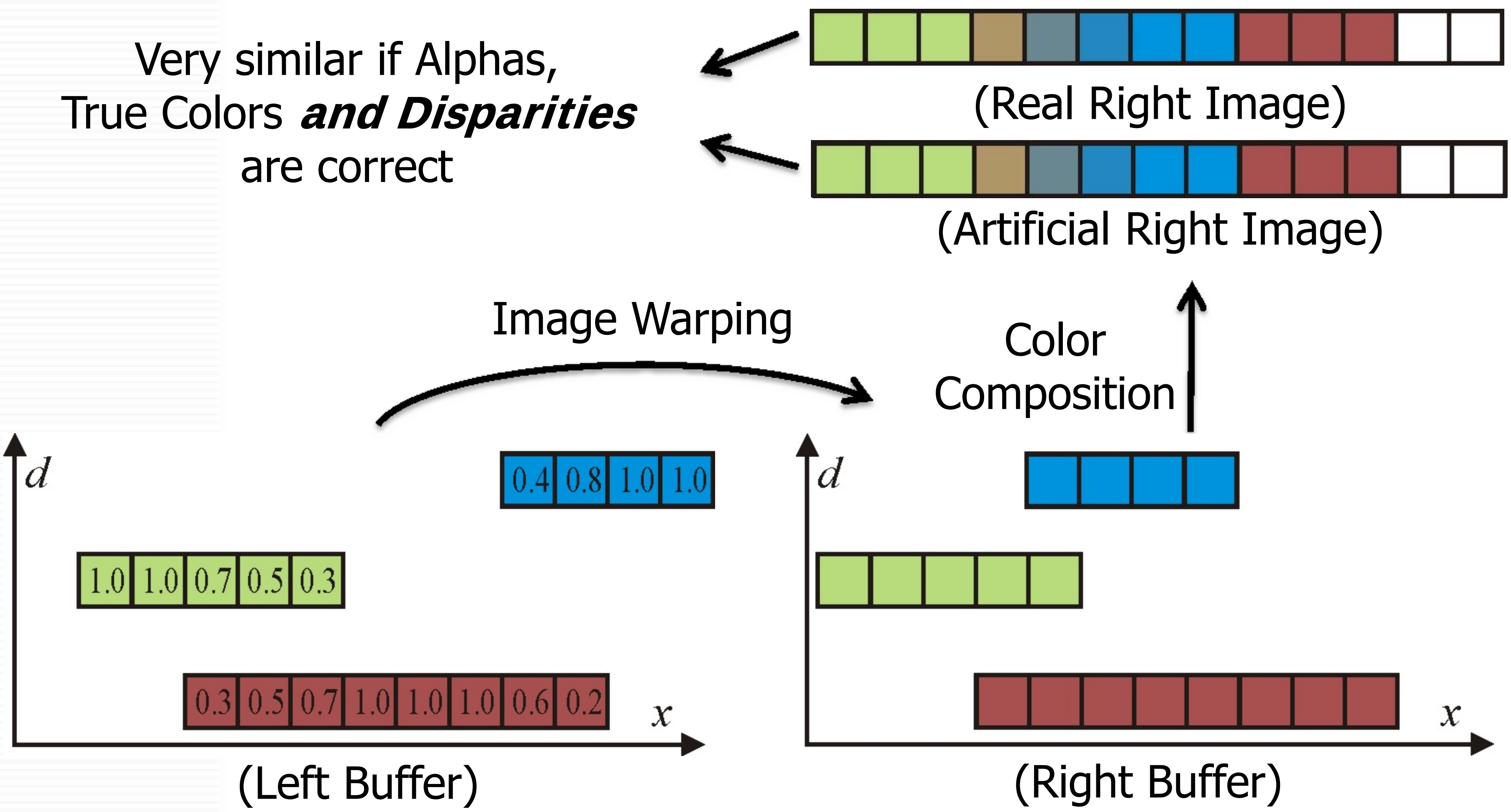
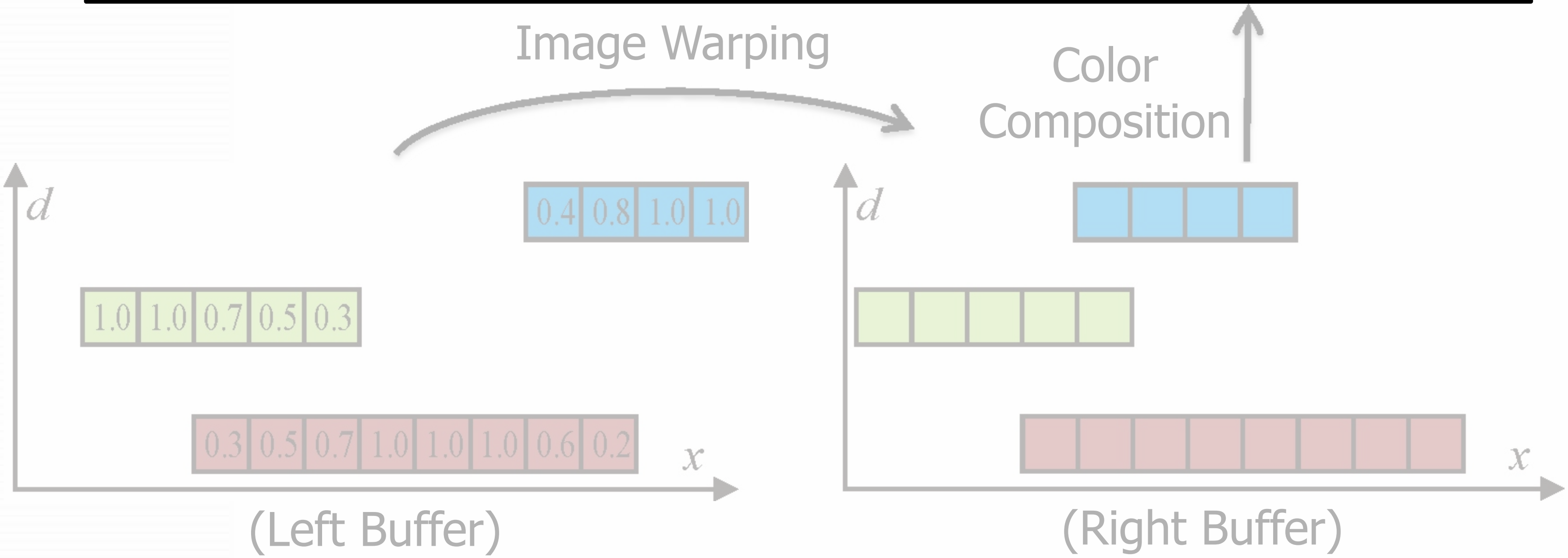
Very similar if Alphas, True Colors ***and Disparities*** are correct



How to measure the Goodness of Alphas, True Colors and Disparities?

**Most critical question:
How are alpha-values affected by image warping?**



How is Alpha affected by Image Warping?

- Assumption of [Xiong and Jia, CVPR 2007]:
  - Alpha remains constant for foreground pixels
  - Problems:
    - No information about background pixels (also need to be warped)
    - Not necessarily true if more than two layers
- Our assumption:
  - *Solidity* of a pixel remains constant
  - More powerful:
    - Holds for all pixels
    - Holds in the *n*-layer case

What is Solidity?

- Solidity of pixel *p* is the percentage to which *p* occludes pixels of lower disparities.
- Solidity o_p is computed by

$$o_p = \frac{\alpha_p}{1 - \sum_{q:d_q > d_p} \alpha_q}$$

with α_p and d_p being the alpha value and disparity of pixel *p*.

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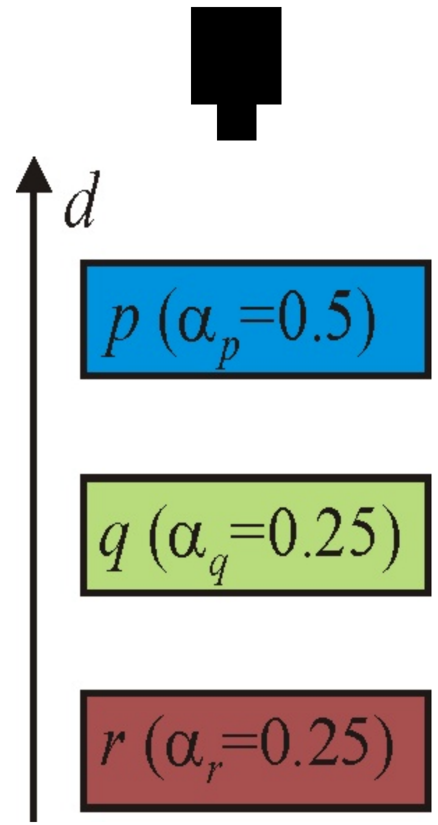

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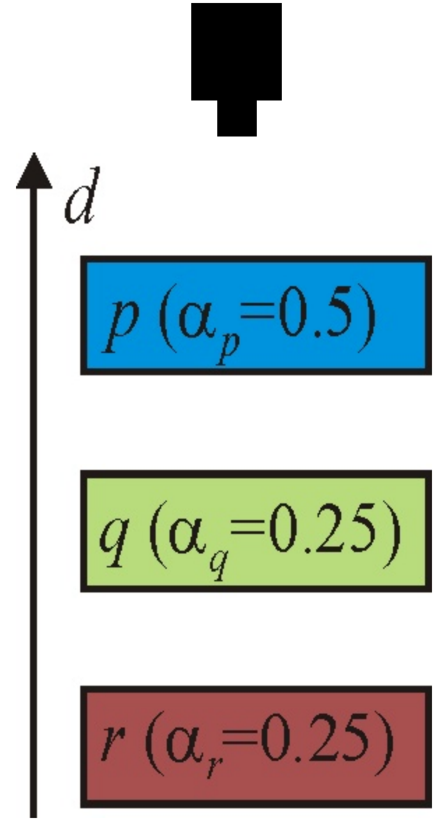

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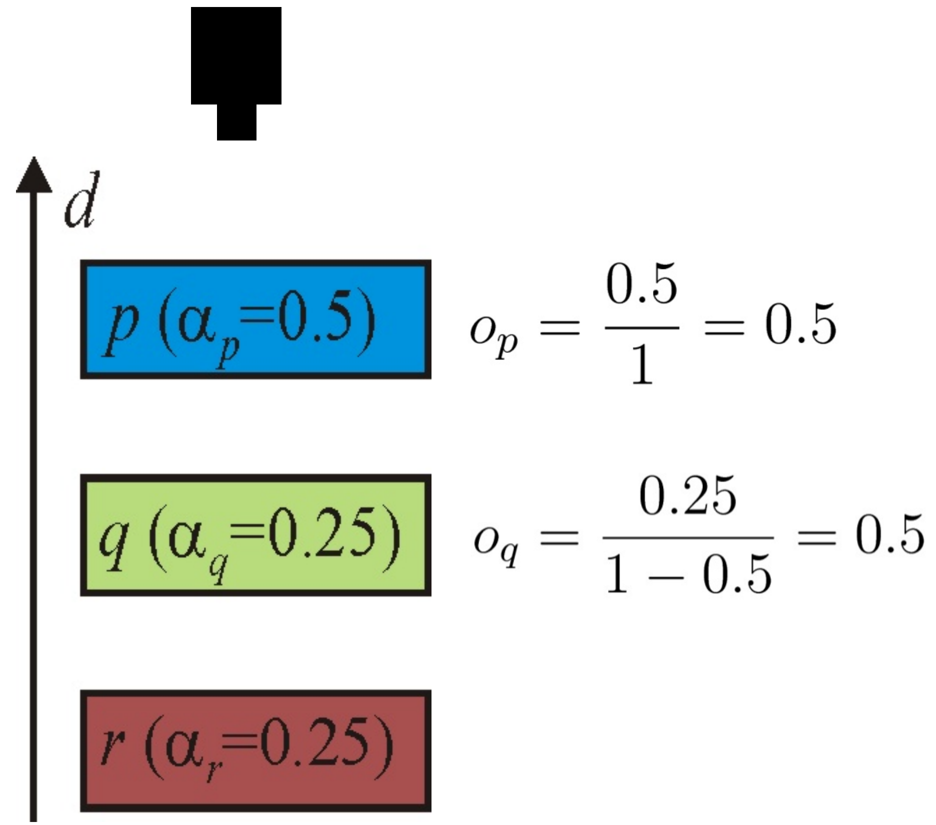

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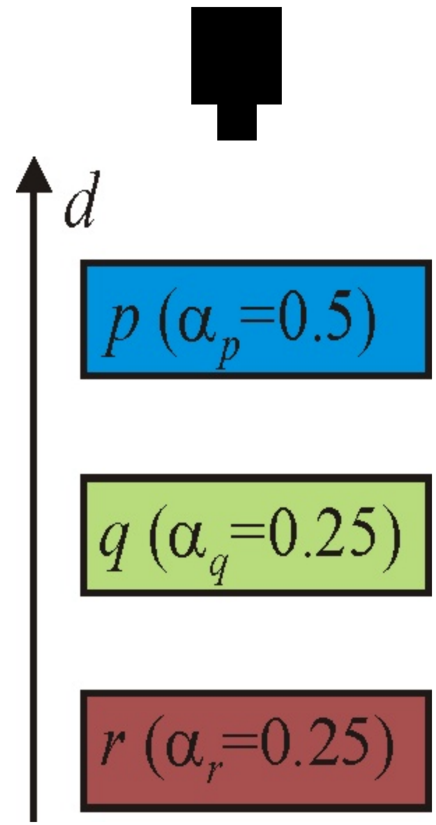
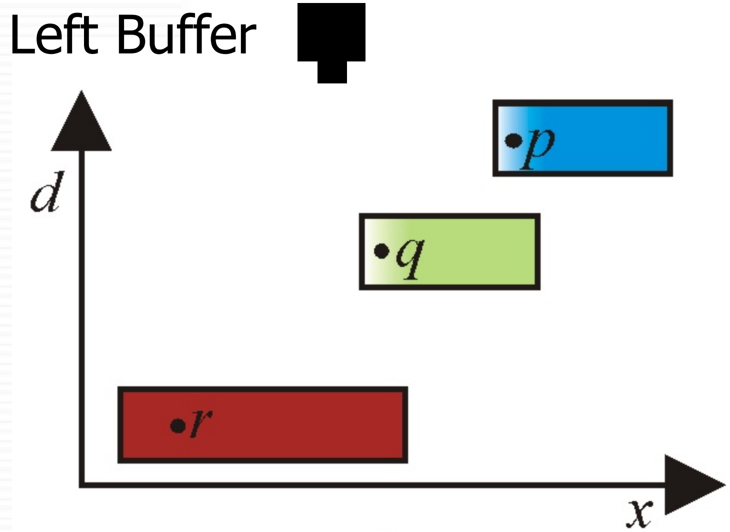


$$o_p = \frac{0.5}{1} = 0.5$$

$$o_q = \frac{0.25}{1 - 0.5} = 0.5$$

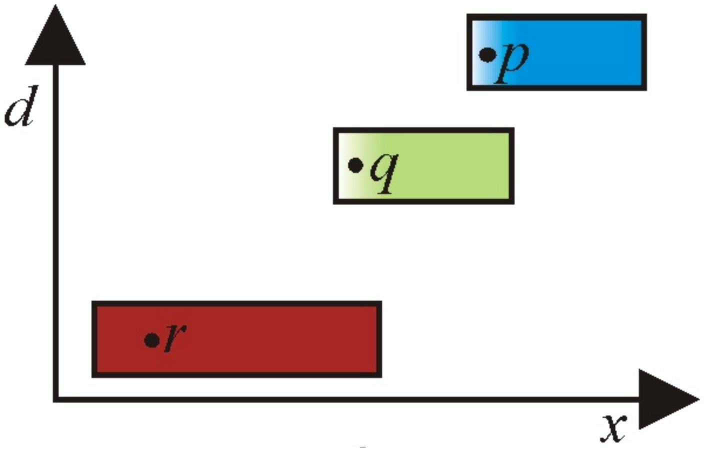
$$o_r = \frac{0.25}{1 - (0.5 + 0.25)} = 1$$

Warping with Transparent Pixels (Example 1)



Warping with Transparent Pixels (Example 1)

Left Buffer



alpha

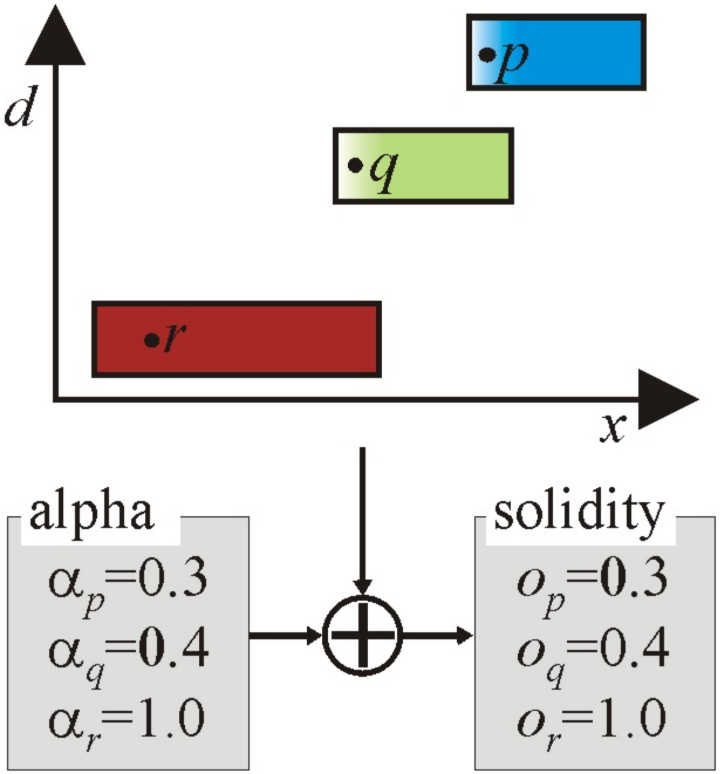
$\alpha_p = 0.3$

$\alpha_q = 0.4$

$\alpha_r = 1.0$

Warping with Transparent Pixels (Example 1)

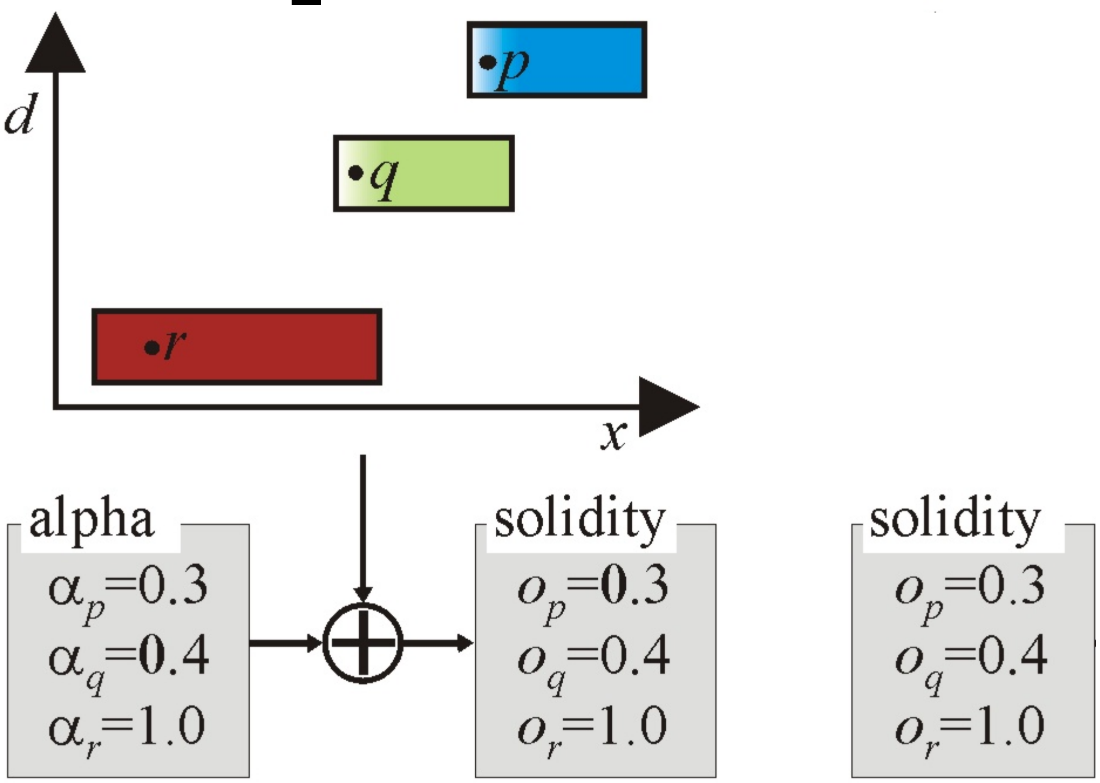
Left Buffer



Warping with Transparent Pixels (Example 1)

Left Buffer

Right Buffer



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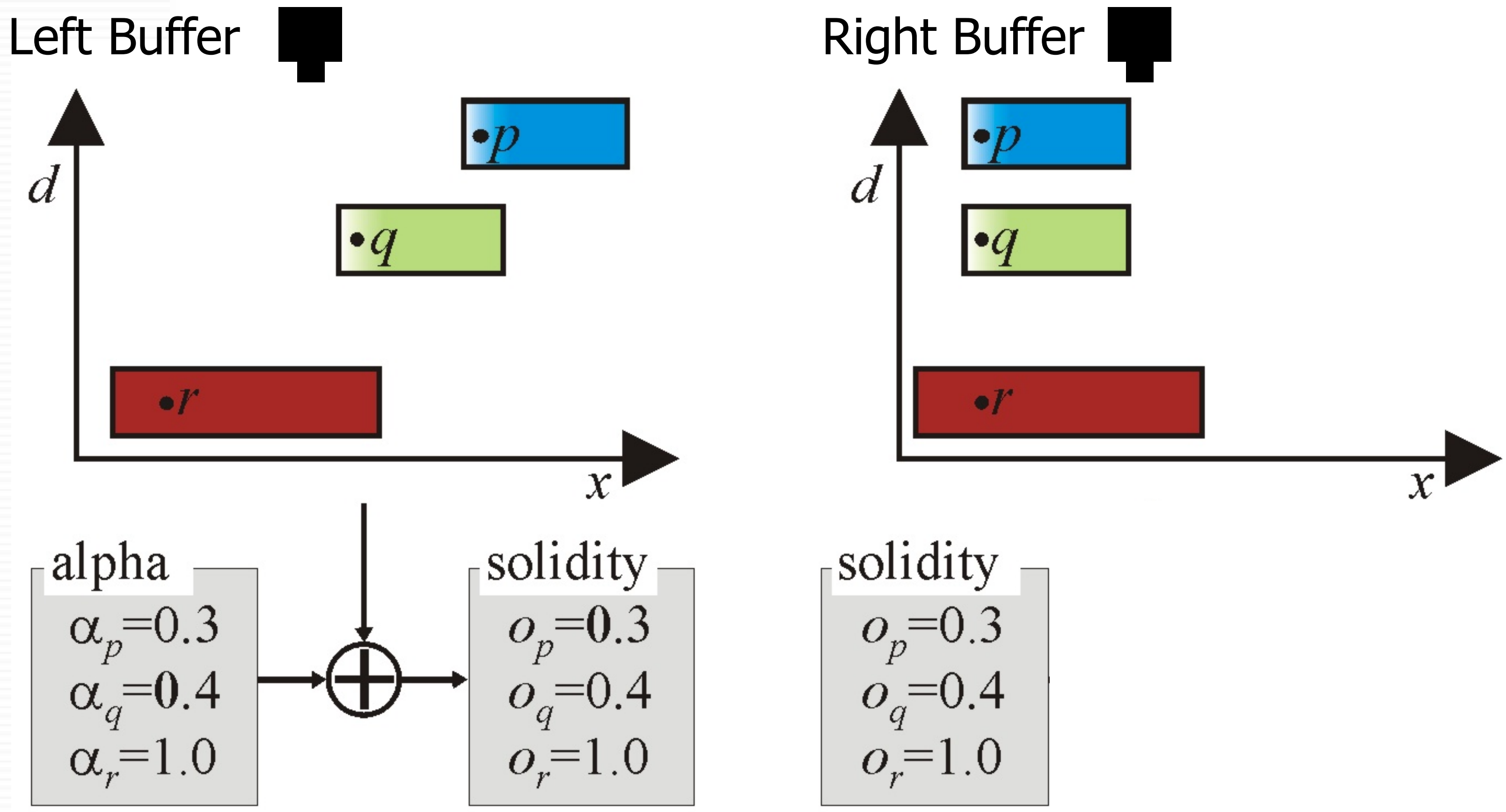

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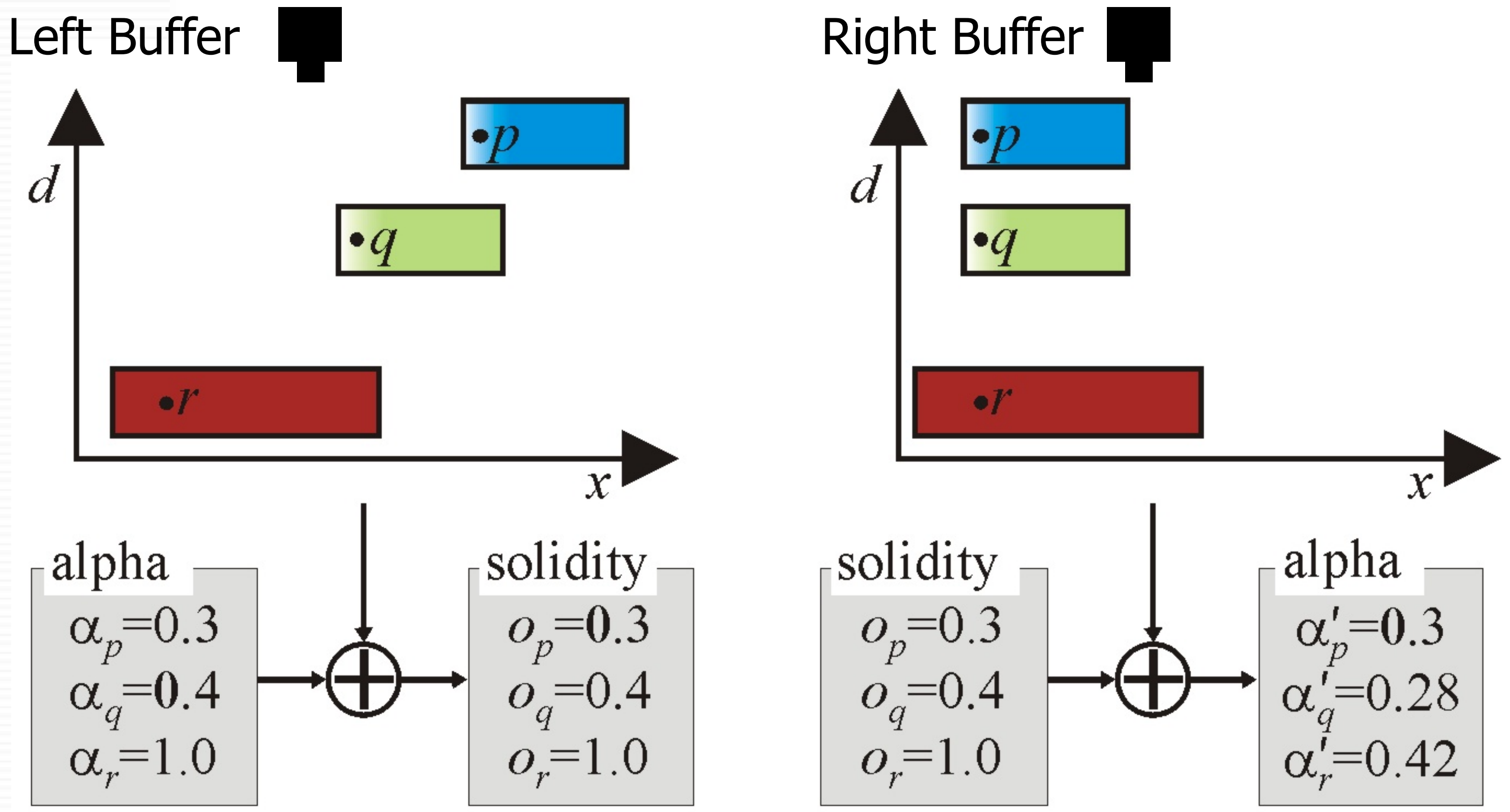

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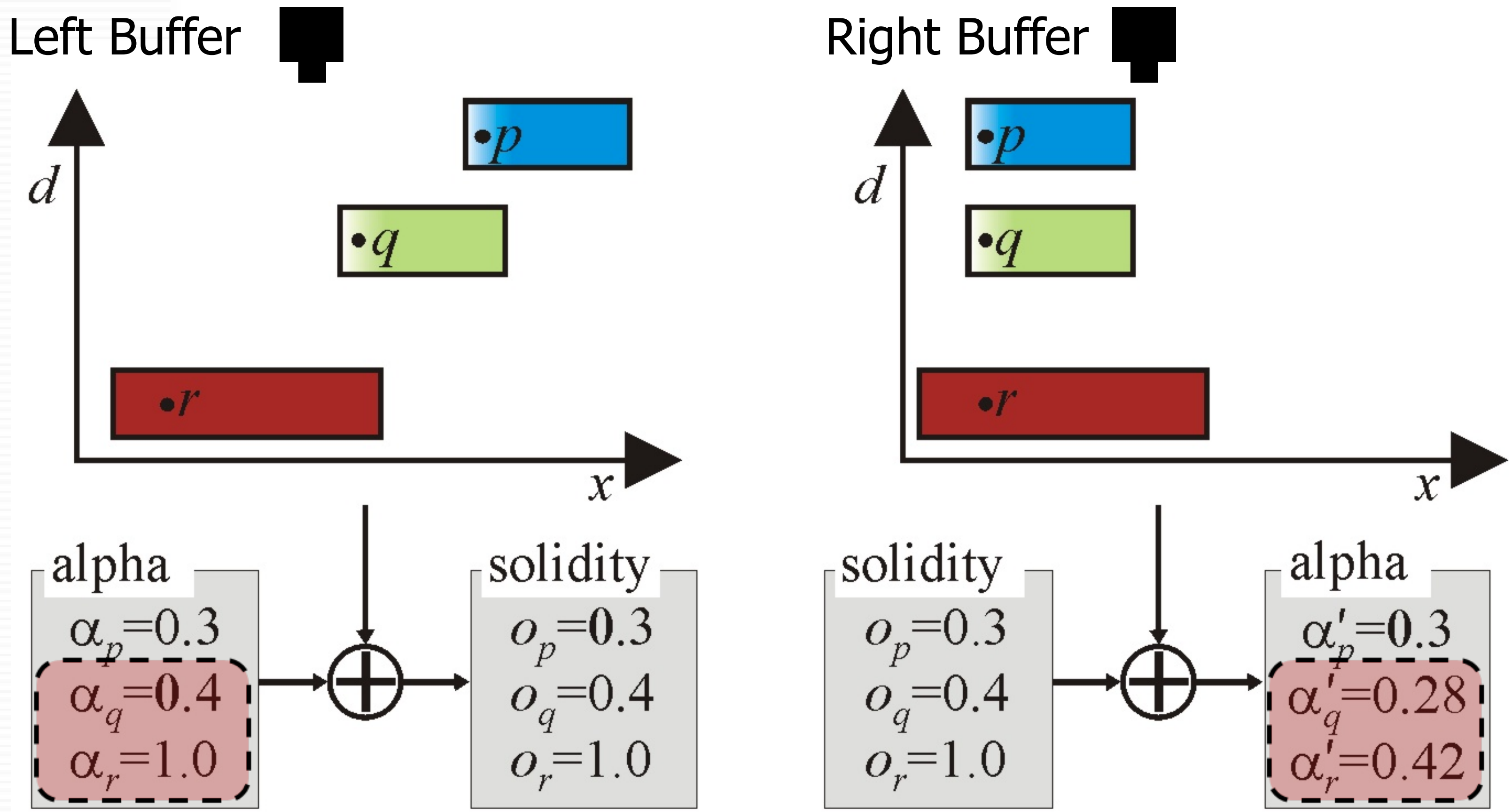
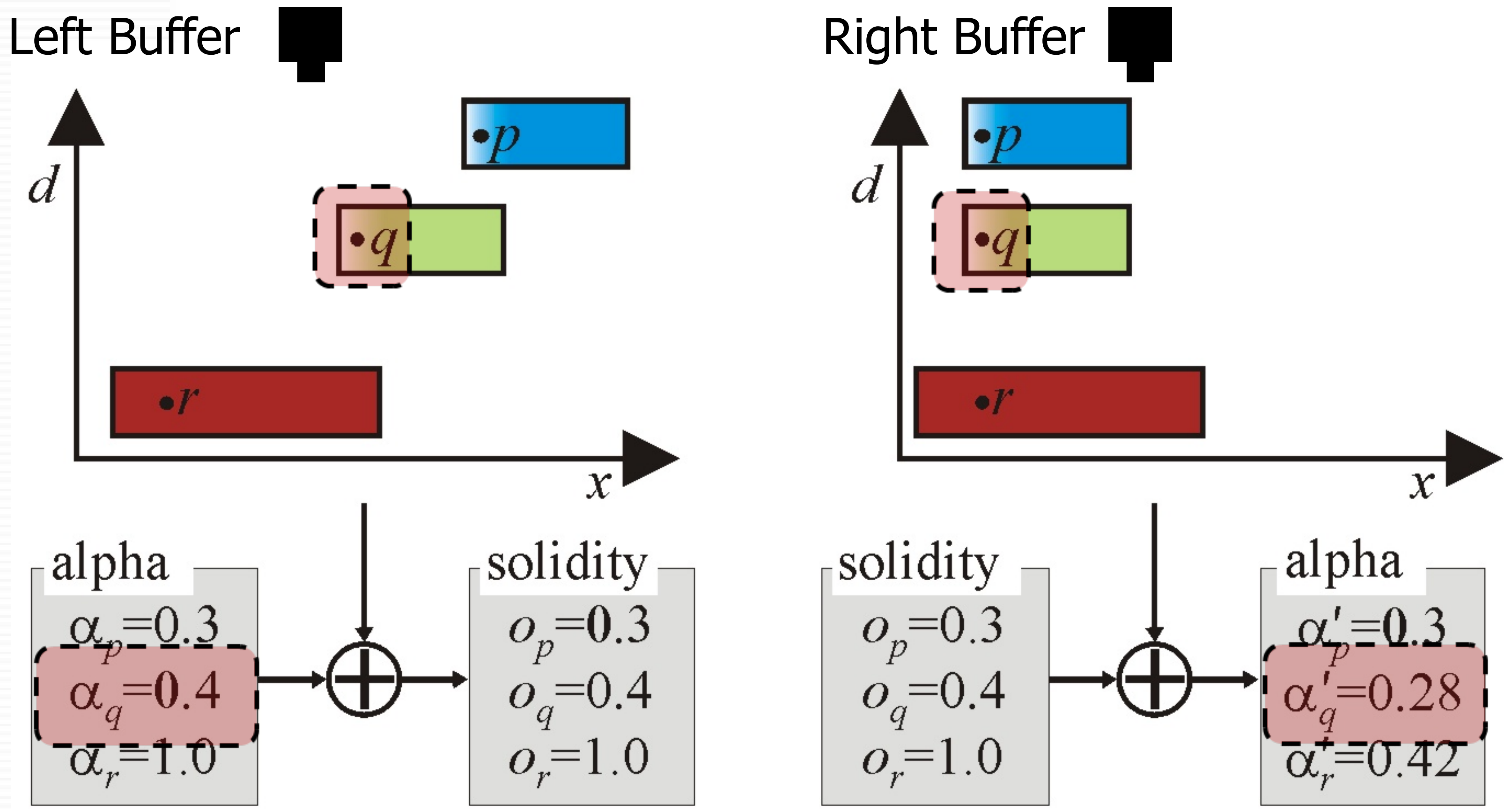


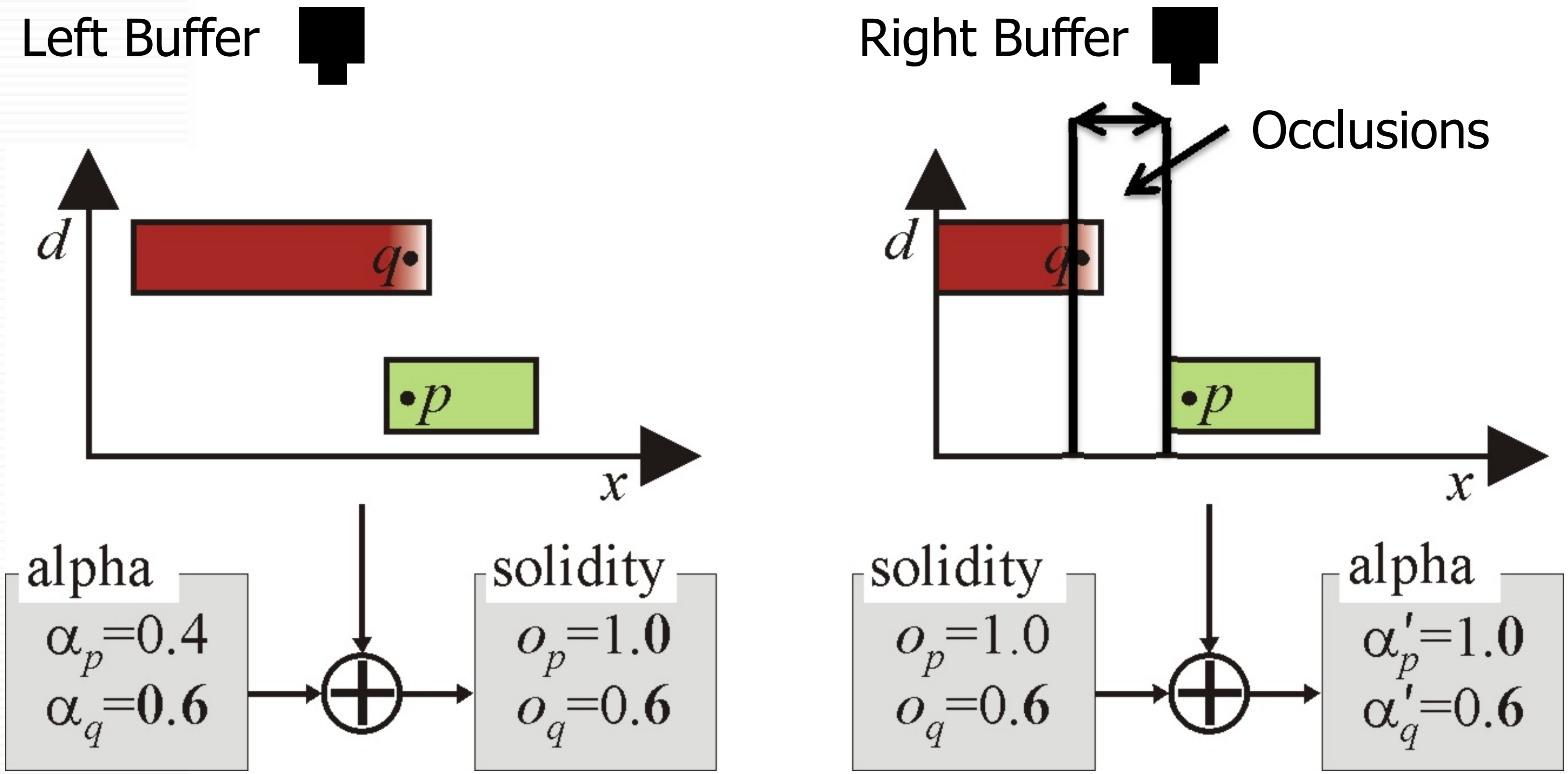
Alpha is different across views

Warping with Transparent Pixels (Example 1)



Assumption of constant foreground alpha violated

Warping with Transparent Pixels (Example 2)



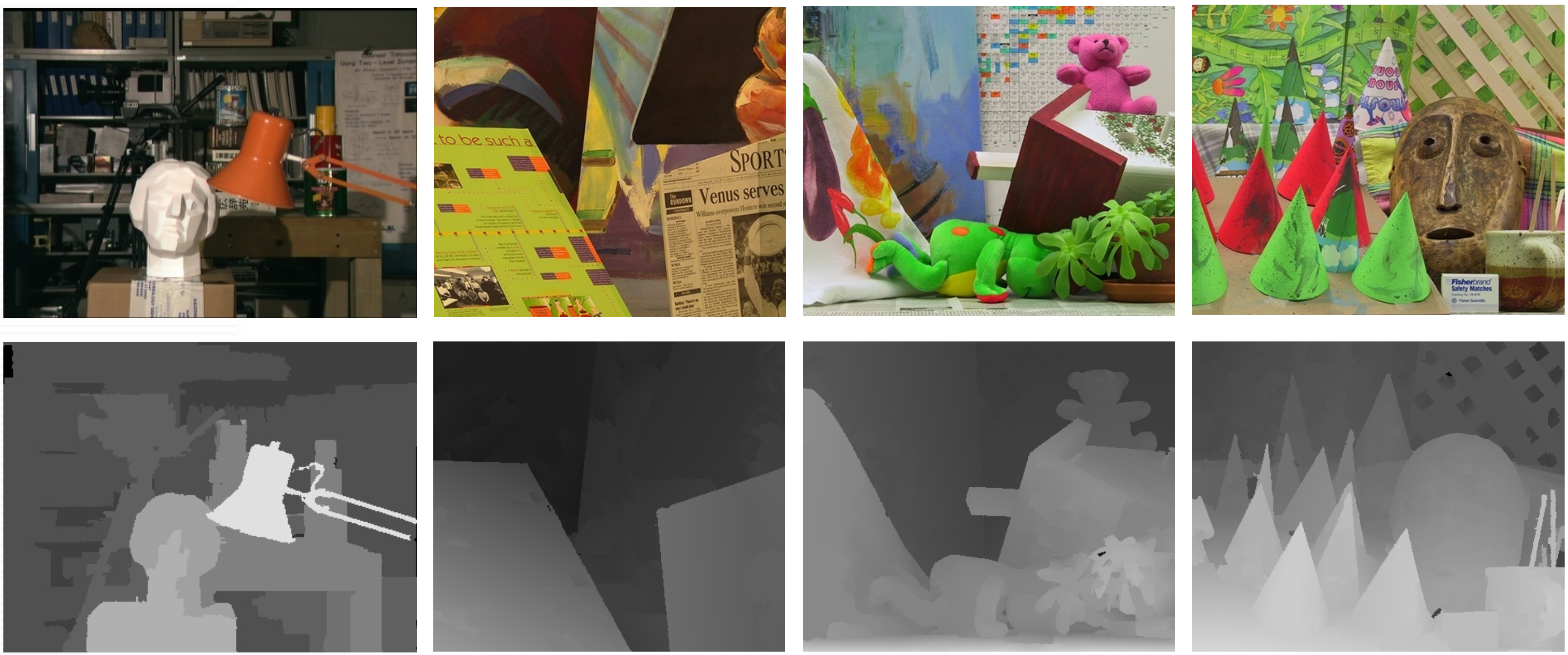
Occlusion if $\Sigma\alpha < 1$ in a cell of the right buffer

Energy Function

- For each pixel of the left buffer, find a true color, alpha value and disparity so that energy E is minimized.
- Data terms of E:
  - Color difference between artificial left and real left images
  - Color difference between artificial right and real right images
- Prior Knowledge in E:
  - Infinite penalty if $\Sigma\alpha \neq 1$ (left buffer)
  - Penalize neighboring pixels of different alphas (Linear smoothness term)
  - Penalize neighboring segments carrying different disparity planes (Potts model)
- See paper for Optimization Strategy

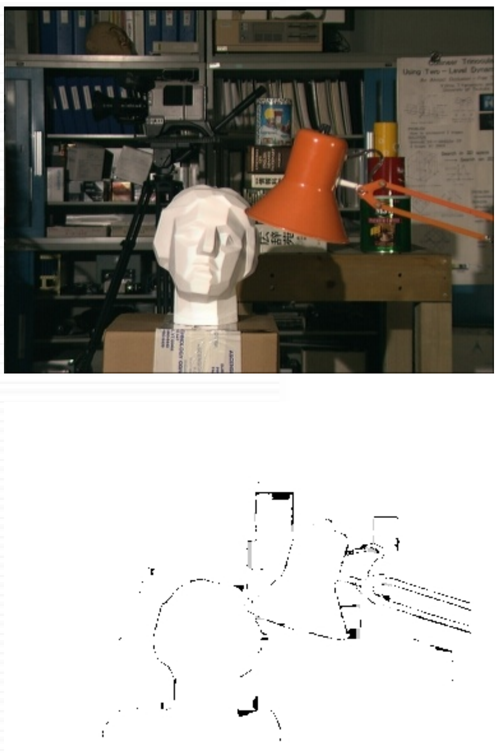
Results

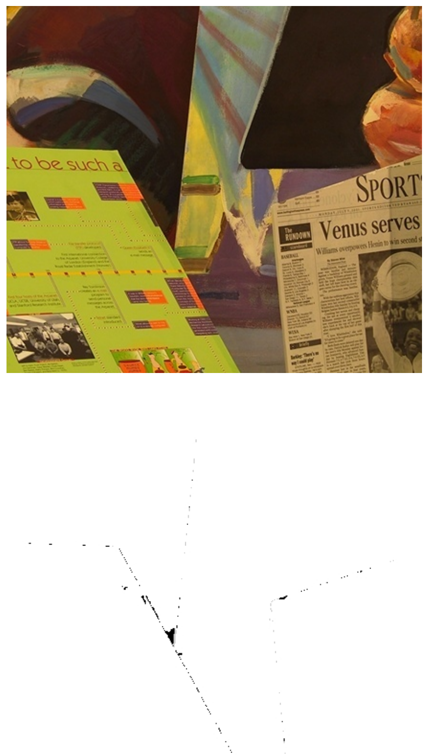
Computed Disparity Maps



(Tsukuba) (Venus) (Teddy) (Cones)

Disparity Errors > 1 Pixel


(Tsukuba)

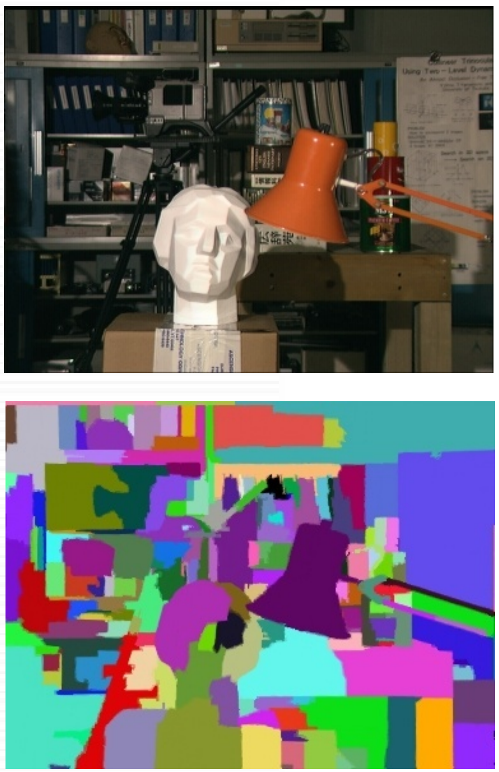


(Venus)


(Teddy)

(Cones)

Assignment of Pixels to Disparity Planes



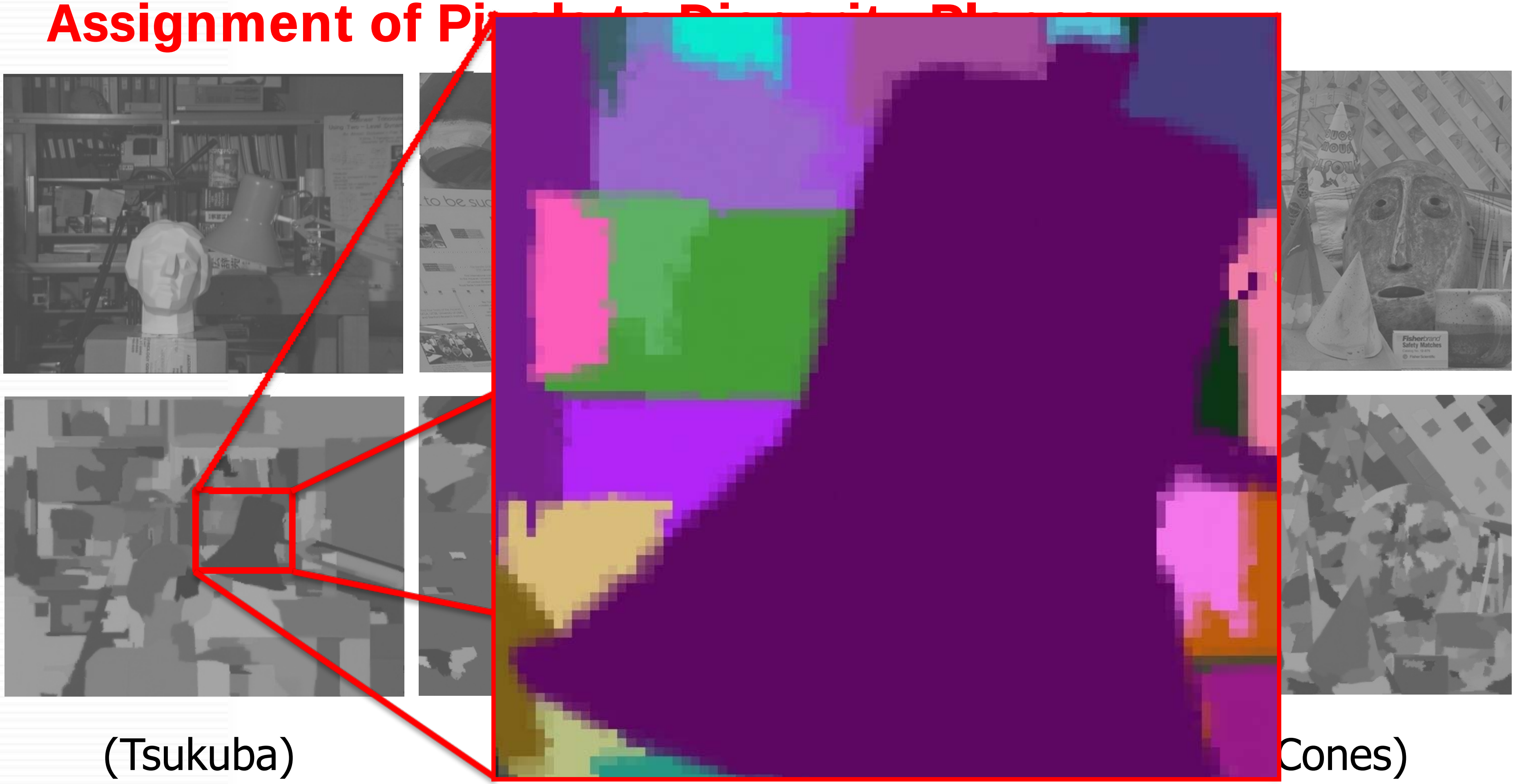
(Tsukuba)

(Venus)

(Teddy)

(Cones)

Assignment of Pi



(Tsukuba) Cones)

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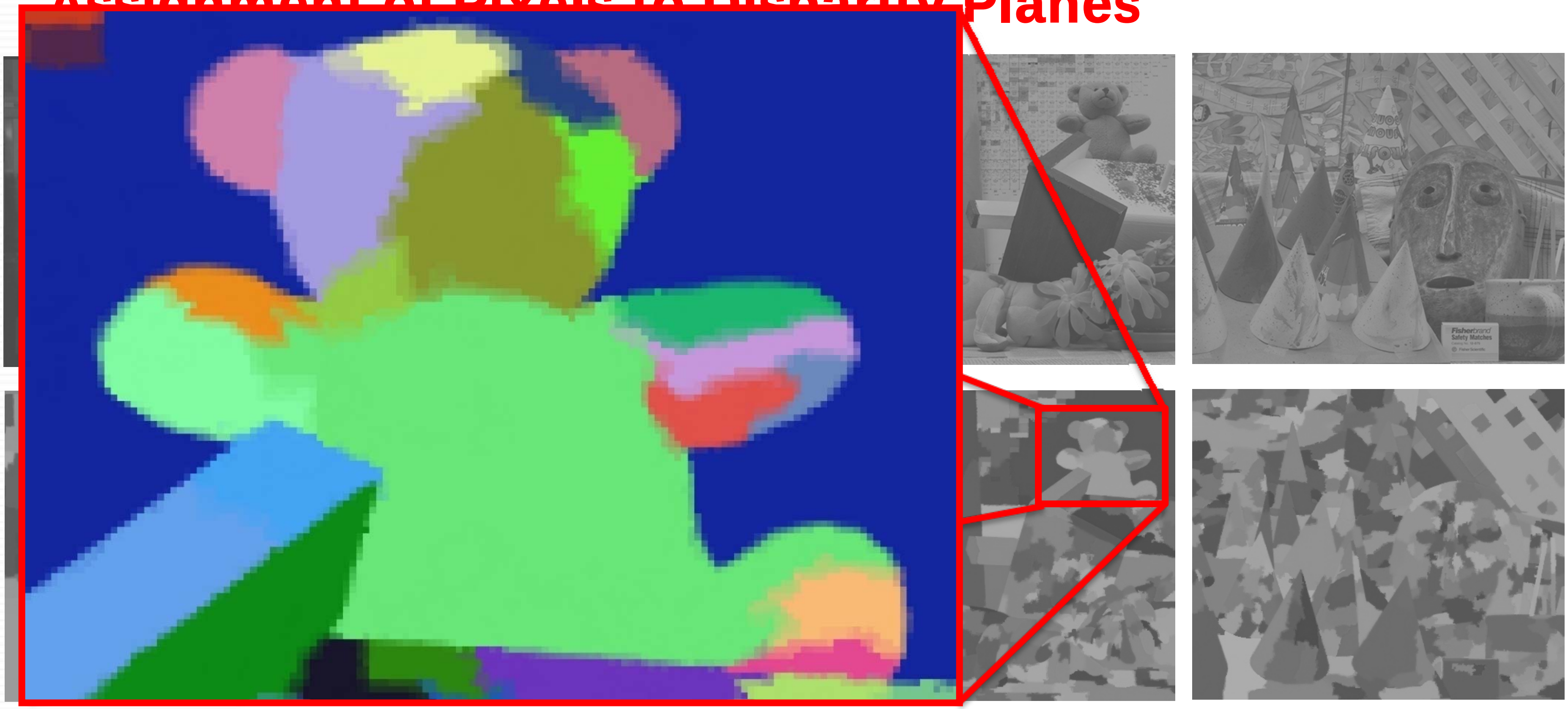
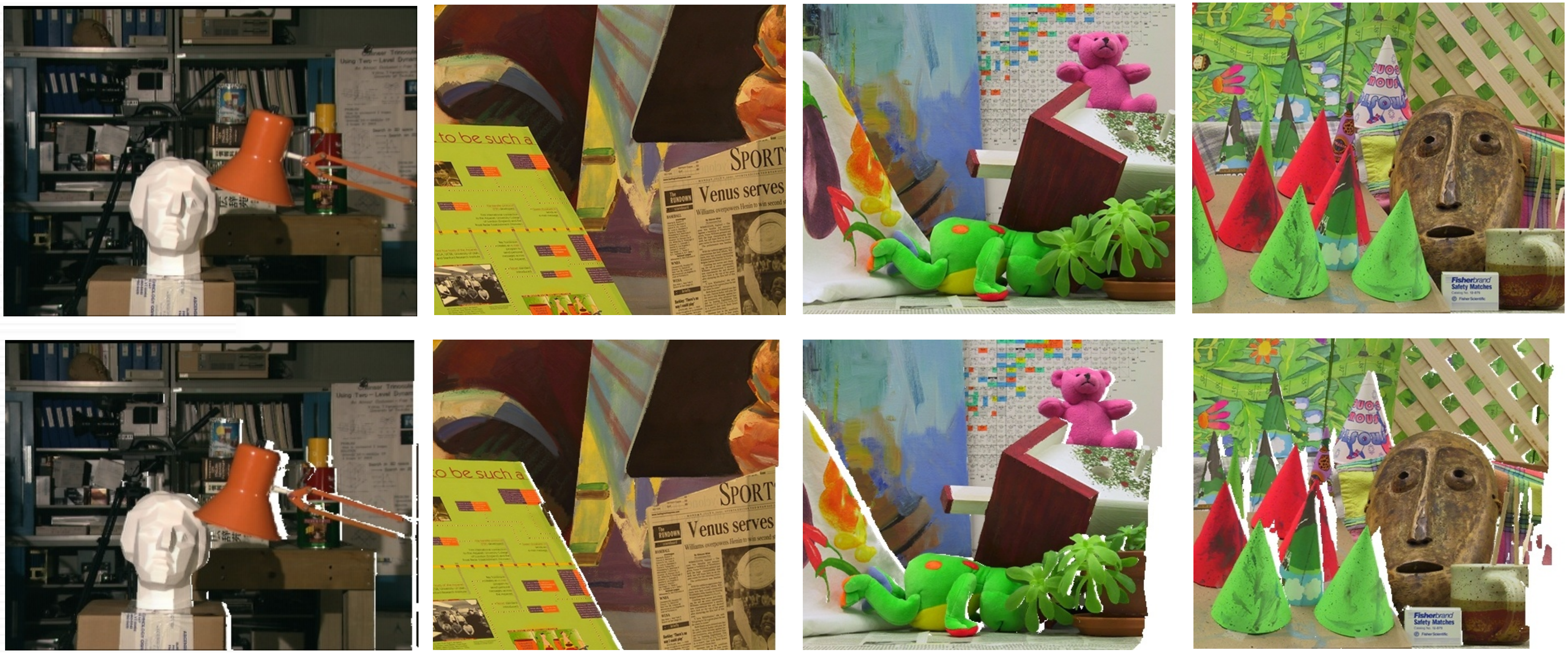


(Tsukuba) (Venus) (Teddy) (Cones)

Artificial Right Views



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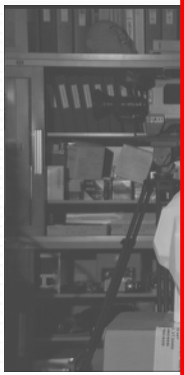
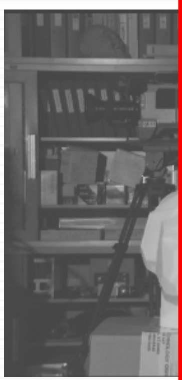
Arti





(Ts

Cones)

Quantitative Results – Middlebury Ranking

Algorithm	Rank	Avg. Error	Tsukuba			Venus			Teddy			Cones		
			nocc	all	disc	nocc	all	disc	nocc	all	disc	nocc	all	disc
AdaptingBP	1	4.23	1.11	1.37	5.79	0.10	0.21	1.44	4.22	7.06	11.8	2.48	7.92	7.32
SubPixBP	5	4.39	1.24	1.76	5.98	0.12	0.46	1.74	3.45	8.38	10.0	2.93	8.73	7.91
WarpMat	**6**	**4.98**	**1.16**	**1.35**	**6.04**	**0.18**	**0.24**	**2.44**	**5.02**	**9.30**	**13.0**	**3.49**	**8.47**	**9.01**
AdaptOvrSeg [16]	8	5.59	1.69	2.04	5.64	0.14	0.20	1.47	7.04	11.1	16.4	3.60	8.96	8.84
HardSeg	**11**	**5.53**	**1.20**	**1.54**	**6.07**	**0.55**	**0.64**	**5.10**	**5.50**	**9.73**	**13.5**	**3.83**	**8.66**	**10.01**
Segm+visib [2]	15	5.40	1.30	1.57	6.92	0.79	1.06	6.76	5.00	6.54	12.3	3.72	8.62	10.2

Our method takes the 6th rank of ~60 submissions

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AdaptingBP	1	4.23	1.11	1.37	5.79	0.10	0.21	1.44	4.22	7.06	11.8	2.48	7.92	7.32
SubPixBP	5	4.39	1.24	1.76	5.98	0.12	0.46	1.74	3.45	8.38	10.0	2.93	8.73	7.91
WarpMat	**6**	**4.98**	**1.16**	**1.35**	**6.04**	**0.18**	**0.24**	**2.44**	**5.02**	**9.30**	**13.0**	**3.49**	**8.47**	**9.01**
AdaptOvrSeg [16]	8	5.59	1.69	2.04	5.64	0.14	0.20	1.47	7.04	11.1	16.4	3.60	8.96	8.84
HardSeg	**11**	**5.53**	**1.20**	**1.54**	**6.07**	**0.55**	**0.64**	**5.10**	**5.50**	**9.73**	**13.5**	**3.83**	**8.66**	**10.01**
Segm+visib [2]	15	5.40	1.30	1.57	6.92	0.79	1.06	6.76	5.00	6.54	12.3	3.72	8.62	10.2

Our method takes the 6th rank of ~60 submissions

Quantitative Results – Middlebury Ranking

Algorithm	Rank	Avg. Error	Tsukuba			Venus			Teddy			Cones		
			nocc	all	disc	nocc	all	disc	nocc	all	disc	nocc	all	disc
AdaptingBP	1	4.23	1.11	1.37	5.79	0.10	0.21	1.44	4.22	7.06	11.8	2.48	7.92	7.32
SubPixBP	5	4.39	1.24	1.76	5.98	0.12	0.46	1.74	3.45	8.38	10.0	2.93	8.73	7.91
WarpMat	**6**	**4.98**	**1.16**	**1.35**	**6.04**	**0.18**	**0.24**	**2.44**	**5.02**	**9.30**	**13.0**	**3.49**	**8.47**	**9.01**
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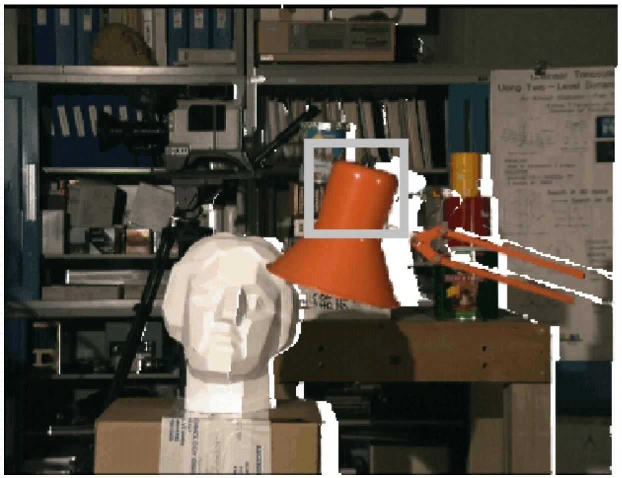
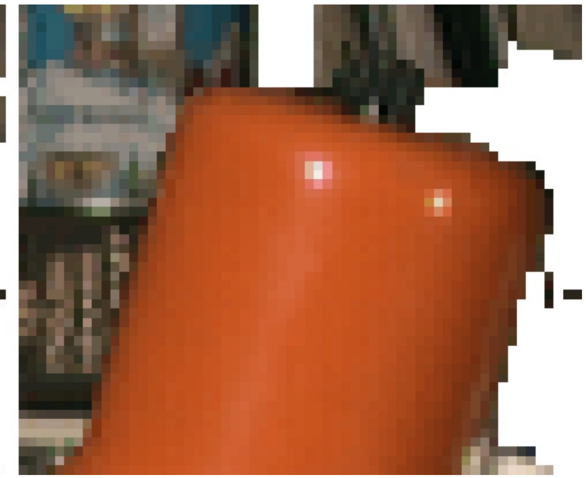
Our method takes the 6th rank of ~60 submissions

Application Example – Novel Viewpoint Generation



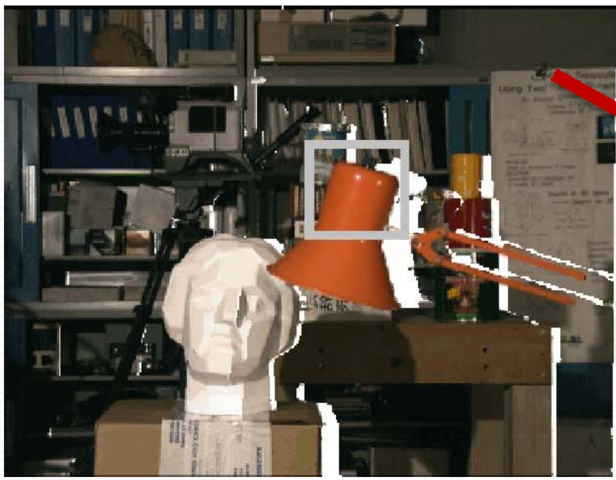
(Novel view generated using our matting and disparity results)

(Zoomed-in view)

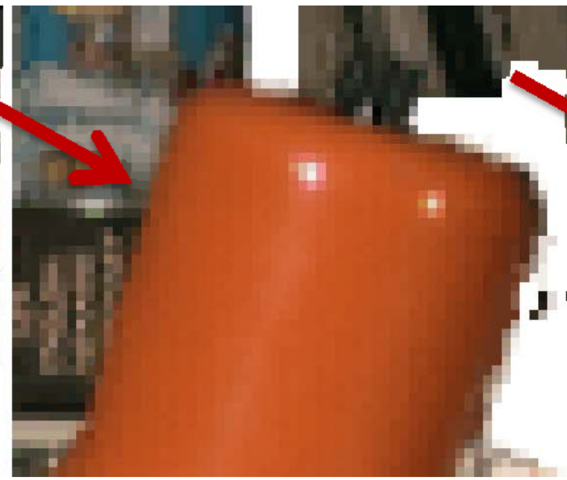


(Result without using matting information)

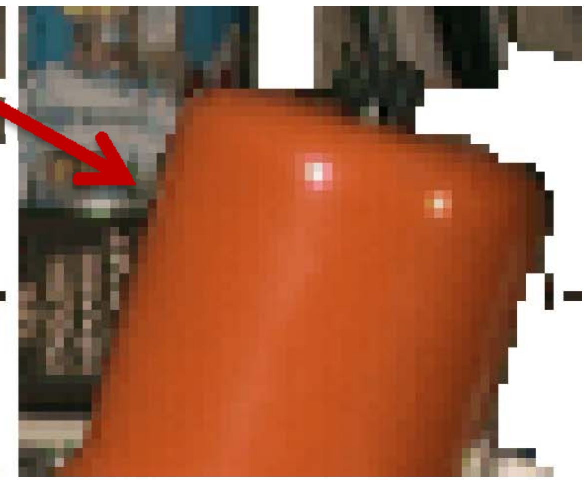
Application Example – Novel Viewpoint Generation



(Novel view generated using our matting and disparity results)



(Zoomed-in view)



(Result without using matting information)

Application Example – Depth Segmentation

(Segmented objects pasted against a white background)

Conclusions

- Combined stereo and matting approach takes advantage of problem synergies
- Proposed the assumption of constant solidity
- Good-quality disparity results
- Matting results look visually satisfying

Energy Optimization

- Two step procedure:
  - Optimize disparity planes (fixed alphas and true colors)
    - Greedy search strategy
  - Optimize alphas and true colors (fixed disparity planes)
    - Belief Propagation (most similar: [Wang, ICCV05], [Wang, CVPR07])
- Iterate a few times