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Stereoscopic 3D Video Depth Adjustment for Viewer Preference and Prevention of Visual Discomfort

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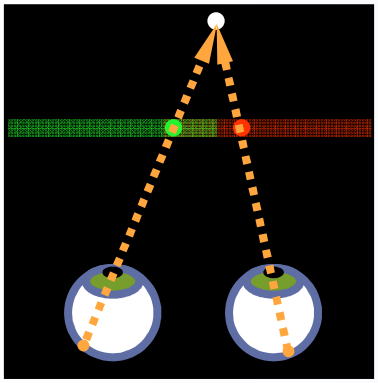
Motivations

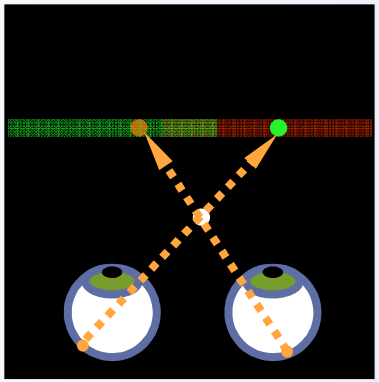
- **Motivation 1:** Viewers' preferences (Increased depth gives higher quality)

Stage Style
(depth behind the display)

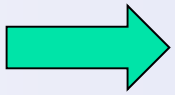
Hologram Style
(depth into the room)



Uncrossed (positive) disparity



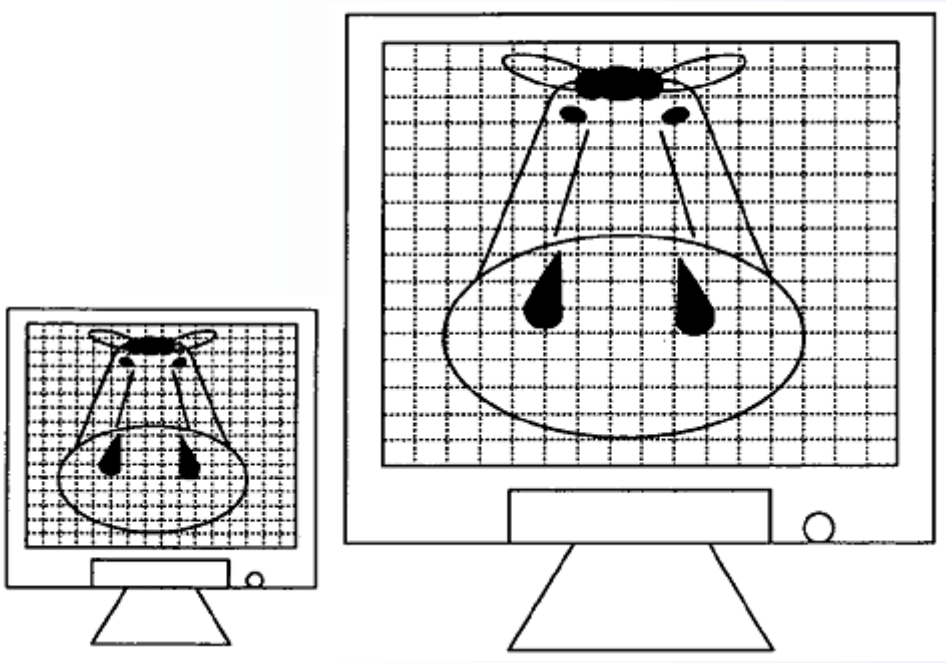
Crossed (negative) disparity

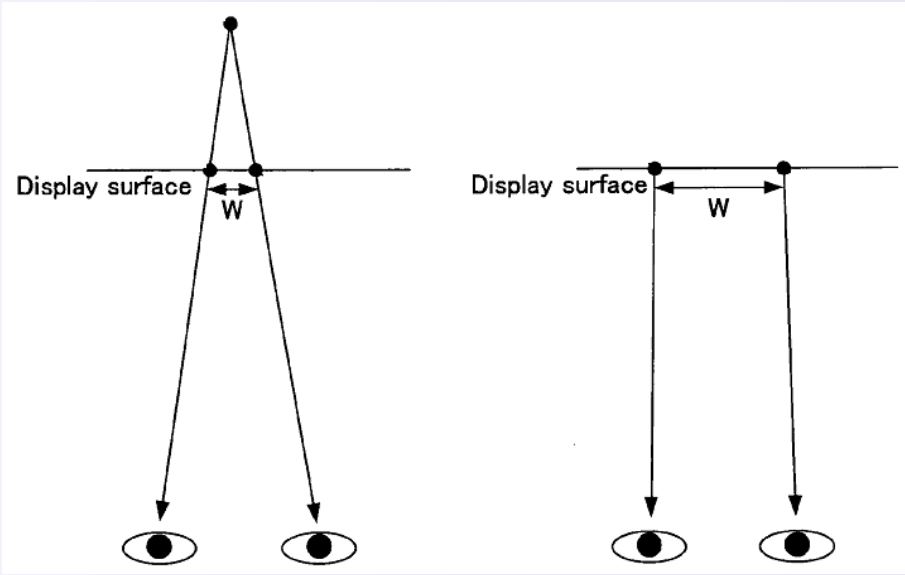


Remote control with 3D knob!

Motivations

- **Motivation 2:** Prevention of visual comfort
  - Excessive disparity will cause eye fatigue
  - The 3D content providers cannot master digital depth rendering for all display sizes, viewing distances, etc.





On-screen disparity = image disparity * pixel size

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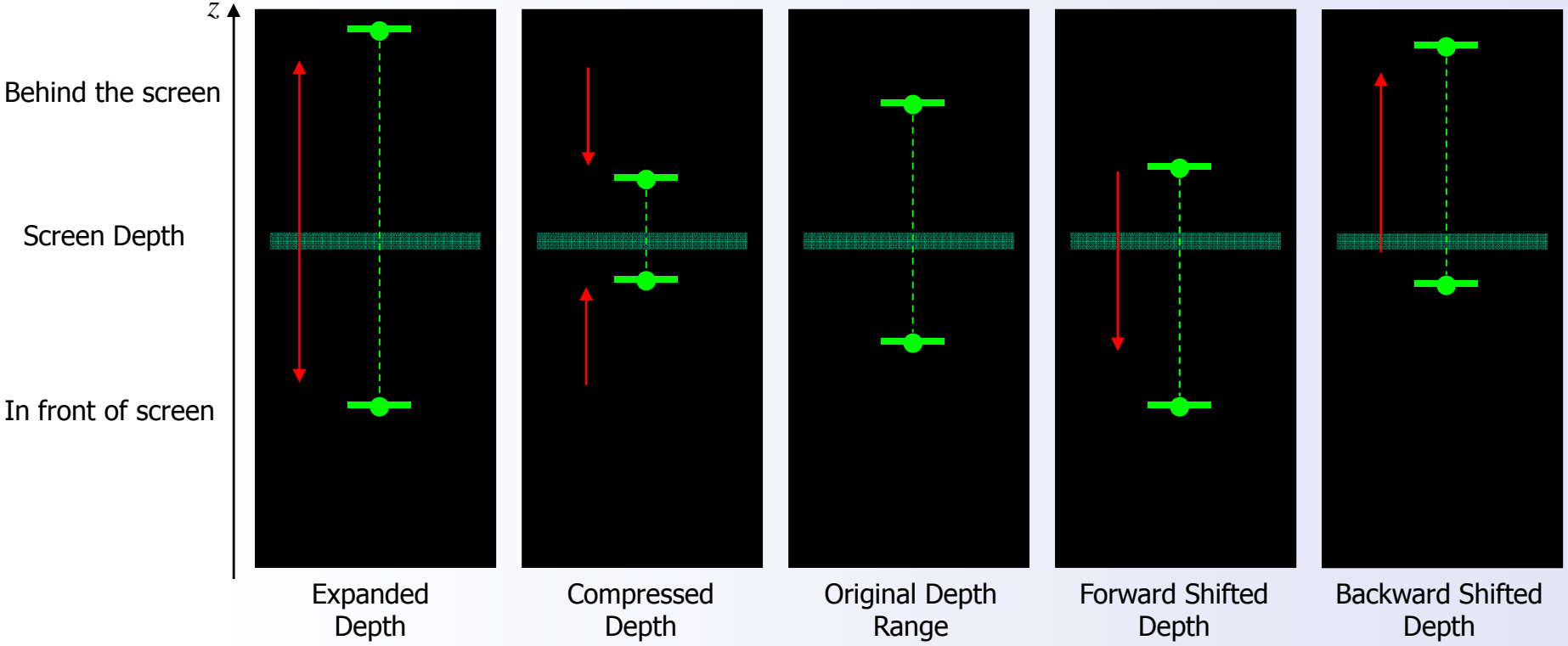
3D Depth Adjustment: Scaling and Shifting

- Disparity scaling => scaled depth range $d'(x, y) = \alpha d(x, y)$
- Disparity shifting => slightly distorted depth range $d'(x, y) = d(x, y) + \delta$



Ref.: Woods et al., "Image Distortions in Stereoscopic Video Systems," SD&A 1993 (assuming parallel camera)

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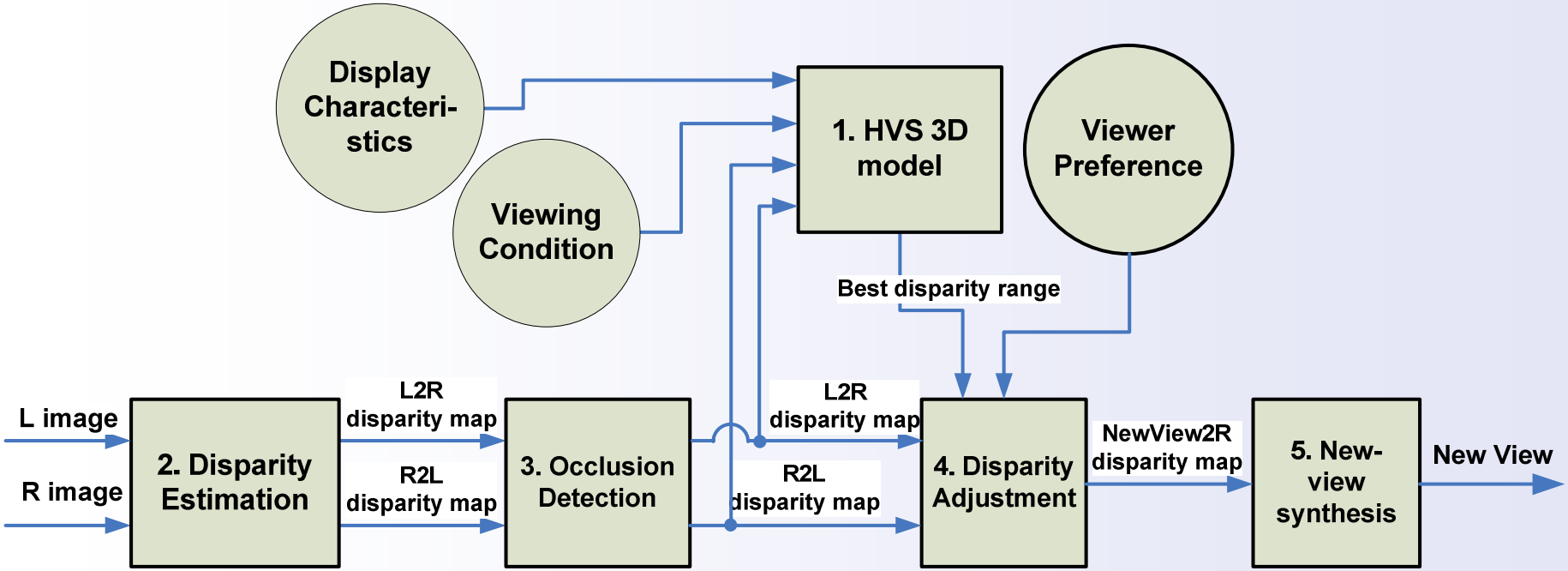
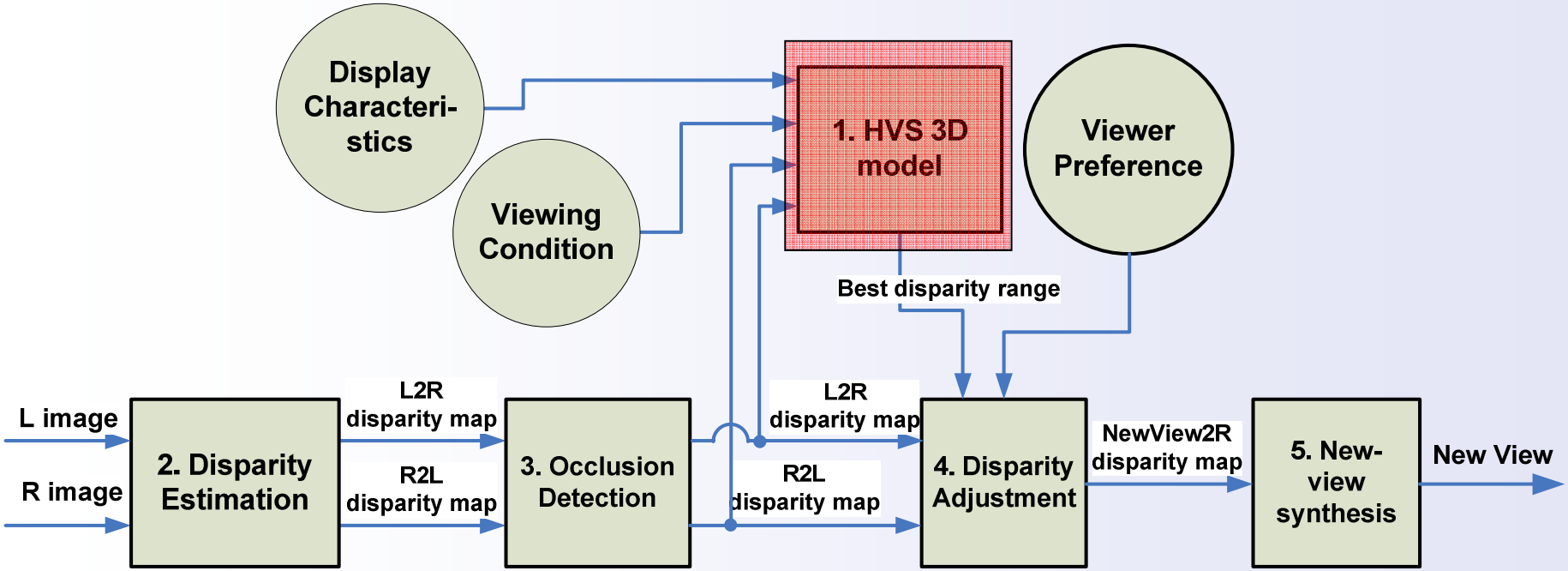
The Overall Block-diagram



New image pairs:
"original L + synthesized R" or
"synthesized L + original R"

1. HVS 3D Model (1)



HVS: Human Visual System

Ref: Hoffman et al., "Vergence-accommodation conflicts hinder visual performance and cause visual fatigue," Journal of Vision, 8(3):33, 1-30 (2008).

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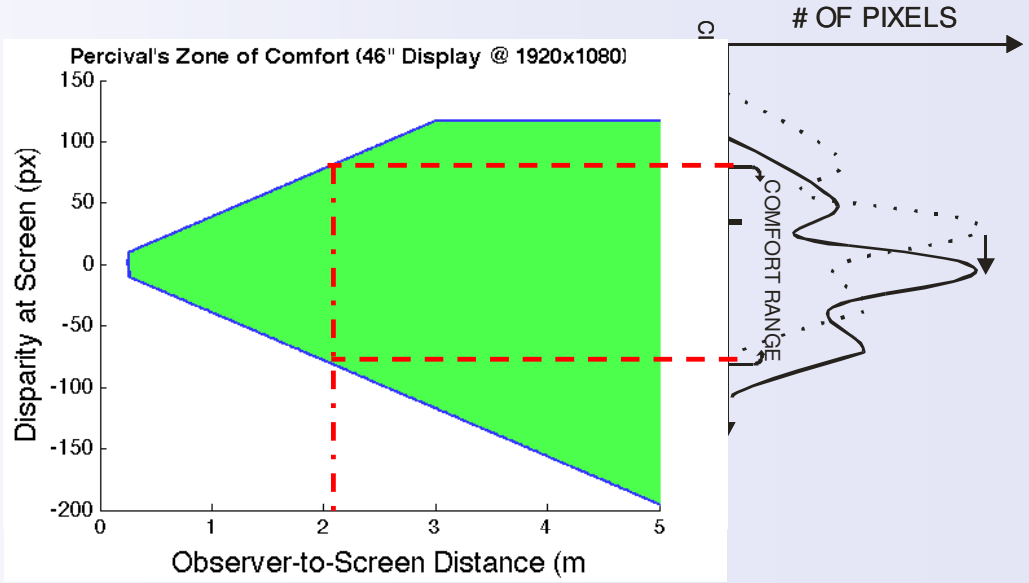
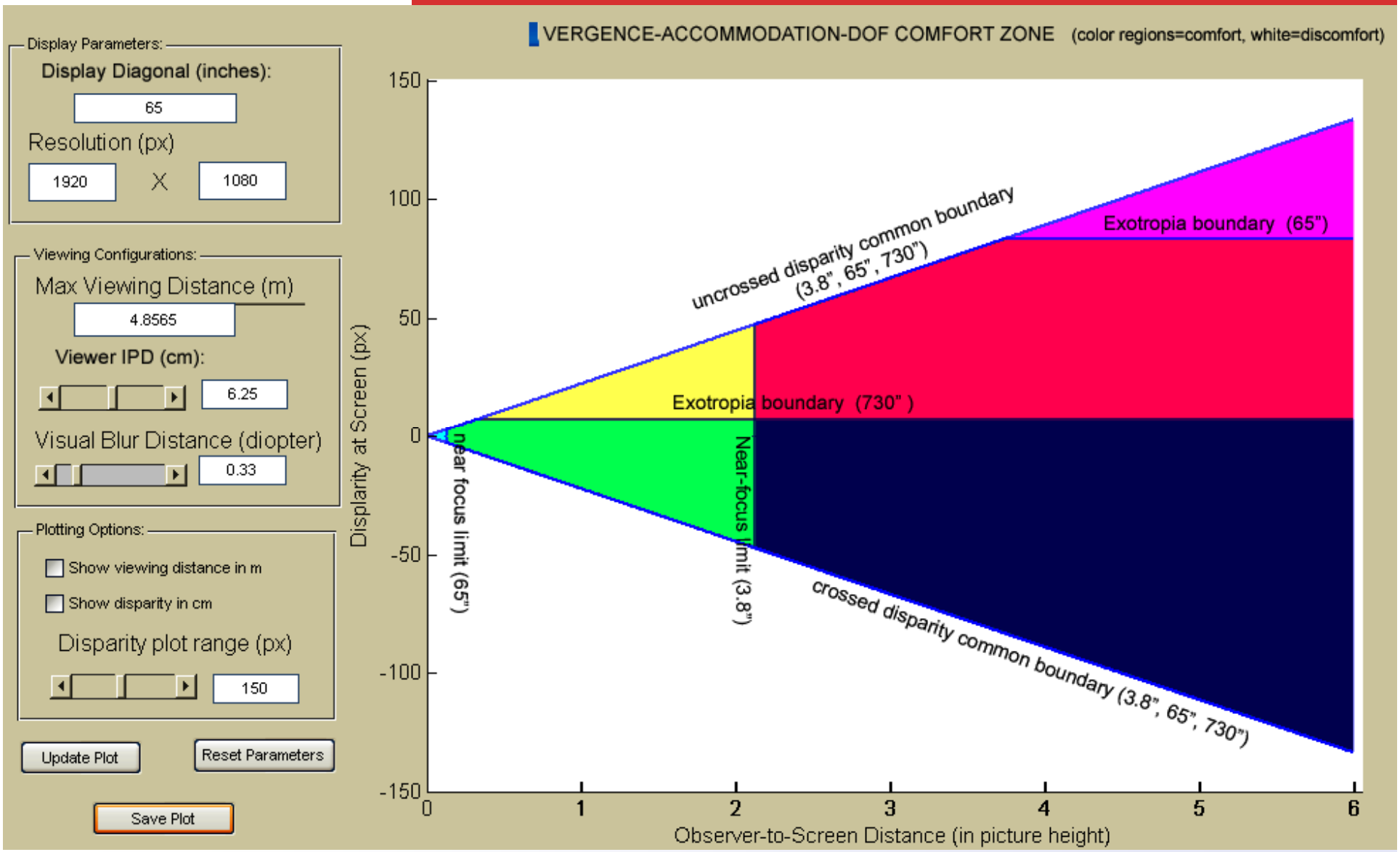
1. HVS 3D Model (2)

- Empirical human visual model: Percival's Zone of Comfort
  - The 3D area which human eyes can see clearly and comfortably
- Image level prediction
  - Check if the disparities in the whole image fall into the comfort zone and decide whether to shift or scale the images
  - Applied in this approach
- Pixel level prediction
  - Check if a certain area in the image is comfortable and then replace these areas with more comfortable versions
- More details in a paper under review



cyan (teal) => blue => red: increasing discomfort

1. HVS 3D Model (3)



Vergence: eyes' fixation point; Accommodation: eyes' "focal length"; Exotropia: normal vergence at infinity

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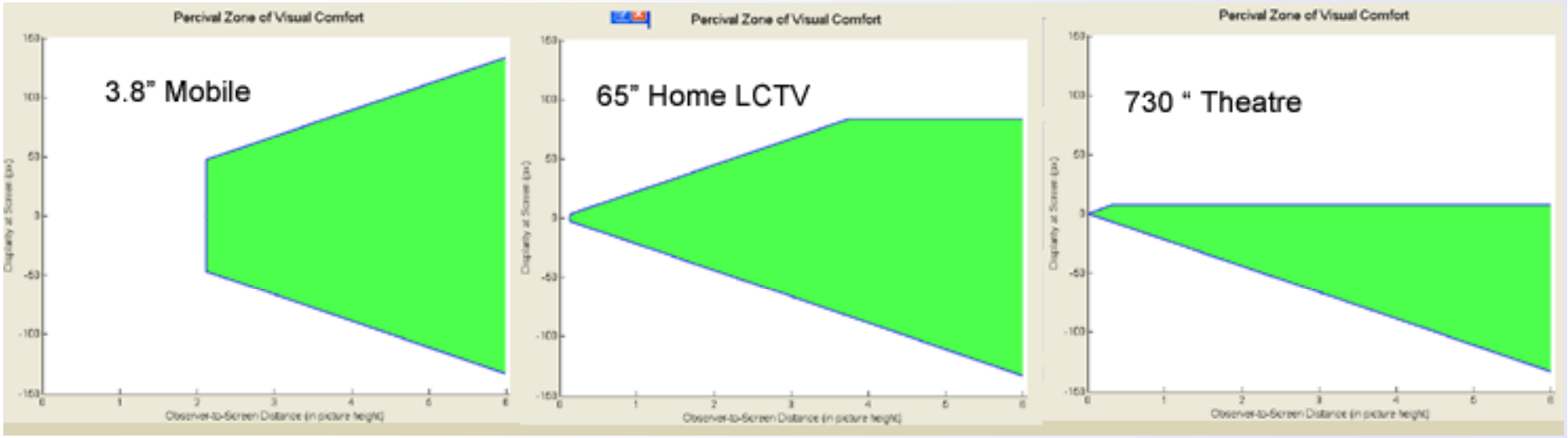
1. HVS 3D Model (4)

- The comfortable disparity range is affected by display size, viewing distance, …



- "Soft" boundary
- Temporal variations ("depth budget") to be considered later

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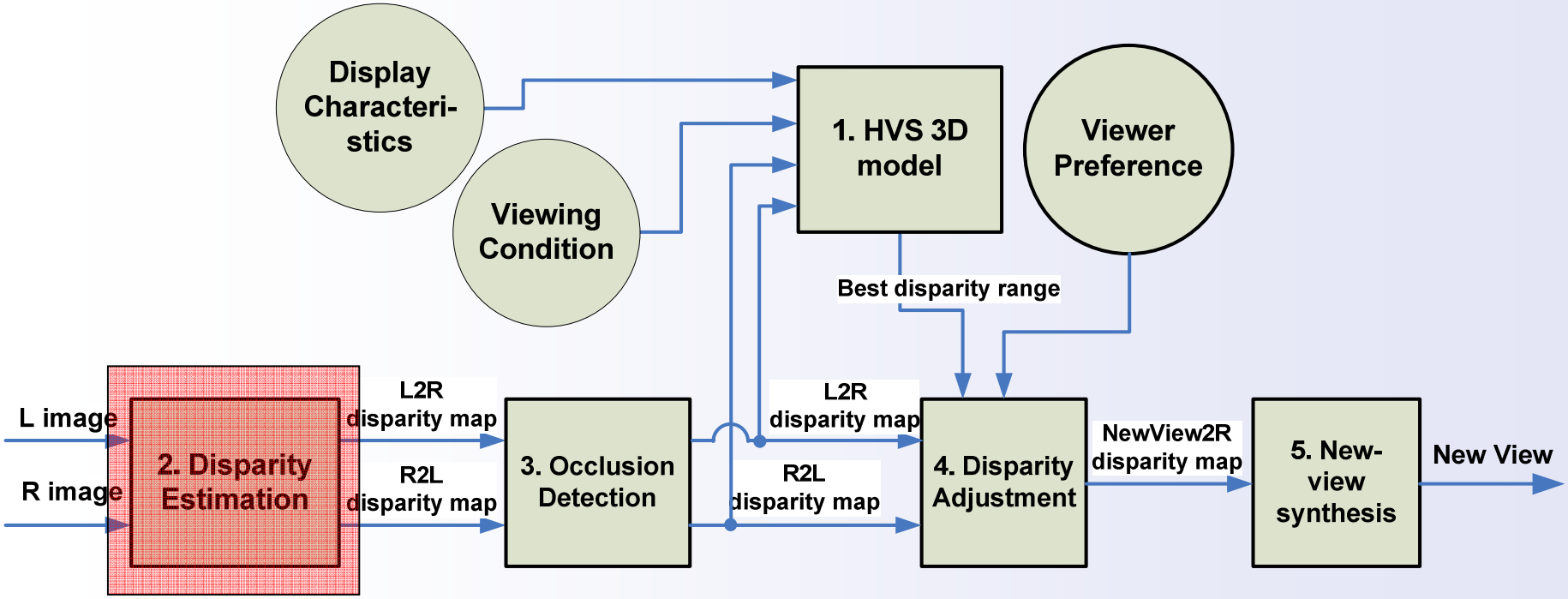
2. Disparity Estimation (1)



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2. Disparity Estimation (2)

- One of the oldest unsolved computer vision problems
  - State-of-the-art algorithms generate disparity maps with holes
- Causes of ambiguities in disparity estimation:
  1. Occlusions: matched regions do not exist
  2. Feature-less regions: matched regions are difficult to determine.
  3. Regions with repetitive features: matched regions are difficult to determine.
  4. Small objects with large disparities
  5. Variations on intensity and colors in two views

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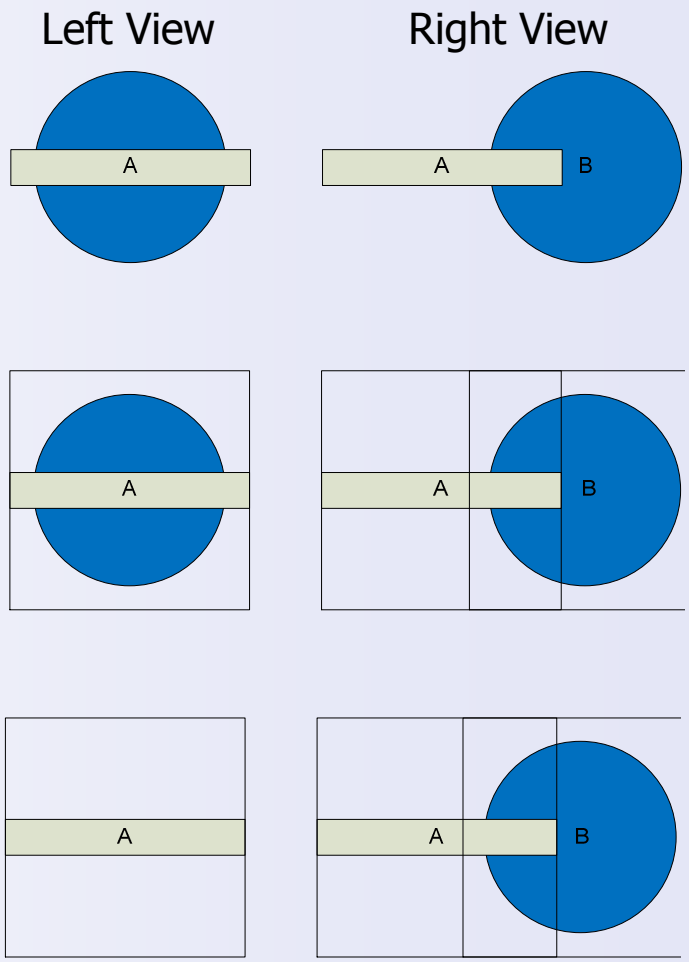
2. Disparity Estimation (3)

- Various methods: block matching, dynamic programming, graph cut, …
- Our solution: regularized block matching algorithm for minimizing the cost function

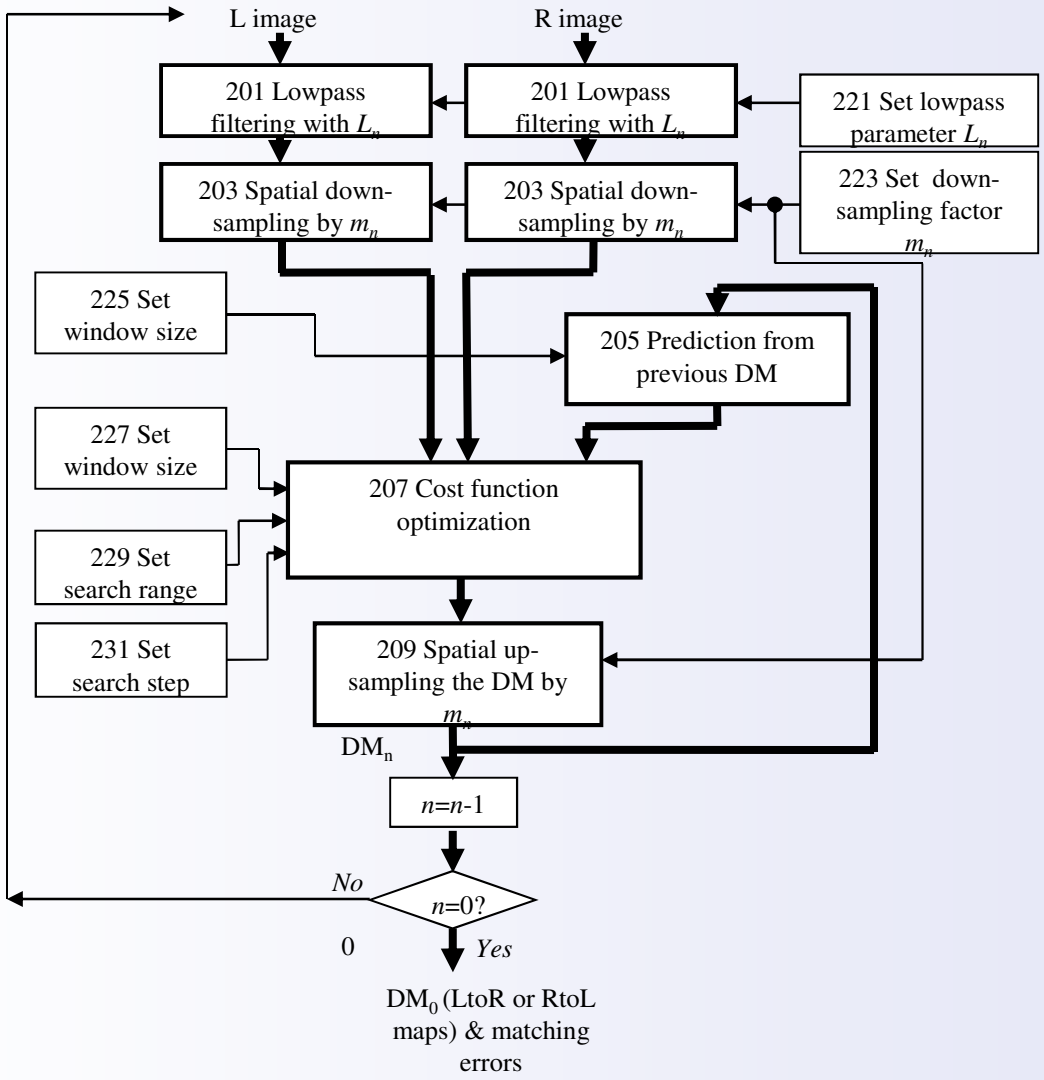
  Σ {Color_difference} + Σ {Disparity_difference}

- A weighting mechanism is used to select pixels in local windows
  - Similar to the bilateral filter: the weight is bigger when the color difference between a pixel and the center is smaller.
  - Benefits:
    - Can use bigger window (resolving ambiguity 2, 3, 4)
    - Faster converging speed
- "Disparity_difference" enforces the smoothness of disparity map



2. Disparity Estimation (4)

Iterative multi-resolution algorithm:



- Other improvement: adaptive search range that changes from layer to layer, and from pixel to pixel

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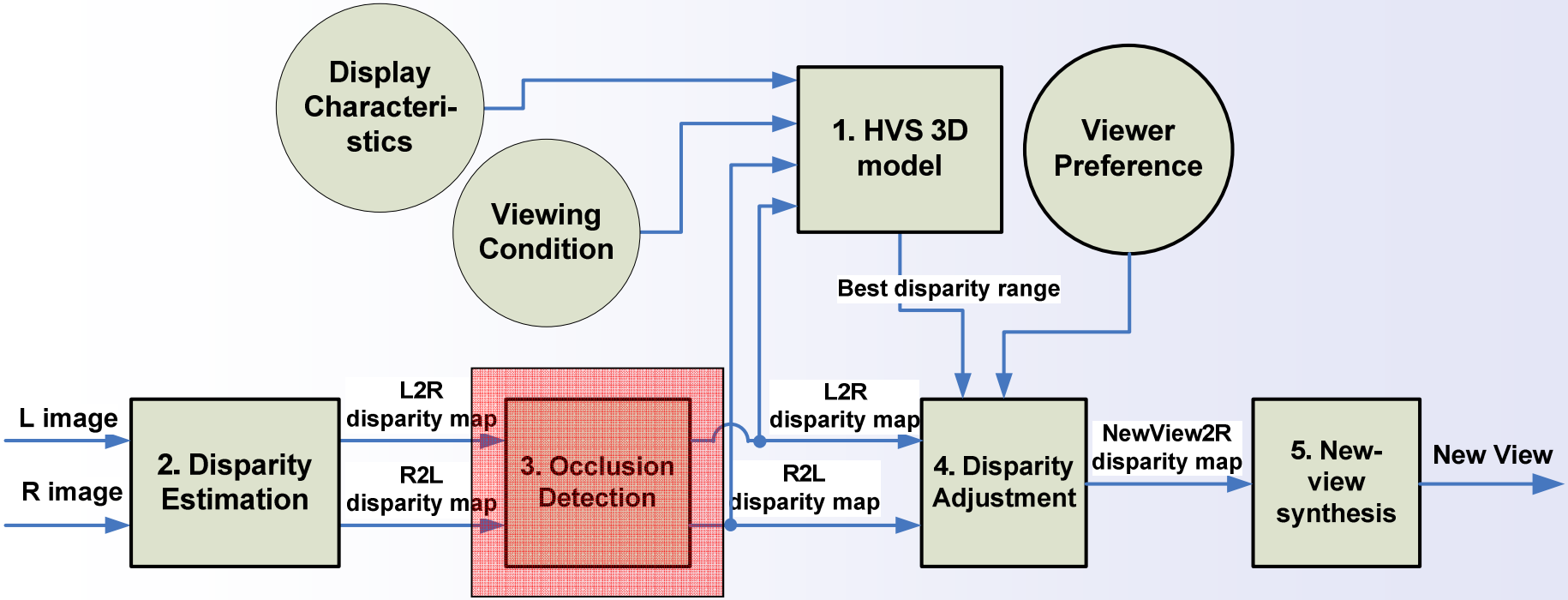
3. Occlusion Detection (1)



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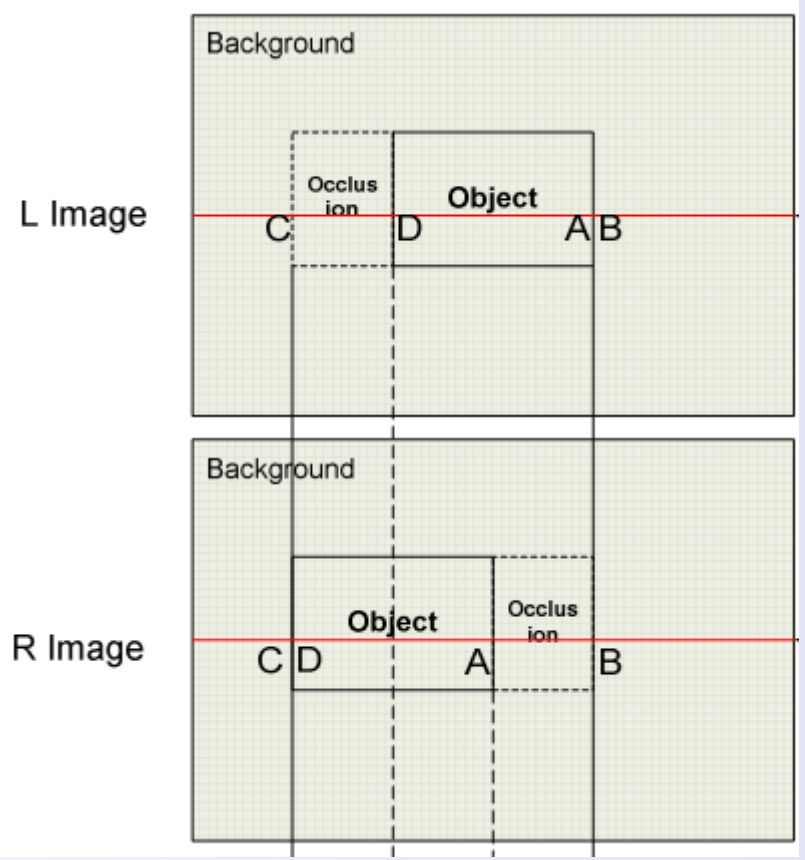
3. Occlusion Detection (2)

- Occlusion detection is important
  - Many artifacts in a synthesized view can be traced back to improper handling of occlusion
  - Separation of foreground and background objects
- Detection using one-side disparity map and the original matching cost value is not reliable
  - Higher matching cost => occlusion: Not always!
  - Occlusion => higher matching error: Not always!



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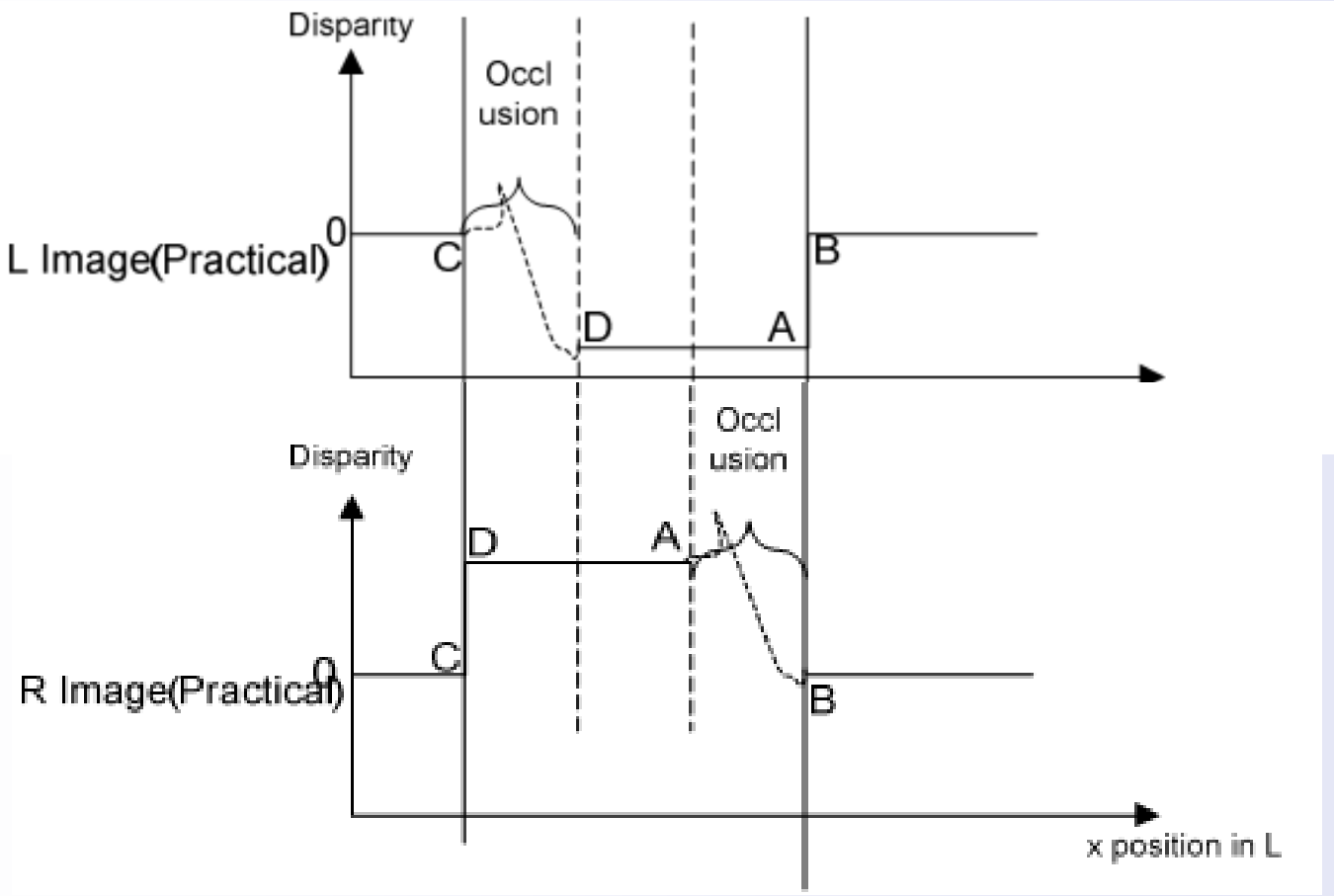
3. Occlusion Detection (3)

- Improvement: Detection using horizontal scan lines in the two-side disparity map
  - Detect occlusion in L image using rising edges in R disparity map: position, height, …
  - Multiple cues are used



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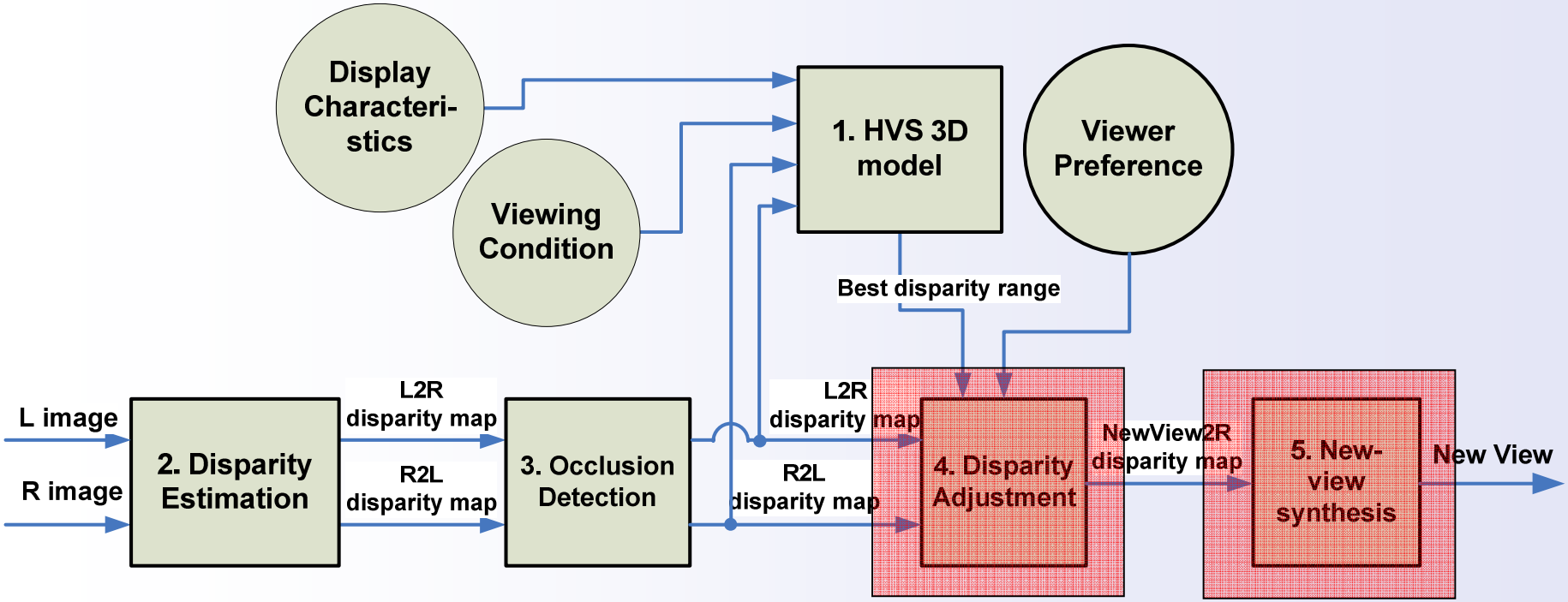
Disparity adjustment & New-view synthesis



- Disparity adjustment generates the disparity map for the new view by scaling the L2R and R2L disparity maps
- New-view synthesis fetches the proper pixels from L and R image (more details in a paper under review)
- Any holes are filled in the disparity maps

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"Monsters vs Aliens 3D": Left View

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"Monsters vs Aliens 3D": Right View

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Synthesized View without Occlusion Detection

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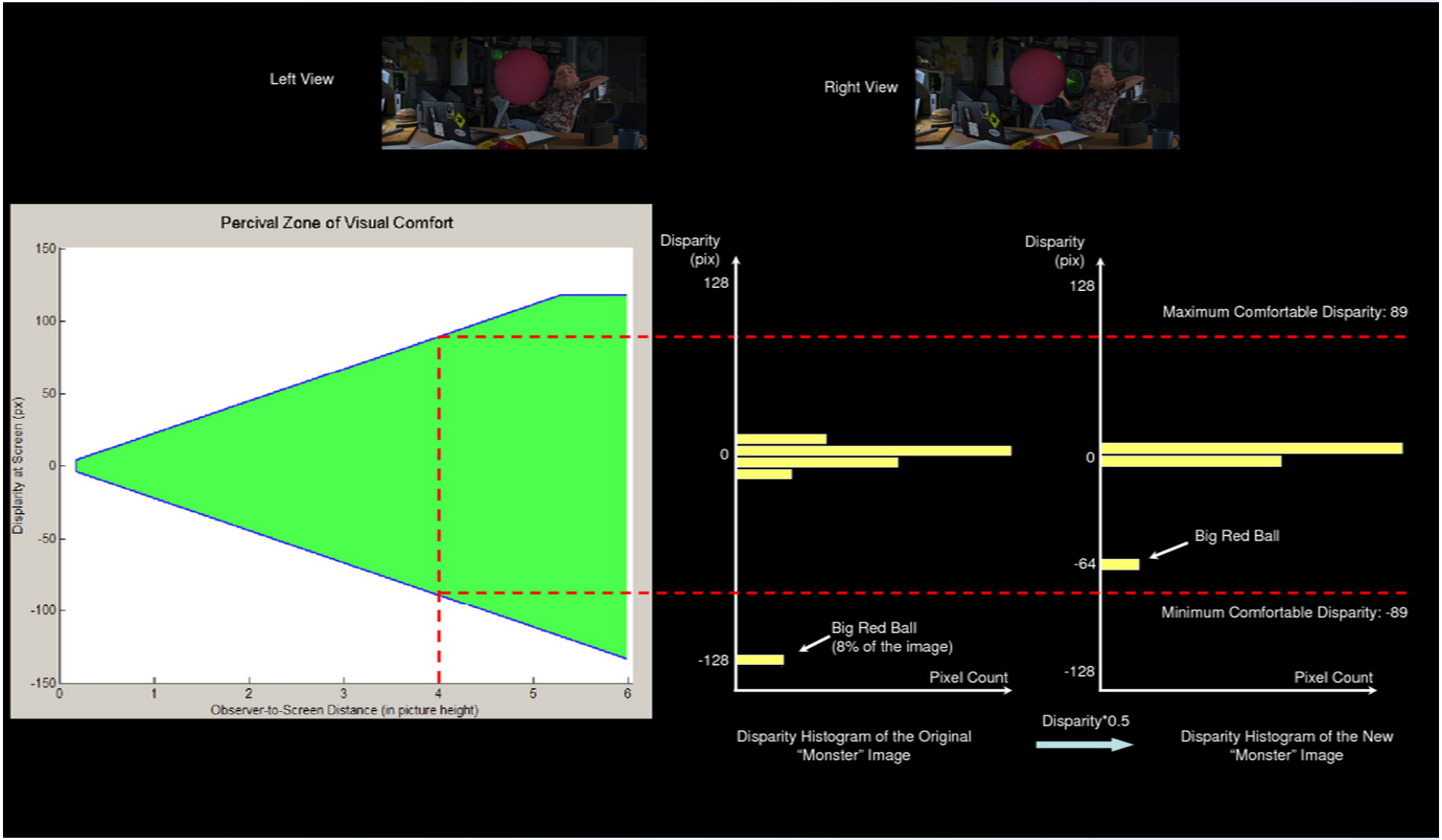
Synthesized View with Occlusion Detection

Under-the-hood Analysis of "Monster" Image



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Anaglyph 3D Images Demo

- Now view the stereo 3D images in anaglyph format
- The time-multiplex version (120Hz + active shutter glasses) of these images and more 3D images/videos will be shown in the interactive session this afternoon!
- Warning: possibly excessive disparities!

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Summary & discussions

- Described a 3D depth adjustment system
  - a HVS 3D model to guide the depth adjustment
  - a multi-resolution disparity estimation algorithm
  - a novel occlusion detection algorithm based on bidirectional disparity maps

- Discussion
  - The performance is content dependent
  - How to hide artifacts.
    - 3D is easier to hide or more difficult to hide?
    - The dominant eye effect.
  - Human factors; visual comfort model

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Q&A

- Thank you!
- We have several full-time and intern job openings. Visit our website (http://www.sharplabs.com) for more information (click on "Careers").
  - Display algorithm researcher, video coding algorithm researcher, summer interns

- Our EI/SD&A 2011 paper is shared at: http://cyuan.org/ei2011.pdf
- This presentation is shared at: http://cyuan.org/3dworkshop2011.pdf