Multidimensional image retargeting

- 9:00: Introduction
- 9:10: Dynamic range retargeting
  - Tone mapping
  - Apparent contrast and brightness enhancement
- 10:45: Break
- 11:00: Color retargeting
- 11:30: LDR to HDR
- 12:20: Temporal retargeting - Part I
- 12:45: Break
- 14:15: Temporal retargeting - Part II
- 15:00: Spatial resolution retargeting
- 16:00: Break
- 16:15: Image and video quality assessment
- **17:00: Stereo content retargeting**
- 17:45: Q&A
- 18:00: End

Stereo content retargeting

Piotr Didyk
MPI Informatik

Why stereo?

Images are no longer flat

- Improves realism
- Images are not longer flat
- Better layout separation

Reproduced view dependent effects

- Improves material perception

History of stereo

1838: different images for both eyes

1890: patent on 3D movies

1900: tripod for taking 3D pictures

1915: exhibition of 3D images

1922: 3D movie

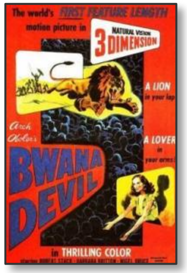
1923: 3D movie with stereo sound

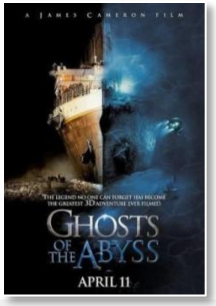
1952: 3D movie in color

90's: IMAX cinemas, TV series

2003: feature film in 3D for IMAX

2009 - now: became very popular





Number of 3D productions

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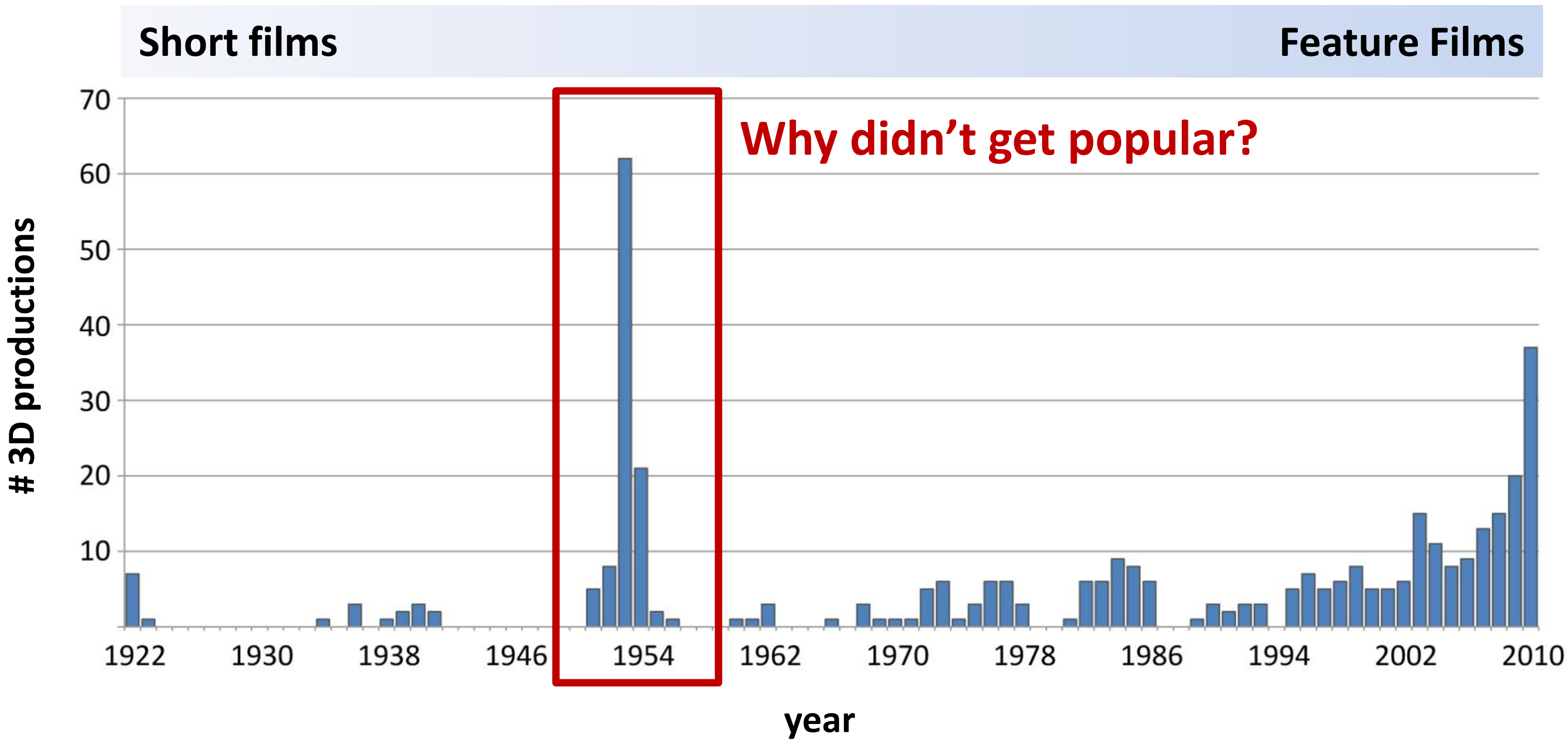

Early 3D production

- Expensive hardware
- Lack of standardized format
- Impossible at home
- Lack of interesting content

Number of 3D productions

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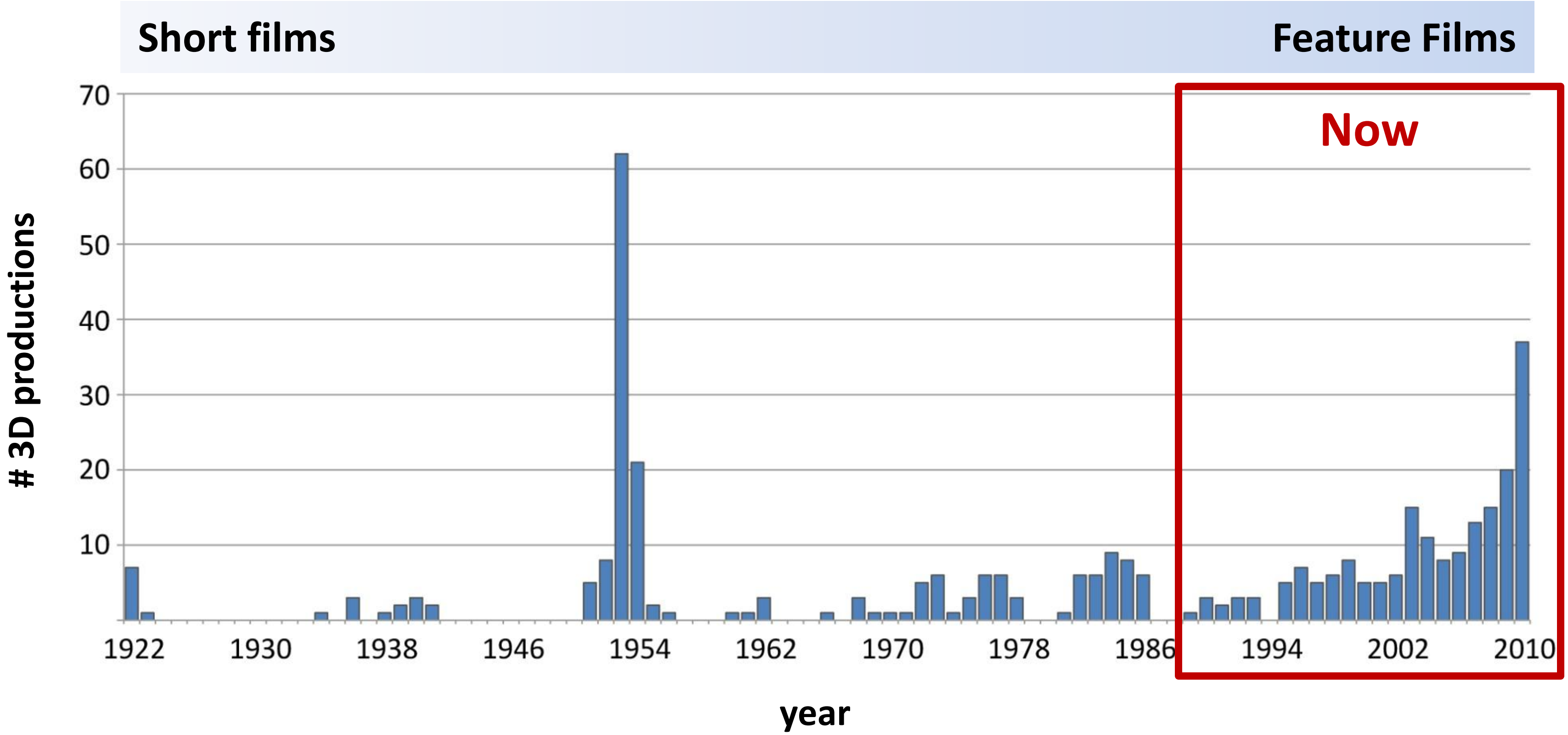


Stereo in daily life

Current 3D production

Great content:

- Beautiful shots with complex depth
- Computer generated special effects

3D is coming to our homes:

- Equipment is getting less expensive
- 3D games / TV

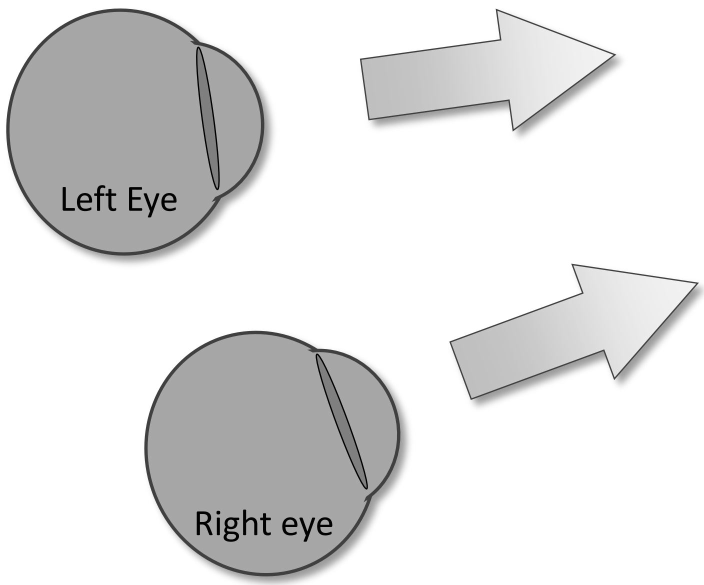
New better 3D equipment:

- Shutter glasses
- Polarized glasses
- Autostereoscopic displays are getting better

They are flat!

Stereo on a flat display

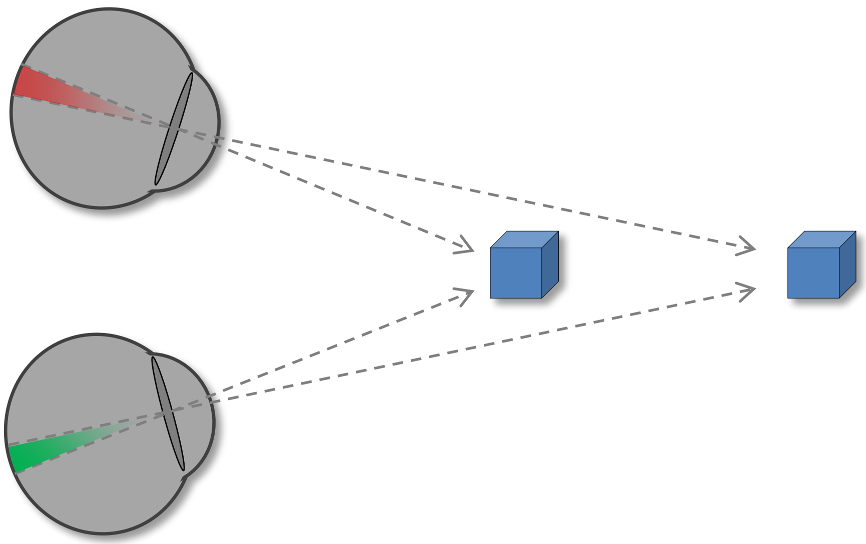
- **Different image for each eye**



Depth perception

We see depth due to depth cues.

Stereoscopic depth cues:
binocular disparity

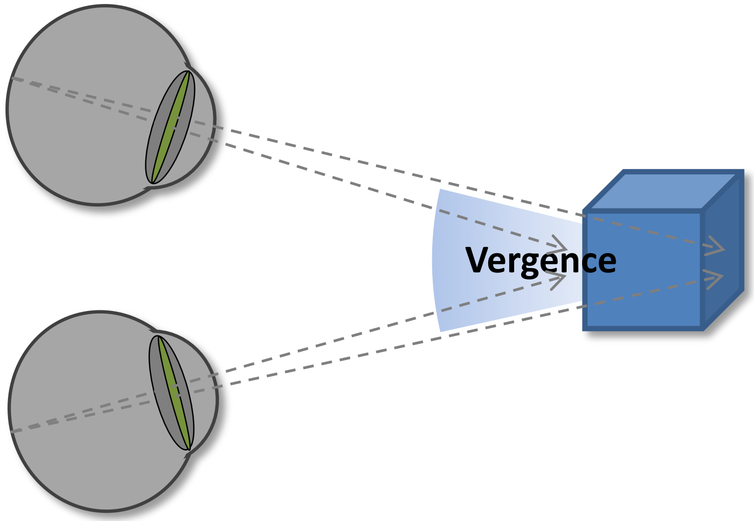


Depth perception

We see depth due to depth cues.

Stereoscopic depth cues:
binocular disparity

Ocular depth cues:
accommodation, vergence



Depth perception

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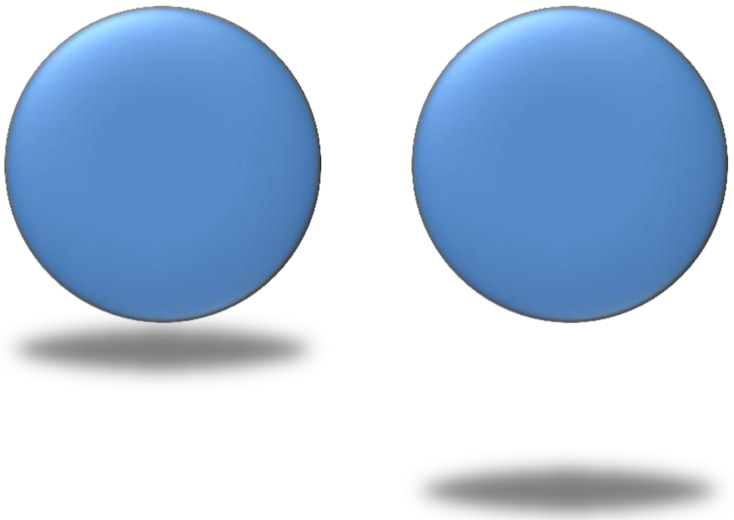
We see depth due to depth cues.

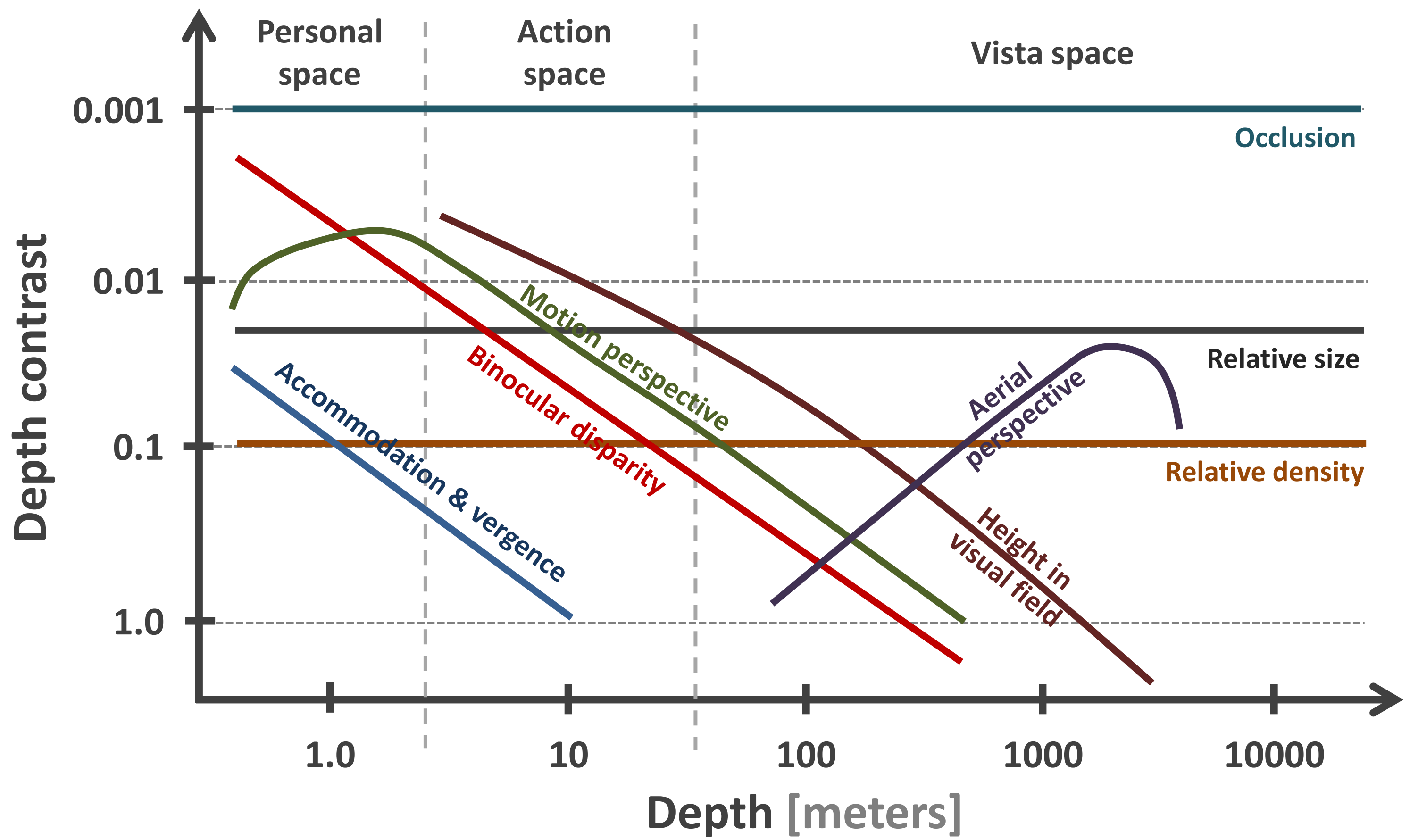
Stereoscopic depth cues:
binocular disparity

Ocular depth cues:
accommodation, vergence

Pictorial depth cues:
occlusion, size, shadows…



Cues sensitivity



"Perceiving layout and knowing distances: The integration, relative potency, and contextual use of different information about depth" by Cutting and Vishton [1995]

Depth perception

We see depth due to depth cues.

Stereoscopic depth cues:
binocular disparity

Ocular depth cues:
accommodation, vergence

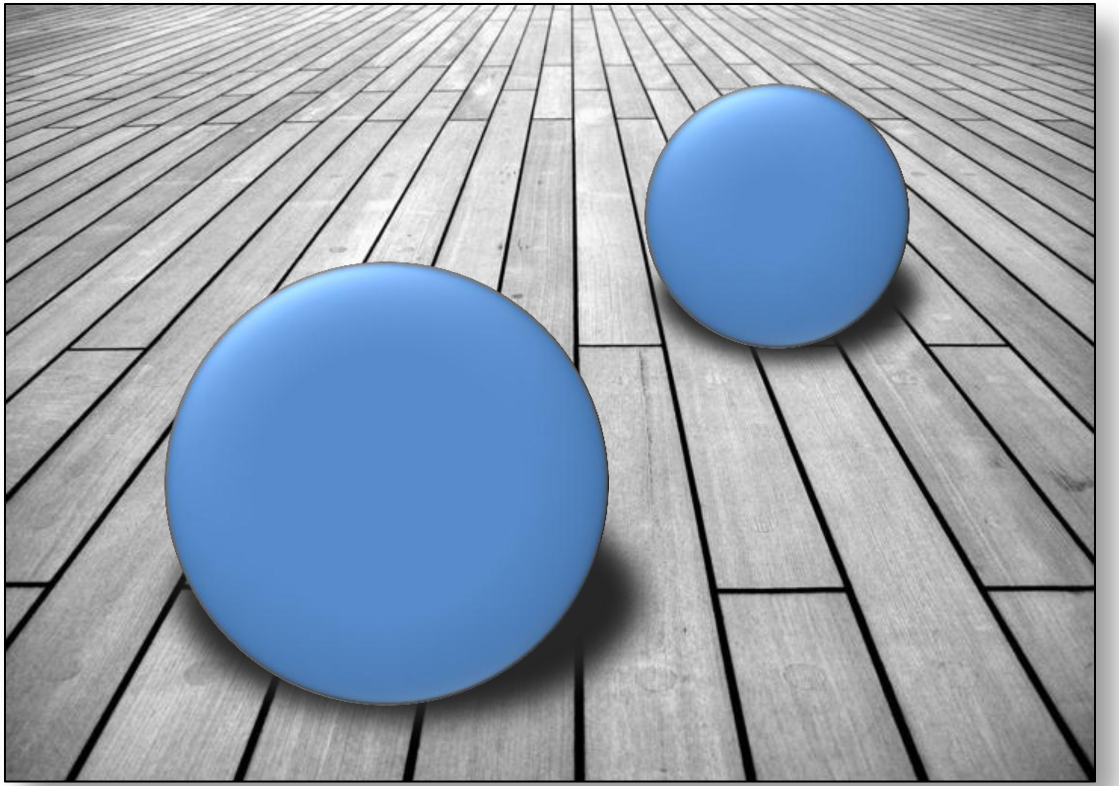
Pictorial depth cues:
occlusion, size, shadows…

Challenge:
Consistency is required!

Simple conflict example

Present cues:

- Size
- Shadows
- Perspective
- **Occlusion**



Disparity & occlusion conflict

Objects in front

Disparity & occlusion conflict

Disparity & occlusion conflict

Depth perception

We see depth due to depth cues.

Stereoscopic depth cues:
binocular disparity

Ocular depth cues:
accommodation, vergence

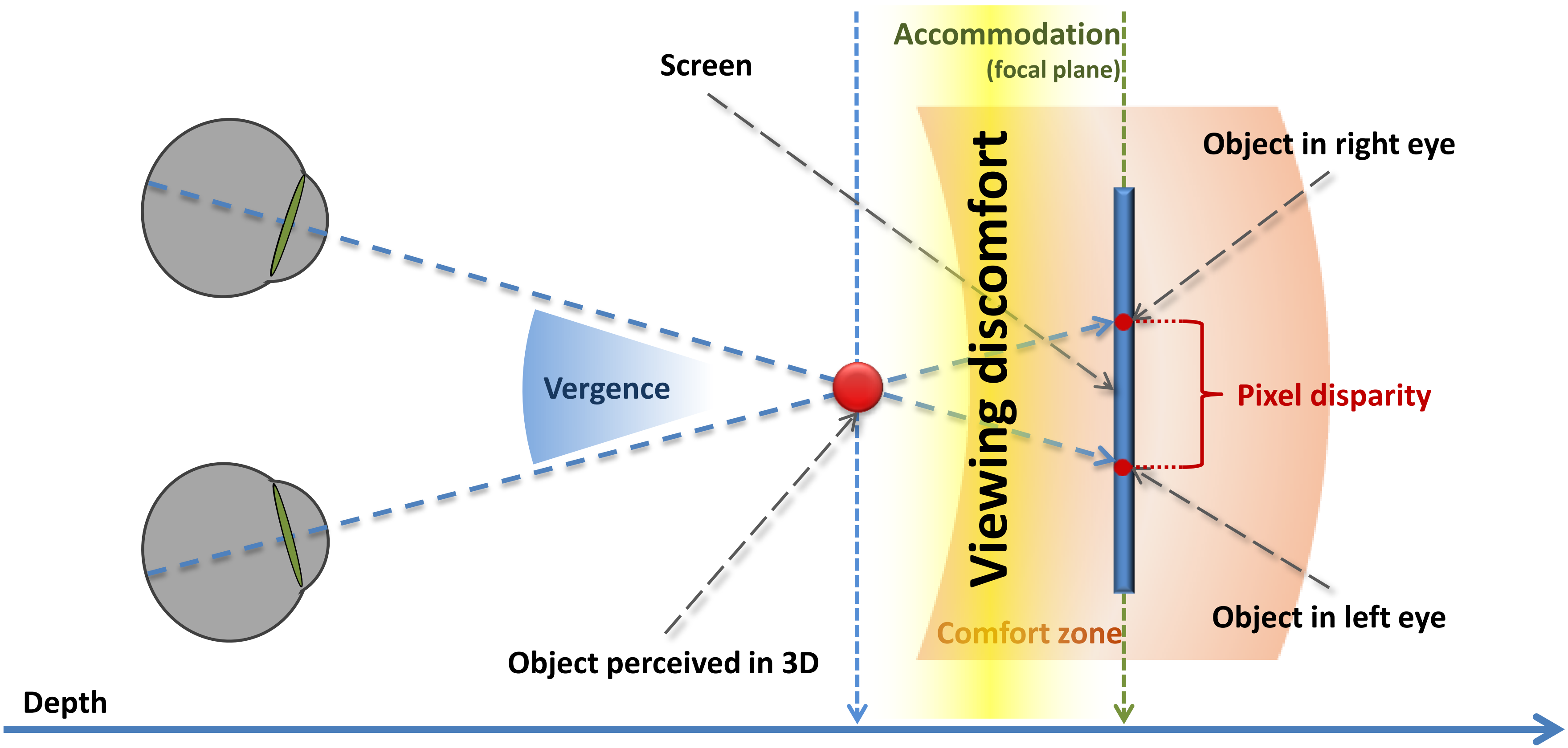
→ **Require 3D space**

We cheat our Human Visual System!

Pictorial depth cues:
occlusion, size, shadows…

→ **Reproducible on a flat displays**

Cheating our HVS



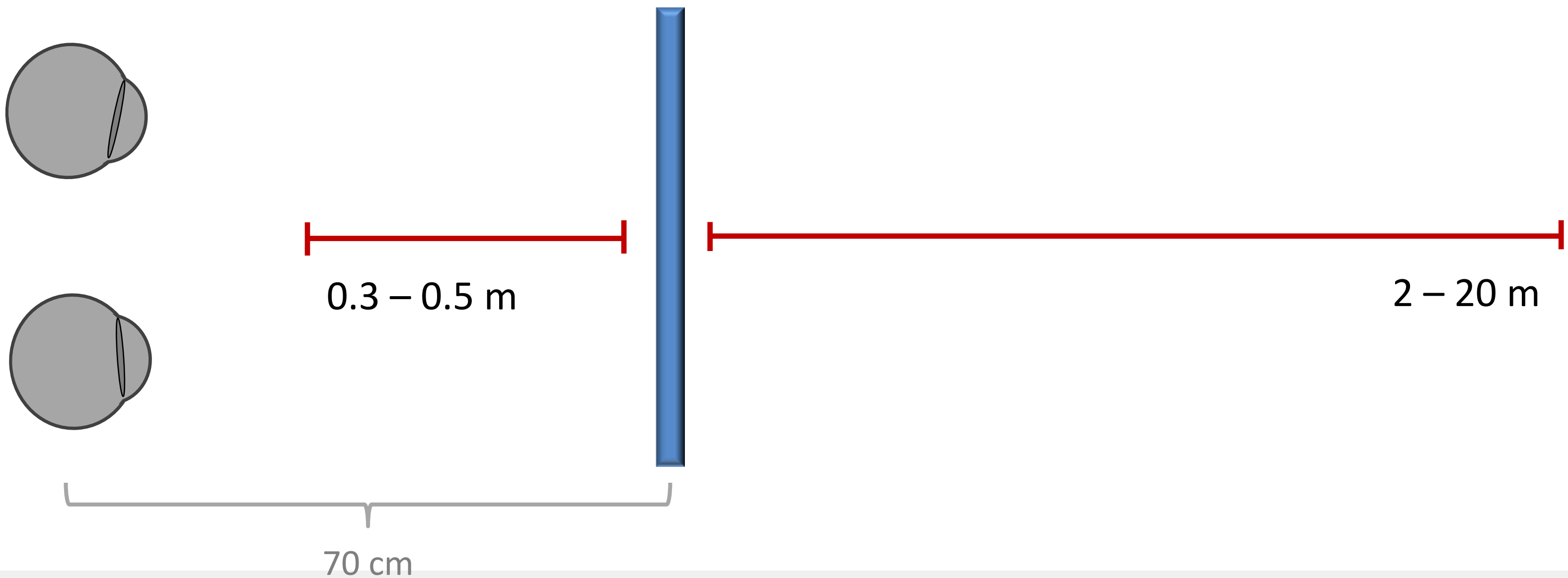
Viewing discomfort

Comfort zones

Comfort zone size depends on:

- Presented content
- Viewing condition

Simple scene



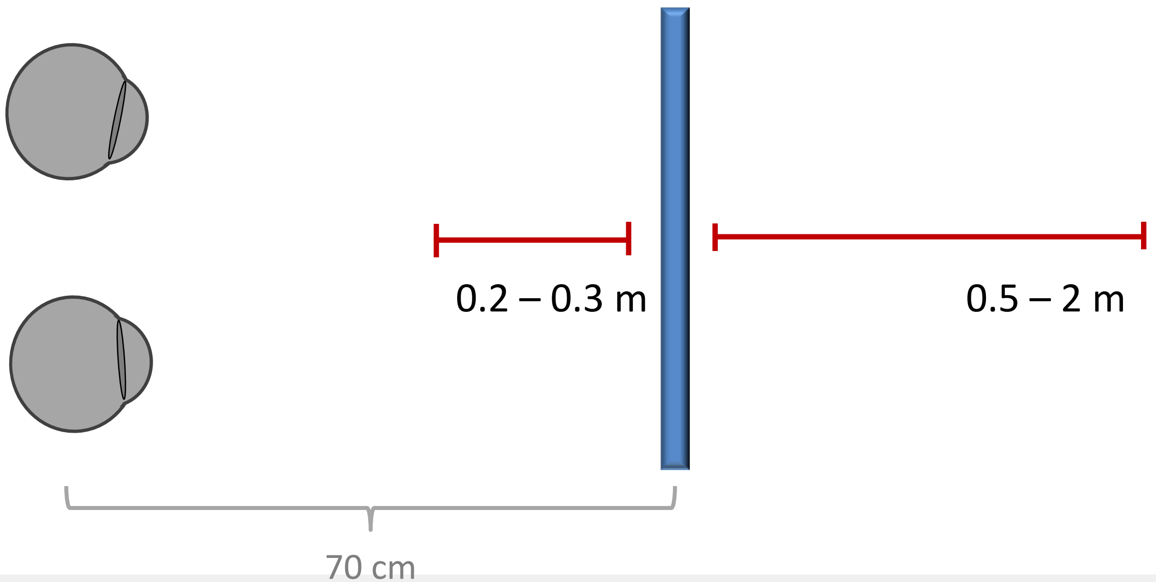
"Controlling Perceived Depth in Stereoscopic Images" by Jones et al. 2001

Comfort zones

Comfort zone size depends on:

- Presented content
- Viewing condition

Simple scene, user allowed to look away from screen



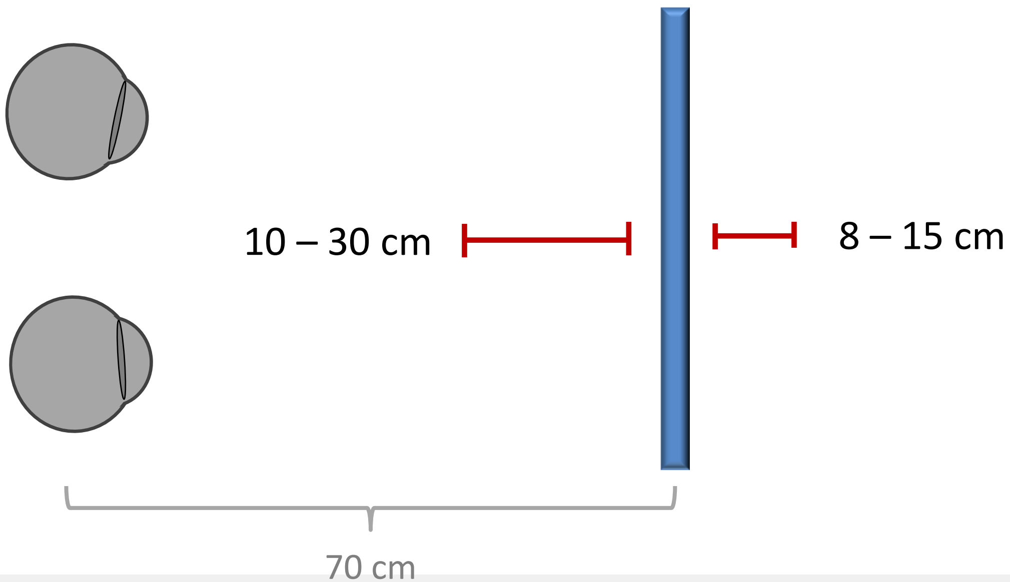
"Controlling Perceived Depth in Stereoscopic Images" by Jones et al. 2001

Comfort zones

Comfort zone size depends on:

- Presented content
- Viewing condition

Difficult scene



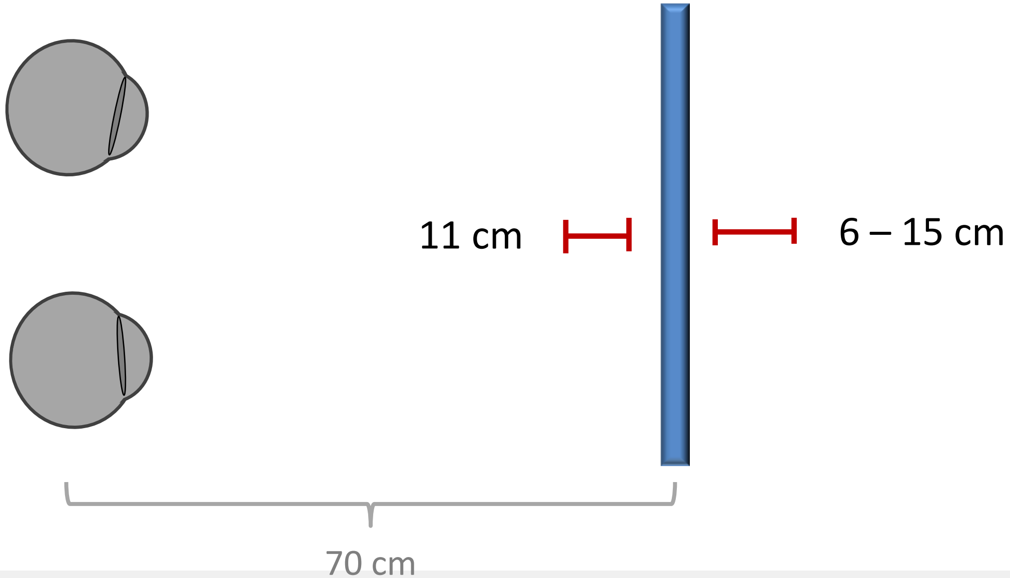
"Controlling Perceived Depth in Stereoscopic Images" by Jones et al. 2001

Comfort zones

Comfort zone size depends on:

- Presented content
- Viewing condition

Difficult scene, user allowed to look away from screen



"Controlling Perceived Depth in Stereoscopic Images" by Jones et al. 2001

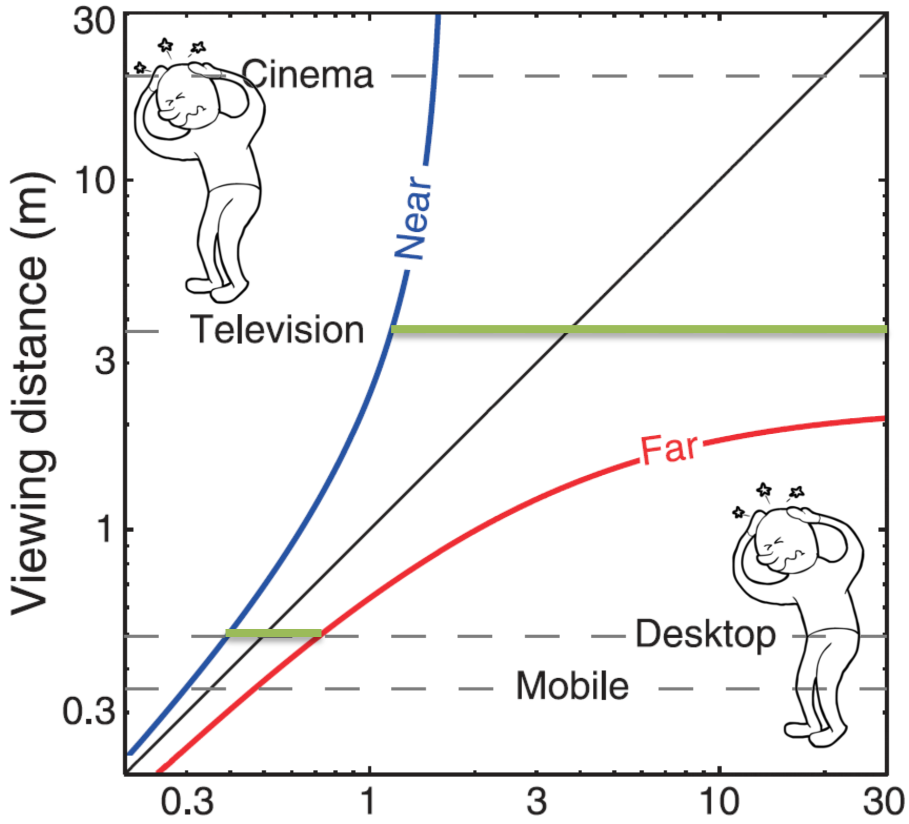
Comfort zones

Comfort zone size depends on:

- Presented content
- Viewing condition
- Screen distance

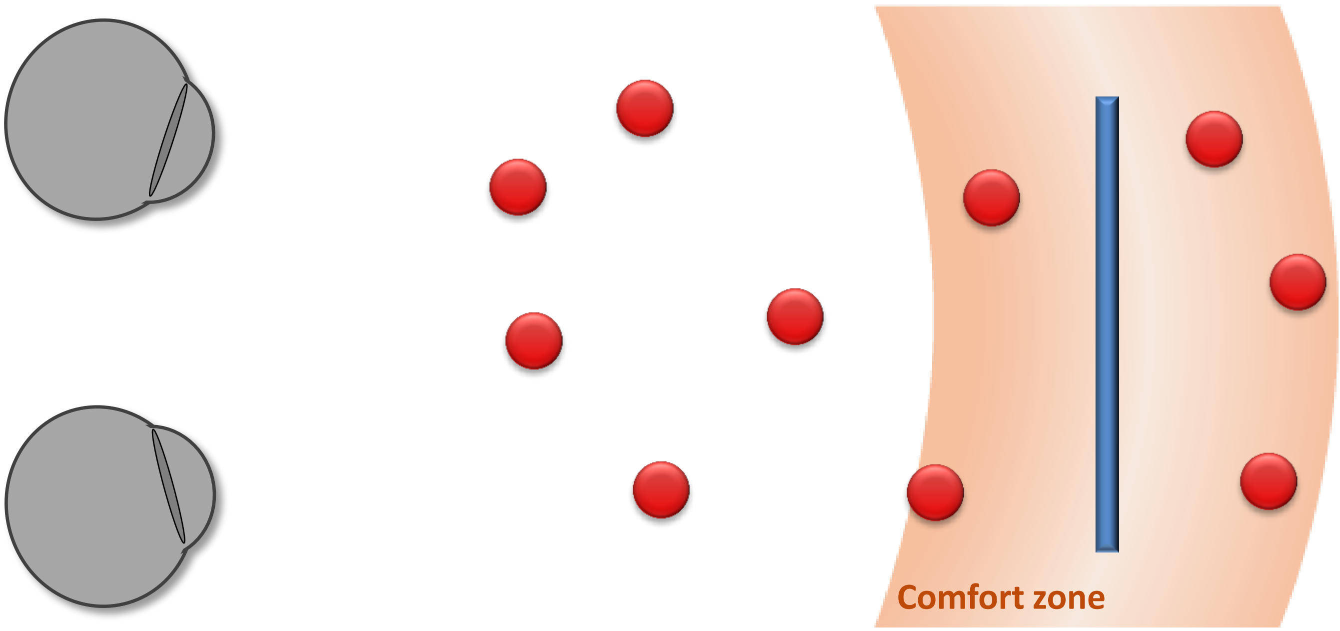
Other factors:

- Distance between eyes
- Depth of field
- Temporal coherence



"The zone of comfort: Predicting visual discomfort with stereo displays" by Shibata et al. 2011

Depth manipulation



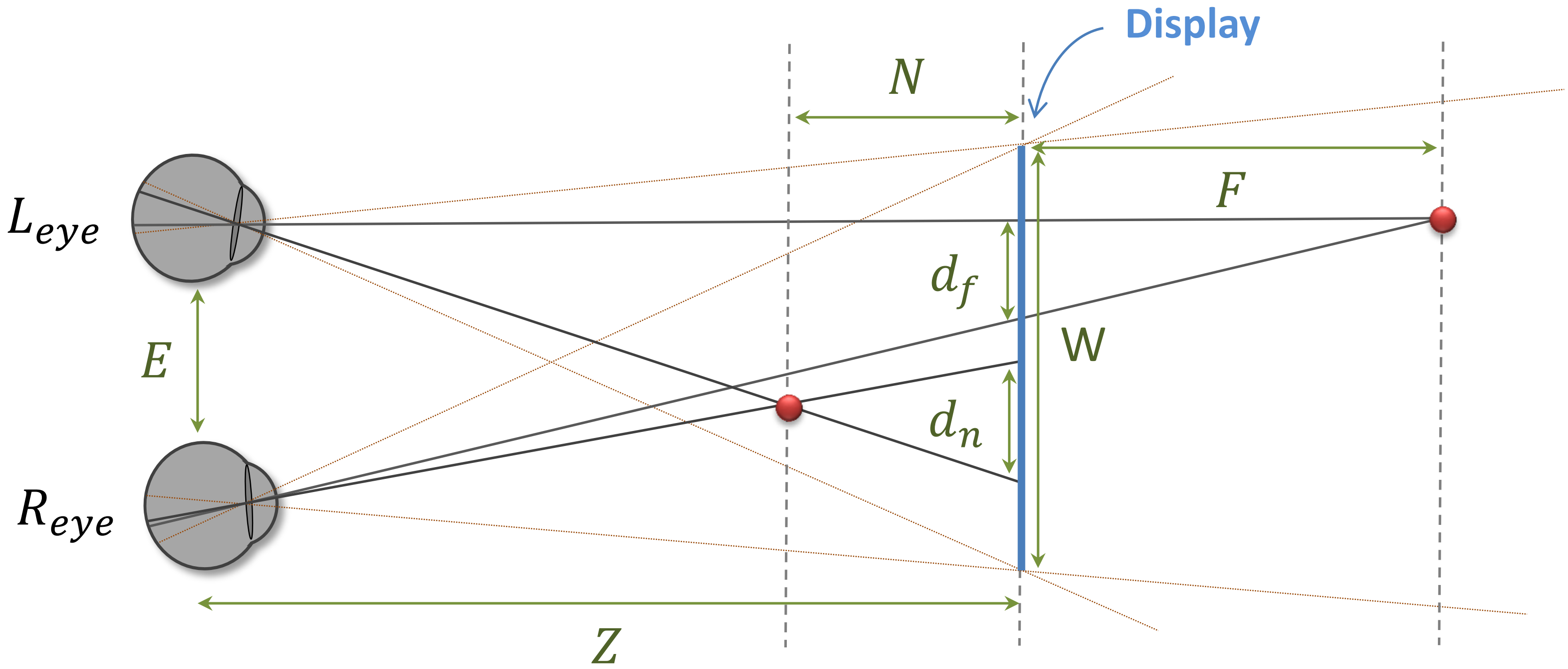
Viewing discomfort

Scene manipulation →

Viewing comfort

Camera manipulations

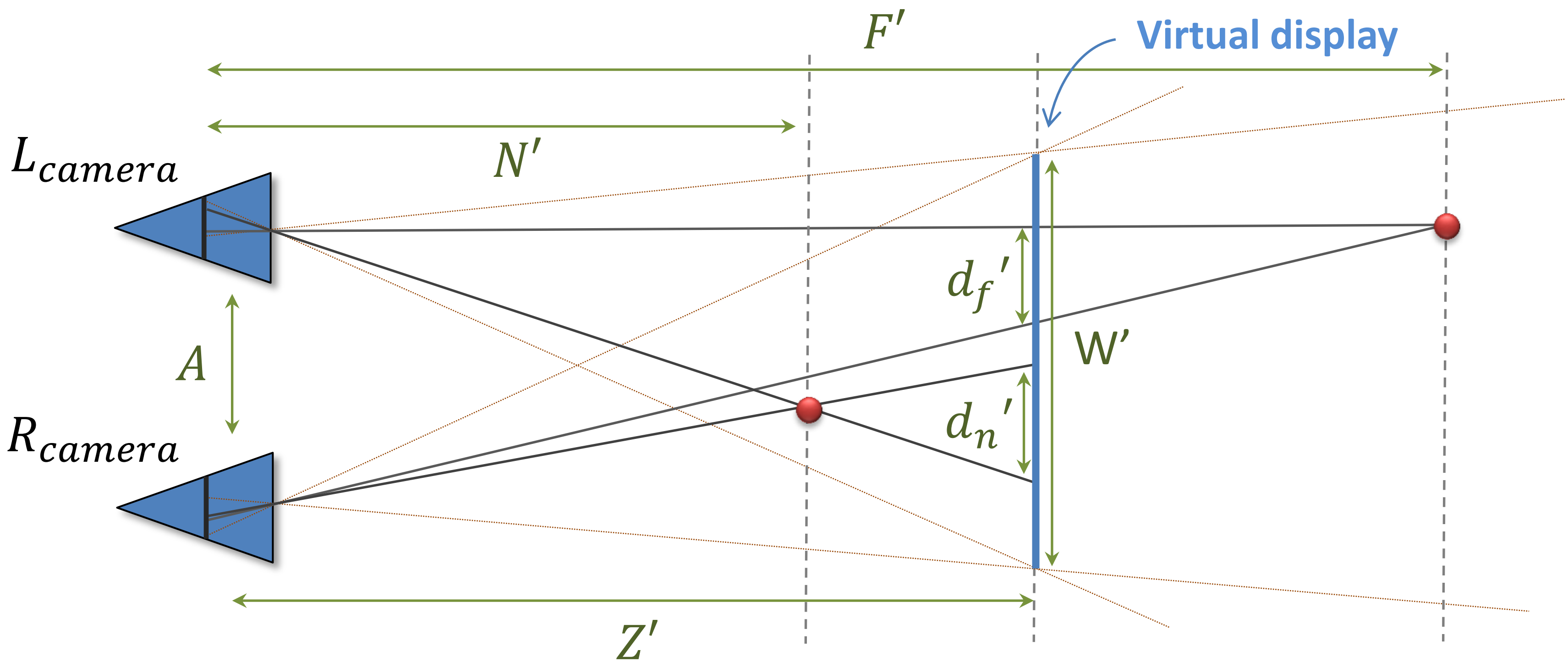
Viewer/Display space



"Controlling Perceived Depth in Stereoscopic Images" by Jones et al. 2001

Camera manipulations

Camera/Scene space



"Controlling Perceived Depth in Stereoscopic Images" by Jones et al. 2001

Camera manipulations

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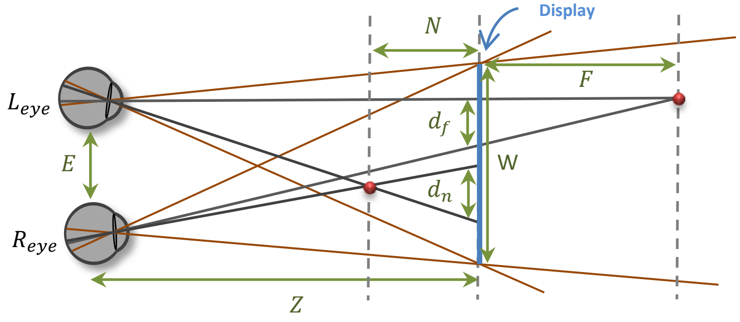
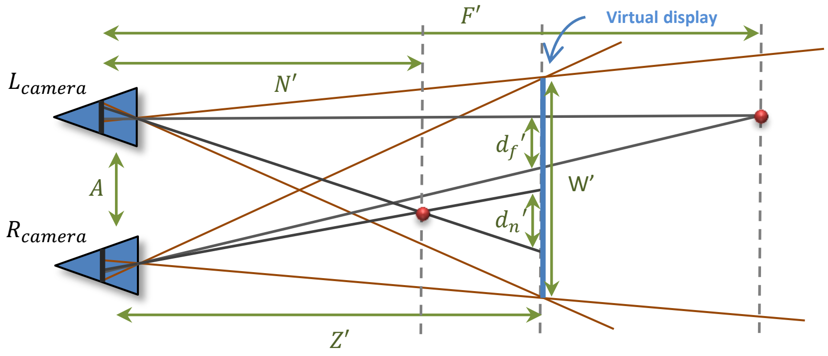
Camera/Scene space





- The parameters can be the same
  - may cause discomfort

$$(Z, W, E, d_f, d_n) = (Z', W', A, d_f', d_n')$$

- Different parameters for capturing the scene

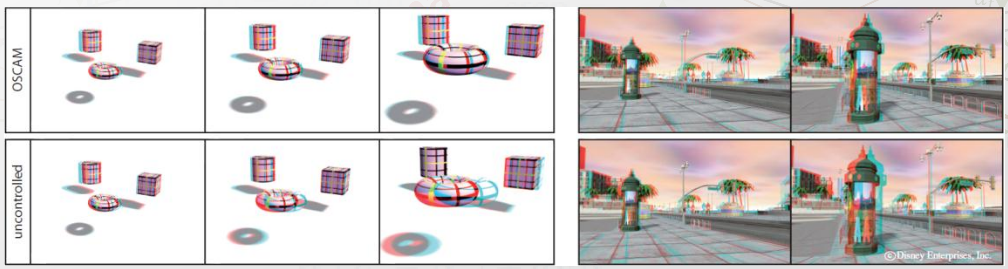
$$(Z, W, E, d_f, d_n) \neq (Z', W', A, d_f', d_n')$$

"Controlling Perceived Depth in Stereoscopic Images" by Jones et al. 2001

Camera manipulations

$$l = -\left(\frac{W'}{2} - \frac{A}{2}\right) \quad r = \frac{W'}{2} + \frac{A}{2} \quad \theta' = 2\arctan\left(\frac{W' + A}{2Z'}\right)$$

Game controller:



"OSCAM - Optimized Stereoscopic Camera Control for Interactive 3D" by Oscam et al. 2011

- Define the disparity limits
- Calculate appropriate camera parameters
- Adjustment in each frame

"Controlling Perceived Depth in Stereoscopic Images" by Jones et al. 2001

"Evaluating methods for controlling depth perception in stereoscopic cinematography" by Sun et al. 2009

Camera manipulations

General procedure:

1. Define viewing condition
2. Adjust cameras parameters
3. Capturing

Displaying on different device:

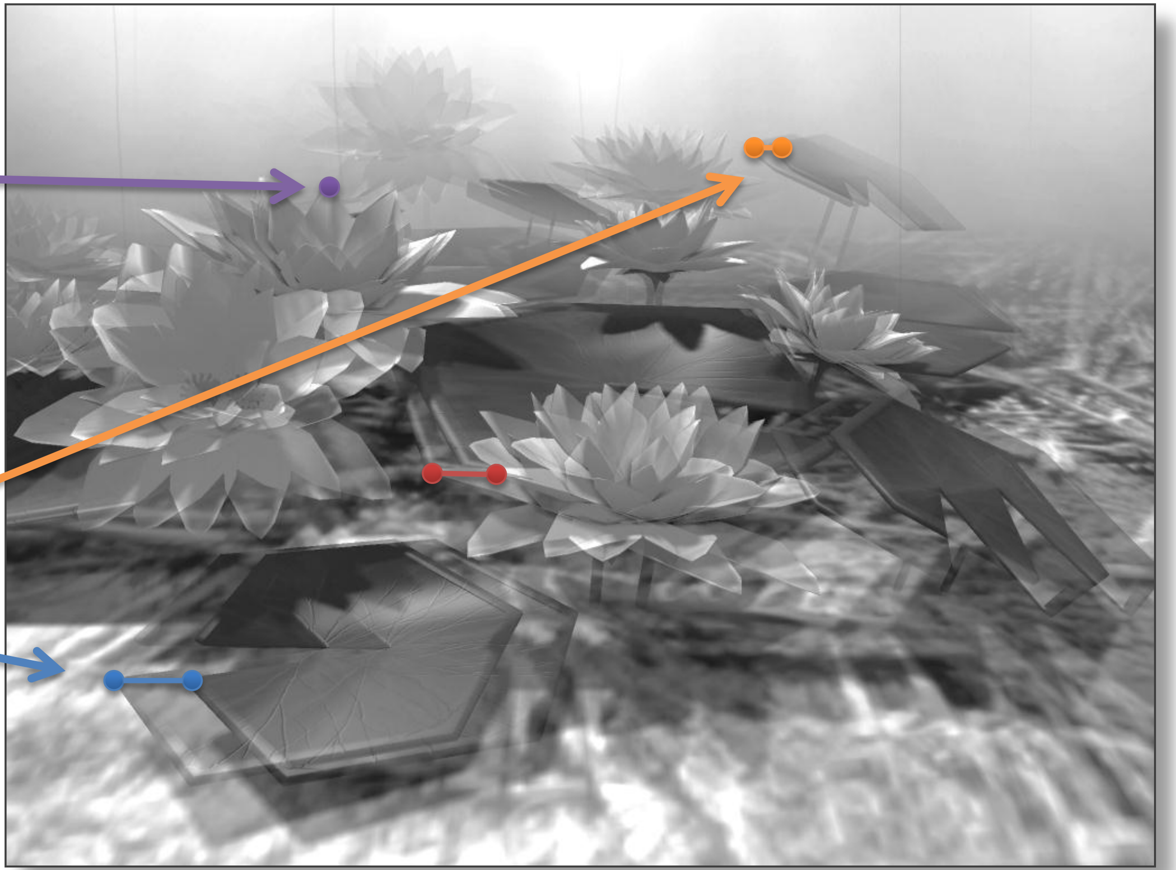
(captured content)

- Potential discomfort
- Recapturing ?

Pixel disparity

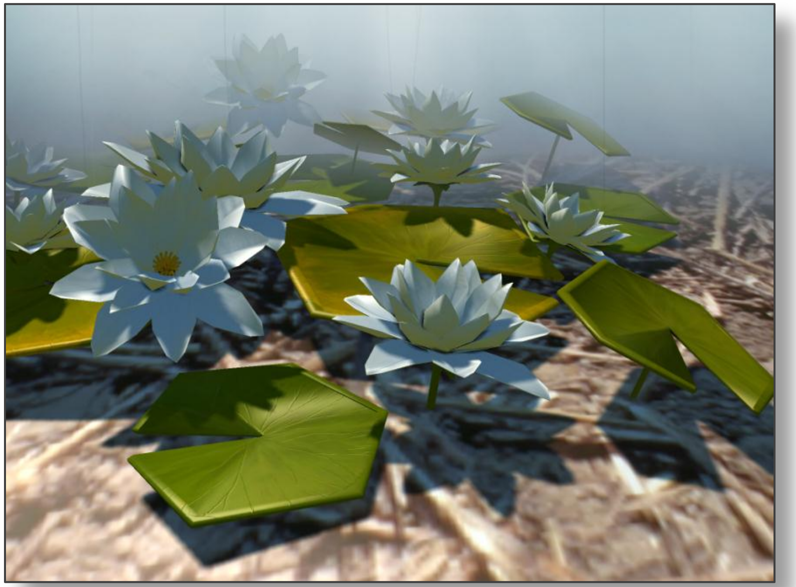
Zero disparity
on the screen plane

Bigger disparities
in front and behind screen



Left + right view

Stereo content

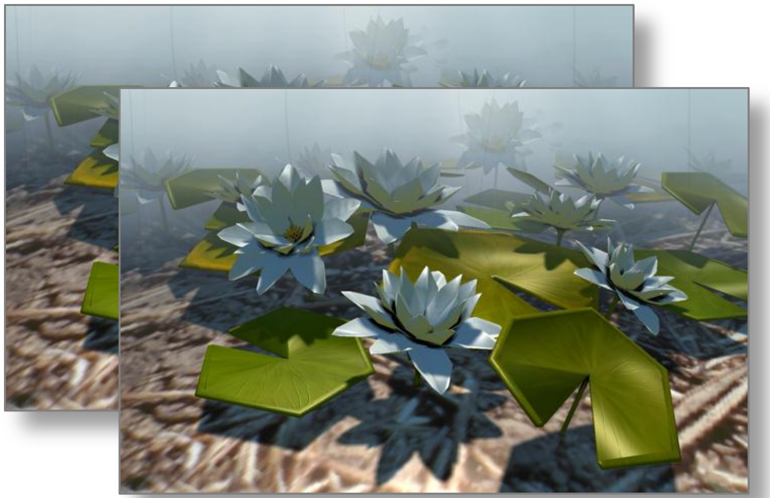


Left view

Right view

Can we have pixel disparity / depth ?

Sources of pixel disparity



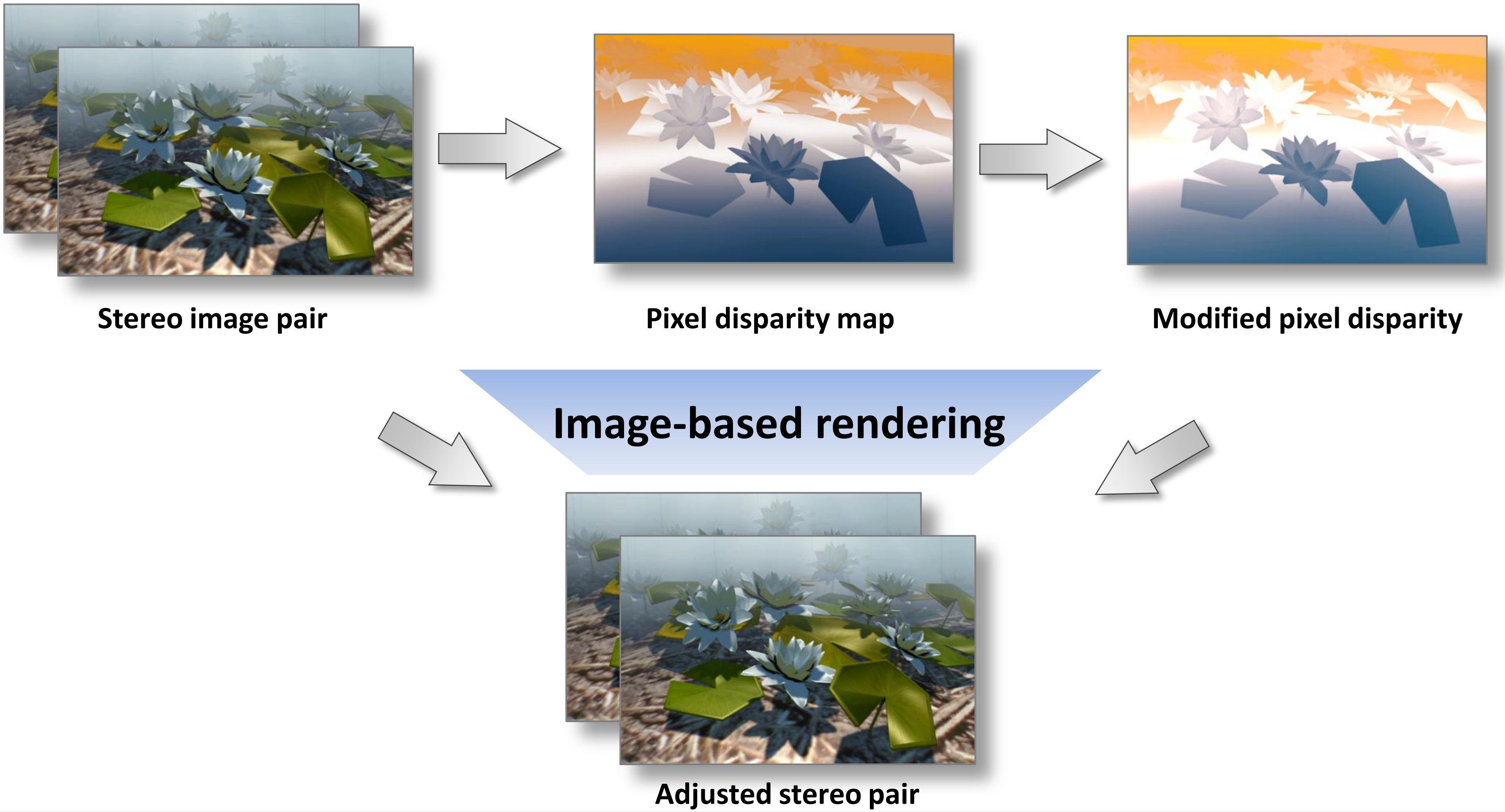
Stereo image pair

Pixel disparity map

Rendering → Usually available

Only image pair → Computer vision technique

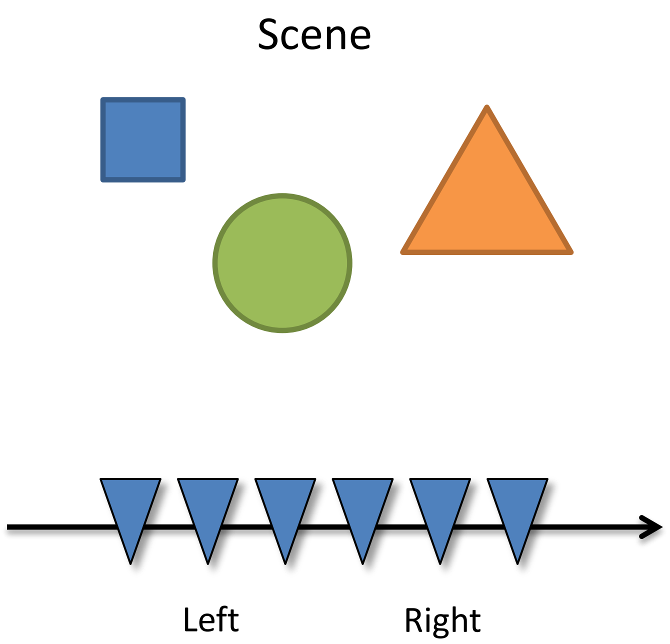
Disparity manipulations



"Adaptive Image-based Stereo View Synthesis" by Didyk et al. 2010
"Nonlinear Disparity Mapping for Stereoscopic 3D" by Lang et al. 2010

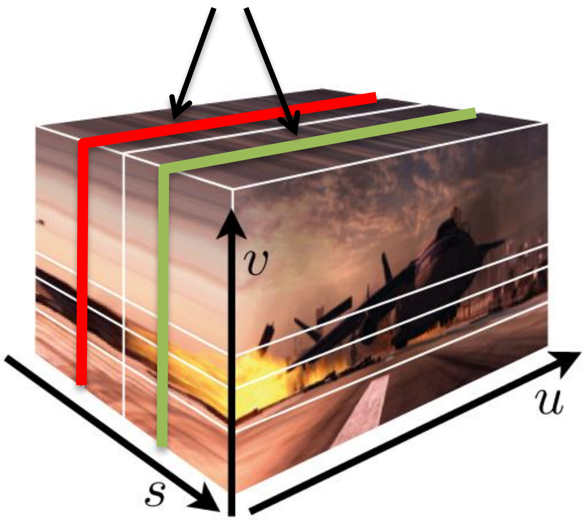
Stereoscopy from Light Fields

Light Field



"Multi-Perspective Stereoscopy from Light Fields" by Kim et al. 2011

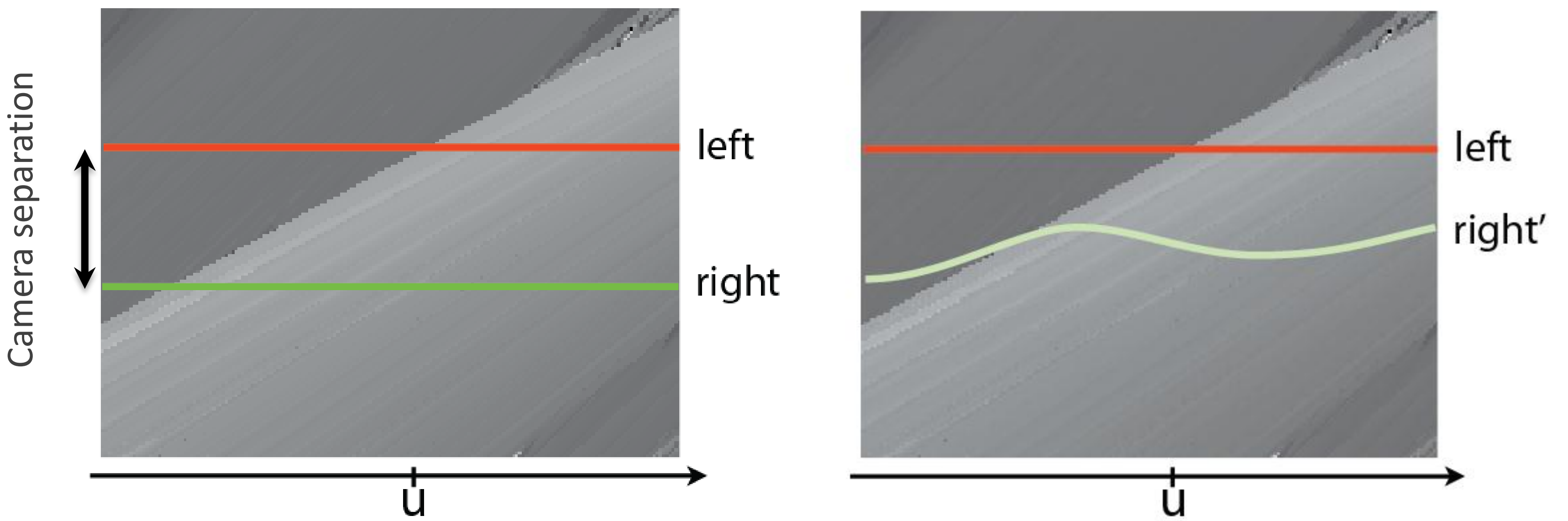
Stereoscopy from Light Fields



Light Field

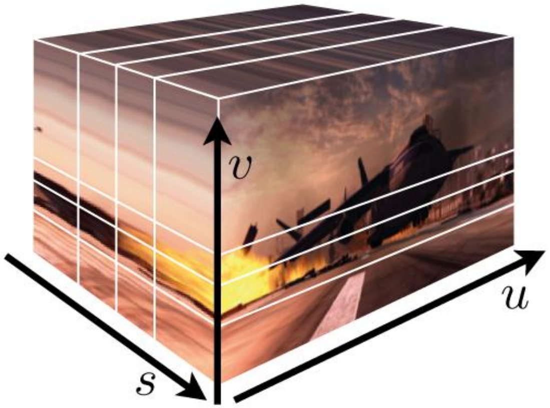
"Multi-Perspective Stereoscopy from Light Fields" by Kim et al. 2011

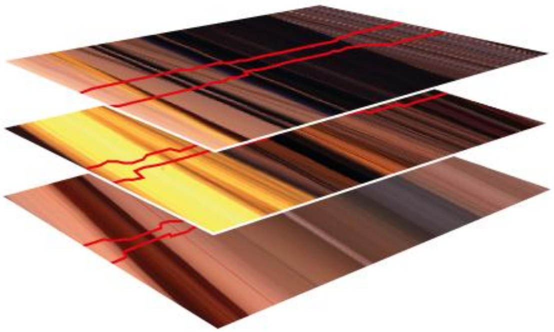
Stereoscopy from Light Fields



"*Multi-Perspective Stereoscopy from Light Fields*" by Kim et al. 2011

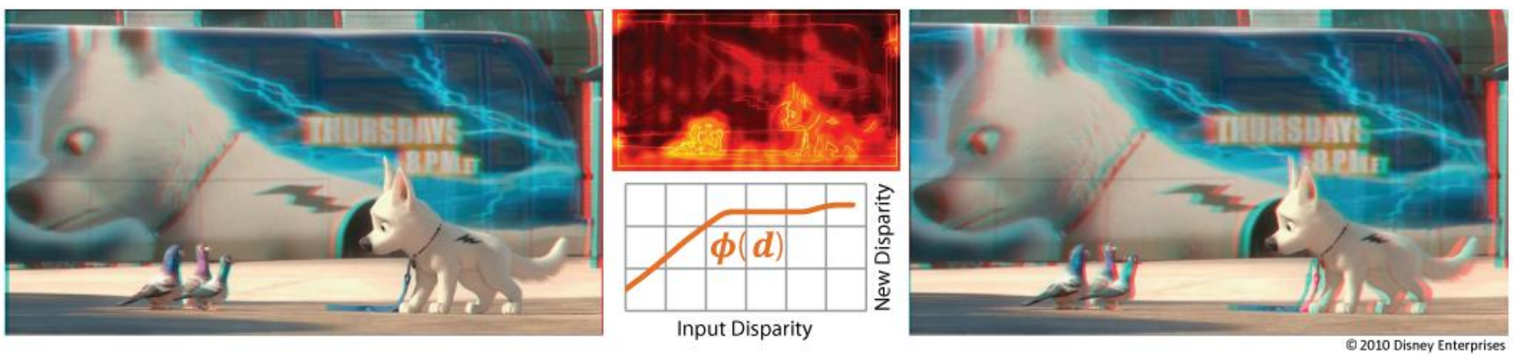
Stereoscopy from Light Fields





“Multi-Perspective Stereoscopy from Light Fields” by Kim et al. 2011

Disparity manipulations

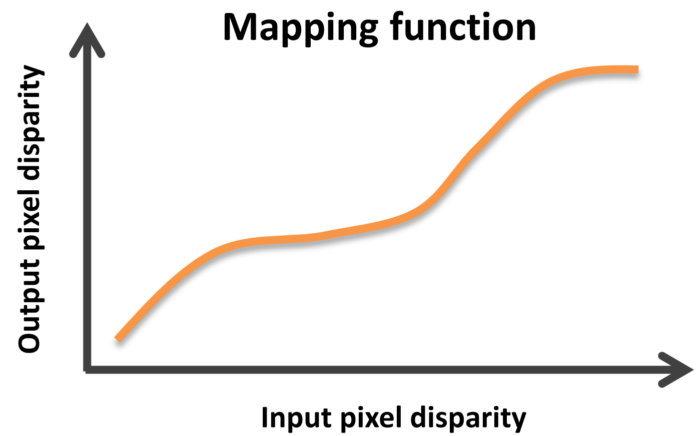


“Nonlinear Disparity Mapping for Stereoscopic 3D” by Lang et al. 2010

Disparity manipulations

Pixel disparity map

Modified pixel disparity



Function:

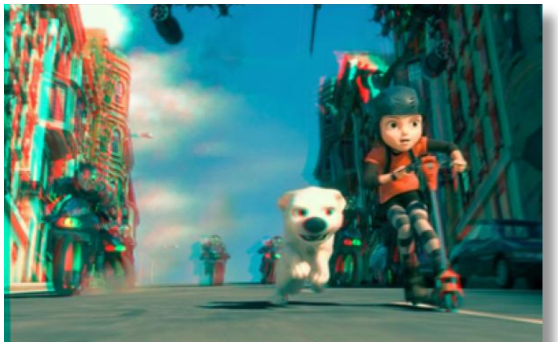
- Liner
- Logarithmic
- Content dependent

Other possibilities:

- Gradient domain
- Local operators

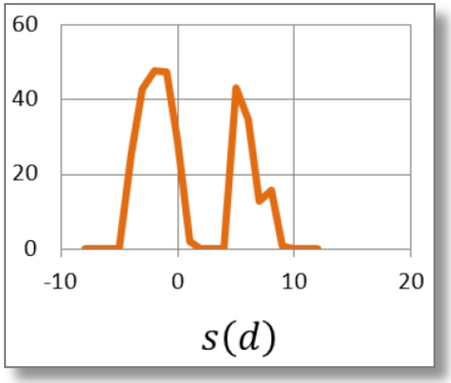
"Nonlinear Disparity Mapping for Stereoscopic 3D" by Lang et al. 2010

Saliency map

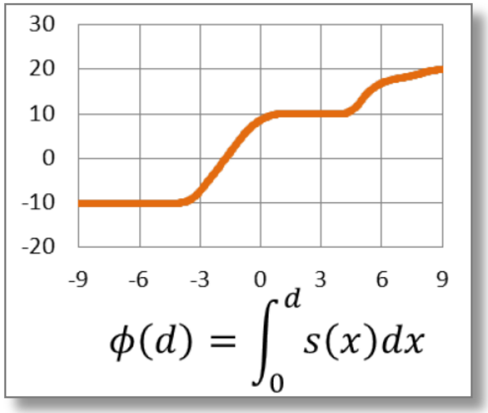


Input stereo image

Saliency map



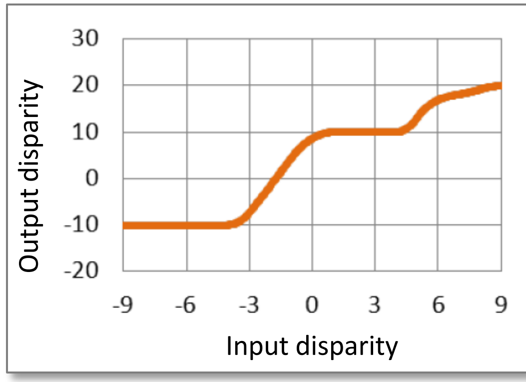
Disparity importance

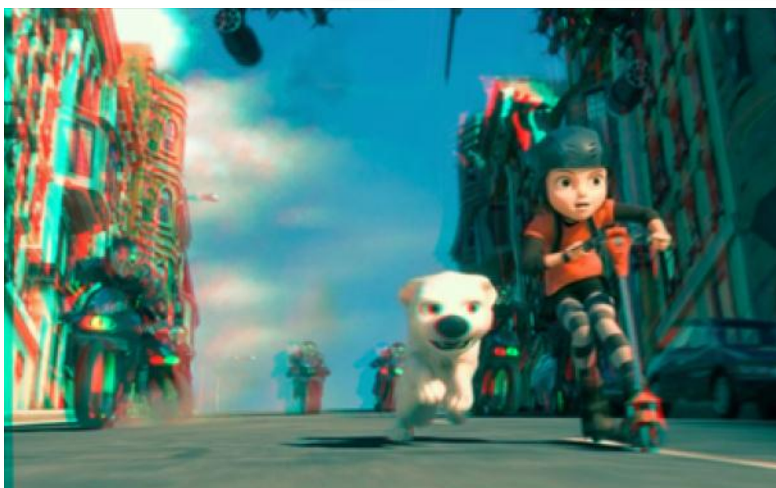


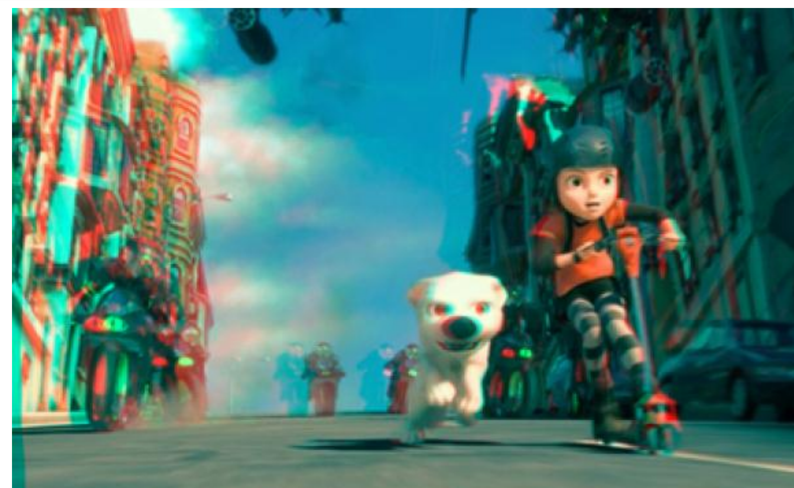
Disparity mapping function

"Nonlinear Disparity Mapping for Stereoscopic 3D" by Lang et al. 2010

Saliency map

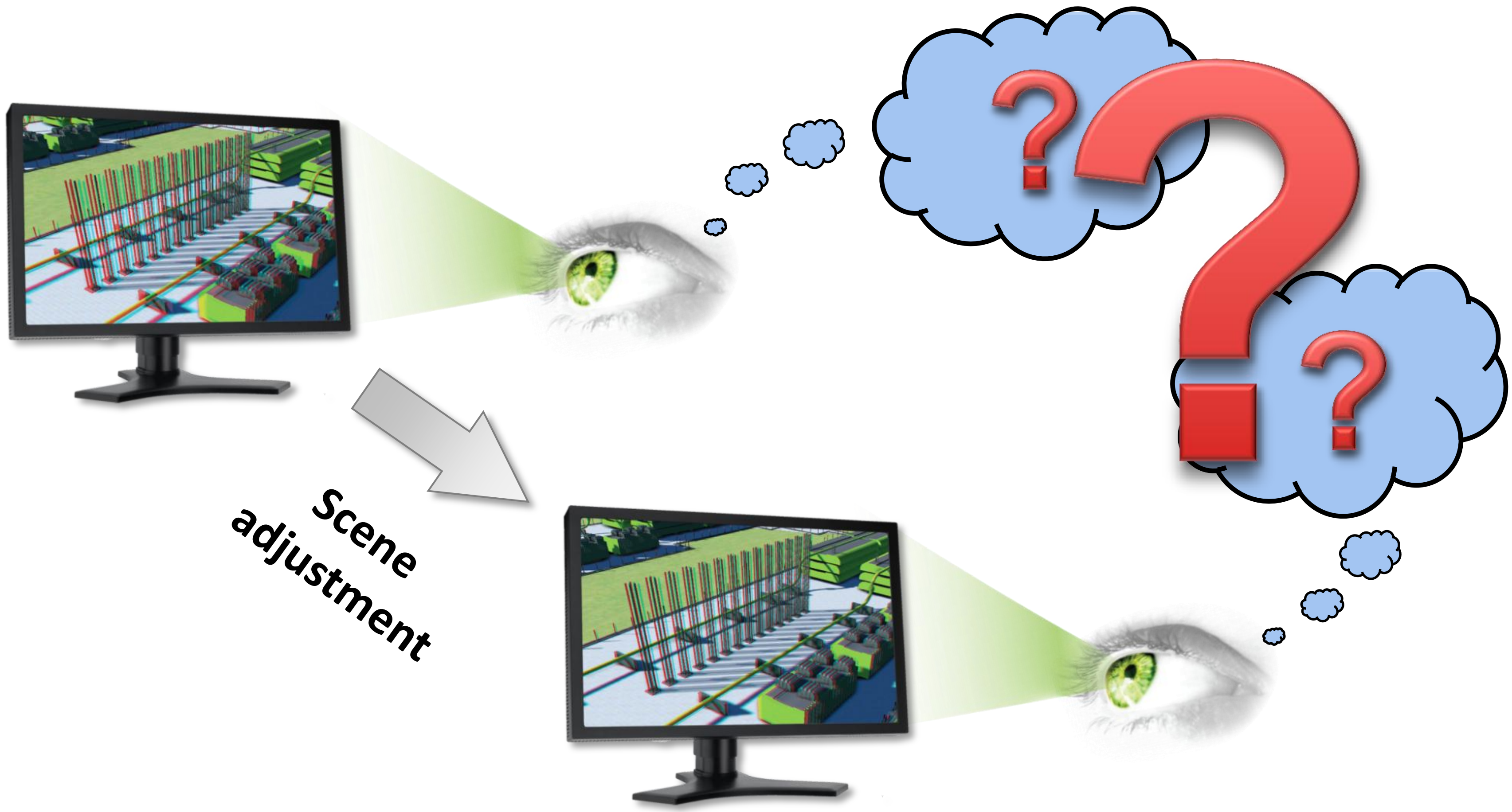




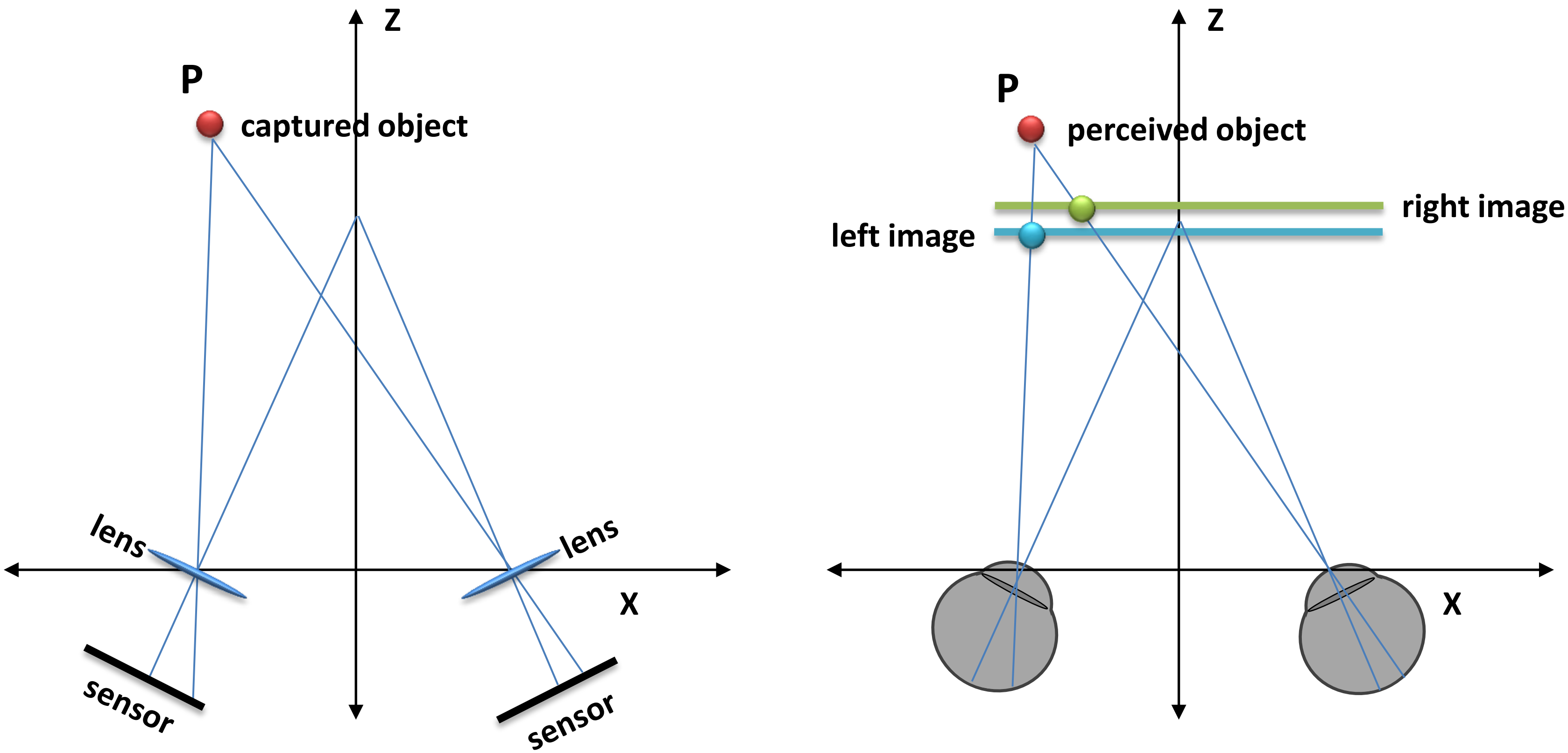


"Nonlinear Disparity Mapping for Stereoscopic 3D" by Lang et al. 2010

Scene manipulation



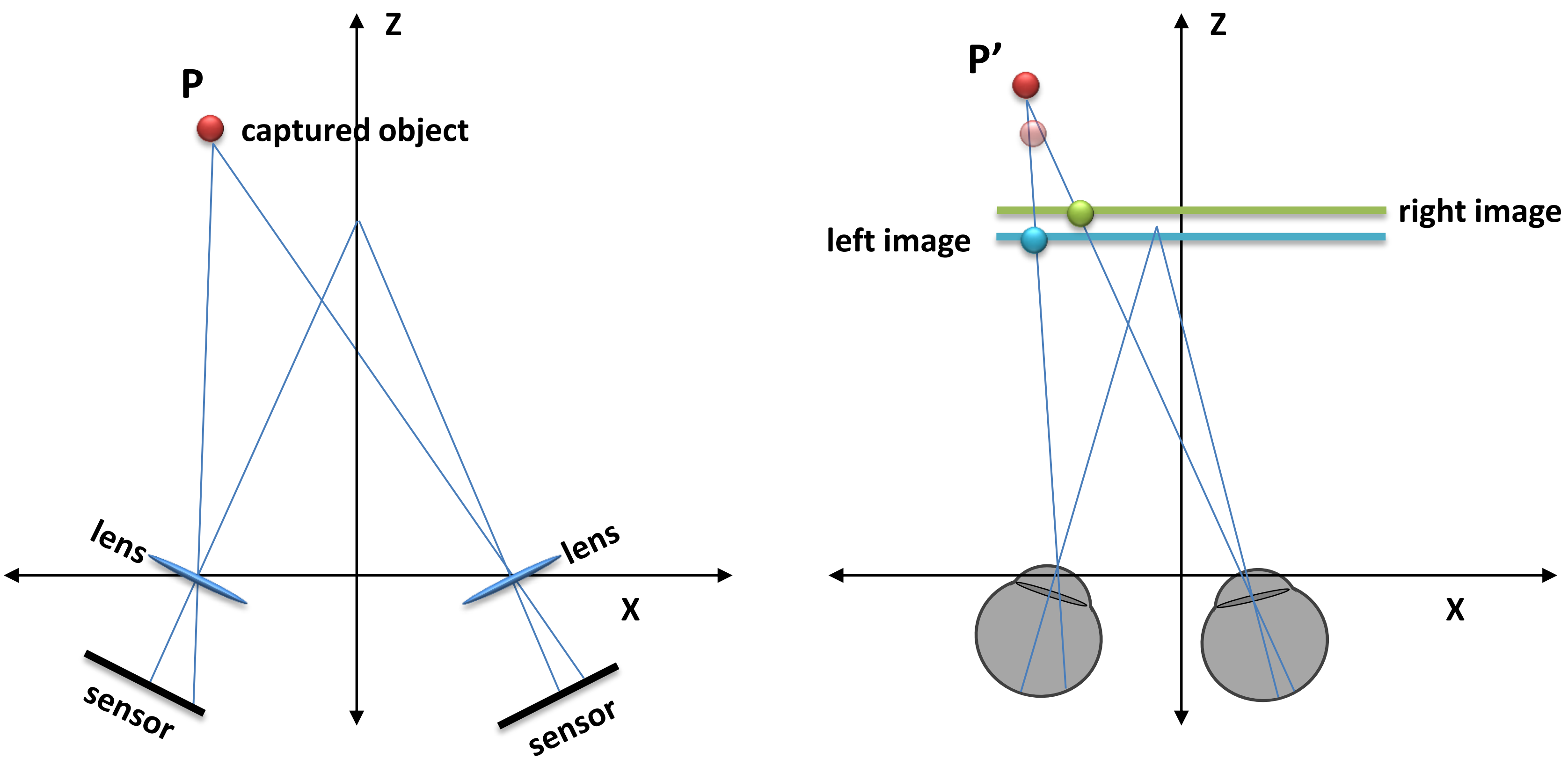
Misperception



Parameters are the same

"Image Distortions in Stereoscopic Video Systems" by Woods et al. 1993

Misperception



Eyes position and interoccular distance changed

“Image Distortions in Stereoscopic Video Systems” by Woods et al. 1993

Misperception

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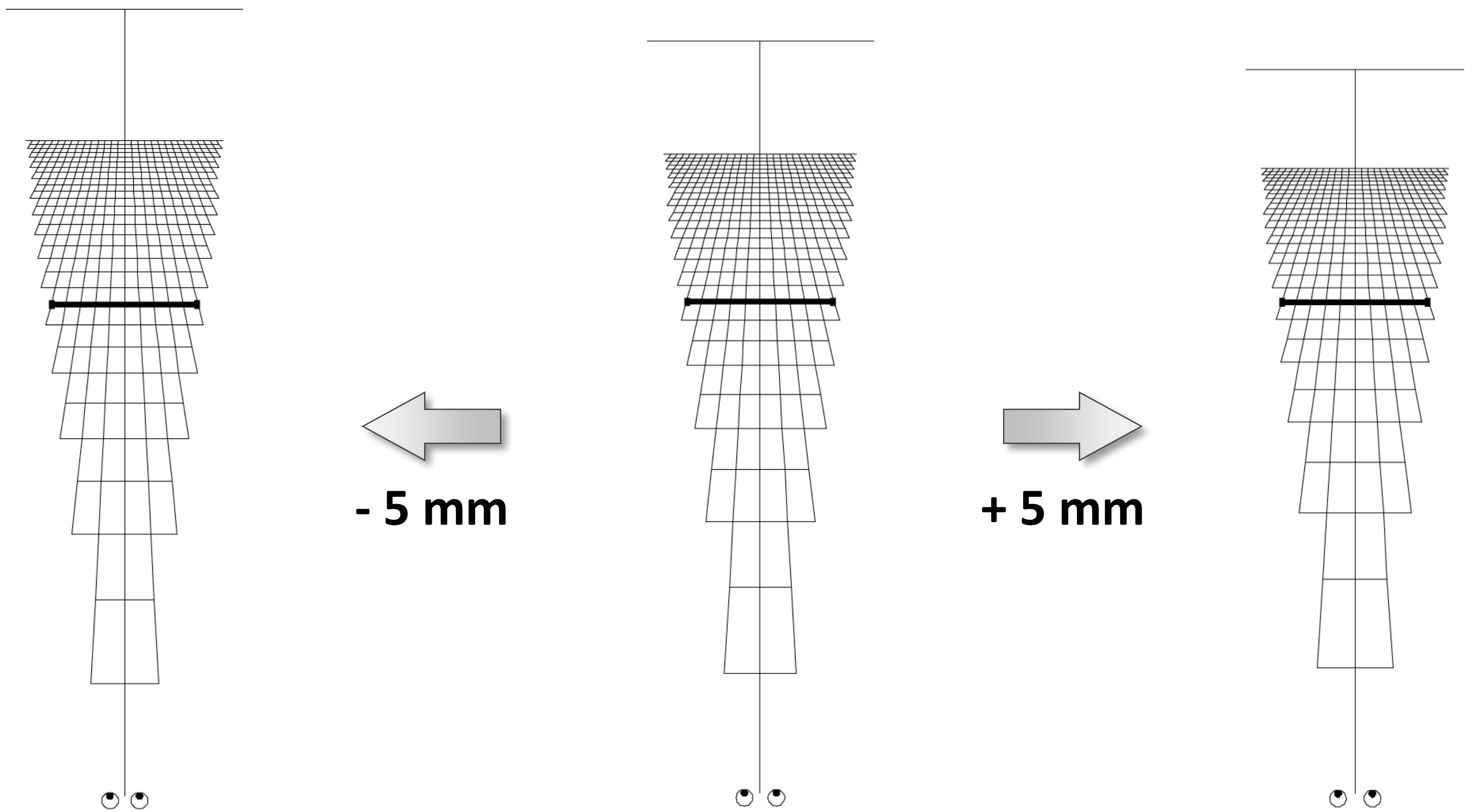
Eye separation = 65 mm



"Image Distortions in Stereoscopic Video Systems" by Woods et al. 1993

Misperception

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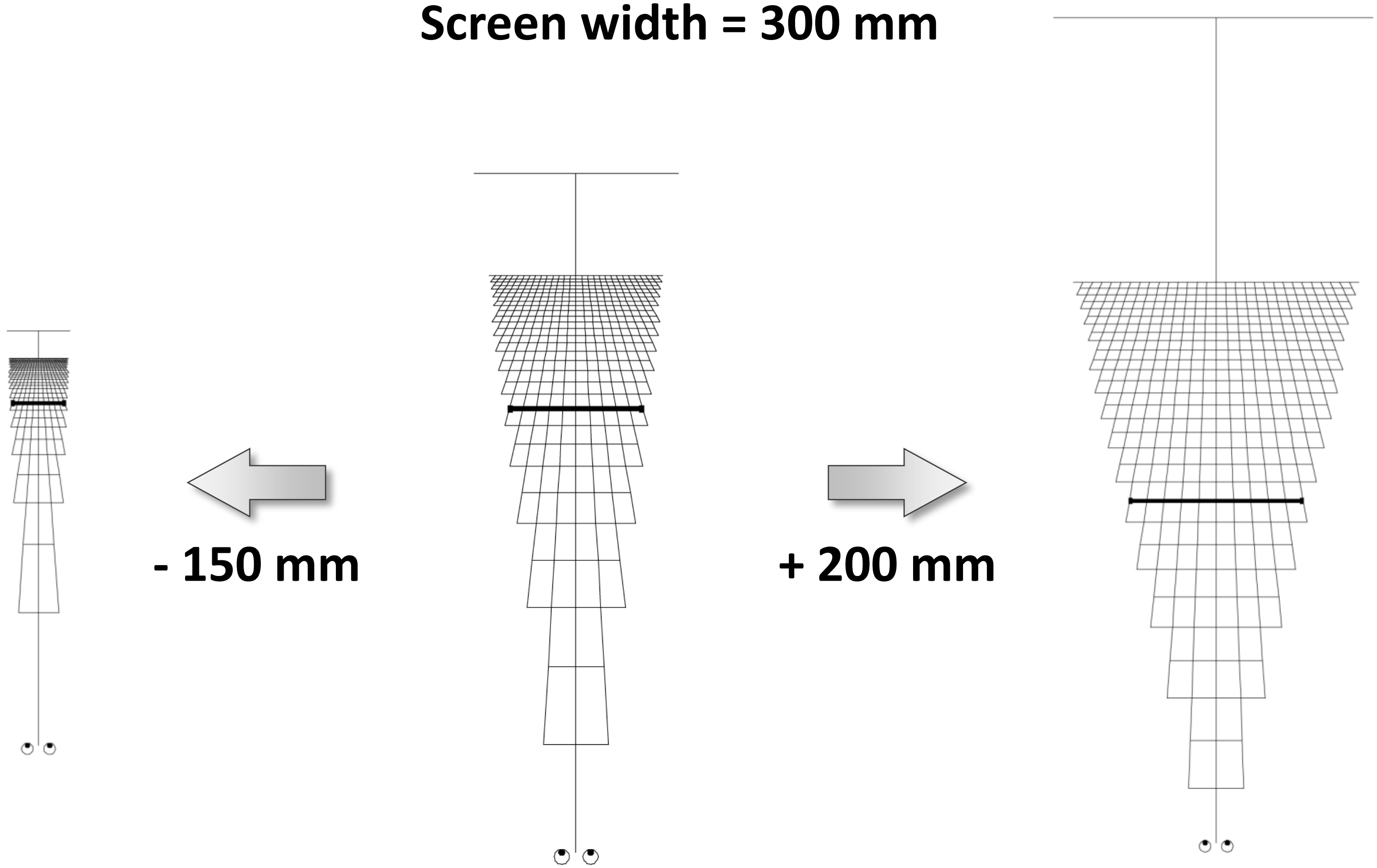
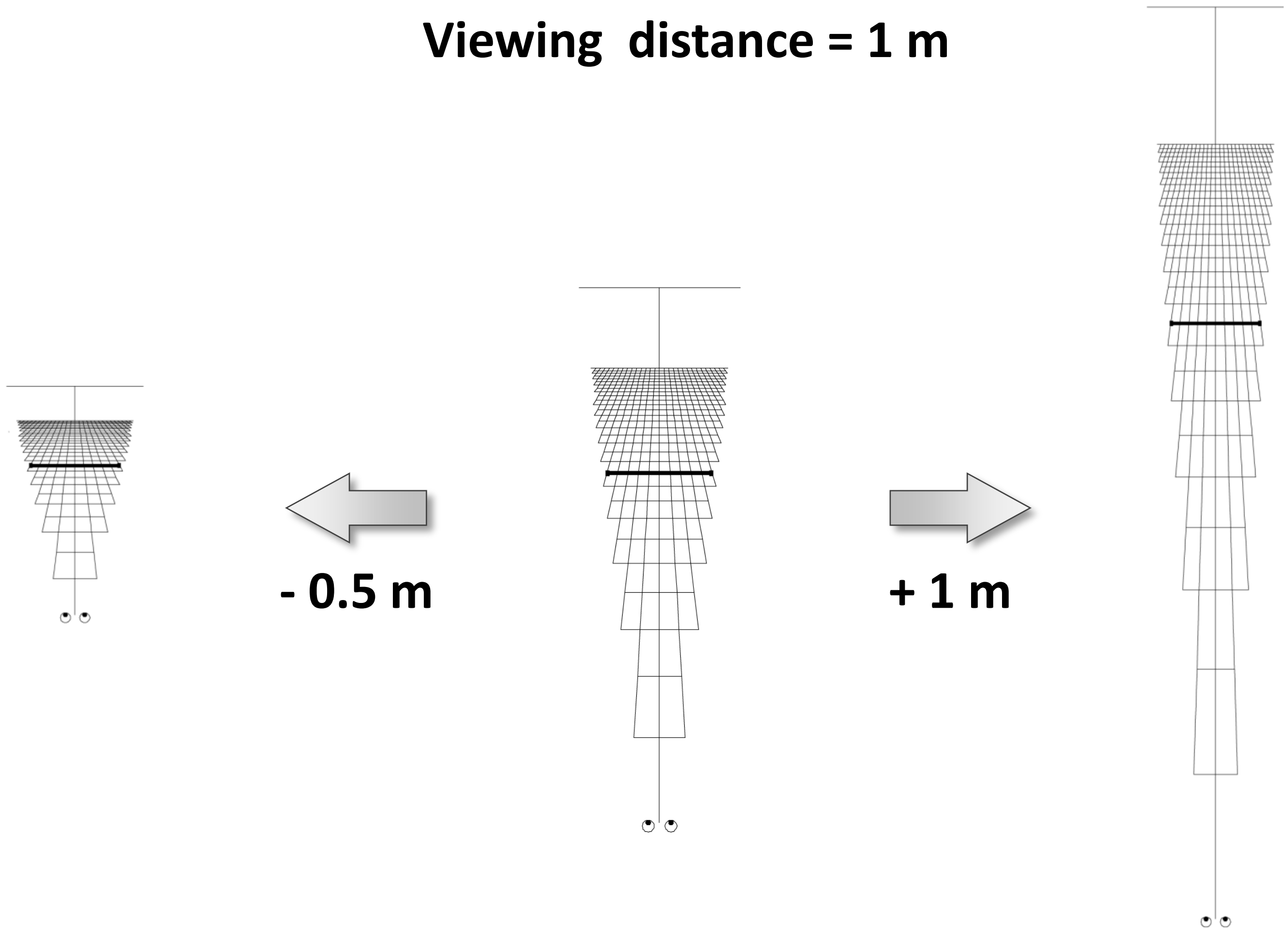
Screen width = 300 mm



"Image Distortions in Stereoscopic Video Systems" by Woods et al. 1993

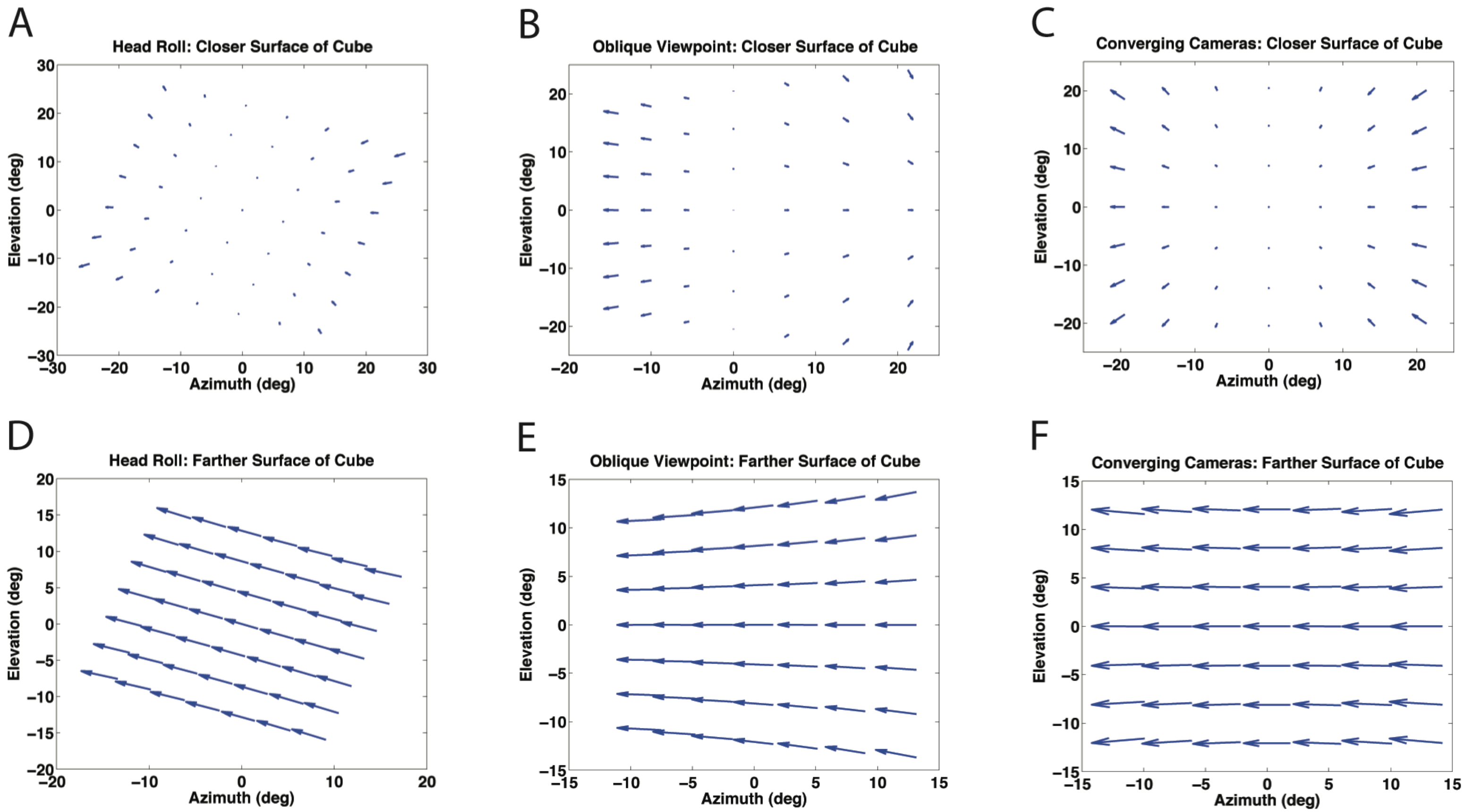
Misperception

Viewing distance = 1 m



"Image Distortions in Stereoscopic Video Systems" by Woods et al. 1993

Misperception



“Misperceptions in Stereoscopic Displays: A Vision Science Perspective” by Held et al. 2008

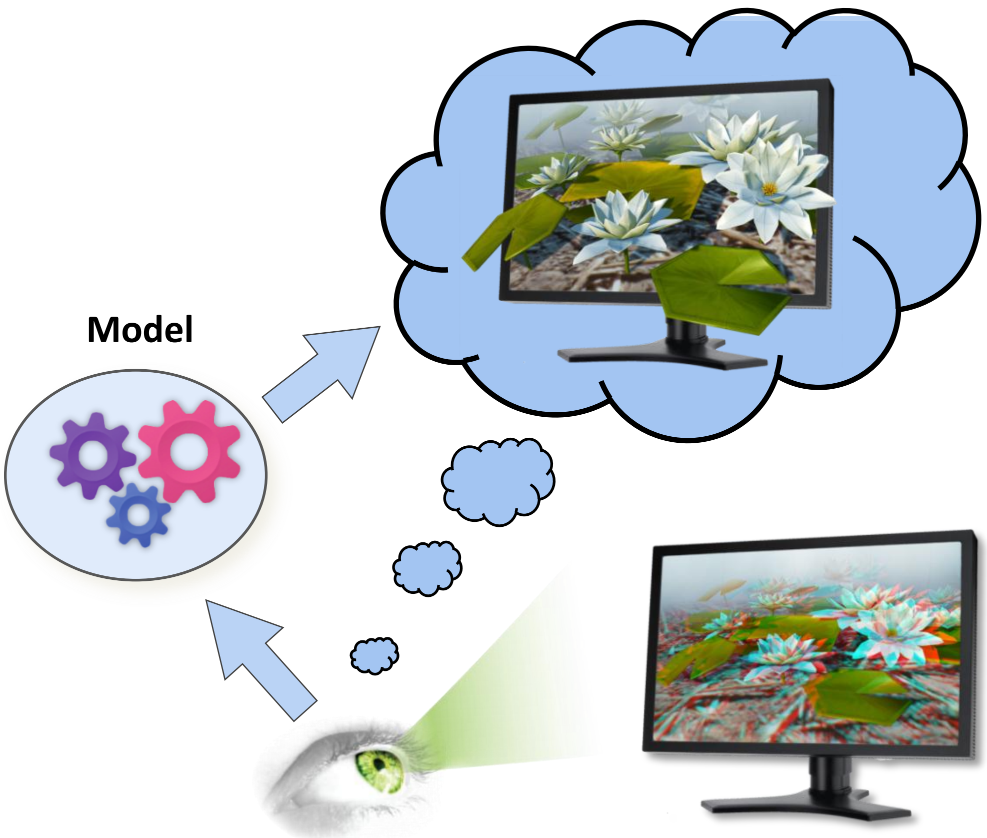
3D image prediction

Depth perception

Stereoscopic depth cues:
binocular disparity

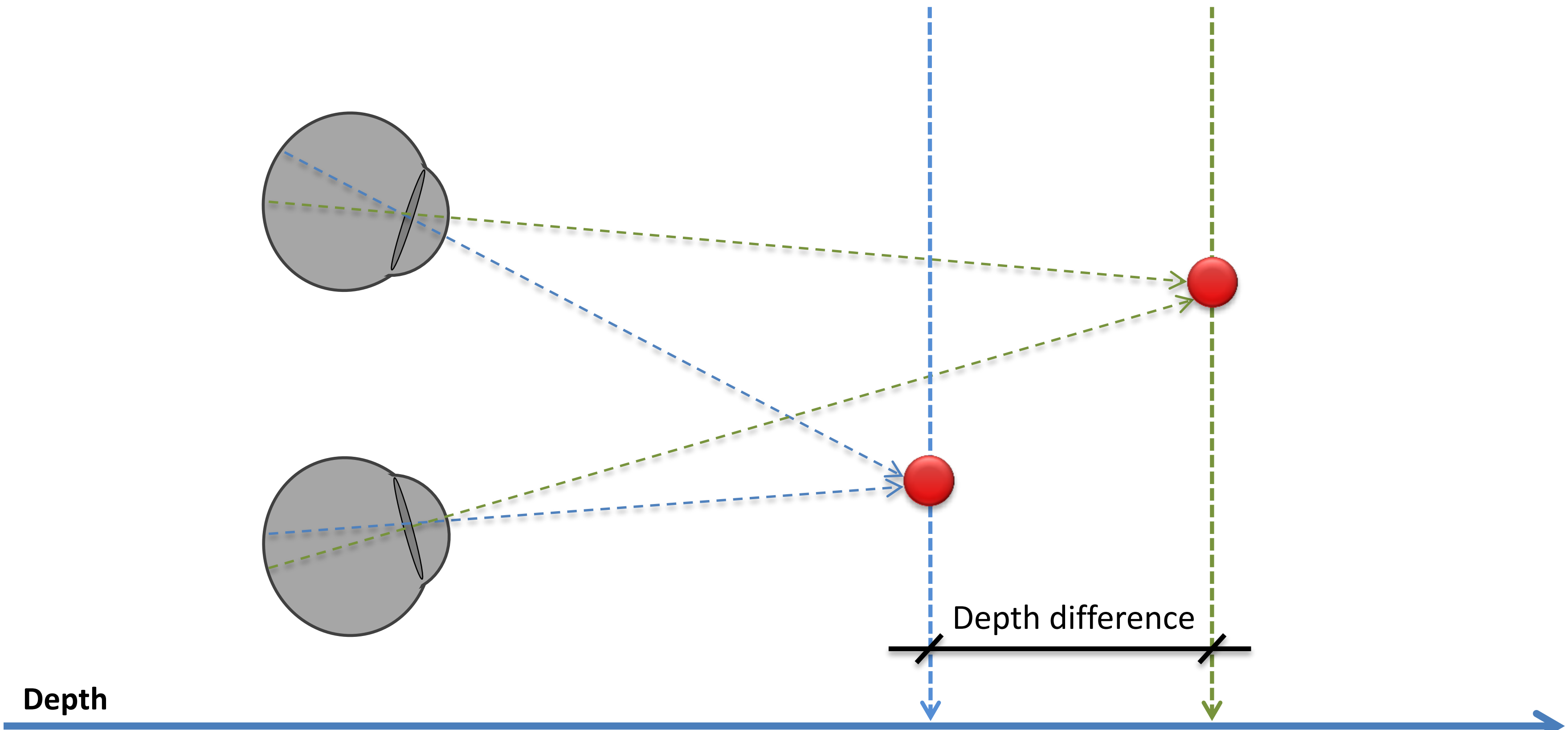
Ocular depth cues:
accommodation, vergence

Pictorial depth cues:
occlusion, size, shadows…

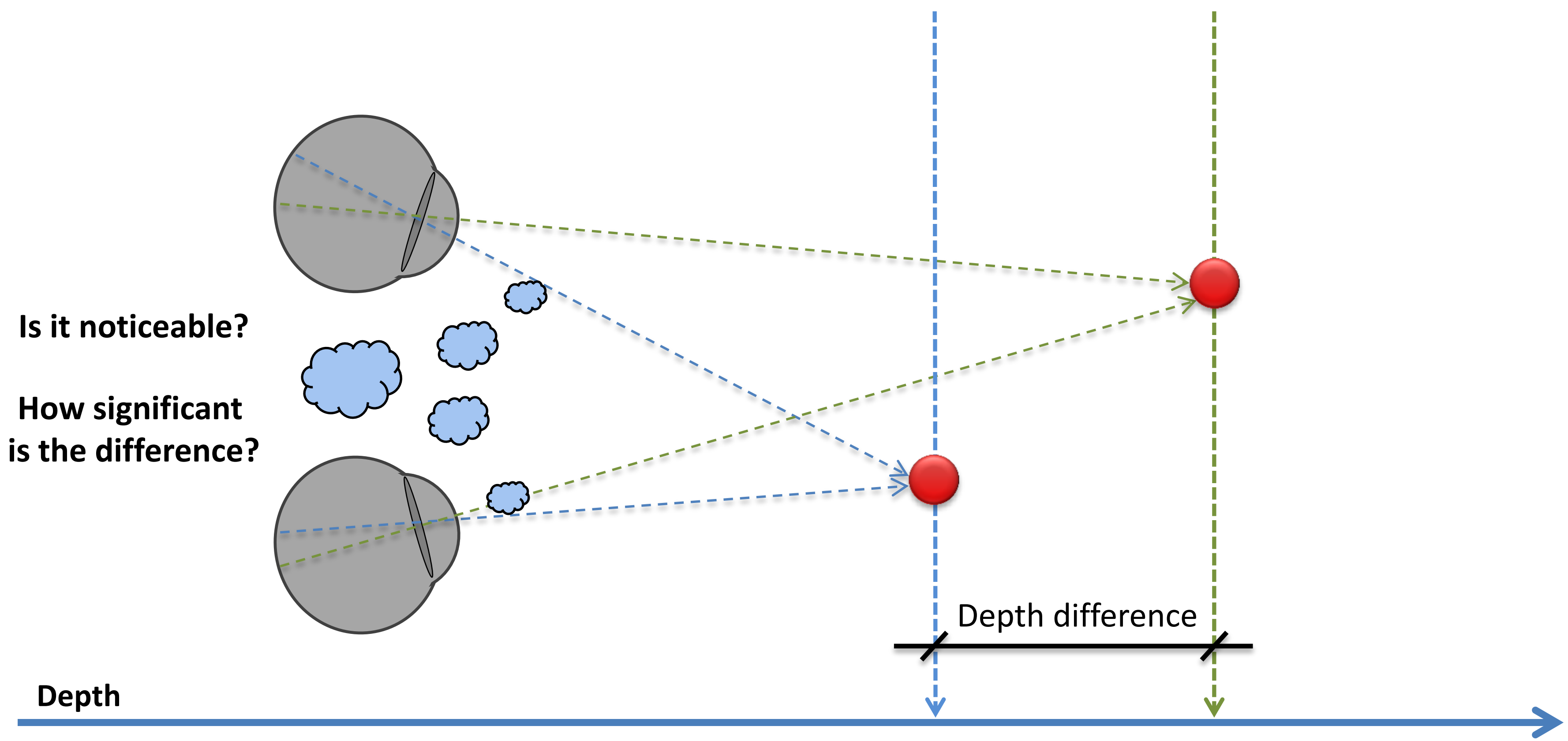


"A perceptual model for disparity" by Didyk et al. 2011

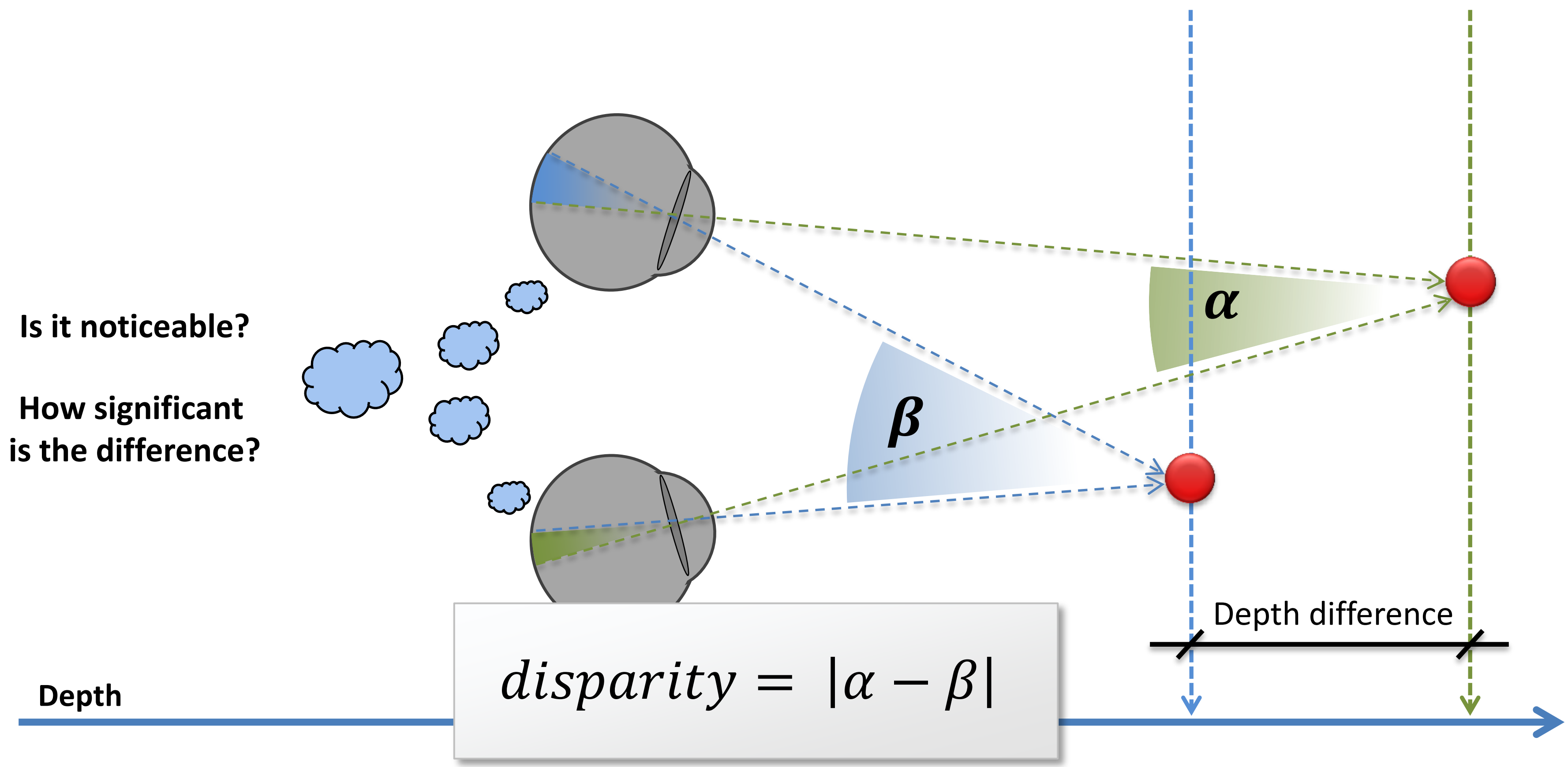
Disparity perception



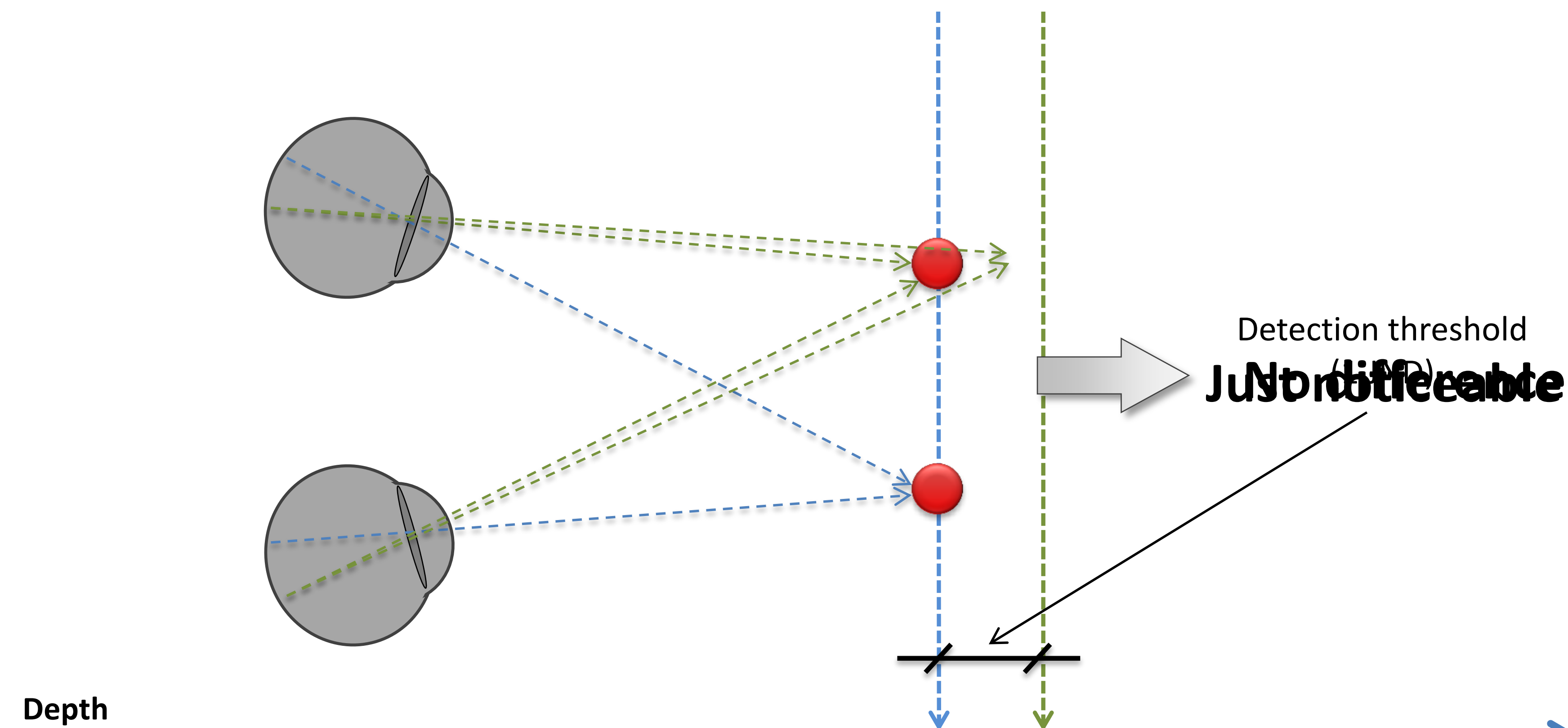
Disparity perception



Disparity perception

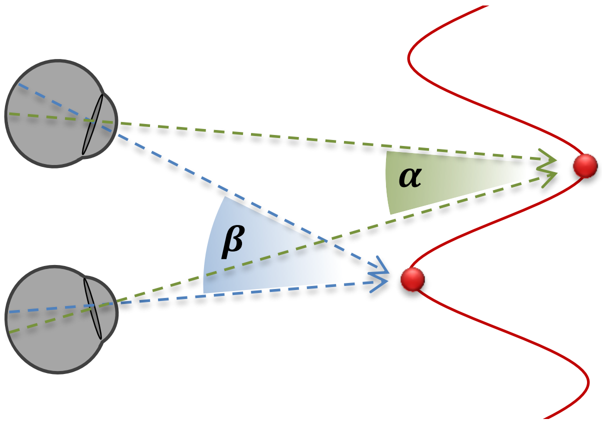


One just-noticeable difference

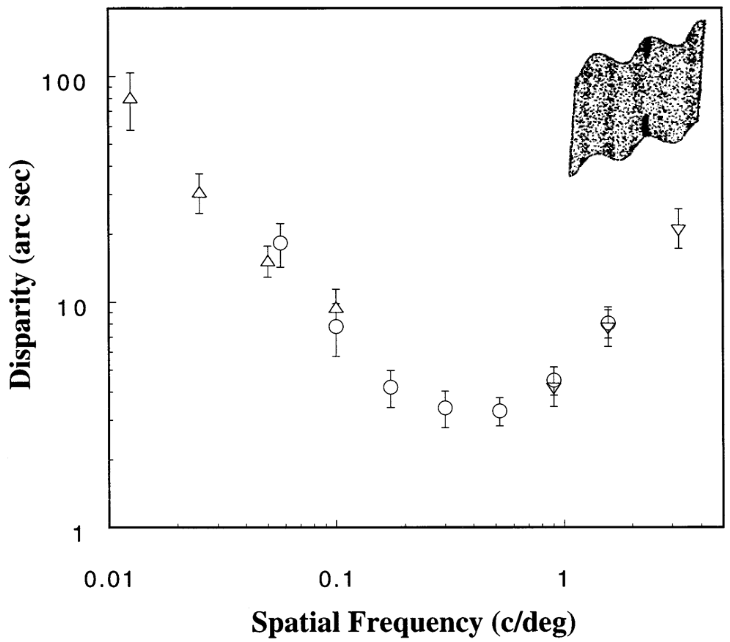


How big is the detection threshold?

For sinusoidal depth corrugation

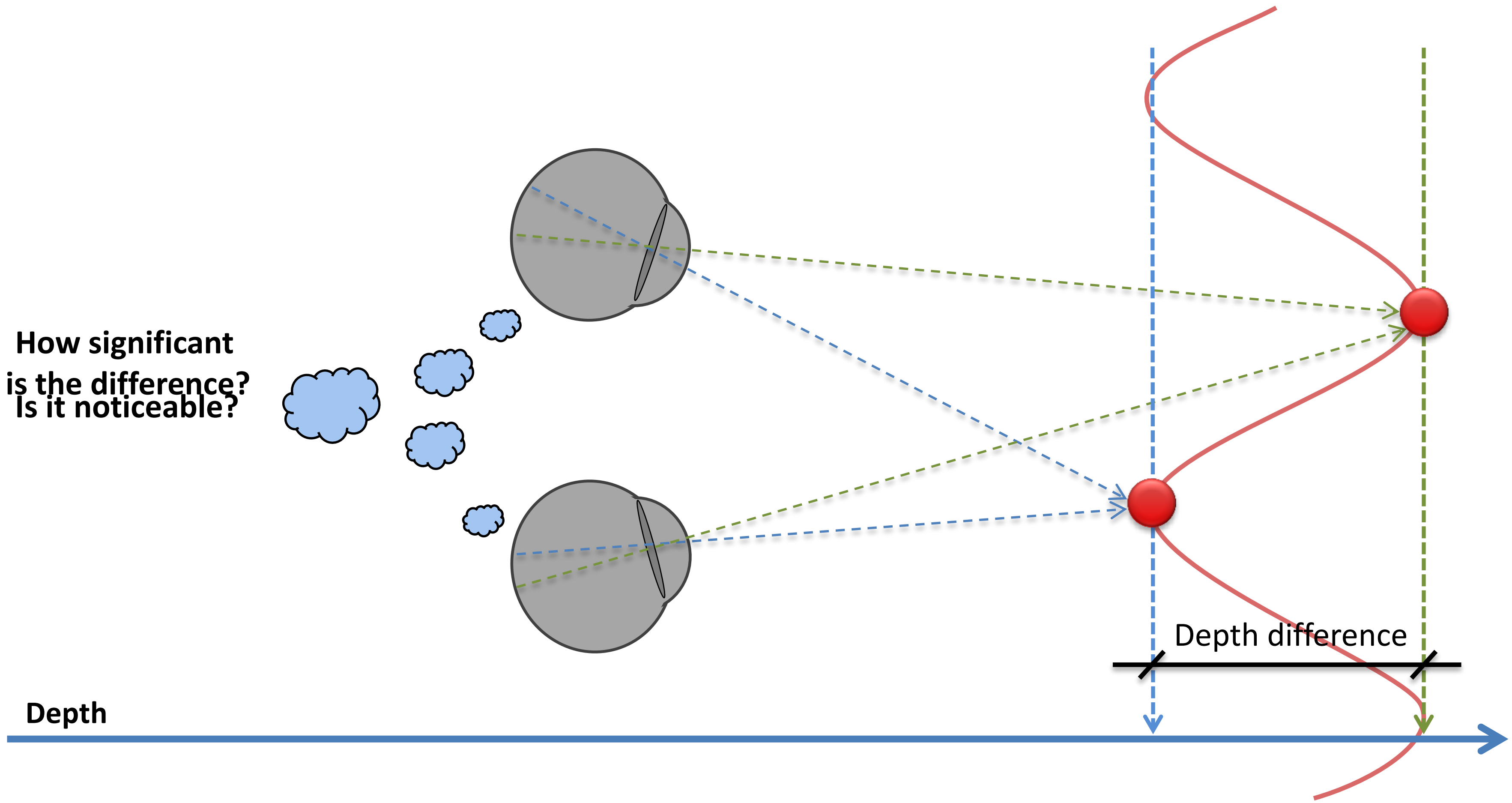


$$disparity = |\alpha - \beta|$$

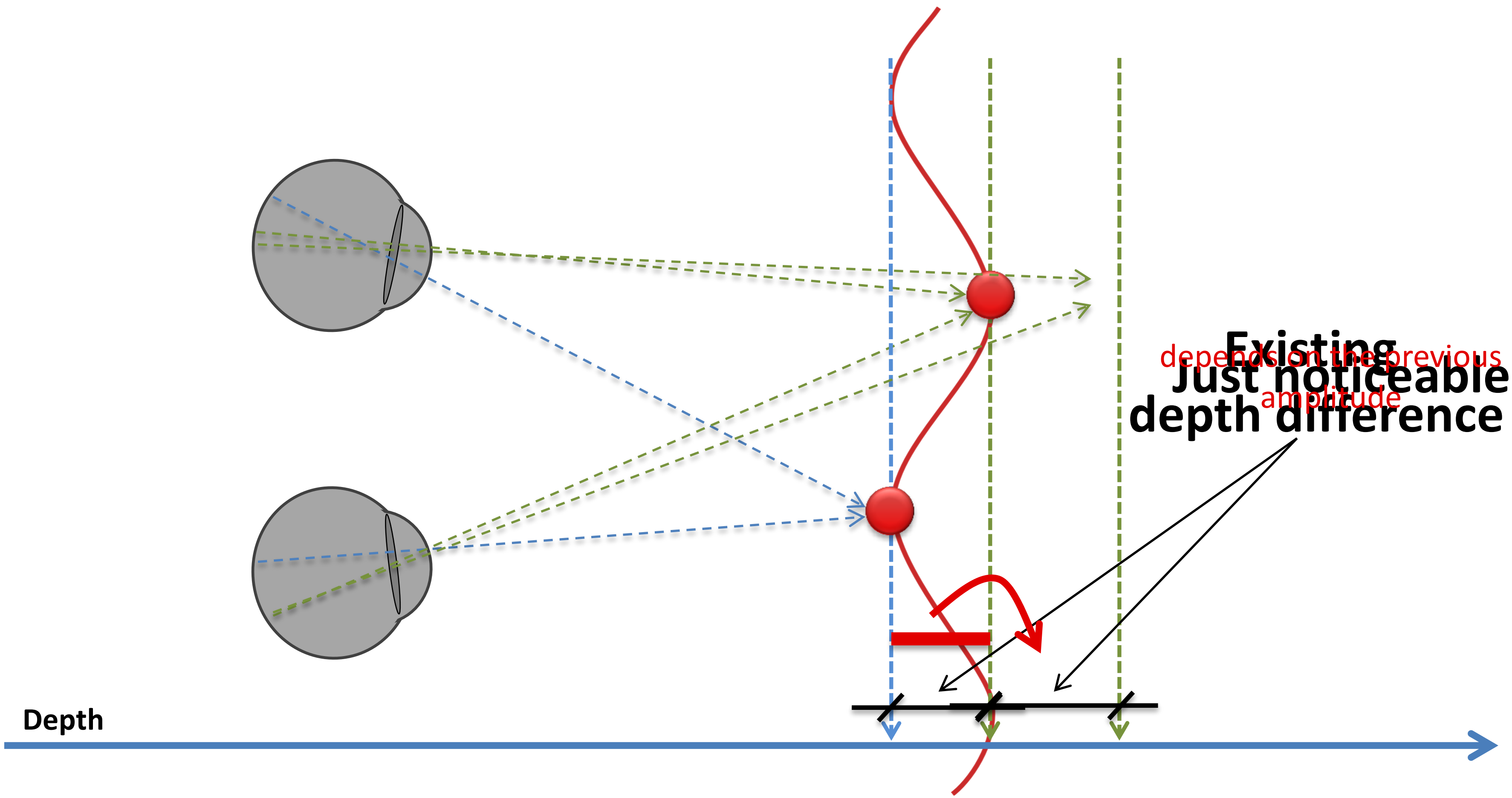


"Sensitivity to horizontal and vertical corrugations defined by binocular disparity."
by Bradshaw et al. 1999

Disparity perception



Discrimination threshold



Disparity perception

Sensitivity to depth changes depends on:

- Spatial frequency of disparity corrugation
- Existing disparity (sinusoid amplitude)

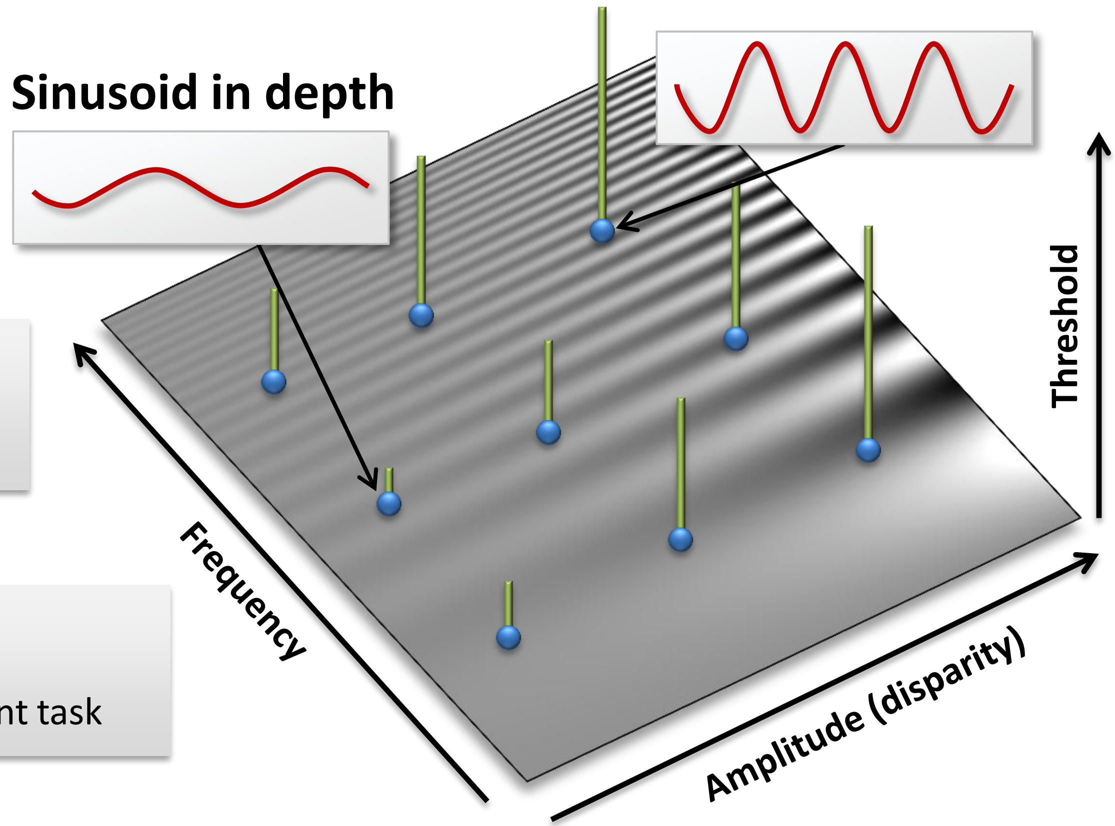
Measurements

Parameter space:

1. Sample the space

3. Measure thresholds

- Experiment with adjustment task



"A perceptual model for disparity" by Didyk et al. 2011

Measurements

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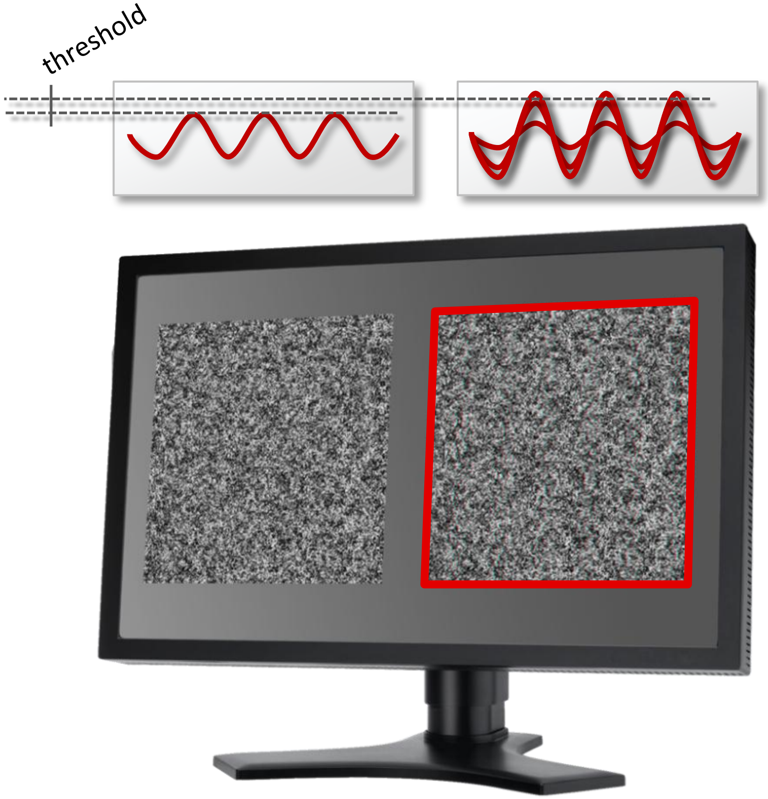


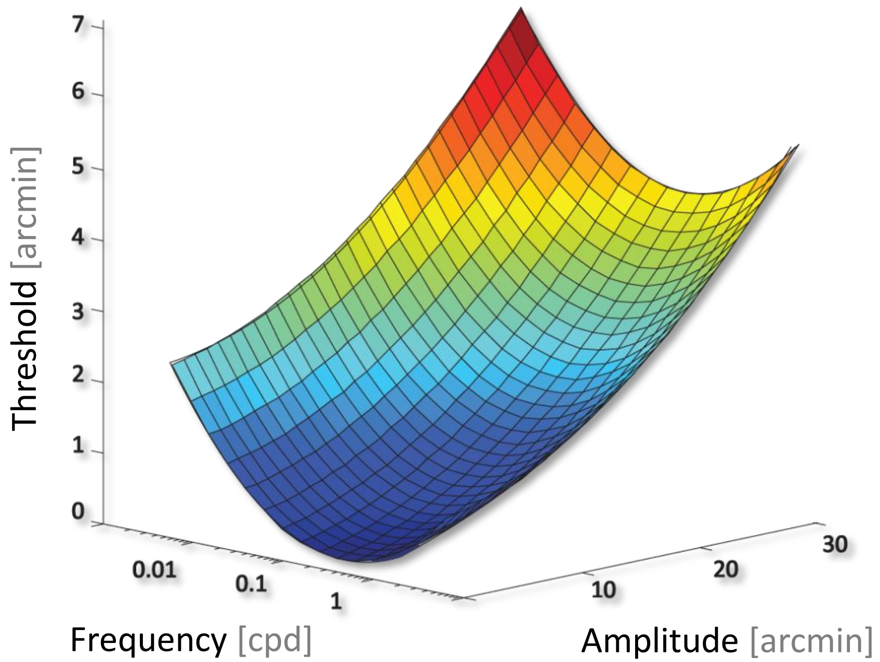
Thresholds measurement:

- Two sinusoidal corrugations
- Which has more depth? (left/right)
- Amplitude adjustment (PEST with 2AFC)
- 12 participants → 300+ samples

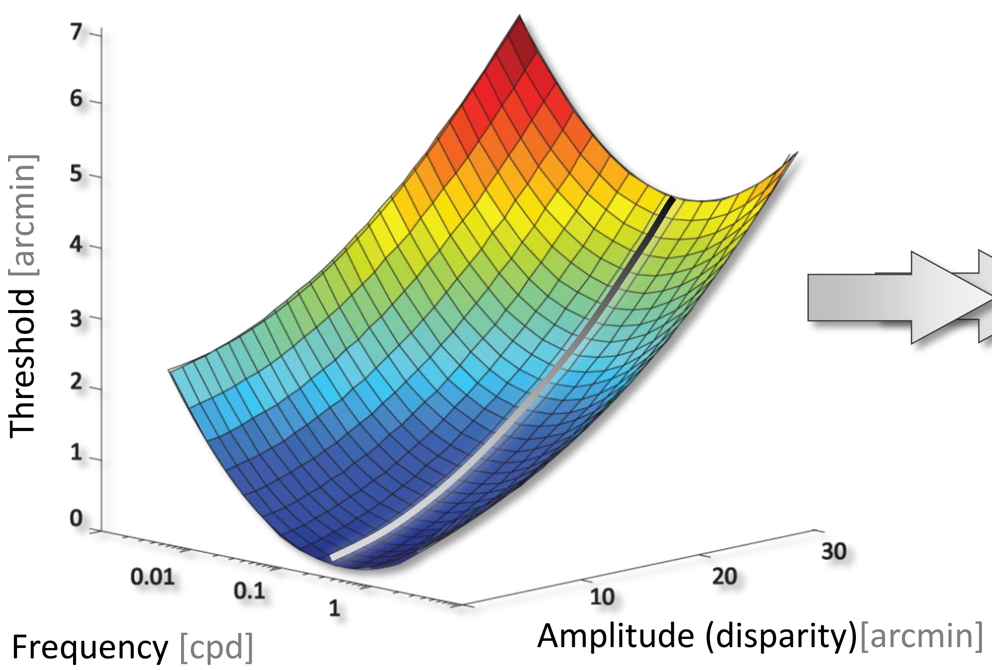
"A perceptual model for disparity" by Didyk et al. 2011

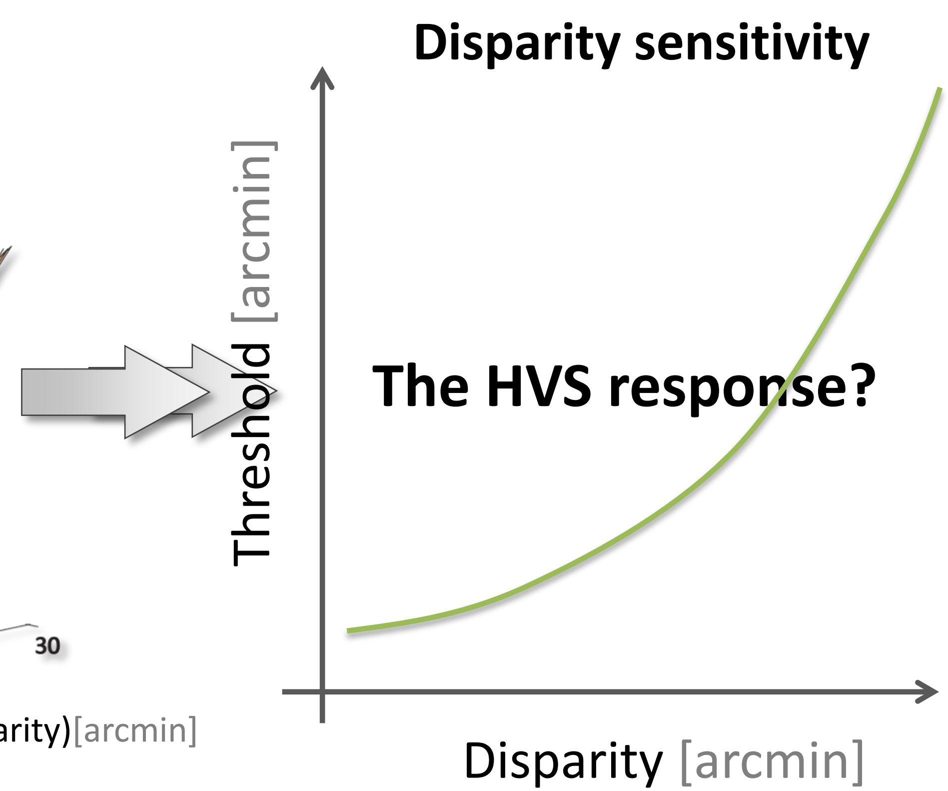
Model

3. Fit analytic function

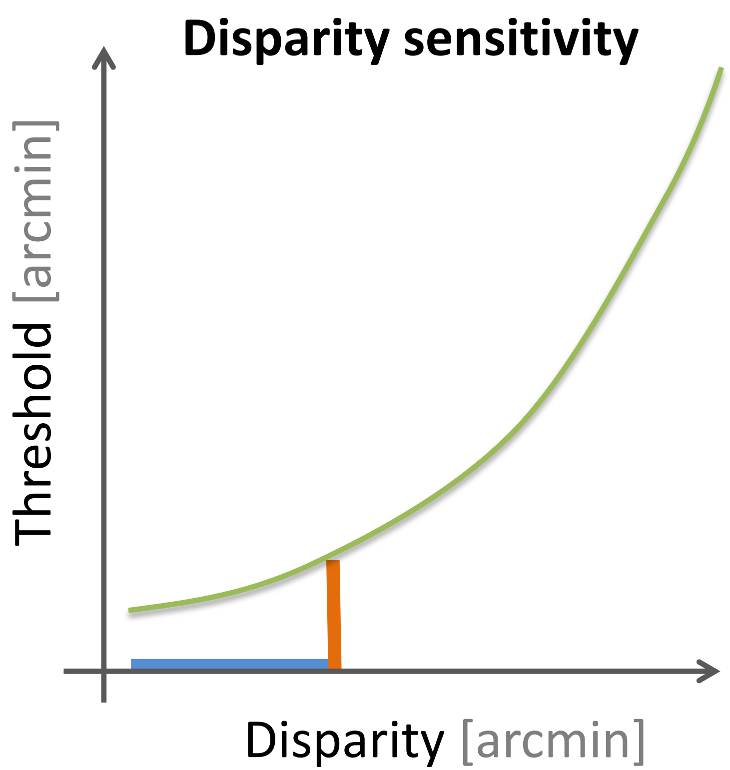


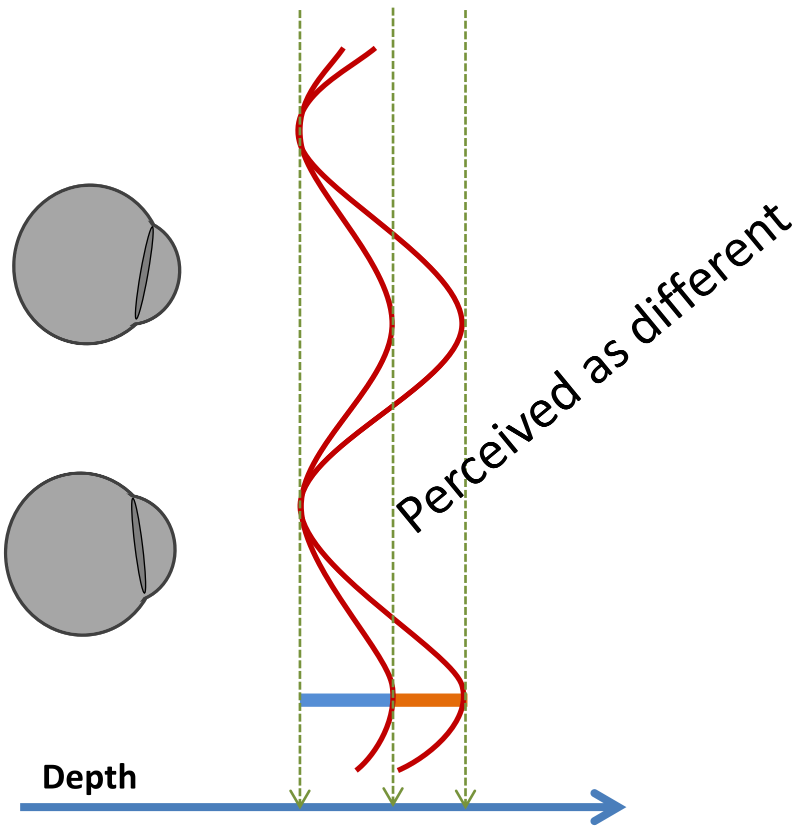
The HVS response



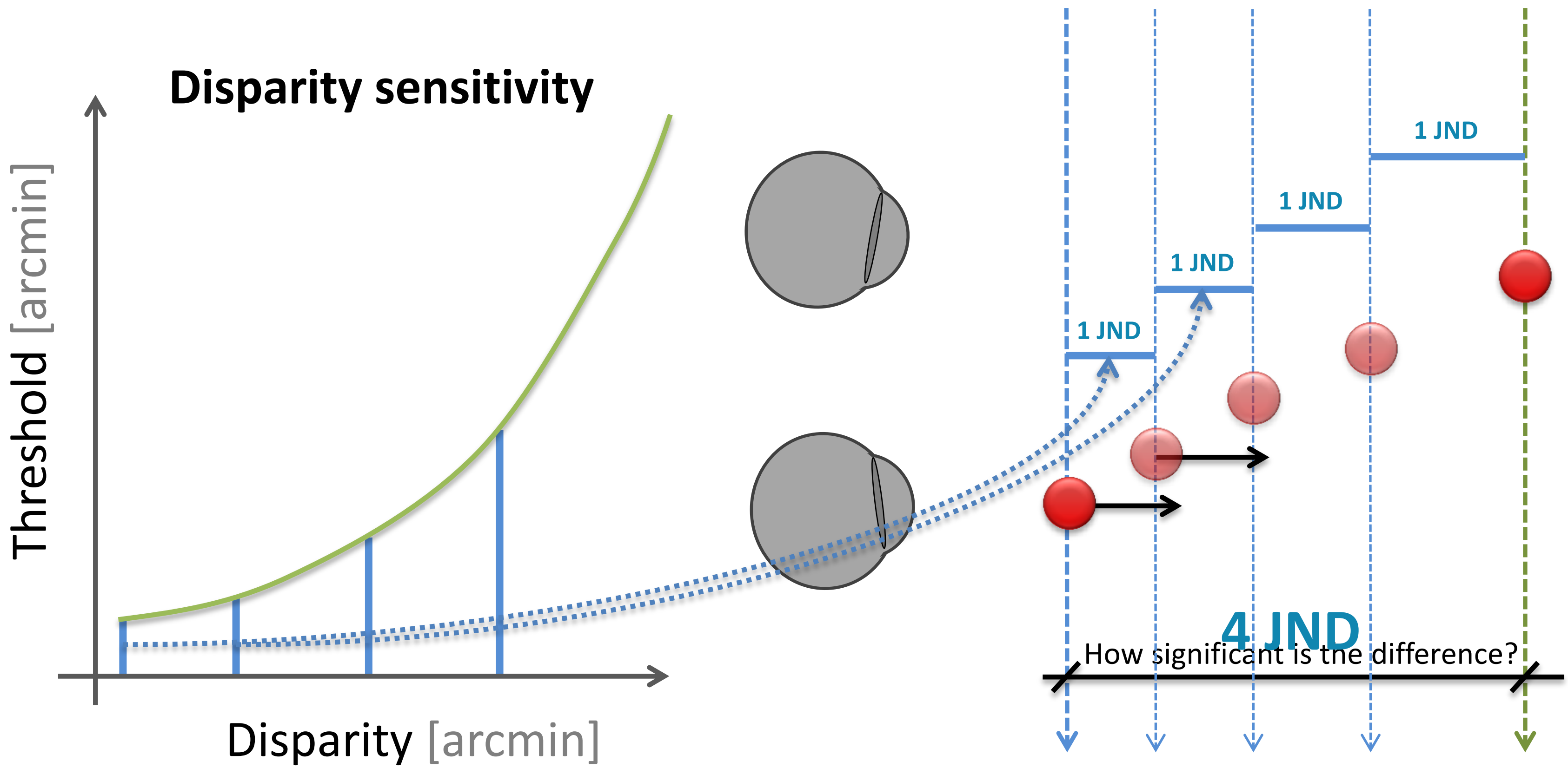


The HVS response

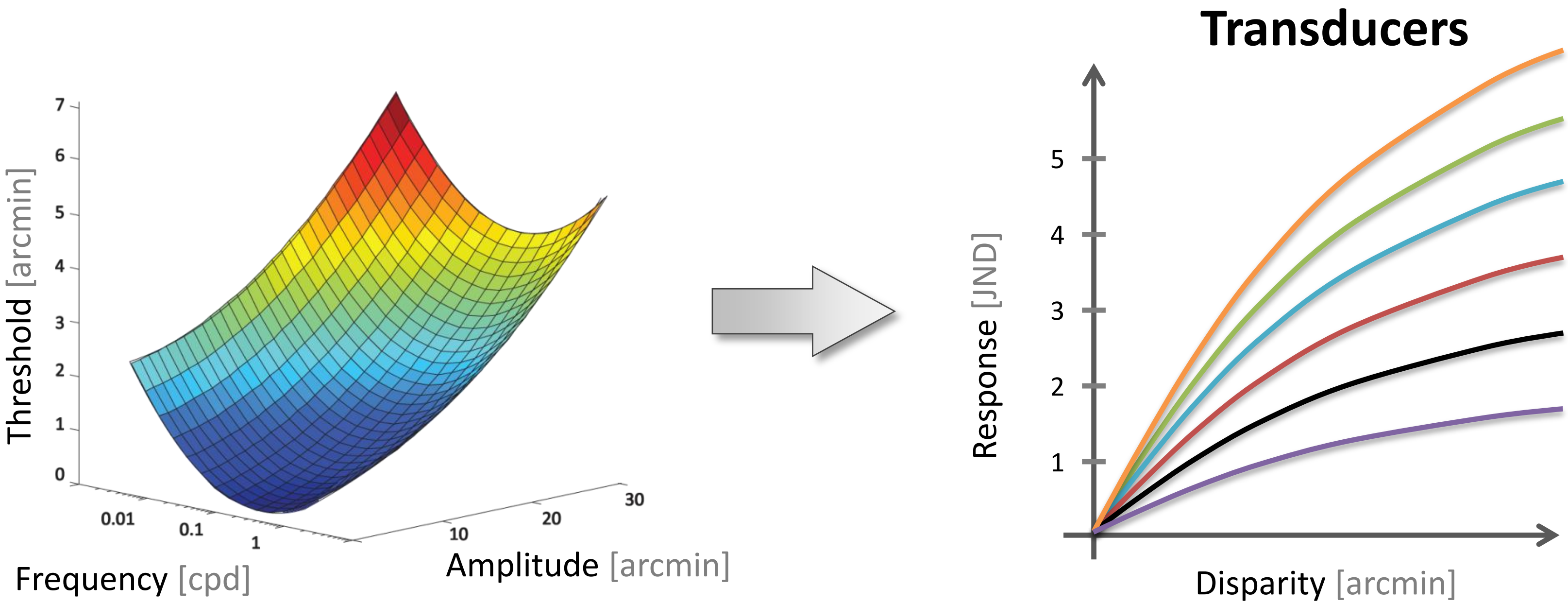




The HVS response



The HVS response



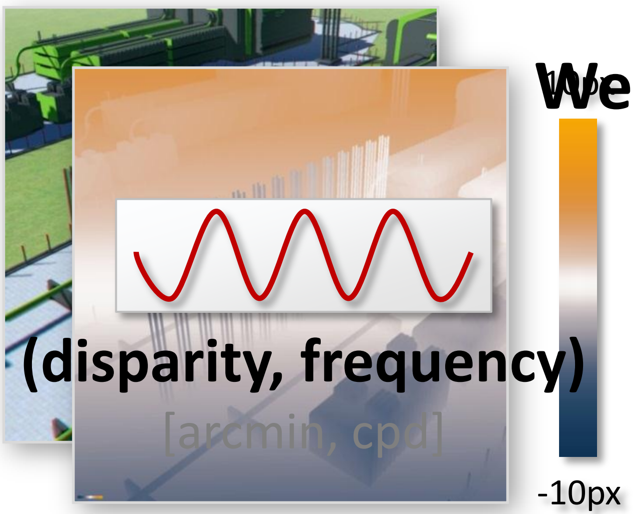
“A transducer function for threshold and suprathreshold human vision” by Wilson 1980

“A perceptual framework for contrast processing of high dynamic range images” by Mantiuk et al. 2005

Perceptual space

Reality is more complex:

We show so far:

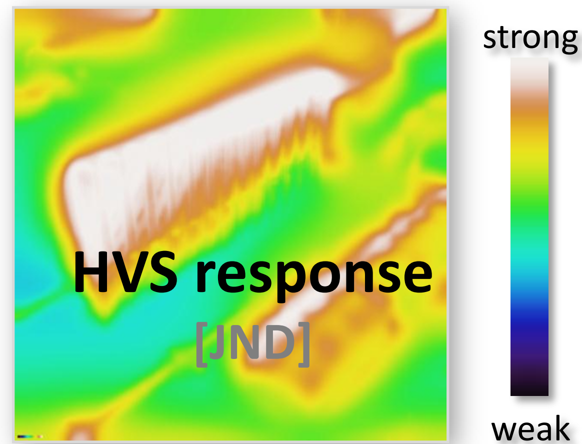


(disparity, frequency)

[arcmin, cpd]

3D scene with pixel disparity

[pixels]



HVS response

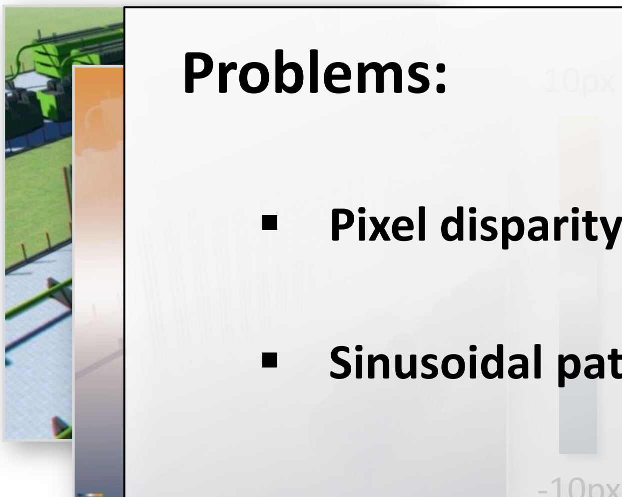
[JND]

Map of HVS response

[JND]

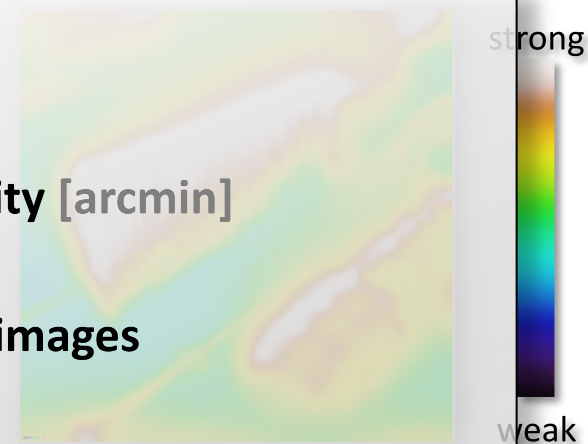
Perceptual space

Our problem:



Problems:

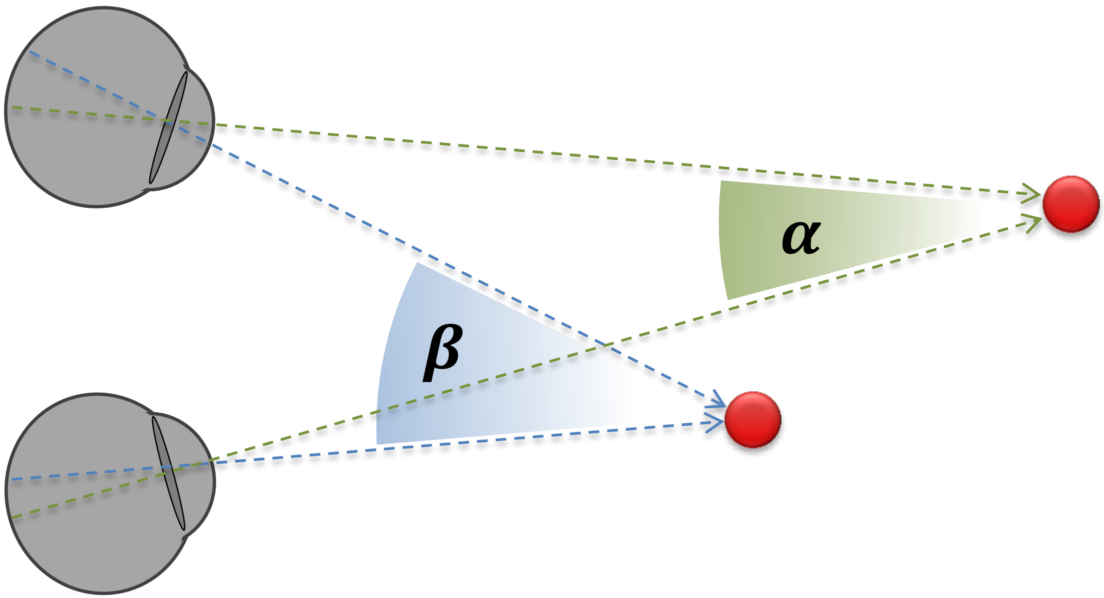
- **Pixel disparity** [pixels] ↔ **Disparity** [arcmin]
- **Sinusoidal patterns → Complex images**



3D scene with pixel disparity
[pixels]

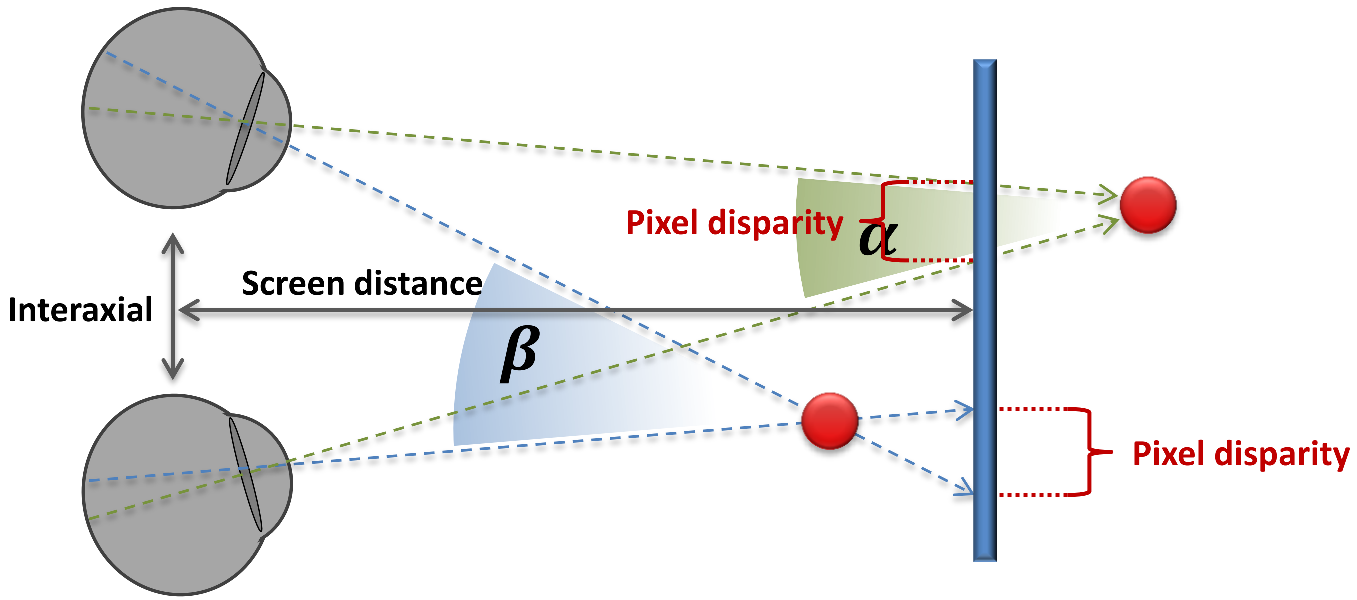
Map of HVS response
[JND]

Pixel disparity to disparity



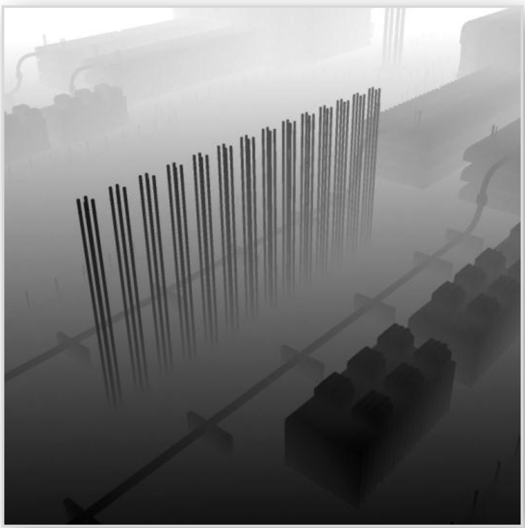
$$disparity = |\alpha - \beta|$$

Pixel disparity to disparity



$$(\boldsymbol{viewing\ conditions, pixel\ disparity}) \rightarrow \boldsymbol{vergence}$$

Vergence to disparity



Vergence [arcmin]

Disparity [arcmin]

How do people deal with luminance?

Luminance (contrast perception)

Luminance

Perceptual space

(Perceived contrast)

Luminance (contrast perception)

Works because:

Disparity / Luminance similarity:

Different frequencies are processed separately.

Luminance ↔ Vergence

For disparity is similar.

Luminance contrast ↔ Disparity

Disparity is processed in independent channels.

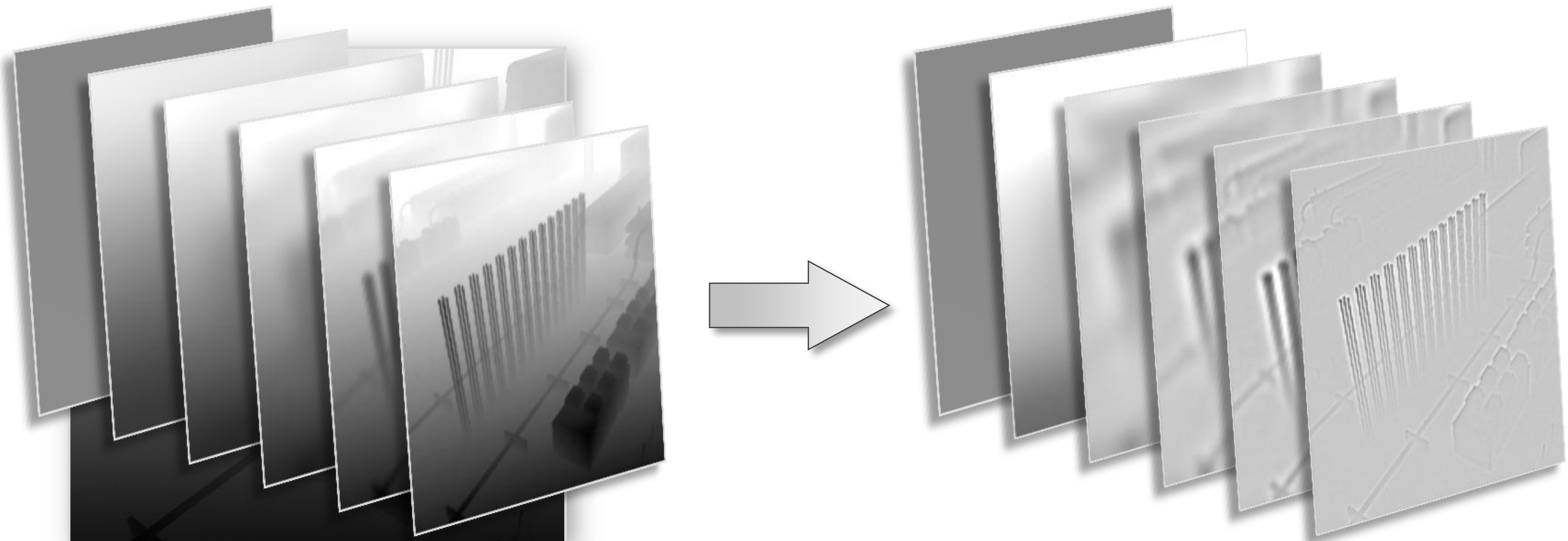
"Seeing in depth" by Howard and Rogers 2002

Lowpass filters

Perceptual operations

into frequency bands

Vergence to disparity

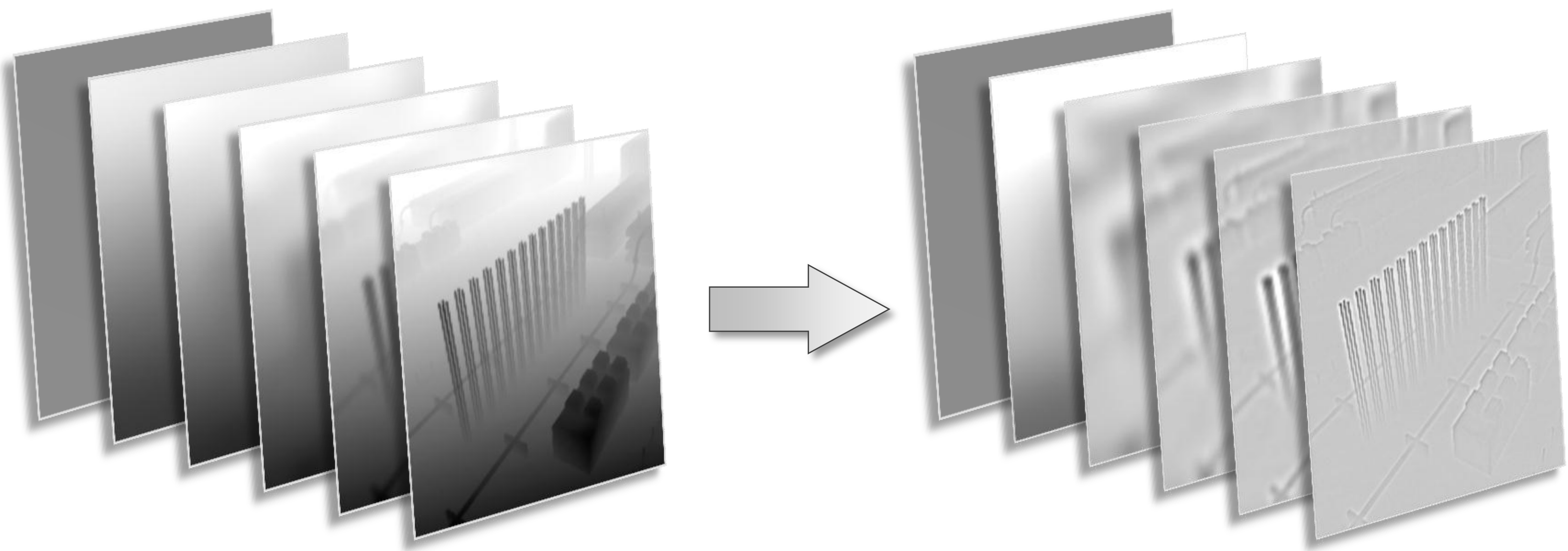


Vergence [arcmin]

Lowpass filters

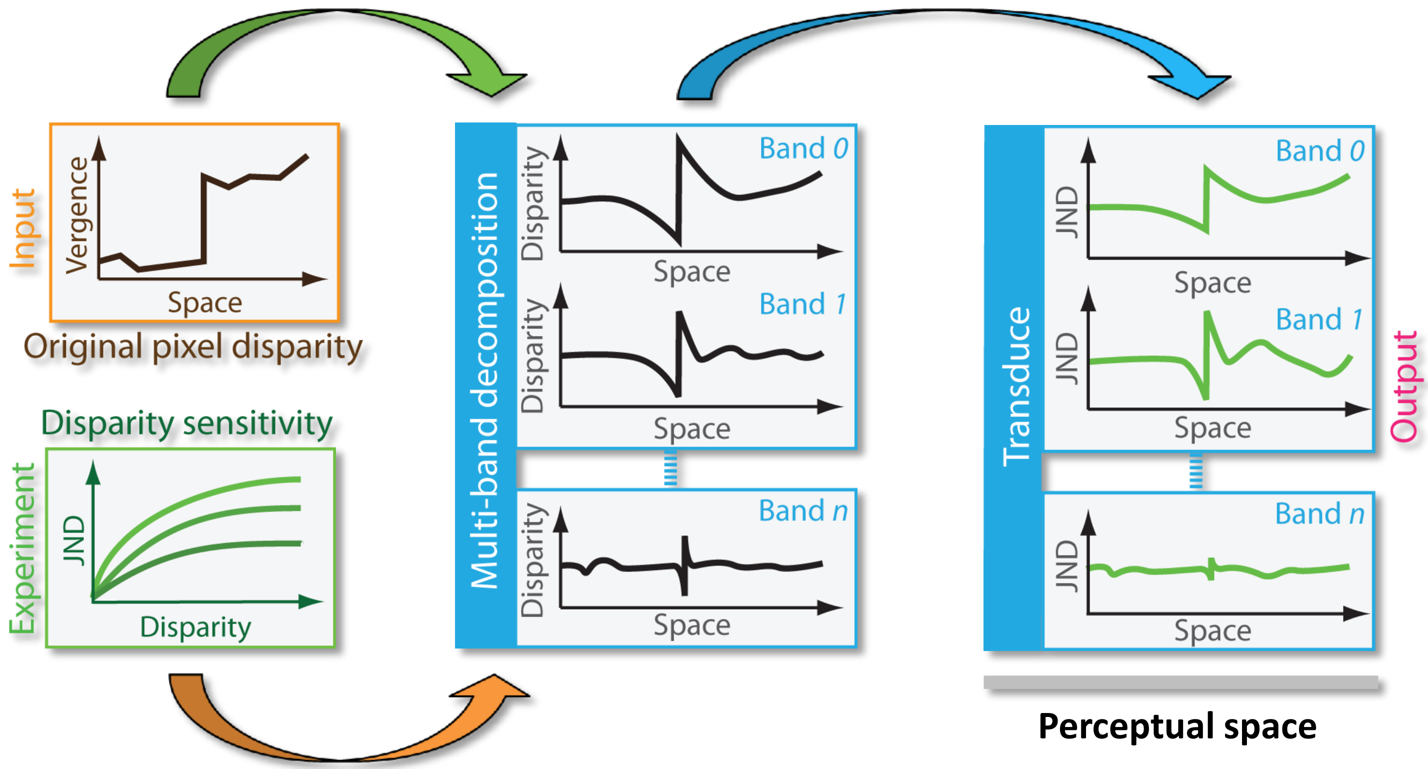
Differences

Vergence to disparity



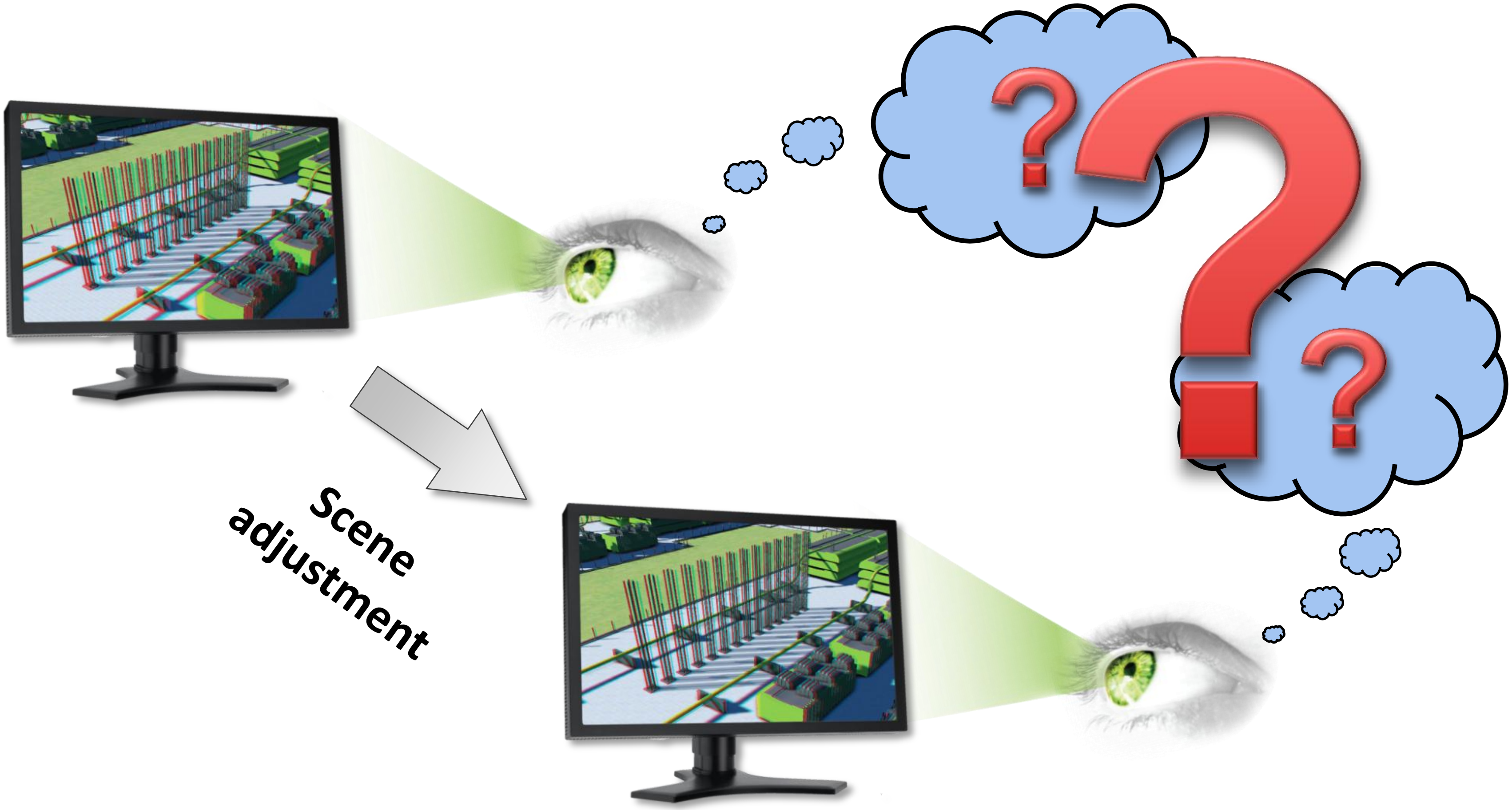
- We can process frequencies independently
- Vergence → Disparity

Perceptual model

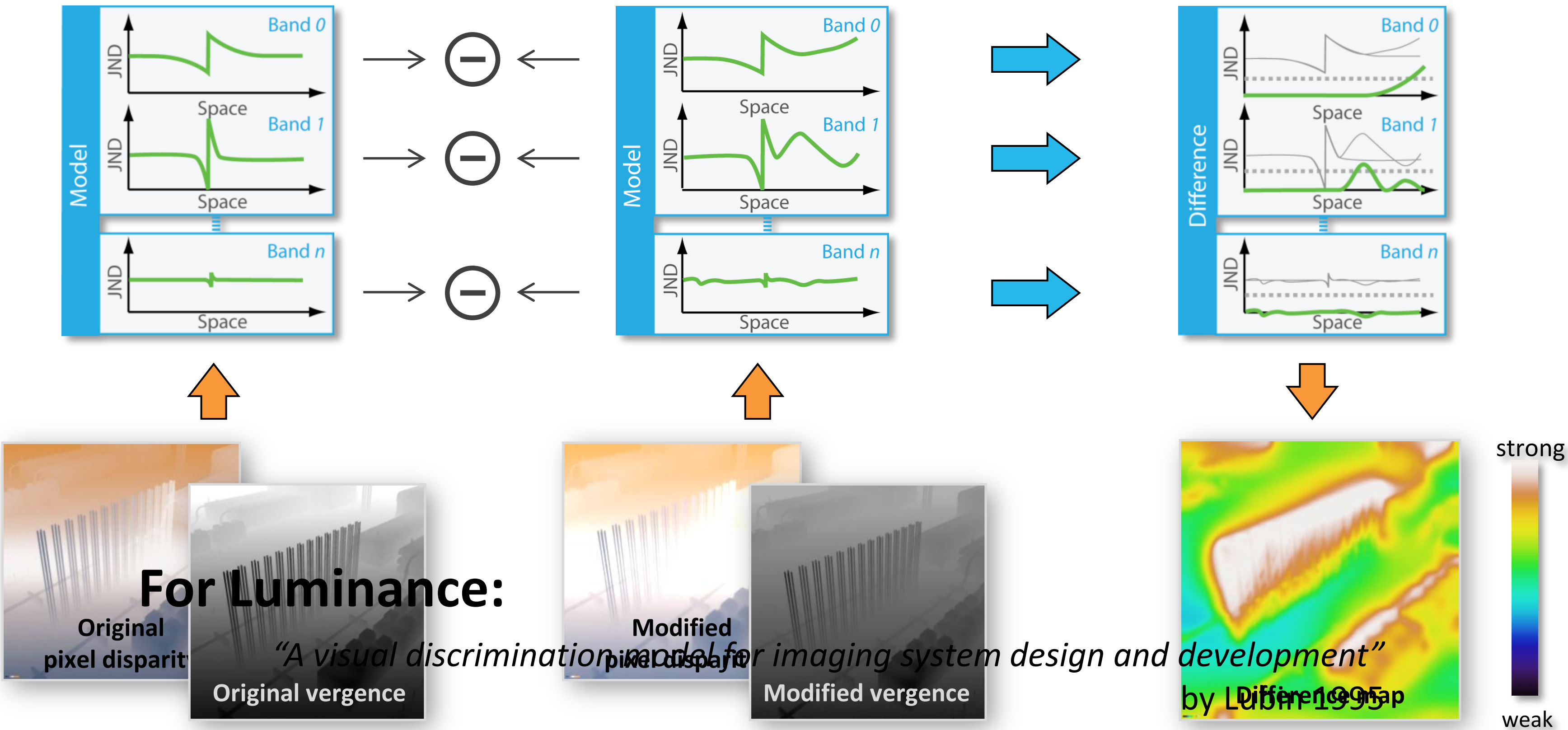


"A perceptual model for disparity" by Didyk et al. 2011

Disparity metric



Disparity metric



For Luminance:

"A visual discrimination model for imaging system design and development" by Lubin 1995

"A perceptual model for disparity" by Didyk et al. 2011

Disparity manipulations

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Manipulations in perceptual space:

→ The HVS is taken into account

→ Efficient disparity reduction

→ Important disparities preserved

"Nonlinear Disparity Mapping for Stereoscopic 3D"
by Lang et al. 2010

Disparity manipulation

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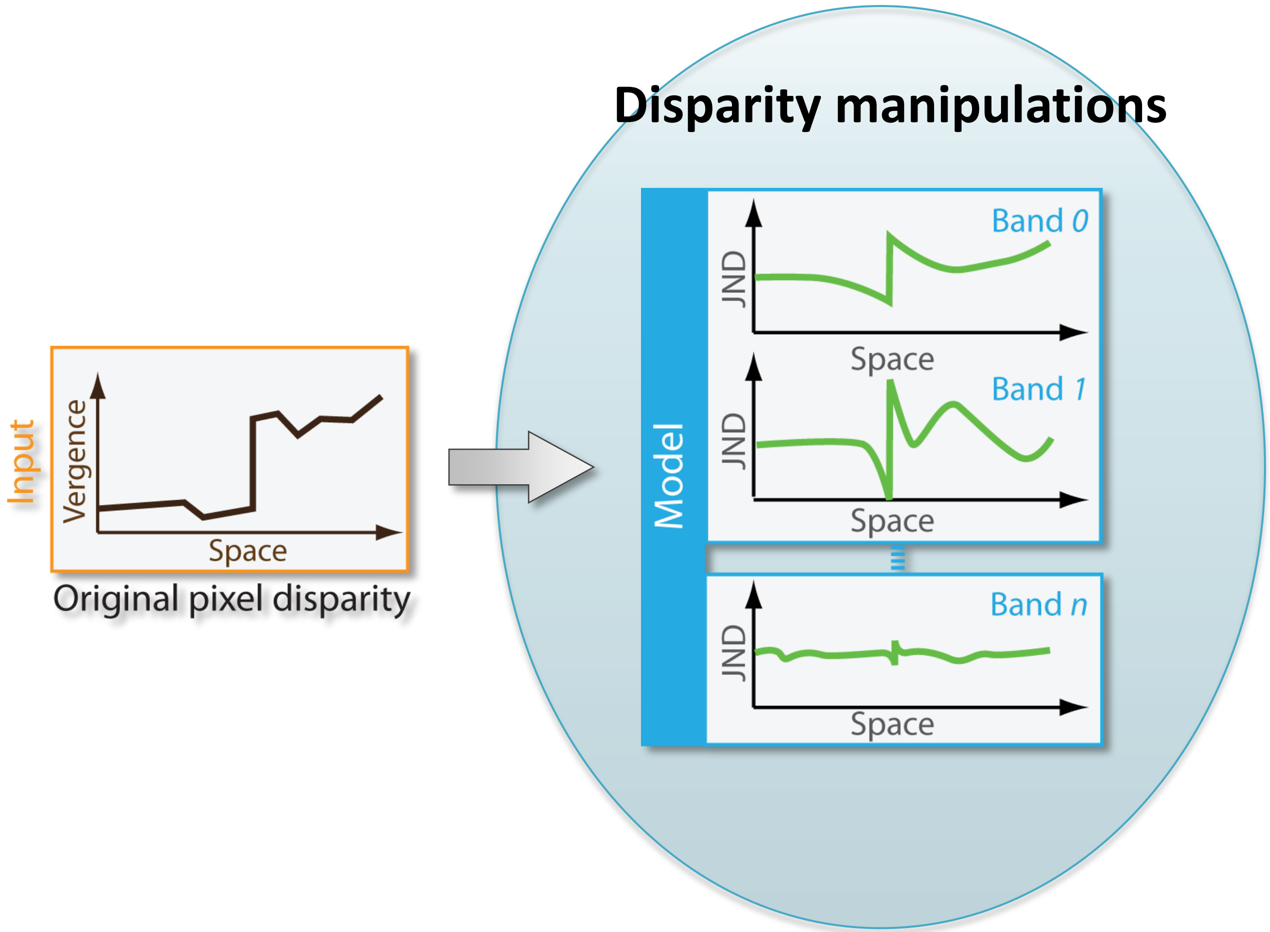
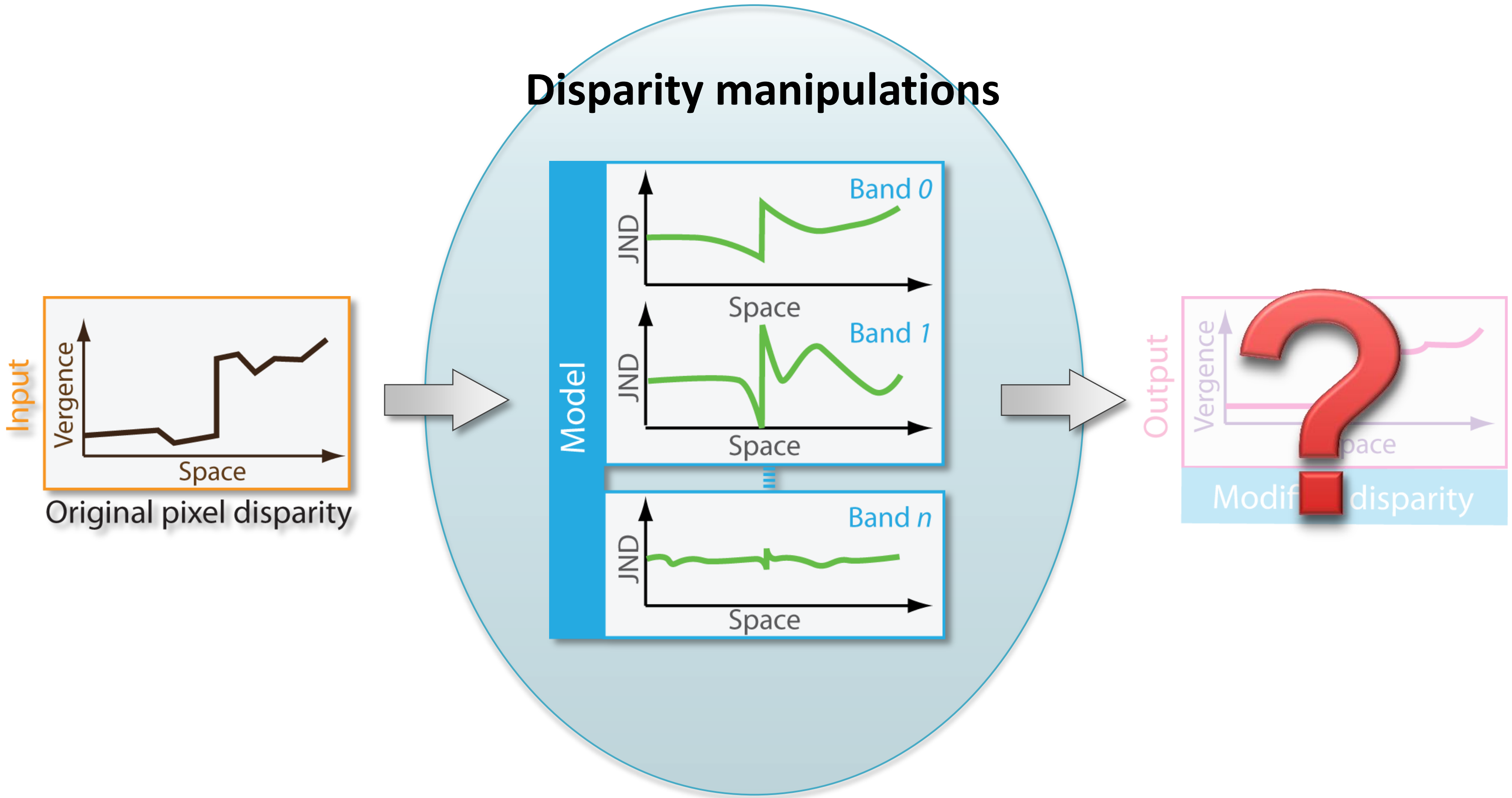


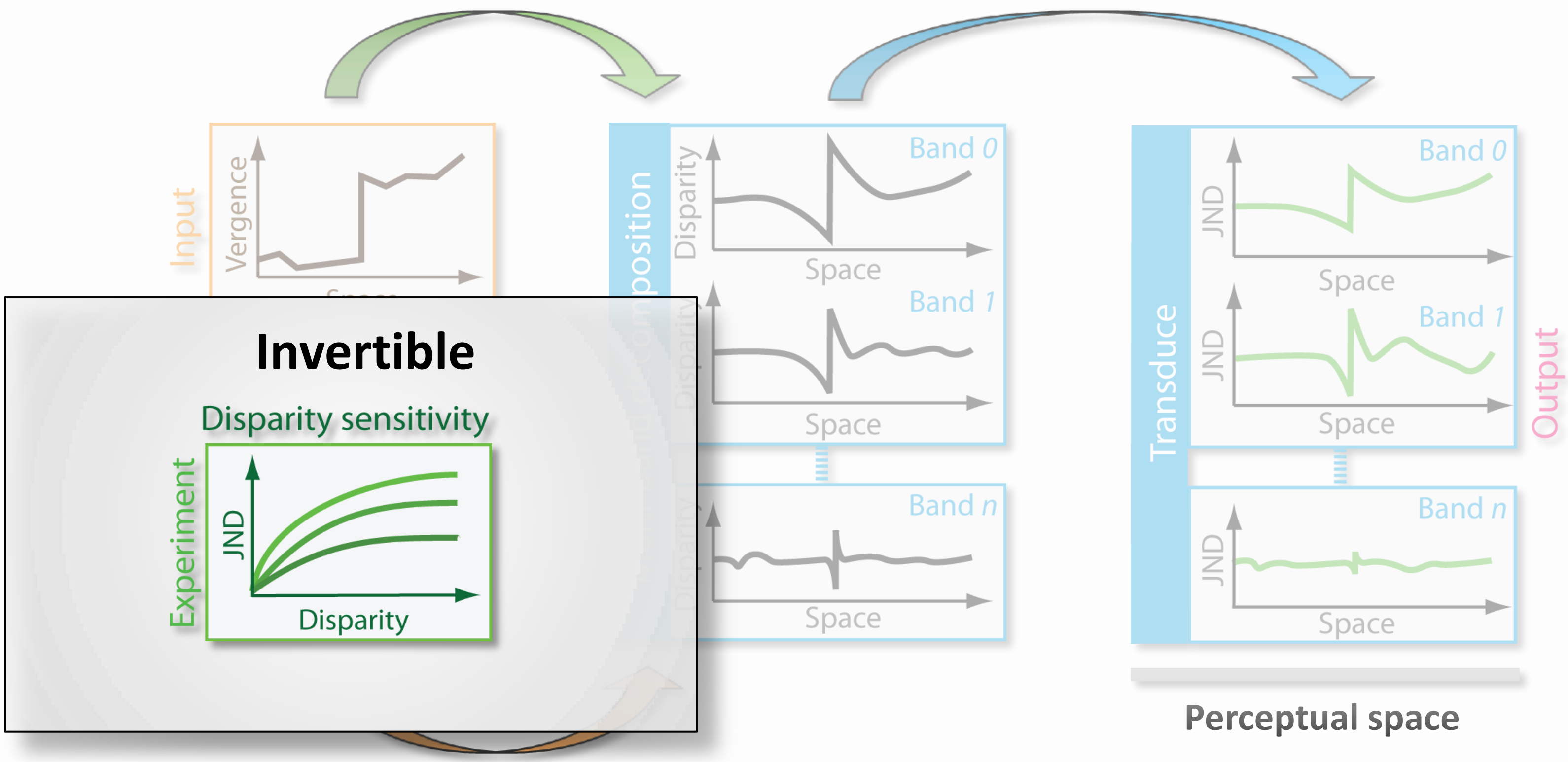
"A perceptual model for disparity" by Didyk et al. 2011

Disparity manipulation



"A perceptual model for disparity" by Didyk et al. 2011

Inverse model



Inverse model

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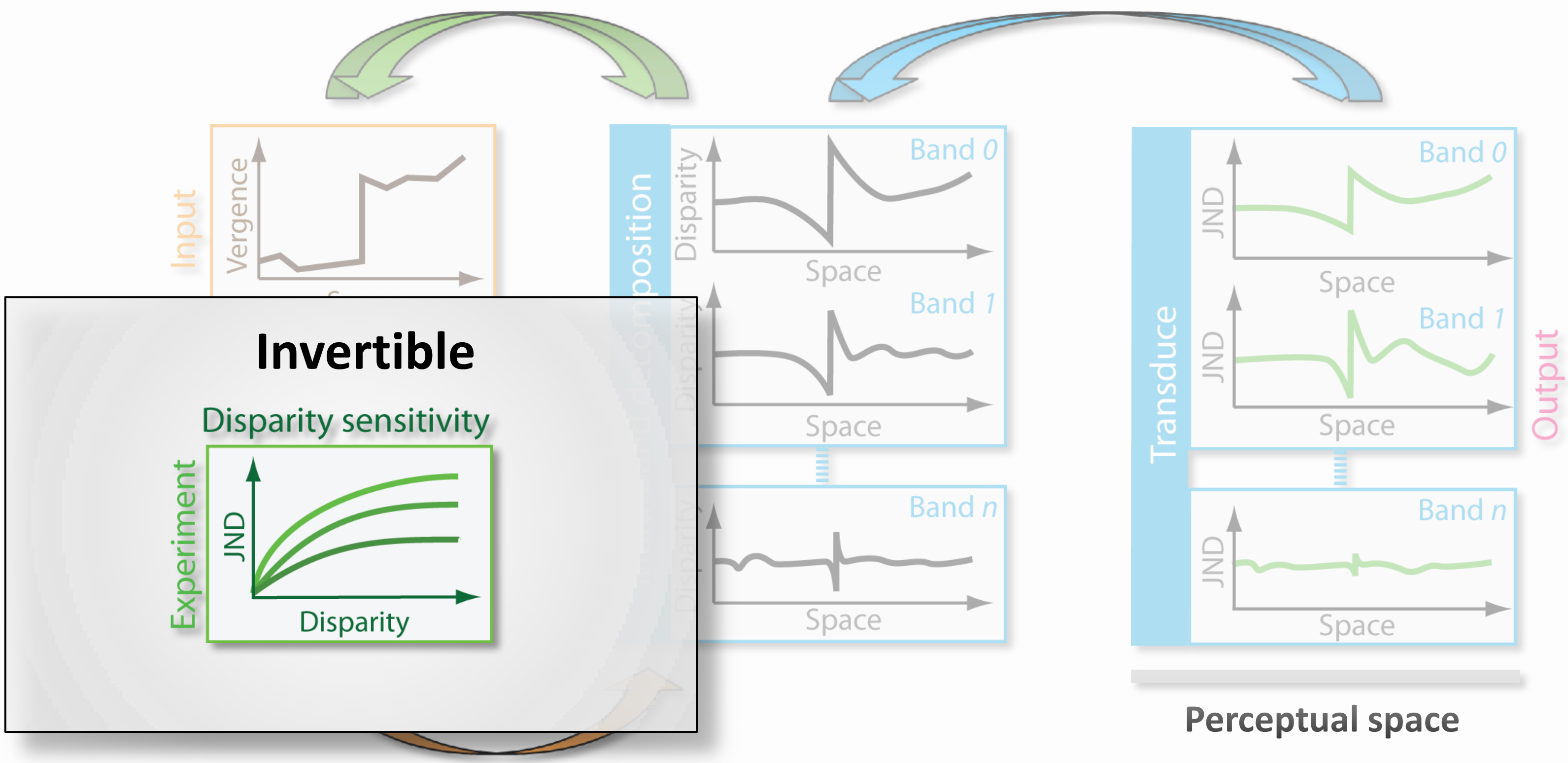
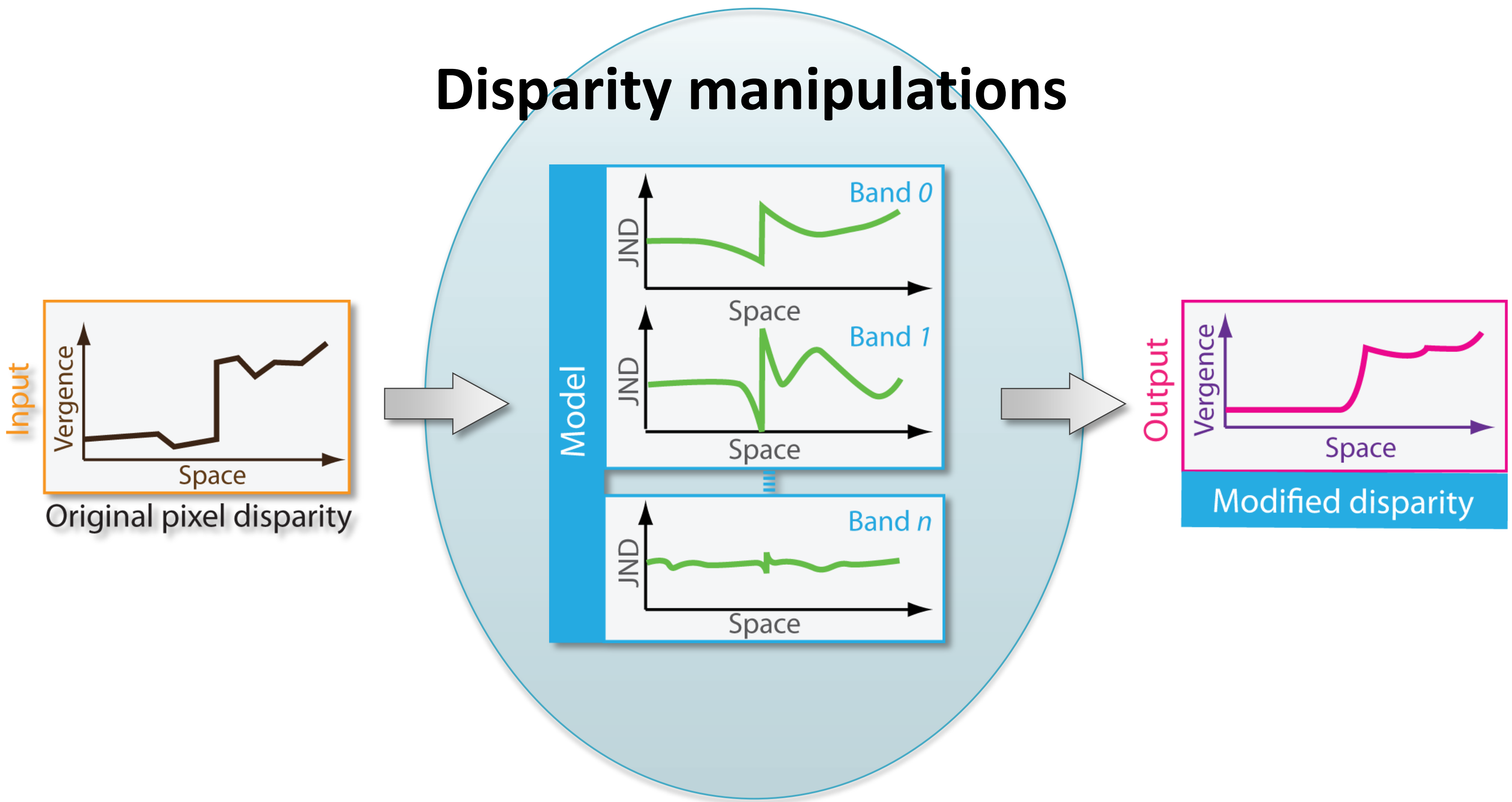
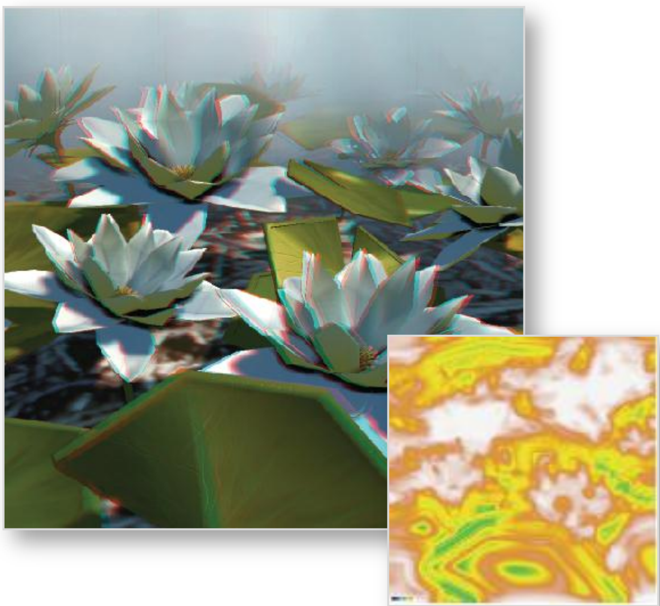


Disparity manipulation



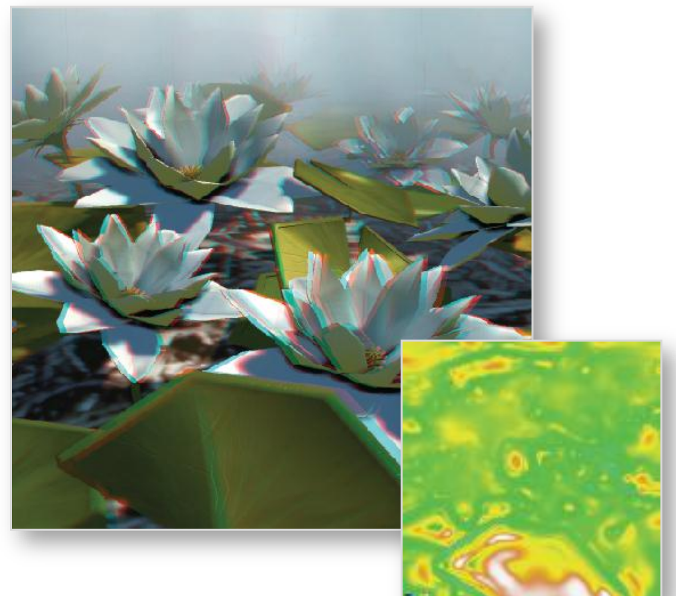
Disparity manipulation

Standard technique



Perceived distortions

In perceptual space



Perceived distortions

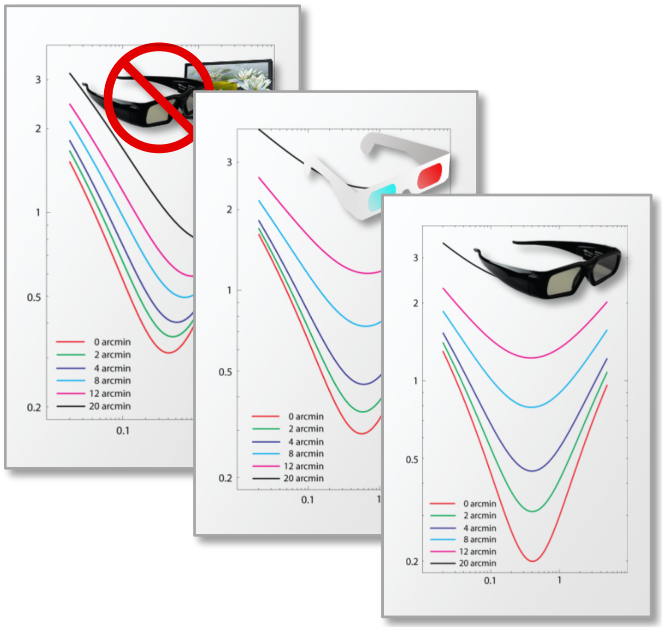
strong

weak

- Important disparities preservation

Personalization

Disparity perception depends on:



Equipment

User

Personalization

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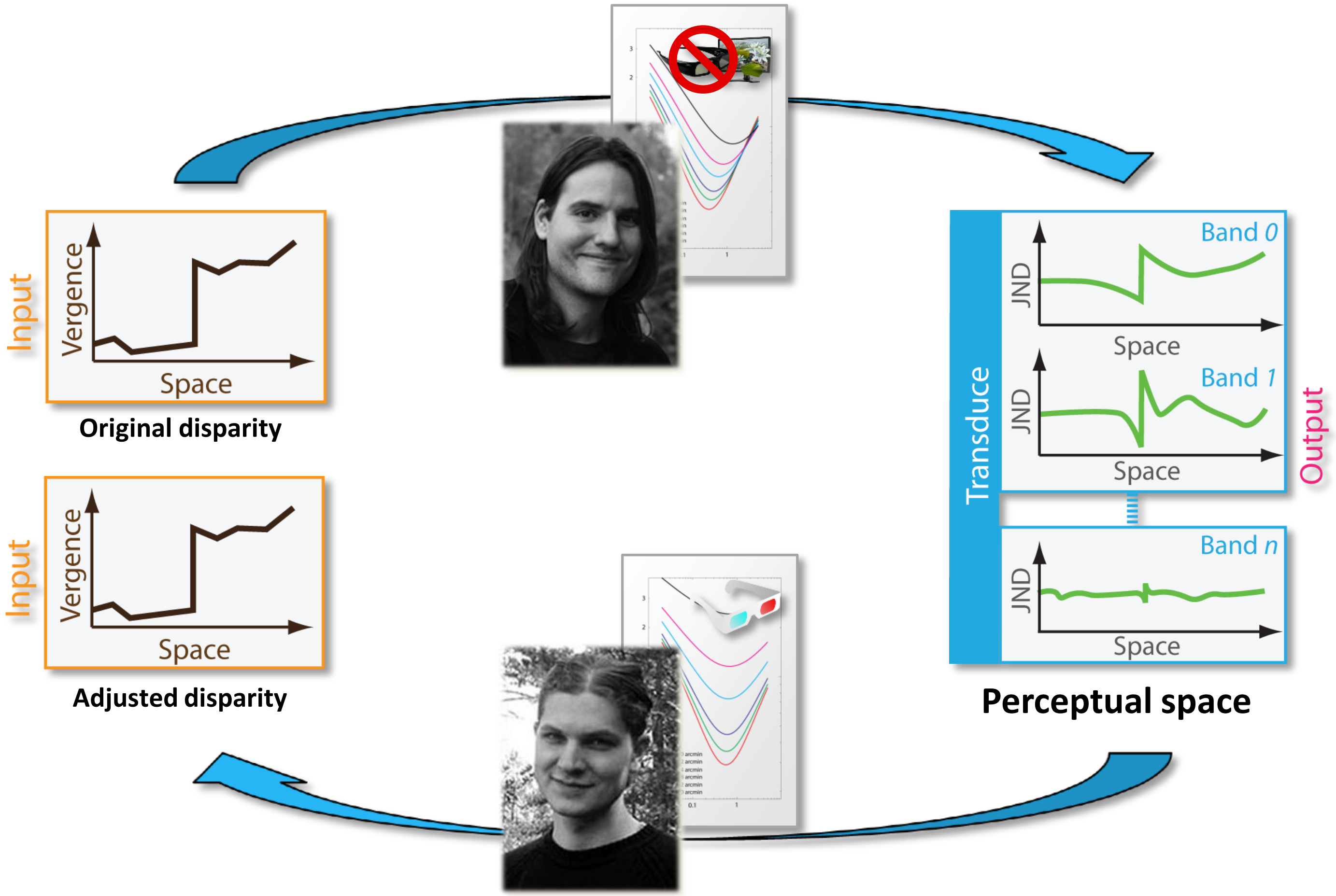
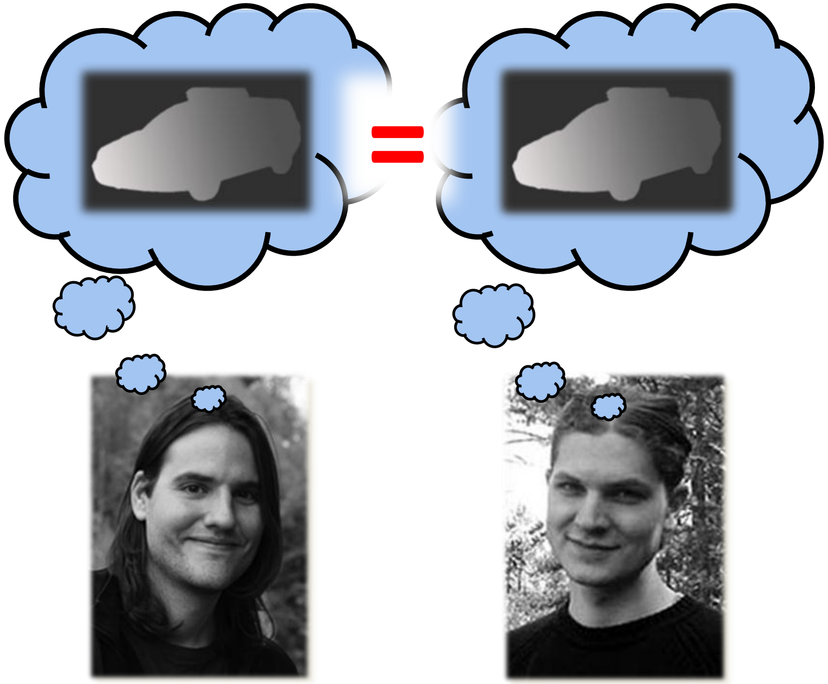


"A perceptual model for disparity" by Didyk et al. 2011

Personalization



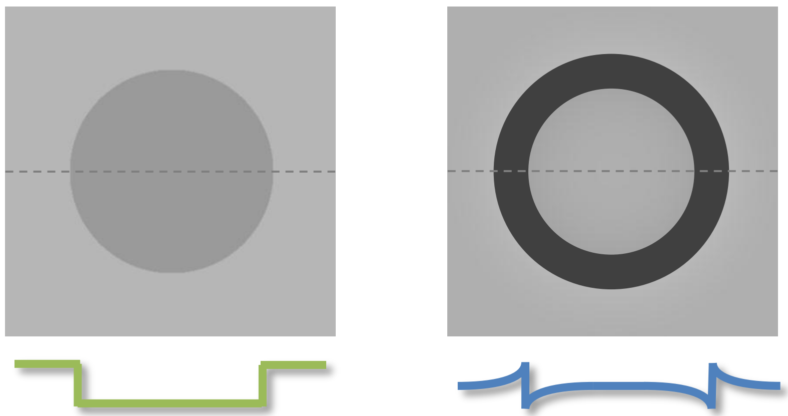
All users perceive the same regardless:

- Equipment
- Disparity sensitivity

Backward-compatible stereo

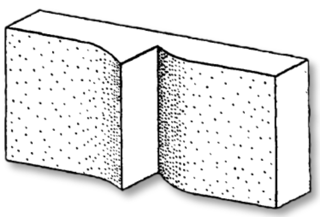
Backward-compatible stereo
Standard 2D image

Cornsweet illusion



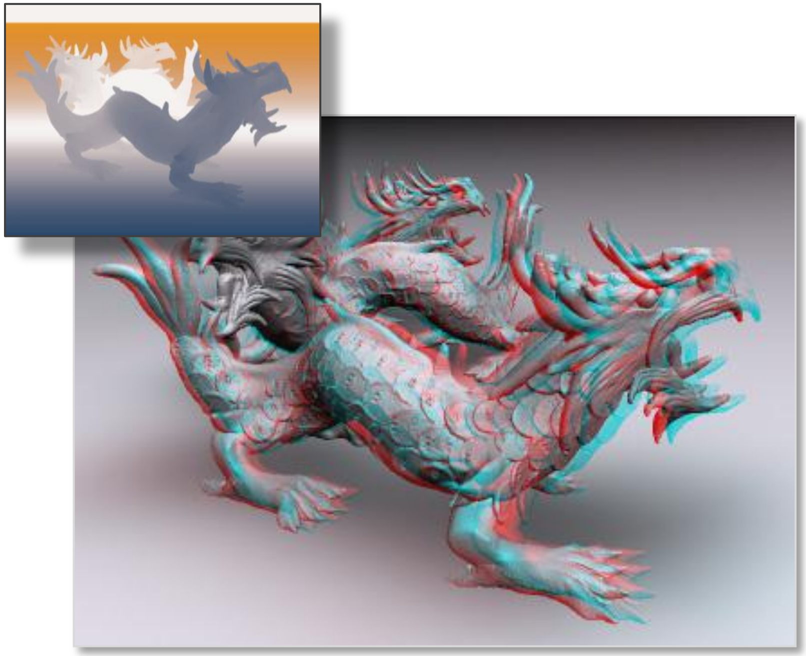
- Similar perceived contrast
- Luminance range reduced

Cornsweet illusion works for depth:



"A Craik-O'Brien-Cornsweet illusion for visual depth" by Anstis et al. 1997

Backward-compatible stereo



Standard stereo

Backward-compatible stereo

- 3D impression preserved
- No artifacts when special equipment is unavailable

"A perceptual model for disparity" by Didyk et al. 2011

Backward-compatible stereo

- 3D impression preserved
- No artifacts when special equipment is unavailable

"A perceptual model for disparity" by Didyk et al. 2011

Conclusions

- Stereo perception is complex phenomena
- Important aspects:
  - Viewing conditions
  - Viewer
  - Equipment
  - Temporal coherence …
- Different adjustment techniques:
  - Camera adjustment
  - Pixel disparity mapping operators
  - Perceptual space

Multidimensional image retargeting

- 9:00: Introduction
- 9:10: Dynamic range retargeting
  - Tone mapping
  - Apparent contrast and brightness enhancement
- 10:45: Break
- 11:00: Color retargeting
- 11:30: LDR to HDR
- 12:20: Temporal retargeting - Part I
- 12:45: Break
- 14:15: Temporal retargeting - Part II
- 15:00: Spatial resolution retargeting
- 16:00: Break
- 16:15: Image and video quality assessment
- 17:00: Stereo content retargeting
- **17:45: Q&A**
- 18:00: End