Stereoscopic 3-D video for the human eyes

Frédéric Devernay, INRIA Grenoble - Rhône-Alpes research done within the 3DLive project

with
Sergi Pujades, Elise Mansilla, Loïc Lefort, Martin Guillon, Matthieu Volat, Sylvain Duchêne

Images 3D : acquisition, synthèse et visualisation
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Three-Dimensional Depth Cues

And also **motion parallax**, **depth of field**, and... **stereoscopy**
Depth of field as a depth cue: focus matters!
Conflicting depth cues

- The 9 cues may give opposite indications on the scene geometry.

- The pseudoscope (Wheatstone) - reverse left and right eyes - causes closer objects to seem even bigger:
  - big in the image
  - binocular disparity indicates they are also far away

William Hogarth, 1754
Conflicting cues: Ames room

Used in *Lord of the Rings*, *Eternal Sunshine of the Spotless Mind*...
Stereoscopic conflicting cues:
Coraline 3D

Coraline (H. Selick & P. Kozachik)

2 vanishing points in the same 3-D scene
Stereoscopic conflicting cues: Coraline 3D

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Stereo-specific processes
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- Correcting causes of visual fatigue
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- Adapt the movie to the screen size
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- Global 3-D changes (interocular, infinity...)
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- Playing with the depth of focus
Stereo-specific processes

• Correcting causes of visual fatigue
• Adapt the movie to the screen size
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• Playing with the proscenium
Stereo-specific processes

• Correcting causes of visual fatigue
• Adapt the movie to the screen size
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• Local 3-D changes (3-D touchup)
• Playing with the depth of focus
• Playing with the proscenium
• 3-D compositing (real or CG scenes)
A few definitions

- Two cameras, two eyes
- Screen plane ... in the viewer space
- Plane of convergence .. in the scene space
- 3-D cone
- Interocular / Interaxial
  - bigger than 65mm (can be 30m) ⟹ hyperstereo (or miniaturization)
  - smaller than 65mm (can be 0cm) ⟹ hypostereo (or gigantism)
- Convergence
Binocular disparity: why we see in 3D

- Objects at different depths cause different disparities
left view
right view
The proscenium arch (or stereoscopic window)

The screen is a window on the world

If object closer than convergence plane touches the image borders...

→ Add black borders to move proscenium arch closer
Visual fatigue (1)
a critical point

• Can lead to:
  • a simple headache
  • temporary or permanent damage to the oculo-motor system (especially on children)

• A public health problem (just as the critical fusion frequency on CRT screens...)

INRIA
Visual fatigue (2)

geometric differences

a. vertical shift
b. size difference
c. distortion difference
d. keystone (toed-in cameras)
e. horizontal shift (divergence...)

1.4 Frédéric Devernay and Paul Beardsley

Fig. 6 Few examples of geometric asymmetries

Vertical shift
Size or magnification difference
Distortion difference
Keystone distortion due to toed-in cameras
Horizontal shift leading to eye divergence in this case (adapted from Ukai and Howarth [..])

Should be avoided. But they also went on to say that "Much experimental work must be carried out to determine limiting values of divergence at different viewing distances which are acceptable without eyestrain"

These limiting values are the maximum disparities acceptable around the convergence point, usually expressed as angular values, such that the binocular fusion of the 3D scene is performed without any form of eyestrain or visual fatigue.

Many publications dealt with the subject of finding the horizontal disparity limits, and the horizontal disparity limits are actually closely related to the depth of field, as noted by Lambooij et al. [89].

An accepted limit for DOF in optical power for a 8 mm pupil diameter, which is common under normal daylight conditions, is one-third of a diopter. With respect to the revisited Panum’s fusion area, disparities beyond one degree are conservative application of the .4 to :4 arcmin recommendation, which means ±4°.7° in disparity cause visual fatigue.

2.5.2 Vertical Disparity

Let us suppose that the line joining both eyes is horizontal, and that the stereoscopic display screen is vertical and parallel to this line. The images of any 3D point projected onto the display screen using each eye optical center as the centers of projection are two points which are aligned horizontally, i.e., have no vertical disparity.

In the human visual system, the space around the current fixation point which can be fused is called Panum’s area or fusion area. It is usually measured in minutes of arc (arcmin).

Yano et al. also showed that images containing disparities beyond the depth of field, which means ±4°.7° in disparity, cause visual fatigue.
Visual fatigue (3)

accommodation and convergence discrepancy

distance of accommodation
= distance to screen
≠ distance of convergence

Different display
⇒ Different depth of field:

- 3DTV (3.5m): 2m → 12m
- Movie theater (16m): 4m → infinity
Visual fatigue (4)  
screen size

One 3-D movie, different screens $\implies$ risk of divergence

Shifting the images solves divergence problems, but creates other problems:

- Breaks the stereoscopic window
- Causes depth distortions
Correcting geometric differences: the problem

- Mechanics and optics are intrinsically imprecise
- Check that the 3D movie can be comfortably viewed on a given screen (movie theater or 3DTV)
- On output, disparity must be purely horizontal
- Transform the images to remove geometric differences
Detect remarkable points or regions in both images

Match these points and regions

Compute image transformations to remove vertical disparities

Real-time correction of HD-SDI stereoscopic streams (2 x 1080p60)
Alerts for a 4m wide screen
Alerts for a 10m wide screen: crowd too close!
Alerts for a 10m wide screen + shift: divergence!
Global depth modifications: adapting to the display

<table>
<thead>
<tr>
<th></th>
<th>camera</th>
<th>display</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>b</strong></td>
<td>camera interocular</td>
<td>eye interocular</td>
</tr>
<tr>
<td></td>
<td>convergence distance</td>
<td>screen distance</td>
</tr>
<tr>
<td><strong>W</strong></td>
<td>width of convergence plane</td>
<td>screen size</td>
</tr>
<tr>
<td><strong>Z</strong></td>
<td>real depth</td>
<td>perceived depth</td>
</tr>
<tr>
<td><strong>d</strong></td>
<td>disparity (as a fraction of W)</td>
<td></td>
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</tbody>
</table>
Global depth modifications: changing $b$ (camera interocular)

**Hyperstereo**: 6.5 cm

**Hypostereo**: 0.5 cm

**Real depth**

**Perceived depth**
Global depth modifications:

$$H = \alpha b$$

Keep object image size constant: object farther/closer, zoom in/out, interocular proportional to distance
Perceived depth distortions

• 3D geometry is not distorted if and only if shooting and viewing geometry are the same

• used for IMAX-3D

• impossible in real situations (sports...)

• may break the stereoscopic window

• Objects don’t look «more 3D» on a bigger screen

• Distance is important: «more 3D» if screen farther

• **New view synthesis** is the only solution (requires depth map)
New view synthesis: baseline modification

Objects on screen are not distorted, but everything else is **very** distorted! **Divergence** may happen!
New view synthesis: viewpoint modification

No distortion at all, but many objects cannot be seen in the original images... bad solution!
New view synthesis: disparity remapping

Best tradeoff: depth is not distorted, no divergence happens, only apparent width is distorted... like on any 2D image.
New view synthesis: how we do it

- Video-rate depth map computation
- Computation done on the GPU
- Will be included in Binocle DisparityTakker in 2011 for the 3DLive project
- Can also be done in a set-top box on the display side (by Technicolor)