Perception of Perspective Distortions in Image-Based Rendering

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Goal & Strategy

- Want to study distortions in IBR
  - Identify applicable vision science ideas
  - Extend to street-level IBR context
  - Validate using rigorous experiments
  - Fit predictive models to results
  - Improve IBR applications
Image-based rendering (IBR)

1. Capture a photograph or panorama

façade

image plane

capture camera
Image-based rendering (IBR)

2. Texture map onto a reconstructed plane
Image-based rendering (IBR)

3. Visualize from any view
   - Angle distortions
Related work

– Street-level image-based rendering
  [e.g., Debevec et al. 1998, Snavely et al. 2006, Kopf et al. 2010]

– Perception of artifacts in IBR
  [e.g., Morvan & O’Sullivan 2009, Steinicke et al. 2011, Vangorp et al. 2011]

– Vision science on picture perception
  [e.g., Perkins 1972, Vishwanath et al. 2005, Yang & Kubovy 1999, Cooper et al. 2012]
Vision science background

Scene hypothesis

Retinal hypothesis
Pointing phenomenon
Extended retinal hypothesis

1. Capture
2. Projection
3. Simulation
4. Display & viewing
Extended retinal hypothesis

1. Capture
   - Perspective projection
     \((x', y') = f \cdot (x, y) / z\)
   - Vanishing points: limit at infinity
Extended retinal hypothesis

2. Projection
   – Perspective unprojection onto proxy
     \textit{aka} projective texture mapping
   – Keep track of vanishing points

\begin{itemize}
\item[] proxy
\item[] vanishing point
\item[] capture camera
\item[] capture camera image
\end{itemize}
Extended retinal hypothesis

3. Simulation
   - Perspective projection with novel viewpoint
   - Keep track of vanishing points
Extended retinal hypothesis

4. Display & Viewing
   - Where are the vanishing points?
Extended retinal hypothesis
Angle between vanishing points

- Angle at viewer = angle on façade
Extended retinal hypothesis

\[ \alpha_{\text{front}} = \arctan \left| \frac{x_{v,\text{front}}}{z_{v,\text{front}}} \right| \]

\[ = \begin{cases} 
90^\circ & \text{if } \theta_s = 0 \\
\arctan \left( \frac{M \cdot f_s}{u \cdot \tan \theta_s} \right) & \text{otherwise}
\end{cases} \]

\[ \alpha_{\text{side}} = \arctan \left| \frac{x_{v,\text{side}}}{z_{v,\text{side}}} \right| \]

\[ = \arctan \left( \frac{M \cdot f_s}{u} \cdot \frac{\tan \theta_e \cdot \cos \theta_s}{\tan \theta_e \cdot \sin \theta_s + 1} \right) \]

\[ \alpha_{\text{total}} = \alpha_{\text{front}} + \alpha_{\text{side}} \]
Parameters

– Eccentricity angle $\theta_e$
Parameters

- Eccentricity angle $\theta_e$
Parameters

- Eccentricity angle $\theta_e$
- Simulation angle $\theta_s$
Parameters

– Eccentricity angle $\theta_e$
– Simulation angle $\theta_s$
– Display size $M$
– Viewing distance $v$
Experiments
Stimuli & Conditions

- 3 synthetic façade designs with 3 depth variations:

- 4 eccentricity angles: −32°, −7.1°, 7.1°, 32°
- 5 simulation angles: −30°, −15°, 0°, 15°, 30°
- 4 display sizes: smartphone (3.5″), tablet (9.7″), PC (24″), TV (55″)
Experiments

- 2 experiments: angle matching + angle rating
- 180 stimulus images, each repeated twice
  - for each experiment and on each display
  - additional repetitions for consistency check
- 6 paid participants, ~7 hours each
- Over 9000 trials per experiment
Experiment 1: Angle Matching
Look at the convex corner at the center of the image. Set the hinge device to the angle you perceive (and not what you think it should be). Press ENTER when the hinge device is set ...
Look at the corner at the center of the image. But the image device is the angle you perceive (and not what you think it should be). Please ENTER when the image device is not...
Angle-matching results

![Graphs showing angle-matching results for different hypotheses: Scene hypothesis, Average results, and Retinal hypothesis. The graphs display perceived angles against simulation angles for different eccentricity angles: $-32^\circ$, $-7.1^\circ$, $7.1^\circ$, and $32^\circ$.](image-url)
Angle-matching results

façade depth: 1 m

0.67 m

0.33 m

Eccentricity Angles: 
-32°  -7.1°  7.1°  32°
Experiment 2: Angle Rating
Look at the convex corner at the center of the image. How close does it look to a right angle?

1 = perfect  2 = close enough  3 = kind of  4 = not really  5 = no way!

Press ENTER to confirm ...
Ratings vs. perceived angles
Fit predictive model

Average ratings (for 1 m)

Predictive model

Eccentricity Angles:
- $-32^\circ$
- $-7.1^\circ$
- $7.1^\circ$
- $32^\circ$
Distortion guideline

Average ratings vs. Predicted ratings

(extended domain)
Validation experiment

- good path
- medium path
- bad path
Validation experiment

Floralies

Church

Balcony

Observed Rating

Predicted Rating
Applications

1. Guideline for capture density
2. Interactive navigation of street-level IBR
3. Visualization of IBR path designs
Capture guidelines

façade

capture camera

perfect close enough kind of not really no way!
Interactive navigation

Capture Camera (hidden)

Simulation Camera

Façade

Novel Viewpoint
Visualization of IBR paths
Summary

– Extension of vision science research to IBR
– Study of distortions in rigorous experiments
– Predictive model of perspective distortions
– Three applications: capture guideline, interactive navigation & path visualization
Future work

– Stereoscopic viewing
– Angles other than right angles
– More complex proxy geometry
– Moving the simulation camera over time
– Study of transition artifacts
Thanks. Questions?

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Extra slides
Pointing phenomenon

- Retinal hypothesis
- Finger/gaze straight out
- VPs at fingertip/eyes
- Perceived direction straight at you