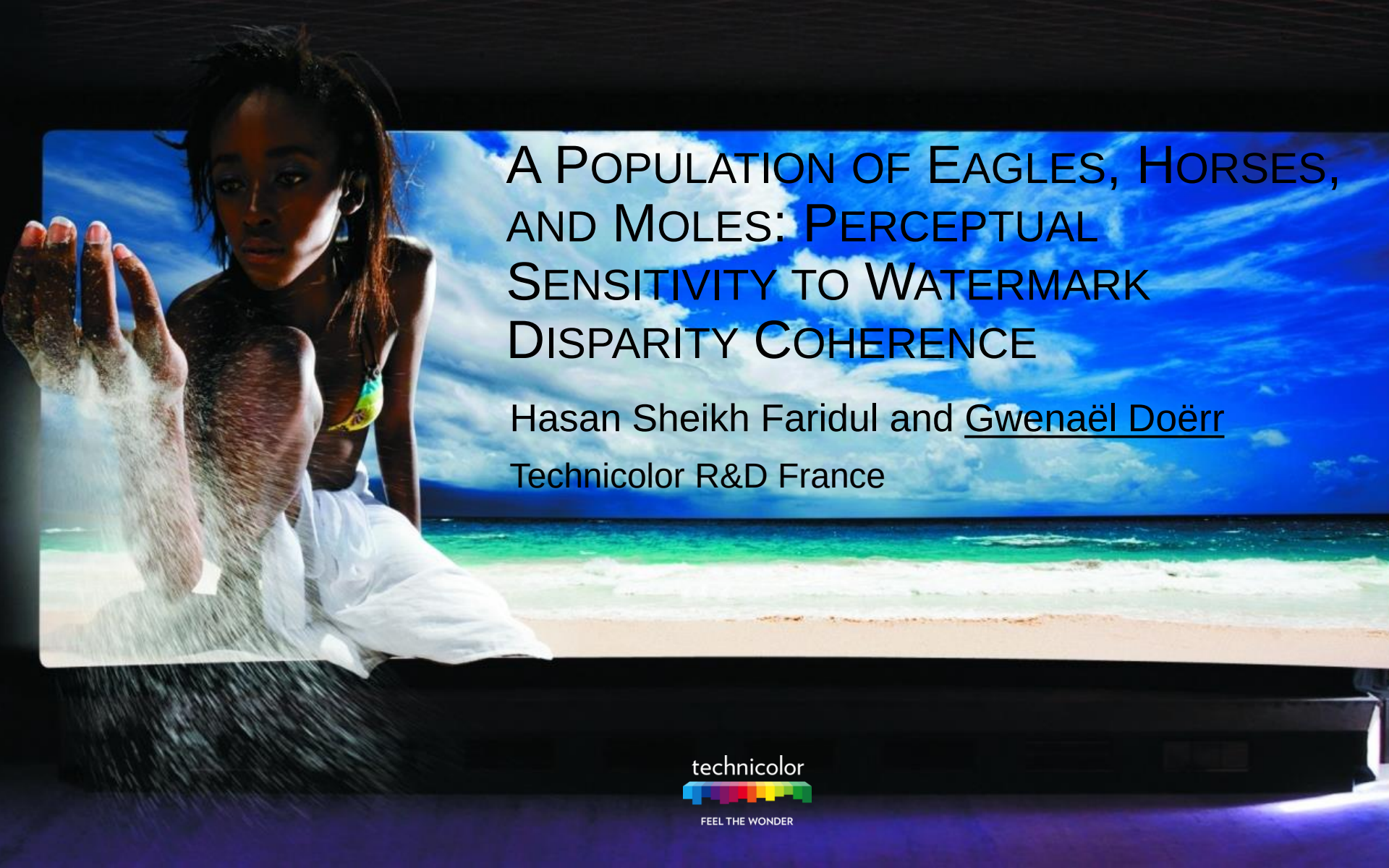

A Population of Eagles, Horses, and Moles: Perceptual Sensitivity to Watermark Disparity Coherence

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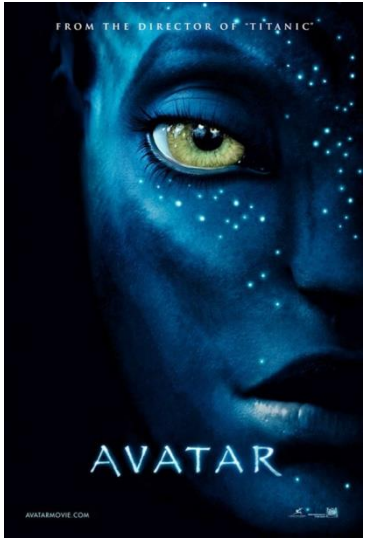
Agenda

- Introduction, incl. a refresher on stereo video watermarking
- Perceptual evaluation protocol
- Preference profiles of the observers
- Stereo video watermarking and content dependency
- Take away lessons

Context

Renewed interest in the late 2000's

- Potential for increased immersive experience
- "Camcord piracy does not work with 3D"



Status after the buzz

- Digital cinema vs. home entertainment
- 3D movie projections have been pirated

Watermarking challenges with stereo video

- Reuse off-the-shelf recipes for the communications layer
- Accommodate for the specificities of the content
  - Perceptual impairment due to depth degradation
  - Robustness to view synthesis

SS Watermarking for Stereo Video

A single embedding equation…

… with three alternate incarnations

$$\mathbf{v}_{\mathrm{L|R}}^{(\mathrm{w})} = \mathbf{v}_{\mathrm{L|R}} + \alpha . \mathbf{w}_{\mathrm{L|R}}, \qquad \mathbf{w}_{\mathrm{L|R}} \sim N(0,1), \quad \alpha > 0$$

1. Same watermark	2. Different watermarks	3. Disparity-coherent watermarks
$\mathbf{w}_{\mathrm{L}} = \mathbf{w}$ $\mathbf{w}_{\mathrm{R}} = \mathbf{w}$	$\mathbf{w}_{\mathrm{L}} = \mathbf{w}_1$ $\mathbf{w}_{\mathrm{R}} = \mathbf{w}_2$	$\mathbf{w}_{\mathrm{L}} = \mathbf{w}$ $\mathbf{w}_{\mathrm{R}} = \mathrm{warp}(\mathbf{w}, \mathbf{d}_{\mathrm{L}}, \boldsymbol{\theta}_{\mathrm{L}}, \boldsymbol{\theta}_{\mathrm{R}})$

Coherent vs. (Same or Different)

- ☺ Improved robustness against view synthesis and lossy compression
- 😐 Alleged improved fidelity
- ☹ Computational overhead

Perceptual Study Protocol

Dataset: 15 stereo pair images from RMIT 3DV dataset

- HD resolution (1920×1080) with aspect ratio 16:9
- Watermarked with specified embedding strength (no perceptual shaping)

Display: Samsung 3D TV with active 3D glasses

Observers: 33 volunteers from Technicolor R&D France

- Good balance age, gender, signal processing expertise
- Depth perception and acuity evaluated with *Randot Stereo Test*

Protocol: Two Alternate Force Choice (2AFC)

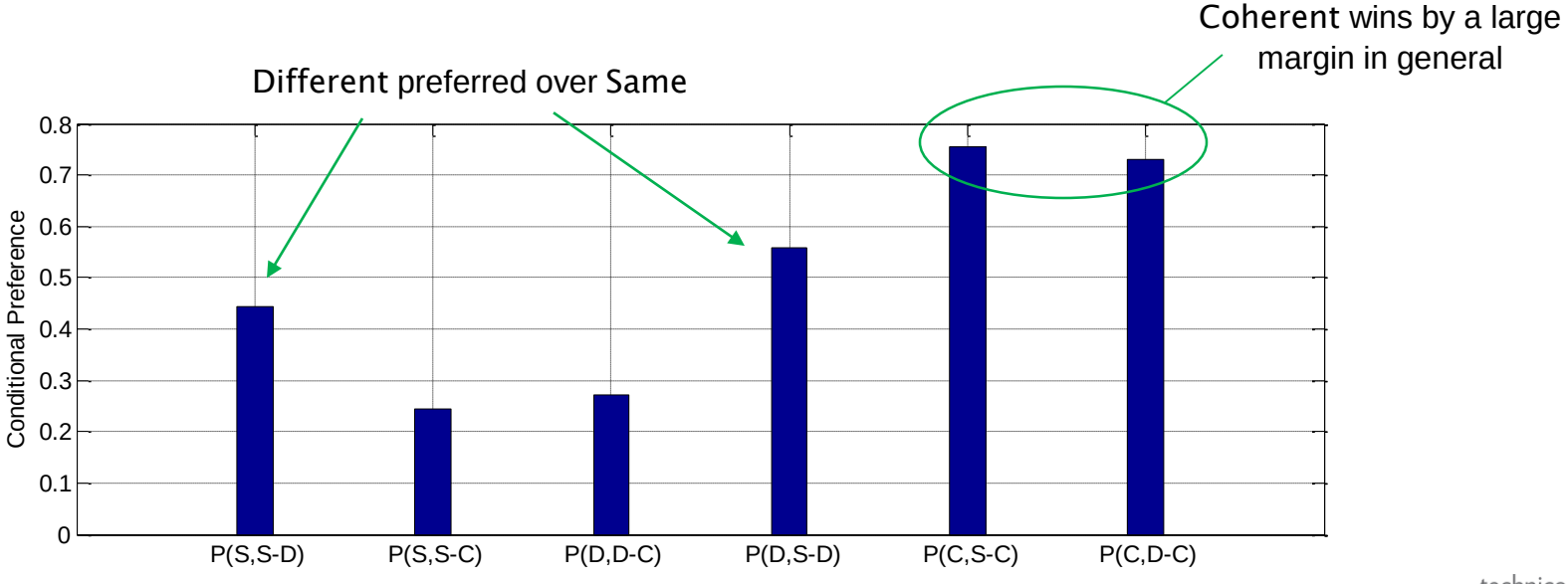
- Question: Which stereo pair is more comfortable (less annoying) to watch?
- Side-by-side display impossible: switch as many times as needed and vote
- 15×3=45 elementary tests in randomized order = 15-20 minutes

Preference of the Observers

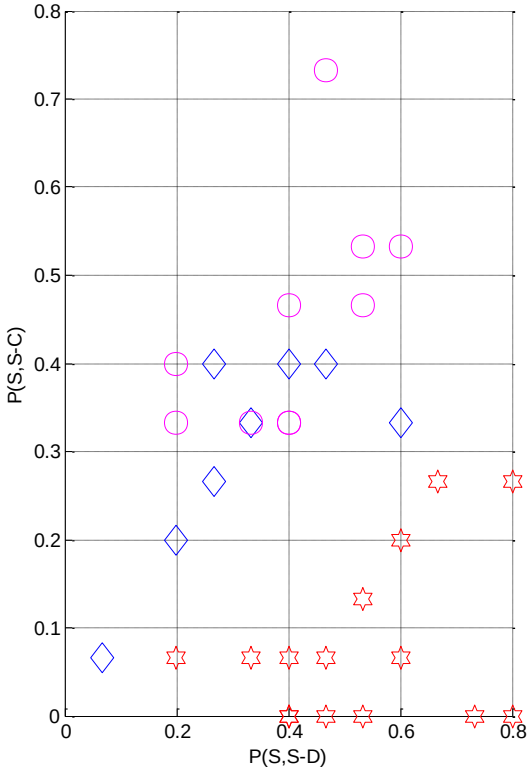
First experiment with strong embedding strength (α=20)

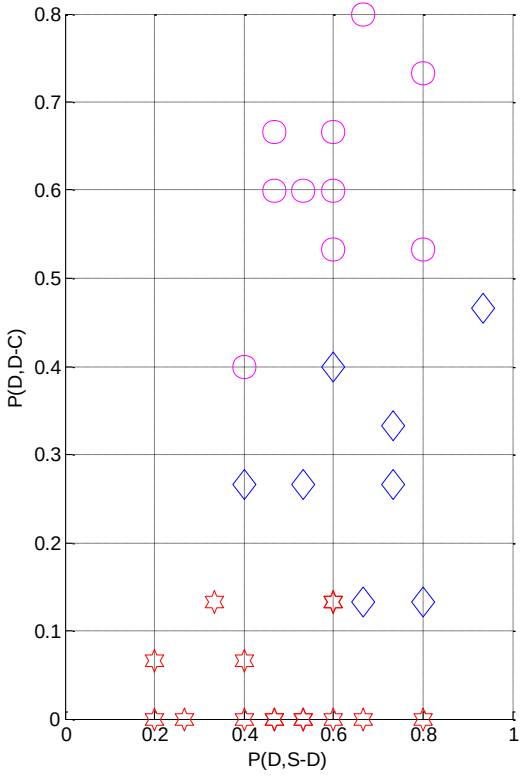
Overall preference: Same (34%) < Different (42%) < Coherent (74%)

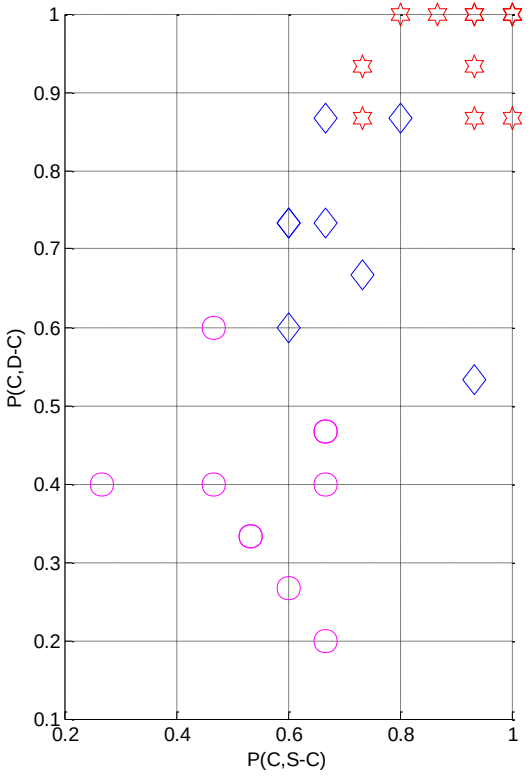
- Nice feeling of overlaid pattern for disparity-coherent watermarks
- Same looks like “dust on the screen” which is very annoying



A Population Split in Three







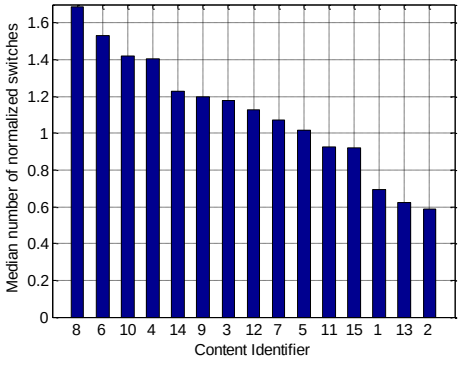
Eagles, Horses, and Moles

Observer category	S vs. D	S vs. C	D vs. C
Eagles	S	**C**	**C**
Horses	**D**	C	C
Moles	D	(C)	(D)

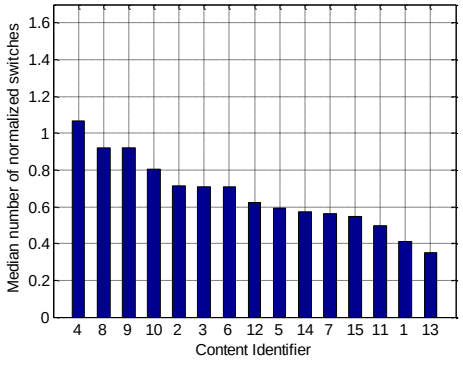
Additional findings

- Eagles + Horses ≈ 2/3 of the population
- Poor correlation with Randot profile ⇒ dedicated perceptual studies needed
- Sensitivity to disparity coherence remains with low-power watermarks (α=3)

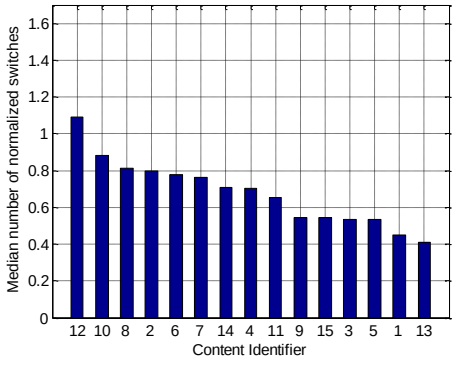
Content Dependency



Same vs. Different



Same vs. Coherent



Different vs. Coherent

Complexity ≈ number of switches prior to making a decision

- Per user normalization for comparative purpose
- S-D comparison are more complex, especially for Eagles “equally bad in a different way”
- Easy/difficult content e.g. {1, 13, 15} vs. {8, 10}

Take Away Lessons

Perceptual sensitivity to disparity-coherence evaluated empirically

- Three categories of observers incl. two that feel/see the virtue of disparity coherence
- Not correlated with Randot test
- Sensitivity remains for nearly invisible watermarks

Future work

- Investigate potential correlation with biological signals
- Understand content dependency to devise relevant perceptual shaping strategies

Perspective

- Severe aversion for Same casts a new light on potential reasons behind the slow adoption of 3D video technologies

Thank you for your attention

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