A Model of Local Adaptation

Peter Vangorp
Karol Myszkowski
Erich W. Graf
Rafał K. Mantiuk

Bangor University and MPI Informatik

MPI Informatik

University of Southampton

Bangor University and University of Cambridge
Contrast Perception

Would you be able to read the print on the light bulb?
Contrast Perception
Contrast Perception
Previous Models of Adaptation

- Physiology and psychophysics
  - Naka-Rushton: \( R = k \frac{L^n}{L^n + \sigma (L_a)^n} \)
    - requires “adaptation luminance” \( L_a \)

- Ad hoc models used in computer graphics
  - Naka-Rushton model with adaptation luminance = ?
    - global average luminance
    - local per-pixel luminance
    - local average computed in 1° Gaussian window
Basic Contrast Detection Model

```
input luminance image \( L \)
```

```
OTF \rightarrow tvi \rightarrow \Delta L/L
```

“traditional” threshold contrast \( \Delta L/L \)
Our Adaptation Model

OTF $\rightarrow$ tvi $\rightarrow$ \( \frac{\Delta L}{L} \) $\rightarrow$ Local Adaptation $\rightarrow$ Threshold Elevation

- Input luminance image \( L \)
- "Traditional" threshold contrast \( \Delta L/L \)
- Elevated threshold contrast \( \Delta L/L \)
- Adaptation luminance \( L_a \)
Our Adaptation Model

Local Adaptation:

\[ \text{input luminance image } L \]

\[ tvi \]

\[ \frac{\Delta L}{L} \]

\[ \text{"traditional" threshold contrast} \]

\[ \text{NL} \]

\[ \text{Pooling} \]

\[ \text{NL}^{-1} \]

\[ \text{adaptation luminance} L_a \]

Threshold Elevation

\[ \times \]

\[ \frac{\Delta L}{L} \]

elevated threshold contrast
Our Adaptation Model

Local Adaptation:

- $\text{NL}_1$ -> Pooling$_1$ -> $\text{NL}^{-1}_1$
- $\text{NL}_2$ -> Pooling$_2$ -> $\text{NL}^{-1}_2$

Threshold Elevation

- "traditional" threshold contrast $\Delta L/L$
- elevated threshold contrast $\Delta L/L$

input luminance image $L$

adaptation luminance $L_a$
Our Adaptation Model

Local Adaptation:

OTF → tvi → / → NL_1 → Pooling_1 → NL^{-1}_1 → + → NL_2 → Pooling_2 → NL^{-1}_2 → Threshold Elevation

"traditional" threshold contrast \( \Delta L/L \)

elevated threshold contrast \( \Delta L/L \)

input luminance image \( L \)

adaptation luminance \( L_a \)
High Dynamic Range Display
High Dynamic Range Display

iPad LCD (retina resolution)

132 cm
High Dynamic Range Display

Projector backlight
0.01 – 5000 cd/m²
Experiments: Baseline Adaptation

1. Adapt similar to [Hood et al. 1979]
Experiments: Baseline Adaptation

2. Flash 200 ms

similar to [Hood et al. 1979]
3. Orientation of the edge?

similar to [Hood et al. 1979]
Experiments: Baseline Adaptation

3. Orientation of the edge?

similar to [Hood et al. 1979]
Experiments: Baseline Adaptation

Adaptation luminance [cd/m²] vs. Detection contrast (G)
Experiments: Baseline Adaptation

Detection contrast (G) vs. Adaptation luminance [cd/m²]
Experiments: Baseline Adaptation

Adaptation luminance [cd/m$^2$] vs. intensity
Experiments: Baseline Adaptation

Detection contrast (G) vs. Adaptation luminance [cd/m²]
Experiments: Baseline Adaptation

Detection contrast (G)

Contrast vs. intensity

Adaptation luminance [cd/m²]
Experiments: Adaptation Patterns

- Extent of pooling
- Long-range effects
- Pooling non-linearity
- Radial symmetry & contrast masking
- Natural images
Experiments: Extent of pooling

1. Adapt
Experiments: Extent of pooling

2. Flash 200 ms
Experiments: Extent of pooling

3. Orientation of the edge?
Experiments: Extent of pooling

- Detection contrast levels off at 0.5°
Experiments: Pooling non-linearity

- Not linear
- Not logarithmic
- Asymmetric

![Graph showing detection contrast G vs. bright half luminance][1]

Central flash luminance

![Graph showing detection contrast G vs. bright half luminance][1]
Experiments: Radial symmetry

- Rotation makes no difference
Experiments: Adaptation Patterns

- Extent of pooling
- Long-range effects
- Pooling non-linearity
- Radial symmetry & contrast masking
- Natural images
- General model → 56 specific candidate models
- Model fitting using parallel genetic optimization
- Cross-validation: maximally differentiating stimuli
Our Best Adaptation Model

- Wider support at lower luminance
  - due to non-linearities
  - adaptation site shifts to postreceptoral mechanisms [Dunn et al. 2007]

- Complex pooling mechanism
  - cross-validated to avoid overfitting
  - more complex than known retinal pooling
  - receptive fields in LGN or visual cortex?
Our Best Adaptation Model

- Wider support at lower luminance
  - due to non-linearities
  - adaptation site shifts to postreceptoral mechanisms [Dunn et al. 2007]

- Complex pooling mechanism
  - cross-validated to avoid overfitting
  - more complex than known retinal pooling
  - receptive fields in LGN or visual cortex?
Our Best Adaptation Model

- Wider support at lower luminance
  - due to non-linearities
  - adaptation site shifts to postreceptoral mechanisms [Dunn et al. 2007]

- Complex pooling mechanism
  - cross-validated to avoid overfitting
  - more complex than known retinal pooling
  - receptive fields in LGN or visual cortex?
Our Best Adaptation Model

- Wider support at lower luminance
  - due to non-linearities
  - adaptation site shifts to postreceptoral mechanisms [Dunn et al. 2007]

- Complex pooling mechanism
  - cross-validated to avoid overfitting
  - more complex than known retinal pooling
  - receptive fields in LGN or visual cortex?
Our Best Adaptation Model

- Wider support at lower luminance
  - due to non-linearities
  - adaptation site shifts to postreceptoral mechanisms [Dunn et al. 2007]

- Complex pooling mechanism
  - cross-validated to avoid overfitting
  - more complex than known retinal pooling
  - receptive fields in LGN or visual cortex?
Application: Adaptive Rendering

- Adaptive sampling until noise contrast undetectable

<table>
<thead>
<tr>
<th>Sample density</th>
<th>Our method</th>
<th>Non-adaptive equal time</th>
<th>Weber adaptive equal quality – 30% slower</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[Image]</td>
<td>[Image]</td>
<td>[Image]</td>
</tr>
</tbody>
</table>

[Image]
Application: HDR Display Design

Front LCD panel  Backlight LED array  Combined HDR image

Visible difference
Application: HDR Display Design

Front LCD panel

Backlight LED array

Combined HDR image

Visible difference
Application: HDR Display Design

Front LCD panel | Backlight LED array | Combined HDR image

Visible difference
Application: Dynamic Range

physical dynamic range: 18 stops

3000 cd/m²

0.01 cd/m²
Application: Dynamic Range

physical dynamic range: 18 stops

500 cd/m²

visible dynamic range: 8.5 stops 3000 cd/m²

1.3 cd/m²

0.01 cd/m²
Application: Afterimages
Applications

Gaze-dependent Tone Mapping
Summary of Contributions

- General model
  - local adaptation luminance
  - contrast detection threshold
- Experiment
  - contrast detection while adapted to various patterns
- Analysis
  - interpretation of results of individual sets of patterns
  - model fitting to all patterns
  - cross-validation using maximally differentiating patterns
- A selection of applications
Thanks! Questions?

Source code available at http://localadapt.pvangorp.be/

Acknowledgments:
High Performance Computing Wales
Fraunhofer and Max Planck cooperation within German Pact for Research and Innovation (PFI)