Computing perceived images: When colour meets texture

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We work on giving visual abilities to machines.

How?

The hardware ...

The software ?? ... is the most difficult

10 years ago ...

**Problem:** Automatic tile classification based on colour texture properties
... 2 years later

**Problem:** Automatic adjustment of colour inks for paper printing

Both problems has in common, that can not be solved using colorimetric devices, since all these surface give equal measurements

... we need to work on the digital image of the surface and measure colour and texture

using computer vision techniques !!!
We need to get digital images to measure colour texture surface properties.

One approach could be ...

Compute colour-texture measurements
But, the problem is
what the camera acquire is not the same as we see

Image formation

Illuminant

Surface

Sensor

Illuminant

Surface

Observer
Why?

Human perception presents *colour induction* phenomena that changes the colour appearance of a stimulus due to the influence of the scene contents.

**Different types of colour induction:**

- Colour adaptation
- Colour contrast
- Colour assimilation

Colour constancy

More related to colour-texture interactions
We focus on the last two ...

**Colour Contrast**

Appears when the chromaticity of the test stimulus changes away from the chromaticity of the inducing stimulus.

**Colour Assimilation**

Appears when the chromaticity of the test stimulus changes towards the chromaticity of the inducing stimulus.

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**Colour Contrast**

![Diagram showing Colour Contrast]

\[ r+g+b=1 \]
**Conclusion:**

Colour contrast & Colour assimilation are complementary effects

**Question:**

When they occur?
Some experiments show a relationship between spatial frequency of patterns and colour induction

The role of spatial frequency in color induction
Vision Research, 41 (2001) 1007-1021

Two different Induction effects:
Two different Induction effects:

...Now, the **question** is:

How to consider induction effects on a computational colour-texture representation?

that is,

Can we build the **perceived image**, instead of the sensor image?
We can build perceived images by doing ...

- Assimilation → Blurring operator
- Contrast → Sharpening operator

\[ I_{A,\sigma} = I * G_\sigma \]

\[ I_{C,\sigma} = I - \nabla^2 I \]

\[ \nabla^2 I = \frac{\partial^2 (I * G_\sigma)}{\partial x^2} + \frac{\partial^2 (I * G_\sigma)}{\partial y^2} \]
With these two operators we can simulate human inspection of colour texture surfaces

Looking from a long distance
Assimilation or Blurring

... a short distance
Contrast or Sharpening

Proposed Schema: Perceptual tower of perceived images simulating a visual process

Perceptual Tower of perceived images
Blurred images
Induction threshold
Sharpened images

Blurred images
Long-distance observation

Sharpened images
Short-distance observation
Considerations to build this perceptual tower computationally:

- Where is the induction threshold?
- On what colour space?
- the blurring operator
- the sharpening operator

Induction operators for a computational colour-texture representation  
Computer Vision and Image Understanding 94 (2004) 92-114

[Petrou et al. 1998] M. Petrou, M. Mirmehdi, M. Coors  
Perceptual smoothing and segmentation of colour textures  
5th European Conference on Computer Vision, Freiburg, Germany, 1998, 623-639
**Problem:** Where we change from assimilation to contrast on this new representation on digital images

Where we change from assimilation to contrast on this new representation on digital images [Smith et al- 2001] V.C. Smith, P.Q. Jin, J. Pokorny
*The role of spatial frequency in color induction*
Vision Research, 41 (2001) 1007-1021

**Induction threshold,** what is 4cpd (cycles per degree)?

It is a measure of the observed spatial frequency, that is, *number of periods in 1° of visual angle*
When working with digital images, we have to translate it by fixing

\[ d \]: Observer distance
\[ l \]: Observed surface in 1 degree of visual angle

\[ \tan(\beta) = \frac{l}{d} \]

Given a digital image of size \( N \times N \),

\[ (T_{\text{pixels}})_{\text{max}} = N_{\text{pixels}} \quad (T_{\text{pixels}})_{\text{min}} = 2_{\text{pixels}} \]

If it is projected as a stimulus with pixel size \( l_d \)

\[ T = 4 \text{cpd} \rightarrow l = 4 \cdot (T_{\text{pixels}} \cdot l_d) \rightarrow T_{\text{pixels}} = \frac{l}{4l_d} = \frac{d \cdot \tan(\beta)}{4l_d} \]

\( l_d \): pixel size
\( l \): Projected image

For a given image, the threshold between assimilation and contrast will change depending on selected \( l, d \)
Considerations to build this perceptual tower computationally:

- Where is the induction threshold?
- On what colour space?
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**Colour opponent space** predicts the colour induction effects

Pattern-color separable pathways predict sensitivity to simple colored patterns  
Vision Research 36(4) (1996) 515-526

\[
\text{Opp}(P) = P \begin{pmatrix} 1 & 1 & 1 \\ 1 & -1 & 1 \\ 1 & 0 & -2 \end{pmatrix}
\]

Example:

RGB | Opponent
--- | ---
![RGB Image](image1.png) | ![Opponent Image](image2.png)
Considerations to build this perceptual tower computationally:

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**Computational operators for assimilation**

*A spatial extension of CIELAB for digital color image reproduction.* In SID, 1996

**Spatial CIELAB:** models human colour assimilation process as a set of gaussian filters in an opponent space

\[ f_k = \sum_i \omega_i k_i \exp \left( -\frac{x^2 + y^2}{\sigma_i^2} \right) \quad k = 1…3 \]

\( \omega_i \): viewing distance factor \( k_i \): normalisation factor

Example:

- Original images
- Perceived images
Considerations to build this perceptual tower computationally:

- Where is the induction threshold?
- On what colour space?
- the blurring operator
- the sharpening operator

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**Computational operators for contrast**

[Baldrich 2001] R. Baldrich  
*A perceptual approach for computation colour-texture representation*  
Phd Thesis, Computer Vision Center – Universitat Autònoma de Barcelona (2001)
**Contrast Operator:**

1. Given Image $I$
2. Laplacian of Gaussian
   
   \[
   \Delta G = \frac{1}{\sigma^2} \left[ 1 - \frac{x^2 + y^2}{2\sigma^2} \right] e^{-\frac{x^2 + y^2}{2\sigma^2}}
   \]
3. Obtaining edges
   
   \[
   Z(I_c) = \text{ZeroCross}(\text{LoG}(I_c))
   \]
4. Interpolate responses
   
   \[
   S\text{LoG} = \text{Int}(Z(I_c))
   \]
5. Subtract (4) from (1) to get the weighted contrast effect
   
   \[
   P\text{Sharp} = I_c - \gamma \cdot S\text{LoG}(I_c)
   \]

**Proposed Schema:**

Computational approach to colour texture perception
**Example:** perceptual tower on natural images

**Properties** of a good contrast operator is maintaining structural properties of the image blobs.
**Result:** Obtaining a good colour segmentation preserving blob structures

**Other Applications:** Image enhancement


*Colour enhancement based on perceptual sharpening*

But, still there are open problems:

Spatial CIELAB and Perceptual Sharpening do not present a unified approach on the image

blurring and sharpening are completely separated

We propose a unified approach based on wavelets

**A unified approach:** Towards a Wavelet Perceptual Model

**Preliminary:** Wavelet decomposition with à trous algorithm

\[
I = \sum_{j=1}^{N} \omega_j + c_N \quad \text{where} \quad \omega_j = c_{j-1} - c_j
\]

\[
c_0 = I
\]

\[
c_1 = I \ast h_1
\]

\[
c_2 = (I \ast h_1) \ast h_2
\]

\[
\vdots
\]

\[
c_{j+1} = c_j \ast h_{j+1} = \cdots ((I \ast h_1) \ast h_2) \ast \cdots) \ast h_{j+1}
\]
Preliminary: Wavelet decomposition with á-trous algorithm

\[
h_j = \frac{1}{256}
\]

Wavelet planes

\[
I_{\text{intensity}} = \sum_{j=1}^{6} \omega_j + c_6
\]
\[ I_{\text{red-green}} = \sum_{j=1}^{6} \omega_j + C_6 C_6 \]

\[ I_{\text{blue-yellow}} = \sum_{j=1}^{6} \omega_j + C_6 C_6 \]
Wavelet recovery

\[ I_{\text{intensity}} = \sum_{j=1}^{6} c_j + c_6 \]
\[ I_{\text{red-green}} = \sum_{j=1}^{6} c_j + c_6 \]
\[ I_{\text{blue-yellow}} = \sum_{j=1}^{6} c_j + c_6 \]

Modified Wavelet recovery

\[ I'_{\text{intensity}} = \sum_{j=1}^{6} a_j \cdot c_j + c_6 \]
\[ I'_{\text{red-green}} = \sum_{j=1}^{6} a_j \cdot c_j + c_6 \]
\[ I'_{\text{blue-yellow}} = \sum_{j=1}^{6} a_j \cdot c_j + c_6 \]

\[ a_j : \text{Weighting function} \]

\( \alpha < 1 \rightarrow \) Differences are reduced (Blurring effect)
\( \alpha > 1 \rightarrow \) Differences are increased (Sharpening effect)

\[ I_{\text{perceived}} = \left( I'_{\text{intensity}} \quad I'_{\text{red-green}} \quad I'_{\text{blue-yellow}} \right) \]

Wavelet planes

\( \omega_1 = c_2 - c_1 \)
\( \omega_2 = c_1 - c_2 \)
\( \omega_3 = c_2 - c_3 \)
\( \omega_4 = c_3 - c_4 \)
\( \omega_5 = c_4 - c_5 \)
\( \omega_6 = c_5 - c_6 \)

Assimilation effect

Induction threshold ?

Contrast effect

4cpd
To compute the induction threshold, again we have to fix \( l, d \)
\[
l = \tan(\beta) \cdot d
\]

The wavelet plane, \( j \), represents the period
\[
T = 2^j
\]

Considering the construction procedure, we have

\[
j = 1 \rightarrow T = 2
\]
\[
j = 2 \rightarrow T = 2^2 = 4
\]
\[
j = 3 \rightarrow T = 2^3 = 8
\]
\[
\vdots
\]

\( l_d \): pixel size

\( l = 4 \cdot 2^{j_{thr}} \cdot l_d \)

Projected image

Wavelet planes

\[
\omega_1 = c_2 - c_1
\]
\[
\omega_2 = c_1 - c_2
\]
\[
\omega_3 = c_2 - c_3
\]
\[
\omega_4 = c_3 - c_4
\]
\[
\omega_5 = c_4 - c_5
\]
\[
\omega_6 = c_5 - c_6
\]

Assimilation effect

Induction threshold

Contrast effect

\( \alpha_j < 1 \)

\( \alpha_j > 1 \)

\[
I_{perceived} = \sum_{j=1}^{j_{thr}} (\alpha_j < 1) \cdot \omega_j + \sum_{j>j_{thr}} (\alpha_j > 1) \cdot \omega_j + c_6
\]
**Problem:** Which is the best function for \( \alpha \)?

\[
I_{\text{perceived}} = \sum_{j=1}^{N} \alpha_j \omega_j + c_N \quad \text{where} \quad \alpha_j = \frac{C}{1 + e^{J_{thr} - J}}
\]

\[C = 1.5 \quad m \approx 2 - 2.5\]
Other examples of perceived images

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