CONTOUR
DETECTION
BY SURROUND
SUPPRESSION
OF TEXTURE
Contour Detection by Surround Suppression of Texture
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SUPPRESSION
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Visual perception

[Solomon & Pelli, 1994]
Visual perception

PETKOV & WESTENBERG, 2003
NON-CRE INHIBITION AND CONTOUR DETECTION.
NON-CRF INHIBITION AND CONTOUR DETECTION
Visual perception

[Galli & Zama, 1931]
Visual perception

Orientation-contrast pop-out
Visual perception
Neurophysiology

Receptive field and response of an orientation selective neuron

[Hubel & Wiesel, 1962]
Neurophysiology

Impulse response of an orientation selective neuron modelled by a 2D Gabor function [Daugman, 1985]
Link to perception?
Neurophysiology

[Blakemore and Tobin, 1972]
Link to perception
Orientation-contrast cell [Nothdurft et. al, 1999]
Link to perception
Neurophysiology

General suppression cell [Nothdurft et. al, 1999]

Mean firing rate [spikes/s]

(a) (b) (c) (d)
Link to perception
Computational models
Gabor filter
Gabor filter

Kernel:

\[ g_{\lambda,\sigma,\theta,\varphi}(x, y) = e^{-\frac{\tilde{x}^2 + \gamma^2 y^2}{2\sigma^2}} \cos\left(2\pi\frac{\tilde{x}}{\lambda} + \varphi\right) \]
Kernel:  
\[ g_{\lambda,\sigma,\theta,\varphi}(x, y) = e^{- \frac{x^2 + \gamma^2 y^2}{2\sigma^2}} \cos\left(\frac{2\pi x}{\lambda} + \varphi\right) \]

Filter:  
\[ R_{\lambda,\sigma,\theta,\varphi}(x, y) = (I \ast g_{\lambda,\sigma,\theta,\varphi})(x, y) \]
Gabor energy filter

\[ g_{\lambda, \sigma, \theta, 0}(x, y) \quad \text{and} \quad g_{\lambda, \sigma, \theta, -\frac{\pi}{2}}(x, y) \]
Gabor energy filter

\[ g_{\lambda, \sigma, \theta, 0}(x, y) \quad \text{and} \quad g_{\lambda, \sigma, \theta, -\frac{\pi}{2}}(x, y) \]

Gabor energy:

\[ E_{\lambda, \sigma, \theta}(x, y) = \sqrt{R_{\lambda, \sigma, \theta, 0}^2(x, y) + R_{\lambda, \sigma, \theta, -\frac{\pi}{2}}^2(x, y)} \]
Gabor energy filter

input $I$

output $E_{0^\circ}$

output $E_{90^\circ}$

max($E_{0^\circ}, E_{90^\circ}$)
Surround suppression

Inhibition

CRF

Inhibition

surround
Surround suppression

Different effects of the surround
Surround weighting function

$g_{\lambda,\sigma,\theta,0}(x, y)$

$w_{\sigma}(x, y)$
Surround weighting function

\[ g_{\lambda, \sigma, \theta, 0}(x, y) \]

\[ w_\sigma(x, y) \]

\[ G_\sigma(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}, \quad \text{DoG}_{4\sigma, \sigma}(x, y) = G_{4\sigma}(x, y) - G_\sigma(x, y) \]
Surround weighting function

\[ g_{\lambda, \sigma, \theta, 0}(x, y) \]

\[ w_{\sigma}(x, y) \]

\[ G_{\sigma}(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}, \quad DoG_{4\sigma, \sigma}(x, y) = G_{4\sigma}(x, y) - G_{\sigma}(x, y) \]

\[ w_{\sigma}(x, y) = \frac{\left| DoG_{4\sigma, \sigma}(x, y) \right|^+}{\left\| \left| DoG_{4\sigma, \sigma} \right|^+ \right\|_1} \]
Orientation-contrast suppression

Mean firing rate [spikes/s]
Orientation-contrast suppression term

\[ S_{\lambda, \sigma, \theta}(x, y) = (E_{\lambda, \sigma, \theta} \ast w_\sigma)(x, y) \]
Orientation-contrast suppression term

\[ S_{\lambda,\sigma,\theta}(x, y) = (E_{\lambda,\sigma,\theta} \ast w_\sigma)(x, y) \]
Orientation-contrast suppression filter

\[ C_{\lambda,\sigma,\theta}(x, y) = |E_{\lambda,\sigma,\theta}(x, y) - \alpha S_{\lambda,\sigma,\theta}(x, y)|^+ \]
Orientation-contrast suppression filter

\[ C_{\lambda,\sigma,\theta}(x, y) = |E_{\lambda,\sigma,\theta}(x, y) - \alpha S_{\lambda,\sigma,\theta}(x, y)|^+ \]
Orientation-contrast suppression

Input $I$

Gabor energy $\max\left\{ E_\theta \mid \forall \theta \right\}$

Modulated output $\max\left\{ C_\theta \mid \forall \theta \right\}$
Back to visual perception

Input $I$

Gabor energy $\max\{E_\theta \mid \forall \theta\}$

Modulated output $\max\{C_\theta \mid \forall \theta\}$
Back to visual perception

Input $I$

Gabor energy

$\max\{E_\theta \mid \forall \theta\}$

Modulated output

$\max\{C_\theta \mid \forall \theta\}$
General suppression

![Graph showing mean firing rate (spikes/s) with bars for different conditions (a), (b), (c), and (d).]
General suppression term

\[ E_{\lambda, \sigma}(x, y) = \max \{ E_{\lambda, \sigma, \theta}(x, y) \mid \forall \theta \} \]

\[ S_{\lambda, \sigma}(x, y) = (E_{\lambda, \sigma} \ast w_\sigma)(x, y) \]
General suppression term

\[ E_{\lambda,\sigma}(x, y) = \max\{E_{\lambda,\sigma,\theta}(x, y) \mid \forall \theta\} \]

\[ S_{\lambda,\sigma}(x, y) = (E_{\lambda,\sigma} \ast w_{\sigma})(x, y) \]

Input Gabor energy Suppression term

\[ I \]

\[ E = \max\{E_{\theta} \mid \forall \theta\} \]

\[ S = w \ast E \]
General suppression filter

\[ \hat{C}_{\lambda, \sigma, \theta}(x, y) = |E_{\lambda, \sigma, \theta}(x, y) - \alpha S_{\lambda, \sigma}(x, y)|^+ \]
General suppression filter

\[ \hat{C}_{\lambda,\sigma,\theta}(x, y) = |E_{\lambda,\sigma,\theta}(x, y) - \alpha S_{\lambda,\sigma}(x, y)|^+ \]

Input \( I \)

Gabor energy \( E_{0^\circ} \)

Suppression term \( S = w \ast E \)

Modulated output \( \hat{C}_{0^\circ} = |E_{0^\circ} - \alpha S|^+ \)
General suppression

Input $I$

Gabor energy $\max\{E_\theta \mid \forall \theta\}$

Modulated output $\max\{\hat{C}_\theta \mid \forall \theta\}$
Back to visual perception

[Petkov & Westenberg, 2003]

Input

Gabor energy

Modulated output

[Petkov & Westenberg, 2003]
Computer vision application
Texture suppression

Input  Gabor energy  With suppression
Contour enhancement by texture suppression

Input  Gabor energy  With suppression
Geometric shape descriptors

Distance set

Shape context
Binary contour maps

Input  Edge strength  Binarized response
Desired output

Input image and associated desired output

Dataset: www.cs.rug.nl/~imaging
Performance measure

Desired output

Operator output
Desired output

Operator output

\[ P = \frac{C}{C + FP + FN} \]

- \( C \): number of correctly detected contour pixels
- \( FP, FN \): number of false positives and negatives
Canny performance

Input

Desired output

Best Canny

\[ P = 0.23 \]
Suppressed Gabor performance

Input

Desired output

Suppressed Gabor

\[ P = 0.42 \]
Performance comparison

Input

Best Canny

Suppressed Gabor

\[ P = 0.23 \]

\[ P = 0.42 \]
## Performance comparison

<table>
<thead>
<tr>
<th>Input</th>
<th>Best Canny</th>
<th>Suppressed Gabor</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Input Image" /></td>
<td><img src="image2.png" alt="Best Canny Image" /></td>
<td><img src="image3.png" alt="Suppressed Gabor Image" /></td>
</tr>
</tbody>
</table>

\[ P = 0.14 \] \[ P = 0.34 \]

[Grigorescu et al., 2003]
Performance comparison

(C) Canny, (G) Gabor, (B1) orientation contrast suppression, (B2) general suppression
Beyond receptive fields and Gabor functions

\[
\frac{\partial G_\sigma(x,y)}{\partial x}
\]

\[
\frac{\partial G_\sigma(x,y)}{\partial y}
\]

\[w_\sigma(x, y)\]
Beyond receptive fields and Gabor functions

\[ \frac{\partial G_\sigma(x,y)}{\partial x} \]

\[ \frac{\partial G_\sigma(x,y)}{\partial y} \]

\[ w_\sigma(x, y) \]

Canny edge detector
Beyond receptive fields and Gabor functions

\[ \frac{\partial G_\sigma(x,y)}{\partial x} \quad \frac{\partial G_\sigma(x,y)}{\partial y} \quad w_\sigma(x,y) \]

Canny edge detector with surround suppression
Canny with surround suppression

Input

Canny

With suppression

[Grigorescu et al., 2004]
Split surround
Input

Best Canny

Suppressed Gabor
Multi-scale Canny with split surround suppression

Input

Suppressed Canny (multi-scale)

Desired output

[Papari et al., 2006]
Camouflage
Camouflage
Camouflage
Camouflage
Camouflage
THE END
THE END
THE END
THE END
THE END
Operators available at

matlabserver.cs.rug.nl