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Edge Detection

Leonhard Applis

TH Nürnberg

05.11.2018

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Figure: Felix

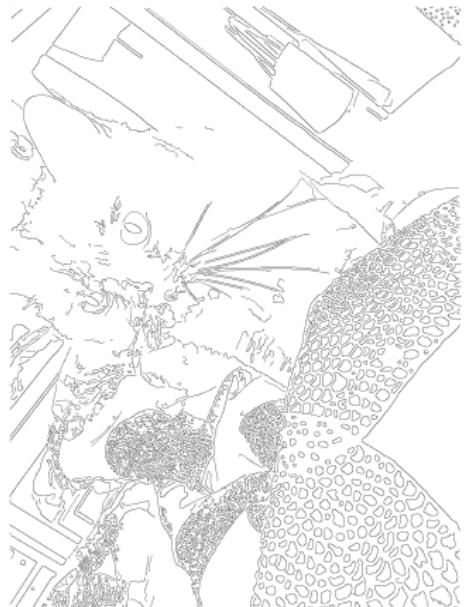


Figure: Felix's Edges

Problem I: Contrast

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Figure: High Contrast Felix



Figure: Low Contrast Felix

Problem II: Smoothness

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Figure: Smooth Felix

Problem III: Noise

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Figure: Salted Felix

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In Image Processing, an edge can be defined as a set of contiguous pixel positions where an abrupt change of intensity, gray- or color-values occur. Edges represent boundaries between objects and background. Sometimes, the edge-pixel-sequence may be broken due to insufficient intensity difference.(Malay K. Pakhira)

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One dimensional approach

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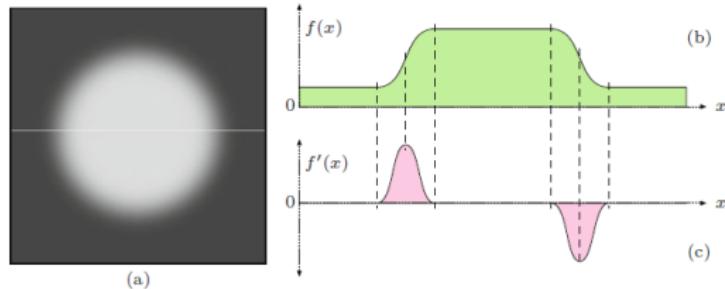


Figure: One dimensional image function and derivation

Only applicable with known, steady functions

Approximating discrete derivation

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Problem: the image function is discrete, therefore we need to approximate the derivation

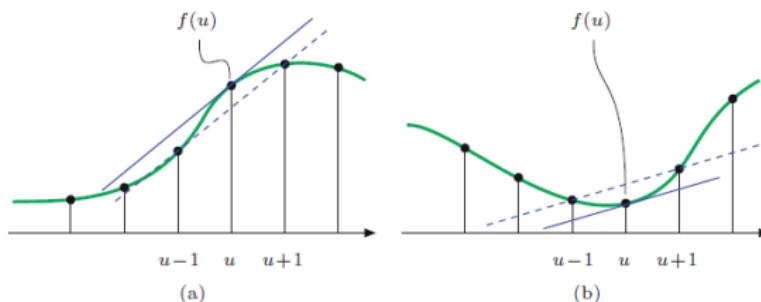


Figure: Approximation of the derivation for discrete imagefunctions

$$\frac{df}{dx}(u) \approx \frac{f(u+1) - f(u-1)}{(u+1) - (u-1)} = \frac{f(u+1) - f(u-1)}{2}$$

Two dimensional approach

If working with full images, we got two dimensions and therefore two partial derivations:

$$I_x = \frac{\partial I}{\partial x}(u, v), I_y = \frac{\partial I}{\partial y}(u, v)$$

the **gradient** at the point (u, v) is

$$\nabla I(u, v) = \begin{pmatrix} I_x(u, v) \\ I_y(u, v) \end{pmatrix}$$

And the **magnitude** is

$$|\nabla I| = \sqrt{I_x^2 + I_y^2}$$

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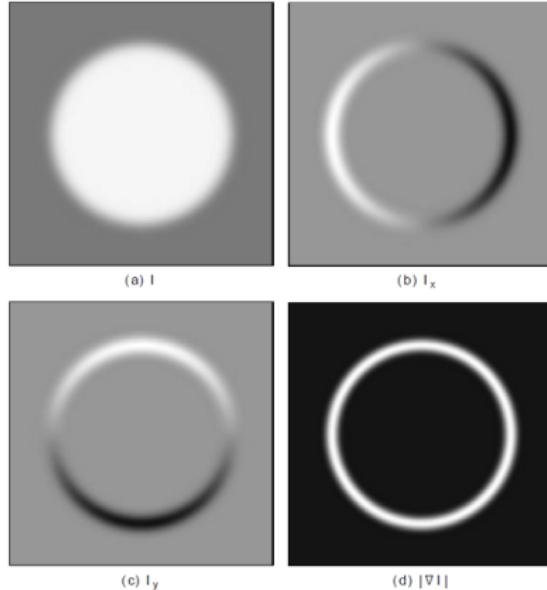


Figure: Visualisation of simple gradient-based edgedetection

Example with Felix

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(a) I



(b) I_x



(c) I_y



(d) $|\nabla I|$

Figure: Simple Filters applied to Felix¹

¹ All images have a 50% increased brightness

Implementation with filters

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Expressing the gradient as a *linear filter* is simple:

$$I_x = [-0.5 \quad 0 \quad 0.5]$$

$$I_y = \begin{bmatrix} -0.5 \\ 0 \\ 0.5 \end{bmatrix}$$

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Prewitt Operator

$$H_x^P = \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix} \quad H_y^P = \begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix}$$

$$\nabla I^P(u, v) \approx \frac{1}{6} \cdot \begin{pmatrix} (I * H_x^P)(u, v) \\ (I * H_y^P)(u, v) \end{pmatrix}$$

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Idea: Include neighbourhood but weight center more

$$H_x^S = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \quad H_y^S = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix}$$

$$\nabla I^S(u, v) \approx \frac{1}{8} \cdot \begin{pmatrix} (I * H_x^S)(u, v) \\ (I * H_y^S)(u, v) \end{pmatrix}$$

Comparison with Felix

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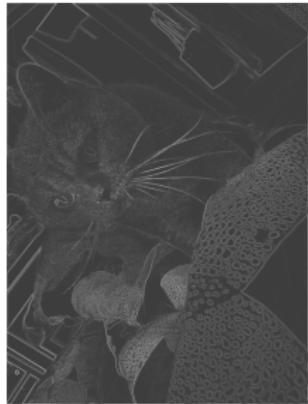


Figure: Simple edge filter

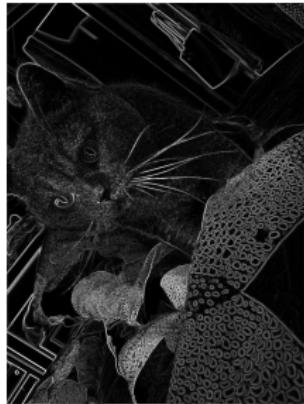


Figure: Prewitt Operator

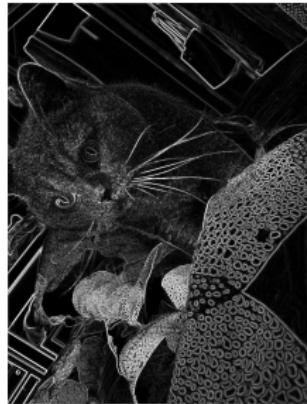


Figure: Sobel Operator

Evaluations

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general magnitude: $E(u, v) = \sqrt{I_x^2(u, v) + I_y^2(u, v)}$
holds for every Operator

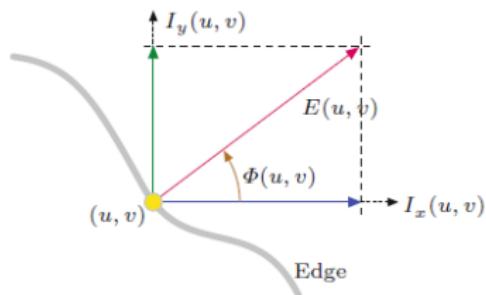


Figure: Visualisation of edge direction

$$\Phi(u, v) = \tan^{-1} \left(\frac{I_y(u, v)}{I_x(u, v)} \right) = \arctan(I_x(u, v), I_y(u, v))$$

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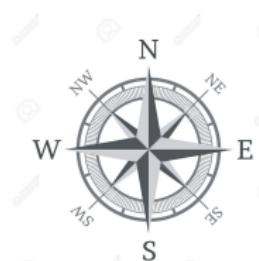
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Problem: The stronger a filter responses to edge-like structures, the more sensitive it is to orientation

$\uparrow \text{Orientation} \approx \downarrow \text{Edges} \uparrow \text{Edges} \approx \downarrow \text{Orientation}$

Solution: Apply 8 filters for each direction of the compass

Produce two pictures: One for the edge-strength taking the magnitude of the strongest activated filter, one for the direction marking the strongest filter with colour



Extended Sobel Operator

$$H_0^{\text{ES}} = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}, \quad H_1^{\text{ES}} = \begin{bmatrix} -2 & -1 & 0 \\ -1 & 0 & 1 \\ 0 & 1 & 2 \end{bmatrix},$$
$$H_2^{\text{ES}} = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix}, \quad H_3^{\text{ES}} = \begin{bmatrix} 0 & -1 & -2 \\ 1 & 0 & -1 \\ 2 & 1 & 0 \end{bmatrix},$$
$$H_4^{\text{ES}} = \begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{bmatrix}, \quad H_5^{\text{ES}} = \begin{bmatrix} 2 & 1 & 0 \\ 1 & 0 & -1 \\ 0 & -1 & -2 \end{bmatrix},$$
$$H_6^{\text{ES}} = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}, \quad H_7^{\text{ES}} = \begin{bmatrix} 0 & 1 & 2 \\ -1 & 0 & 1 \\ -2 & -1 & 0 \end{bmatrix}.$$

Note: Its only required to apply 4 filters, as they are symmetric

Figure: Extended Sobel Operator

Extended Sobel Example

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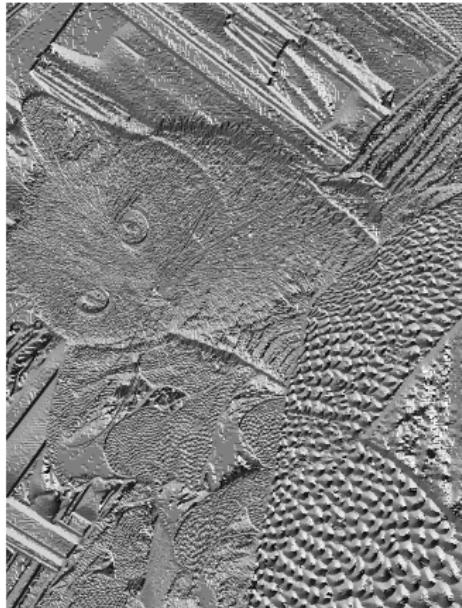


Figure: $\Phi^{ES}(Felix)$

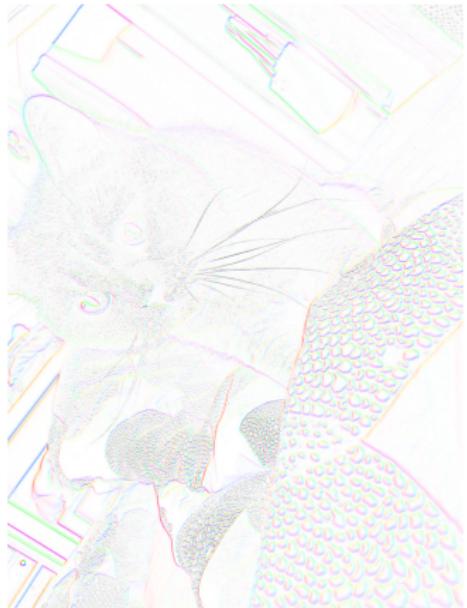


Figure: Colour encoding

Kirsch Operator

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$$H_0^K = \begin{bmatrix} -5 & 3 & 3 \\ -5 & 0 & 3 \\ -5 & 3 & 3 \end{bmatrix}, \quad H_4^K = \begin{bmatrix} 3 & 3 & -5 \\ 3 & 0 & -5 \\ 3 & 3 & -5 \end{bmatrix},$$
$$H_1^K = \begin{bmatrix} -5 & -5 & 3 \\ -5 & 0 & 3 \\ 3 & 3 & 3 \end{bmatrix}, \quad H_5^K = \begin{bmatrix} 3 & 3 & 3 \\ 3 & 0 & -5 \\ 3 & -5 & -5 \end{bmatrix},$$
$$H_2^K = \begin{bmatrix} -5 & -5 & -5 \\ 3 & 0 & 3 \\ 3 & 3 & 3 \end{bmatrix}, \quad H_6^K = \begin{bmatrix} 3 & 3 & 3 \\ 3 & 0 & 3 \\ -5 & -5 & -5 \end{bmatrix},$$
$$H_3^K = \begin{bmatrix} 3 & -5 & -5 \\ 3 & 0 & -5 \\ 3 & 3 & 3 \end{bmatrix}, \quad H_7^K = \begin{bmatrix} 3 & 3 & 3 \\ -5 & 0 & 3 \\ -5 & -5 & 3 \end{bmatrix}.$$

Figure: Kirsch Operator

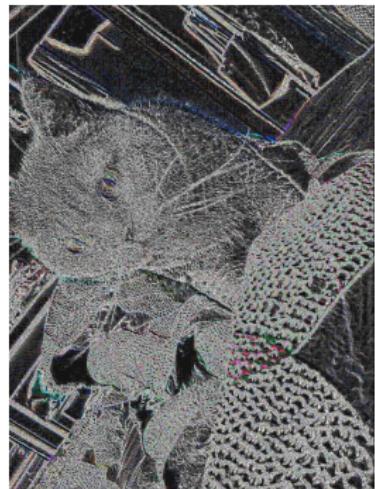


Figure: Felix with Kirsch

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Canny-Edge Operator

- ① Pre-Processing
- ② Edge Localization
- ③ Edge Tracing and hysteresis thresholding

For complex applications the Canny-Edge-Algorithm is done with more than 3x3 Filters

Canny-Edge Pre-Processing

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Summary

- ➊ Smooth Image with Gaussian-Filter
- ➋ Apply simple filters (See 14)
- ➌ Calculate magnitude

Also required: σ as Gauss-Radious and t_1, t_2 for thresholding edges

Canny-Edge Edge-Localization

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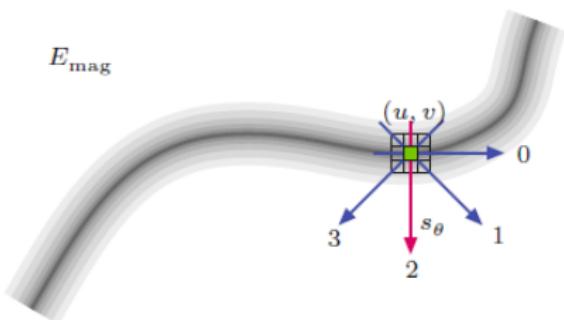


Figure: Edge-Localization

Operate over the magnitude-image:
Null every value that is not a local-maximum in any direction

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Hysteresis Thresholding

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Summary

- ① Find points with $E \geq t_1$
- ② Add Every Neighboor with $E \geq t_2$
- ③ Repeat 2 until image is processed



Figure: Canny-Edge Felix

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Laplacian-Filter

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Idea: Alter *steep* imagepoints

$$\hat{f}(x) = f(x) + \omega \cdot f''(x)$$

Where ω is a weight for alternation,
 $f(x)$ is the image function

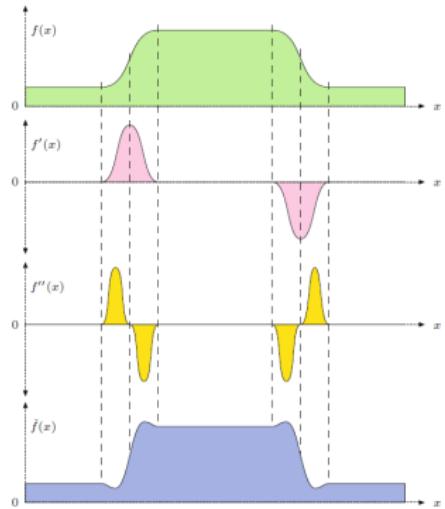


Figure: Applying the Laplacian-Filter

Laplacian-Filter Implementation

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Laplacian Operator: $(\nabla^2 f)(x, y) = \frac{\partial^2 f}{\partial^2 x}(x, y) + \frac{\partial^2 f}{\partial^2 y}(x, y)$

Expressed as filters:

$$\frac{\partial^2 f}{\partial^2 x}(x, y) \approx [1 \quad -2 \quad 1], \quad \frac{\partial^2 f}{\partial^2 y}(x, y) \approx \begin{bmatrix} 1 \\ -2 \\ 1 \end{bmatrix}$$

$$\Rightarrow H^L \approx \begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix}$$

Laplacian-Filter Variants and Example

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common variants:

$$H^L \approx \begin{bmatrix} 1 & 1 & 1 \\ 1 & -8 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

$$H^L \approx \begin{bmatrix} 1 & 2 & 1 \\ 2 & -12 & 2 \\ 1 & 2 & 1 \end{bmatrix}$$



Figure: Laplacian Filter applied to Felix

Unsharp Masking (USM)

Concept

- ➊ produce a smoothed version of the image
- ➋ subtract the smoothed version from original
→ **mask** of *sharp* points
- ➌ add the mask with a weight α to original image

Any smoothing-filter can be used, but gaussian filters are common
Notable:

- highly adaptable through exchangeable filters and α
- Laplacian filters are a implementation of USM with very simple smoothing
- vulnerable to *boost* noise, therefore often combined with a threshold

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Summary

- Edges are found via gradient-based filters
- Most algorithms are simple
- Most algorithms require thresholds from user
- Best results are achieved when combined with smoothing
- Iteratively trying multiple variants can improve results
- Images with sharpened edges shouldn't be trusted 100%

Primary Sources

Digital Image Processing - An Algorithmic Introduction Using Java
2nd Edition

Wilhelm Burger, Mark J.Burge

Source for every non-felix picture.

User Guide and Documentation for HIPR

<https://homepages.inf.ed.ac.uk/rbf/HIPR2/>

Sometimes longer explanations and additional variants of the filters