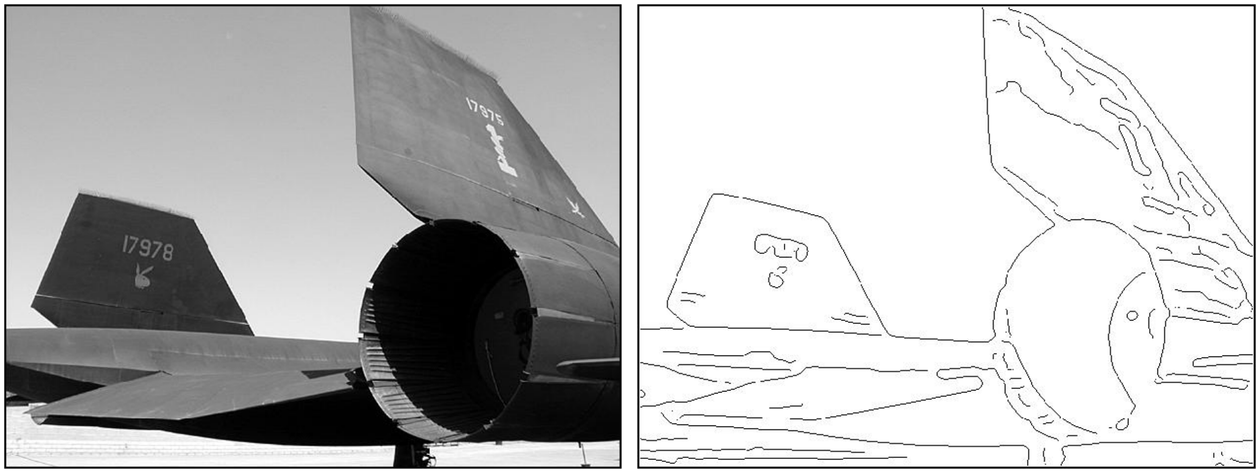
Vaje pri predmetu Računalniško zaznavanje 08/09

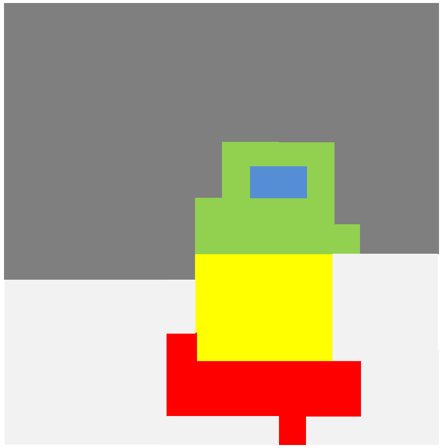
LOKALNE ZNAČILKE

Lokalne značilke



Robovi

Lokalne značilke

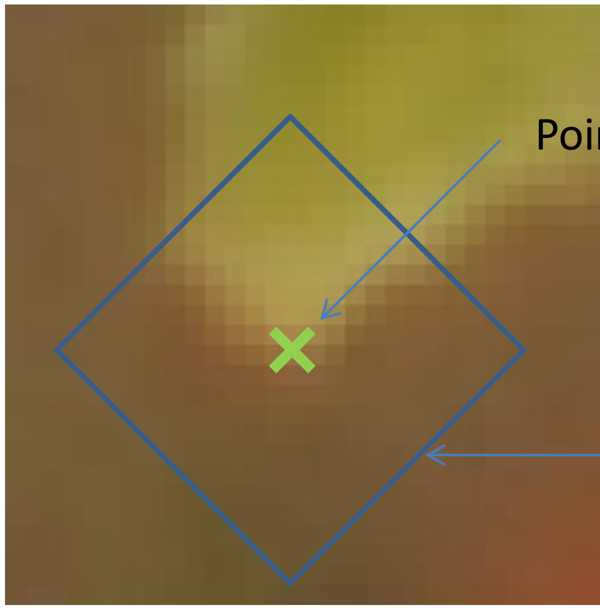


Lokalne regije

Lokalne značilke

Značilne točke (oglišča, scale space maxima, ...)

Lokalne značilke



Point of interest (POI)

lega, karakteristična skala

Region of interest (ROI)

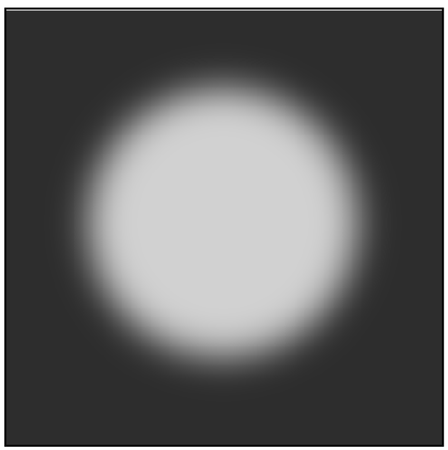
lokalna regija

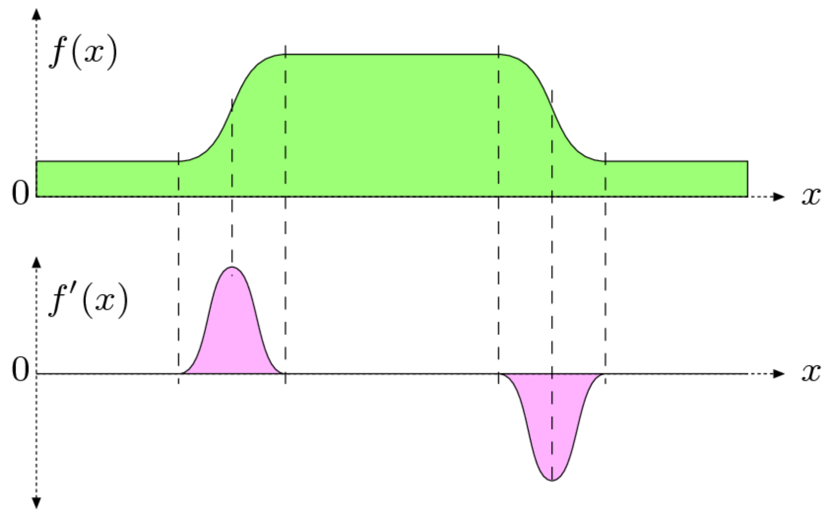
velikost, orientacija, oblika, opisnik

ROBOVI

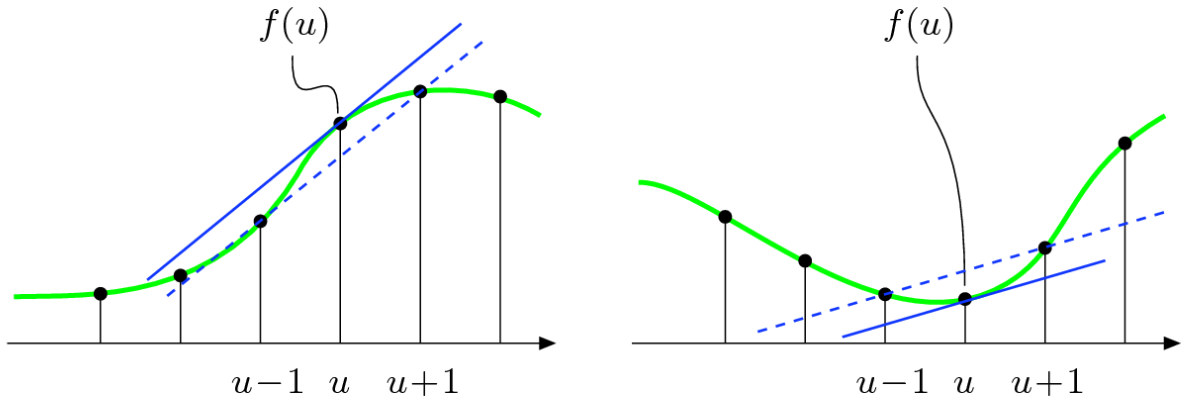
Odvod funkcije intenzitete

$$f'(x) = \frac{df}{dx}(x)$$





Diferenca kot diskretna aproksimacija odvoda



$$\frac{df}{du}(u) \approx \frac{f(u+1) - f(u-1)}{2} = 0.5 \cdot \big(f(u+1) - f(u-1)\big)$$

Realizacija z diferenčnim filtrom: $H_D = [-1 \quad 0 \quad 1]$

Parcialni odvodi funkcije I(u, v)

$$\frac{\partial I}{\partial u}(u, v) \qquad \frac{\partial I}{\partial v}(u, v)$$

$$\nabla I(u, v) = \begin{bmatrix} \frac{\partial I}{\partial u}(u, v) \\ \frac{\partial I}{\partial v}(u, v) \end{bmatrix}$$

Vektor gradienta v (u, v)

Moč gradienta v (u, v)

$$|\nabla I|(u, v) = \sqrt{\left(\frac{\partial I}{\partial u}(u, v)\right)^2 + \left(\frac{\partial I}{\partial v}(u, v)\right)^2}$$

Prewittov in Sobelov operator

Prewitt

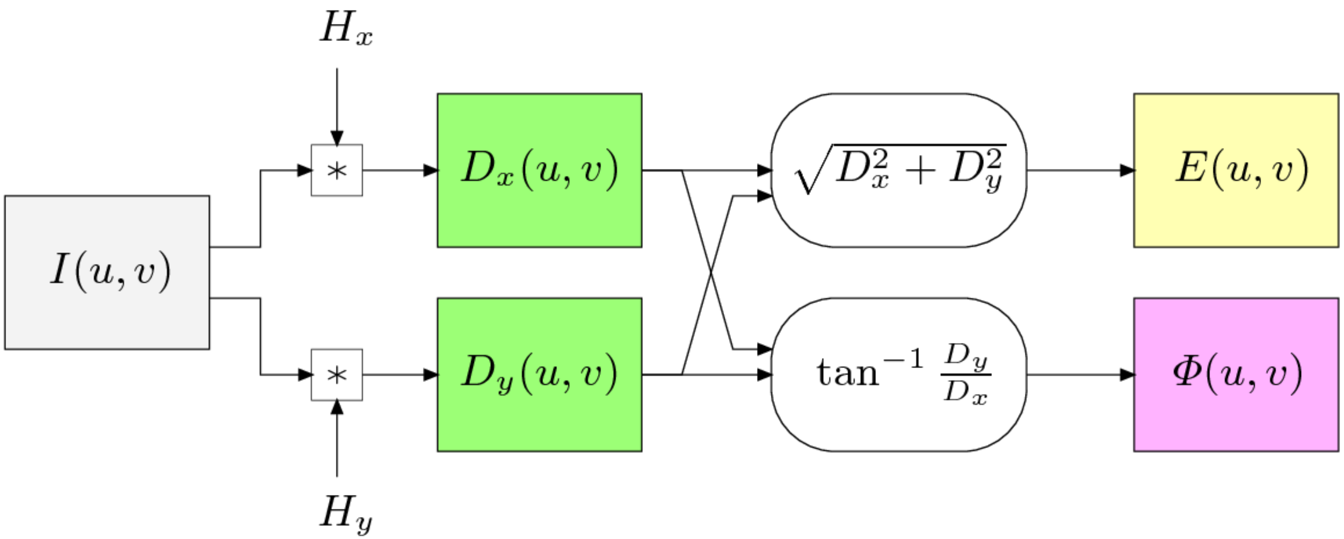
$$H_x^P = \begin{bmatrix} -1 & 0 & 1 \\ -1 & \mathbf{0} & 1 \\ -1 & 0 & 1 \end{bmatrix} \qquad H_y^P = \begin{bmatrix} -1 & -1 & -1 \\ 0 & \mathbf{0} & 0 \\ 1 & 1 & 1 \end{bmatrix}$$

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

Sobel

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

Prewittov in Sobelov operator

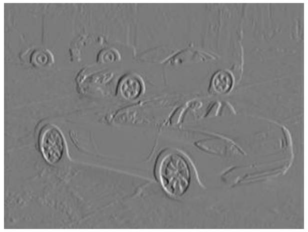


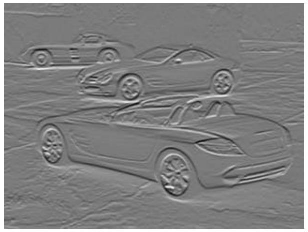
$$D_x(u,v) = H_x * I \quad \text{and} \quad D_y(u,v) = H_y * I$$

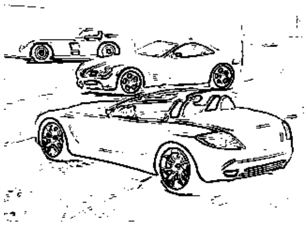
$$E(u,v) = \sqrt{\big(D_x(u,v)\big)^2 + \big(D_y(u,v)\big)^2}$$

$$\Phi(u,v) = \tan^{-1}\left(\frac{D_y(u,v)}{D_x(u,v)}\right) = \mathrm{ArcTan}\big(D_x(u,v), D_y(u,v)\big)$$

Prewittov in Sobelov operator







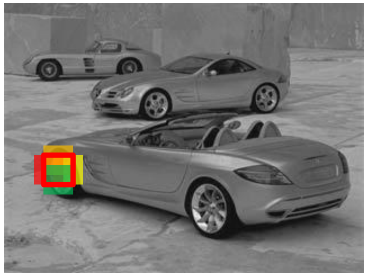
OGLIŠČA

Harrisov detektor oglišč [Harris & Stephens '88]

$$a(x,y) = \sum_{(x_k, y_k) \in W(x,y)} \left(I(x_k, y_k) - I(x_k + \Delta x, y_k + \Delta y) \right)^2$$

Avtokorelacija v točki (x,y) za lokalno soseščino W in odmik (Δ x, Δ y)

Avtokorelacija



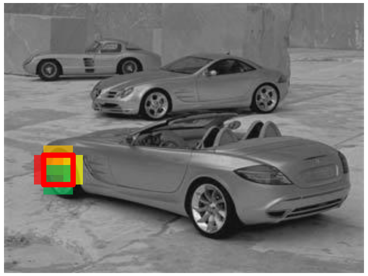
$$a(x,y) = \sum_{(x_k,y_k)\in W(x,y)} (I(x_k,y_k) - I(x_k+\Delta x, y_k+\Delta y))^2$$

Avtokorelacija v točki (x,y) za lokalno soseščino W in odmik (Δ x, Δ y)

a(x, y) majhen v vseh smereh – homogeno področje
izrazit v eni smeri – rob
izrazit v vseh smereh - oglišče

Realizacija kot filter - zamudno!

Aproksimacija avtokorelacije



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

$$a(x,y) = \sum_{(x_k,y_k)\in W(x,y)} \left(I(x_k,y_k) - I(x_k+\Delta x, y_k+\Delta y)\right)^2$$

Aproksimacija 1. reda

$I(x_k+\Delta x, y_k+\Delta y) = I(x_k, y_k) + \big[$ [redacted] $_x(x_k,y_k) \quad I_y(x_k,y_k)\big] \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix}$

Avtokorelacijska matrika

$$a(x,y) = \sum_{(x_k,y_k)\in W} \left(\begin{bmatrix} I_x(x_k,y_k) & I_y(x_k,y_k) \end{bmatrix} \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix} \right)^2$$

$$= \begin{bmatrix} \Delta x & \Delta y \end{bmatrix} \begin{bmatrix} \sum\limits_{(x_k,y_k)\in W} (I_x(x_k,y_k))^2 & \sum\limits_{(x_k,y_k)\in W} I_x(x_k,y_k) I_y(x_k,y_k) \\ \sum\limits_{(x_k,y_k)\in W} I_x(x_k,y_k) I_y(x_k,y_k) & \sum\limits_{(x_k,y_k)\in W} (I_y(x_k,y_k))^2 \end{bmatrix} \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix}$$

Avtokorelacijska matrika

$$a(x,y) = \begin{bmatrix} \Delta x & \Delta y \end{bmatrix} \begin{bmatrix} \sum\limits_{(x_k,y_k)\in W} (I_x(x_k,y_k))^2 & \sum\limits_{(x_k,y_k)\in W} I_x(x_k,y_k) I_y(x_k,y_k) \\ \sum\limits_{(x_k,y_k)\in W} I_x(x_k,y_k) I_y(x_k,y_k) & \sum\limits_{(x_k,y_k)\in W} (I_y(x_k,y_k))^2 \end{bmatrix} \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix}$$

$$= \begin{bmatrix} \Delta x & \Delta y \end{bmatrix} G \otimes \begin{bmatrix} I_x^{\;2} & I_x I_y \\ I_x I_y & I_y^{\;2} \end{bmatrix} \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix}$$

vsoto lahko aproksimiramo z Gaussovim glajenjem

Avtokorelacijska matrika

$$M = \begin{bmatrix} I_x^{\ 2} & I_x I_y \\ I_x I_y & I_y^{\ 2} \end{bmatrix} = \begin{bmatrix} A & C \\ C & B \end{bmatrix}$$

$$\overline{M} = G \otimes \begin{bmatrix} I_x^{\ 2} & I_x I_y \\ I_x I_y & I_y^{\ 2} \end{bmatrix} = \begin{bmatrix} I_x^{\ 2} \otimes G & I_x I_y \otimes G \\ I_x I_y \otimes G & I_y^{\ 2} \otimes G \end{bmatrix} =$$

$$= \begin{bmatrix} A \otimes G & C \otimes G \\ C \otimes G & B \otimes G \end{bmatrix} = \begin{bmatrix} \overline{A} & \overline{C} \\ \overline{C} & \overline{B} \end{bmatrix}$$

$$A(u,v) = I_x^2(u,v)$$

$$B(u,v) = I_y^2(u,v)$$

$$C(u,v) = I_x(u,v) \cdot I_y(u,v)$$

Avtokorelacijska matrika (matrika lokalne strukture)

$$\overline{M} = \begin{bmatrix} \overline{A} & \overline{C} \\ \overline{C} & \overline{B} \end{bmatrix}$$

Avtokorelacijska matrika opisuje strukturne lastnosti soseščine

Matrika je simetrična – lahko jo diagonaliziramo

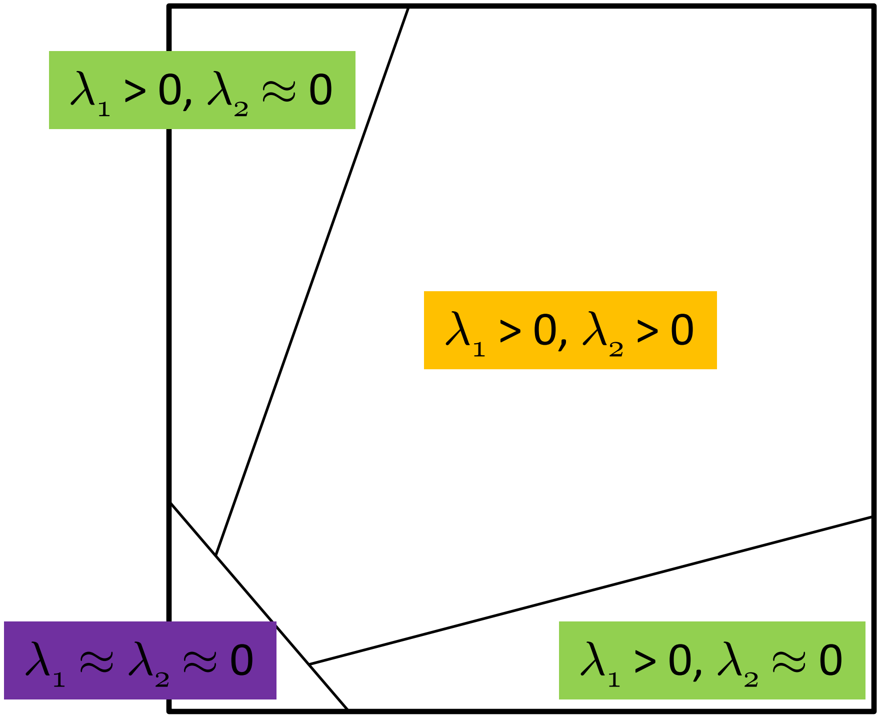
$$\overline{M} = U \begin{bmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{bmatrix} U^T$$

λ_1 in λ_2 sta lastni vrednosti:

$\lambda_1 = \lambda_2 = 0$: homogena soseščina
$\lambda_1 > 0, \lambda_2 = 0$: rob
$\lambda_1 > 0, \lambda_2 > 0$: oglišče

Lastne vrednosti

$\lambda_1 \approx \lambda_2 \approx 0$: homogena soseščina
$\lambda_1 > 0, \lambda_2 \approx 0$: rob
$\lambda_1 > 0, \lambda_2 > 0$: oglišče



Ocena oglatosti (Corner Response Function, CRF)

$$\lambda_{1,2} = \frac{\mathrm{trace}(\bar{M})}{2} \pm \sqrt{\left(\frac{\mathrm{trace}(\bar{M})}{2}\right)^2 - \det(\bar{M})}$$
$$= \frac{1}{2}\left(\bar{A} + \bar{B} \pm \sqrt{\bar{A}^2 - 2\bar{A}\bar{B} + \bar{B}^2 + 4\bar{C}^2}\right)$$

$$\lambda_1 - \lambda_2 = 2 \cdot \sqrt{\frac{1}{4} \cdot \left(\mathrm{trace}(\bar{M})\right)^2 - \det(\bar{M})}$$

$$Q(u,v) = \det(\bar{M}) - \alpha \cdot \left(\mathrm{trace}(\bar{M})\right)^2$$
$$= (\bar{A}\bar{B} - \bar{C}^2) - \alpha \cdot (\bar{A} + \bar{B})^2$$

Ocena oglatosti CRF

občutljivost Harrisovega detektorja

- Detekcija oglišč
  - Za vsak slikovni element izračunaj oceno oglatosti
  - Upragovi (absoluten ali relativen prag, lahko glede na število oglišč)
  - Poišči lokalne maksimume

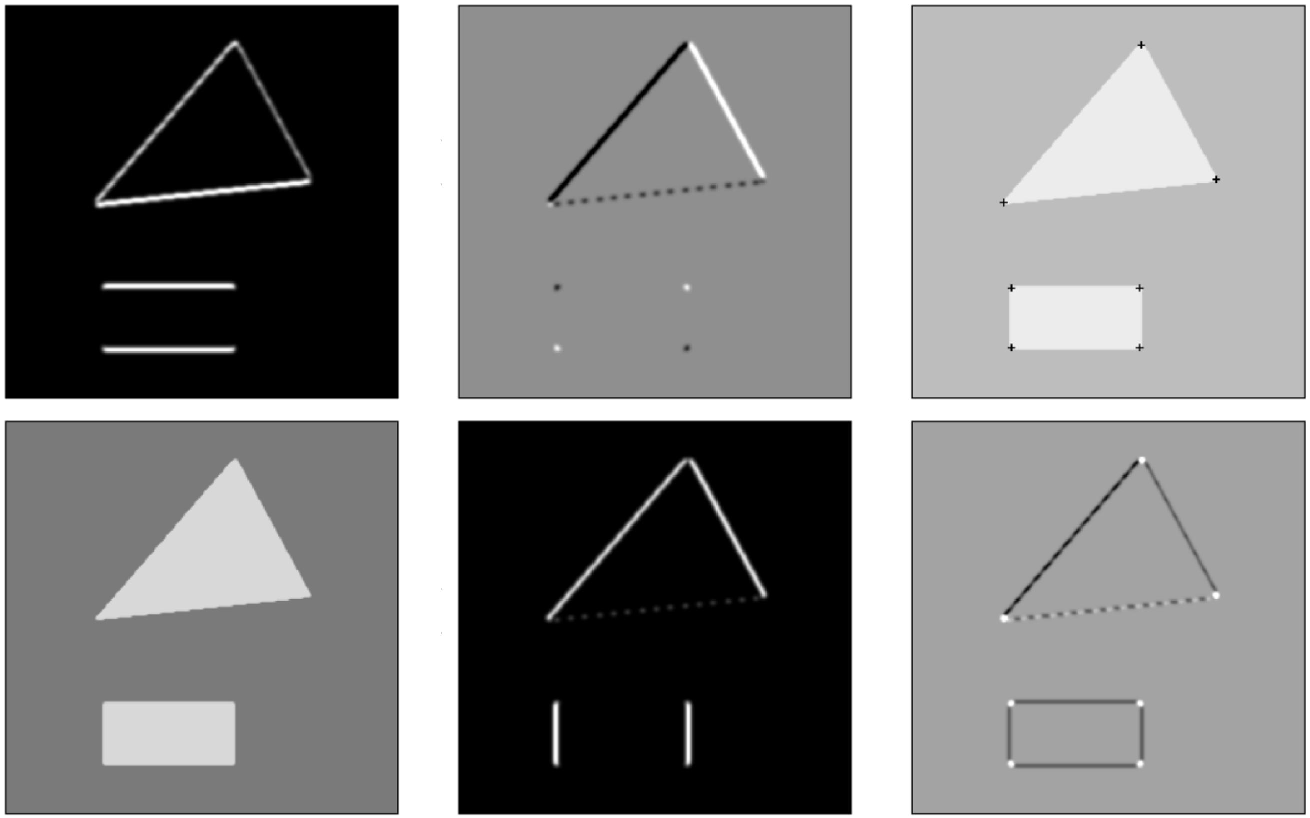
$$Q(x,y) > prag \;\wedge\; \forall x', y' \in 8-sosescini:\; Q(x,y) \geq Q(x', y')$$

Harrisov detektor oglišč

A

C

Detektirana oglišča

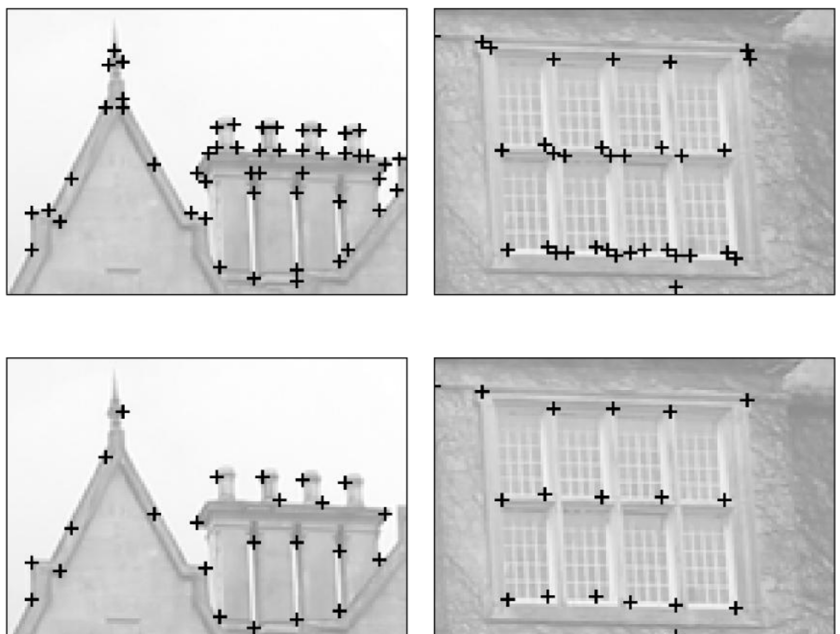


I

B

Q

Harrisov detektor oglišč



Harrisov detektor oglišč

1: HarrisCorners(I)
Returns a list of the strongest corners found in the image I.

2: Step 1—compute the corner response function:
3: Prefilter (smooth) the original image: $I' \leftarrow I * H_p$
4: Compute the horizontal and vertical image derivatives:
$I_x \leftarrow I' * H_{dx}$
$I_y \leftarrow I' * H_{dy}$
5: Compute the local structure matrix $M(u,v) = \begin{pmatrix} A & C \\ C & B \end{pmatrix}$:
$A(u,v) \leftarrow I_x^2(u,v)$
$B(u,v) \leftarrow I_y^2(u,v)$
$C(u,v) \leftarrow I_x(u,v) \cdot I_y(u,v)$
6: Blur each component of the structure matrix: $\bar{M} = \begin{pmatrix} \bar{A} & \bar{C} \\ \bar{C} & \bar{B} \end{pmatrix}$:
$\bar{A} \leftarrow A * H_b$
$\bar{B} \leftarrow B * H_b$
$\bar{C} \leftarrow C * H_b$
7: Compute the corner response function:
$Q \leftarrow (\bar{A} \cdot \bar{B} - \bar{C}^2) - \alpha \cdot (\bar{A} + \bar{B})^2$

8: Step 2—collect corner points:
9: Create an empty list:
$Corners \leftarrow [\,]$
10: **for** all image coordinates (u,v) **do**
11: **if** $Q(u,v) > t_H$ **and** IsLocalMax(Q,u,v) **then**
12: Create a new corner:
$\boldsymbol{c}_i \leftarrow \langle u_i, v_i, q_i \rangle = \langle u, v, Q(u,v) \rangle$
13: Add $\boldsymbol{c}_i$ to *Corners*
14: **Sort** *Corners* by q_i in *descending* order (strongest corners first)
15: *GoodCorners* $\leftarrow$ CleanUpNeighbors(*Corners*)
16: **return** *GoodCorners*.

17: IsLocalMax(Q,u,v) ▷ determine if $Q(u,v)$ is a local maximum
18: Let $q_c \leftarrow Q(u,v)$ (center pixel)
19: Let $\mathcal{N} \leftarrow Neighbors(Q,u,v)$ ▷ values of all neighboring pixels
20: **if** $q_c \geq q_i$ for all $q_i \in \mathcal{N}$ **then**
21: **return** *true*
22: **else**
23: **return** *false*.

24: CleanUpNeighbors(*Corners*) ▷ *Corners* is sorted by descending q
25: Create an empty list:
$GoodCorners \leftarrow [\,]$
26: **while** *Corners* is not empty **do**
27: $\boldsymbol{c}_i \leftarrow$ RemoveFirst(*Corners*)
28: Add $\boldsymbol{c}_i$ to *GoodCorners*
29: **for** all $\boldsymbol{c}_j$ in *Corners* **do**
30: **if** $Dist(\boldsymbol{c}_i, \boldsymbol{c}_j) < d_{\min}$ **then**
31: Delete $\boldsymbol{c}_j$ from *Corners*
32: **return** *GoodCorners*.

Harrisov detektor oglišč

Prefilter (line 3): Smoothing with a small xy-separable filter $H_p = H_{px} * H_{py}$, where

$$H_{px} = \frac{1}{9}\begin{bmatrix} 2 & \mathbf{5} & 2 \end{bmatrix} \quad \text{and} \quad H_{py} = H_{px}^T = \frac{1}{9}\begin{bmatrix} 2 \\ \mathbf{5} \\ 2 \end{bmatrix}.$$

Gradient filter (line 4): Computing the first partial derivative in the x and y directions with

$$H_{dx} = \begin{bmatrix} -0.453014 & \mathbf{0} & 0.453014 \end{bmatrix} \quad \text{and} \quad H_{dy} = H_{dx}^T = \begin{bmatrix} -0.453014 \\ \mathbf{0} \\ 0.453014 \end{bmatrix}.$$

Blurfilter (line 6): Smoothing the individual components of the structure matrix M with separable Gaussian filters $H_b = H_{bx} * H_{by}$ with

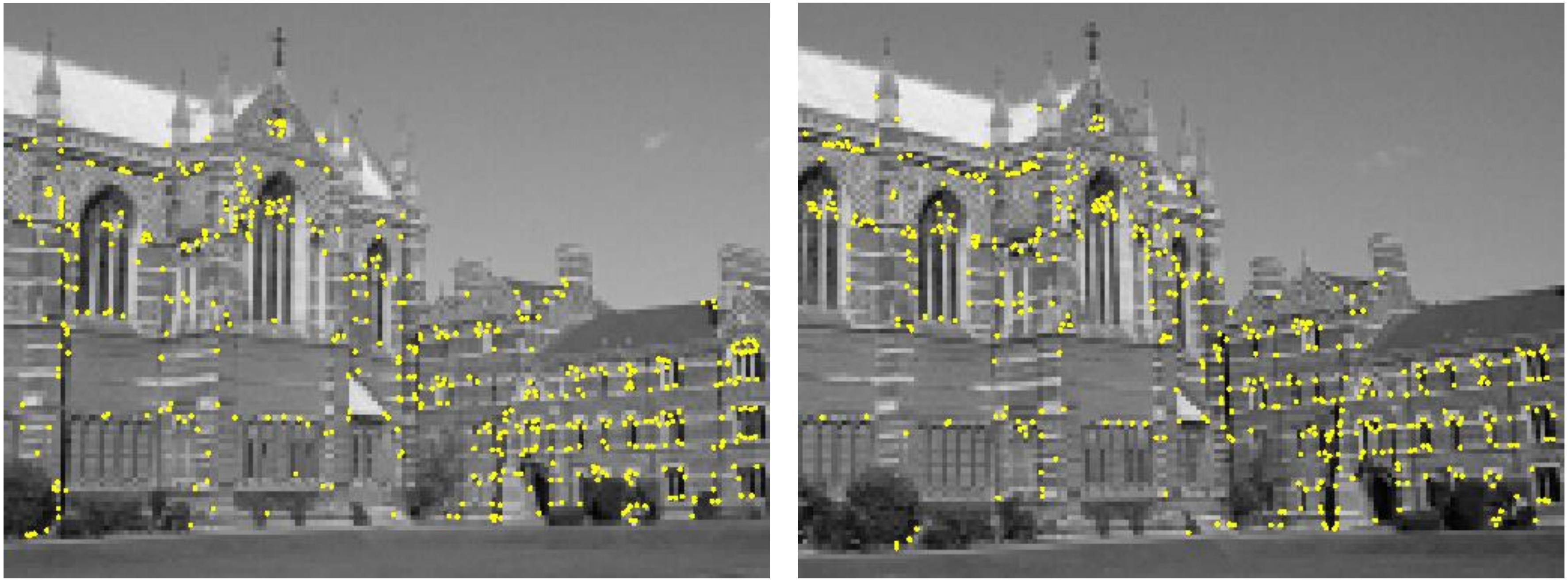
$$H_{bx} = \frac{1}{64}\begin{bmatrix} 1 & 6 & 15 & \mathbf{20} & 15 & 6 & 1 \end{bmatrix}, \qquad H_{by} = H_{bx}^T = \frac{1}{64}\begin{bmatrix} 1 \\ 6 \\ 15 \\ \mathbf{20} \\ 15 \\ 6 \\ 1 \end{bmatrix}.$$

Steering parameter (line 7): $\alpha = 0.04$ to 0.06 (default 0.05)

Response threshold (line 13): $t_H = 10{,}000$ to $1{,}000{,}000$ (default 25,000)

Neighborhood radius (line 31): $d_{\min} = 10$ pixels

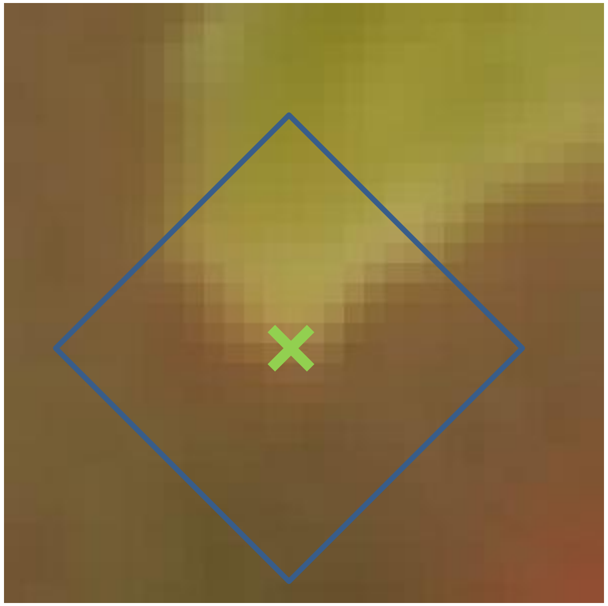
Lokalna ujemanja

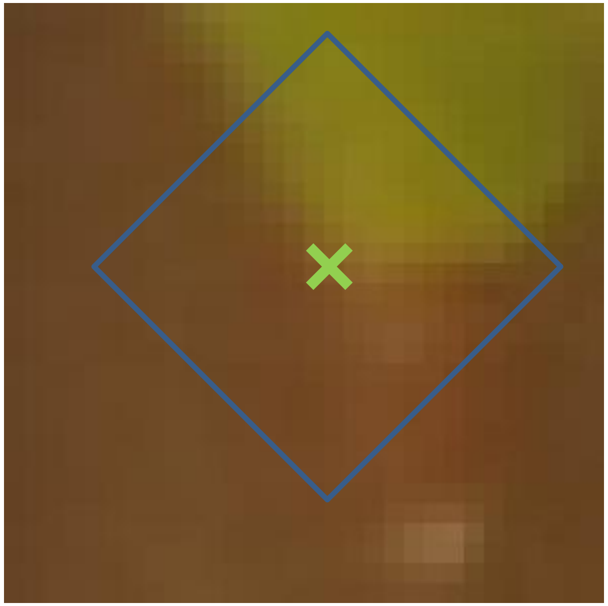


- Sledenje lokalnih regij
- Ujemanje slik (razpoznavanje objektov, stereo, zlepki, panorame...)
- Oglišča so primer značilnih točk. Potrebujemo še opisnike.

Vir: Cordelia Schmid

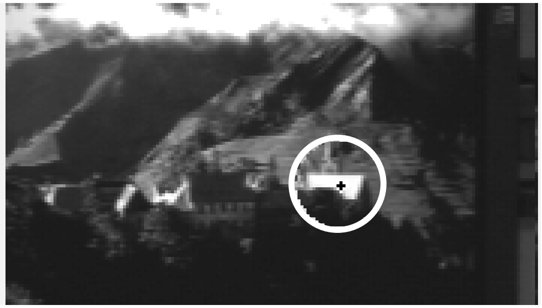
Lokalna ujemanja

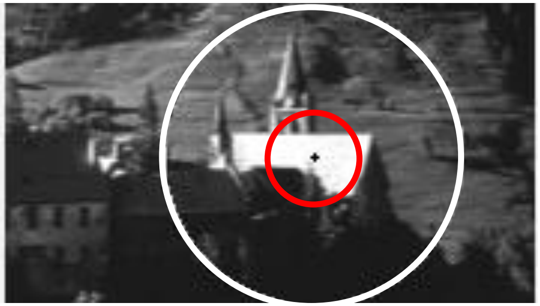




Za izračun opisnikov potrebujemo podporno regijo
Spremembe v osvetlitvi
Spremembe v legi, orientaciji, velikosti

Detektor oglišč neodvisen od merila (scale invariant)





Sprememba velikosti:

$$I_1\begin{pmatrix}x_1\\y_1\end{pmatrix}=I_2\begin{pmatrix}x_2\\y_2\end{pmatrix}=I_2\begin{pmatrix}sx_1\\sy_1\end{pmatrix}$$

Vir: Cordelia Schmid

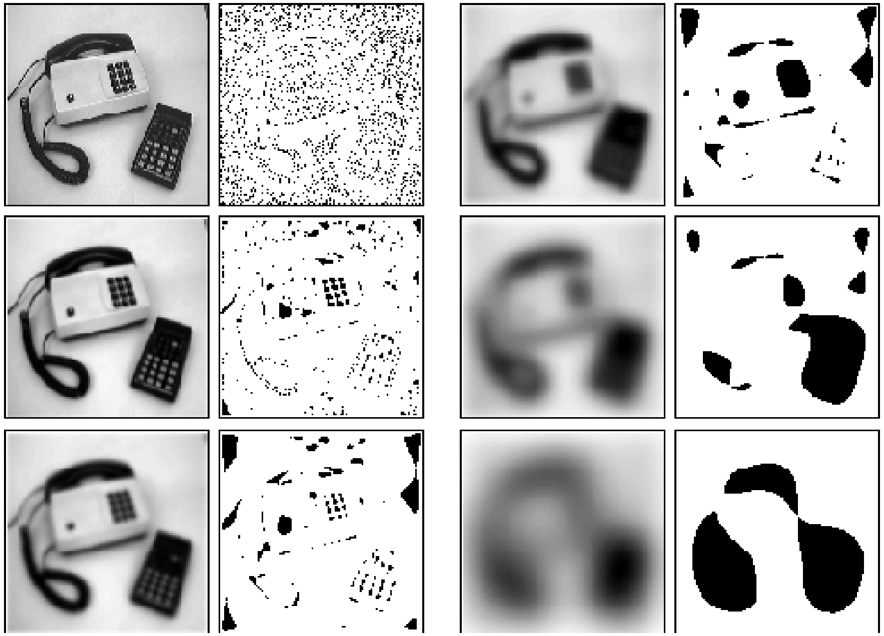
Prostor merila (scale space)

Scale-space: A framework for handling image structures at multiple scales
T. Lindenberg

Prostor merila je predstavitev slikovne informacije pri različnih nivojih podrobnosti

Pogoj: sprememba merila ne dodaja nove strukturne informacije (robovi...)

Pokazati se da, da je ustrezen prostor merila natanko tista predstavitev, ki jo dobimo s konvolucijo z Gaussovim jedrom.



Prostor merila (scale space)

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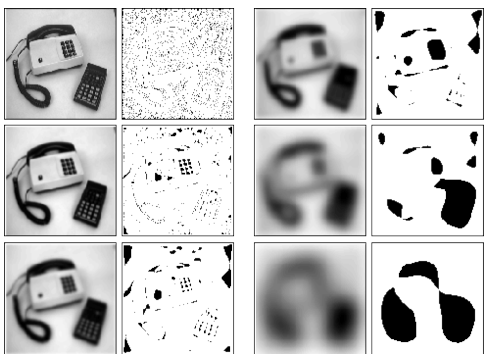


$$L(x, y, \sigma) = G(x, y, \sigma) * I(x, y),$$

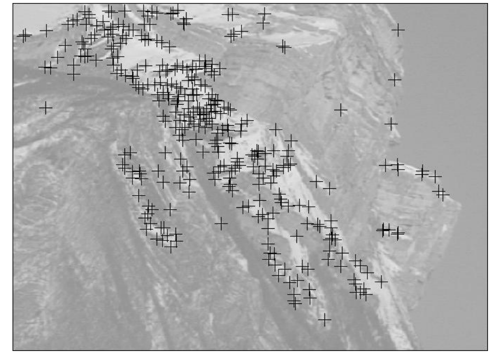
$$G(x, y, \sigma) = \frac{1}{2\pi\sigma^2} e^{-(x^2+y^2)/2\sigma^2}.$$

Witkin (1983), Koenderink(1984), Lindeberg(1994)

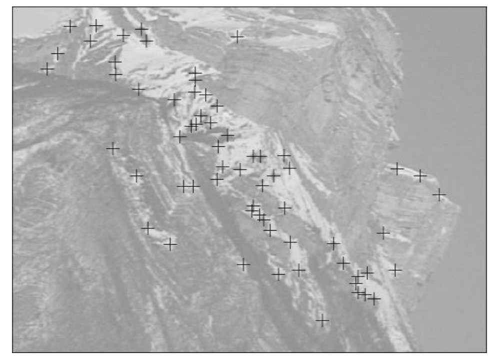
$$L(x, y, s\sigma); \quad s = 1, 2, \ldots, k$$

Harrisov detektor na več merilih

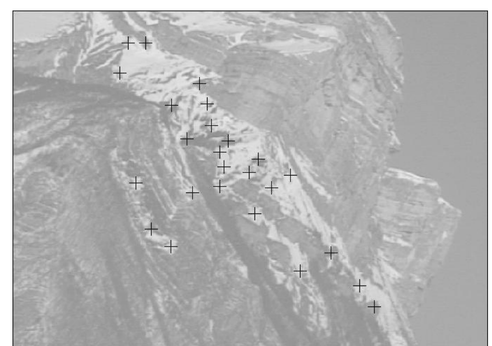
$$M_s = s^2 G(s\tilde{\sigma}) \otimes \begin{bmatrix} L_x^2(s\sigma) & L_x L_y(s\sigma) \\ L_x L_y(s\sigma) & L_y^2(s\sigma) \end{bmatrix}$$



$s = 1$



$s = 3$



$s = 5$

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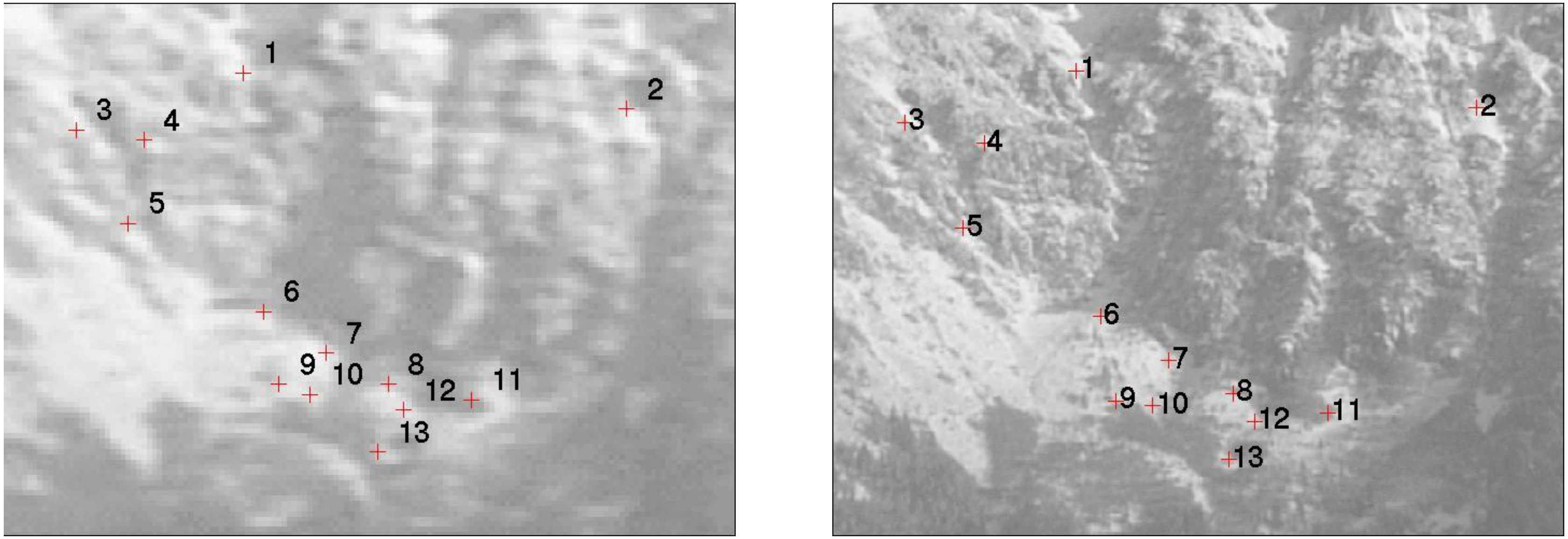
Harrisov detektor na več merilih

$$M_s = s^2 G(s\tilde{\sigma}) \otimes \begin{bmatrix} L_x^2(s\sigma) & L_x L_y(s\sigma) \\ L_x L_y(s\sigma) & L_y^2(s\sigma) \end{bmatrix}$$



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