$$x[k,l]$$

$$x[k,l] = \begin{bmatrix} x[0,0] & x[0,1] & \cdots & x[0,L-1] \\ x[1,0] & x[1,1] & \cdots & x[1,L-1] \\ \vdots & & & \vdots \\ x[K-1,0] & x[K-1,1] & \cdots & x[K-1,L-1] \end{bmatrix}$$

$$y[k,l] = x[k,l] + const.$$

$$y[k,l] = x[k,l] \times const.$$

$$y[k,l] = 0, \quad \text{pokud} \;\; y[k,l] < 0$$

$$y[k,l] = 1, \quad \text{pokud} \;\; y[k,l] > 1$$

$$y[k,l] = 0, \quad \text{if} \;\; y[k,l] < 0$$

$$y[k,l] = 1, \quad \text{if} \;\; y[k,l] > 1$$

——— filtry ———

$$y[n] = x[n] \star h[n] = \sum_{k=0}^{Q} h[k]x[n-k]$$

$$y[n] = x[n] \star h[n] = \sum_{k=0}^{Q} x[k]h[n-k]$$

$$y[k,l] = x[k,l] \star h[k,l] = \sum_{m=-\frac{I-1}{2}}^{\frac{I-1}{2}} \sum_{n=-\frac{J-1}{2}}^{\frac{J-1}{2}} h[m,n]x[k-m,l-n]$$

new one

$$y[k,l] = x[k,l] \star h[k,l] = \sum_{m=-\frac{I-1}{2}}^{\frac{I-1}{2}} \sum_{n=-\frac{J-1}{2}}^{\frac{J-1}{2}} x[m,n]h[k-m,l-n]$$

¿¿¿ better w/o limits

$$y[k,l] = x[k,l] \star h[k,l] = \sum_{m} \sum_{n} x[m,n]h[k-m,l-n]$$

1	2	3
4	5	6
7	8	9

9	8	7
6	5	4
3	2	1

$$\sum_{k} \sum_{l} |h[k,l]| = 1$$

—— filtry ———

$$h[k,l] = [1]$$

smooth

$$h[k,l] = \frac{1}{9} \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

new sharpen

$$h[k,l] = \begin{bmatrix} -1 & -1 & -1 \\ -1 & 9 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

sobels - without 1/8 ...

$$h_v[k,l] = \begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{bmatrix}$$

$$h_h[k,l] = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$$

$$y[k,l] = |y_v[k,l]| + |y_h[k,l]|$$

$$y[k,l] = \text{median}_{k=-\frac{I-1}{2}\dots\frac{I-1}{2},\quad l=-\frac{J-1}{2}\dots\frac{J-1}{2}} x[k,l]$$

$$c = \sum_{n=0}^{N-1} x[n]a[n]$$

$$\cos(2\pi\frac{k}{N}n)$$

$$e^{-j2\pi\frac{k}{N}n} = \cos(2\pi\frac{k}{N}n) - j\sin(2\pi\frac{k}{N}n)$$

$$e^{jx} = \cos(x) + j\sin(x)$$

$$c = \sum_{k=0}^{K-1}\sum_{l=0}^{L-1} x[k,l]a[k,l]$$

$$a[k,l] = 1$$

$$a[k,l] = \cos(2\pi\frac{1}{100}l)$$

$$a[k,l] = \cos(2\pi\frac{2}{100}l)$$

$$a[k,l] = \cos(2\pi\frac{1}{100}k)$$

$$a[k,l] = \cos(2\pi\frac{2}{100}k)$$

$$a[k,l] = \cos(2\pi\frac{7}{100}k)$$

$$a[k,l] = \cos(2\pi\frac{3}{100}l)$$

$$a[k,l] = \cos\left[2\pi(\frac{7}{100}k + \frac{3}{100}l)\right]$$

$$X[m,n] = \sum_{k=0}^{K-1}\sum_{l=0}^{L-1} x[k,l]\cos\left[2\pi(\frac{m}{K}k + \frac{n}{L}l)\right]$$

$$x[k,l]$$

$$X[m,n]$$

——— frequencies ———

$$Hz = \frac{1}{s}$$

$$F_s = \frac{\#samples}{s}$$

$$f_{norm} = \frac{f_{true}}{F_s}$$

$$f_{norm,DFT} = \frac{k}{N}$$

$$f_{true} = \frac{k}{N} F_s$$

$$dpi = \frac{1}{inch}$$

$$F_s = \frac{\#pixels}{inch}$$

$$f_{norm} = \frac{f_{true}}{F_s}$$

$$f_{norm,vert} = \frac{m}{K}, \quad f_{norm,horiz} = \frac{n}{L}$$

$$f_{true,vert} = \frac{m}{K} F_s, \quad f_{true,horiz} = \frac{n}{L} F_s$$

—— 1d dft

$$X[k] = \sum_{n=0}^{N-1} x[n] e^{-j2\pi \frac{k}{N} n}$$

—— 2d dft

$$X[m,n] = \sum_{k=0}^{K-1} \sum_{l=0}^{L-1} x[k,l] e^{-j\left[2\pi\left(\frac{m}{K}k + \frac{n}{L}l\right)\right]}$$

examples

$$X[0,0] = \sum_{k=0}^{K-1} \sum_{l=0}^{L-1} x[k,l] e^{-j\left[2\pi\left(\frac{0}{K}k + \frac{0}{L}l\right)\right]} = \sum_{k=0}^{K-1} \sum_{l=0}^{L-1} x[k,l]$$

$$X[0,1] = \sum_{k=0}^{K-1} \sum_{l=0}^{L-1} x[k,l] e^{-j\left[2\pi\left(\frac{0}{K}k + \frac{1}{L}l\right)\right]} = \sum_{k=0}^{K-1} \sum_{l=0}^{L-1} x[k,l] e^{-j2\pi \frac{1}{L} l}$$

$$X[3,0] = \sum_{k=0}^{K-1} \sum_{l=0}^{L-1} x[k,l] e^{-j\left[2\pi\left(\frac{3}{K}k + \frac{0}{L}l\right)\right]} = \sum_{k=0}^{K-1} \sum_{l=0}^{L-1} x[k,l] e^{-j2\pi \frac{3}{K} k}$$

$$X[4,7]$$

—— 2d dft as 2 x 1d dft

$$X[m,n] = \sum_{k=0}^{K-1} \sum_{l=0}^{L-1} x[k,l] e^{-j2\pi\left(\frac{mk}{K} + \frac{nl}{L}\right)} = \sum_{k=0}^{K-1} e^{-j2\pi \frac{mk}{K}} \sum_{l=0}^{L-1} x[k,l] e^{-j2\pi \frac{nl}{L}}, \quad \ldots \quad \text{or vice versa}$$

$$2DDFT\{x[k,l]\} = 1DDFT_{columns}\{1DDFT_{rows} x[k,l]\} \quad \ldots \quad \text{or vice versa}$$

—— symetrie ...

$$X[k] = X^{\star}[N-k]$$

$$X[m,n] = X^{\star}[K-m, L-n]$$

$$x[k,l] = \frac{1}{KL} \sum_{m=0}^{K-1} \sum_{n=0}^{L-1} X[m,n] e^{+j2\pi\left(\frac{mk}{K} + \frac{nl}{L}\right)}.$$

$$X[k] = \sum_{n=0}^{N-1} x[n] \cos\left[\frac{\pi}{N}(n + \frac{1}{2})k\right]$$

$$\sqrt{\frac{1}{N}} \quad \text{for} \quad X[0]$$

$$\sqrt{\frac{2}{N}} \quad \text{for} \quad X[1 \ldots N-1]$$

$$X[m,n] = \sum_{k=0}^{K-1} \sum_{l=0}^{L-1} x[k,l] \cos\left[\frac{\pi}{K}(k + \frac{1}{2})m\right] \cos\left[\frac{\pi}{L}(l + \frac{1}{2})n\right]$$

not used

$$2DDCT\{x[k,l]\} = 1DDCT_{sloupce}\{1DDCT_{radky} x[k,l]\}$$