Digital Image Modifications

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References

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- R.C.Gonzales, R.E.Woods: Digital Image Processing, 3rd Edition, Prentice Hall, 2007
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- ....

Image for us : a matrix of a) intensity pixels, b) colour components triples (R,G,B)

1. Geometrical transformations

- A source image is transformed to a destination image:

$S(u_p,v_q) \rightarrow D(x_j,y_k)$

- $0 \le p \le P-1$, $0 \le q \le Q-1$,
- $0 \le j \le J-1$, $0 \le k \le K-1$

Geometrical transformations:

Most often translation, rotation, scale

- Translation:
  - Forward mapping – computed for each pixel $[u_p,v_q]$ of source image

    $x_j = u_p + t_x \quad y_k = v_q + t_y$,

    where (t_x, t_y) is a translation vector

    x_j,y_k are not necessarily integers (<= t_x,t_y),

    due to rounding, holes may appear
  - Backward mapping – computed for each pixel $[x_j,y_k]$ of destination image:

    $u_p = x_j - t_x \quad v_q = y_k - t_y$,

    where (t_x, t_y) is a translation vector

    u_p,v_q are not necessarily integers (<= t_x,t_y),

    then interpolation

Geometrical transformations:

- Similar equations are possible for rotation and scale but more often, matrix equations are used

Translation:

$$\begin{bmatrix} x_j \\ y_k \end{bmatrix} = \begin{bmatrix} u_p \\ v_q \end{bmatrix} + \begin{bmatrix} t_x \\ t_y \end{bmatrix}$$

Scaling:

$$\begin{bmatrix} x_j \\ y_k \end{bmatrix} = \begin{bmatrix} s_x & 0 \\ 0 & s_y \end{bmatrix} \begin{bmatrix} u_p \\ v_q \end{bmatrix}$$

Rotation:

$$\begin{bmatrix} x_j \\ y_k \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} u_p \\ v_q \end{bmatrix}$$

- Translation, then scale, then rotation:

$$\begin{bmatrix} x_j \\ y_k \end{bmatrix} = \begin{bmatrix} s_x \cos\theta & -s_y \sin\theta \\ s_x \sin\theta & s_y \cos\theta \end{bmatrix} \begin{bmatrix} u_p \\ v_q \end{bmatrix} + \begin{bmatrix} s_x t_x \cos\theta & -s_y t_y \sin\theta \\ s_x t_x \sin\theta & +s_y t_y \cos\theta \end{bmatrix}$$

Geometrical transformations:

- It can be rewritten as

$$\begin{bmatrix} x_j \\ y_k \end{bmatrix} = \begin{bmatrix} c_0 & c_1 \\ d_0 & d_1 \end{bmatrix} \begin{bmatrix} u_p \\ v_q \end{bmatrix} + \begin{bmatrix} c_2 \\ d_2 \end{bmatrix}$$

or

$$\begin{bmatrix} x_j \\ y_k \end{bmatrix} = \begin{bmatrix} c_0 & c_1 & c_2 \\ d_0 & d_1 & d_2 \end{bmatrix} \begin{bmatrix} u_p \\ v_q \\ 1 \end{bmatrix}$$

- (c_0 .. d_2 see previous equations)
- The same relations expressed using a square matrix:

$$\begin{bmatrix} x_j \\ y_k \\ 1 \end{bmatrix} = \begin{bmatrix} c_0 & c_1 & c_2 \\ d_0 & d_1 & d_2 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} u_p \\ v_q \\ 1 \end{bmatrix}$$

Geometrical transformations:

- The inverse computation is:

$$\begin{bmatrix} u_p \\ v_q \\ 1 \end{bmatrix} = \begin{bmatrix} a_0 & a_1 & a_2 \\ b_0 & b_1 & b_2 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_j \\ y_k \\ 1 \end{bmatrix}$$

- Translation:

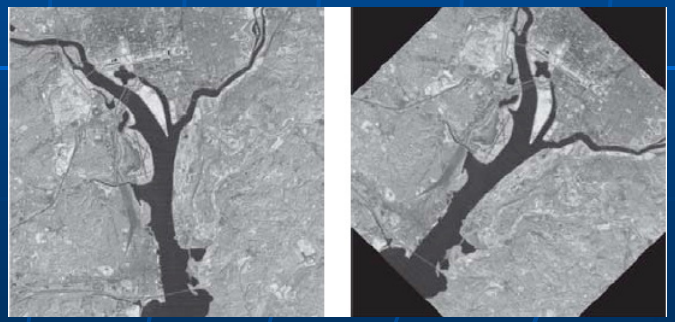
  $a_0 = 1, a_1 = 0, a_2 = -t_x,$
  $b_0 = 0, b_1 = 1, b_2 = -t_y$

- Scale:

  $a_0 = 1/s_x, a_1 = 0, a_2 = 0,$
  $b_0 = 0, b_1 = 1/s_y, b_2 = 0$

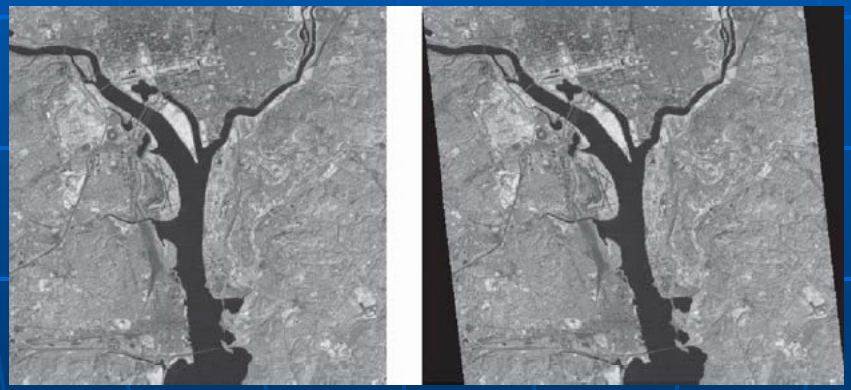
- Rotation:

  $a_0 = \cos\theta, a_1 = \sin\theta, a_2 = 0,$
  $b_0 = -\sin\theta, b_1 = \cos\theta, b_2 = 0$



Geometrical transformations:

- Another example:
  Shear: $c_0=d_1=1$, $c_1=0.1$, $d_0=0$, $c_2=d_2=0$



2. Emboss
    1. An auxiliary image – an inverse of the source
    2. Translation/shift of the auxiliary image (user-given, usually 1 pixel in both x and y)
    3. Sum of the source and shifted auxiliary image
    4. All pixel intensities are divided by 2 (the average of the source and auxiliary iamges)

- More precisely:

  D[i,j] = 1/2*(S[i,j] + (1-S[i+1,j+1]))

  where S[i,j] – a source image pixel,

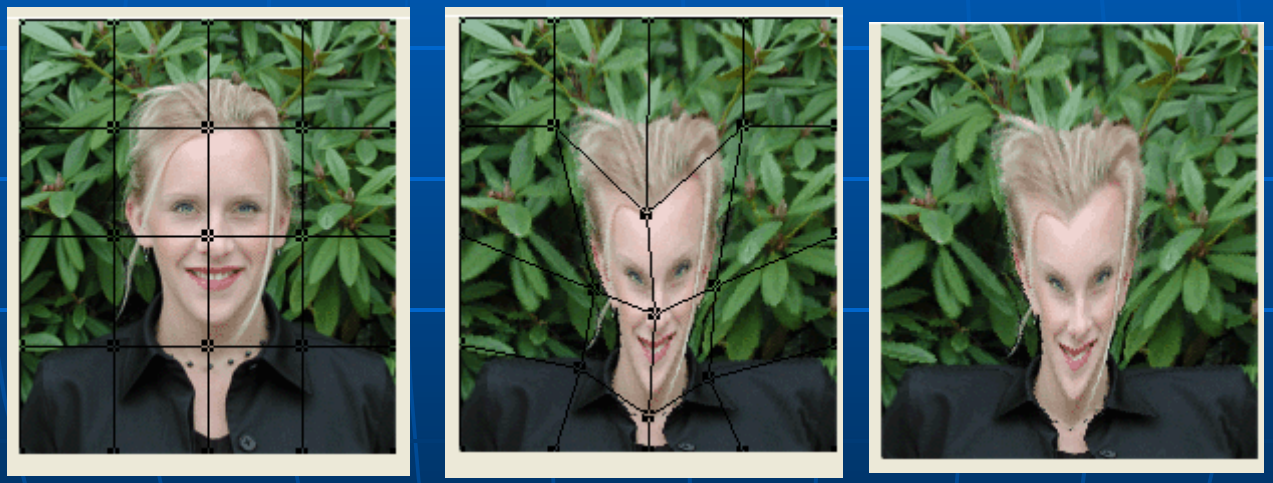
  D[i,j] – a destination image pixel

An example - emboss

Can be done
in colour components,
or in intensity (weighted
sum of components)

3. Warping

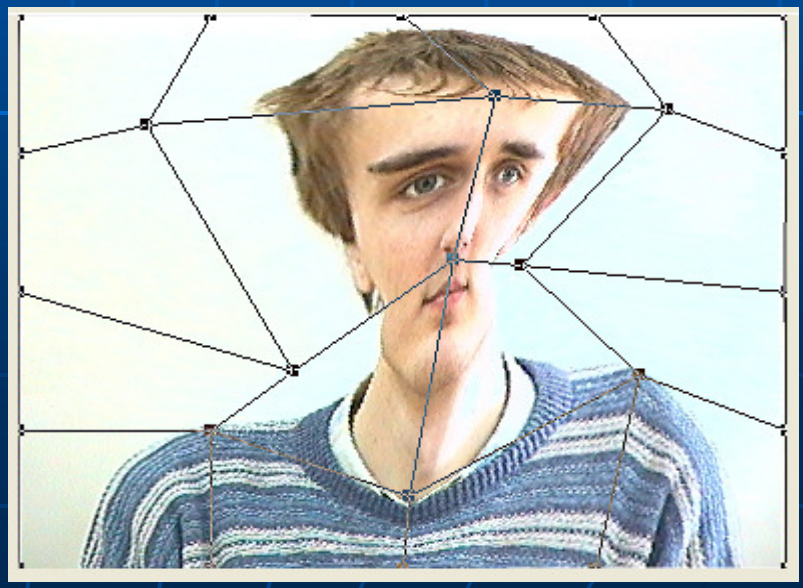
- A “free deformation” of the image
- 2 basic algorithms: grid-based or line-segments-based



An example of grid-based warping

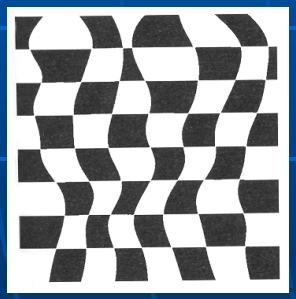
Grid-based warping

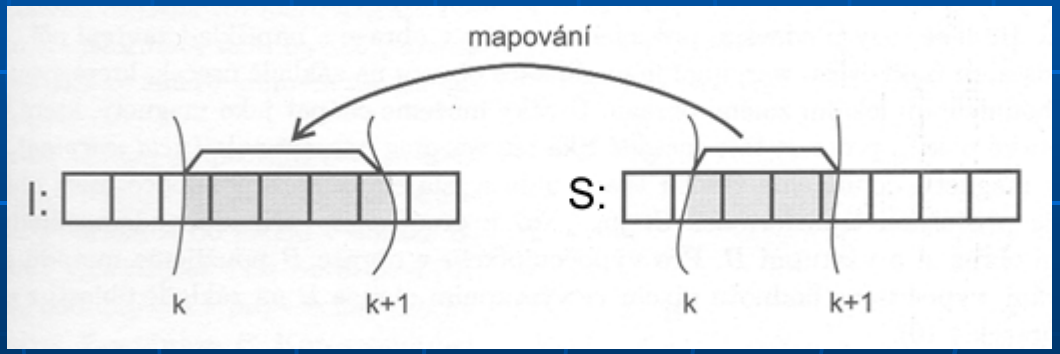
- Defined by a grid put on the image
- Polylines, Bézier cubics or sple curves are used as boundaries of cells
- The user moves the nodes
- 4gones then change their shape correspondigly
- Suitable for global changes in the image



Grid-based warping

- 2 iterations
- 1st iteration: points moved in rows
  - Computation of intersections of vertical curves/polylines with image rows => new intervals on the rows
  - Resampling of intervals (most often a linear interpolation), output is an inter-image I





- 2nd iteration: points of inter-image moved in columns (using horizontal curves/polylines)

Line segment warping

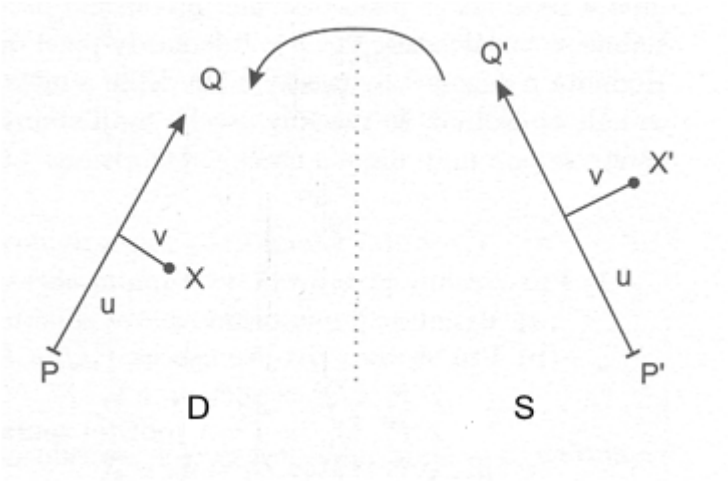
- Also called field warping, feature-based warping
- For local changes in the image (e.g., to close eyes)
- Backward mapping is used – a corresponding pixel of the source image S is looked for the pixel of the destination image D
- Local changes are defined by line segments (each line segment in S has a corresponding line segment in D)

Line segment warping

- Compute *u*,*v*, then a source pixel *X'* can be found for a destination pixel *X*
- *v* – absolute distance,
- *u* - normalized

dot product and projection of *XP* to *QP*

$$u = \frac{(X - P) \cdot (Q - P)}{\|Q - P\|^2}$$



perpendicular vector

$$v = \frac{(X - P) \cdot (Q - P)_{\perp}}{\|Q - P\|}$$

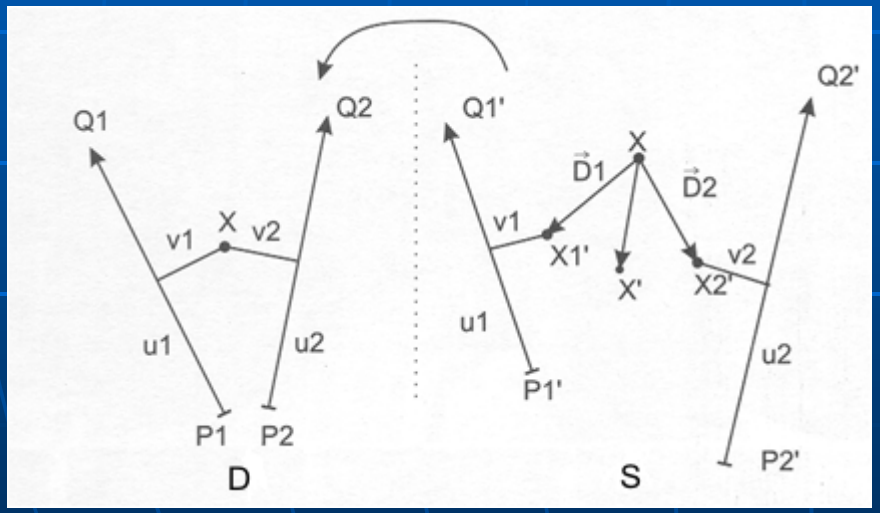
$$X' = P' + u(Q' - P') + \frac{v.(Q' - P')_{\perp}}{\|Q' - P'\|}$$

Rotation, translation and scale in the direction of line segment

Line segment warping

- More line segments used:
  - To find *u*,*v* for all lines segments and one destination pixel *X*,
  - Each line segment provides one X_i'
  - Resulting X' is a weighted sum of all X_i'

$$D_i = X_i' - X$$



$$X' = X + \frac{\sum_{i=1}^{n} \vec{D}_i \, w_i}{\sum_{i=1}^{n} w_i}$$

$$w_i = \left(\frac{|Q_i' - P_i'|^p}{(a + dist)} \right)^b$$

- Line segment should not cross, otherwise strange effects

Line segment warping - parameters

- *a*,*b*,*p* given by the user
- Influence of particular segment on the transformation

$$w_i = \left(\frac{|Q'_i - P'_i|^p}{(a + dist)} \right)^b$$

- Suitable values: e.g., *a*=0.001, *b*=2, *p*=0.5
- *a* – line segment influence, *a*->0; a bigger value – a smoother warp, but less exact user control
- *b* – fading influence of the line segment with the distance (*b*=0 – all line segments the same influence, *b* big – only the nearest line segments influence)
- *p* from <0,1>, a bigger value – bigger influence of longer line segments
- *dist* – distance of the point *X* from l.s. P_iQ_i; *dist* = abs(*v*) for *u* from <0,1>, *dist*=|*PX*| for *u*<0, *dist*=|*QX*| for *u*>1

Line segment warping

- The algorithm for the whole image:
- For all pixels X of destination image
  - $d_{sum} = (0,0)$, $w_{sum} = 0$ // accumulated vector of sums, accumulated sum of weights
  - For all pairs of line segment P_iQ_i and $P_i'Q_i'$
    - Compute P_i and Q_i from u_i and v_i
    - Compute X_i' from P_i', Q_i', u_i and v_i
    - $D_i = X_i' - X$
    - Compute *dist* between X and P_iQ_i
    - Compute w_i
    - Compute $d_{sum} = d_{sum} + w_iD_i$
    - $w_{sum} = w_{sum} + w_i$
  - Compute $X' = X + d_{sum}/w_{sum}$
  - D(X) = Source(X')
- More images: line segment vertices gradually change, usually by linear interpolation

4. Morphing

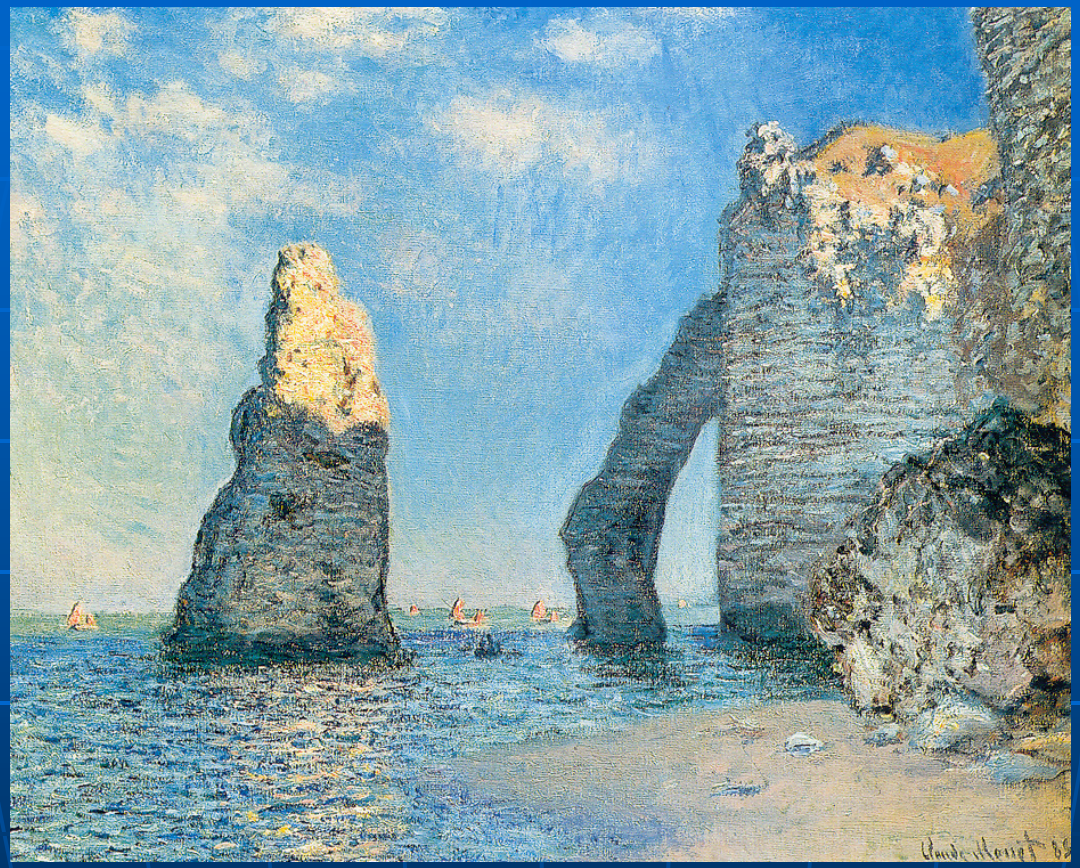
- Transfer of one image into another (also possible for geometric objects)
- Warp of source image S to S_i, destination D to D_i and interpolation between S_i and D_i
- Eitehr interpolation of corresponding pixels of both images, or with the computation of correspondence of pixels from both images

5. Imitation of painters' techniques

- Impressionism – 2nd half of 19th cent., capturing of countryside in a time point (spreading pure tones in spots, halftones obtained as late as on the retina of the observer)

- Pointilism – colours placed with the stress on the contrast of complementary
- Given: A simple shape (circle, ellipse, square), thickness of the brush, a direction to draw (a vector) and a template (a dig. image)

- Subdivide the template into squares a x a, average a square and find the closest colour in the palette, make a dot or a draw in the given direction; the draws overlap without colour blending
- All randomly modified (the direction, draw length, colour)



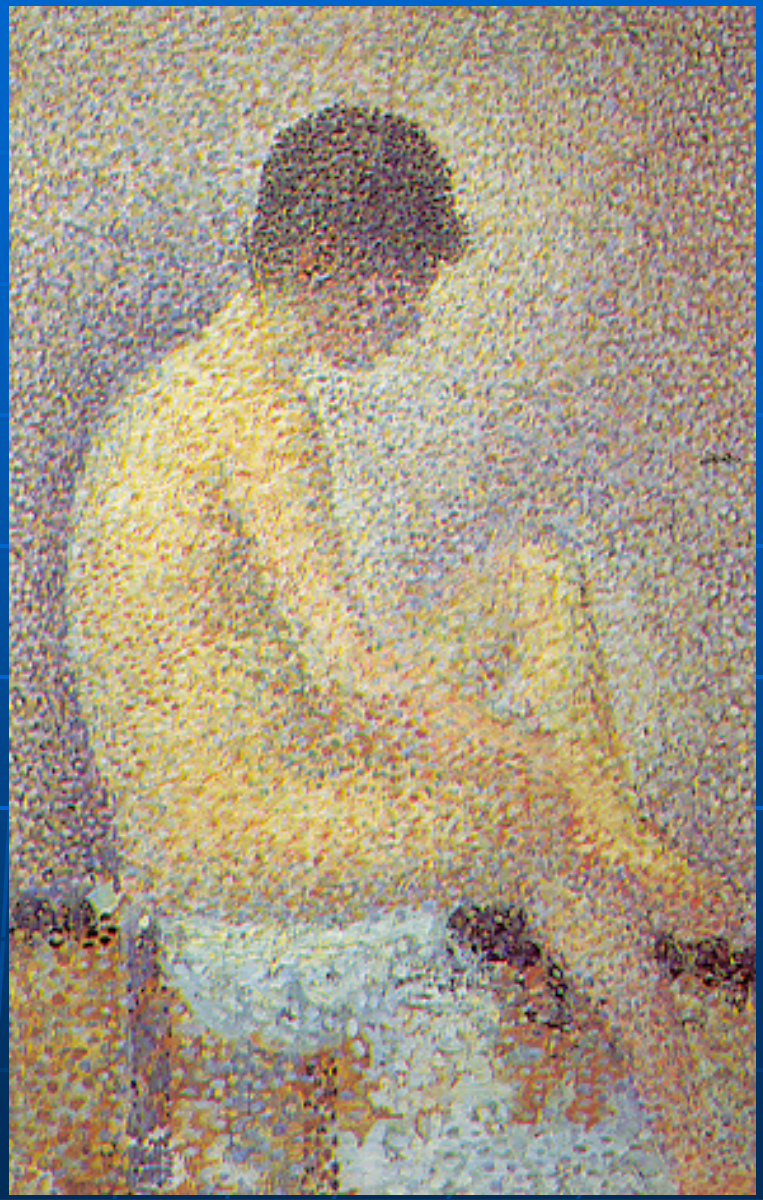
Claude Monet: The Cliffs at Etretat, 1885

Claude Monet:
Woman with a Parasol,
Facing Right
(also known as
Study of a Figure Outdoors
(Facing Right)),
1886

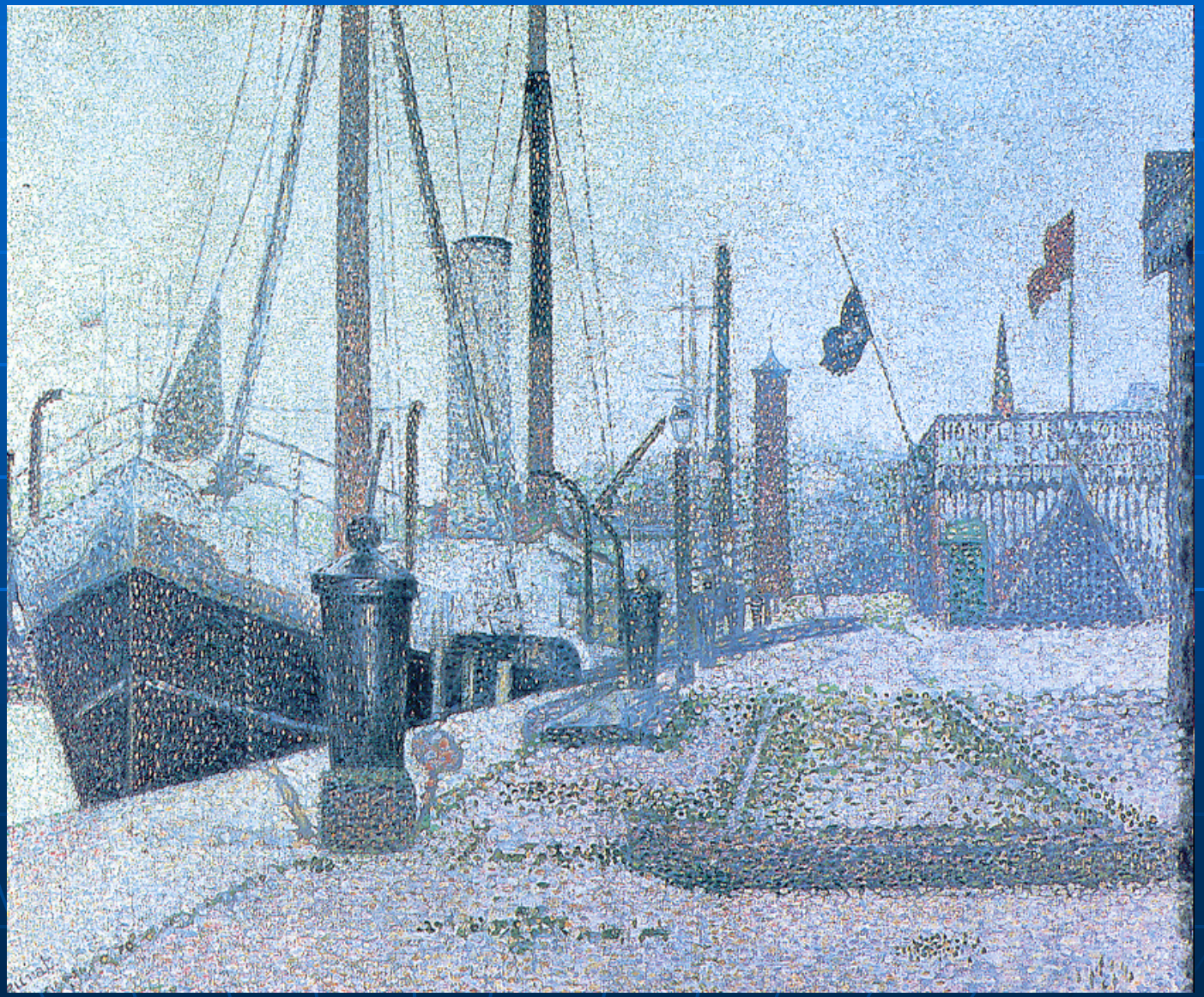
lonet:
athedral in the morning sun,
1894

KPG

Georges Seurat:
Sitting model, profile,
1886

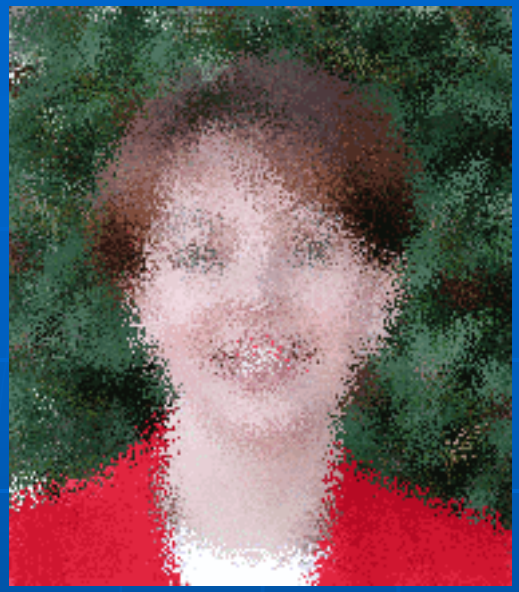


Georges Seurat:
La Maria, Honfleur,
1886

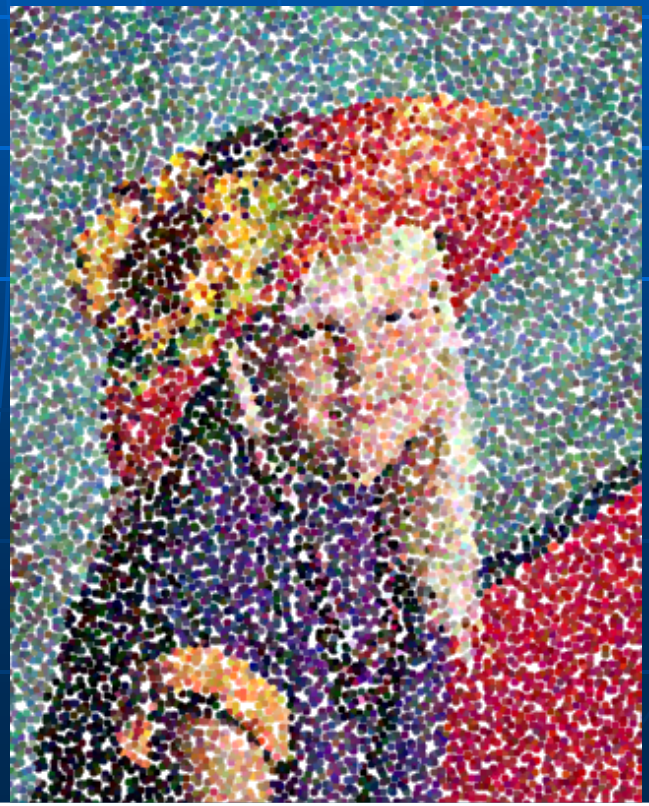


Georges Seurat:
Le Chahut,
1889-90

Computer-produced impressionism



Computer-produced pointilism



6. Image sharpening

- Based on edge detection and enhacement
- An edge given by the value and direction of the gradient

$$\nabla f(x,y) = \left(\frac{\partial f(x,y)}{\partial x}, \frac{\partial f(x,y)}{\partial y} \right)$$

vector operator nabla

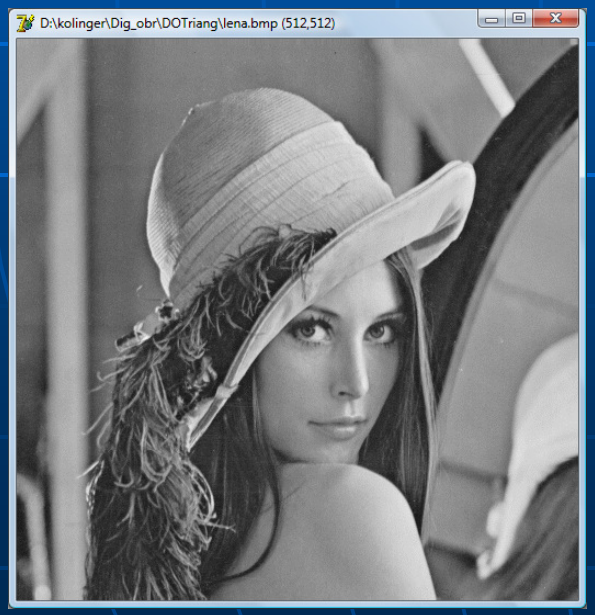
$$|\nabla f(x,y)| = \sqrt{\left(\left(\frac{\partial f(x,y)}{\partial x} \right)^2 + \left(\frac{\partial f(x,y)}{\partial y} \right)^2 \right)}$$

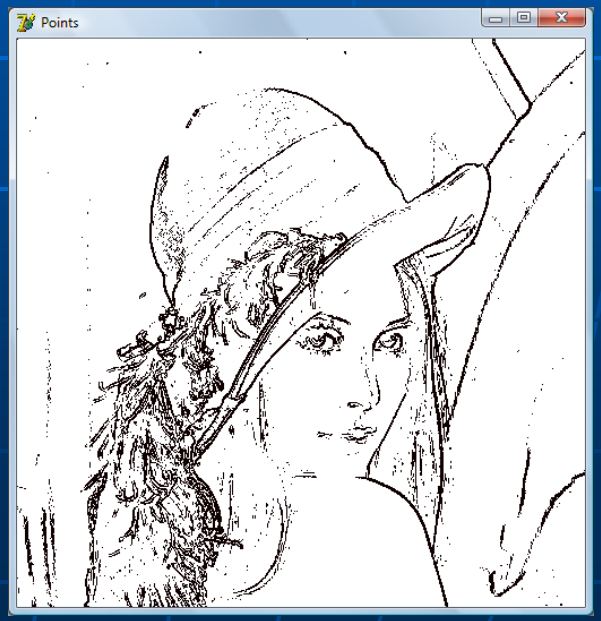
- Let s(i,j) be the value of the gradient of the image f in a point i,j, then the image g obtained by sharpening f in the point i,j is

$$g(i,j) = f(i,j) + c * s(i,j)$$, c – sharp. coeff.

- Gradient in the digital image - ambiguous
- The simplest: Roberts operator- intensity change in the direction of the main and side diagonals

$$|\nabla f(i,j)| = |f(i,j) - f(i+1,j+1)| + |f(i,j+1) - f(i+1,j)|$$





- Laplace operator- differences of intensity in the directions perpendicular to the coordinate axes

4-NB

$$h = \begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix}$$

$$h = \begin{bmatrix} 1 & 1 & 1 \\ 1 & -8 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

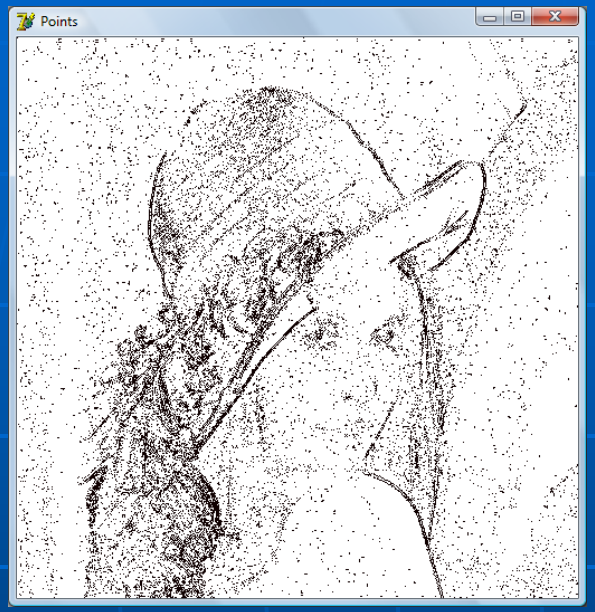
8-NB

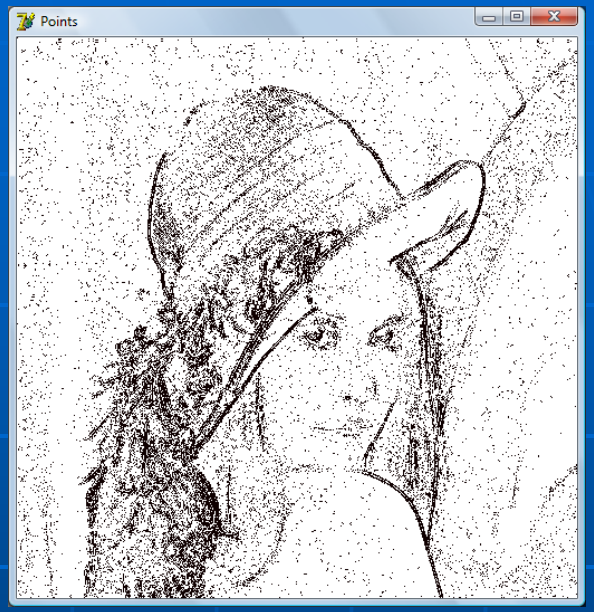
- h is used in the so-called discrete convolution:

$$I'[x, y] = \sum_{i=-k}^{k} \sum_{j=-k}^{k} I[x+i, y+j]h[i+k, j+k]$$

Edge points extraction using Laplace operator

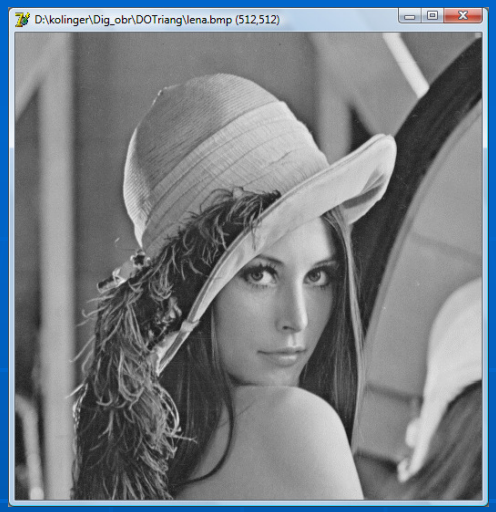
4x4



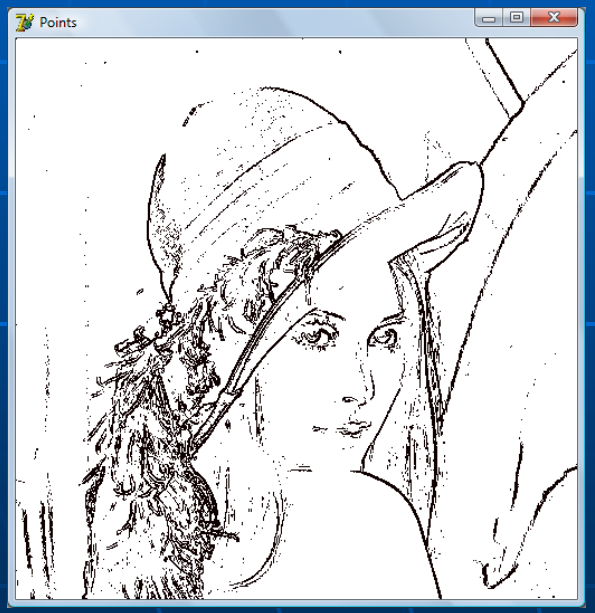


8x8

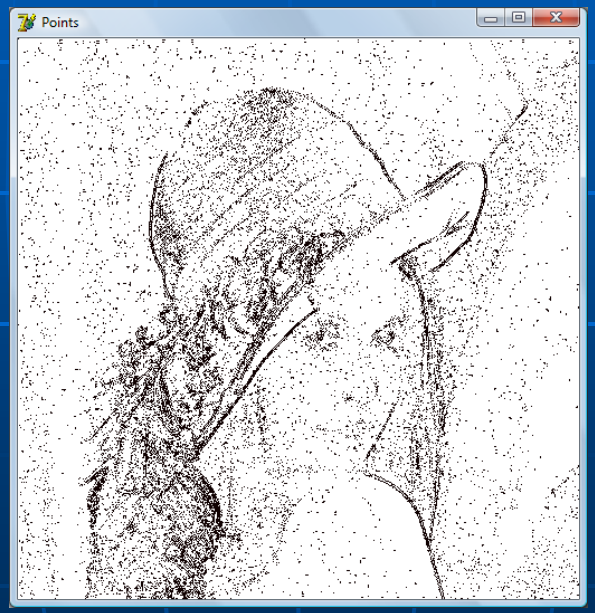
8x8



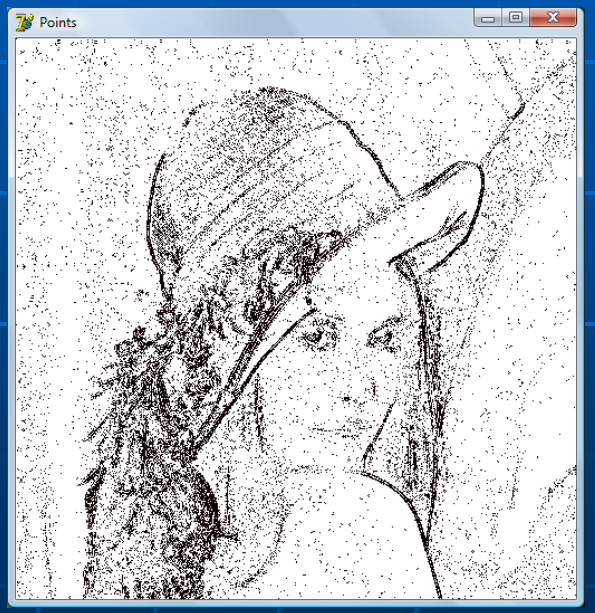
Original



Roberts,
~10% points

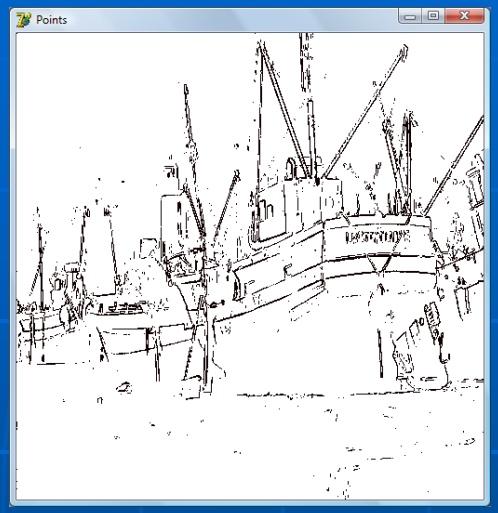


Laplace 4x4,
~10% points

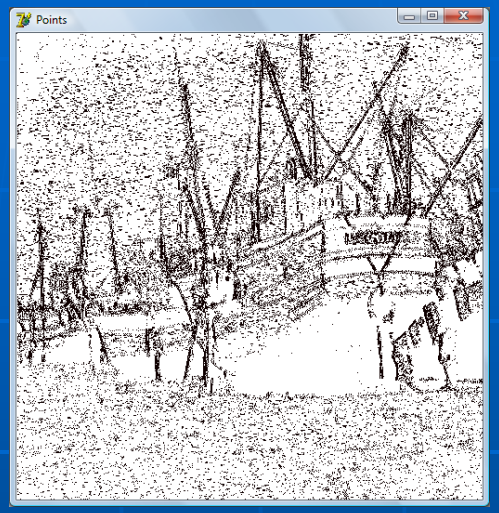


Laplace 8x8,
~10% points

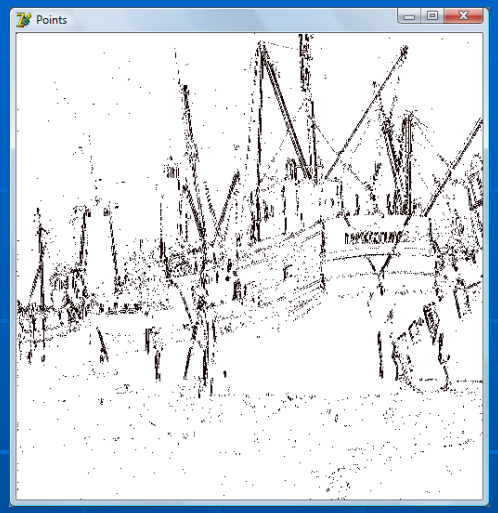
Extraction ~10% edge points + triangulation + interpolation



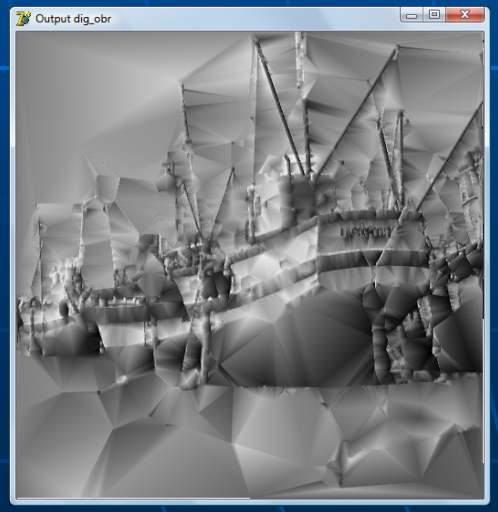
Roberts



Laplace 4x4

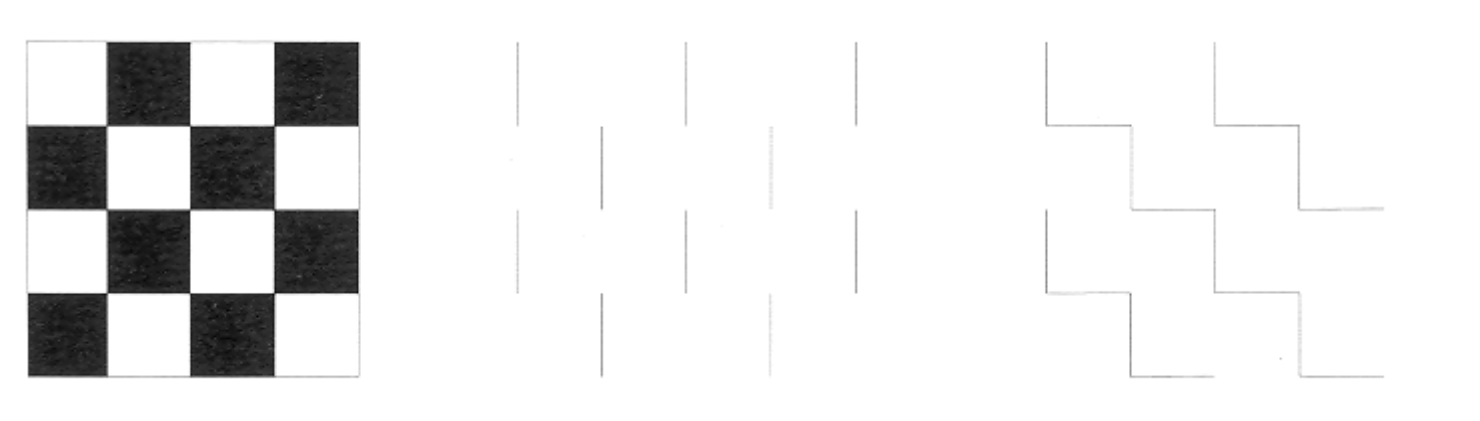


Laplace 8x8



Examples –
edge enhancement
(here too much - see artefacts)

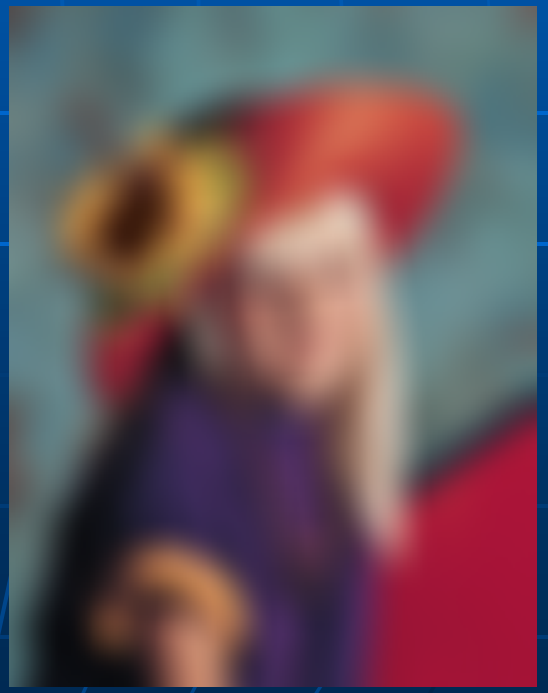
- Other operators: Sobel operator – directional, 8 variant, etc.
- Operators enhancing edges enhance all high frequencies, thus they are sensitive to noise, sensitivity decreases with a growing neighbourhood



Sobel operators detecting
vertical and horizontal lines

7. Blur

- Replace the pixel by the average of the neighbourhood

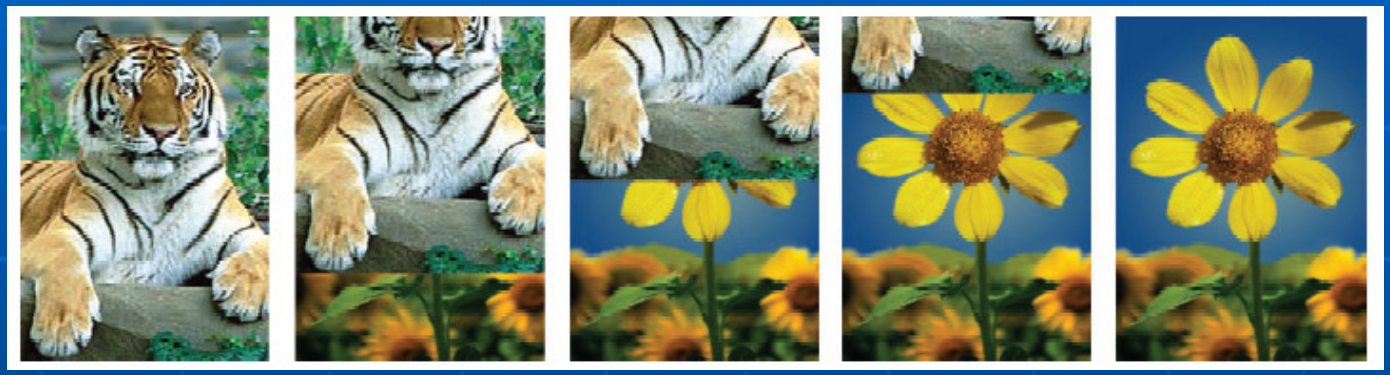


8. Image transitions

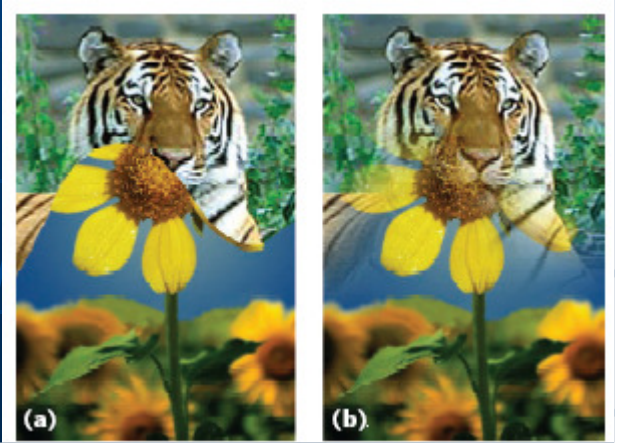
- Visual effects transforming a scene A to a scene B
- Not too much stress – it should transform the attention from A to B, not to disturb
- The simplest solution: dissolve, alfa-blending
- Fading out – dissolve A to black, from black to B

Wipe

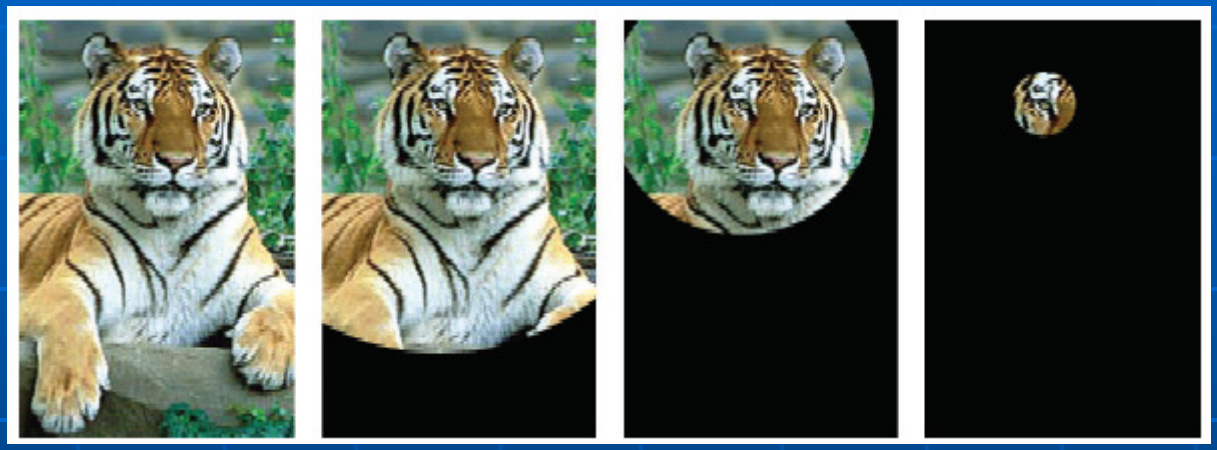
- Vertical, horizontal or other directions



- The boundary can be complex (a), fuzzy (b)



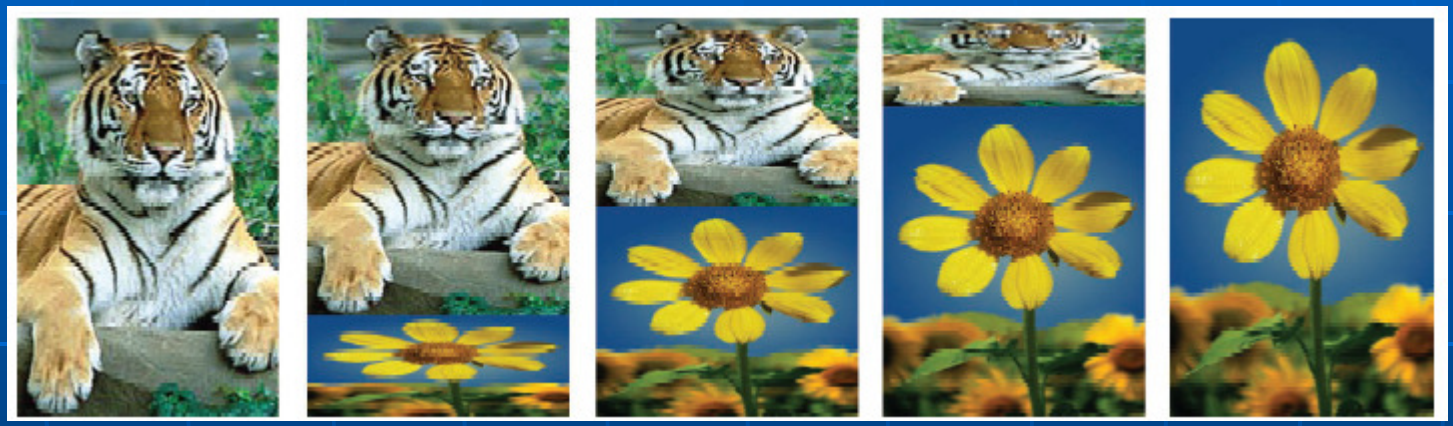
- Iris effect



Cliche: heart-shaped iris effect ☺

Biased wipe

- Besides images transition also, e.g., a scale



- Suitable, e.g., to emphasize something in A, B (scaling down and up)