Interest points

Properties of good features
• Local: robust to <u>occlusion</u> and <u>clutter</u>
• Accurate: precise localization
• Covariant
• Robust: noise, blur, compression
• Efficient: close to real-time performance

Use interest point to build panorama
1. Detect corners in both images
2. Find corresponding corner pairs by comparing <u>the corner descriptors</u>
3. Use these pairs to align images

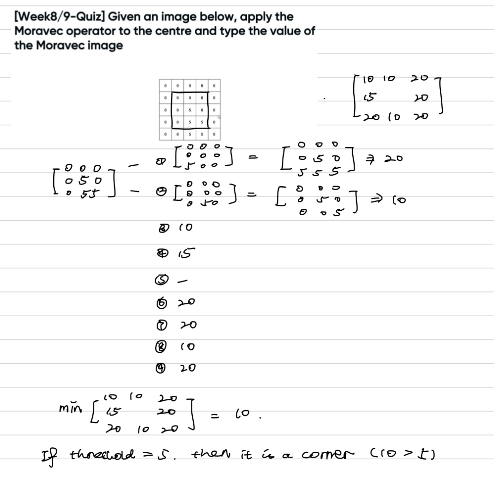
Moravec operator

Given a grayscale image *I(x,y)*
- Centre a 3x3 pixel array on each pixel in turn
- Define another array one pixel up to the right of the first array
- Calculate the absolute differences between the values of the corresponding pairs of pixels in the two arrays
- Sum all these absolute differences values (9 values)
- Repeat for arrays moved one pixel relative to the initial array up, down, right, left, diagonally up left, diagonally down left and diagonally down right.
- Take the minimum of these 8 values and this is the new value for the pixel in the Moravec image *M(i,j)*
- Threshold the new image *M(i,j)* to isolate corners in the image

Moravec operator features:
1. Maximal in pixels with high contrast
2. Simple implementation
3. Diagonal edges will falsely be detected as corners
4. Computationally efficient —> works well for real-time applications

Issue:
1. Use a discrete rectangular window
2. Use a simple min function

Example:



Harris corner detector (good for rotation)
Basic idea, should easily recognize the point by looking through a small window, shifting a window in any direction should give a large change in intensity

Change of intensity for the shift [*u*,*v*]:

$$E(u,v)=\sum_{x,y}\underbrace{w(x,y)}_{\text{Window function}}[\underbrace{I(x+u,y+v)}_{\text{Shifted intensity}}-\underbrace{I(x,y)}_{\text{Intensity}}]^2$$

Window function: 1 in window, 0 outside window (rectangular)

$$E(u,v)\cong[u,v]\quad M\quad\begin{bmatrix}u\\v\end{bmatrix}\qquad M=\sum_{x,y}w(x,y)\begin{bmatrix}I_x^2 & I_xI_y\\ I_xI_y & I_y^2\end{bmatrix}$$

Measure of corner response:

$$R=\det M-k\left(\operatorname{trace} M\right)^2$$

$$\det M=\lambda_1\lambda_2$$
$$\operatorname{trace} M=\lambda_1+\lambda_2$$

(k – empirical constant, k = 0.04-0.06)

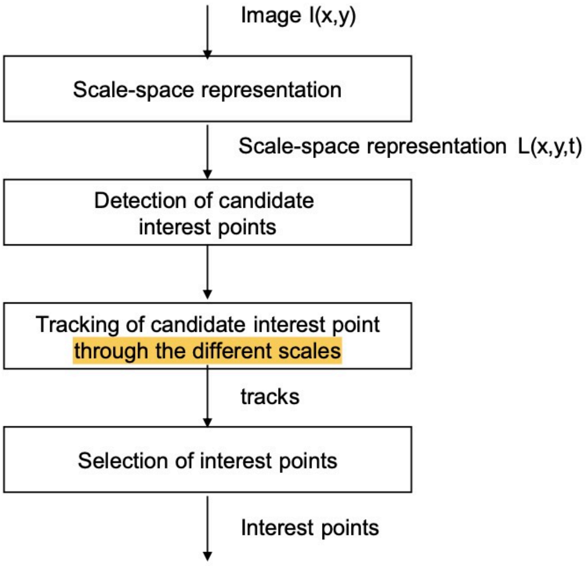
Classification:
- R > 0 —> corner (λ_1, λ_2 are large)
- R < 0 —> edge ($\lambda_1 >> \lambda_2$ or $\lambda_1 << \lambda_2$)
- |R| is small —> flat region (λ_1, λ_2 are small)

Procedure:
1. Calculate Ix, Iy, IxIy —> M
2. Calculate R according to $\lambda_1\lambda_2 \;-\; k\;\left(\lambda_1+\lambda_2\right)^2$
3. Corner point —> large positive R

(Note: 注意IxIy相乘是指对应元素相乘，IxIx， IyIy同理)

Evaluation of interest points
- Repeatability: stability of interest points when the view point changes or geometric transformations
- Accuracy: high accuracy in localization (the position of the interest point), compare the estimated interest point and real interest point

Improvements on Moravec —> scale-space approach



Criteria: life-span of a track

Repeatability evaluation: (# of interest points repeated) / (total number of interest points)
Rotate the image, interest points should always be identified —> not influenced by geometric change

Accuracy: rotate the objects, measure the position. Calculate the error between positions use RMSE

$$\text{RMSE} = \sqrt{\frac{1}{N}\sum_{n=1}^{N}\left[(x_{n0}-x_n)^2+(y_{n0}-y_n)^2\right]}$$

Practice

b) This question is about **Interest Points**.

[7 marks]

i) Give the Harris matrix M and the corner response measure R in mathematical terms for the Harris detector with image $f(x, y)$.

(4 marks)

ii) Fill the following table in the three cases of R for the classification of image points.

(3 marks)

corner response measure R	classification of image points
$\lvert R \rvert < 1$	
$R \leq -1$	
$R \geq 1$	

(1)

$$M = \begin{bmatrix} I_x^2 & I_xI_y \\ I_xI_y & I_y^2 \end{bmatrix}$$

$$R = \det(M) - k \cdot (\mathrm{trace}(M))^2$$ k usually ranges in $(0.04, 0.06)$

$$= \lambda_1\lambda_2 - k \cdot (\lambda_1 + \lambda_2)^2$$

(2)

Flat region
Edge
Corner

b) This question is about **Interest Points**.

[7 marks]

i) By using Harris detector with 3 × 3 window of equal weighting, the empirical constant k = 0.05, and differentiation kernel below (*d*/*dx* and *d*/*dy*), **1)** find the Harris matrix, and **2)** the corner response for the centre of the following image *I*, and **3)** determine whether the point is flat, edge, or corner:

(7 marks)

$$d/dx = \begin{bmatrix} 0 \\ -1 \\ 1 \end{bmatrix}, \qquad d/dy = \begin{bmatrix} 0 & -1 & 1 \end{bmatrix}$$

$$I = \begin{bmatrix} 6 & 6 & 6 & 6 & 6 \\ 6 & 6 & 6 & 6 & 6 \\ 1 & 1 & 2 & 7 & 7 \\ 6 & 6 & 6 & 6 & 6 \\ 6 & 6 & 6 & 6 & 6 \end{bmatrix}$$

① Find the Harris matrix M

$M = \begin{bmatrix} I_x^2 & I_xI_y \\ I_xI_y & I_y^2 \end{bmatrix}$.

First calculate I_x, I_y

I_x: apply $\begin{bmatrix} 0 \\ -1 \\ 1 \end{bmatrix}$

$6\times0+6\times(-1)+1\times1=-5$

$$\begin{bmatrix} 6 & 6 & 6 & 6 & 6 \\ 6 & 6 & 6 & 6 & 6 \\ 1 & 1 & 2 & 7 & 7 \\ 6 & 6 & 6 & 6 & 6 \\ 6 & 6 & 6 & 6 & 6 \end{bmatrix} \Rightarrow I_x = \begin{bmatrix} -5 & -4 & 1 \\ 5 & 4 & -1 \\ 0 & 0 & 0 \end{bmatrix}$$

calculate this part

$6\times0+6\times(-1)+2\times1=-4$

I_y: (same calculation) $\Rightarrow I_y = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 5 & 0 \\ 0 & 0 & 0 \end{bmatrix}$

$I_x^2 = (-5)^2+(-4)^2+1^2+5^2+4^2+(-1)^2 = (25+16+1)\times2 = 84$

各元素之乘再相加

$I_y^2 = 5^2+1^2 = 26$

$I_xI_y = 5\times1+4\times5 = 25$

$M = \begin{bmatrix} 84 & 25 \\ 25 & 26 \end{bmatrix}$

② $R = \lambda_1\lambda_2 - K\cdot(\lambda_1+\lambda_2)^2$

$\begin{cases} \lambda_1\lambda_2 = |M| \Rightarrow \text{行列式} \\ \lambda_1+\lambda_2 = \text{主对角线之和} \end{cases}$

$\lambda_1\lambda_2 = 84\times26 - 25\times25 = 1559$

$\lambda_1+\lambda_2 = 84+26 = 110$

$R = 1559 - 0.05\cdot110^2 = 954$

③ R is relatively big and $R>0$ $\Rightarrow$ this is a corner