UNIVERSITÀ DEGLI STUDI DI PADOVA

Detecting corners and blobs

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Agenda

- What are salient points?
- Harris corners
- USAN/SUSAN
- Blob features: MSER

Feature pipeline

Feature detection
AKA keypoint detection - find points easily recognizable

Feature description
Describe a region around the keypoint to make matching easy

Feature matching
Find similar descriptors in two images

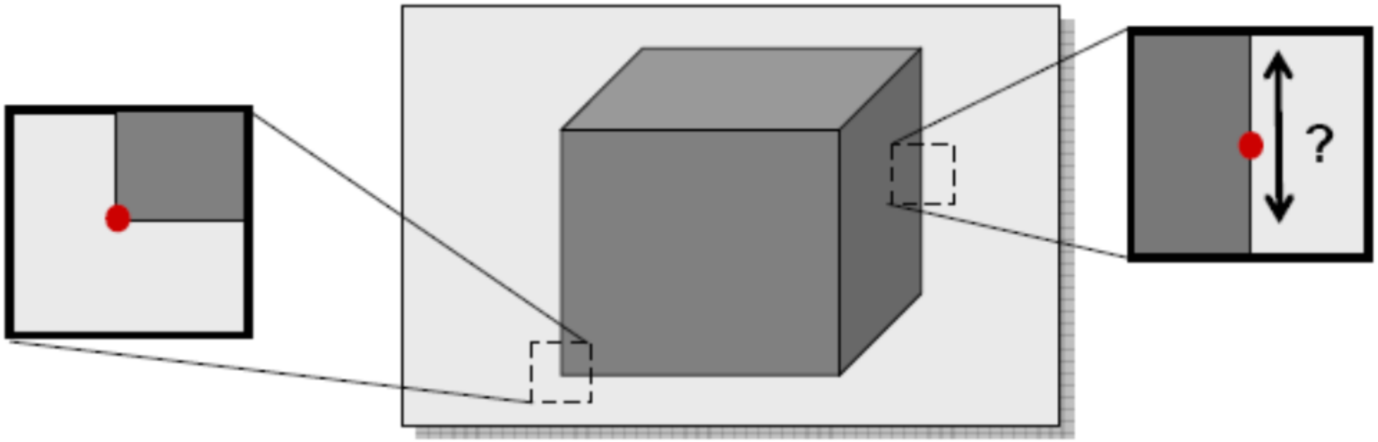
Feature tracking
Find similar descriptors in a neighborhood

Detecting salient points

- Consider patches A-F
- Which ones are easier to be found in the main image?

Detecting salient points

- What are good points?
  - Uniform regions?
  - Edge points?
  - Corner points?



Salient points

- Salient points (keypoints) can be detected in many different ways
- Several algorithms exist
- One of the first & most famous: Harris (or Harris-Stephens) corner detector

C. Harris, M. Stephens, "A combined corner and edge detector" Alvey vision conference, Vol. 15, No. 50, pp. 10-5244, 1988

Harris corners

- Intuition: consider a patch in an image and a shifted version of the patch
  - Uniform region: the two patches will be similar
  - Salient point: the two patches will be different
- A corner is a region producing a large difference if the patch is moved

Harris corners

- Consider a patch in a given position (x_i, y_i)
- Consider a displacement $(\Delta x, \Delta y)$
- Similarity is measured by means of the auto-correlation, a function of the displacement

Auto-correlation

- Auto-correlation:

$$E(\Delta x, \Delta y) = \sum_i w(x_i, y_i)[I(x_i + \Delta x, y_i + \Delta y) - I(x_i, y_i)]^2$$

Where:

- I is the image
- w is a weight expressing the image window
- $(\Delta x, \Delta y)$ are the displacements
- i goes over all the pixels in the patch

Auto-correlation

- Now approximate E using the Taylor series

$$I(x_i + \Delta x, y_i + \Delta y) \approx I(x_i, y_i) + I_x \Delta x + I_y \Delta y$$

Where

- $I_x = \frac{\partial I}{\partial x}(x_i, y_i)$ and $I_y = \frac{\partial I}{\partial y}(x_i, y_i)$
- This holds for **small displacements**

Auto-correlation

- Substituting into the auto-correlation function and neglecting the weights yields

$$E(\Delta x, \Delta y) = \sum_i \left[I_x \Delta x + I_y \Delta y\right]^2$$

Auto-correlation matrix

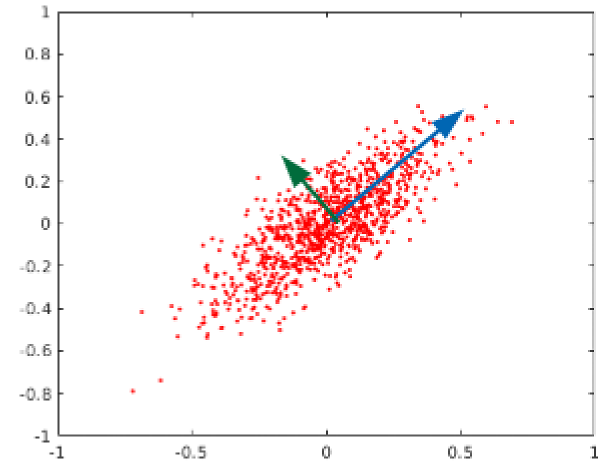
- Rewriting in matrix form:

$$E(\Delta x, \Delta y) = \begin{bmatrix} \Delta x & \Delta y \end{bmatrix} \boxed{\begin{bmatrix} \sum I_x^2 & \sum I_x I_y \\ \sum I_x I_y & \sum I_y^2 \end{bmatrix}} \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix}$$

Auto-correlation matrix A

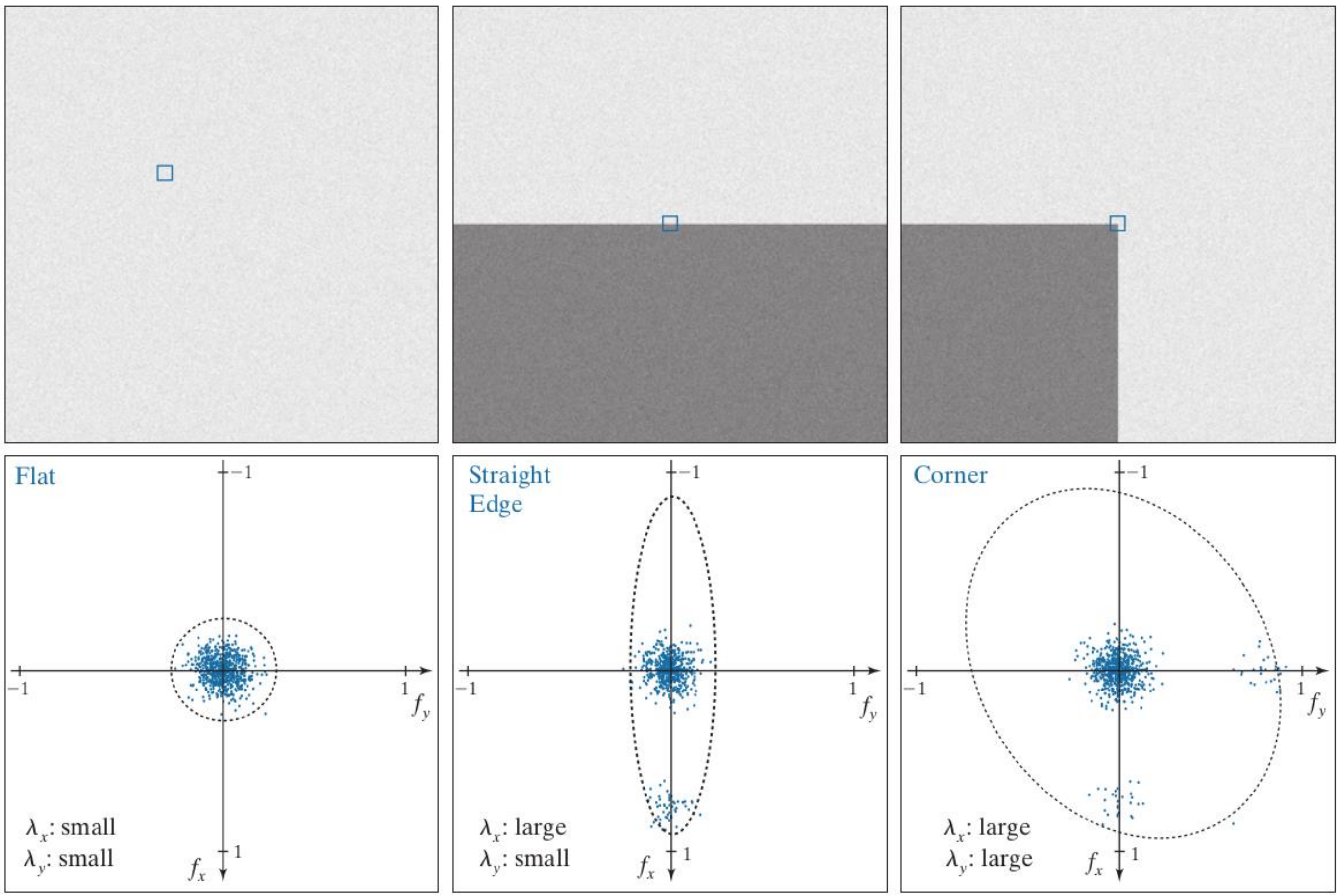
The auto-correlation matrix describes how the region changes for a small displacement

Auto-correlation matrix properties



- The matrix A is
  - Real
  - Symmetric
- Under these conditions, the eigenvectors
  - Are orthogonal
  - Point to the directions of max data spread
- The corresponding eigenvalues are proportional to the amount of data spread in the direction of the eigenvectors

- Visualizing eigenvalues and eigenvectors

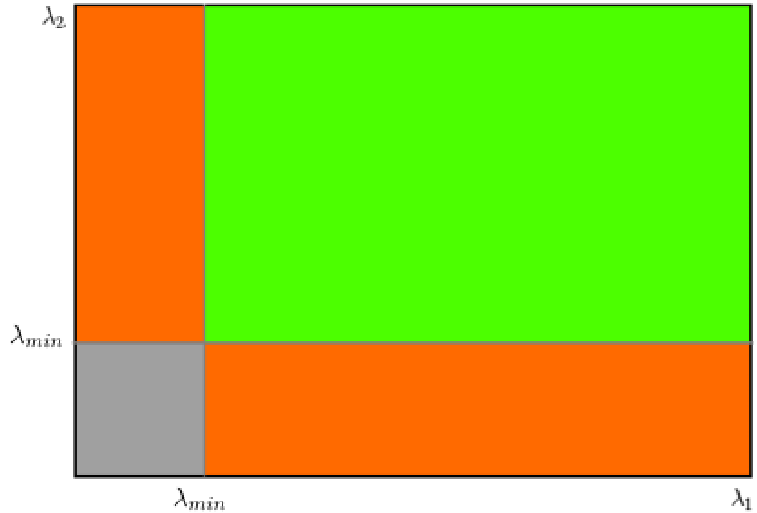


Noisy images and patch candidates

Plots of value pairs (f_x, f_y) (Ix,Iy) showing the characteristics of the eigenvalues

Eigenvalues

- Studying the eigenvalues we get information about the type of patch
  - If both eigenvalues are small: uniform region
  - Only one large eigenvalue: edge
  - Two large eigenvalues: corner



Weighting factor

- The weights of the auto-correlation function were neglected
- They can be introduced into our formulation, expressed by means of convolution

$$A = w * \begin{bmatrix} \sum I_x^2 & \sum I_x I_y \\ \sum I_x I_y & \sum I_y^2 \end{bmatrix}$$

- Two main choices for the weights
  - Box: 1 inside the patch, 0 elsewhere
  - Gaussian – more emphasis on changes around the center

Keypoint selection criteria

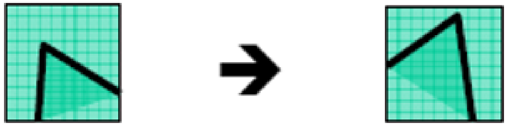
- Given matrix A and the eigenvalues/vectors, how is a keypoint selected?
- Several options presented in the literature:
  - Minimum eigenvalue [Shi, Tomasi]
  - $\det(A) - \alpha \cdot \operatorname{trace}(A)^2 = \lambda_0\lambda_1 - \alpha(\lambda_0+\lambda_1)^2$ [Harris]
    - This defines the **Harris corners**
  - $\lambda_0 - \alpha\lambda_1$ [Triggs]
  - $\frac{\det(A)}{\operatorname{trace}(A)} = \frac{\lambda_0\lambda_1}{\lambda_0+\lambda_1}$ [Brown, Szeliski, Winder]

Invariance

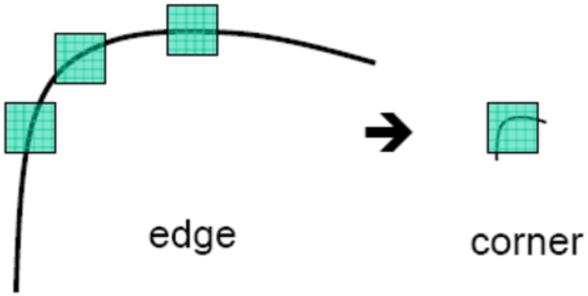
- The Harris corner detector is
  - Invariant to brightness offset:

$$I(x,y) \rightarrow I(x,y) + c$$

  - Invariant to shift and rotations (corners maintain their shape)



  - Not invariant to scaling



Example

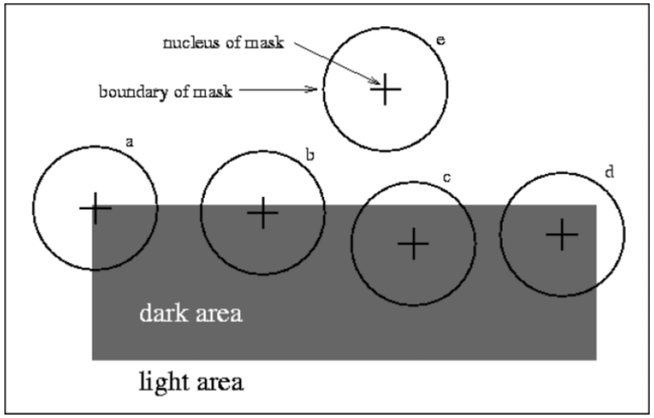
Example

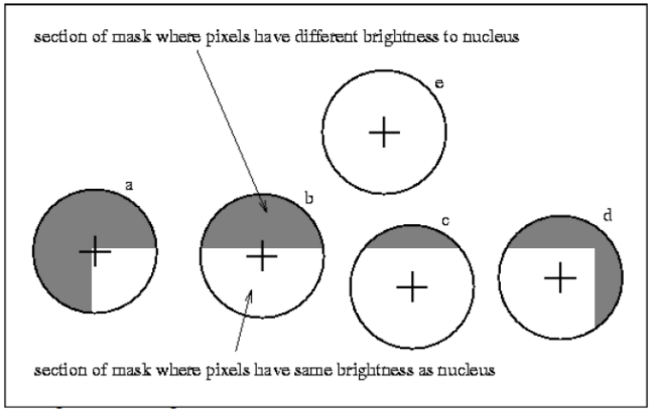
Beyond Harris corners

- Several other detectors exist
- E.g.: USAN/SUSAN corner detector
  - Analyzes a circular window around the point
  - No derivatives involved
  - Edge+corner detector
  - Robust to noise

USAN

- Comparison between the nucleus (central point) and pixels in the mask
  - USAN (Univalue Segment Assimilating Nucleus)
- USAN: the portion of window with intensity difference from the nucleus within a given threshold





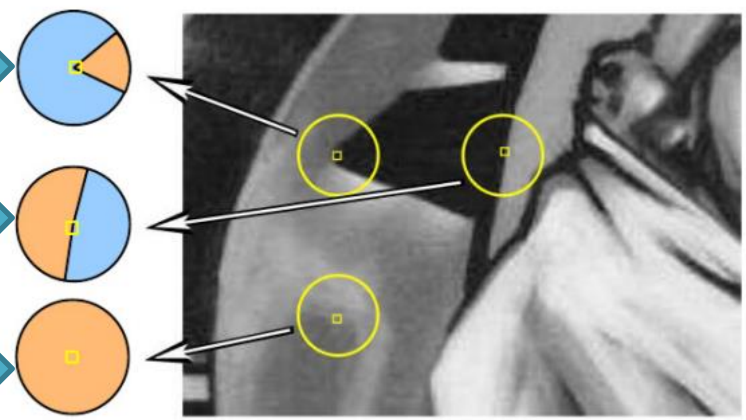
SUSAN

- If the USAN is…

Smaller than half mask area: corner

Similar to half mask area: edge

Similar to mask area: uniform region

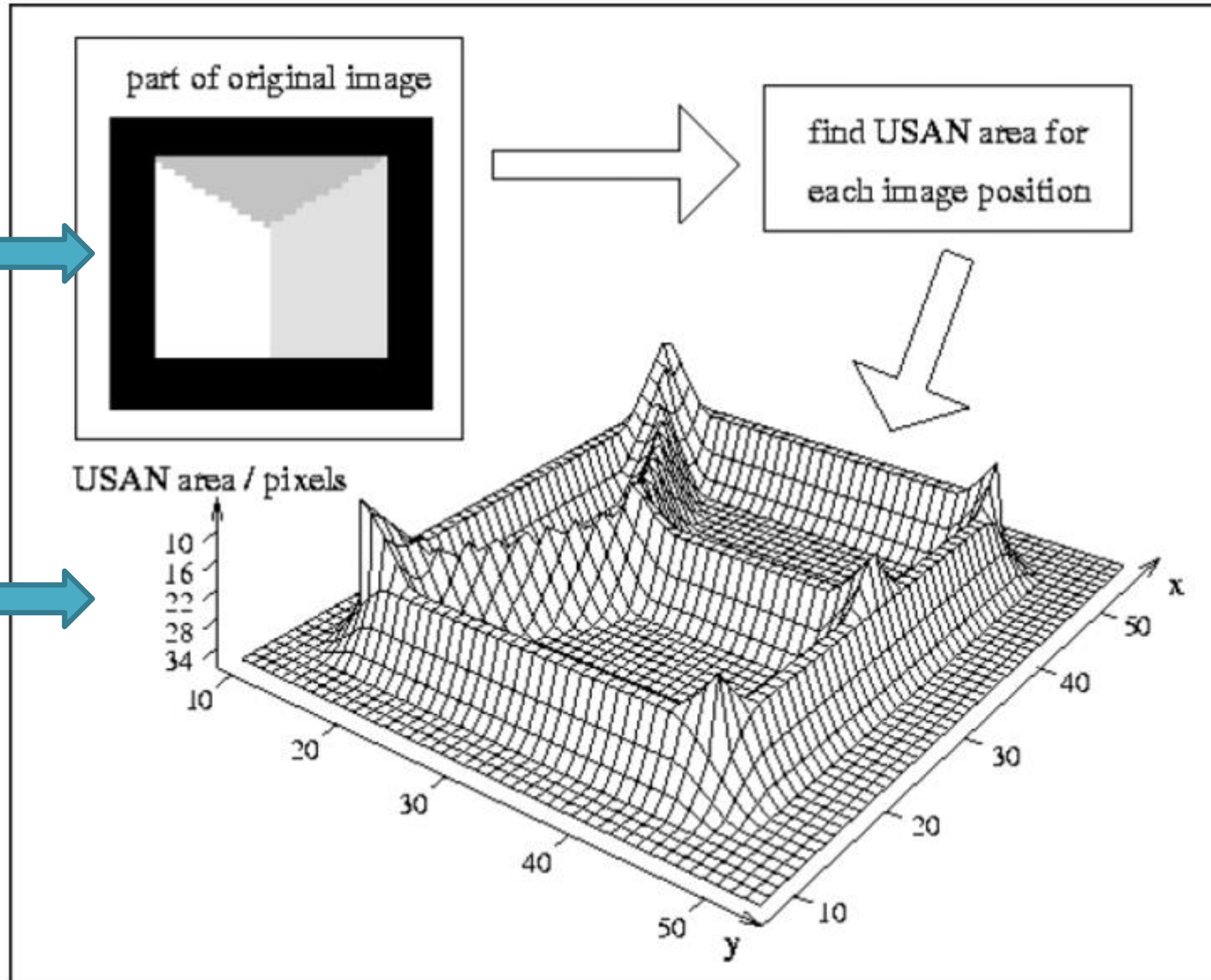


SUSAN: Smallest USAN

Example

Sample image

USAN 3D plot (lower values going up)



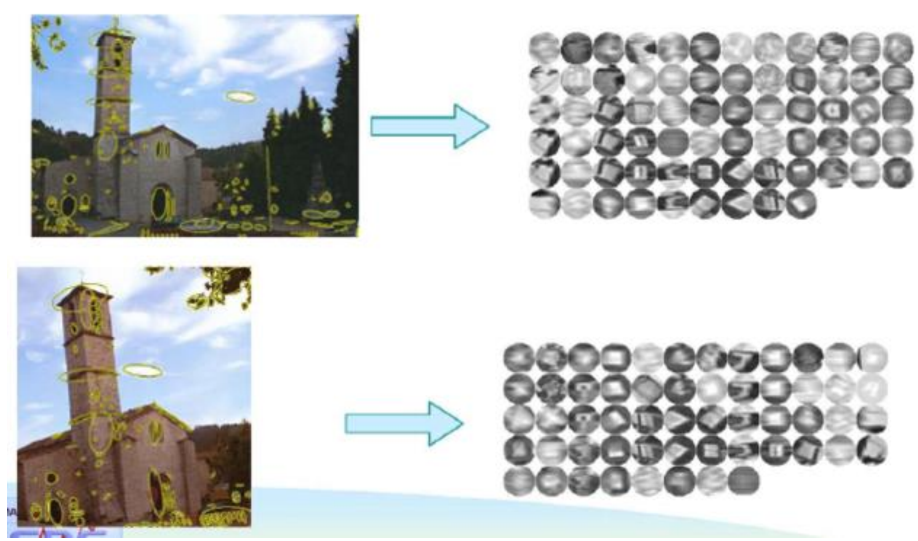
Example

Blob features

- Harris corners focus on specific points
- Other features focus on blobs
- A blob is a region where
  - Properties taken into account are different from surrounding regions
  - Properties are (approximately) constant inside the region

MSER

- MSER are connected areas characterized by almost uniform intensity, surrounded by contrasting background (blobs)
- MSER feature detector can be used as a blob detector



MSER

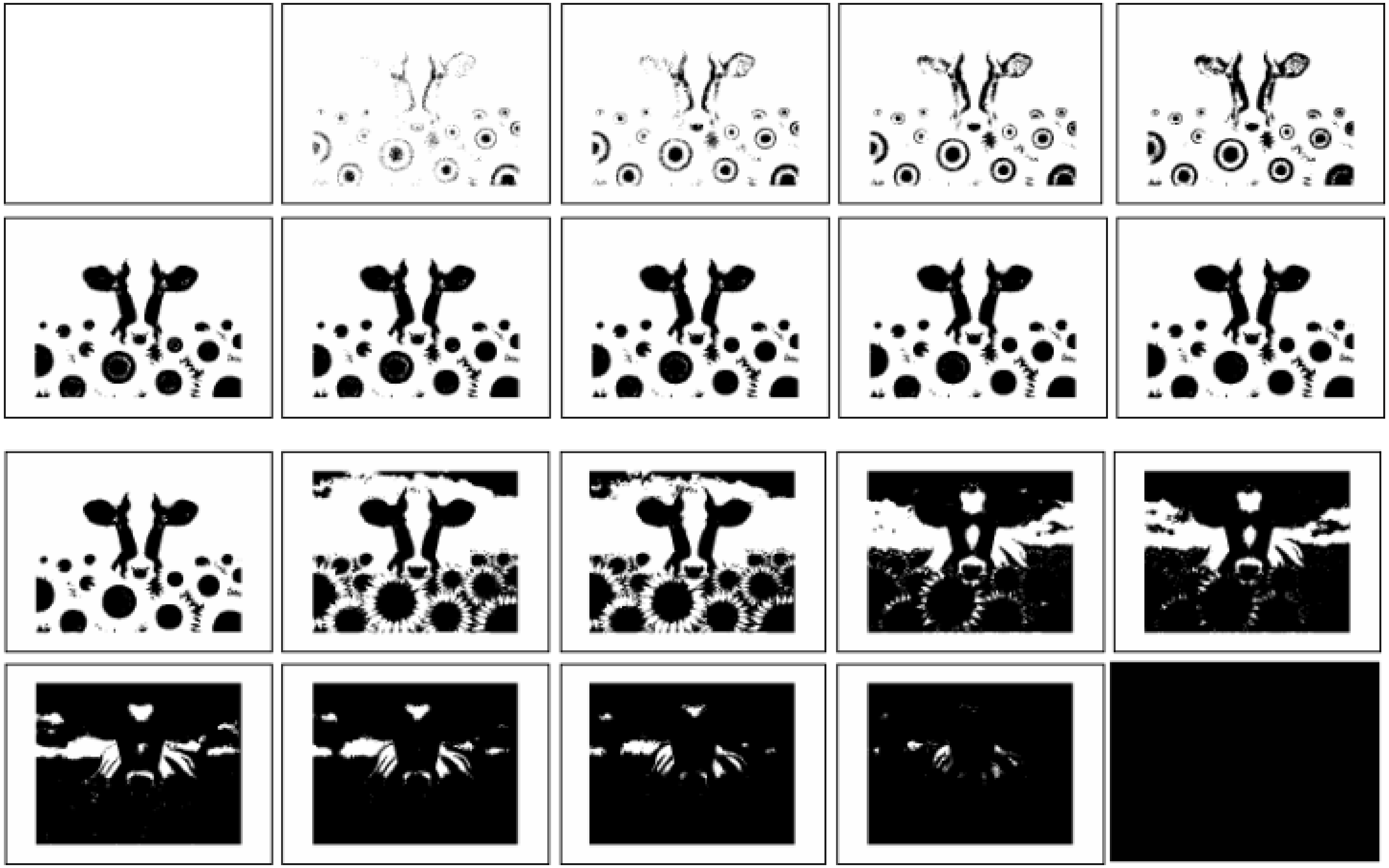
- Maximally Stable Extremal Regions (MSER)
- Algorithm in a nutshell:
  - Apply a series of thresholds (e.g., one for each gray level)
  - Compute the connected binary regions
  - Compute some statistics for each region
    - E.g.: area, convexity, circularity, …
  - Analyze how persistent each blob is

J.Matas, O.Chuma, M.Urbana, T.Pajdla, "Robust wide-baseline stereo from maximally stable extremal regions", Image and Vision Computing, 2004

MSER

- Maximally Stable Extremal Regions (MSER)
- "Extremal" refers to the property that all pixels inside the MSER have either higher (bright extremal regions) or lower (dark extremal regions) intensity than all the pixels on its outer boundary

Multiple thresholding example



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