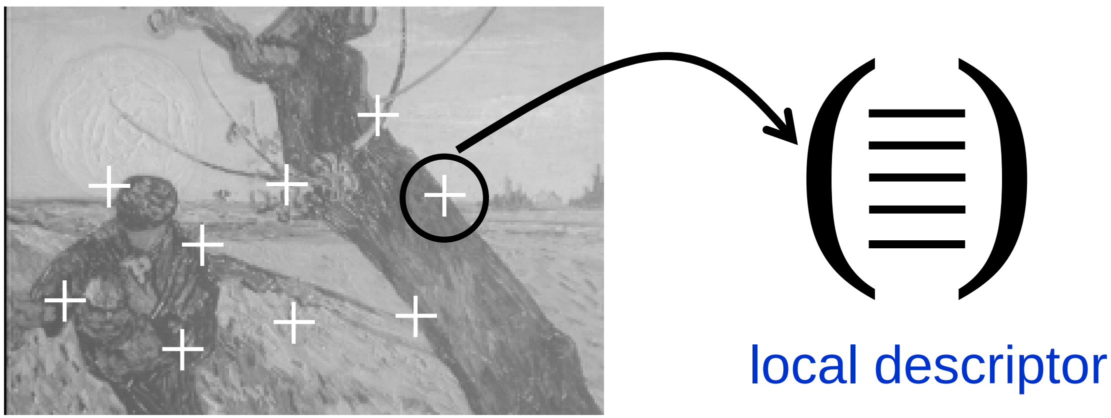
Interest Operators

- Find “interesting” pieces of the image
- Multiple possible uses
  - image matching
    - stereo pairs
    - tracking in videos
    - creating panoramas
  - object recognition

Goal:
Local invariant photometric descriptors



Local : robust to occlusion/clutter + no segmentation

Photometric : distinctive

Invariant : to image transformations + illumination changes

History - Matching

Matching based on correlation alone

Matching based on line segments

$\Rightarrow$ Not very discriminating (why?)

$\Rightarrow$ Solution : matching with interest points & correlation

[A robust technique for matching two uncalibrated images through the recovery of the unknown epipolar geometry,

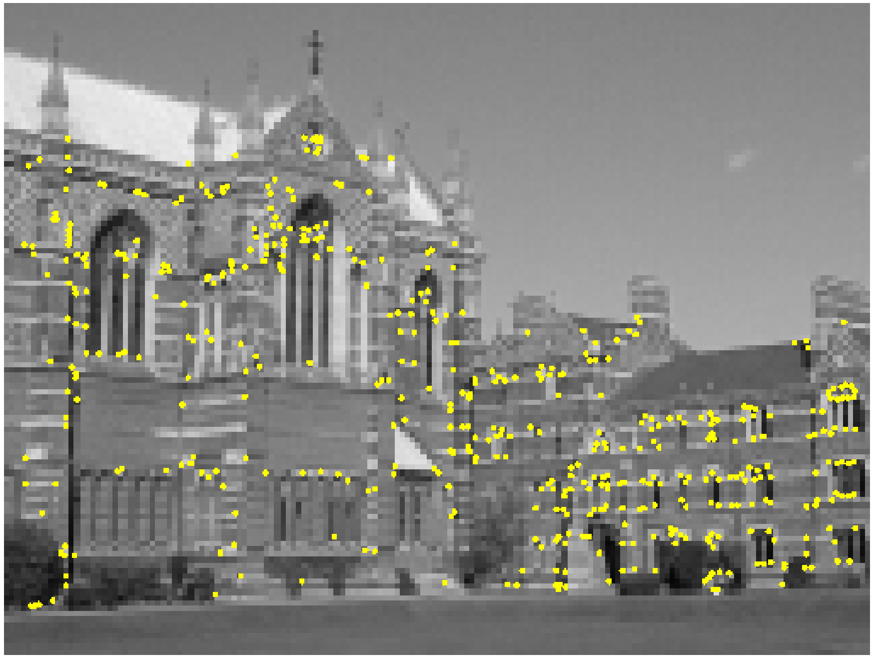
Z. Zhang, R. Deriche, O. Faugeras and Q. Luong,

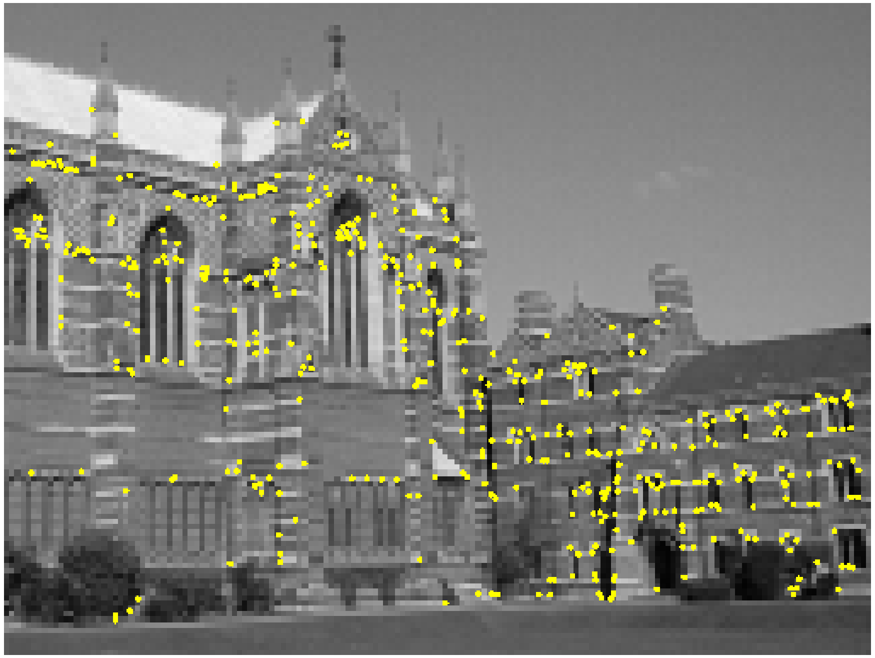
Artificial Intelligence 1995]

Approach

- Extraction of interest points with the Harris detector
- Comparison of points with cross-correlation
- Verification with the fundamental matrix
  (later in the course)

Harris detector





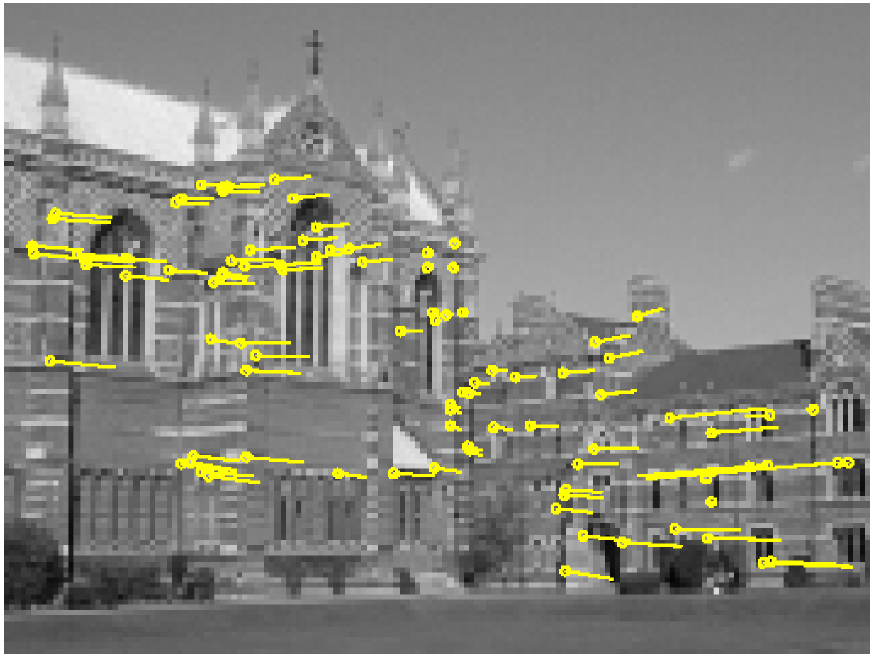
Interest points extracted with Harris (~ 500 points)

Cross-correlation matching

Initial matches (188 pairs)

Global constraints

Robust estimation of the fundamental matrix



99 inliers 89 outliers

Summary of the approach

- Very good results in the presence of occlusion and clutter
  - local information
  - discriminant greyvalue information
  - robust estimation of the global relation between images
  - for limited view point changes

- Solution for more general view point changes
  - wide baseline matching (different viewpoint, scale and rotation)
  - local invariant descriptors based on greyvalue information

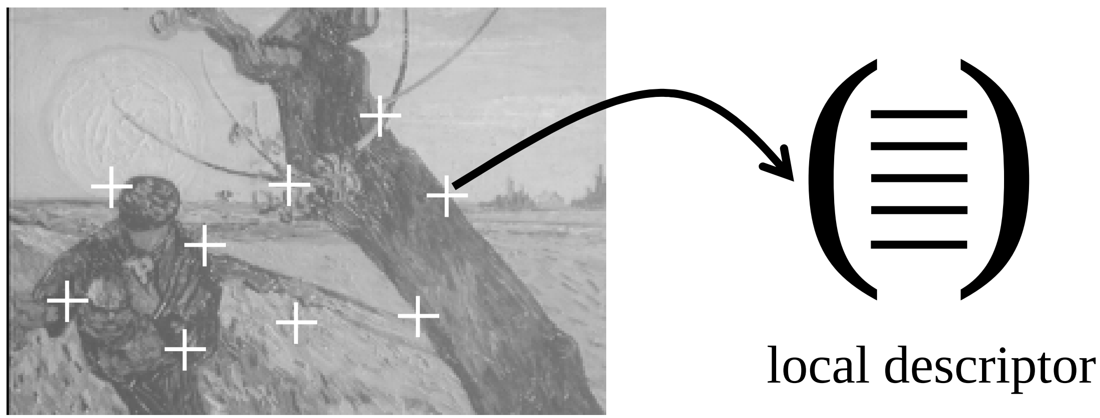
History - Recognition

Problems : occlusion, clutter, image transformations, distinctiveness

$\Rightarrow$ Solution : recognition with local photometric invariants

[Local greyvalue invariants for image retrieval,
C. Schmid and R. Mohr,
PAMI 1997]

Approach



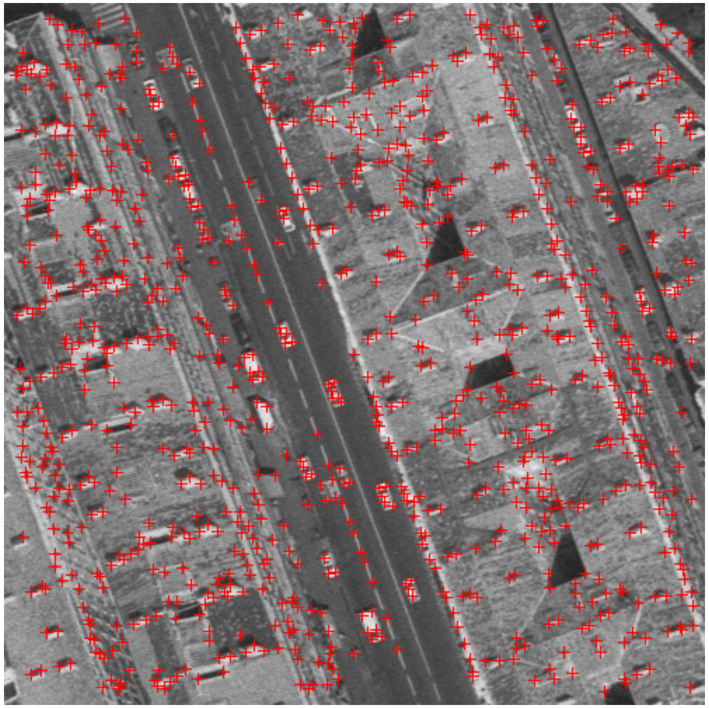
1) Extraction of interest points (characteristic locations)

2) Computation of local descriptors

3) Determining correspondences

4) Selection of similar images

Interest points



Geometric features

➡ repeatable under transformations

2D characteristics of the signal

➡ high informational content

Comparison of different detectors [Schmid98] ➡ Harris detector

Harris detector

Based on the idea of auto-correlation

Important difference in all directions => interest point

Background: Moravec Corner Detector

- take a window w in the image
- shift it in four directions (1,0), (0,1), (1,1), (-1,1)
- compute a difference for each
- compute the min difference at each pixel
- local maxima in the min image are the corners

$$E(x,y) = \sum_{u,v \text{ in } w} w(u,v)\, |I(x+u,y+v) - I(u,v)|^2$$

Shortcomings of Moravec Operator

- Only tries 4 shifts. We'd like to consider "all" shifts.
- Uses a discrete rectangular window. We'd like to use a smooth circular (or later elliptical) window.
- Uses a simple min function. We'd like to characterize variation with respect to direction.

Result: Harris Operator

Harris detector

Auto-correlation function for a point (x, y) and a shift $(\Delta x, \Delta y)$

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

Discrete shifts can be avoided with the auto-correlation matrix

$$\text{with} \quad I(x_k + \Delta x, y_k + \Delta y) = \underbrace{I(x_k, y_k) + \begin{pmatrix} I_x(x_k, y_k) & I_y(x_k, y_k) \end{pmatrix}}_{\text{what is this?}} \begin{pmatrix} \Delta x \\ \Delta y \end{pmatrix}$$

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

Harris Math Manipulation

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

$$= \sum_{(x_k,y_k)\in W} (I(x_k,y_k) - [I(x_k,y_k) + (I_x(x_k,y_k)\ I_y(x_k,y_k)) \begin{pmatrix} \Delta x \\ \Delta y \end{pmatrix}])^2$$

$$= \sum_{(x_k,y_k)\in W} (I(x_k,y_k) - I(x_k,y_k) - (I_x(x_k,y_k)\ I_y(x_k,y_k)) \begin{pmatrix} \Delta x \\ \Delta y \end{pmatrix})^2$$

$$= \sum_{(x_k,y_k)\in W} (-(I_x(x_k,y_k)\ I_y(x_k,y_k)) \begin{pmatrix} \Delta x \\ \Delta y \end{pmatrix})^2$$

$$= \sum_{(x_k,y_k)\in W} (I_x(x_k,y_k)\ I_y(x_k,y_k)) \begin{pmatrix} \Delta x \\ \Delta y \end{pmatrix})^2$$

$$= \sum_{(x_k,y_k)\in W} ((I_x(x_k,y_k)\ I_y(x_k,y_k) \begin{pmatrix} \Delta x \\ \Delta y \end{pmatrix}))((I_x(x_k,y_k)\ I_y(x_k,y_k)) \begin{pmatrix} \Delta x \\ \Delta y \end{pmatrix})$$

$$= \sum_w ((\Delta x\ \Delta y)) \begin{pmatrix} I_x \\ I_y \end{pmatrix} (I_x\ I_y) \begin{pmatrix} \Delta x \\ \Delta y \end{pmatrix})$$

$$= \sum_w (\Delta x\ \Delta y) \begin{pmatrix} I_xI_x & I_xI_y \\ I_xI_y & I_yI_y \end{pmatrix} \begin{pmatrix} \Delta x \\ \Delta y \end{pmatrix})$$

$$= (\Delta x\ \Delta y) \begin{pmatrix} \Sigma_w I_x^2 & \Sigma_w I_xI_y \\ \Sigma_w I_xI_y & \Sigma_w I_y^2 \end{pmatrix} \begin{pmatrix} \Delta x \\ \Delta y \end{pmatrix}$$

Harris detector

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

Auto-correlation matrix M

Harris detection

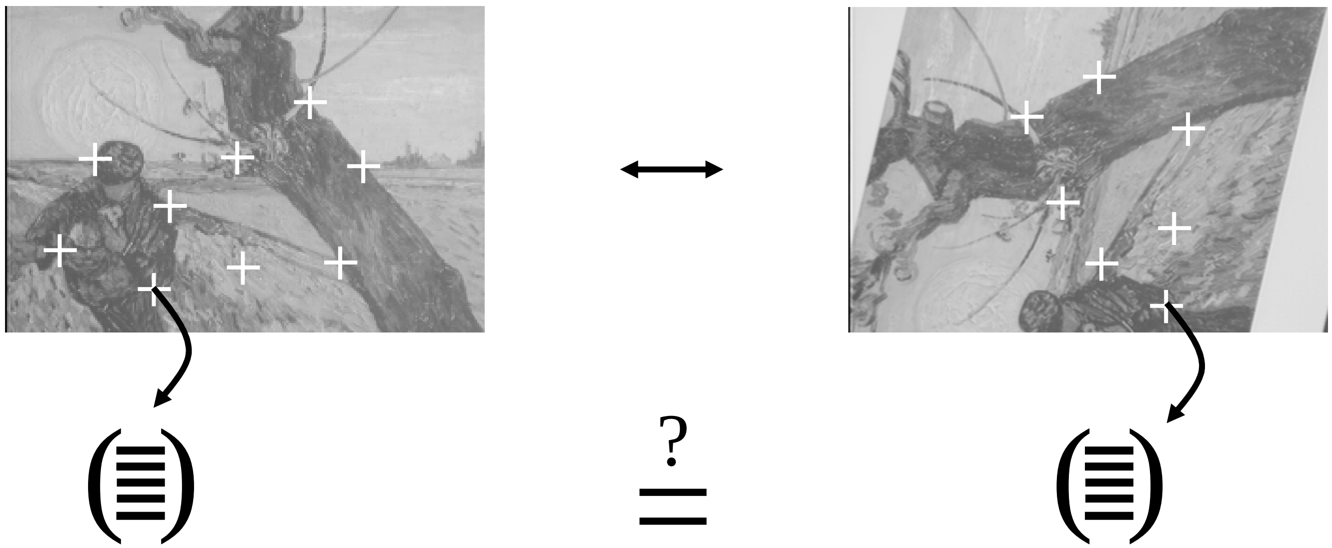
- Auto-correlation matrix
  - captures the structure of the local neighborhood
  - measure based on eigenvalues of M which form a rotationally invariant descriptor.
    - 2 strong eigenvalues => interest point
    - 1 strong eigenvalue => contour
    - 0 eigenvalue => uniform region
- Interest point detection
  - threshold on the eigenvalues
  - local maximum for localization

Some Details from the Harris Paper

- Let α and β be the two eigenvalues
- $Tr(M) = \alpha + \beta$
- $Det(M) = \alpha\beta$
- Response $R = Det(M) – k\ Tr(M)$
- R is positive for corners, - for edges, and small for flat regions
- Select corner pixels that are 8-way local maxima

Trace and determinant are easy to compute.

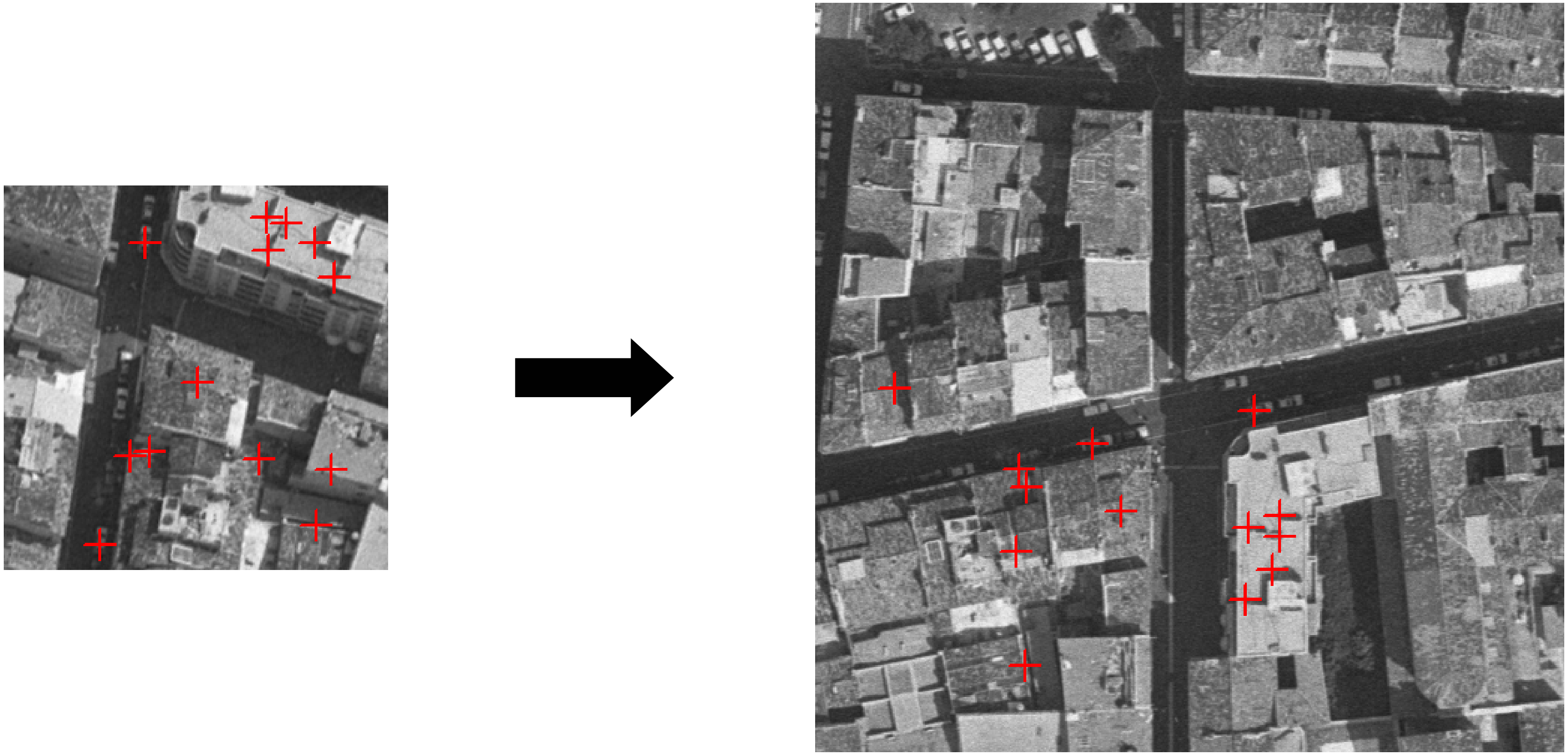
Determining correspondences



Vector comparison using a distance measure

What are some suitable distance measures?

Some Matching Results



Summary of the approach

- Very good results in the presence of occlusion and clutter
  - local information
  - discriminant greyvalue information
  - invariance to image rotation and illumination

- Not invariance to scale and affine changes

- Solution for more general view point changes
  - local invariant descriptors to scale and rotation
  - extraction of invariant points and regions