Image Processing II - Detectors

INTELLIGENT SYSTEMS FOR PATTERN RECOGNITION (ISPR)

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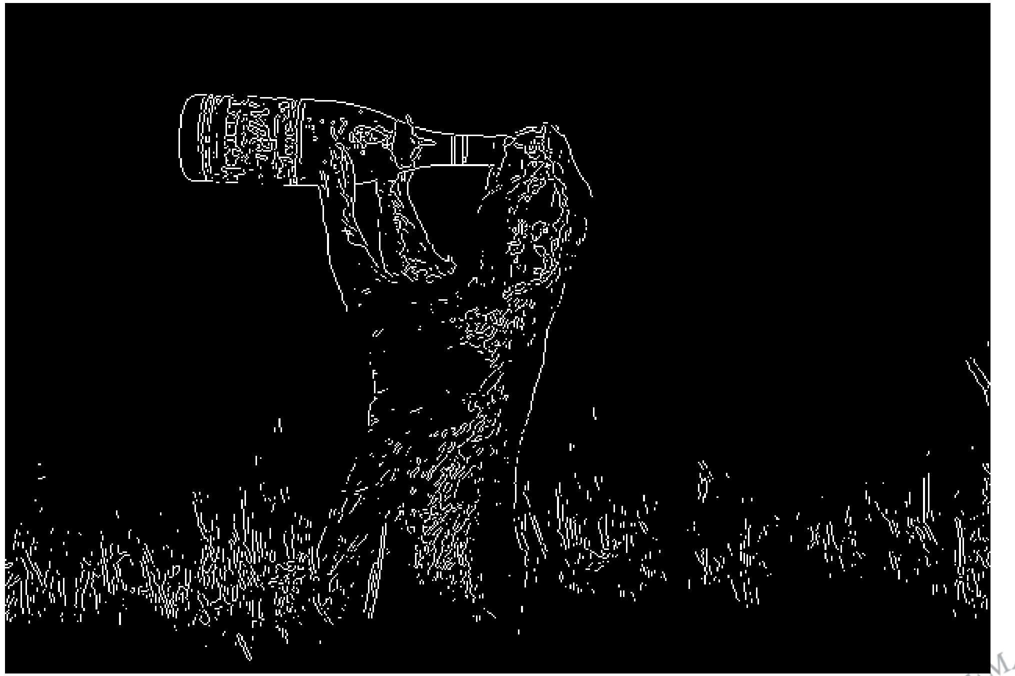
Visual Feature Detector

Repeatability

Detect the same feature in different image portions and in different images

- Photometric - Changes in brightness and luminance
- Translation - Changes in pixel location
- Rotation - Changes to absolute or relative angle of keypoint
- Scaling - Image resizing or changes in camera zoom
- Affine Transformations - Non-isotrophic changes

Edge Detection



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Edges and Gradients

- Image gradient (graylevel)

$$\nabla I = \left[\frac{\partial I}{\partial x}, \frac{\partial I}{\partial y}\right]$$

direction of change of intensity

- Edges are pixel regions where...
  - Intensity gradient changes abruptly
- The return of finite difference methods

$$G_x = \frac{\partial I}{\partial x} \approx I(x+1, y) - I(x-1, y)$$

$$G_y = \frac{\partial I}{\partial y} \approx I(x, y+1) - I(x, y-1)$$

$$G_x$$

$$\begin{bmatrix} +1 & 0 & -1 \\ +1 & 0 & -1 \\ +1 & 0 & -1 \end{bmatrix}$$

$$G_y$$

$$\begin{bmatrix} +1 & +1 & +1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{bmatrix}$$

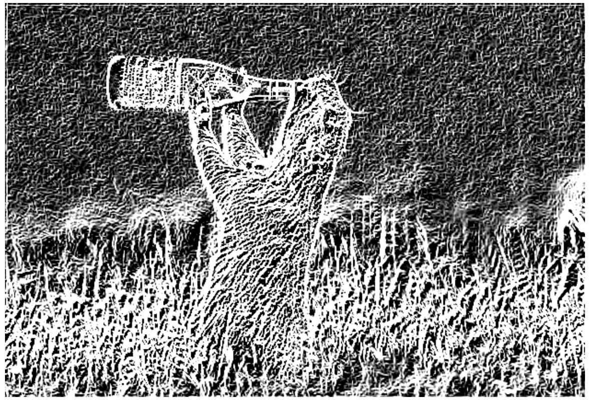
Prewitt operators

Convolving Gradient Operators

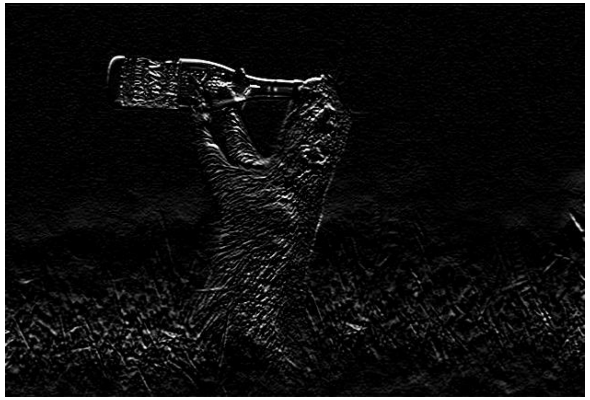
Image

G_x

Magnitude



G_y

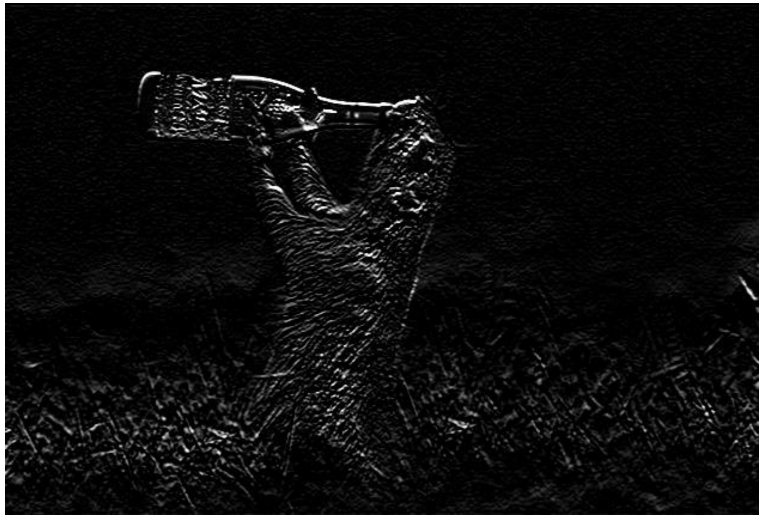


Sobel Operator

An additional level of smoothing of the central difference

$$G_x = \begin{bmatrix} +1 & 0 & -1 \\ +2 & 0 & -2 \\ +1 & 0 & -1 \end{bmatrix}$$

$$G_y = \begin{bmatrix} +1 & +2 & +1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$$



In Code

Matlab

```
% Create an horizontal ( x ) Prewitt filter
 h = fspecial ( 'prewitt' ) ;  % Try also 'sobel '
% Convolve it to the image Ig
 imH = imfilter ( Ig , h , 'replicate' ) ;
% Transpose filter for the y−derivative
 imV = imfilter ( Ig , h ' , 'replicate' ) ;
% Magnitude
M = uint8 ( sqrt ( double (( imHor .^2 ) + ( imVer .^2 )) ) ) ;
% Then plot . . .
 imtool ( imH ) ;
% etc . . .
```

Python

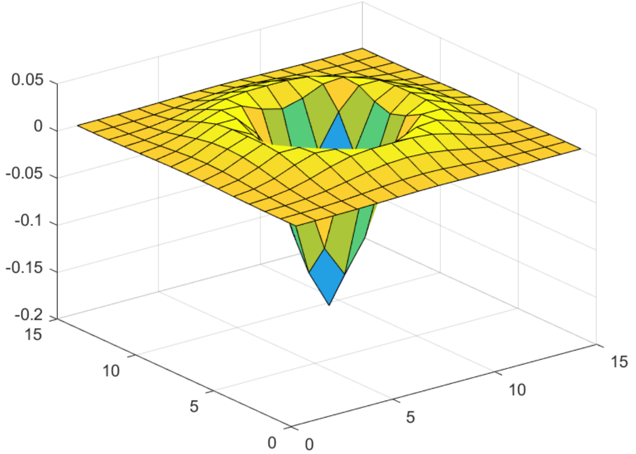
```
# prewitt masks
kernelx = np . array ( [[ 1 , 1 , 1 ], [ 0 , 0 , 0 ], [ −1 , −1 , −1 ]] )
kernely = np . array ( [[ −1 , 0 , 1 ], [ −1 , 0 , 1 ], [ −1 , 0 , 1 ]] )

# convolving filters
img_prewittx = cv2 . filter2D ( img_gray, −1, kernelx )
img_prewitty = cv2 . filter2D ( img_gray, −1, kernely )

# sobel (CV_8U is the output data type, ksize is the kernel size)
img_sobelx = cv2 . Sobel ( img_gray, cv2 . CV_8U, 1, 0, ksize = 3)
img_sobely = cv2 . Sobel ( img_gray, cv2 . CV_8U, 0, 1, ksize = 3)
```

Blob Detection

- Blobs are connected pixels regions with little gradient variability
- Laplacian of Gaussian (LoG) $g_\sigma(x, y)$ has maximum response when centered on a circle of radius $\sqrt{2}\sigma$



$$\nabla^2 g_\sigma(x, y) = \frac{\partial^2 g_\sigma}{\partial x^2} + \frac{\partial^2 g_\sigma}{\partial y^2}$$

Typically using a scale normalized response

$$\nabla^2_{norm}\, g_\sigma(x, y) = \sigma^2 \left(\frac{\partial^2 g_\sigma}{\partial x^2} + \frac{\partial^2 g_\sigma}{\partial y^2} \right)$$

LoG Blob Detection

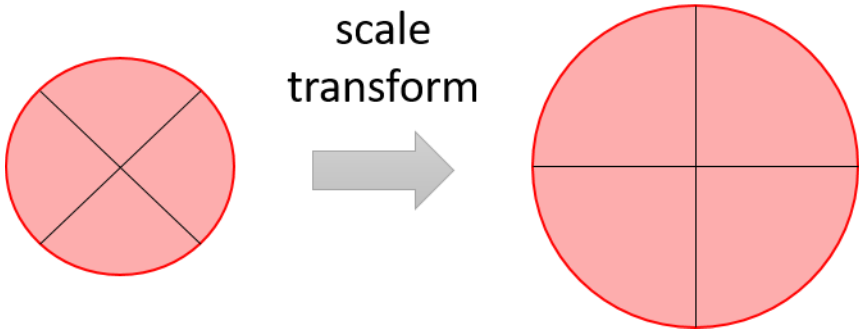
1. Convolve image with a LoG filter at different scales
   - $\sigma = k\sigma_0$ by varying k
2. Find maxima of squared LoG response
   1. Find maxima on space-scale
   2. Find maxima between scale
   3. Threshold

The LoG filter can be approximated as a Difference of Gaussians (DoG) for efficiency

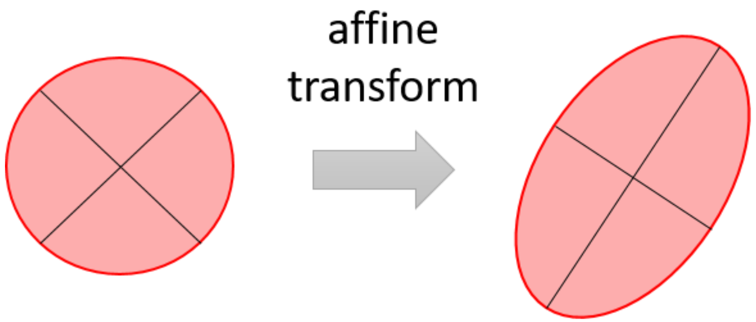
$$g_{k\sigma_0}(x,y) - g_{\sigma_0}(x,y) \approx (k-1)\sigma_0^2\nabla^2 g_{(k-1)\sigma_0}$$

Affine Detectors

- Laplacian-based detectors are invariant to scale thanks to the maximization in scale-space



- Still not invariant to affine transformations



Maximally Stable Extremal Regions (MSER)

- Extract covariant regions (blobs) that are stable connected components of intensity sets of the image
- Key idea is to take blobs (Extremal Regions) which are nearly the same through a wide range of intensity thresholds
- The blobs are generated (locally) by binarizing the image over a large number of thresholds
  - Invariance to affine transformation of image intensities
  - Stability (they are stable on multiple thresholds)
  - Multi-scale (connected components are identified by intensity stability not by scale)
  - Sensitive to local lighting effects, shadows, etc..
- You can then fit an ellipse enclosing the stable region

Intuition on the MSER Algorithm

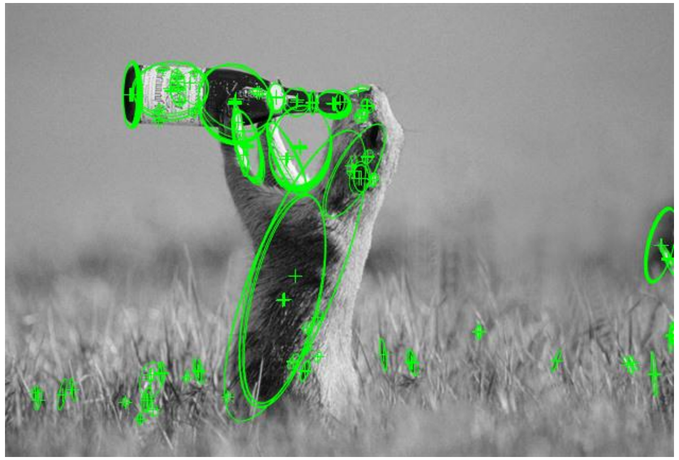
Generate frames from the image by thesholding it on all graylevels

- Capture those regions that from a small seed of pixel grow to a stably connected region
- Stability is assessed by looking at derivatives of region masks in time (most stable ⇒ minima of connected region variation)

MSER in Code

Matlab

```
% Run MSER and returns regions
 regions = detectMSERFeatures ( Ig ) ;
 figure ; imshow ( Ig ) ;  % plot image
 hold on ;
 plot ( regions ) ; % overlap regions
% Alternatively can plot actual regions
 plot ( regions , 'showPixelList' , true , 'showEllipses' , false ) ;
```



Again, in OpenCV

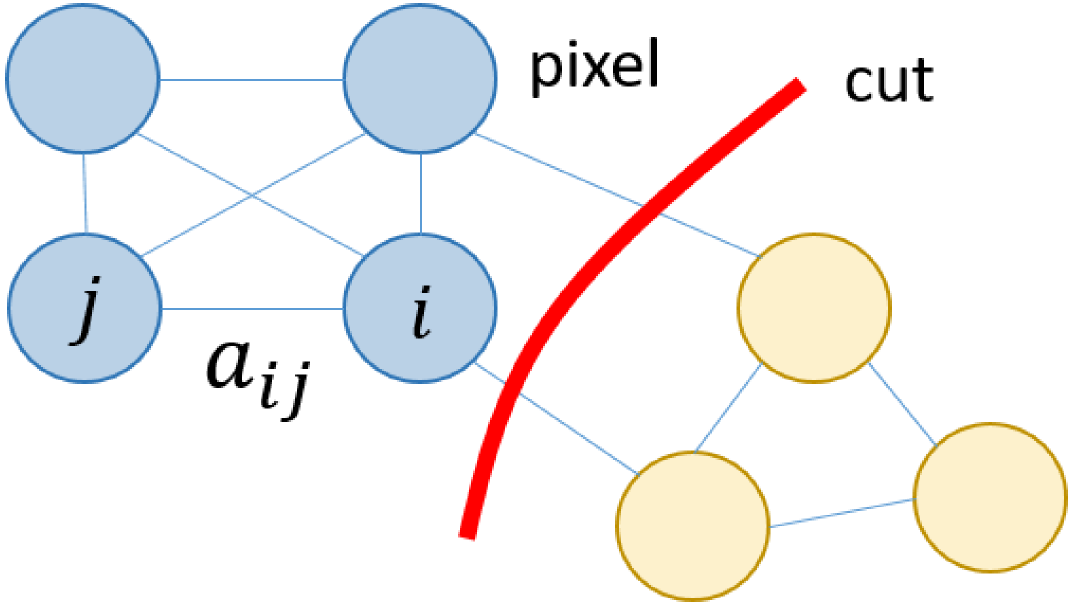
```
import cv2
. . .
# Load the mser detector from OpenCV
mser = cv2 . MSER_create ( )
regions = mser . detectRegions ( img , None )
# Create a convex hull enclosing stable regions
hulls = [ cv2 . convexHull ( p . reshape (−1, 1 , 2 ) ) for p in regions ]
# Draw detected regions on image copy
vis = img . copy ( )
cv2 . polylines ( vis , hulls , 1 , ( 0 , 255 , 0 ) )
cv2 . imshow ( 'img' , v i s )
```

Image Segmentation

The process of partitioning an image into set of homogeneous pixels, hoping to match object or their subparts

- A naive approach?
  - Apply k-means to pixels color (typically $L * a * b$) hoping to cluster together regions
- A slightly less naive approach?
  - Apply k-means to pixels color and (x, y) position hoping to enforce some level of spatial information in clusters

Normalized Cuts (Ncut)



- Node = pixel
- a_{ij} = affinity between pixels (at a certain scale σ)

- A cut of G is the set of edges such whose removal makes G a disconnected graph
- Breaking graph into pieces by cutting edges of low affinity
- Normalized cut problem
  - NP-hard
  - Approximate solution as an eigenvalue problem

Code: https://www.cis.upenn.edu/~jshi/software/

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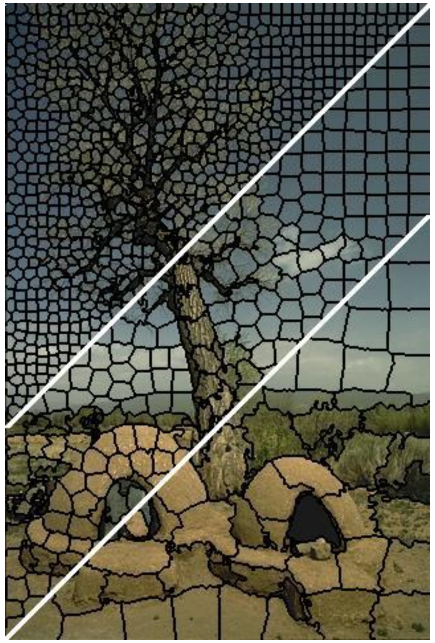
Pixel Issue

Pixels in image are a lot!

- Ncut can take ages to complete
- Likewise many other advanced segmentation algorithms



- Efficiency trick ⇒ Superpixels
  - Group together similar pixels
  - Cheap, local oversegmentation
  - Important that superpixels do not cross boundaries
- Now apply segmentation/fusion algorithms to superpixels: Ncut, Markov Random Fields, etc.

Code: https://ivrl.epfl.ch/research/superpixels

Take Home Messages

- Image processing is very much about convolutions
  - Linear masks to perform gradient operations
  - Gaussian functions to apply scale changes (zooming in and out)
- Computational efficiency is often a driving factor
  - Convolutions in Fourier domain
  - Superpixels
  - Lightweight feature detector? Random sampling