Machine Visions and
Digital Image Analysis

Scale Invariant Feature Transform

developed by David Lowe
University of British Columbia
Initial paper ICCV 1999
Newer journal paper IJCV 2004

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Introduction

Scale-Invariant Feature Transform (SIFT) [1][2]

- by David G. Lowe, 1999,2004
- Feature detection algorithm
- Feature usefull for : Image matching, object or scene recognition, solving for 3D structure from multiple images, stereo correspondence and motion tracking,...
- Features properties (invariance) :
  - Scale
  - Rotation
  - Affine transform
  - 3D viewpoint
  - Illumination changes
  - Occlusion

Features invariance

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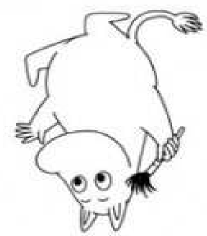

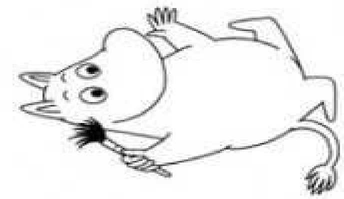

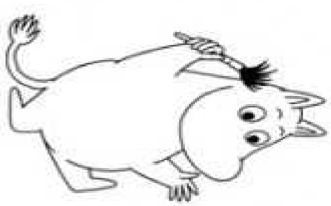

Images source : wikipedia.org

Sift Method Steps [1]

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SIFT algorithm:

1.Scale-space extrema detection

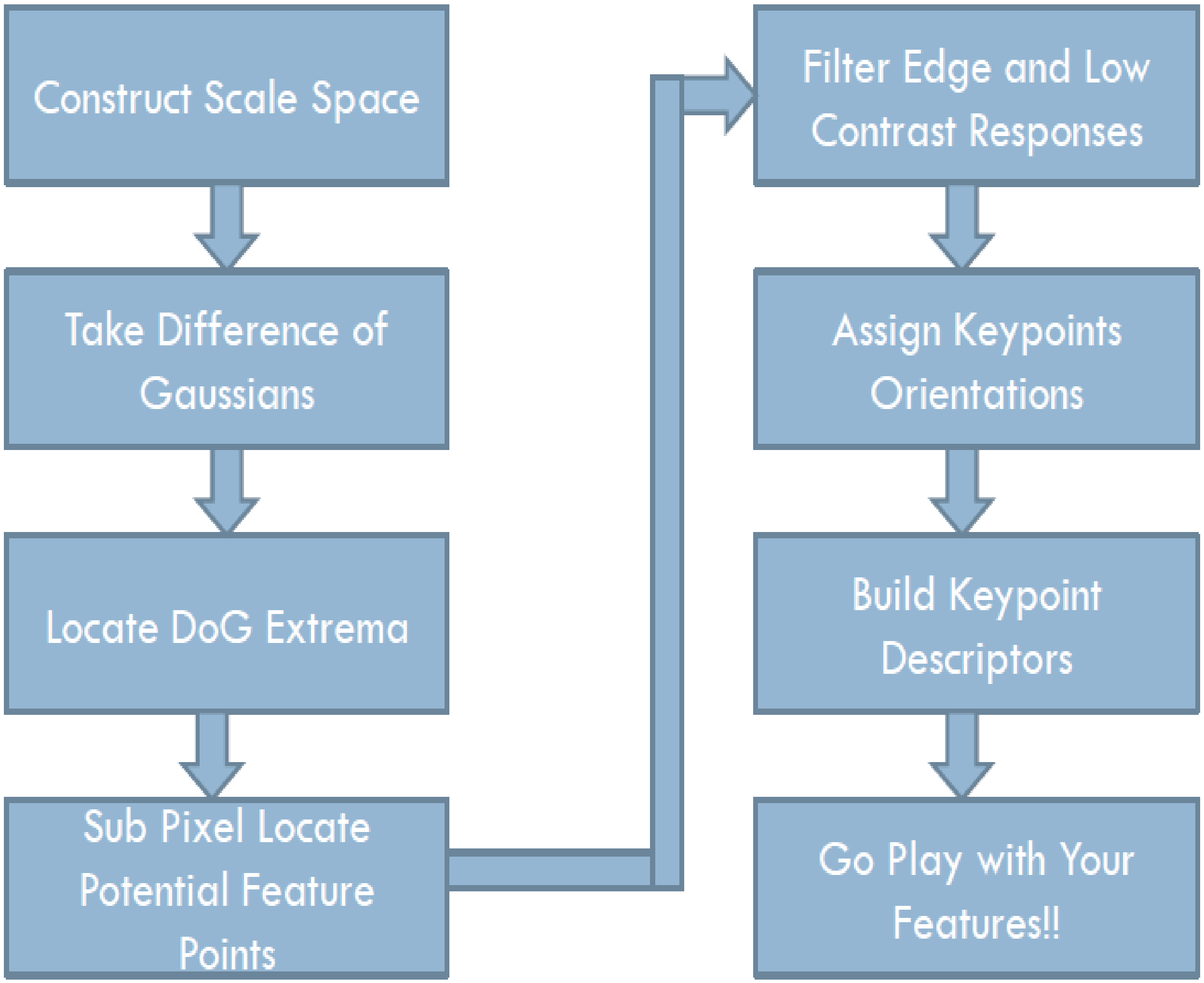
2. Keypoint localization.

3. Orientation assignment.

4. Keypoint descriptor.

Output : feature descriptors

Sift Algorithm overview [1][4]



Images source : Jason Clemons presentation [4]

Scale Space Construction [1][4][15]

- Gaussian kernel used to create scale space
- Only possible scale space kernel (Lindberg , 94)

$$L(x, y, \sigma) = G(x, y, \sigma) * I(x, y),$$

$$G(x, y, \sigma) = \frac{1}{2\pi\sigma^2} e^{-(x^2+y^2)/2\sigma^2}.$$

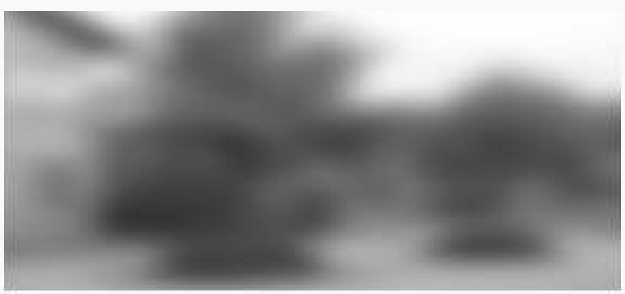
Scale Space representation [1][15]

Scale-space representation $L(x,y;t)$ at scale $t = 0$, corresponding to the original image f

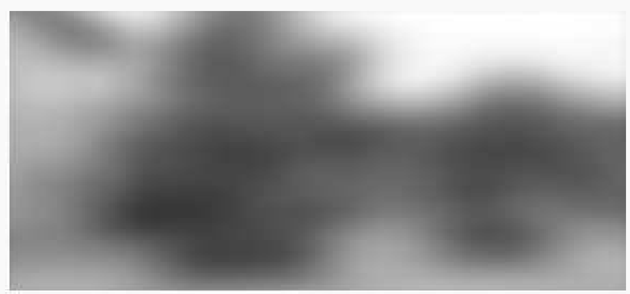
Scale-space representation $L(x,y;t)$ at scale $t = 1$

Scale-space representation $L(x,y;t)$ at scale $t = 4$

Scale-space representation $L(x,y;t)$ at scale $t = 16$



Scale-space representation $L(x,y;t)$ at scale $t = 64$

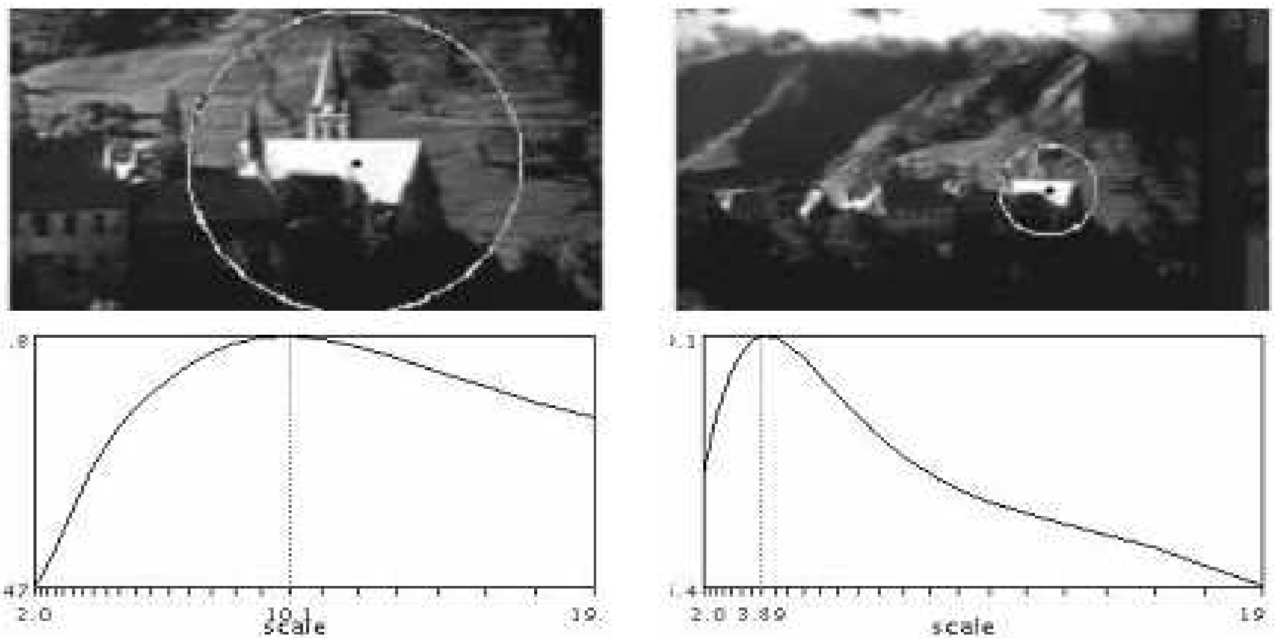


Scale-space representation $L(x,y;t)$ at scale $t = 256$

Images source : wikipedia.org [15]

Scale Space extrema [1][3][12][15]

Mikolajczyk (2002): Experimentally, extrema of LoG gives best notion of scale



Credit and image source : Ilan Shimshoni slides [12]

Scale Space extrema localization

[1][4]

- Approximation of Laplacian of Gaussians

$$\frac{\partial G}{\partial \sigma} = \sigma \nabla^2 G.$$

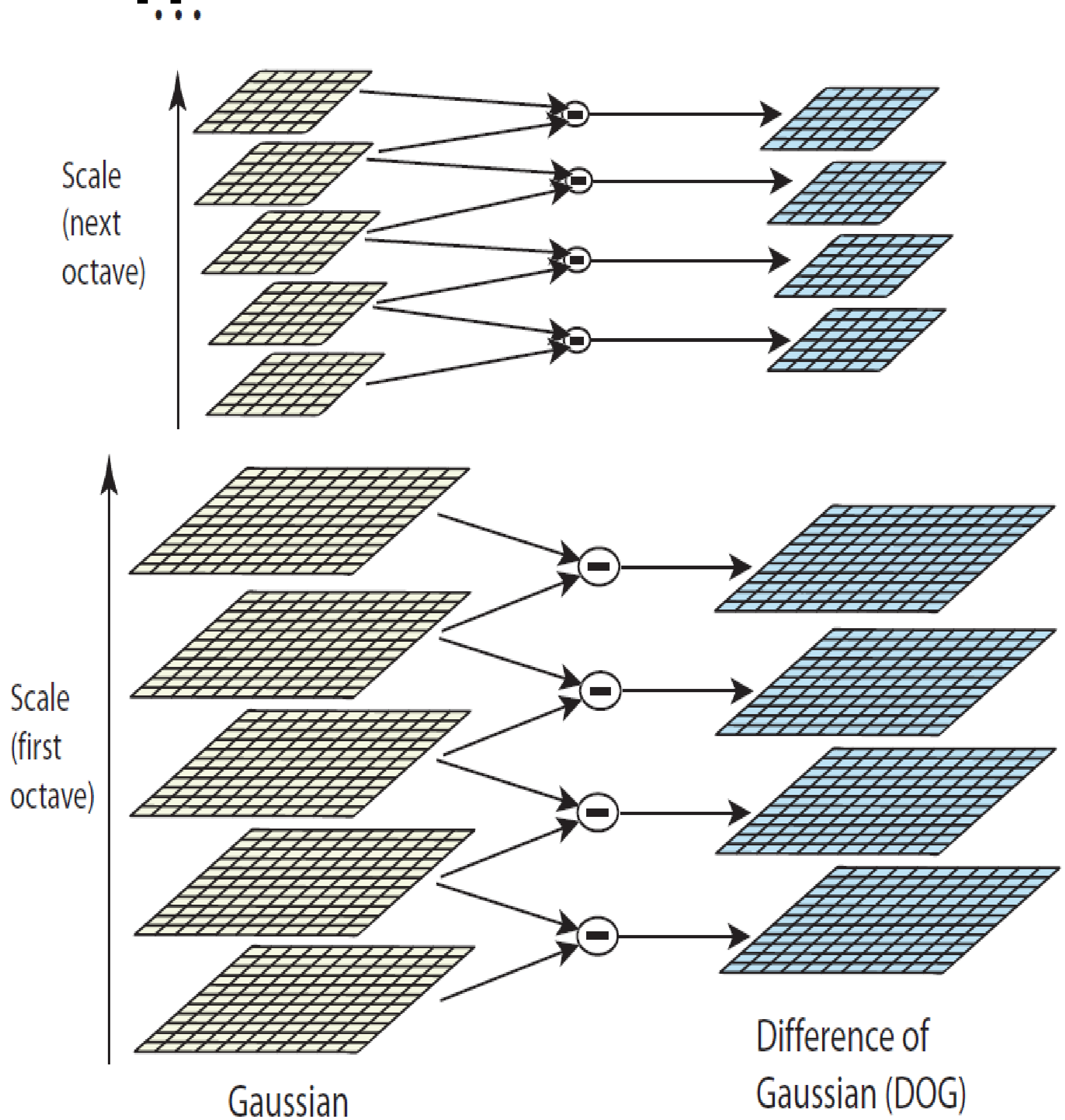
$$\sigma \nabla^2 G = \frac{\partial G}{\partial \sigma} \approx \frac{G(x, y, k\sigma) - G(x, y, \sigma)}{k\sigma - \sigma}$$

$$G(x, y, k\sigma) - G(x, y, \sigma) \approx (k-1)\sigma^2 \nabla^2 G.$$

$$\begin{aligned} D(x, y, \sigma) &= (G(x, y, k\sigma) - G(x, y, \sigma)) * I(x, y) \\ &= L(x, y, k\sigma) - L(x, y, \sigma). \end{aligned}$$

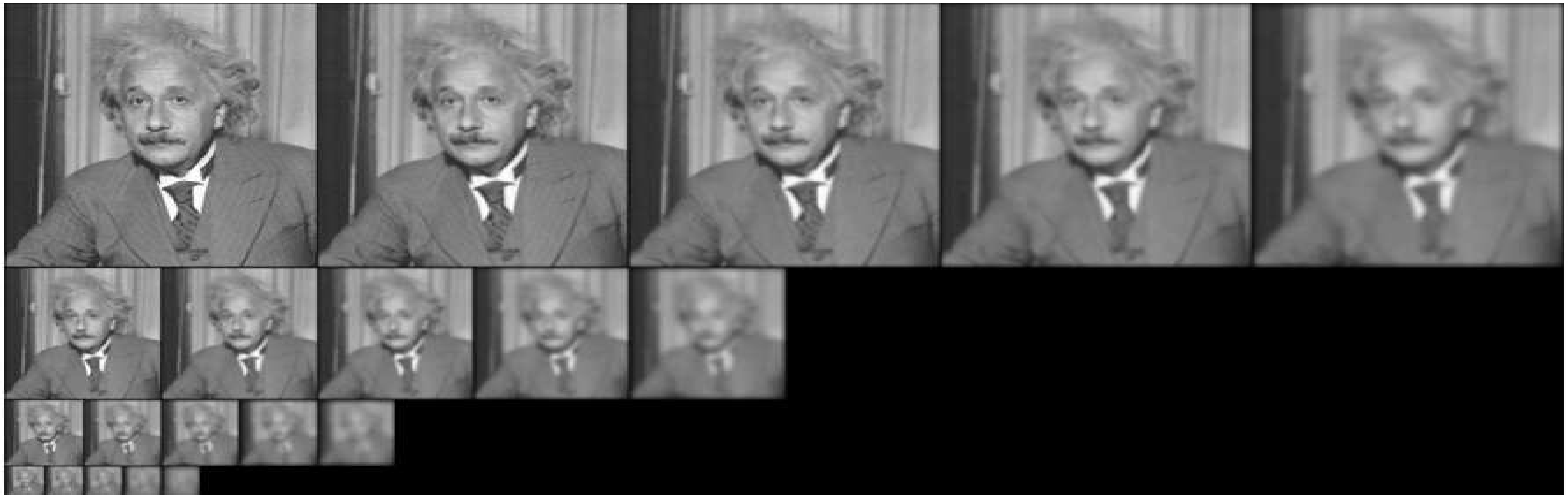
$s = 3$ and $k = 2^{1/s}$.

Scale Space extrema localization (keypoint) overview [1]

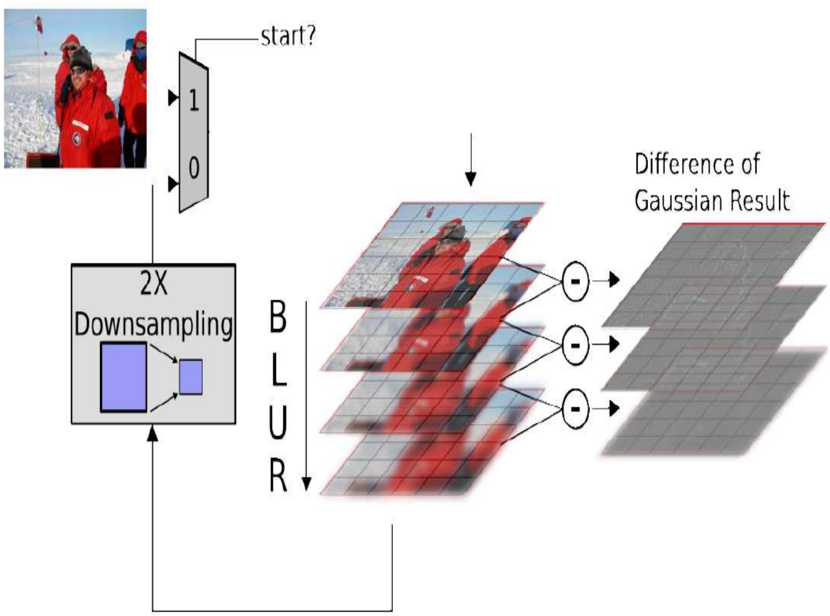


Images source :Lowe 2004 [1]

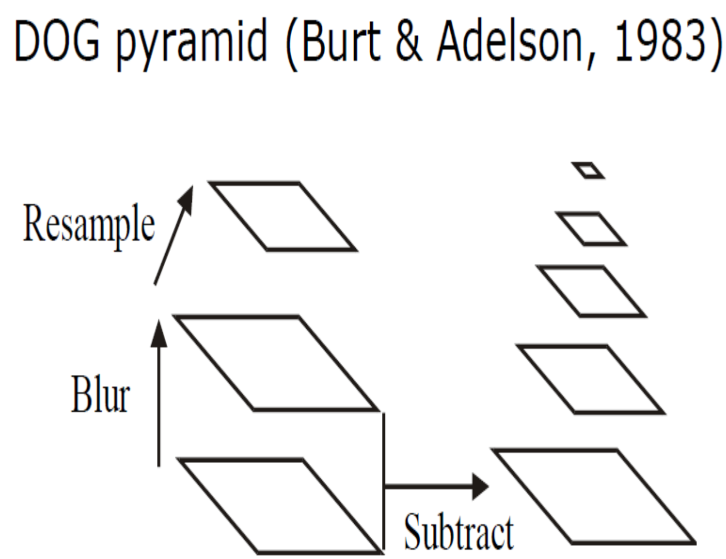
Example of DOG 1/2 [1][8][13]



Images source :Allan Jepson [8]

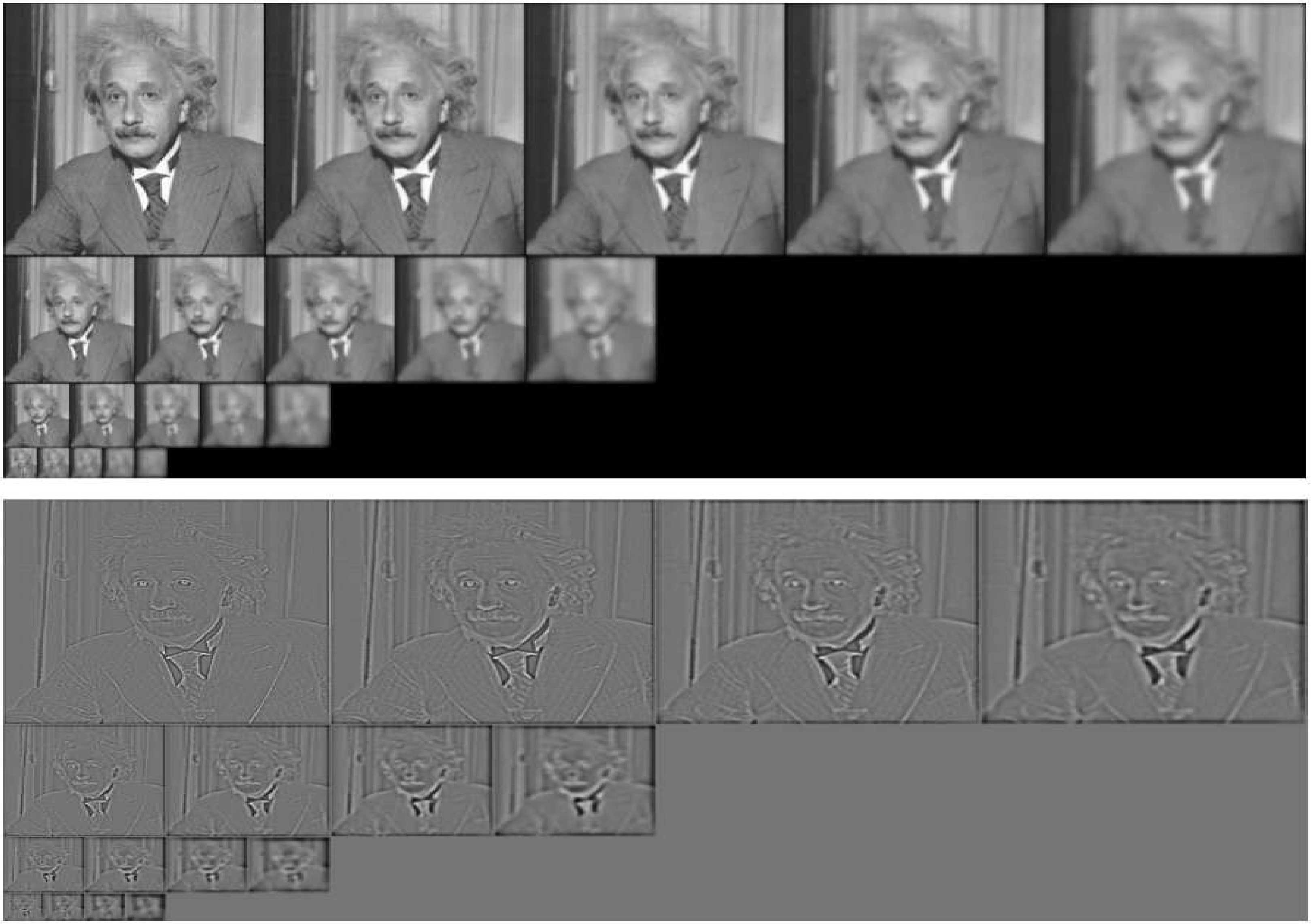


Images source :[13]



Images source :
[13]

Example of DOG 2/2 [1][8]



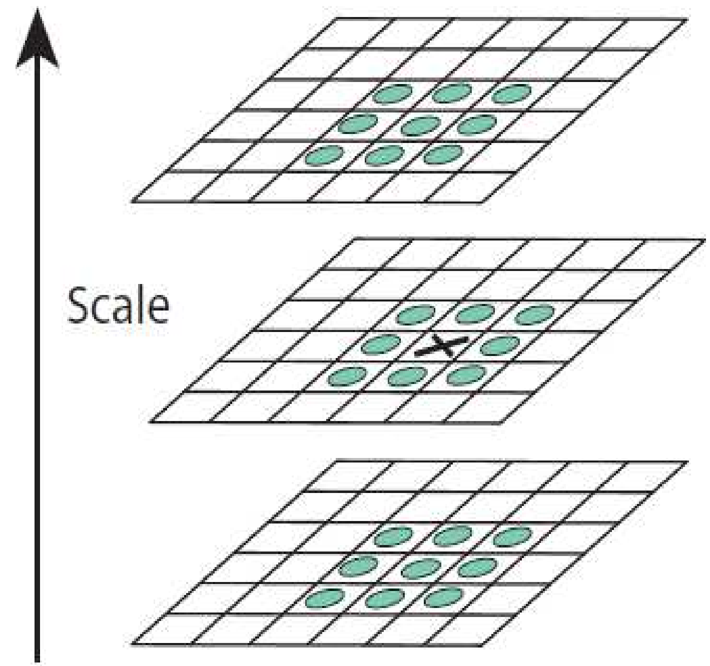
Range: [−0.11, 0.131]
Dims: [959, 2044]

Images source :Allan Jepson [8]

DOG exterma localization [1][4]

- ✓Scan each DOG image
- ✓Look at all neighboring points (including scale)
- ✓Identify Min and Max

26 Comparisons



Slide credit : Jason clemons [4]

Images source :Lowe 2004 [1]

Extra keypoints elimination 1/2 [1] [4]

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3D Curve Fitting for localization : Taylor Series Expansion + differentiation

$$D(\mathbf{x}) = D + \frac{\partial D}{\partial \mathbf{x}}^T \mathbf{x} + \frac{1}{2}\mathbf{x}^T \frac{\partial^2 D}{\partial \mathbf{x}^2}\mathbf{x}$$

$$\hat{\mathbf{x}} = -\frac{\partial^2 D}{\partial \mathbf{x}^2}^{-1} \frac{\partial D}{\partial \mathbf{x}}.$$

Low Contrast Points Filter

$$D(\hat{\mathbf{x}}) = D + \frac{1}{2}\frac{\partial D}{\partial \mathbf{x}}^T \hat{\mathbf{x}}.$$

Slide credit : Jason clemons [4]

Extra keypoints elimination 2/2 [1] [4]

Edge Response Elimination :

- ✓Hessian
- ✓Eigenvalues Proportional to principle
- ✓CurvaturesTrace and Determinant

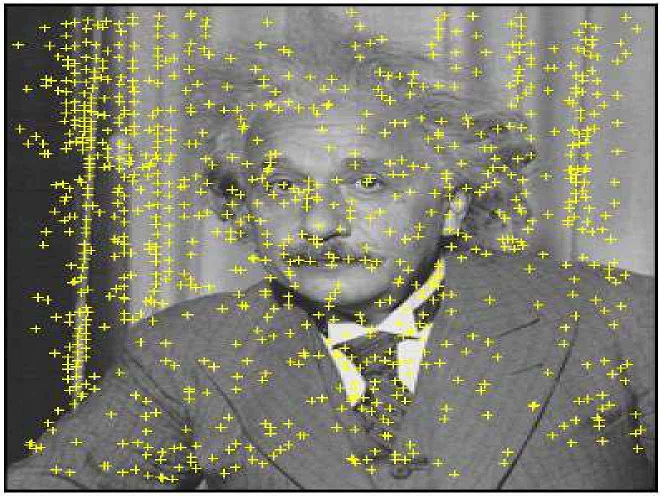
$$H = \begin{bmatrix} D_{xx} & D_{xy} \\ D_{xy} & D_{yy} \end{bmatrix}$$

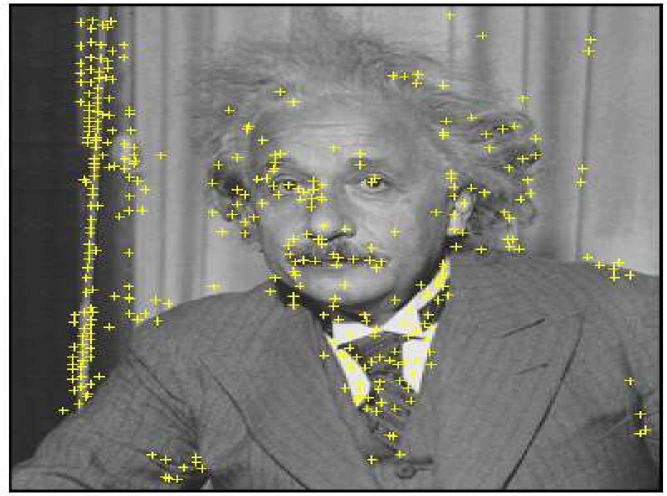
$$\frac{Tr(H)^2}{Det(H)} < \frac{(r+1)^2}{r}$$

$$Tr(H) = D_{xx} + D_{yy}$$
$$Det(H) = D_{xx} D_{yy} - (D_{xy})^2$$

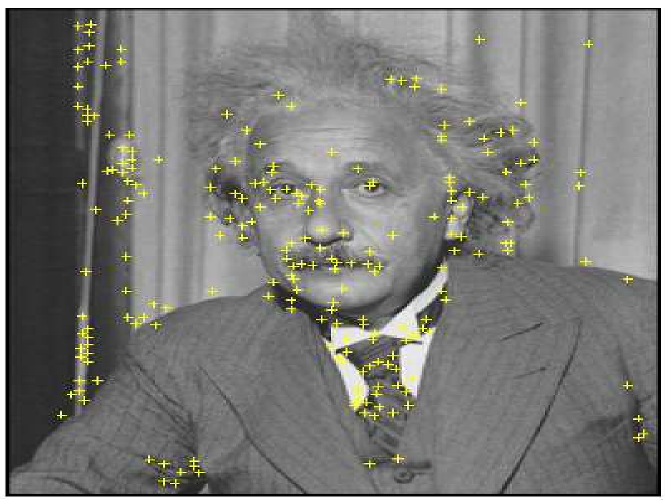
Slide credit : Jason clemons [4]

Extra keypoints elimination example [8]





a) b)



c)

Images source :Allan Jepson [8]

Orientation and feature descriptor [1][4][6]

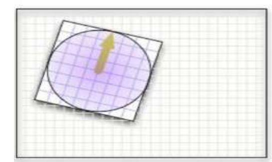
Compute Gradient for each blurred image

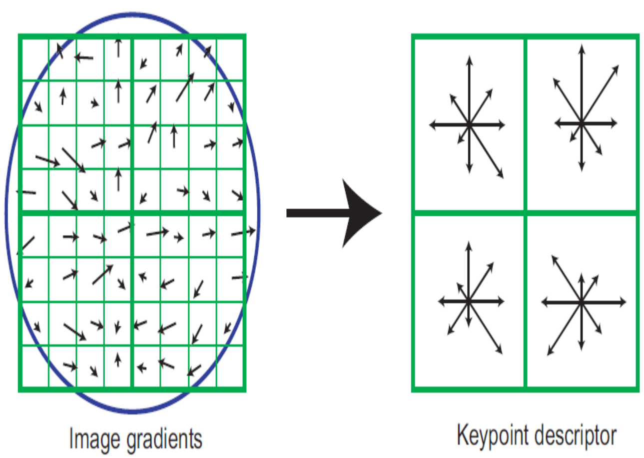
$$L(x,y)=G(x,y,\sigma)*I(x,y)$$

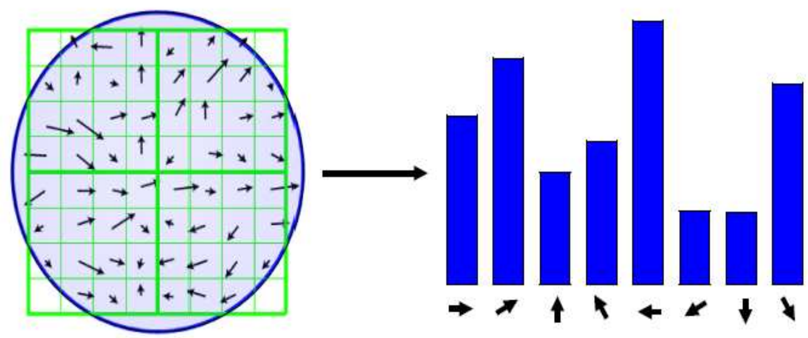
$$m(x,y)=\sqrt{(L(x+1,y)-L(x-1,y))^2+(L(x,y+1)-L(x,y-1))^2}$$

$$\theta(x,y)=\tan^{-1}\left(\frac{(L(x,y+1)-L(x,y-1))}{(L(x+1,y)-L(x-1,y))}\right)$$

Implementation uses 4x4 descriptors
from 16x16 which leads to a 4x4x8=128 element vector





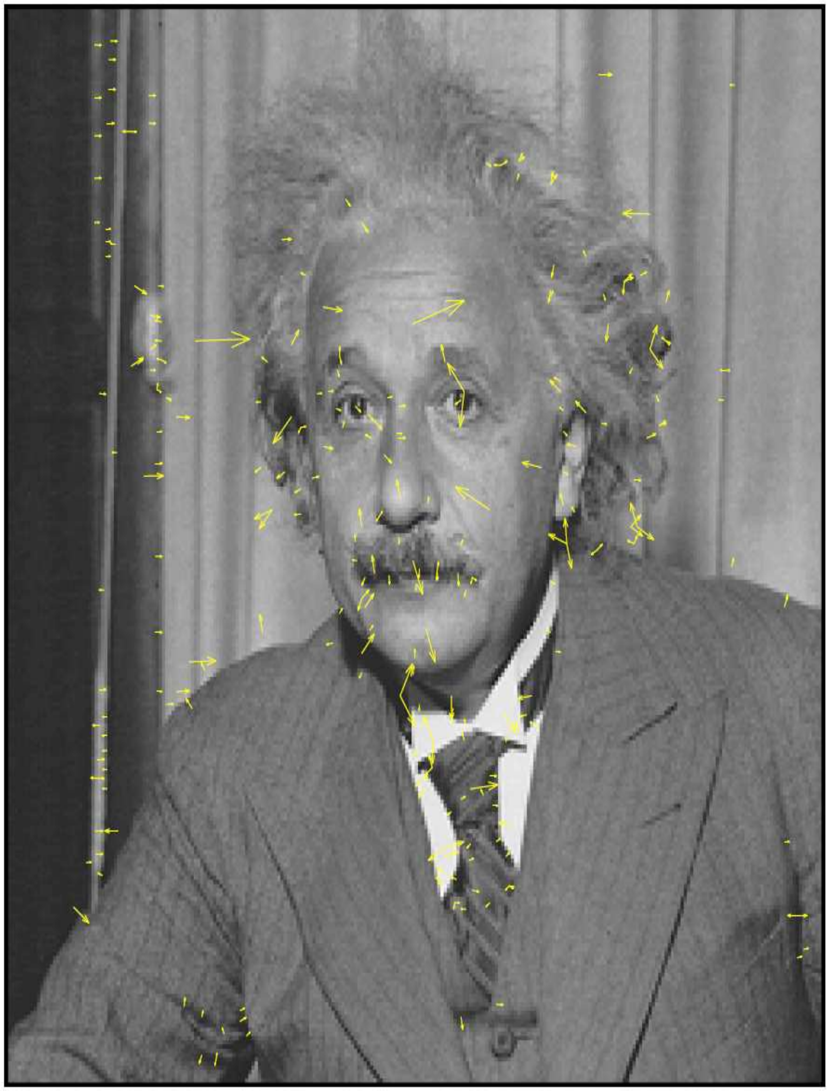


Images source :Lowe 2004 [1]

Slide credit : Jason clemons [4]

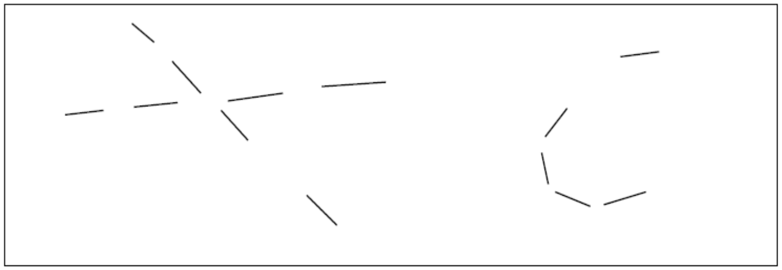
Images source : Ofir Pele [6]

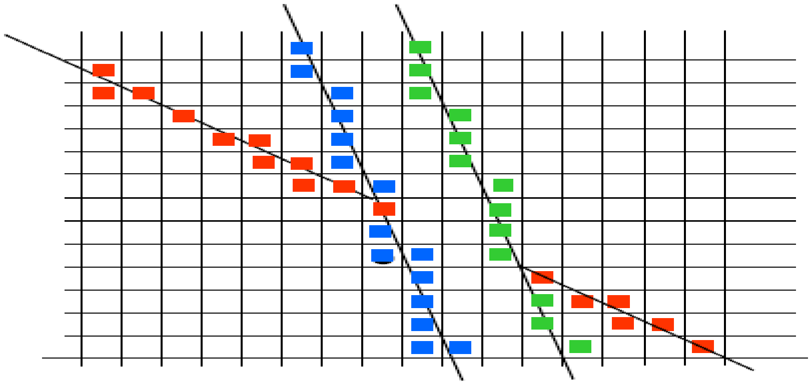
Orientation example [8]

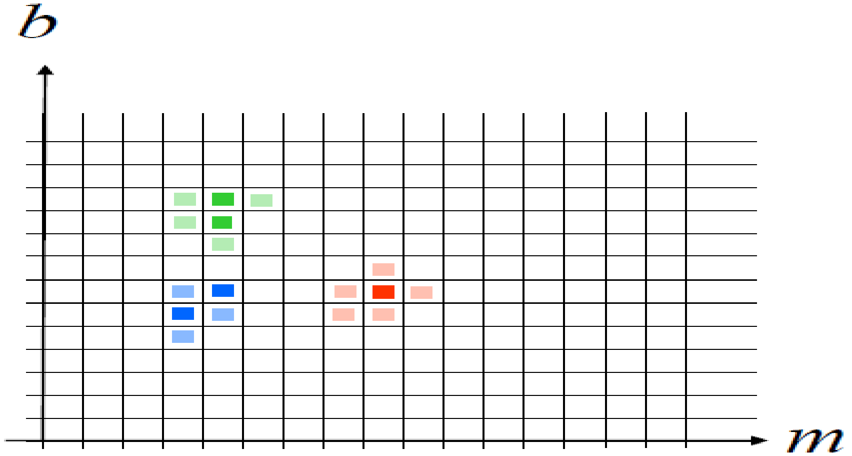


Images source :Allan Jepson [8]

Hough transform : Global features [1][13]



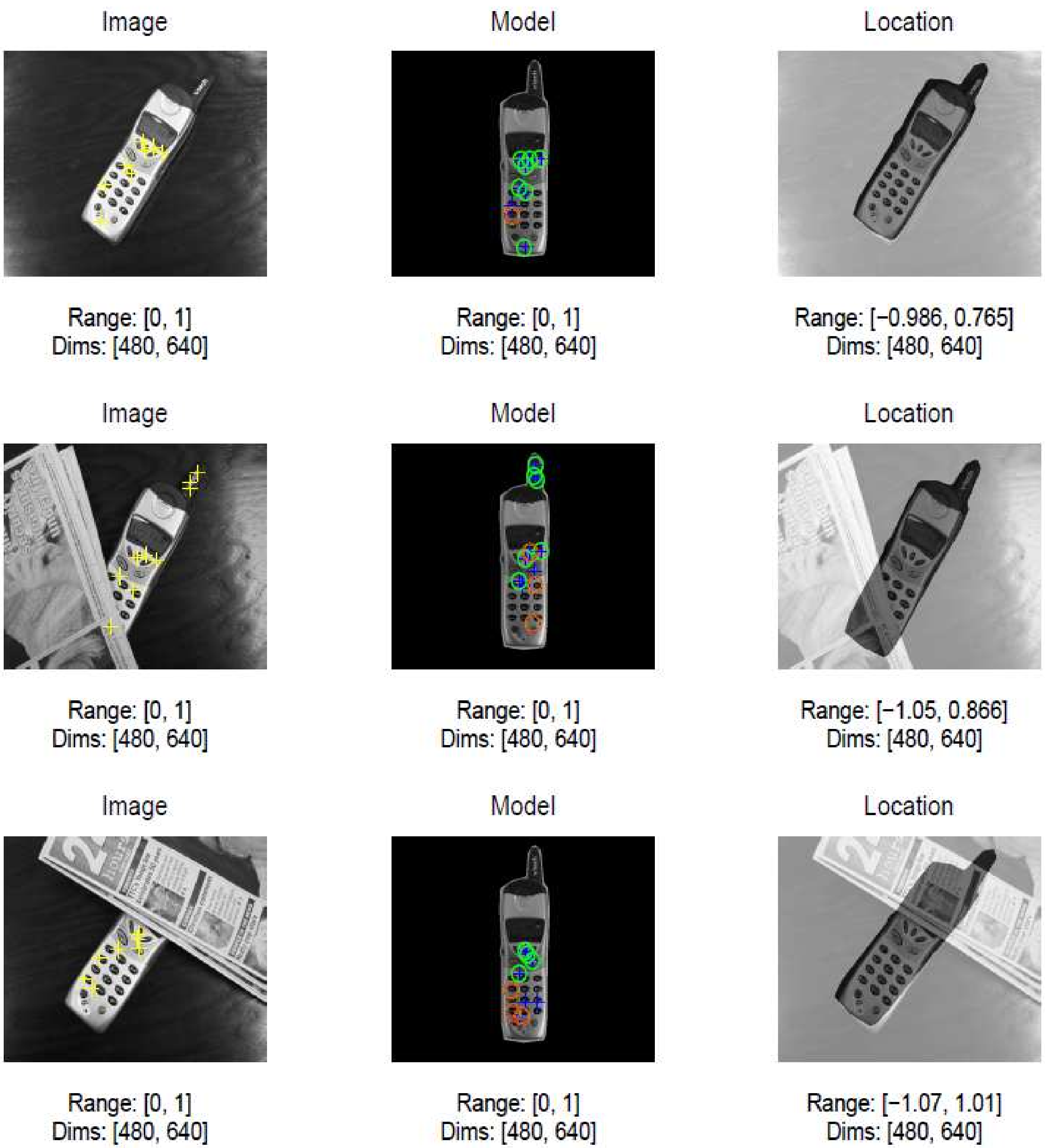




Images source :[13]

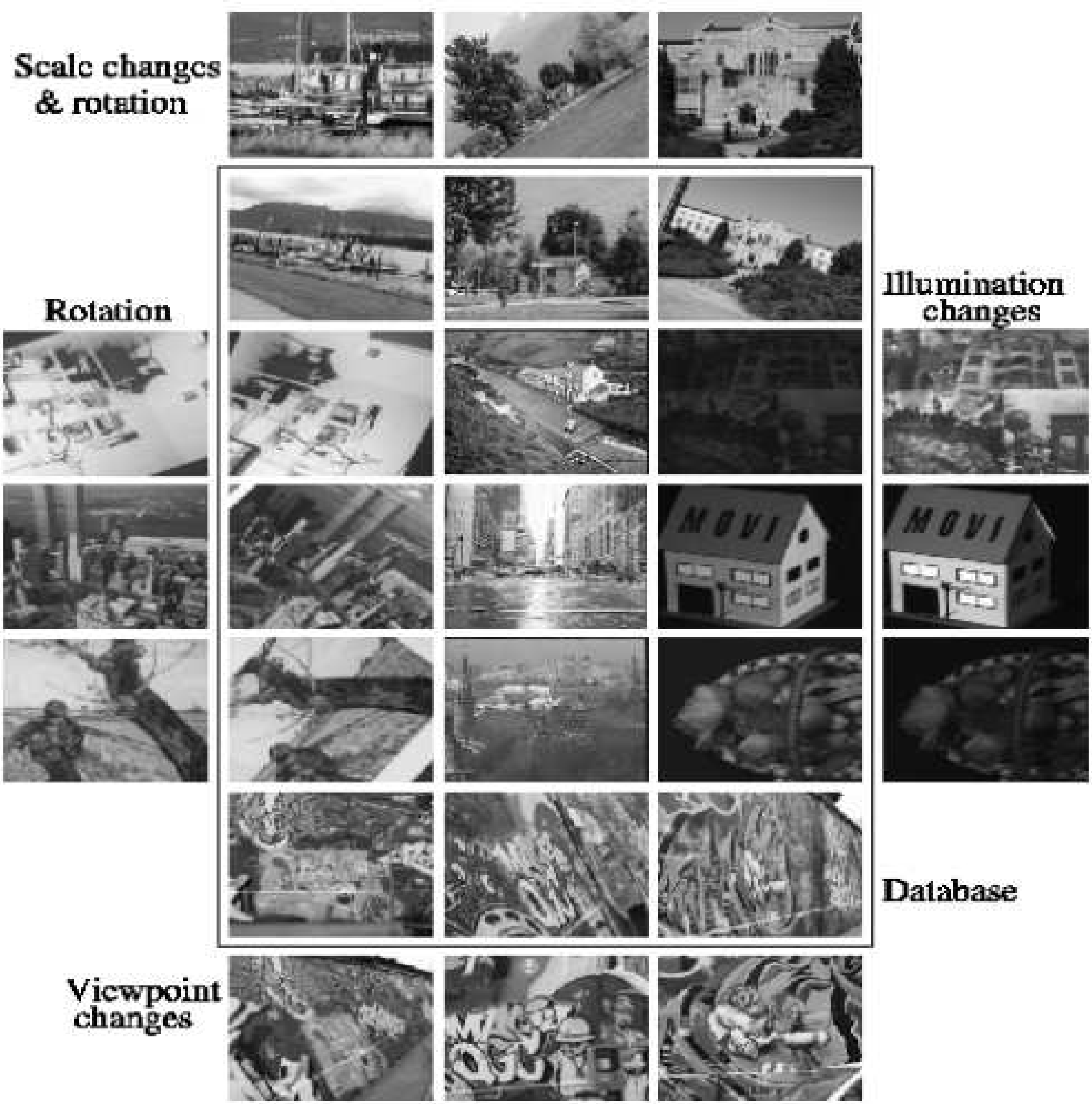
SIFT example : Find the cellphone ?

[8]



Images source : Allan jepson [8]

SIFT , Features database [13]

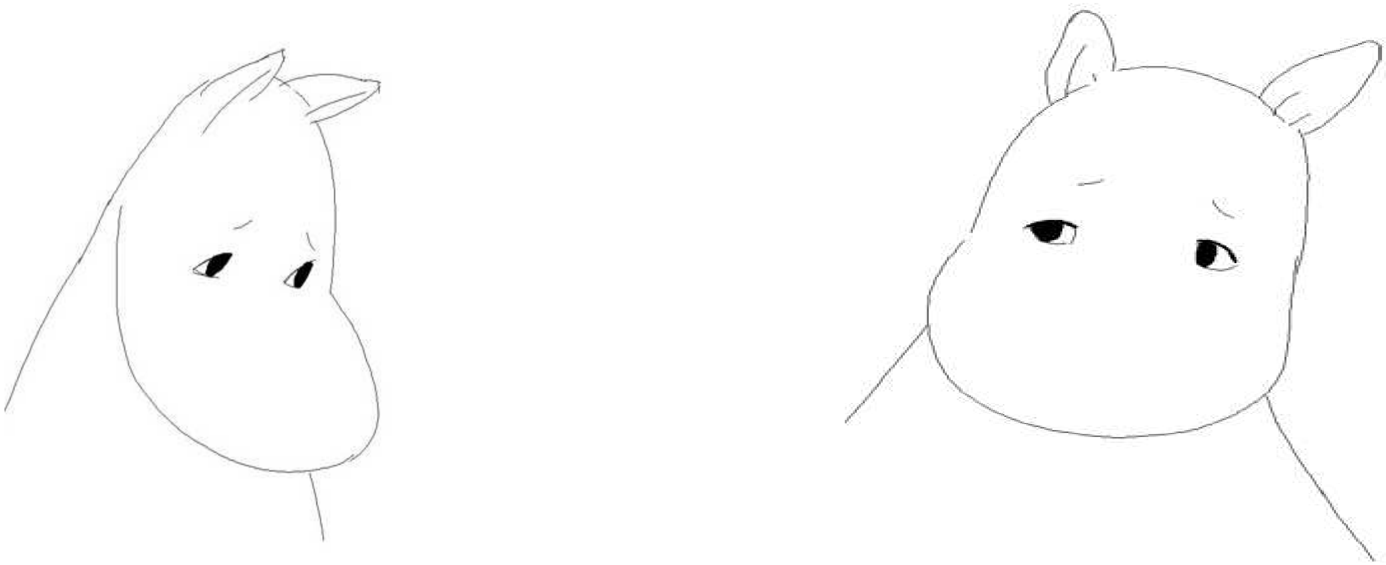


Images source :[13]

SIFT limitation [6]

Large illumination change

Non rigid deformations



SIFT Application [5]

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- Object recognition using SIFT features
- Robot localization and mapping
- Panorama stitching
- 3D scene modeling, recognition and tracking
- Others,(human action recognition)

SIFT Demo, Visual. Geometry Group Oxford University [7]

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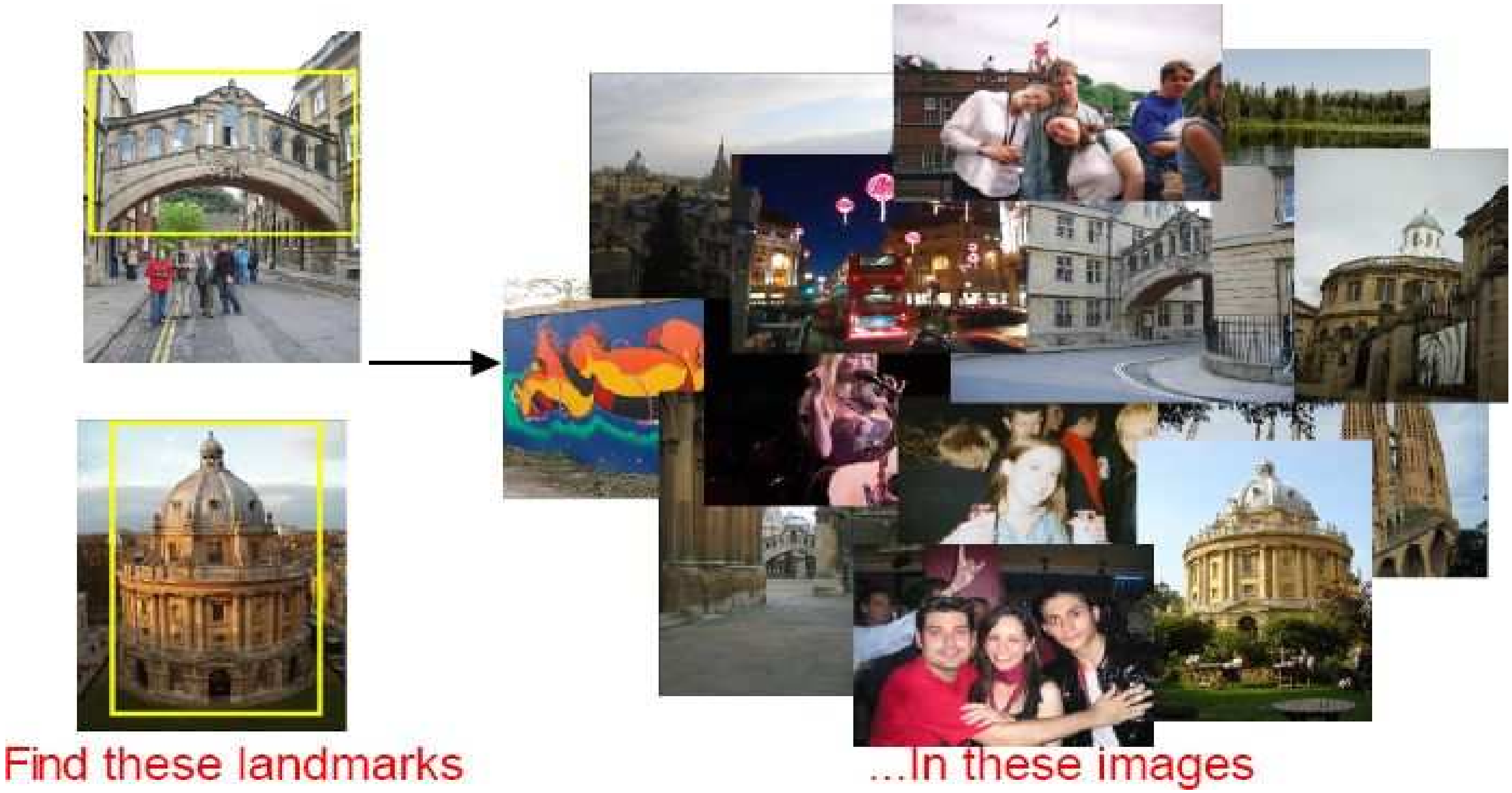
http://www.robots.ox.ac.uk/~vgg/research/oxbuildings/index.html



Images source :Visual. Geometry Group[7]

Conclusion [6]

- In wide use both in academia and industry
- Many available implementations:
  - Binaries available at Lowe's website
  - C/C++ open source by A. Vedaldi (UCLA)
  - C# library by S. Nowozin (Tu-Berlin)
- Protected by a patent

Slide credit : Ofir Pele [6]

References

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[2] David G. Lowe, "Object recognition from local scale-invariant features," International Conference on Computer Vision, Corfu, Greece (September 1999), pp. 1150-1157 retreived 3-11-2011 from : http://www.cs.ubc.ca/~lowe/papers/iccv99.pdf

[3] K. Mikolajczyk, C. Schmid, A performance evaluation of local descriptors. In PAMI 27(10):1615-1630 . retreived 3-11-2011 from : http://www.robots.ox.ac.uk/~vgg/research/affine/det_eval_files/mikolajczyk_pami2004.pdf

[4] Jason Clemons, University of Michigan ,course EECS598, lecture presentation 10_1 retreived from : http://www.eecs.umich.edu/~silvio/teaching/EECS598/lectures/lecture10_1.pdf

[5] http://en.wikipedia.org/wiki/Scale-invariant_feature_transform

[6] Ofir Pele,The Rachel and Selim Benin School of Computer Science and Engineering , computer vision 2006 course slides retrieved 3-11-2011 from : http://www.cse.huji.ac.il/course/2006/compvis/lectures/SIFT.ppt

[7] Visual. Geometry Group,. University of Oxford , Web-scale particular object search : http://www.robots.ox.ac.uk/~vgg/research/oxbuildings/index.html

[8] Allan Jepson,Sift tutorial , University of Toronto,CS department, course csc2503 : http://www.cs.toronto.edu/~jepson/csc2503/tutSIFT04.pdf

[9] http://en.wikipedia.org/wiki/Image_matching

[10] http://en.wikipedia.org/wiki/Feature_detection_%28computer_vision%29

[11] http:// en.wikipedia.org/wiki/Blob_detection

[12] Ilan Shimshoni, University of Haifa, Slide presentation about SIFT from 048972 Course in Multiple View Geometry : http://mis.hevra.haifa.ac.il/~ishimshoni/MVG/SIFT_KA.ppt

[13] Presentation slides : Cornell University, CS department , CS664 course Lecture 21: SIFT, object recognition, dynamic programming : http://www.cs.cornell.edu/courses/cs664/2005fa/Lectures/lecture21.pdf

[14] Ballard J.S. Blair, MIT-WHOI joint program, difference of Gaussian paper retrieved 2-11-2011 from : http://www.ballardblair.com/projects/Difference_of_Gaussian_paper.pdf

[15] http://en.wikipedia.org/wiki/Scale-space