UNIVERSITY OF Southampton
School of Electronics and Computer Science

COMP3204 Computer Vision

Revision – Part 1

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Exam Format

Time: 19th January 2022, 9:30am-12:00am

3 hours duration

Please double check the latest timetable

Format: Choose 3 questions from 6

- Each question worth 33 marks (99 marks total)
- Jon wrote (the last) 3; I wrote (the first) 3
  - Expect that mine will typically cover lower level vision & Jon's will cover higher level vision
  - but there will probably be some overlap!

Typical Mark Scheme

- 80% from lectures and notes; 20% from independent reading
  - Each question will be broken down into sub-parts
  - The marks for each question are there to help you
  - Use them to judge how much to write and how much time to spend

- Questions are more focusing on problem solving and applying your knowledge

- Some mathematical/calculation questions to be expected

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Typical Mark Scheme

few

more

design and explain

4.
Feature morphology and segmentation

(a) ~~**Describe**~~ with the aid of sketches three different morphologies of image feature. [6 marks]

(b) **Describe** two strategies for segmenting an image. [13 marks]

(c) **Compare** the two strategies from the previous answer, highlighting advantages and disadvantages of one with respect to the other. [8 marks]

(d) **Identify** parameters that will need to be set, either manually or automatically for the segmentation methods you described and strategies to choose them. [6 marks]

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Past Exam Papers

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University of Southampton > ECS > Intranet > Modules > 2020-2021 > COMP6223 > **Past Papers**

COMP6223: Computer Vision (MSc) (2020-2021)

Overview | Resources | Past Papers | Syllabus | Evaluation | Send Message | Students | Help

You are a lecturer on this module.

- COMP6223_rubric_201516.pdf
- COMP6223_rubric_201415.pdf
- COMP6223-201617-exam.pdf
- 201516_COMP6223.pdf
- 201415_COMP6223W1 Computer Vision (MSC).pdf

Is this page inaccurate, incomplete or out of date? Do you have a suggestion?

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Questions?

Title	Slides	Handouts	Recording
A Framework for Computer Vision	PDF	N/A	N/A
Lecture 1: Eye and Human Vision	PDF	Animations	link
Lecture 2: Image Formation	PDF	PDF	link
Lecture 3: Image Sampling	PDF	link; link	link
Lecture 4: Point Operators	PDF	N/A	link
Lecture 5: Group Operators	PDF	N/A	link
Lecture 6: Edge Detection	PDF	N/A	link
Lecture 7: Further Edge Detection	PDF	link	link
Lecture 8: Finding Shapes	PDF	N/A	link
Lecture 9: Finding More Shapes	PDF	link	link
Lecture 10: Data-driven & Model-driven Methods in Computer Vision	PDF	N/A	link
Bonus Lecture by Mark (20-21): State of Art/Deep Learning	PDF	N/A	N/A
Bonus Lecture by Mark (20-21): Survey of Gait	PDF	N/A	link

> *Demonstration material (download only): Worksheets (zipped Matlab)*

Don't forget

A Framework for Computer Vision

Grey level image

↓ Spatial gradient operators

..... Edge points .....

↓ Thinning and linking

Lines and boundaries

↓ Feature extraction

Shapes

↓

Organisation

↓ Real world knowledge

Recognition

Tony!
(CBE)

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Lecture 1 Eye and Human Vision

COMP3204 Computer Vision

Is human vision a good model for computer vision?

Book pp 1-28

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Lecture 2 Image Formation

Lecture 3 Image Sampling

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Book pp
29-66

Effects of differing image resolution

(a) 64×64 (b) 128×128 (c) 256×256

Low resolution lose information but *N* by *N* points implies much storage

How do we choose an appropriate value for *N*?

Step up Fourier…

A time−variant signal

j: the complex number $j = \sqrt{-1}$

Fourier transform of signal p

at angular frequency ω

$$Fp(\omega) = \int_{-\infty}^{\infty} p(t)\, e^{-j\omega t}\, dt$$

$$e^{-j\omega t} = \cos(\omega t) - j\sin(\omega t)$$

ω: angular frequency;

ω = 2 π ξ, where frequency ξ is $1/t$

Inverse Fourier…

Fourier coefficients

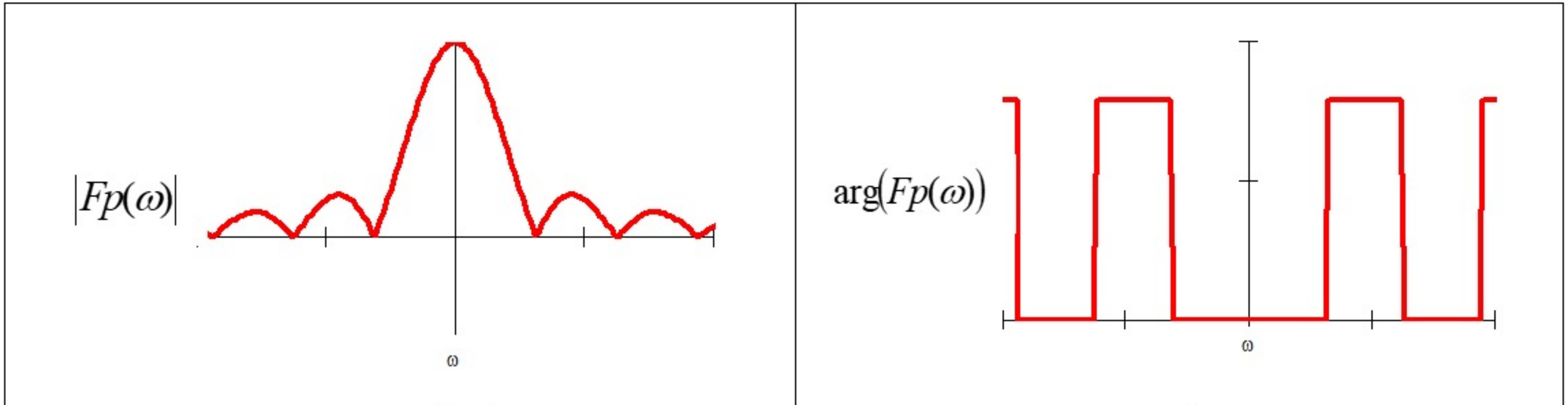
Original signal in time domain

$$p(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} Fp(\omega)\, e^{j\omega t}\, d\omega$$

$$e^{j\omega t} = \cos(\omega t) + j\sin(\omega t)$$

Magnitude and phase of Fourier transform of a pulse

$$Fp(\omega) = \int_{-\infty}^{\infty} p(t) e^{-j\omega t} dt = \mathrm{Re}\left(Fp(\omega)\right) + j\,\mathrm{Im}\left(Fp(\omega)\right)$$

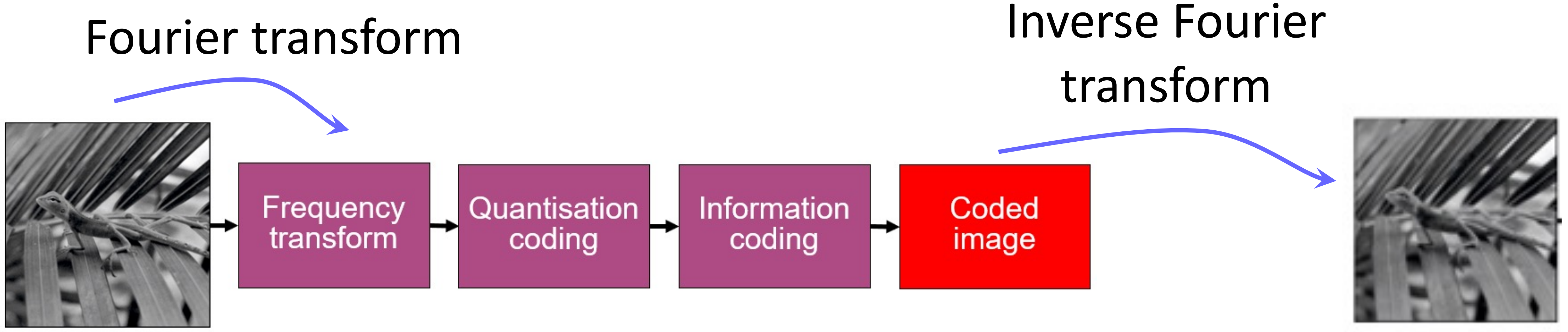


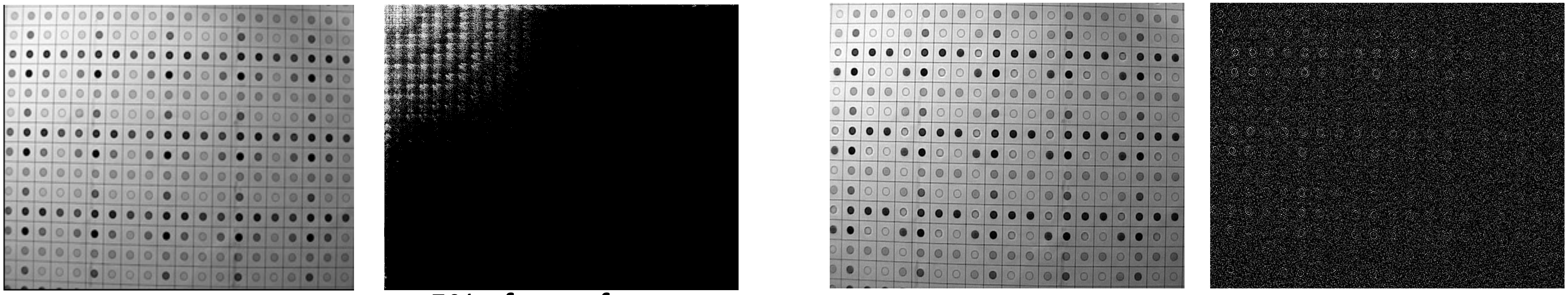
(a) magnitude **(b)** phase

$$|Fp(\omega)| = \sqrt{\mathrm{Re}\left(Fp(\omega)\right)^2 + \mathrm{Im}\left(Fp(\omega)\right)^2}$$

$$\arg\left(Fp(\omega)\right) = \tan^{-1}\left(\frac{\mathrm{Im}\left(Fp(\omega)\right)}{\mathrm{Re}\left(Fp(\omega)\right)}\right)$$

Inverse Fourier transform is used for reconstruction





image

5% of transform components

reconstructed image

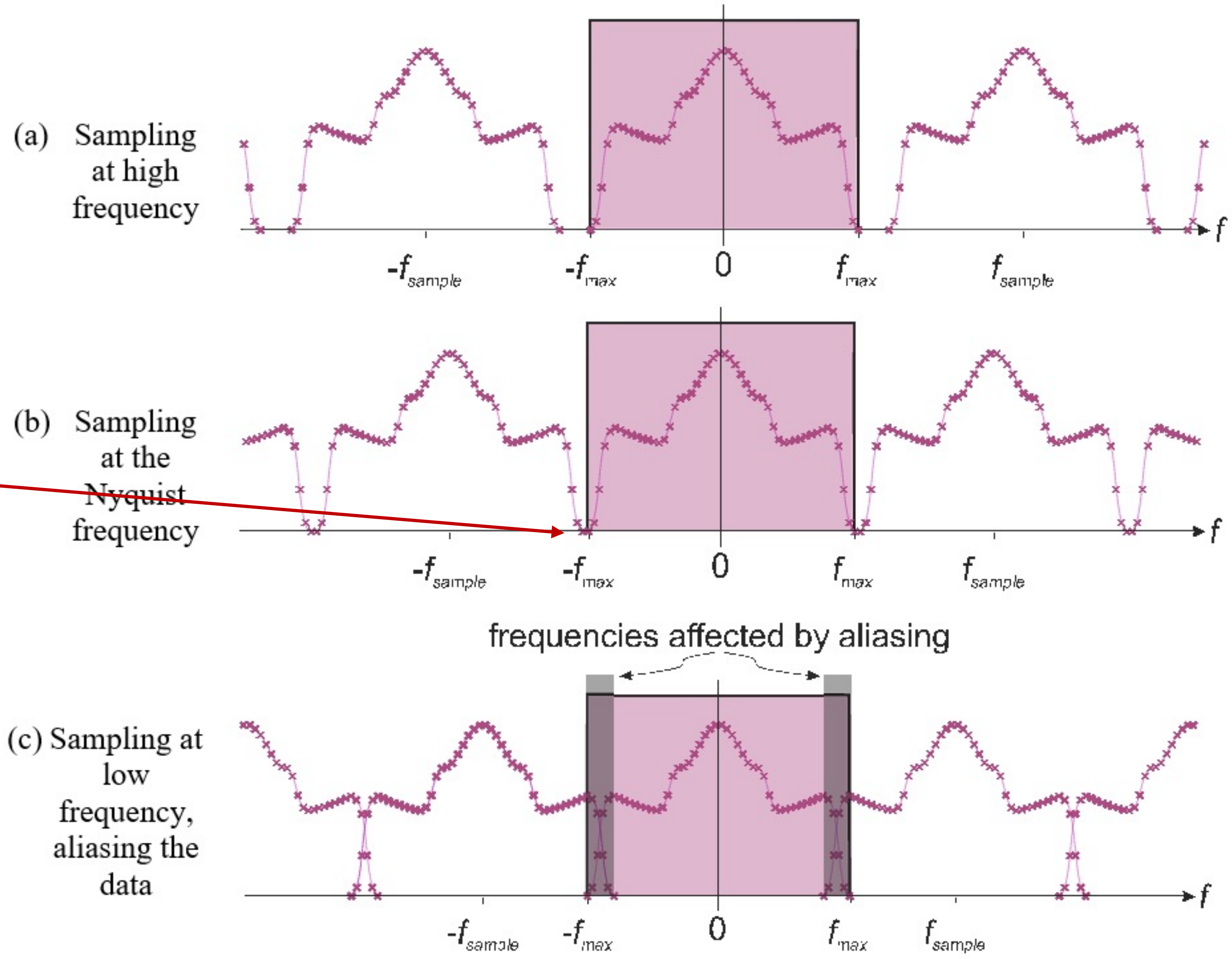
error

In the frequency domain

Spectra repeat

If sampling is just right, spectra just touch

Minimum sampling frequency = 2 × max



Sampling process in the frequency domain

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Lecture 4 Point Operators
Lecture 5 Group Operators

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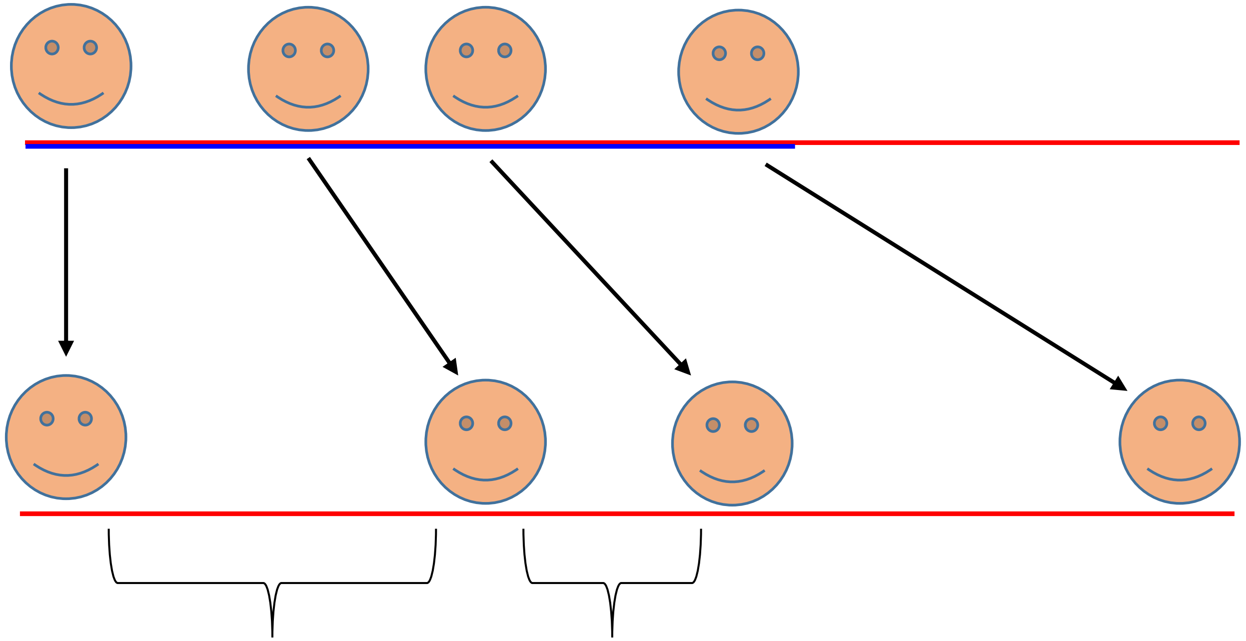
Book
pp
72-114

Intensity normalisation

Toy example

Before normalization:

After normalization
(whole range used):



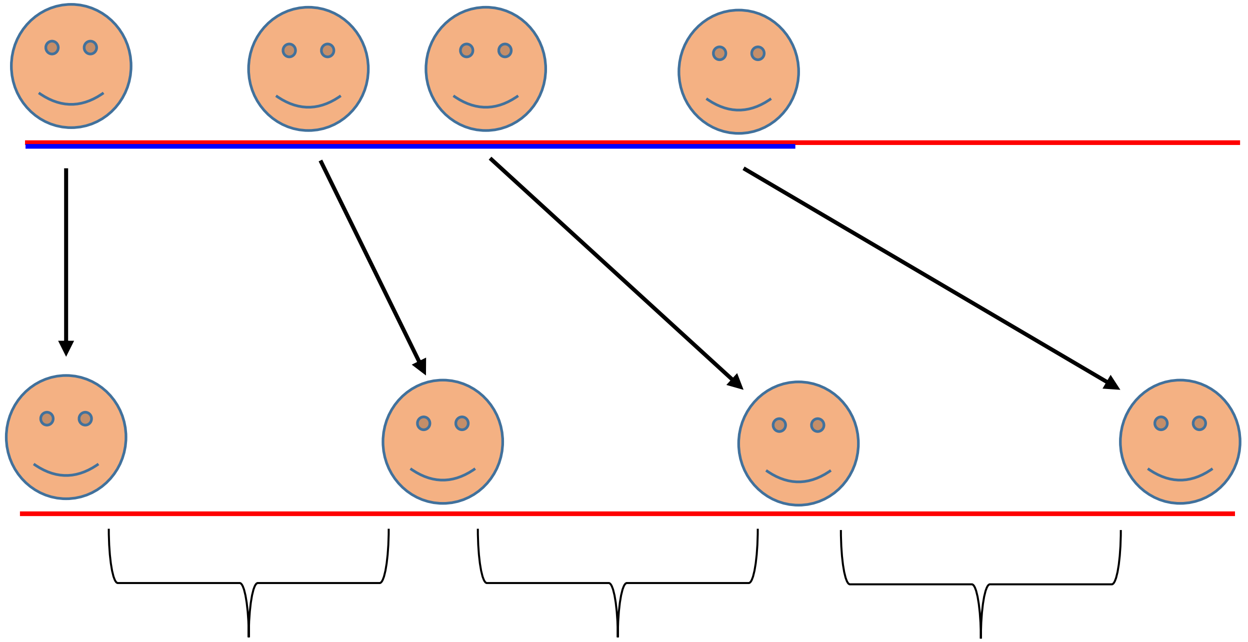
The ratio between the distances of these smileys is kept

Histogram Equalisation

Toy example

Before normalization:

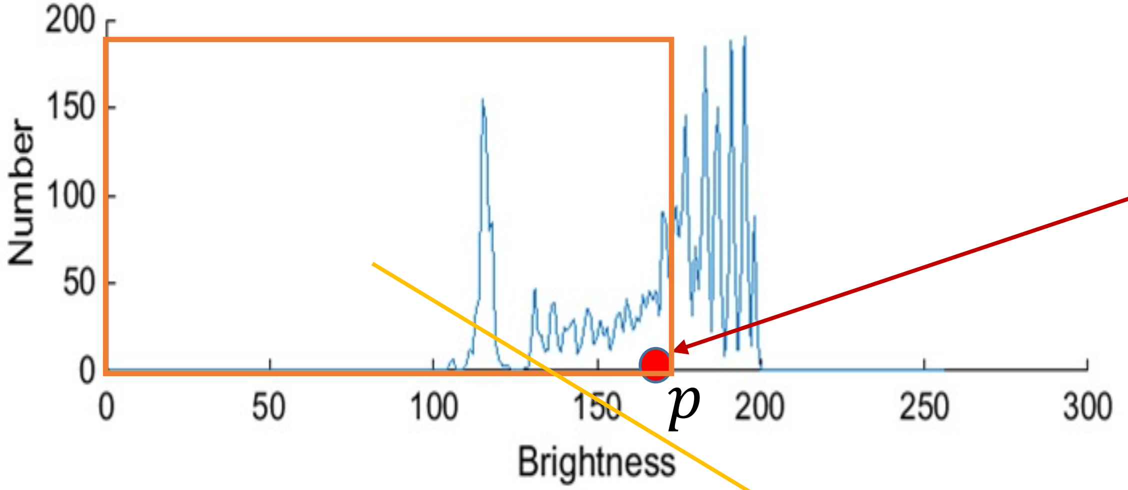
After equalisation
(whole range used):



Same distance between
two adjacent smileys

Histogram Equalisation – aim is a flat histogram

Original histogram



N^2 points in the original and equalised images

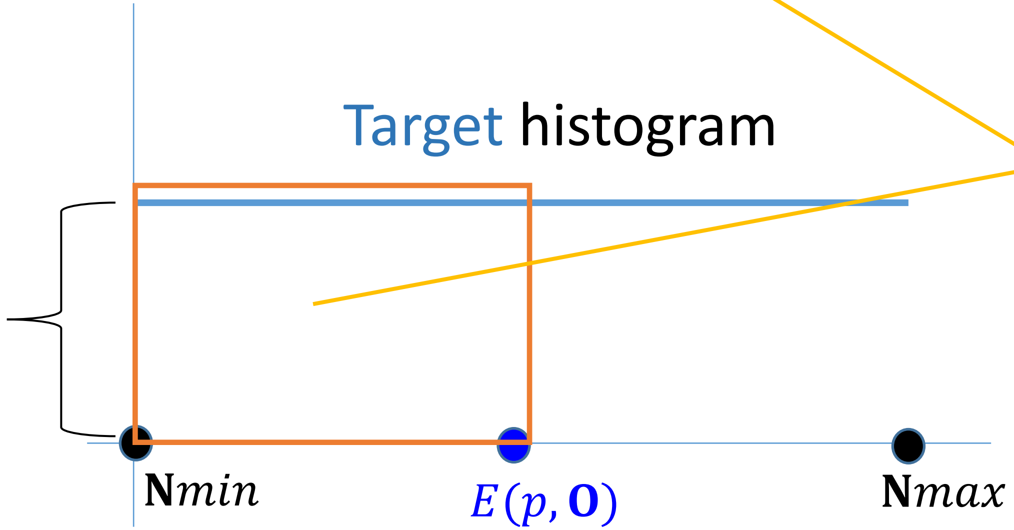
$\mathbf{O}(p)$: the histogram at level p

$\sum_{l=0}^{p} \mathbf{O}(l)$: the cumulative histogram up to level p

$E(p, \mathbf{O})$: the level after equalisation

$$\frac{N^2}{\mathbf{N}max - \mathbf{N}min}$$

Target histogram



$$\frac{N^2}{\mathbf{N}max - \mathbf{N}min}(E(p, \mathbf{O}) - \mathbf{N}min) = \sum_{l=0}^{p} \mathbf{O}(l)$$

$$E(p, \mathbf{O}) = \frac{\mathbf{N}max - \mathbf{N}min}{N^2}\sum_{l=0}^{p} \mathbf{O}(l) + \mathbf{N}min$$

Thresholding

Thresholding selects points that exceed a chosen threshold τ

$$\mathbf{N}_{x,y} = \begin{cases} 255, & \text{if } \mathbf{O}_{x,y} > \tau \\ 0, & \text{otherwise} \end{cases}$$

coordinates

An eye image

After thresholding

3×3 template and its inverse

Original template

w_{00}	w_{01}	w_{02}
w_{10}	w_{11}	w_{12}
w_{20}	w_{21}	w_{22}

Its inverse

w_{22}	w_{21}	w_{20}
w_{12}	w_{11}	w_{10}
w_{02}	w_{01}	w_{00}

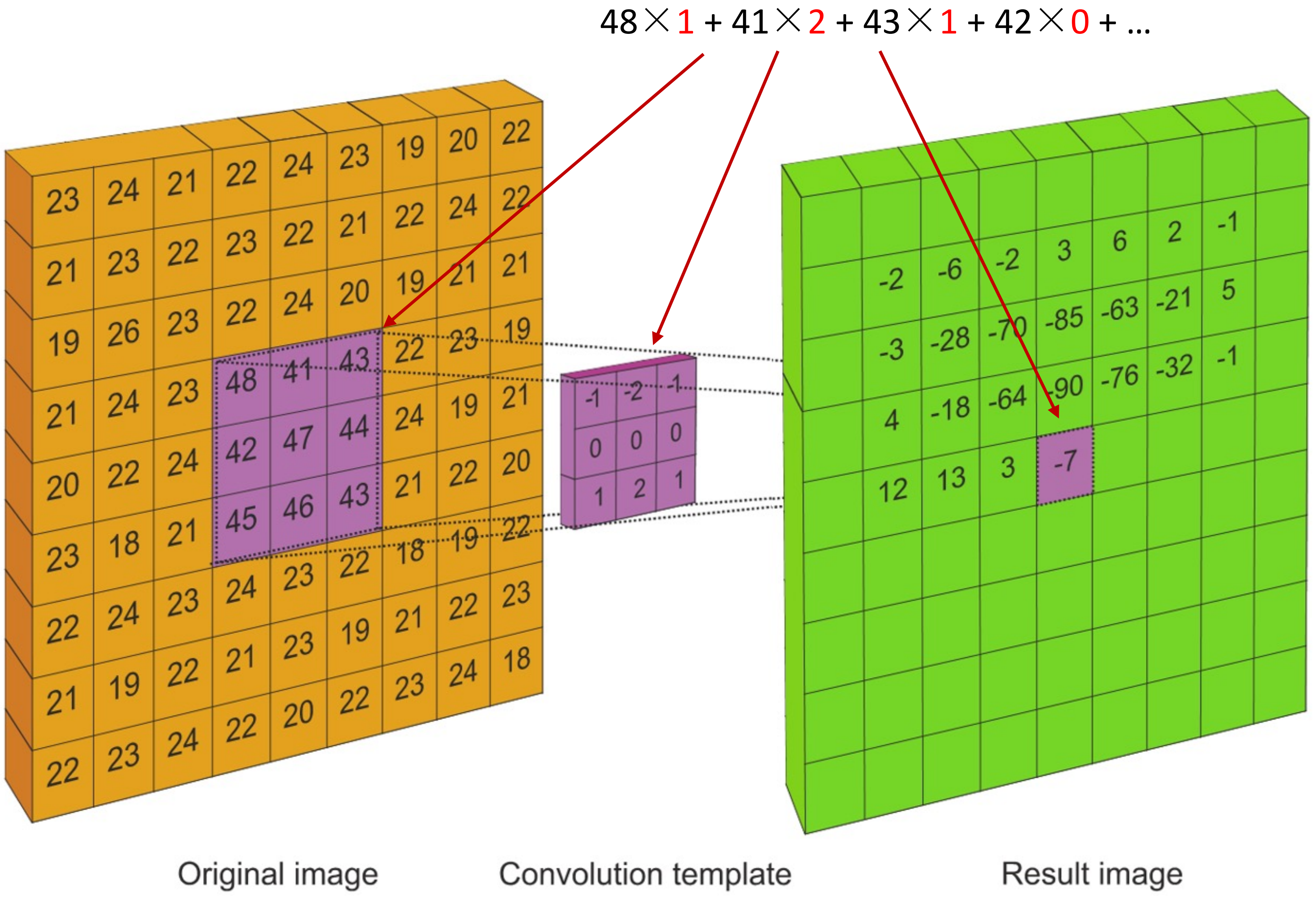
Flip corresponding to
both directions

Template convolution

Calculate a new image from the original

Template is inverted for convolution

Template is convolved in a raster fashion



Template convolution via the Fourier transform

Convolution theorem allows for **fast** computation via FFT for template size ≥ 7×7

Fourier transform of the picture, $\Im(\mathbf{P})$

Template convolution $*$

Fourier transform of the template, $\Im(\mathbf{T})$

$$\mathbf{P} * \mathbf{T} = \Im^{-1}\left(\Im(\mathbf{P}) .\times \Im(\mathbf{T})\right)$$

Picture and the template

Inverse Fourier

Point by point multiplication

The inversion is implicit in Fourier
The theory is at end, for information only

Border?

Options:

- Set border to black

- Padding the original image
  1. constant
  2. wrap-around (periodic or cyclic)
  3. symmetric

- Make template smaller near edges

Normally we assume object of interest is near centre so set border to black

Question 2.

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(a) **Explain** the difference between the spatial domain (that the above image is in) and the frequency domain after applying the Fourier transform on the above image. **List** some advantages and disadvantages of analysing the image in its frequency domain.

[8 marks]

(b) Suppose you are not satisfied with the noise present in the image above. **Design** a system which can remove the noise using the *frequency* information.

[4 marks]

(c) Suppose the noise type in the above image is Gaussian. **Design** a noise removal filter which works in the *spatial domain* of the image. When the filter size is large, **design** a way to improve the noise removal efficiency, and **explain** why this works.

[12 marks]

(d) **Explain** how the image boundaries impact the size of the image with noise removed in the noise removal techniques you developed in (c).

[9 marks]

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Lecture 6 Edge Detection

Lecture 7 Further Edge Detection

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Book
pp
118 -
171

Templates for Sobel operator

Sobel is **most popular basic operator**
Double the centre coefficients of Prewitt

1	0	-1
2	0	-2
1	0	-1

(a) Mx

1	2	1
0	0	0
-1	-2	-1

(b) My

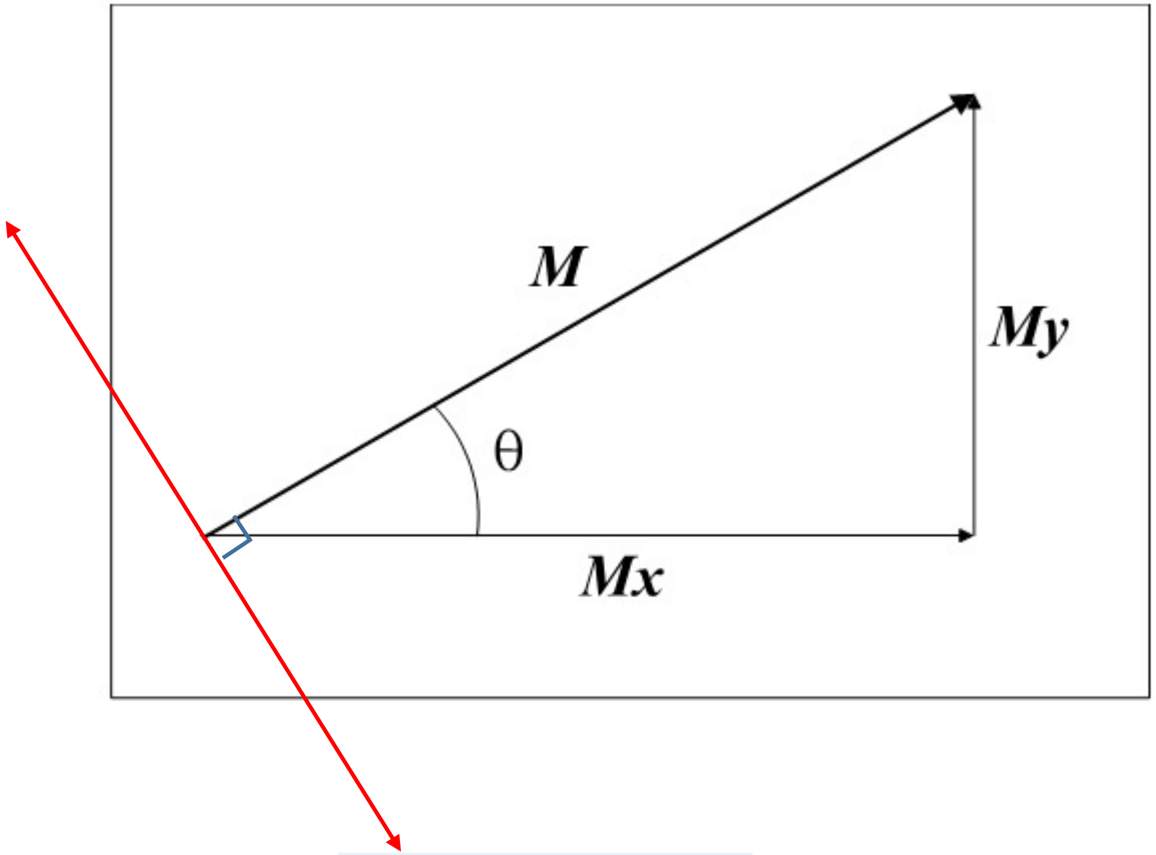
WHY?

Edge Detection in Vector Format

Vectors have magnitude (strength) and direction

Magnitude: $M = \sqrt{M_x^2 + M_y^2}$

Direction: $\theta = \tan^{-1}\left(\frac{M_y}{M_x}\right)$



Edge direction

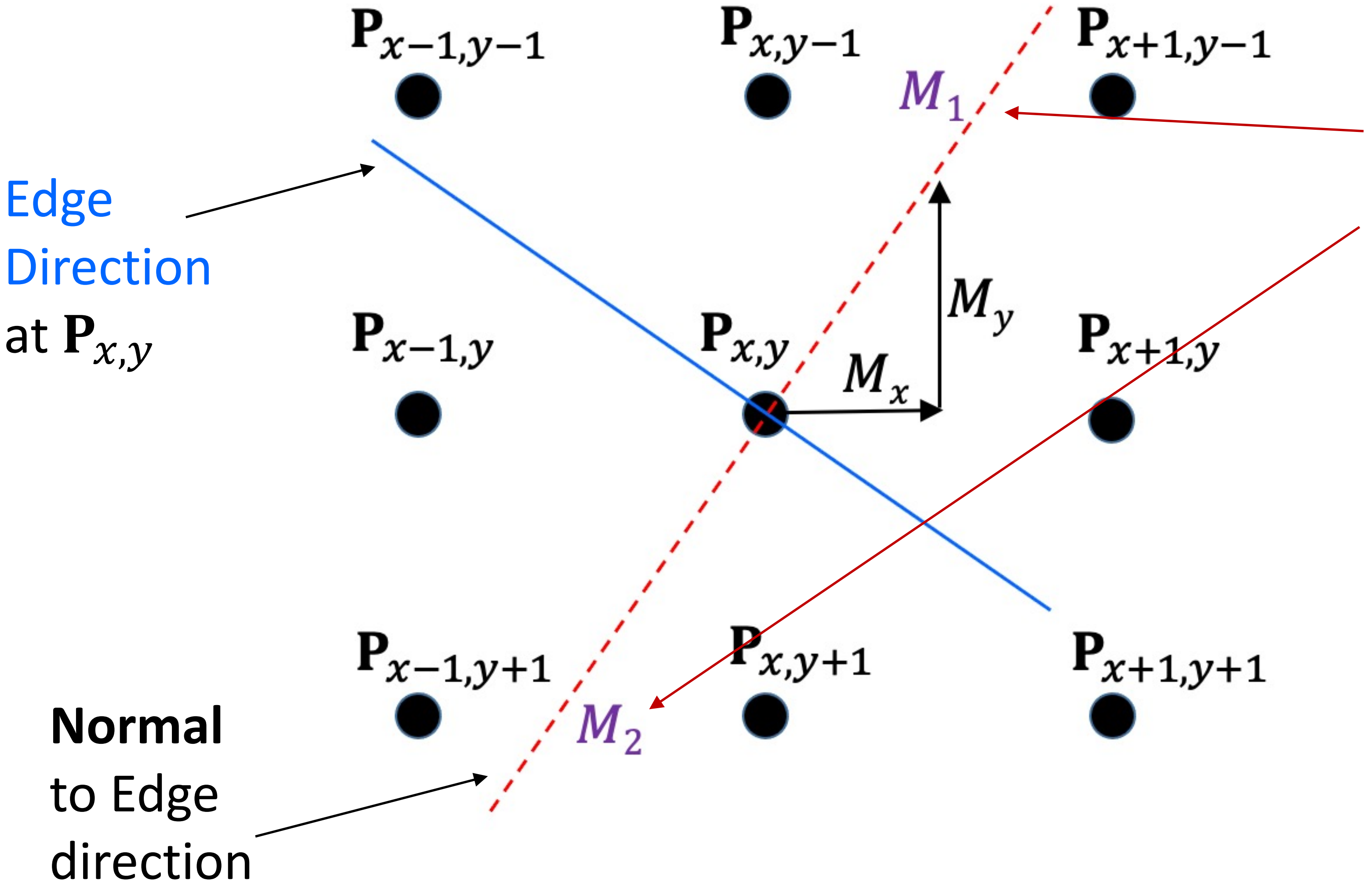
Stages in Canny edge detection operator

(a) Gaussian smoothing	(b) Sobel edge detection	(c) non-maximum suppression	(d) hysteresis thresholding

Stages in Canny Edge Detection

Canny gives thin edges in the right place,
but is more complex

Interpolation in Non-maximum Suppression

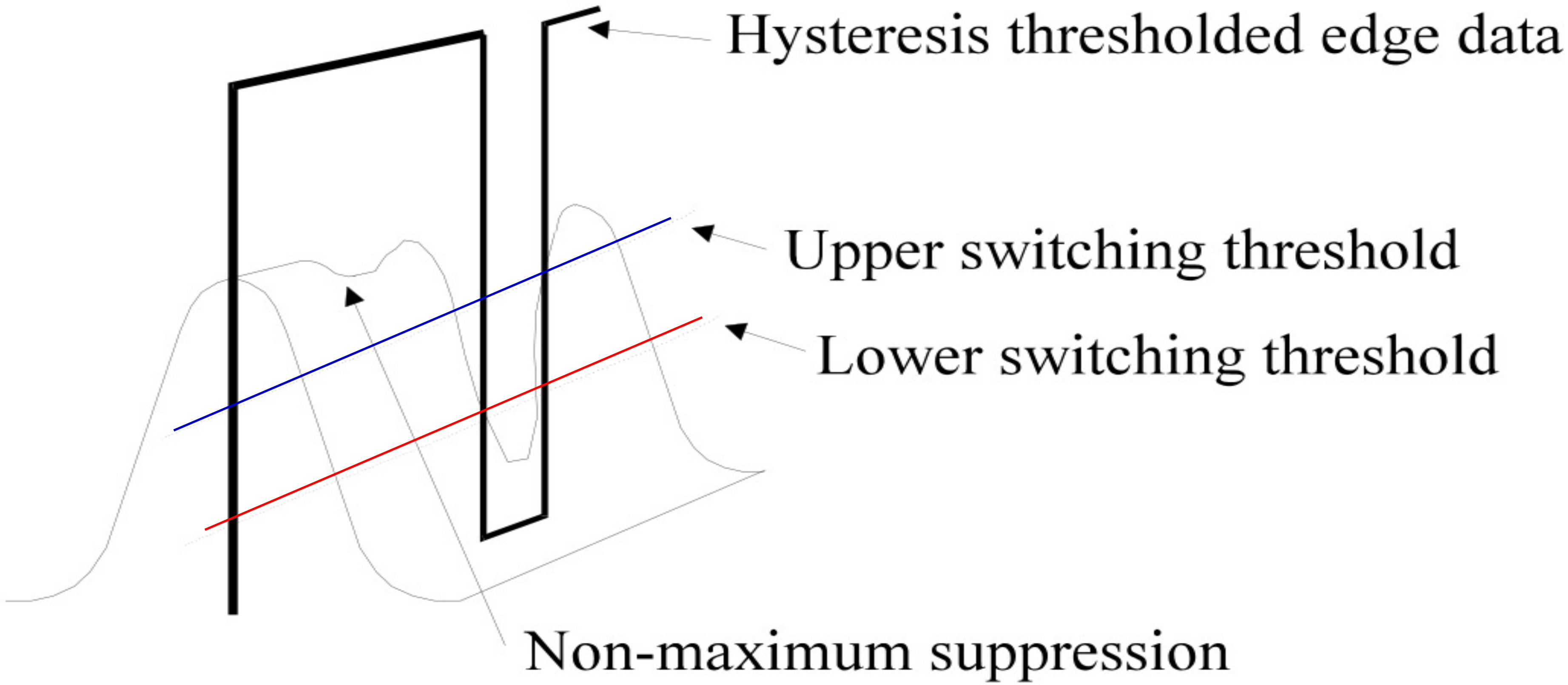


Need to use points which are not on the image grid

Use linear interpolation

Mark the point $\mathbf{P}_{x,y}$ as a maximum if its gradient magnitude is larger than both at M_1 and M_2; otherwise set it to 0.

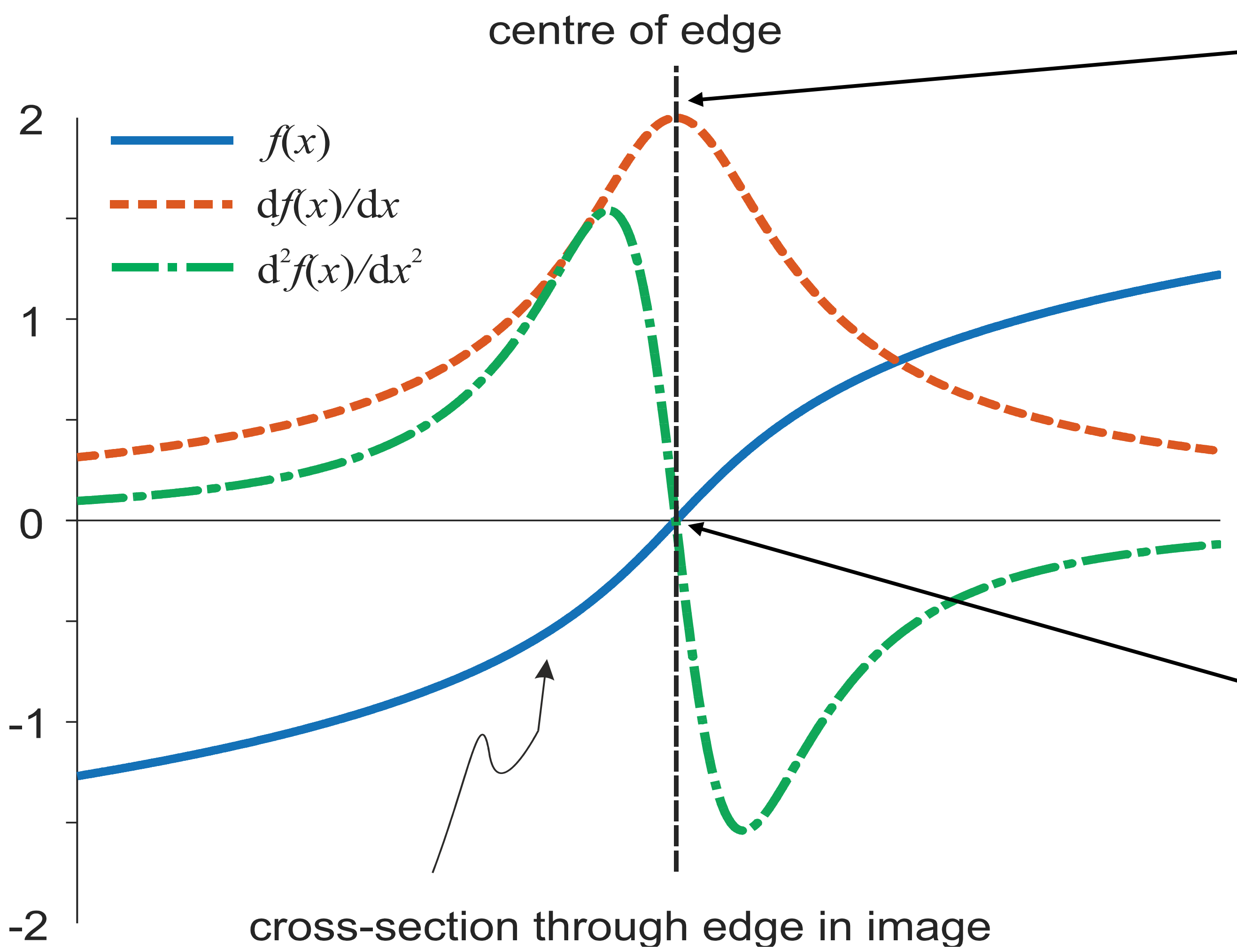
Action of non-maximum suppression and hysteresis thresholding



Walk along top of ridge

Gives thin edges in the right place

First and second order edge detection



First order:
single differentiation
with **thresholding**

Second order:
twice differentiation
with **zero-crossing detection**

Google: “Laplacian of Gaussian”

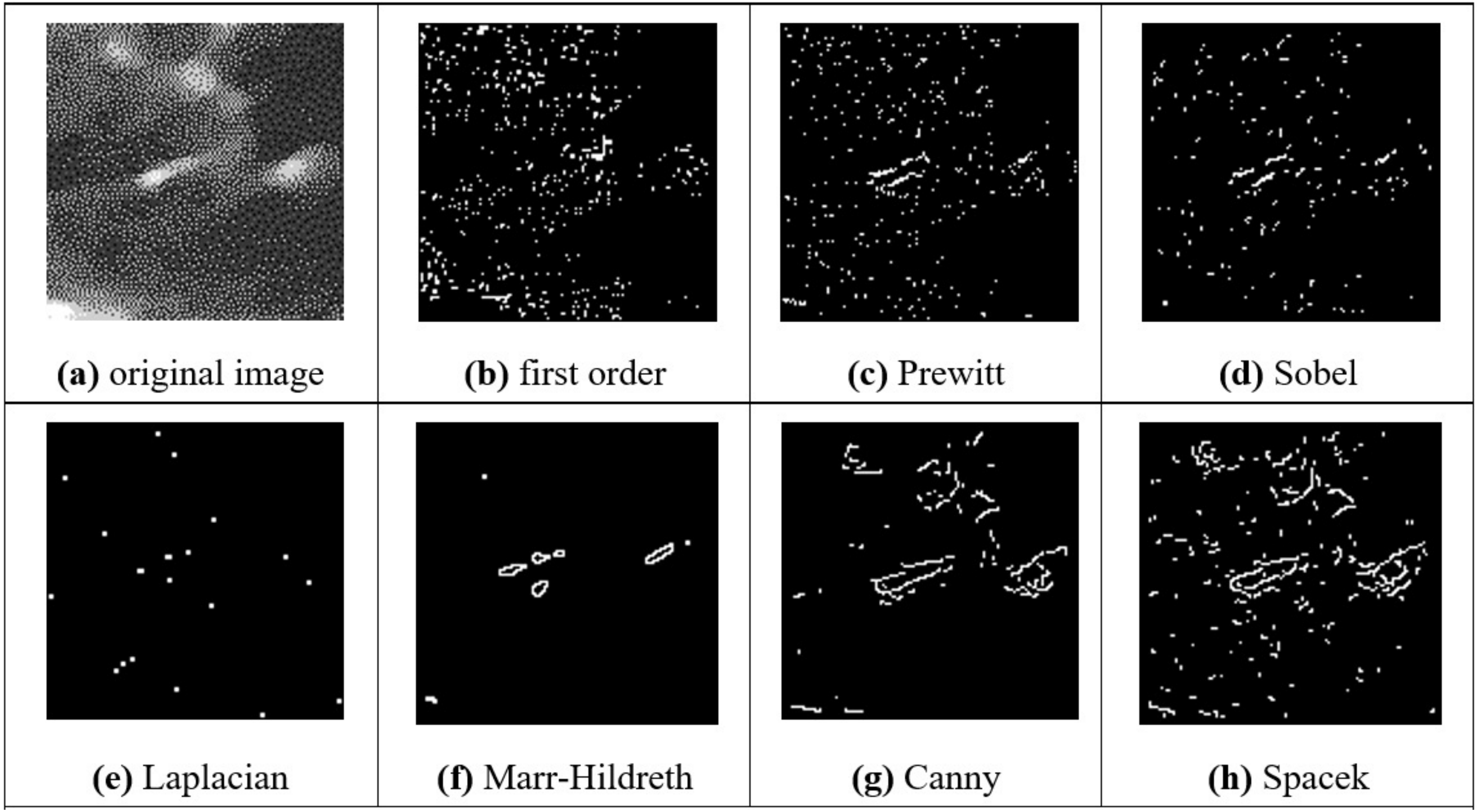
$$LoG \triangleq \Delta G_\sigma(x,y) = \frac{\partial^2}{\partial x^2}G_\sigma(x,y)+\frac{\partial^2}{\partial y^2}G_\sigma(x,y) = \frac{x^2+y^2-2\sigma^2}{\sigma^4}e^{-(x^2+y^2)/2\sigma^2}$$

$$\mathrm{LoG}(x,y) = -\frac{1}{\pi\sigma^4}\left[1-\frac{x^2+y^2}{2\sigma^2}\right]e^{-\frac{x^2+y^2}{2\sigma^2}}$$

Difference comes from the constant: $\frac{1}{2\pi\sigma^2}$ in front of the Gaussian function.

http://homepages.inf.ed.ac.uk/rbf/HIPR2/log.htm; http://fourier.eng.hmc.edu/e161/lectures/gradient/node8.html ; http://academic.mu.edu/phys/matthysd/web226/Lab02.htm

Comparison of edge detection operators



(a) original image
(b) first order
(c) Prewitt
(d) Sobel
(e) Laplacian
(f) Marr-Hildreth
(g) Canny
(h) Spacek

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Lecture 8 Finding Shapes
Lecture 9 Finding More Shapes

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Book
pp
187-201;
208-246

Template Matching - basis

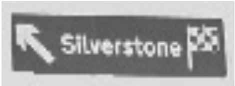
$$\| \mathbf{I}_{\Omega} - \mathbf{T} \|^{2}$$

Process of template matching

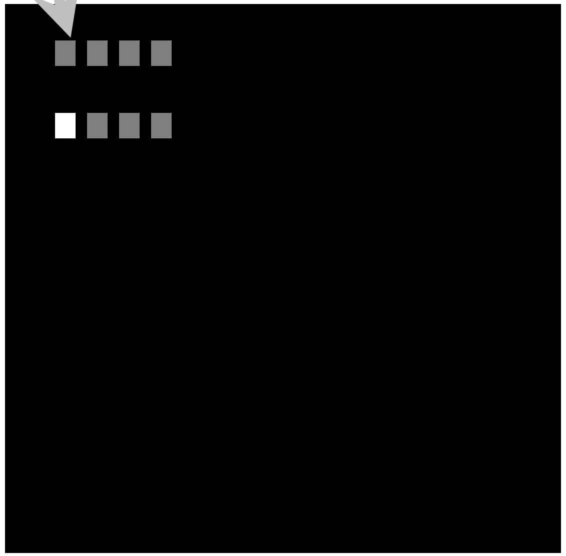
count of matching points

$\boldsymbol{\Omega}$

Image $\mathbf{I}$



Template $\mathbf{T}$



accumulator space

Suggestions for improving the process?

Use edges!

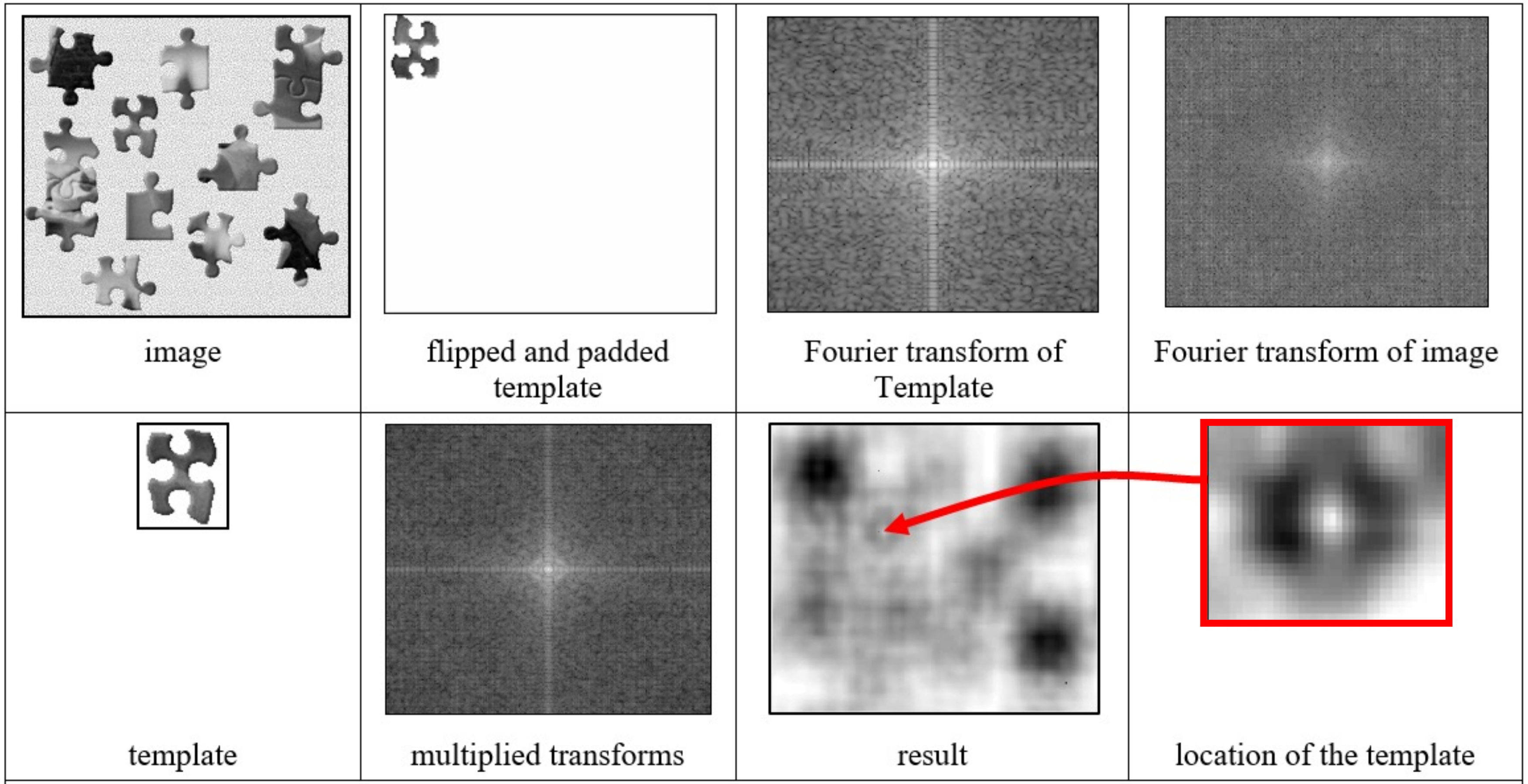
Encore, Baron Fourier!

Template matching is slow, so use FFT

$$(\mathbf{I} \otimes \mathbf{T})(i,j) = \sum_{(x,y)\in W} \mathbf{I}_{x,y}\mathbf{T}_{x+i,y+j}$$

$$\Updownarrow$$

$$F^{-1}(F(\mathbf{I}).\times F(\mathbf{T}_{\text{flip}}))$$



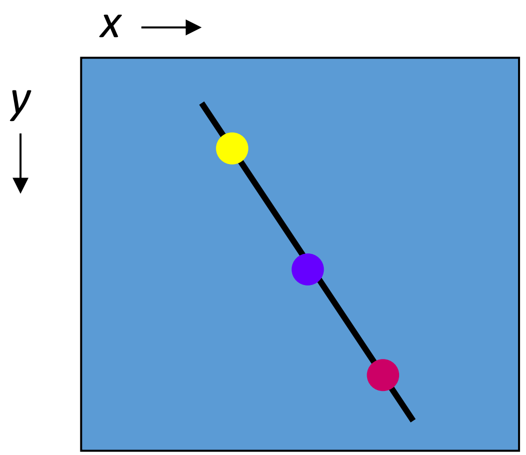
Template Matching via Fourier Transform

No sliding of templates here

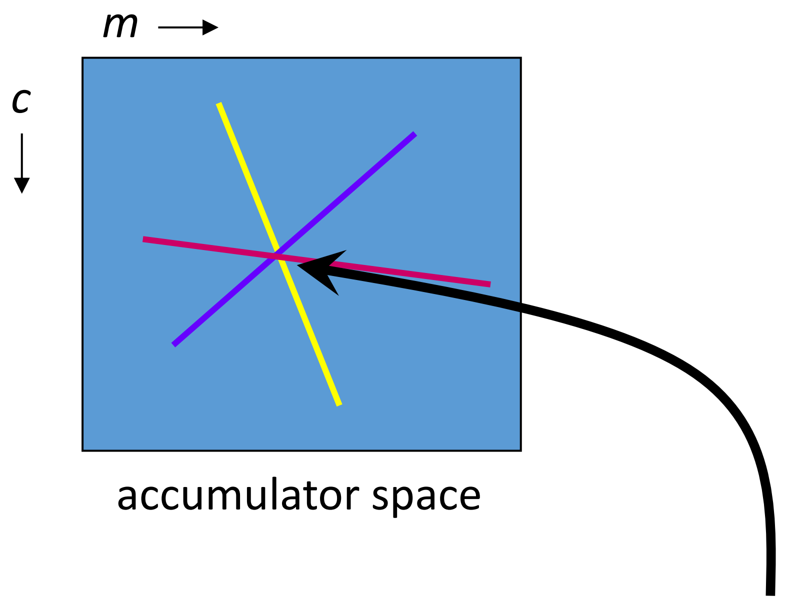
Cost is 2×FFT plus multiplication

Hough Transform

- Performance same as template matching, but faster
- A line is points *x*, *y* gradient *m* intercept *c* $y = m \times x + c$
- and is points *m*, *c* gradient -*x* intercept *y* $c = -x \times m + y$



image



accumulator space

The coordinates of the peak are the parameters of the line

In maths it's the principle of duality

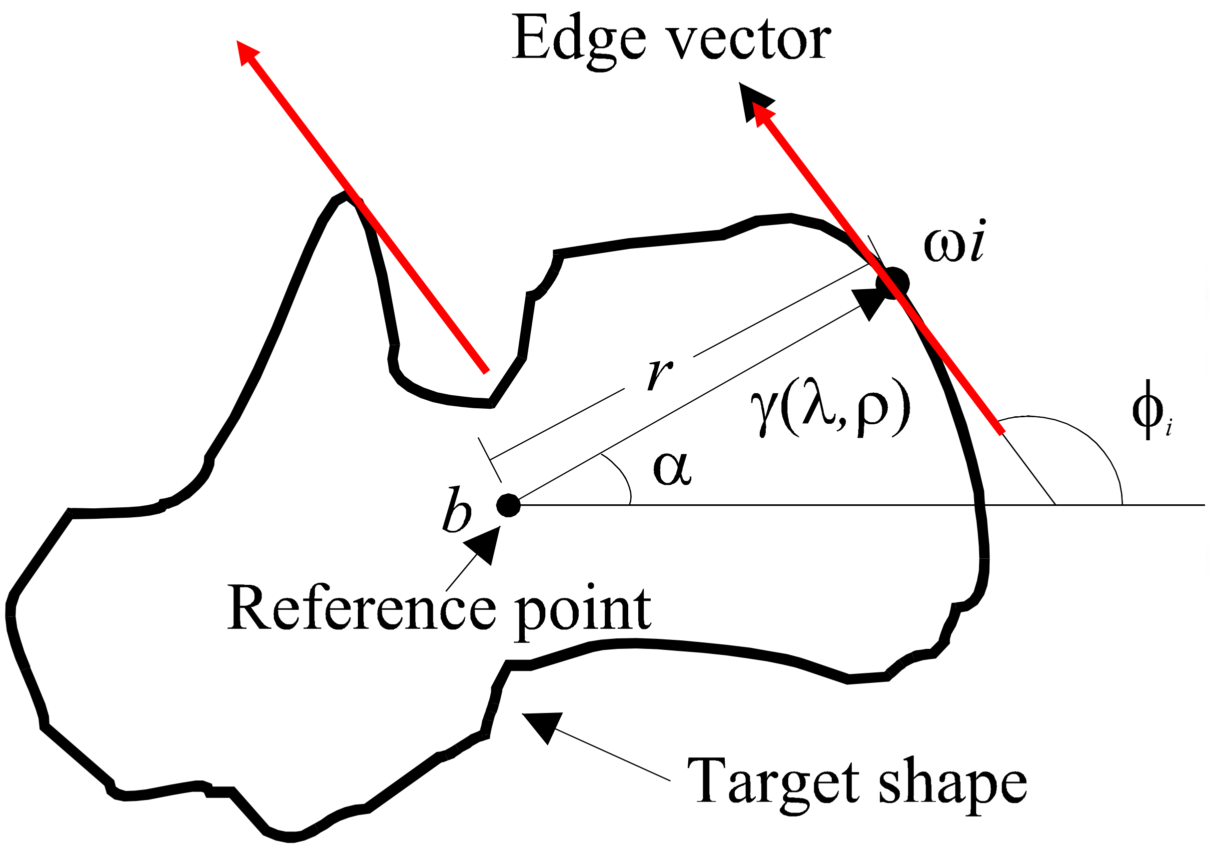
Pseudocode for HT

```
accum=0
for all x,y                              !look at all points
    if edge(y,x)>threshold               !check significance
        for m = -10 to +10               !if so, go thru m
            c = -x*m+y                   !calculate c
            accum(m,c) PLUS 1            !vote in accumulator
m,c = argmax(accum)                      !peak gives parameters
```

R-table Construction

$$x_c = x_i - r\cos(\alpha)$$

$$y_c = y_i - r\sin(\alpha)$$



$\hat{\varphi}'_i$	$\gamma = (r,\alpha)$
0	$(r_0,\alpha_0),(r_1,\alpha_1),(r_2,\alpha_2)$
$\Delta\phi$	⋮
$2\Delta\phi$	⋮
...	...

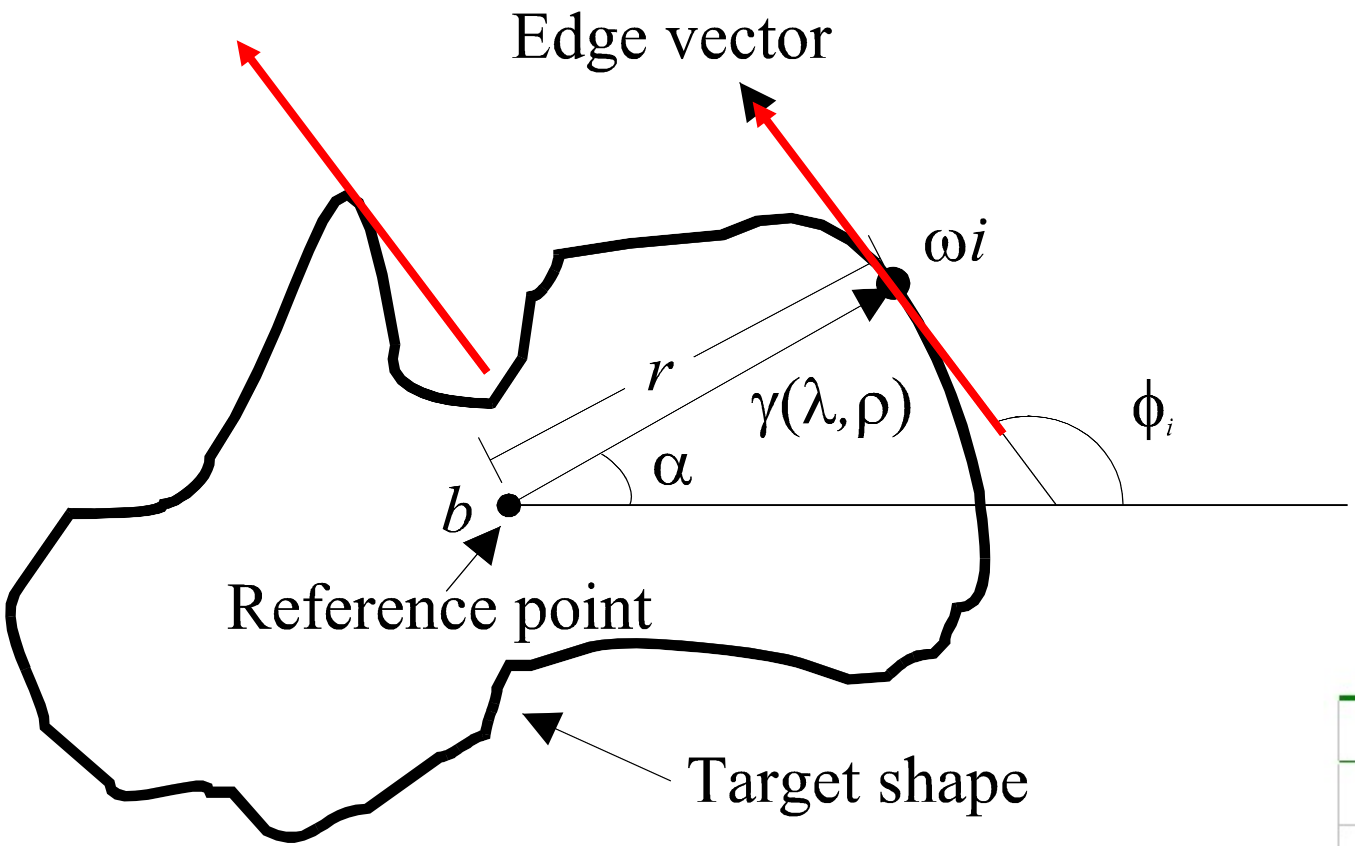
Edge direction is not a unique description

Gives noise in accumulator

R-table Construction

$$x_c = x_i - rS\cos(\alpha + \theta)$$
$$y_c = y_i - rS\sin(\alpha + \theta)$$

Scale Orientation



Important: for the case of rotation, before checking with the R-table, the edge direction of the edge point needs to minus the rotation θ

$\hat{\varphi}'_i$	$\gamma = (r, \alpha)$
0	$(r_0, \alpha_0), (r_1, \alpha_1), (r_2, \alpha_2)$
$\Delta\phi$	⋮
$2\Delta\phi$	⋮
...	...

Question 1.

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First Image of a Black Hole (`https://www.eso.org/public/images/`)

(a) The above image is the first image of a black hole. As we can see, it looks quite blurry. **Provide** an explanation as to why it is so blurred.

[5 marks]

(b) **Design** an edge detection system to detect the edge of the black hole, and **explain** how you address the blurred edges within the image.

[12 marks]

(c) **Design** a shape detection system to detect as many shapes in the image as you can when you have *no template to use*. **Explain** how to *improve* your shape detection system if you are allowed to use templates.

[16 marks]

Thanks and Good luck!