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COMP-2032

Introduction to Image Processing

Lecture 7

Whole Image Methods

Learning Outcomes

IDENTIFY

1. Why Histogram?
2. Histogram Equalisation - Theory
3. Histogram Equalisation - Practical
4. Image Matching with Colour Histogram
5. Histogram Intersection
6. Using Histogram - Object Location

Why Histograms?

Histograms

The histogram of a digital image with grey levels in the range [0, L-1] is a discrete function

$$P(r_k) = n_k$$

Where:

- $K = 0, 1, \ldots, L-1$
- r_k is the k^{th} grey level,
- n_k is the number of pixels in the image with that grey level

Histograms provide useful global information about the image, ease computation of some image properties, and can be manipulated to improve the image

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Normalised Histograms

A normalised histogram is a discrete function

$$P(r_k) = n_k / n$$

Where:

- N = width x height is the total number of pixels in the image

- The bins in a normalised histogram sum to 1.0
- Each bin gives the probability of the corresponding grey level appearing in the image
- The probabilistic interpretation is valuable in e.g., *contrast enhancement* and *automatic thresholding*

REMEMBER

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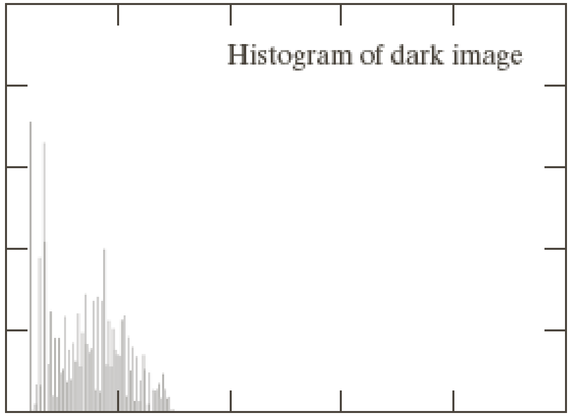
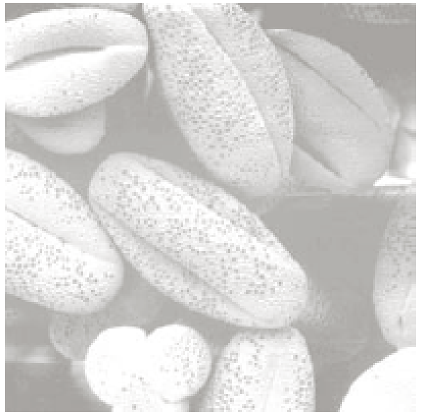
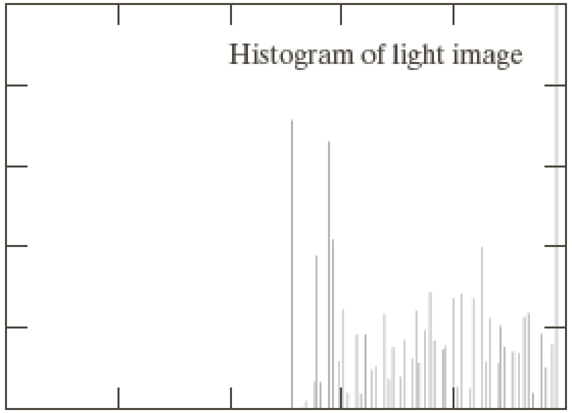
Histogram

Dark



Light





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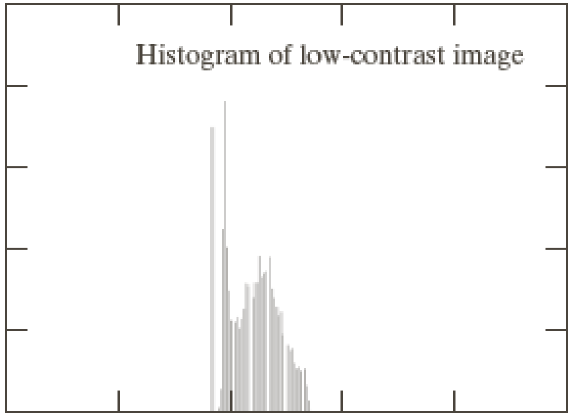
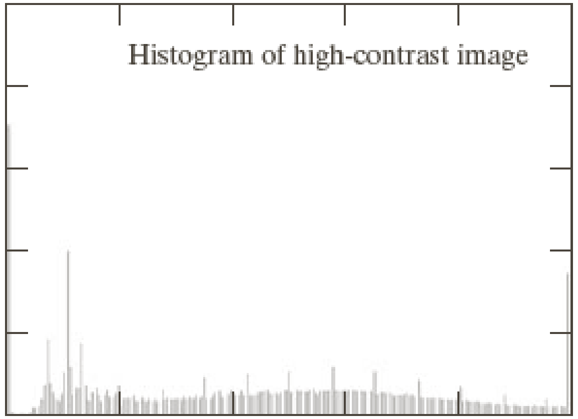
Histogram

Low Contrast



High Contrast



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Histogram Equalisation (Theory)

Histogram Equalisation

To improve the contrast of an image

- To transform an image in such a way that the transformed image has a nearly uniform distribution of pixel values
- More general than linear or piecewise contrast stretching

- No parameters to specify, "apply a transform that makes the output histogram **FLAT**"

Histogram Transform

- Map an input histogram r onto a new histogram s
- Assume r has been normalised to the interval [0,1], with $r = 0$ representing black and $r = 1$ representing white

$$s = T(r) \qquad 0 \le r \le 1$$

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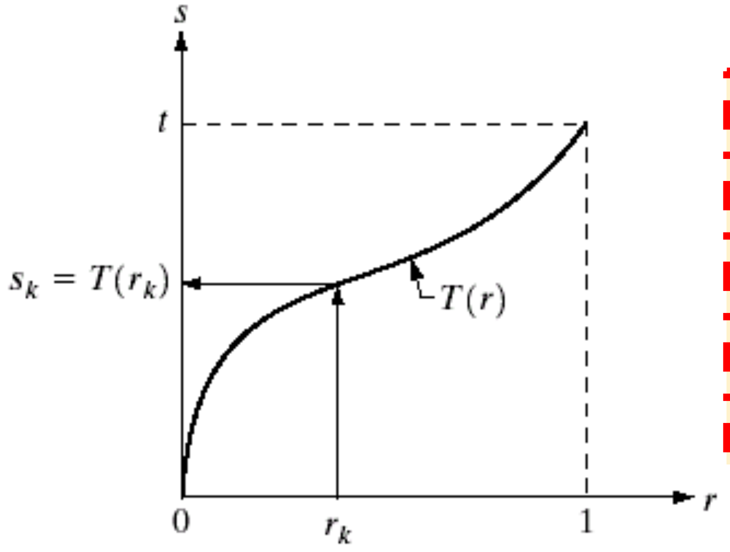
A Histogram Transform?

We need a transformation function that satisfies the following conditions

- $0 \le T(r) \le 1$ for $0 \le r \le 1$
- $T(r)$ is single-valued and strictly monotonically increasing

- This means it is possible to invert the process
- It also gives us the relationship that allow the derivation of histogram equalisation



As intensity transforms, but now applied to all the pixels in each bin of a histogram

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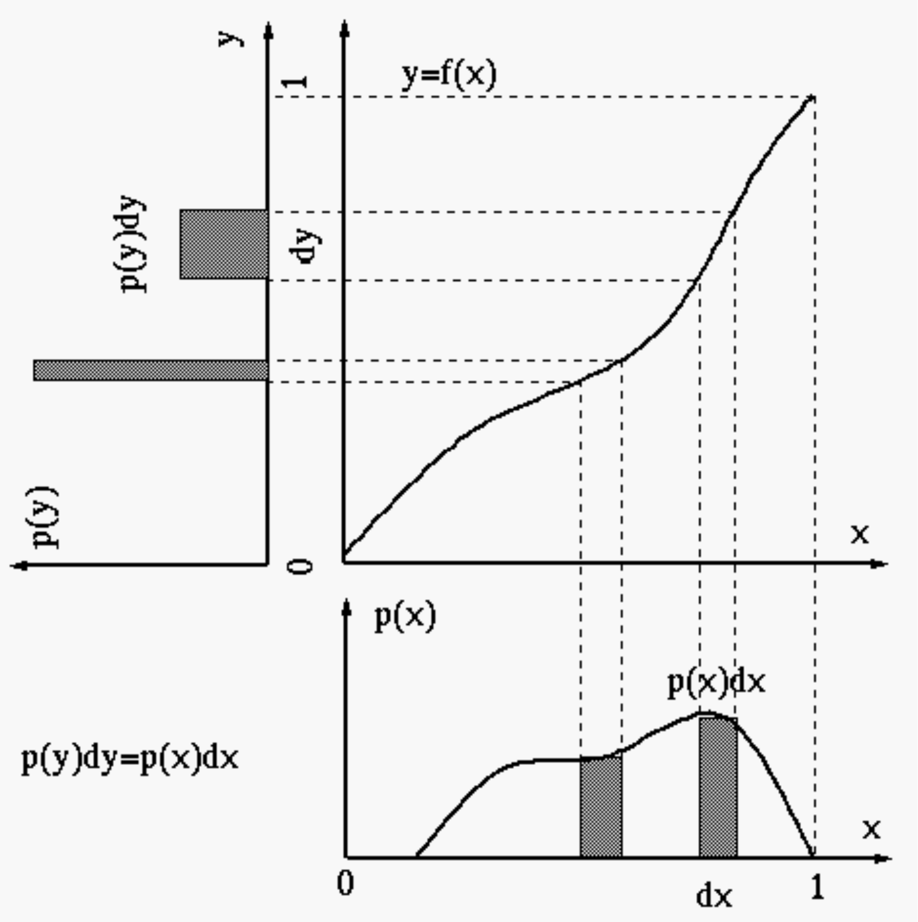
Histogram Equalisation



$$p(y).dy = p(x).dx$$

$$\text{So } p(y) = \frac{p(x).dy}{dy}$$

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Histogram Equalisation

- In Gonzalez and Woods' notation….
- Let $p_r(r)$ and $p_s(s)$ denote the probability density function of random variables r and s, respectively
- If $p_r(r)$ and $T(r)$ are known, then the probability density function $p_s(s)$ of the transformed variable s can be obtained

$$s = T(r) \qquad 0 \le r \le 1$$

and

$$p_s(s) = p_r(r)\left|\frac{dr}{ds}\right|$$

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Histogram Equalisation

If we choose as the transformation function the cumulative distribution function or CDF

$$T(r) = \int_0^r p_r(w)dw$$

$$\frac{ds}{dr} = \frac{dT(r)}{dr} = \frac{d}{dr}\left[\int_0^r p_r(w)dw\right] = p_r(r)$$

$$p_s(s) = p_r(r)\left|\frac{dr}{ds}\right| = p_r(r)\left|\frac{1}{p_r(r)}\right| = 1 \quad 0 \le s \le 1$$

T(r) depends on $p_r(r)$, but the resulting $p_s(s)$ is always uniform

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Histogram Equalisation

- We have a discrete histogram, not a PDF of a continuous random variable
- The probability of occurrence of gray level r_k in an image is

$$p_r(r_k) = \frac{n_k}{n} \quad k = 0,1,2,\ldots,L-1$$

The transformation function is

$$s_k = T(r_k) = \sum_{j=0}^{k} p_r(r_j) = \sum_{j=0}^{k} \frac{n_j}{n} \quad k = 0,1,2,\ldots,L-1$$

An output image is obtained by mapping each pixel with level r_k in the input image into a corresponding pixel with level s_k

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Histogram Equalisation (Practice)

The Algorithm

To perform histogram equalisation

1. Compute the CDF of the input image
2. For each pixel in the input image, the corresponding output pixel intensity is calculated by using the CDF as a look-up table
3. CDF values will be in the range of 0 – 1, scale the equalised image to fit the range supported by the output image format

The histogram of the output image will be **approximately** uniform

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An Example

Consider a 64 x 64 pixel, 3 bit (8 grey level) image

(Example from Gonzalez & Woods)

r_k	n_k	$P_r(r_k)$	$T(r_k)$	s_k	Round
0	790	0.19	0.19	1.33	1
1	1023	0.25	0.44	3.08	3
2	850	0.21	0.65	4.55	5
3	656	0.16	0.81	5.67	6
4	329	0.08	0.89	6.23	6
5	245	0.06	0.95	6.65	7
6	122	0.03	0.98	6.86	7
7	81	0.02	1.00	7.00	7

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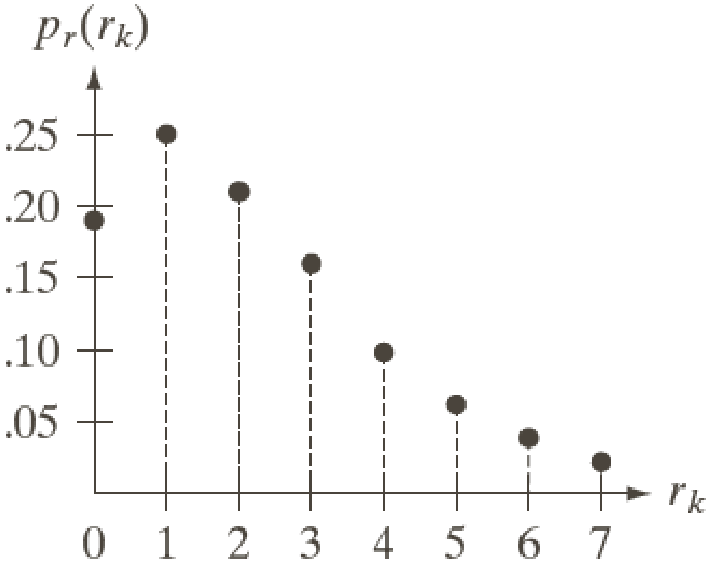
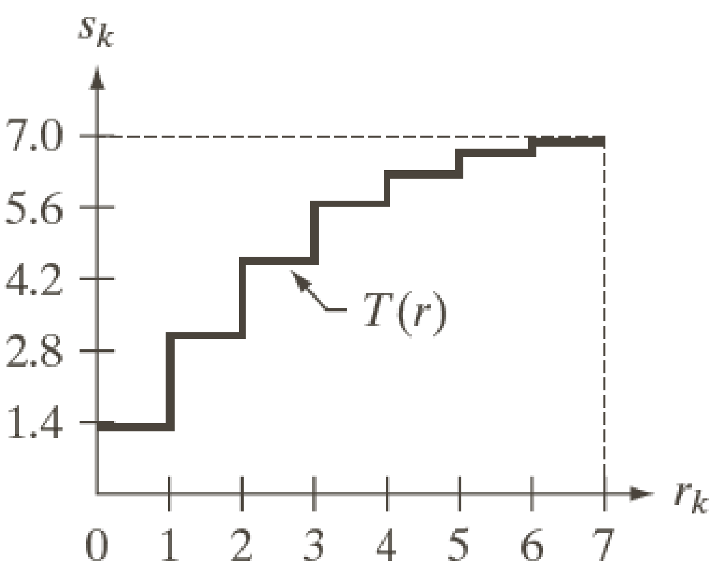
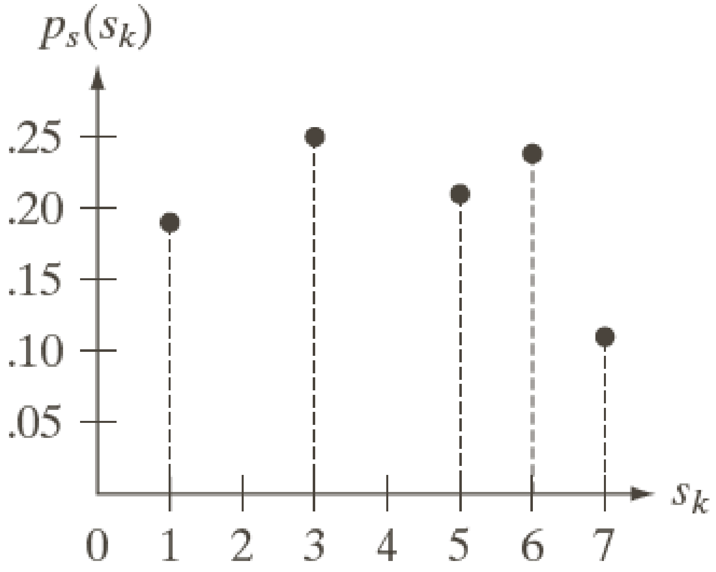
An Example



Input histogram



$T(r_k)$ scaled back to 0 - 7



Equalised histogram

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Real Images

Dark

Light

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Results

Low Contrast

High Contrast

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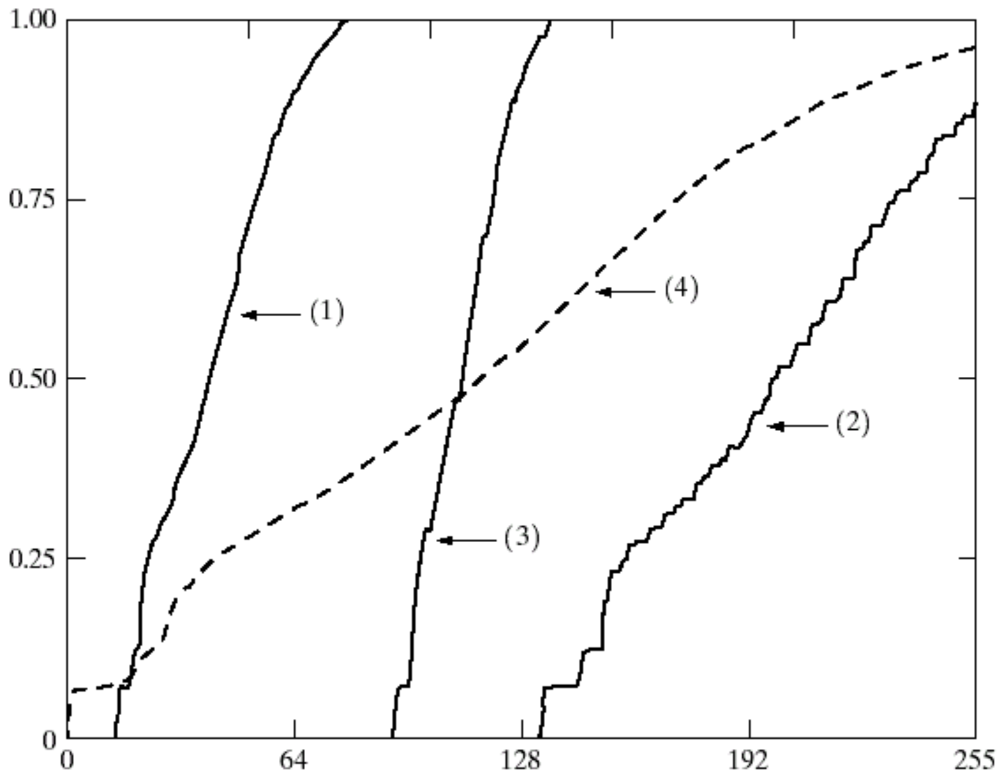
Results

Each of the four transformations below used a different transform, tuned to the input histogram



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Strengths & Weaknesses

Histogram equalisation works well when the input images

- Don’t have large bright or dark areas
- Aren’t too noisy

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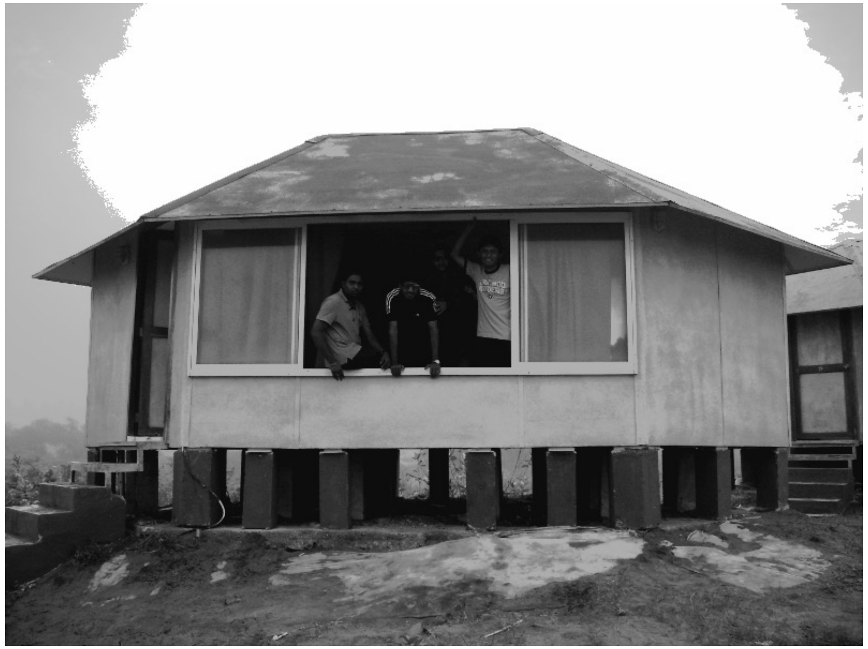
Strengths & Weaknesses

Here the bright sky has dominated the process, equalisation has introduced an artificial boundary between sunlight and sky but not enhanced the three people



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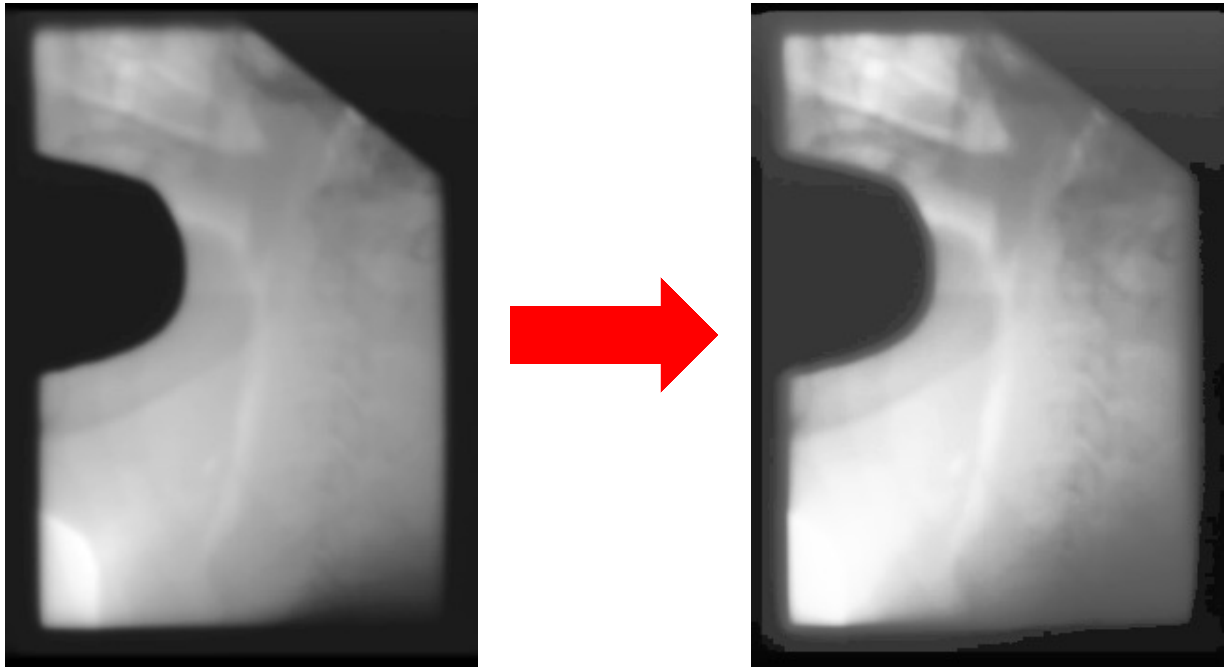
Strengths & Weaknesses

Here the bright area of interest is enhanced, but the noise in the upper dark region is also more obvious



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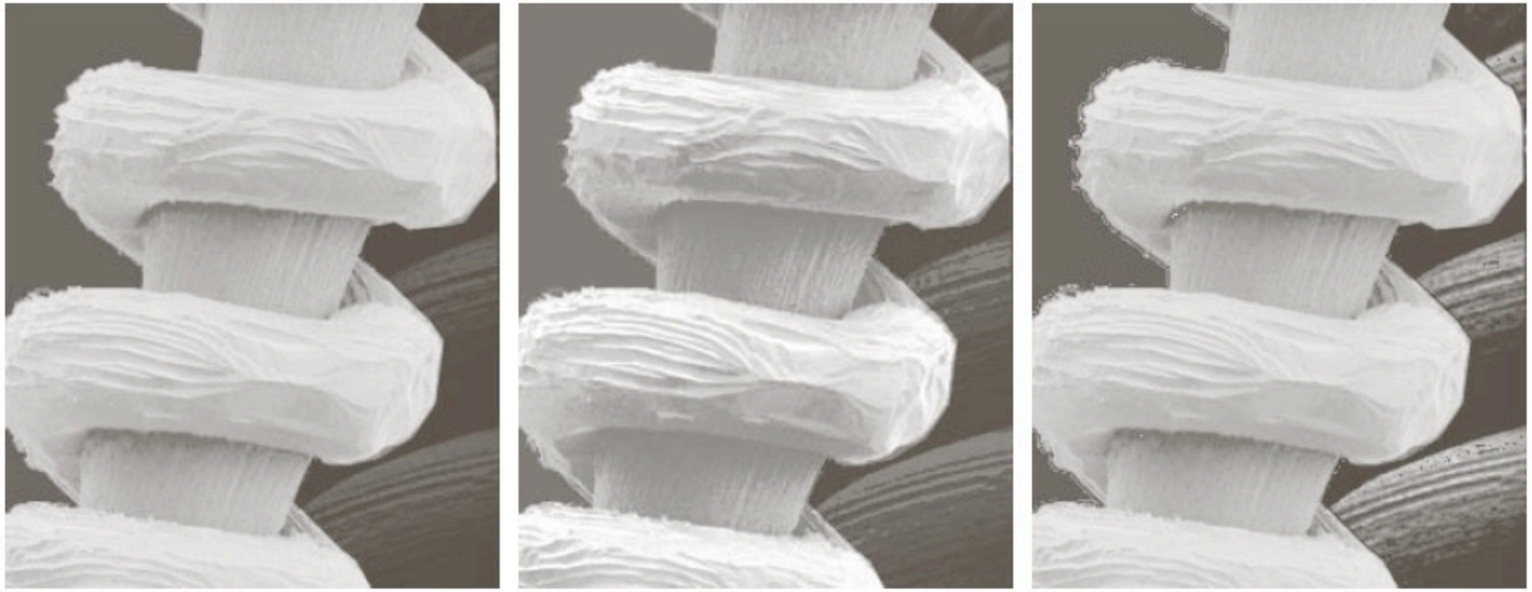
Local Enhancement

If some areas are much darker or lighter than the rest of the image, they may not be enhanced enough



SEM image of a tungsten filament

Global equalisation gives artefacts

Local equalisation

As in adaptive thresholding, local histograms may be better suited to equalisation

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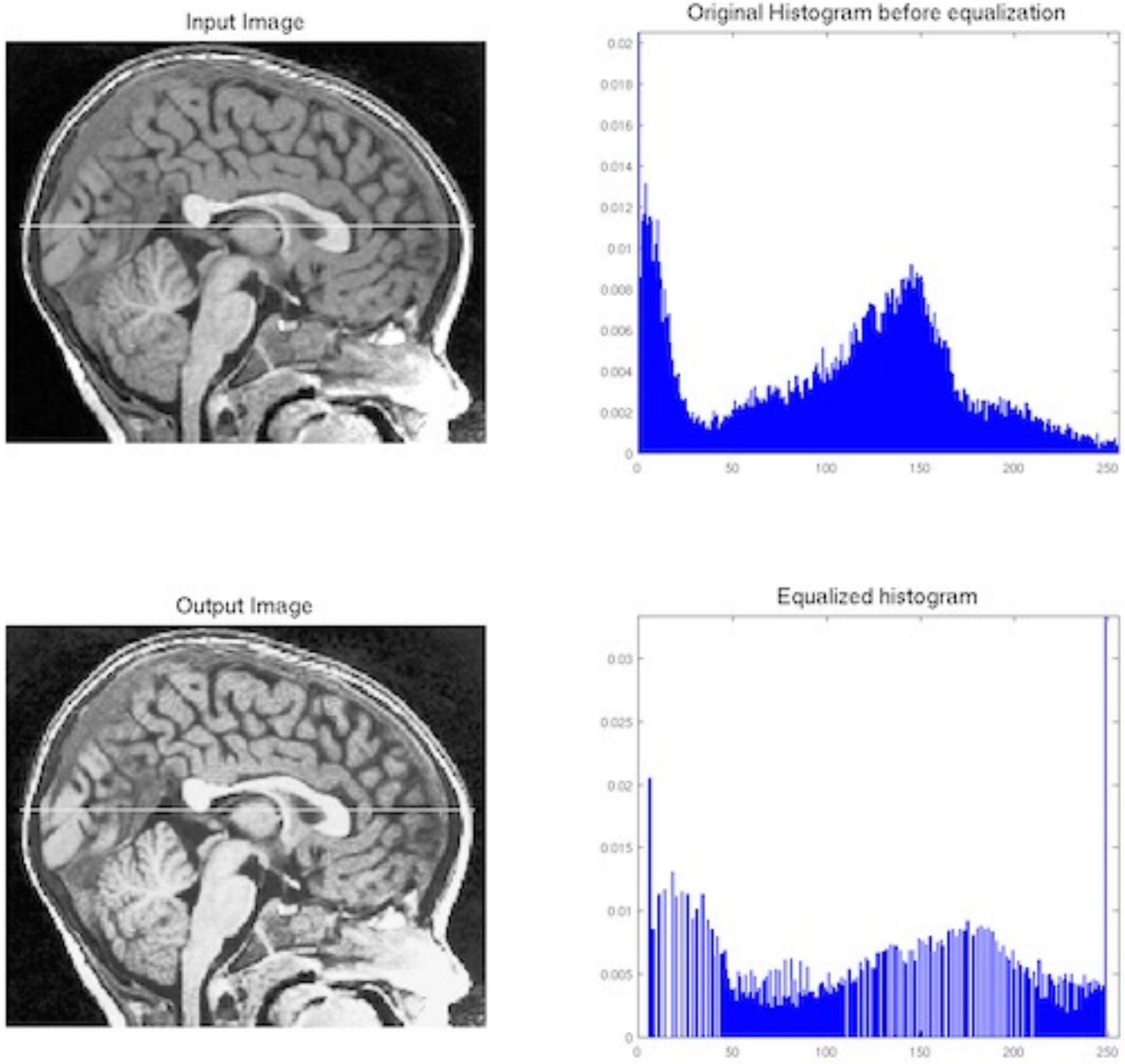
Medical Applications (MRI)



Histogram Specification is a related method which transforms an image's histogram so that it matches a target histogram

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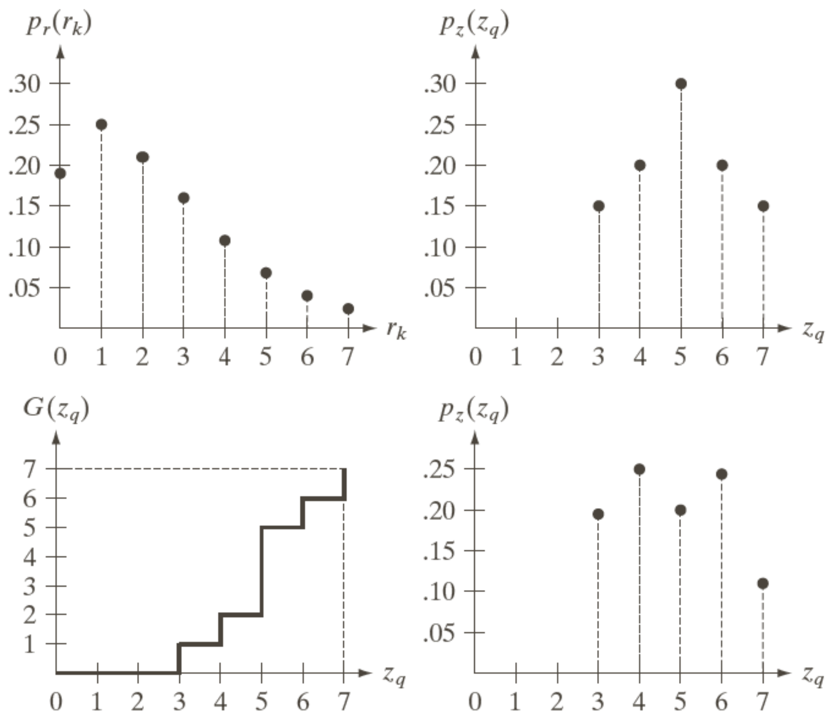
More Generally…

Input Histogram

Target Histogram

Transform

Result



Histogram Specification is a related method which transforms an image's histogram so that it matches a target histogram

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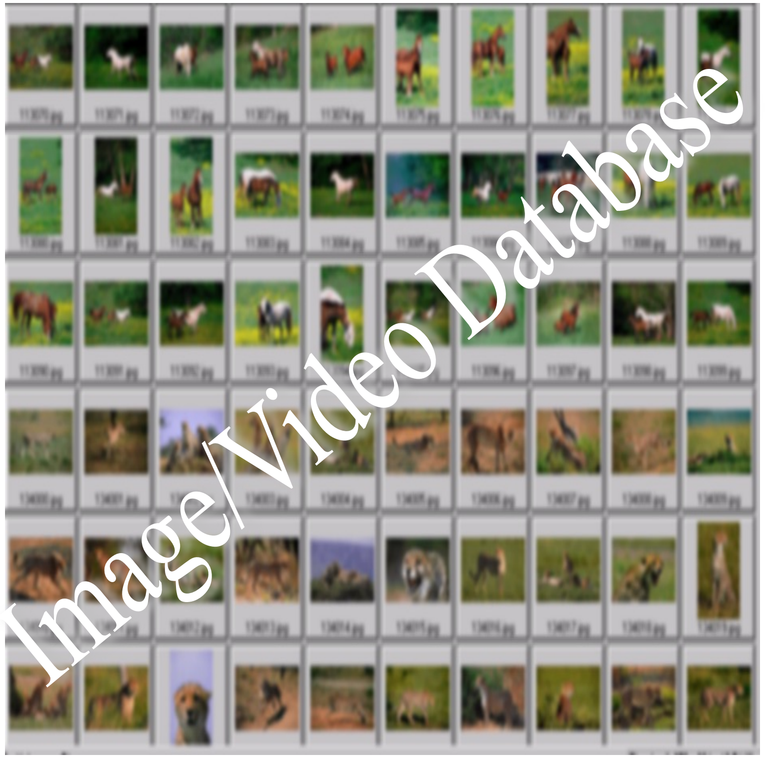
Break

Image Matching with Colour Histogram

Storing & Retrieving Images

Given a large image database, find all the images containing…, e.g., horses

We will focus on individual images, but many of the problems & methods discussed extend to video databases too



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Text-based Approaches

- Annotation: Relevant words/phrases are added to each image
- Retrieval is via text search
- But annotation is

  - Subjective
  - Laborious
  - Unnecessary????

Mother, Child, Vegetable, Yellow, Green, Purple, …

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Content-based Retrieval

Indexes the image database on visual features

- Colour
- Shape
- Texture

Queries are expressed in those terms or via visual examples

- Simple approaches compute metric distances between the query image and each image in the database
- Advanced approaches use AI techniques, machine learning, etc., and may be interactive
- Some simple measures and data structures can be very useful

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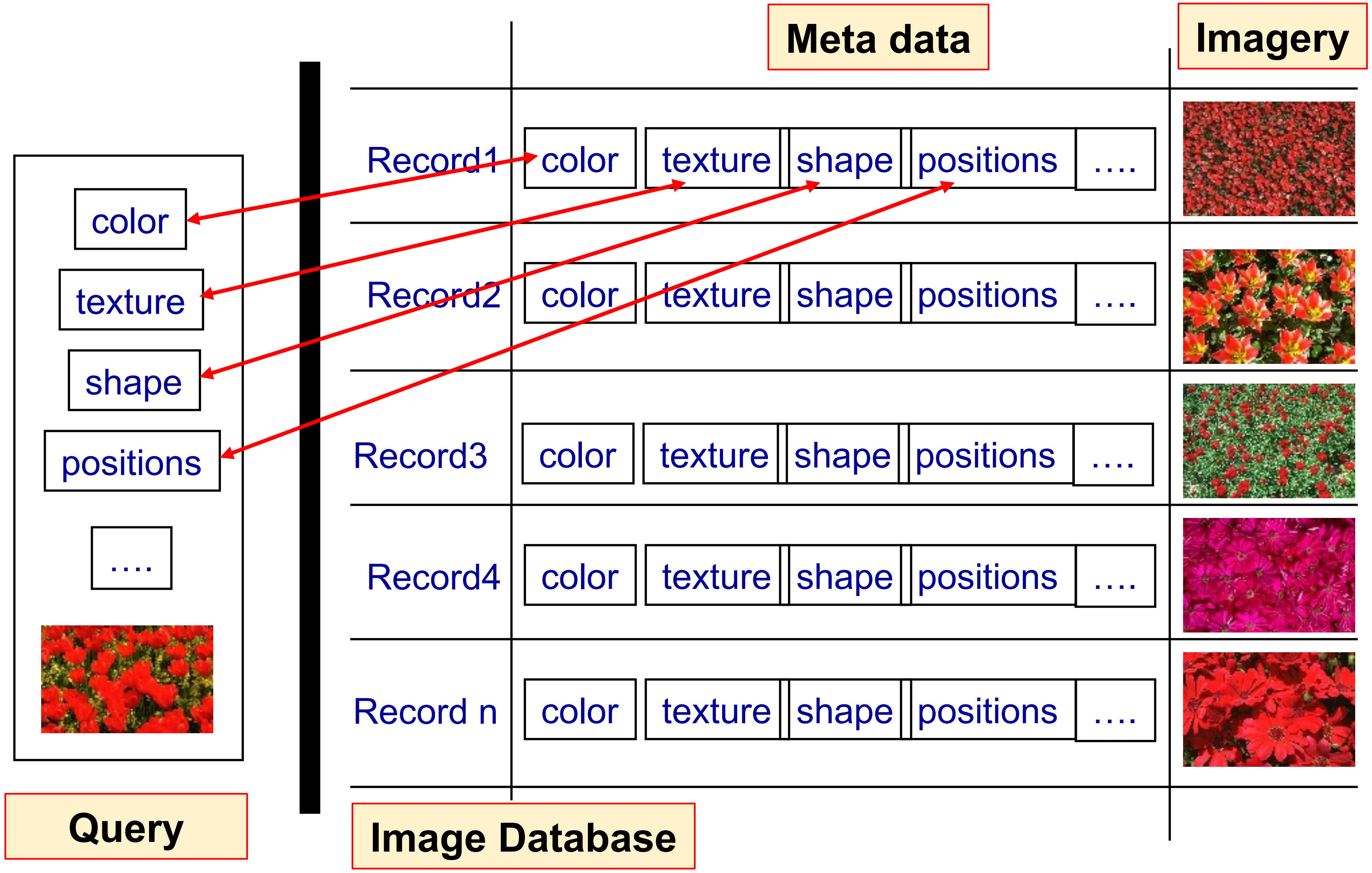
Content-based Retrieval



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Colour Histograms

Choose a colour space

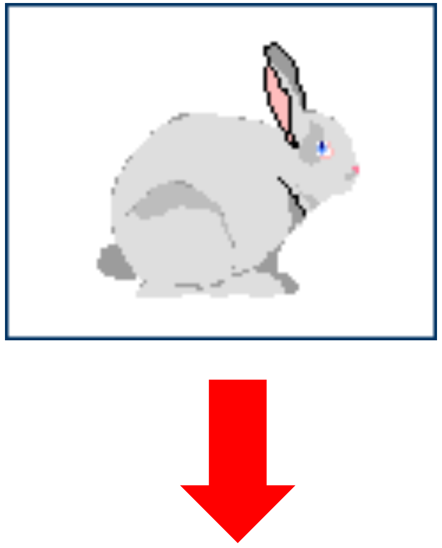
- RGB, HSV, …

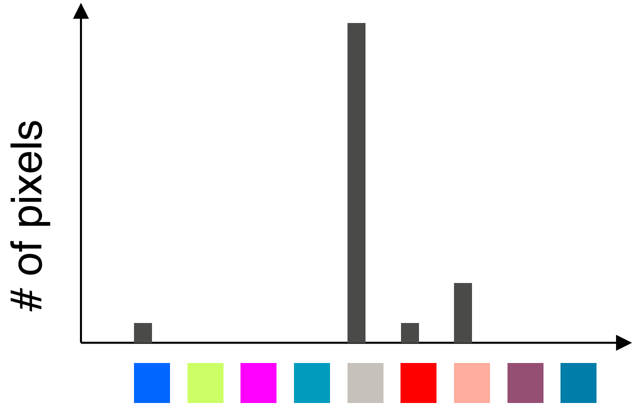
Divide the axes to create a reasonable number of division

- Trade-off detail against memory/computational cost

Build a histogram

Normalise if images are different sizes or colour resolution





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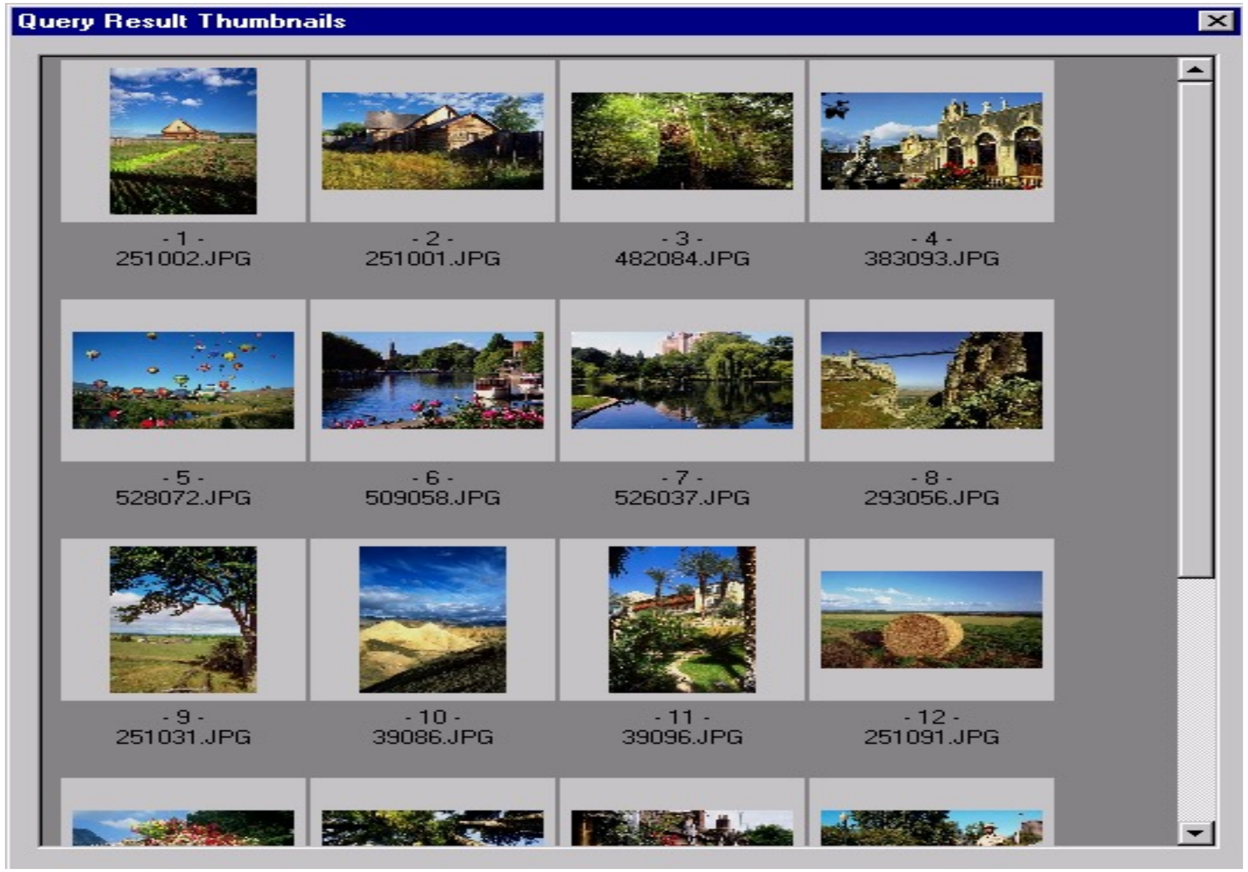
Why Colour Histograms?

Images with similar colour distributions look similar:

Colour distribution = Colour histogram



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Why Colour Histograms?

Colour correlates well with class identity

Human vision works hard to preserve colour constancy: presumably because colour is useful

Histograms

- Are invariant to translation and rotation
- Change slowly as viewing direction changes
- Change slowly with object size
- Change slowly with occlusion

Colour histograms summarise target objects quite well, and should match a good range of images

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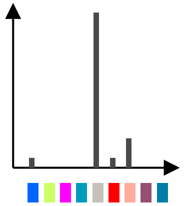
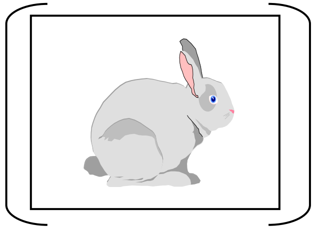
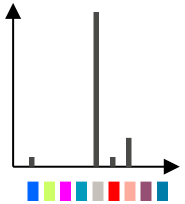
Colour Histograms



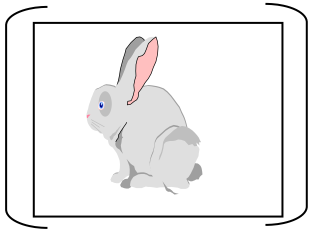
Colour Distribution



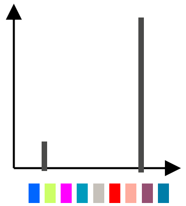
= (10,0,0,0,100,10,30,0,0)



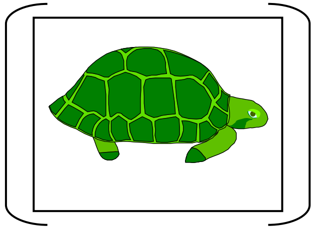
Colour Distribution



= (10,0,0,0,90,10,40,0,0)



Colour Distribution



= (0,40,0,0,0,0,0,0,110,0)

Points in a high dimensional space or compact representations of images?

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Common Distance Metrics

Euclidean or straight-line distance or L2-norm, D^2

$$D^2(H^1,H^2)=\sqrt{\underbrace{\sum_i\left(H_i^1-H_i^2\right)^2}_{\text{Root-mean square error}}}=\left\|H^1-H^2\right\|_2$$

Euclidean or straight-line distance or L2-norm, D^2

$$D^1(H^1,H^2)=\underbrace{\sum_i\left|H_i^1-H_i^2\right|}_{\text{sum of absolute differences}}=\left\|H^1-H^2\right\|_1$$

How far apart are two points?

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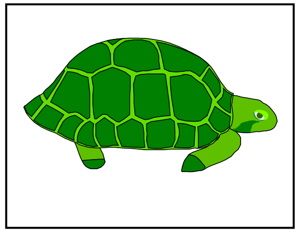
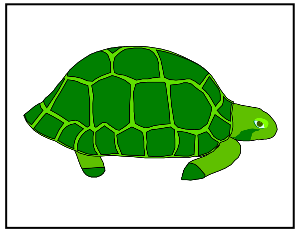
Some Problems

Colour quantisation

- Noise and/or different camera responses can give similar images very different histograms



(0,40,0,0,0,0,0,110,0)



(0,0,40,0,0,0,0,0,110)

Histogram Resolution

- May need many bins (4096) to accurately store colour distributions
- Expensive

The illumination may be coloured

- Same object may generate a different histogram under different lighting

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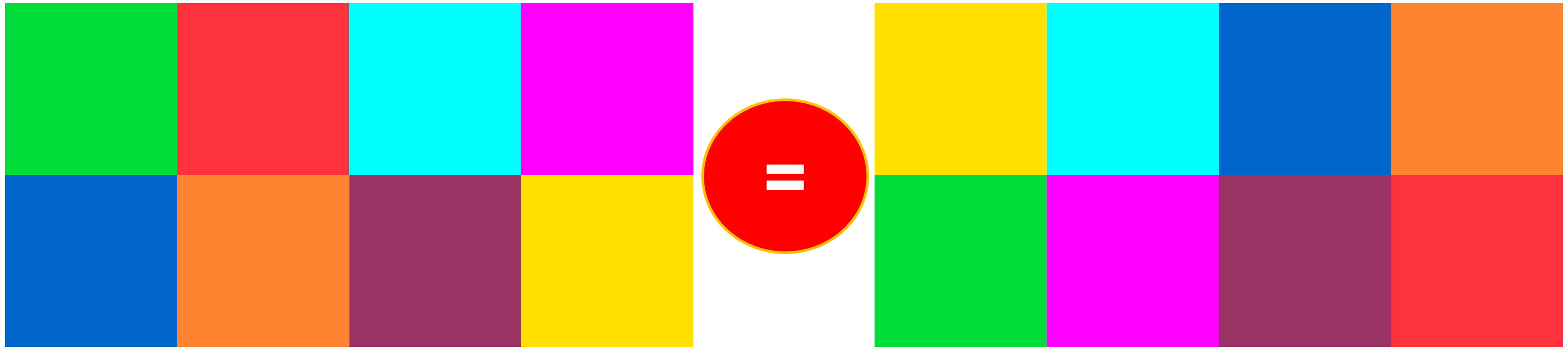
Some Problems

Colour histograms ignore spatial information

More advanced methods take special relationships into account



But the comparatively simple image processing methods and representations methods covered so far can do useful things

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Histogram Intersection

Histogram Intersection

- Measure how much of the query may be present in the target image (and vice-versa)
- A bin in the target histogram can have a larger value than the corresponding query bin (and vice-versa)

$$HI(H^1, H^2) = \sum_{i=1}^{n} \min(H_i^1, H_i^2)$$

$H^1 = (10, 0, 0, 0, 100, 10, 30, 0, 0)$

$H^2 = (0, 40, 0, 0, 0, 6, 0, 110, 0)$

$\mathbf{HI(H^1, H^2) = 0 + 0 + 0 + 0 + 0 + 6 + 0 + 0}$

$\mathbf{= 6}$

How much do two representation overlaps?

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Histogram Intersection

In the first histogram intersection paper (*Ballard and Swain, 1991*):

- A database of 66 colour histogram
- 32 query images

Recognition rate was almost 100%

?

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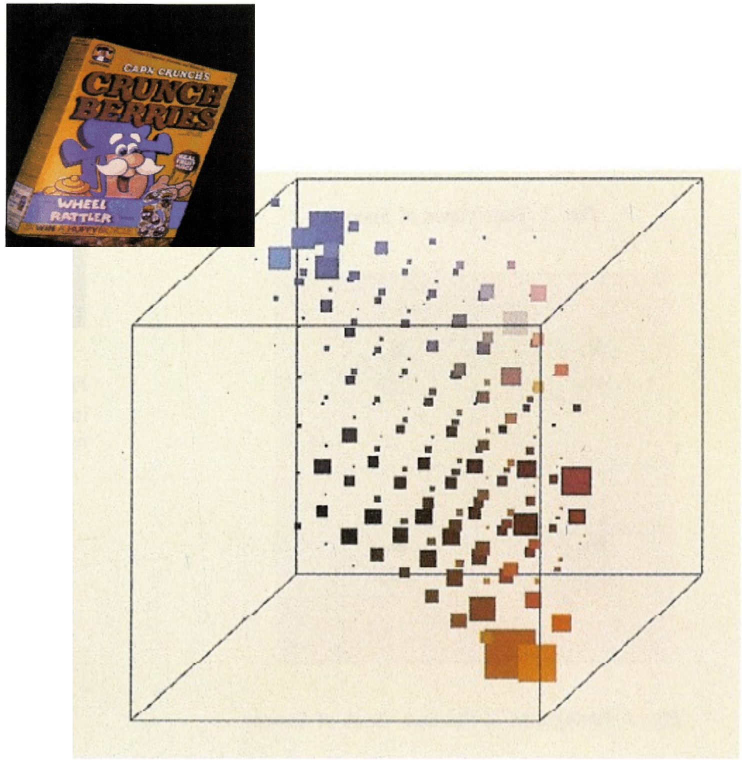
Histogram Intersection

Ballard and Swain used opponent colour axes

- RG = R – G
- BY = 2 * B – R – G
- WB = R + G + B (*intensity*

& matched images under a range of conditions

- Normal condition
- Varying in view
- Varying in image resolutions
- Occlusion (*of bottom 1/3 and/or side 1/3 of image*)
- Varying in bin resolutions
- Varying in light intensity



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Histogram Intersection

Condition	Placement			
	1st	2nd	3rd	>3rd
Full size	29	3	0	0
128 x 90	29	3	0	0
64 x 45	27	5	0	0
32 x 22	14	7	1	0
16 x 11	15	6	4	0
8 x 5	4	4	3	21
Bottom occluded	27	4	1	0
Bottom & side occluded	22	6	5	0

Good until images are very small

Not bad when object only partly visible

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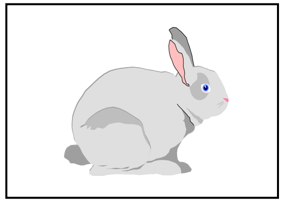
Using Histogram: Object Location

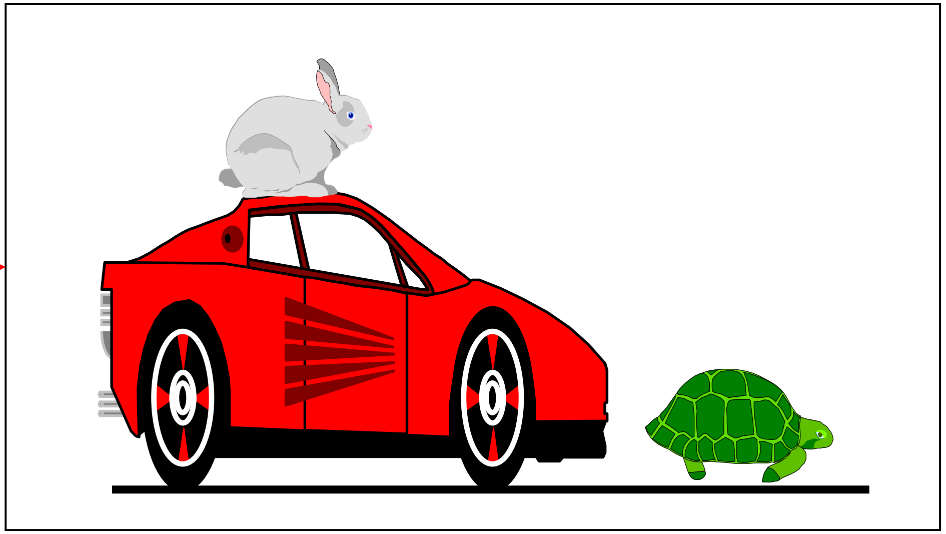
Object Location

Matching whole images isn't always appropriate…

E.g., if the target object is only expected to fill part of the image or you want to know where it is



Where is the 'rabbit'?



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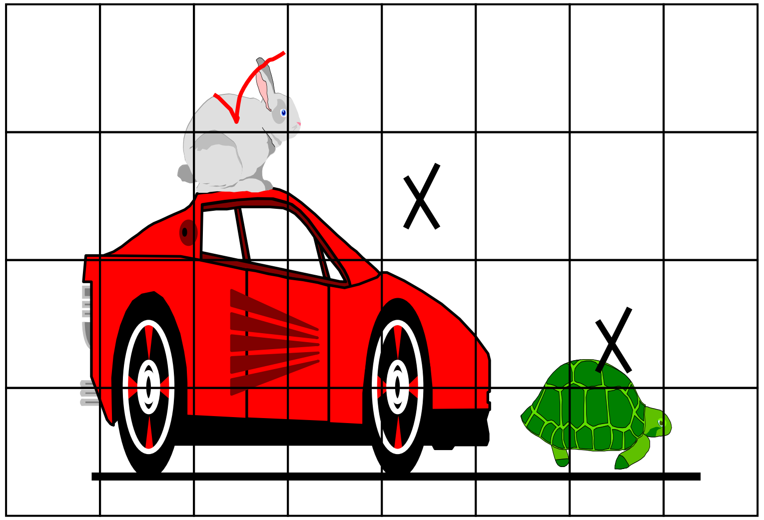
Region/Object-based Queries

- We know the rabbit is mostly grey
- Divide the image into windows and see how grey each window is
  - Highlight pixels in the image that are similar to those in the query
  - Look for regions with lots of these pixels



✓ Similar colours

X Dissimilar colours

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The Histogram Ratio

the image is usually much bigger than the query region

BUT

- Other objects in the image may be the same colour as parts of the query object
- So some colours are not reliable cues: if you're looking for a zebra at night, look for white pixels

$$R_j = \min(\frac{M_j}{I_j}, 1)$$

- *Compute the ratio of corresponding Model and Image histogram bins*
- *If the image has many more pixels of a given colour R_j is small and that colour is not useful*
- *If the model has more, R_j is 1 and that colour is useful*

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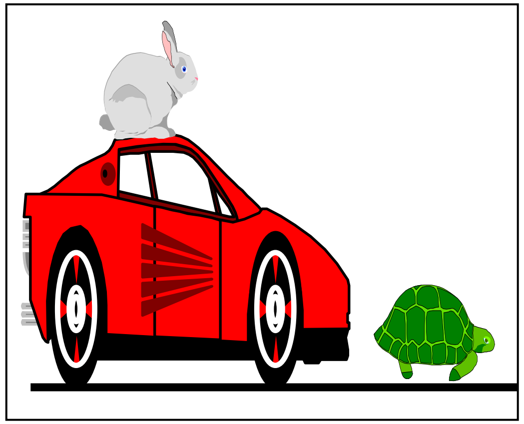
Backprojection

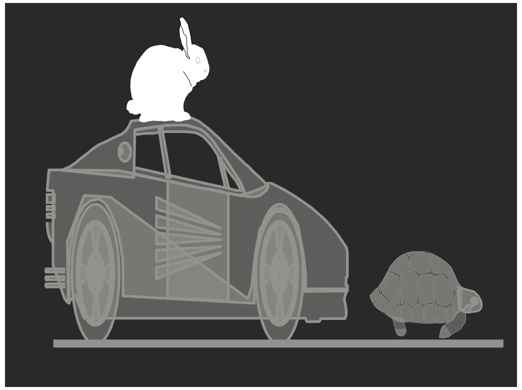
The greater the value of R_j, the more valuable the colour(s) represented by bin j

- Consider each image pixel
- If that pixel maps to histogram bin k, replace the pixel value with a grey value = R_k



This is still image processing: we've processed an image to create an image

- The pixel values are related to the likelihood of their showing the target



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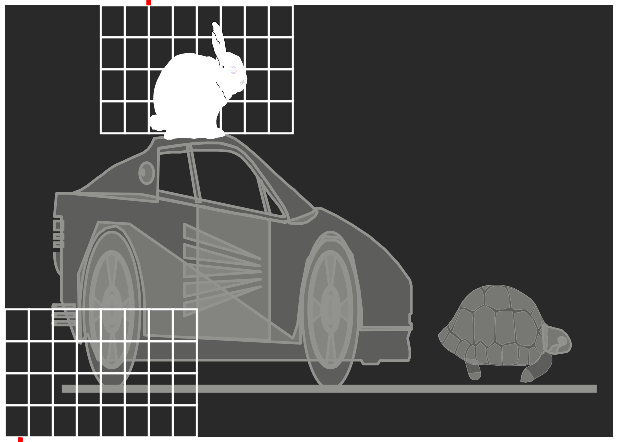
Backprojection

High average brightness



Low average brightness

Regions with high average brightness are likely to contain the rabbit – its more complex, but still a histogram matching approach (*see Ballard and Swain*)

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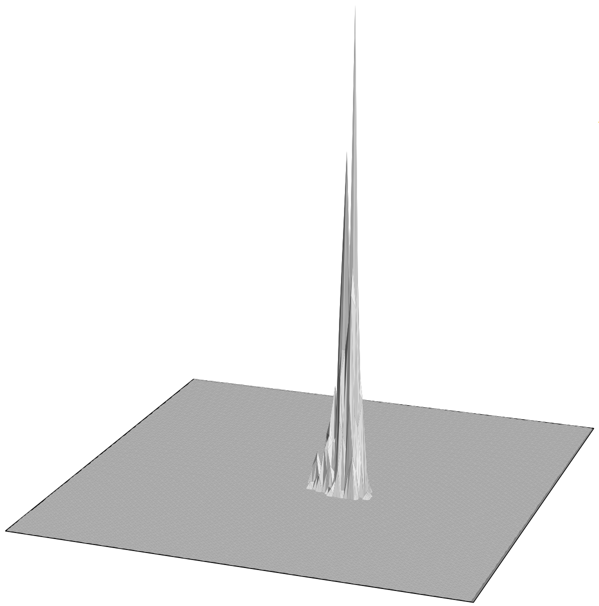
We’ve seen Backprojection before

REMEMBER

Skin shows a very clear peak and narrow range in U,V



ACK: Prof. Tony Pridmore, UNUK

Summary

1. Why Histogram?
2. Histogram Equalisation - Theory
3. Histogram Equalisation - Practical
4. Image Matching with Colour Histogram
5. Histogram Intersection
6. Using Histogram - Object Location

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Questions

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NEXT:

Segment and Superpixels