Colour Image Processing & Analysis

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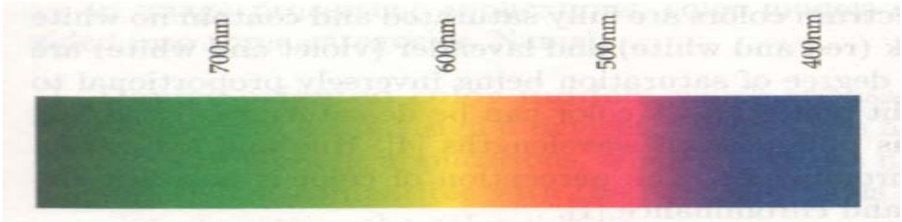
Introduction to Colour

- Colour is a sensation created in response to having our visual system excited by electromagnetic radiation known as light.
  - Colour is the perceptual result of light in the visible region of the electromagnetic spectrum, having wavelengths in the region of 400nm to 700nm incident upon the retina of the human eye.



Introduction to Colour

- The human eye has 3 types of colour photo-receptor cells called cones which respond to radiation with somewhat different spectral response curves.
- The human eye can detect only in the neighborhood of 30 grayscale intensity levels at any point in an image due to brightness adaptation, but it can differentiate thousands of colour shades and intensities.

Introduction to Colour

- Three components are necessary and sufficient to describe a colour.
  - A colour can be specified as a tri-component vector
  - The set of all colours form a vector space called colour space, or colour model.
  - The three components of a colour can be defined in many different ways leading to various colour spaces.

Introduction to Colour

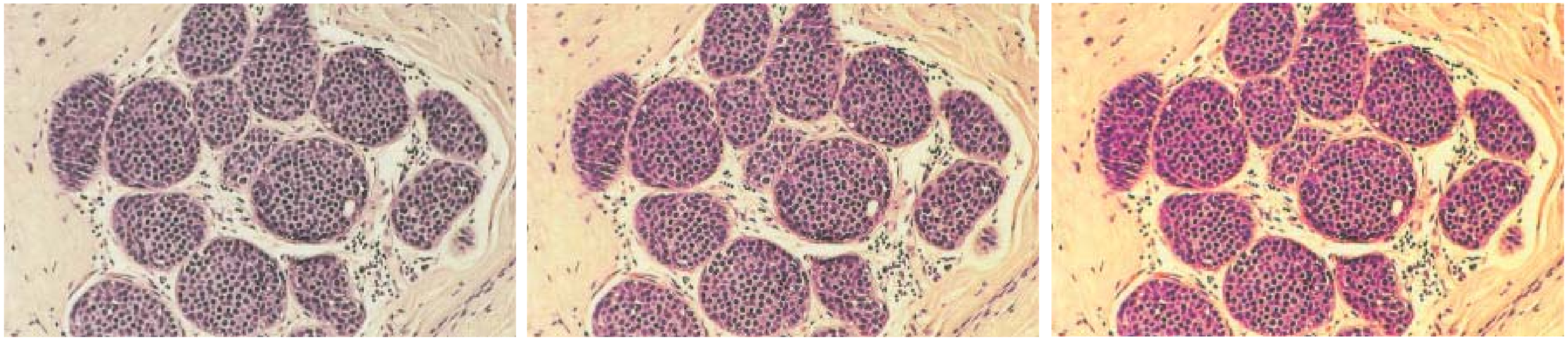
- Humans interpret a colour based on its lightness, hue and saturation.
- Colour can be described using a combination of three perceptual attributes:
  - Hue
  - Saturation (or chroma)
  - Intensity (or value, lightness)

Hue

- Hue is a colour attribute associated with the dominant wavelength in a mixture of wavelengths.
  - Spectral wavelength composition
  - e.g. “red”, “blue”

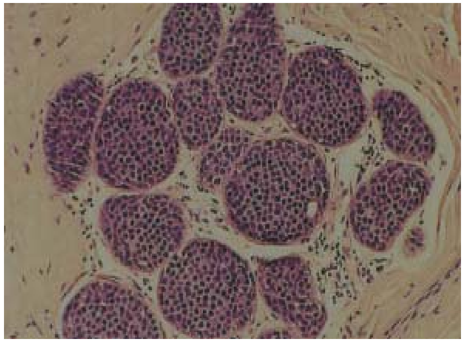
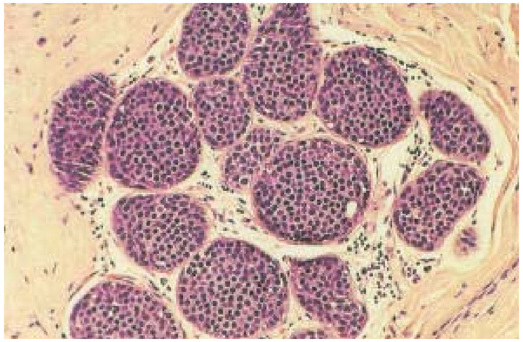
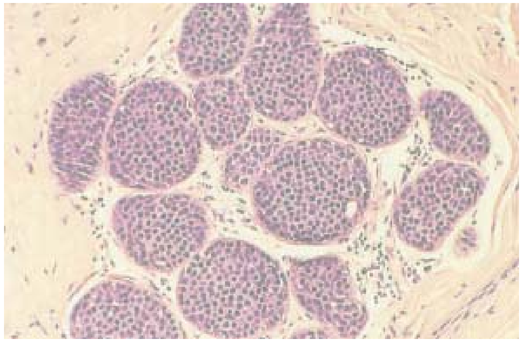
Saturation

- Saturation refers to the relative purity, or the amount of white light mixed with a hue.
  - Pure spectrum colours are fully saturated and contain no white light
  - Colours such as lavender (violet and white) are less saturated.
  - S=0, the colour appears completely gray.



Intensity

- Intensity refers to the relative lightness or darkness of a colour.
  - I=0, no light appears at all (black)
  - I→255, the colour is first dark, then bright
  - I=255, pure light (white)

Introduction to Colour

- Chromaticity = Hue + Saturation
- Types of colour models
  - Psychophysical colour models
    - Based on the human perception of colour

      e.g. HIS, HLS
  - Physiologically inspired colour models
    - Based on the three primaries, the three types of cones in the human retina

      e.g. RBG

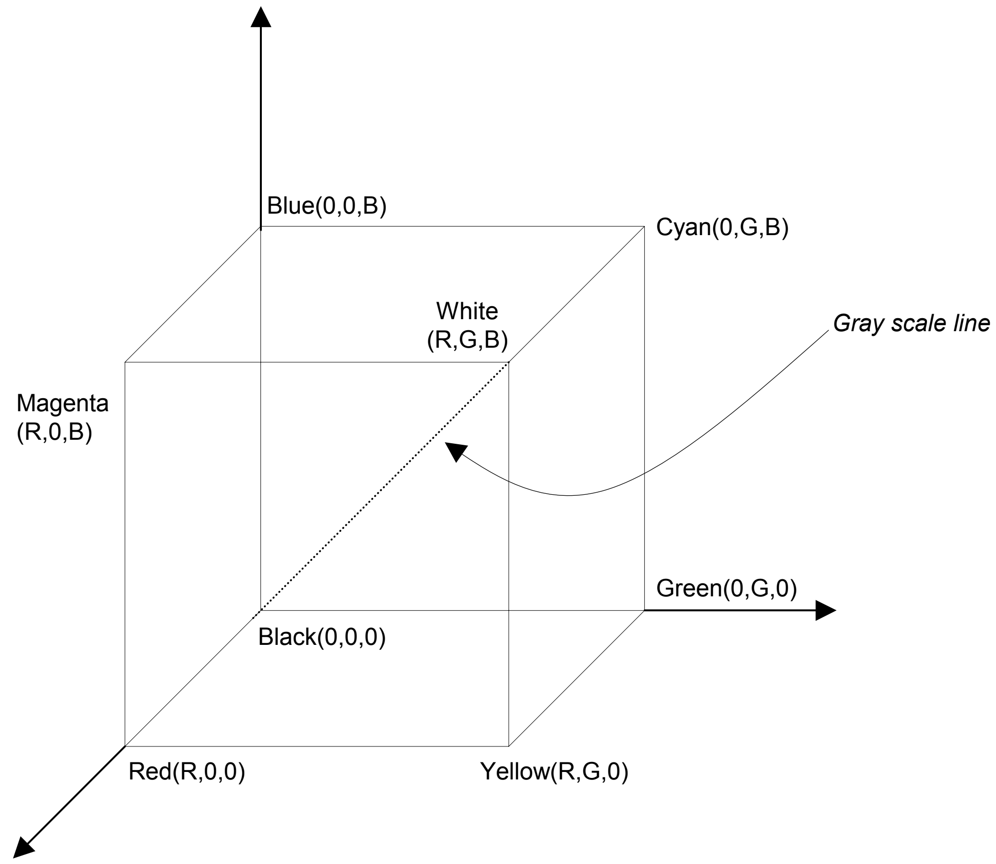
RGB Model

- The RGB model: red (R), green, (G) and blue (B) are described as the primary colours
  - This model is additive because colours are created by adding components to black (0,0,0).
  - In a colour image conforming to the RGB model, the value of f(x,y) is a vector with three components corresponding to R, G, and B.
  - In a normalised model these components each vary between 0.0 and 1.0.

RGB Model

- R,G, and B can be regarded as orthogonal axes defining a three-dimensional colour space → cube
- The primary colours red, green and blue are at the corners (1,0,0), (0,1,0), and (0,0,1); the colours cyan, magenta, and yellow are at the opposite corners.
- Each of these three components is quantised using 8-bits, therefore an image made up of these components is commonly described as a 24-bit colour image → 16,777,216 colours

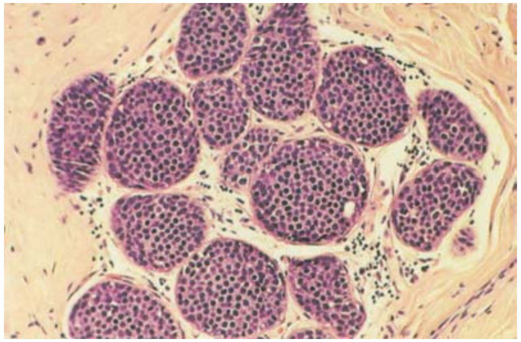
RGB Model


Blue(0,0,B)
Cyan(0,G,B)
White
(R,G,B)
Gray scale line
Magenta
(R,0,B)
Green(0,G,0)
Black(0,0,0)
Red(R,0,0)
Yellow(R,G,0)

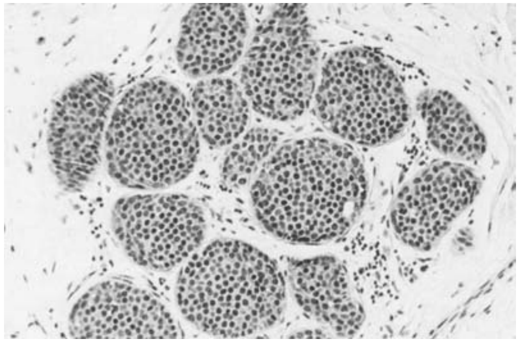
RGB Model

- The RGB model is not a perceptual model.
  - In perceptual terms, colour and intensity are distinct from one another, but the R, G, and B components each contain both colour and intensity information.

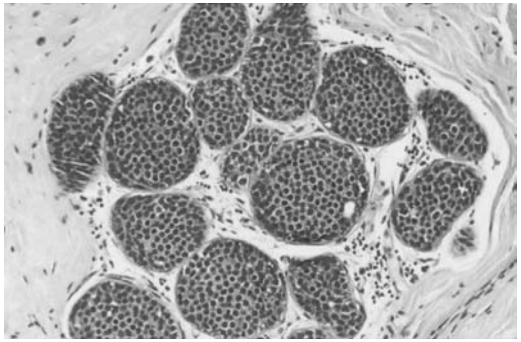
RGB Model



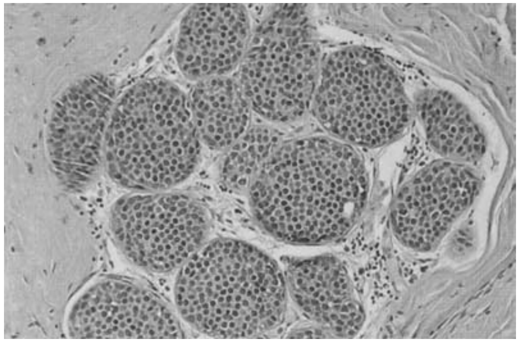
Red



Green



Blue



CMY Model

- The CMY model is based on the secondary colours: cyan (C), magenta (M) and yellow (Y).
  - This model is subtractive because colours are created by subtracting components from white.
  - Cyan absorbs red, magenta absorbs green and yellow absorbs blue.

CMY Model

– A CMY colour is derived from an RGB colour as follows:

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

– In theory almost any colour can be produced, however this process does not produce a satisfactory black, so a fourth component, representing black pigment (K) is added, resulting in the CMYK model.

HSI Model

- The HSI model has three components: hue (H), saturation (S) and intensity (I).
  - Hue specifies the dominant pure colour perceived.
  - Saturation meaures the degree to which that pure colour has been “diluted” by white light.
  - Sometimes known as HSV: hue, saturation and value

HSI Model

- The HSI model is described by a cylindrical coordinate system and is commonly represented as a “double cone”.
  - A colour is a singe point inside, or on the surface of the double cone.
  - The height of the point corresponds to intensity.
  - Define a vector on a horizontal plane from the axis of the cones to the point. Saturation is the length of this vector, and hue is its orientation, expressed as an angle in degrees.

HSI Model

- To convert from RGB to HIS, assume the primary colours have been normalised so that

$$0 \le R, G, B \le 1$$

$$H = \cos^{-1}\left\{ \frac{\frac{1}{2}\left[(R-G)+(R-B)\right]}{\left[(R-G)^2+(R-B)(G-B)\right]^{1/2}} \right\}$$

$$I = \frac{R+G+B}{3} \qquad S = 1 - \frac{3}{R+G+B}\min(R, G, B)$$

HSI Colour Models

- Models based on hue, saturation and intensity are considered better suited for human interaction.
  - The HSI family of colour models is used to specify colours using the artistic notion of tints, shades and tones.
  - All HSI models are derived from the RGB colour model by coordinate transformations.

HSI Colour Models

- The HSI family of colour models use approximately cylindrical coordinates.
  - The saturation is proportional to the radial distance
  - The hue is a function of the angle in the polar coordinate system
  - The intensity or lightness is the distance along the axis perpendicular to the polar coordinate plane.

HLS Model

- The double hexcone HLS (hue, lightness, saturation) model can be defined by modifying the contrast-lightness surface.
  - Lightness is defined as:

$$L = \frac{\max(R,G,B) + \min(R,G,B)}{2}$$

HSV Model

- The hexcone HSV (hue, saturation, value) model:

$$H_1 = \cos^{-1}\left\{\frac{\frac{1}{2}\left[(R-G)+(R-B)\right]}{\sqrt{(R-G)^2+(R-B)(G-B)}}\right\}$$

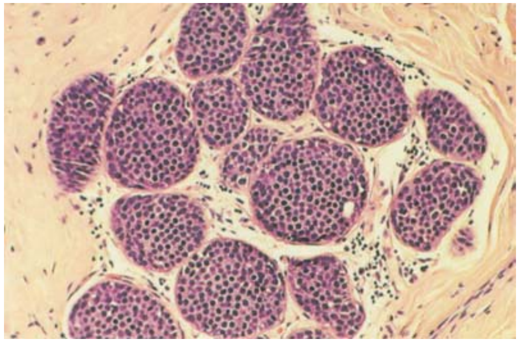
$$H = H_1 \qquad \text{if } B \le G$$

$$H = 360^\circ - H_1 \qquad \text{if } B > G$$

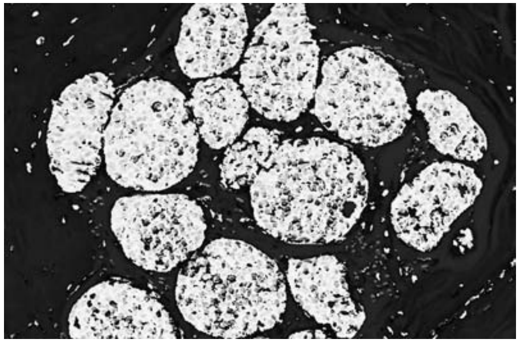
$$S = \frac{\max(R,G,B)-\min(R,G,B)}{\max(R,G,B)}$$

$$V = \frac{\max(R,G,B)}{255}$$

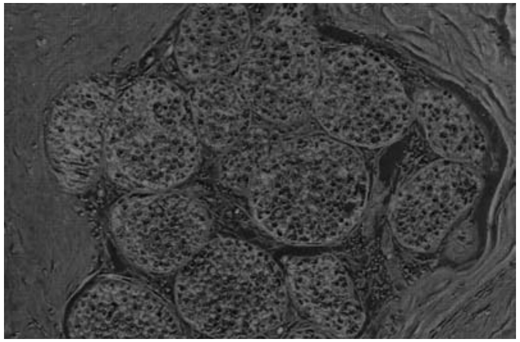
HSV Model



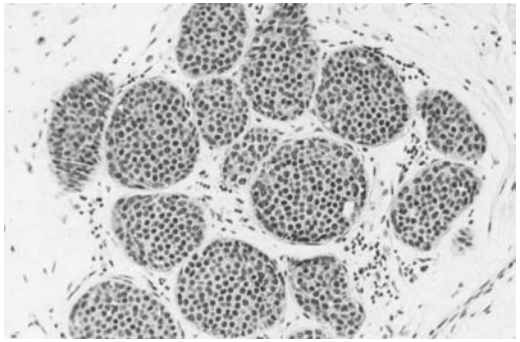
Hue



Saturation



Value



Colour Edge Detection

- In a grayscale image an edge usually corresponds to object boundaries or changes in physical properties such as illumination.
- Colour plays a significant role in the *perception* of boundaries.
- If the colour image is considered as 3D vector space, a colour edge can be defined as a *significant discontinuity* in the vector field representing the colour image function.

Colour Edge Detection

– An abrupt change represents a colour *step* edge
– A gradual change represents a colour *ramp* edge

Gradient Operators

- The first derivative of any point in an image is obtained using the magnitude of the gradient at that point.
  - Sobel, Prewitt, Roberts,

    e.g. Sobel provides both a differencing and a smoothing effect

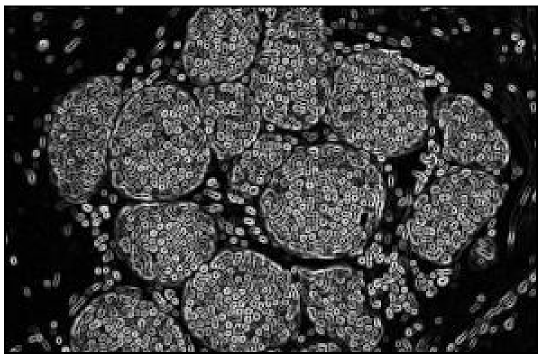
$$M_x = \begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{bmatrix} \qquad M_y = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$$

Gradient Operators

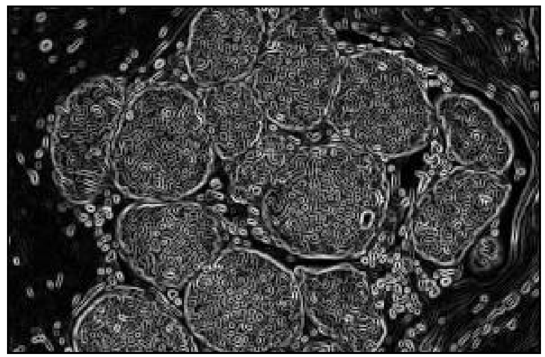
- The two kernels are applied to each colour channel independently and the sum of the squared convolution results are an approximation of the magnitude of the gradient in each channel.
- A pixel is regarded as an edge point if the mean of the gradient magnitude values in the three colour channels exceeds a given threshold.

Gradient Operators: Sobel

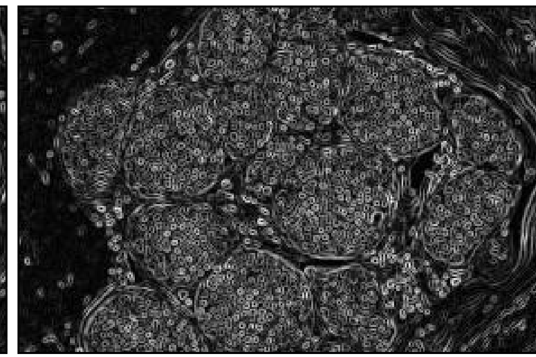
Red



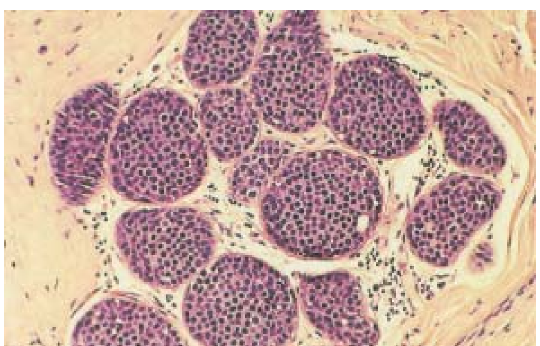
Green



Blue

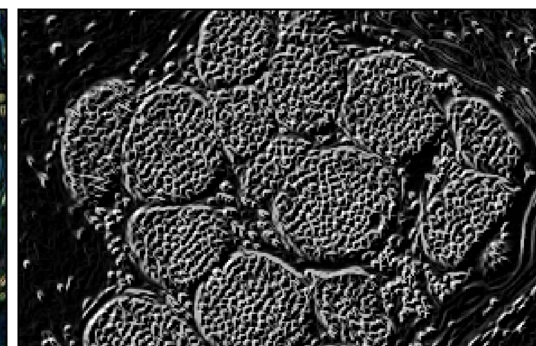


Original



Colour Sobel

Grayscale Sobel



Laplacian

- The second derivative at any point in an image is obtained by using the Laplacian operator.
  - A 3×3 Laplacian operator can be defined using the following convolution kernel.

$$M_L = \begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

  - The Laplacian kernel is applied to the three colour channels independently.

Laplacian

- and the edge points are located by thresholding the maximum gradient magnitude.
- Many of the Laplacian zero-crossings are spurious edges which really correspond to local minima in the gradient magnitude.
- Zero-crossings in a second-order derivative indicates an extremum in the first-order derivative, but not necessarily a local maximum.
  - To improve performance, the sign of the third-derivative may have to be examined

Laplacian

- Differentiation amplifies noise → the Laplacian zero-crossing for an image may have numerous false edges caused by noise.
  - Apply a smoothing function *a-priori*

Laplacian-of-Gaussian

- The LoG convolution kernel is based on the negative Laplacian derivative of the Gaussian distribution:

$$LoG(x,y) = \frac{x^2 + y^2 - 2\sigma^2}{2\pi\sigma^6} e^{\left(\frac{x^2+y^2}{2\sigma^2}\right)}$$

- Edge points are located if zero-crossings occur in any colour channel.

Grayscale Approaches

- These traditional approaches to edge detection fail to take into account the correlation among the colour channels, and as a result are not able to extract certain information conveyed by colour.
  – They tend to miss edges that have the same strength but are in opposite direction in two of their colour components.

References

- Koschan, A., “A comparative study on colour edge detection”, *Proc. 2nd Asian Conference on Computer Vision*, 1995, **3**, pp.574-578 [Sobel]
- Shiozaki, A., “Edge extraction using entropy operator”, *Computer Vision, Graphics and Image Processing*, 1986, **36**, pp.116-126
- Nevatia, R., “A color edge detector and its use in scene segmentation”, *IEEE Transactions on Systems, Man and Cybernetics*, 1977, **7**(11), pp.820-825
- Robinson, G.S., “Color edge detection”, *Optical Engineering*, 1977, **16**(5), pp.479-484

Vector Space Approaches

- Colour images can be viewed as a two-dimensional 3-channel vector field.
  - The value of this function at each point is defined by a 3D vector in a given colour space.
  - In RGB colour space f(x,y)=(R(x,y),G(x,y),B(x,y)) where (x,y) refers to the spatial dimensions in the 2D plane.
  - Existing edge detection algorithms use either first or second differences between neighboring pixels for edge detection.
    - A sign change gives rise to a peak in the first derivative and a zero-crossing in the second derivative.

Vector Gradient Operators

- Employs the concept of a gradient operator with modifications such that instead of a scalar space the operator performs on a 2D three color channel vector space.
  - Employ a (3×3) window centred on each pixel and obtain eight distance values D_i (i=1,..,8) by computing the Euclidean distance between the centre vector and its neighboring eight vectors. The vector gradient magnitude is then chosen as:

$$M_G = \max(D_1, \ldots, D_8)$$

Vector Gradient Operators

- One approach employs directional operators:
  - Let the image be a vector function **f**(x,y)=(*R*(x,y),*G*(x,y),*B*(x,y)), and let ***r,g,b*** be the unit vectors along the R,G,B axes, respectively.
  - The horizontal and vertical directional operators can be defined as:

$$u = \frac{\delta R}{\delta x} r + \frac{\delta G}{\delta x} g + \frac{\delta B}{\delta x} b \qquad v = \frac{\delta R}{\delta y} r + \frac{\delta G}{\delta y} g + \frac{\delta B}{\delta y} b$$

Vector Gradient Operators

$$g_{xx} = u \cdot u = \left|\frac{\delta R}{\delta x}\right|^2 + \left|\frac{\delta G}{\delta x}\right|^2 + \left|\frac{\delta B}{\delta x}\right|^2$$

$$g_{yy} = v \cdot v = \left|\frac{\delta R}{\delta y}\right|^2 + \left|\frac{\delta G}{\delta y}\right|^2 + \left|\frac{\delta B}{\delta y}\right|^2$$

$$g_{xy} = \frac{\delta R}{\delta x}\frac{\delta R}{\delta y} + \frac{\delta G}{\delta x}\frac{\delta G}{\delta y} + \frac{\delta B}{\delta x}\frac{\delta B}{\delta y}$$

Vector Gradient Operators

– The maximum rate of change of **f** and the direction of the maximum contrast can be calculated as:

$$\theta = \frac{1}{2}\arctan\left(\frac{2g_{xy}}{g_{xx}-g_{yy}}\right)$$

$$F(\theta) = \frac{1}{2}\left\{(g_{xx}+g_{yy}) + \cos 2\theta(g_{xx}-g_{yy}) + 2g_{xy}\sin\theta\right\}$$

– The edges can be obtained by thresholding $\sqrt{F(\theta)}$

Vector Gradient Operators

– The image derivatives along the *x* and *y* directions can be calculated by convolving the vector function **f** with two kernels as follows:

$$\frac{\delta f_i}{\delta x} \simeq \frac{1}{6}\begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix} * f_i \qquad \frac{\delta f_i}{\delta y} \simeq \frac{1}{6}\begin{bmatrix} 1 & 1 & 1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{bmatrix} * f_i$$

– The vector gradient is very sensitive to small texture variations and Gaussian and impulse noise.

Other Operators

- Directional operators
  - A class of directional vector operators to detect the location and orientation of edges in colour images.
    - Scharcanski, J., Venetsanopoulos, A.N., "Edge detection of colour images using directional operators", *IEEE Transactions on Circuits and Systems*, 1997
- Compound edge detectors
  - The simple colour gradient operator can be used to implement compound gradient operators.
  - e.g. Gaussian Operator: Each channel of the colour image is initially convolved with a Gaussian smoothing function and then the gradient operator is applied to the smoothed colour image to detect edges.
    - Scharcanski, J., Venetsanopoulos, A.N., "Edge detection of colour images using directional operators", *IEEE Transactions on Circuits and Systems*, 1997

Other Operators

- Entropy operator
- Second derivative operators
    - Cumani, A., “Edge detection in multispectral images”, *CVGIP: Graphical Models and Image Processing*, 1991, **53**, pp.40-51

Vector Order Statistic Edge Operators

- This class of colour edge detectors is characterized by linear combinations of the sorted vector samples.
  - Different sets of coefficients of the linear combination give rise to different edge detectors.

  e.g.
    - Vector dispersion edge detector (VDED) measures the dispersion of the ordered vectors.
    - Vector range edge detector (VR) expresses the deviation of the vector outlier in the highest rank from the vector median.
  - Tranhanias, P.E., Venetsanopoulos, A.N., “Vector order statistics operators as color edge detectors”, *IEEE Transactions on Systems, Man and Cybernetics – Part-B*, 1996, **26**(1), pp.135-143

Difference Vector Operators

- Difference vector (DV) operators are viewed as first-derivative-like operators.
  - Each pixel represents a vector in the RGB colour space, and a gradient is obtained in each of the four possible directions (0°, 45°, 90°, 135°) by applying convolution kernels to the pixel window.
  - A threshold can be applied to the maximum gradient vector to locate edges:

$$DV = \max(G_{0^\circ}, G_{45^\circ}, G_{90^\circ}, G_{135^\circ})$$

Difference Vector Operators

$$G_{0^\circ} = \|y_{0^\circ} - x_{0^\circ}\| \qquad G_{90^\circ} = \|y_{90^\circ} - x_{90^\circ}\|$$

$$G_{45^\circ} = \|y_{45^\circ} - x_{45^\circ}\| \qquad G_{135^\circ} = \|y_{135^\circ} - x_{135^\circ}\|$$

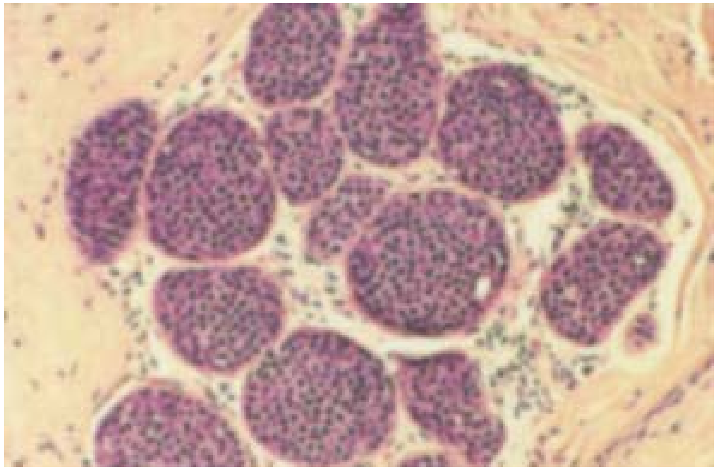
where $\|\cdot\|$ denotes the norm, and *x* and *y* are 3D vectors used as convolution kernels.

– Various filters to deal with noise:
  - vector median filter, arithmetic mean filter, α-trimmed mean filter, adaptive nearest-neaighbor filter

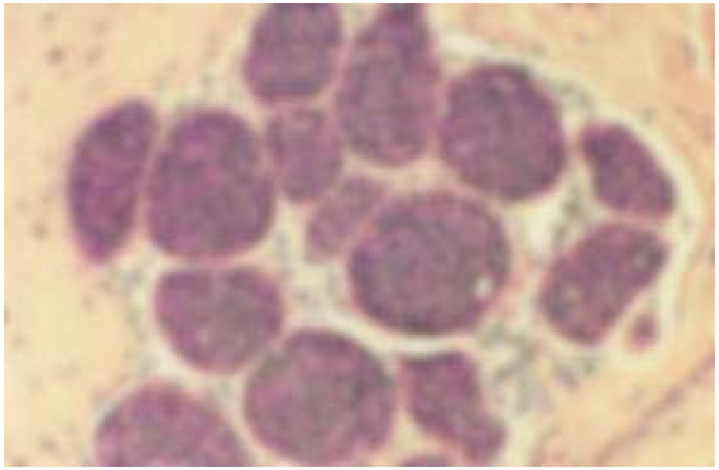
Colour Image Smoothing

- In colour Gaussian smoothing the Gaussian kernel is applied to each colour channel independently.

$\sigma=1.0$



$\sigma=2.3$

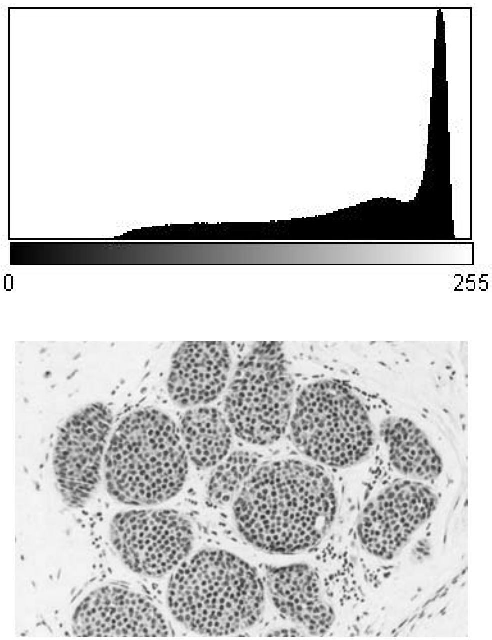


Colour Histograms

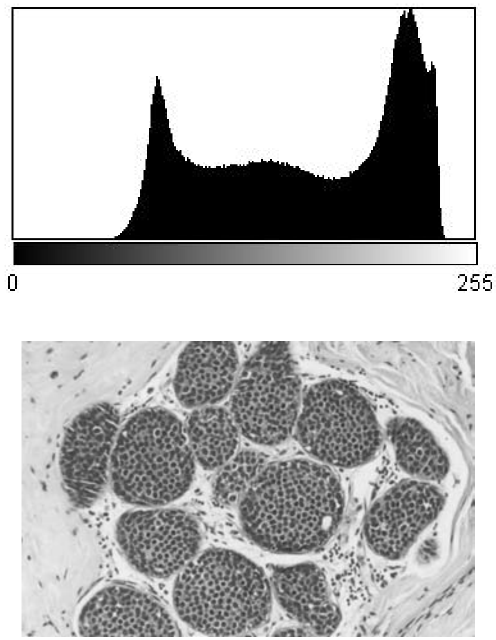
- Computing the histogram of a colour image may give us three separate histograms: one for each of the R, G, and B components.
- A true histogram of a colour image is *three-dimensional*.
  - The RGB colour cube is divided up into bins, giving a 256×256×256 array. There is a bin for every colour in the 24-bit colour image.
  - Such 3D histograms may be sparse and difficult to visualise.

Colour Histograms

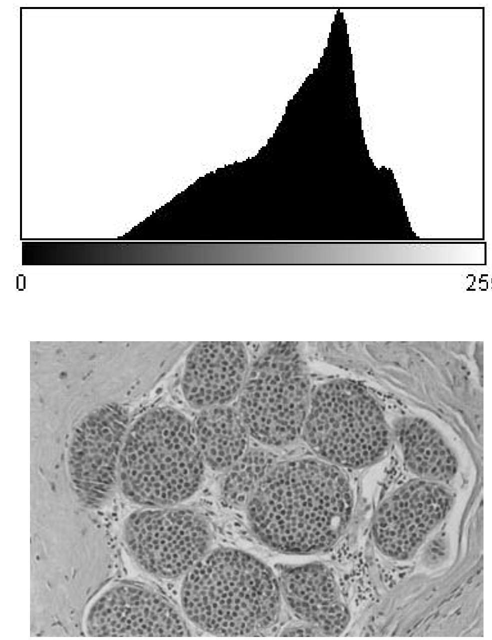
Red



Green

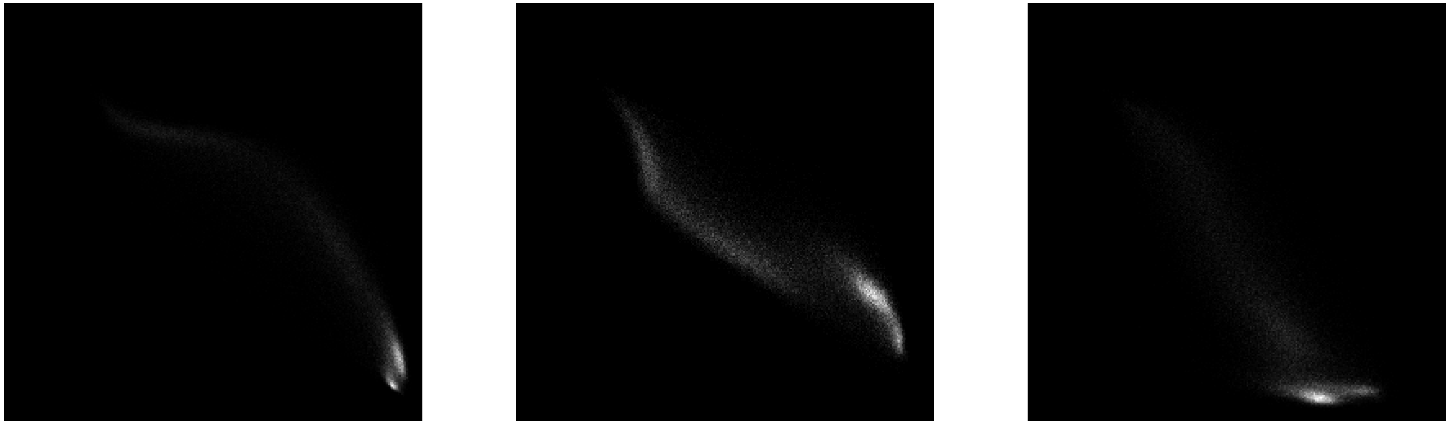


Blue



Colour Histograms

- As a compromise, calculate 2D histograms.
  - These are calculated for R--G, R--B and G--B
  - The R–G histogram can be thought of as the projection of the 3D histogram onto the B=0 plane.

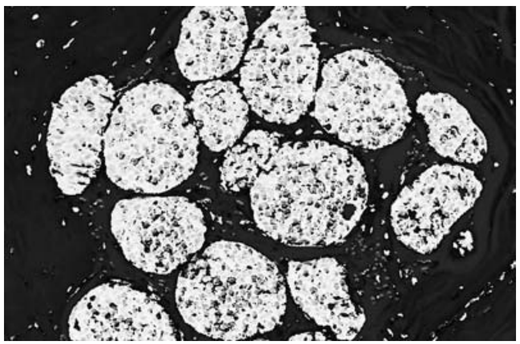


Colour Image Enhancement

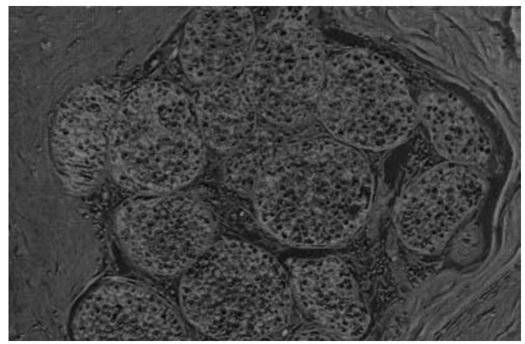
- Histogram equalization:
  - Direct 3D histogram equalization approaches such as histogram specification
  - Histogram equalization and modification can be applied directly on RGB images
    - May cause significant colour hue shifts
    - Use luminance, hue and saturation colour models
  - Histogram equalization is applied to the luminance and saturation components.

Histogram Equalization

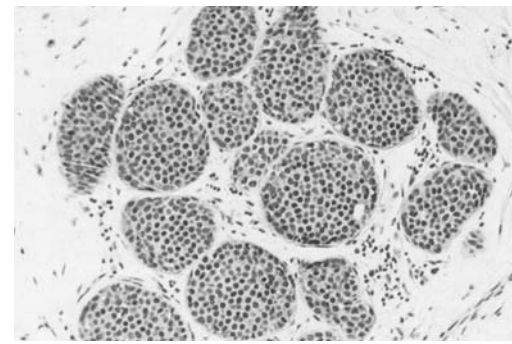
Hue



Saturation

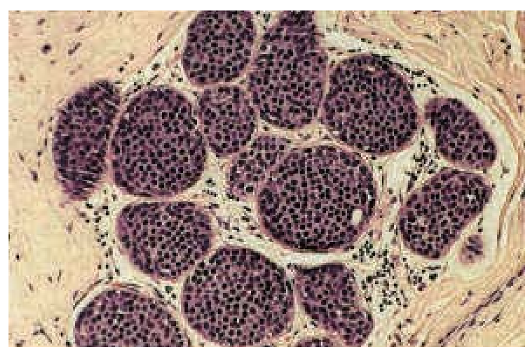


Intensity



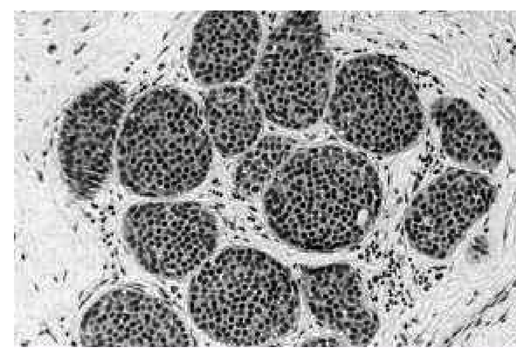
Original

HE Original

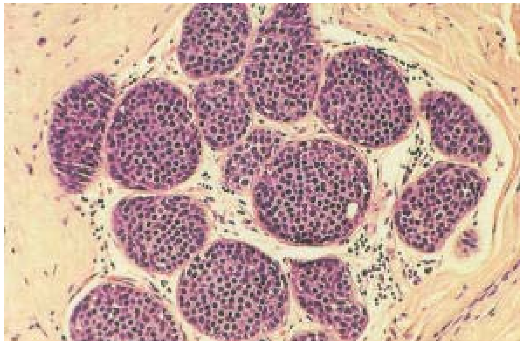


HE:

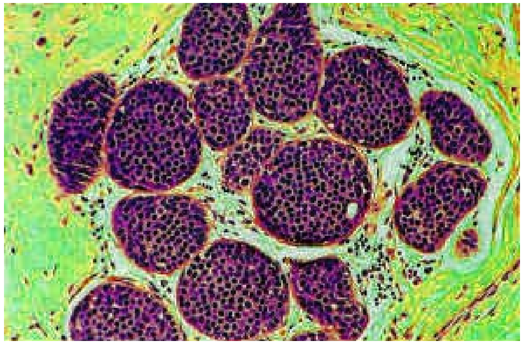
Intensity



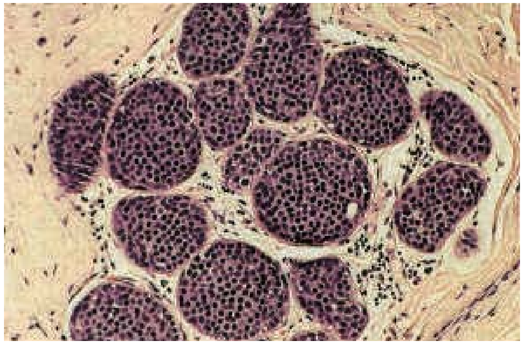
Histogram Equalization



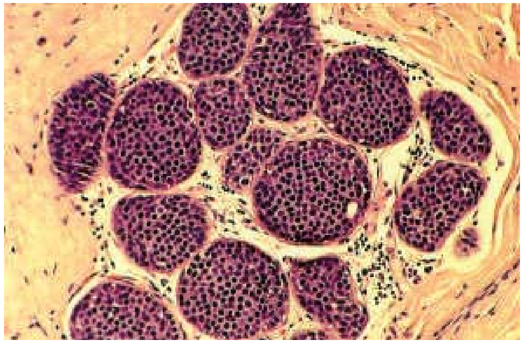
HE: H,S & I



HE (Intensity)



HE: S & I



Colour Segmentation

- Image segmentation refers to partitioning an image into different regions that are homogeneous with respect to some property.
  - Image segmentation is usually the first task of the image analysis process.
  - All subsequent tasks such as feature extraction rely heavily on the quality of image segmentation.
    - over-segmentation will split an object into different regions
    - under-segmentation will group various objects into one region.
  - The segmentation step determines the eventual success or failure of the analysis.

Colour Segmentation

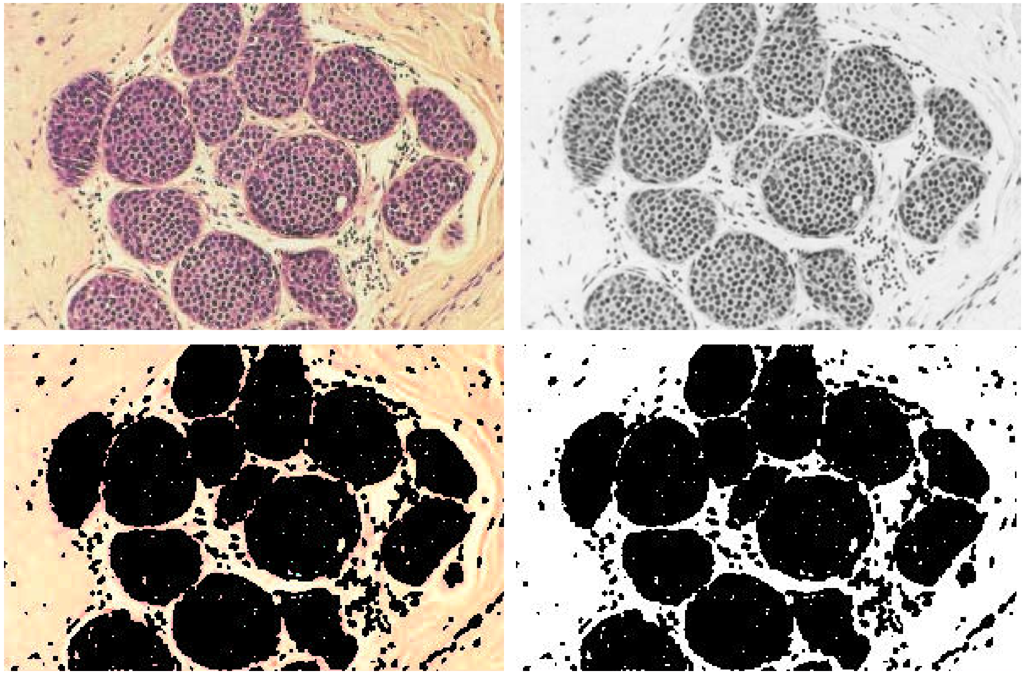
- There are four major classes of colour image segmentation:
    1. pixel based
    2. edge-based
    3. region-based
    4. model-based

Pixel-based Segmentation

- Pixel-based techniques do not consider the spatial context but decide solely on the basis of the colour features at individual pixels.
  - histogram thresholding
  - clustering (k-means algorithm, fuzzy k-means algorithm)

Histogram Thresholding

- In histogram thresholding, colour regions are determined by thresholding peak(s) in the histogram(s).



Clustering

- The rationale for clustering is that, typically, the colours in an image tend to form clusters in the histogram, one for each object in the image.
  - In a clustering-based approach, a histogram is first obtained, by the colour values at all pixels, and the shape of each cluster is found.
  - Then each pixel in the image is assigned to the cluster that is closest to the pixel colour.
  - k-means, fuzzy k-means clustering

Region-based Segmentation

- Region-based segmentation methods focus on the continuity of a region in an image.
  - Unlike pixel-based techniques, region-based techniques consider both colour space and spatial characteristics.

Region Growing

- Region growing is the process of growing neighboring pixels, or a collection of pixels of similar colour properties into larger regions.
  - Testing for similarity is usually achieved through a homogeneity criterion.
  - A region growing algorithm typically starts with a number of seed pixels in an image and from these grows regions by iteratively adding unassigned neighboring pixels that satisfy some homogeneity criterion with the existing region of the seed pixel.

Region Growing

- If the pixel is assigned to the region, the pixel set of the region is updated to include this pixel.
- Region growing techniques differ in choice of homogeneity criterion and choice of seed pixels.
- Region growing is often followed by region merging to improve partitioning

Region Growing

- For example the Euclidean distance in colour space can be used to determine which picels in the image satisfy the homogeneity criterion:
  - If the colour of the seed pixel is given as $S=(s_1,s_2,s_3)$ and the colour of the pixel under consideration is $P=(p_1,p_2,p_3)$, all pixels which satisfy: $(s_1 - p_1)^2 + (s_2 - p_2)^2 + (s_3 - p_3)^2 < T^2$
  - would be included in the region. *T* is the threshold value.

Split-and-Merge

- The split and merge process subdivides an image initially into a set of arbitrary, disjointed regions and then merge and/or split the regions in an attempt to satisfy a homogeneity criterion between the regions.

References

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- Tremeau, A., Borel, N., “A region growing and merging algorithm to color segmentation”, *Pattern Recognition*, 1997, **30**(7), pp.1191-1203
- Ohta, Y., Kanade, T., Sakai, T., “Color information for region segmentation”, *Computer Graphics and Image Processing*, 1980, **13**, pp.222-241
- Celenk, M., “A color clustering algorithm for image segmentation”, *Computer Vision Graphics and Image Processing*, 1990, **52**, pp.145-170

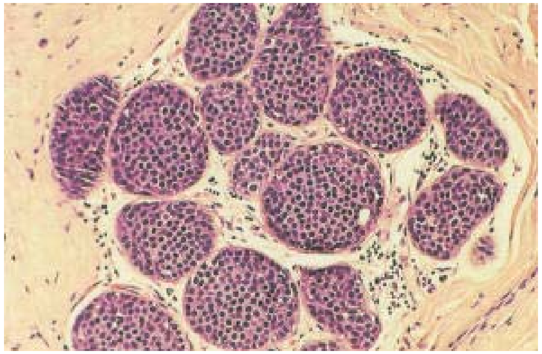
Model-based Segmentation

- In model-based segmentation, regions are modeled as random fields, and the segmentation is posed as a statistical optimisation problem.
  - Most techniques use the spatial interaction models like Markov random field (MRF), or Gibbs random field (GRF).

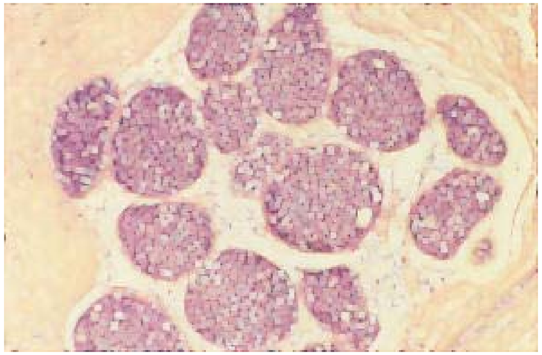
Colour Morphology

- Morphological techniques developed for use with grayscale images can be extended to colour images by applying the algorithm to each of the colour components separately.
  - Deng-Wong, P., Cheng, F., Venetsanopoulos, A.N., “Adaptive morphological filters for color image enhancement”, *Journa of Intelligence and Robotic Systems*, 1996, **15**: pp.181-207

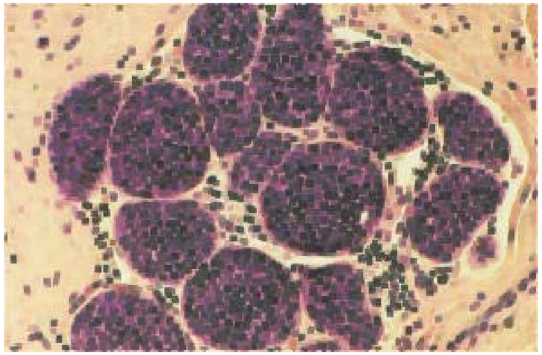
Colour Morphology

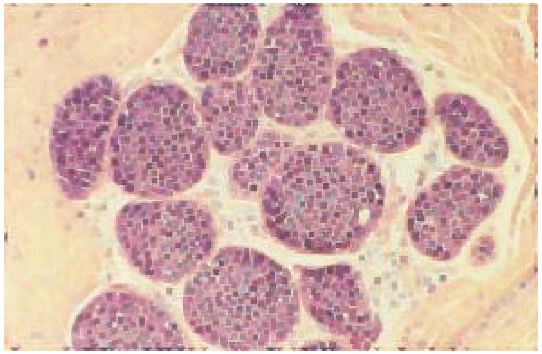


Erode

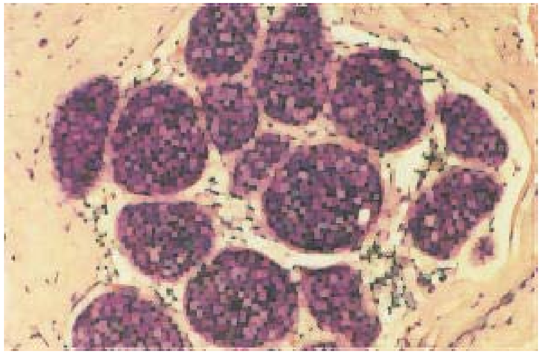


Dilate





Open



Close