Digital image processing and analysis
5. Image enhancement: global operations

Professor Ela Claridge
School of Computer Science

Previous lecture:

- Digital representation of colour images
  - Colour mixing (vector arithmetics)
  - Pixel arrays
  - Colour models

In this lecture we shall find out about:

- Image enhancement and restoration
  - Image histogram
  - Manipulating image brightness
  - Contrast enhancement
  - LUT operations

Image enhancement
Scope

- Elimination or significant reduction of image distortions caused by imperfect image generation process
- Improvement of visual qualities of an image (brightness, contrast, sharpness, etc.)

Image enhancement
Causes

- Contrast distortions
  - Causes
    - exposure error
    - limited dynamic range of sensors

- Geometric distortions (not covered in the lectures)
  - Causes
    - sensor or camera geometry
    - lens geometry (e.g. wide-angle)
    - object geometry (e.g. projection of the Earth)

Image enhancement
Contrast enhancement: methods

- Contrast enhancement
  - Exposure correction - statistical methods
  - "histogram manipulation"
  - Sensor distortion correction - camera model
  - "de-illumination"
  - Sharpening - filtering

Image enhancement
Histogram

- Histogram is a frequency distribution graph.
- It shows the number of pixels in the image having a particular image value or a range of values.

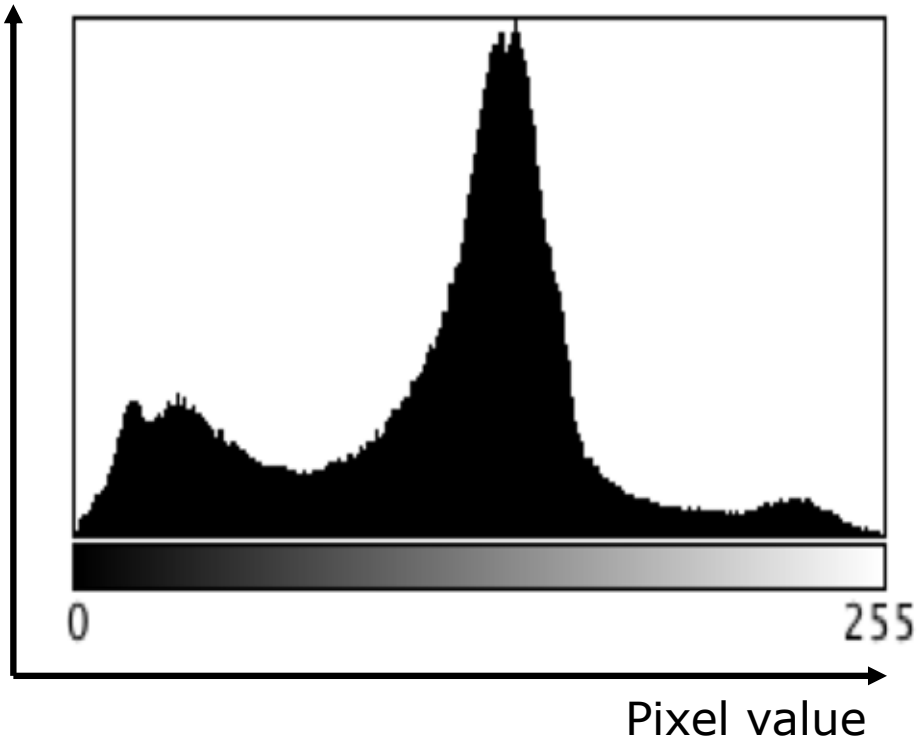
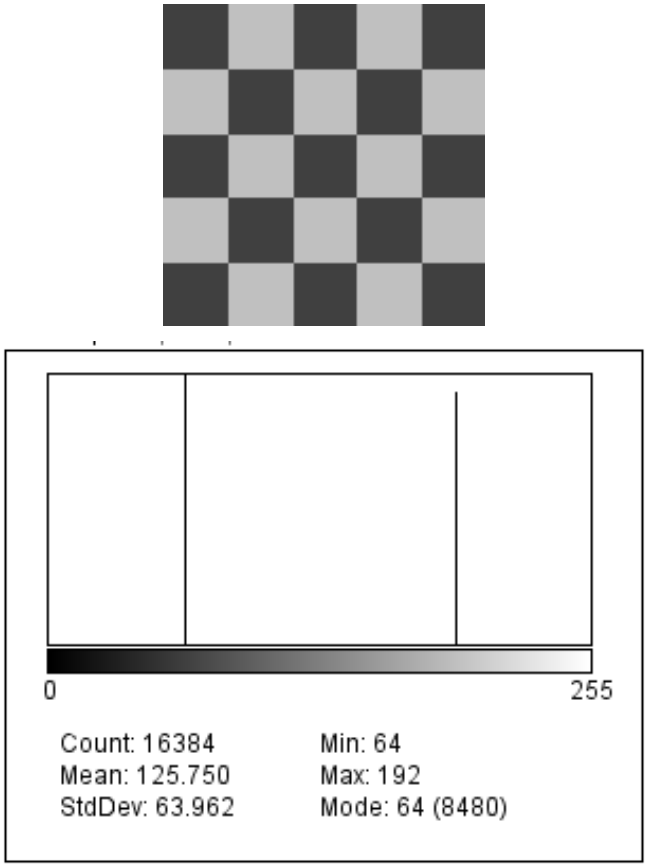
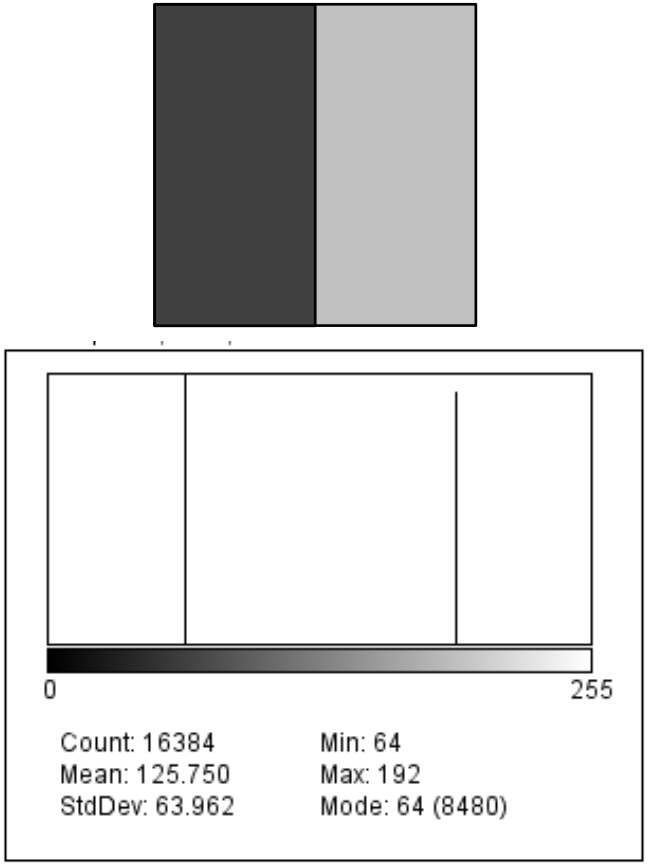


Image enhancement
Histogram

Two images with the same **statistical distribution** of pixel values but with different **spatial distribution** of pixel values





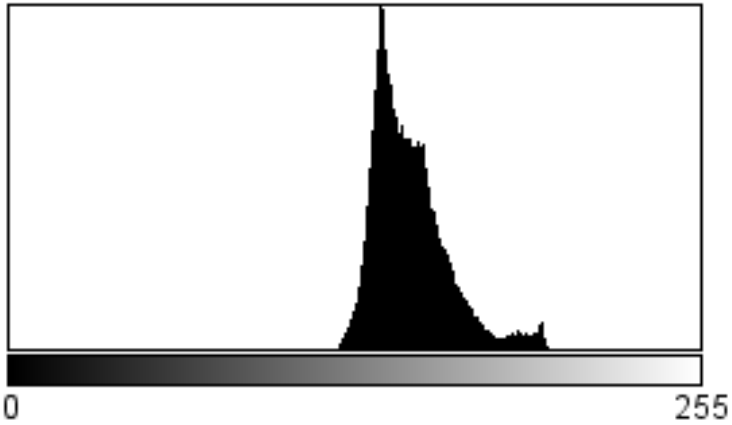
Identical histograms

Image enhancement
Histogram

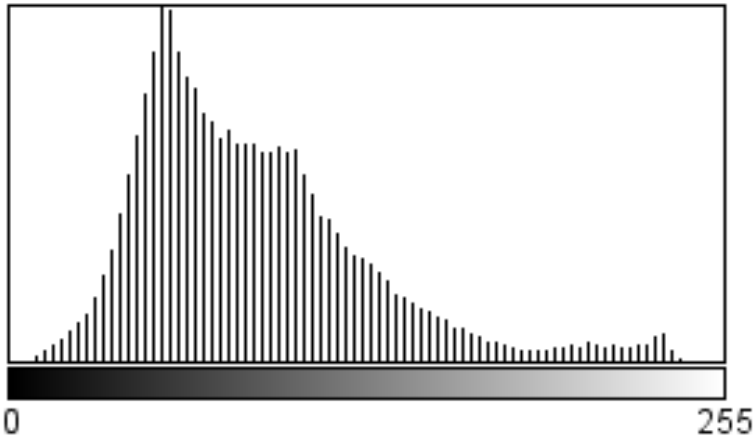
- Image properties depicted by histogram
  - **Contrast**
    - low - most pixels within a small portion of grey scale
    - high - bimodal histogram with peaks at outer brightness regions
  -
  - **Dynamic range**
    - how widely occupied the grey scale is
    - small - all the pixels in a small portion of a grey scale
    - large - wide grey level scale distribution
  -
- Desired characteristics
  - Medium or high contrast
  - Large dynamic range

Image enhancement
Histogram

Low contrast, low dynamic range



Medium contrast, high dynamic range



Source: By original Phillip Capper, modified by User:Konstable - modified Hawkes Bay NZ.jpg, CC BY 2.0, https://commons.wikimedia.org/w/index.php?curid=855363

Image enhancement
Histogram manipulations

- Aim : to "redistribute" the histogram so that contrast and dynamic range may be enhanced.

- General principles
  - The only information used is the statistics of image values (referred to as **statistical image model**)
  - The same transformation is applied to each pixel (referred to as **pixel point processing**)

- Mathematical notation

$$I'(x,y) = T\ (\ I(x,y)\ )$$

$x, y\ - pixel\ location$
$T - transformation$
$I - original\ image$
$I' - image\ after\ transformation$

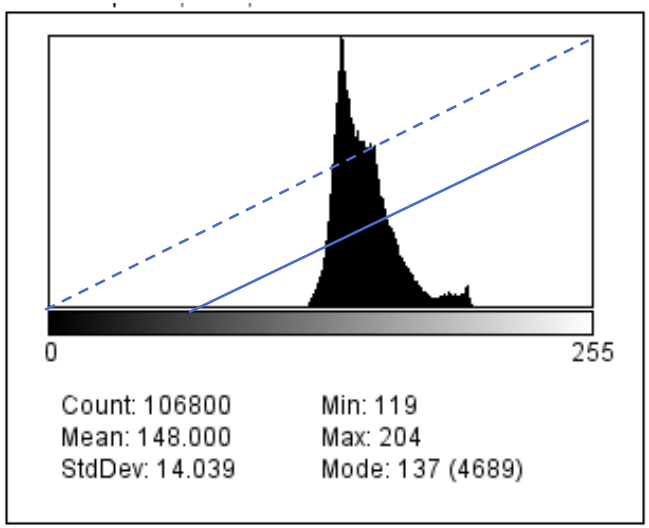
Image enhancement
Histogram manipulations: shifting

- The effect on the image: lightning or darkening.
- The effect on the histogram: shifted to the right or left from that of the original.
- The operation: adding or subtracting a constant value to all pixels.
- Mathematical notation:

$$I'(x,y) = I(x,y) + B$$

$B > 0 - increasing\ brightness$
$B < 0 - decreasing\ brightness$

Image enhancement
Histogram manipulations: shifting



$$I' = I - 70$$

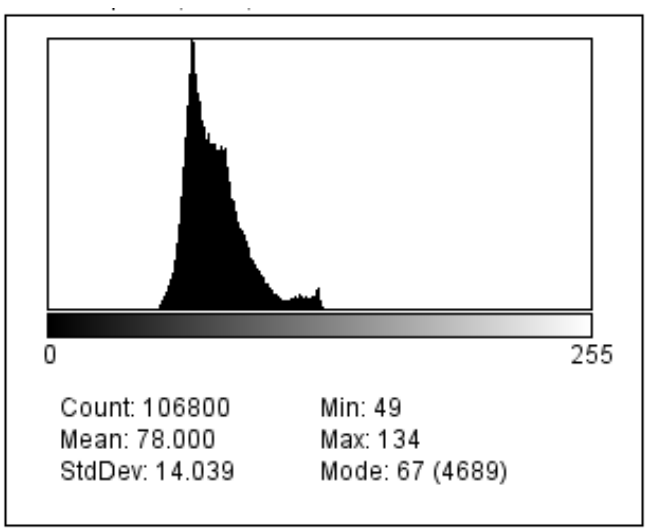
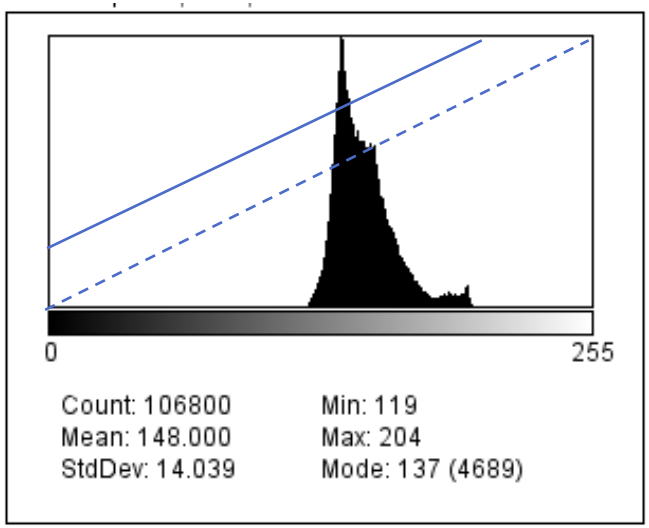


Image enhancement
Histogram manipulations: shifting



$$I' = I + 50$$

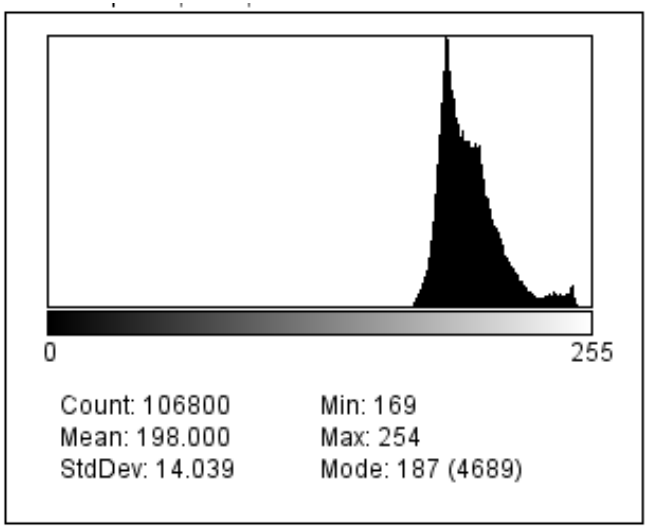


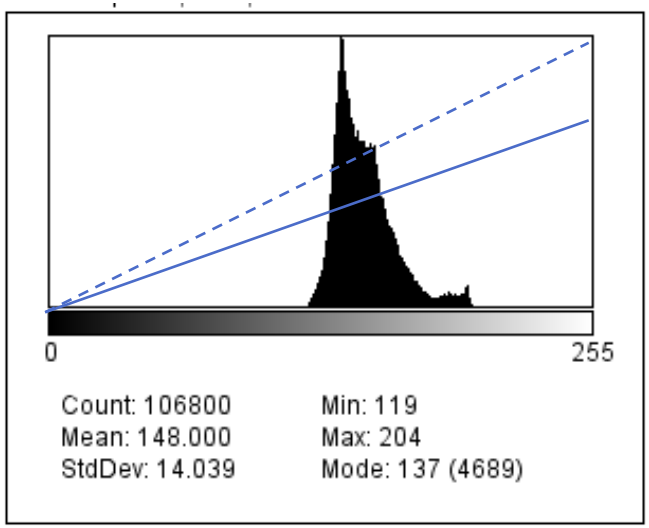
Image enhancement
Histogram manipulations: stretching

- The effect on the image: changing contrast and / or dynamic range.
- The effect on the histogram: broader or narrower distribution in relation to that of the original.
- The operation: multiplying all pixels by a constant value.
- Mathematical notation:

$$I'(x,y) = C \cdot I(x,y)$$

$C > 1 - broadening\ distribution, increasing\ contrast$
$0 < C < 1 - narrowing\ distribution, decreasing\ contrast$

Image enhancement
Histogram manipulations: stretching



$$I' = 0.65 \cdot I$$

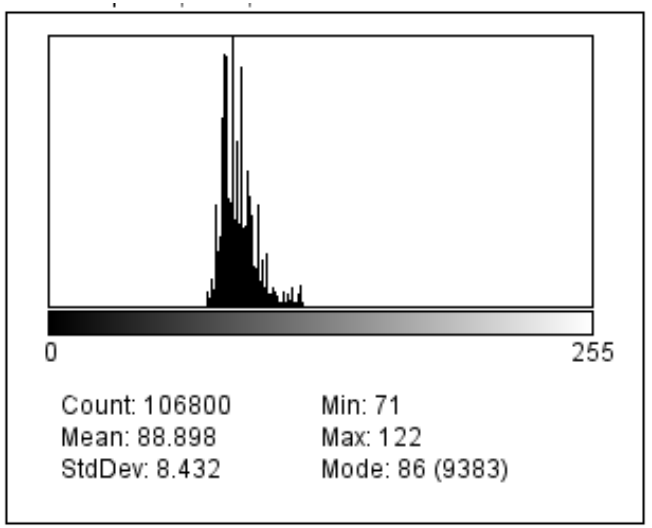
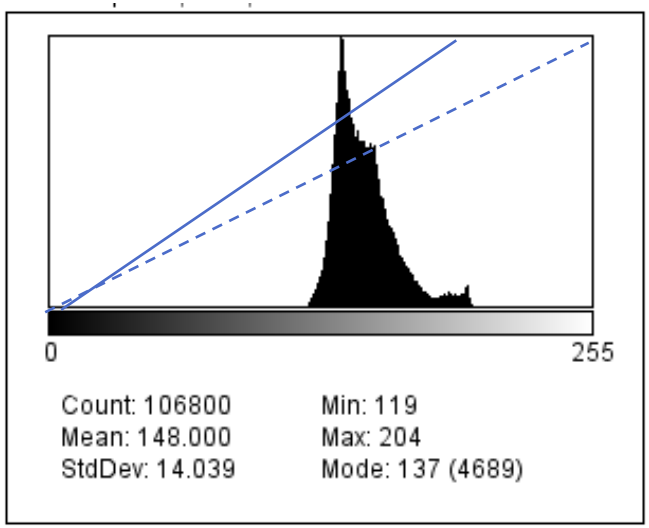


Image enhancement
Histogram manipulations: stretching



$$I' = 1.25 \cdot I$$

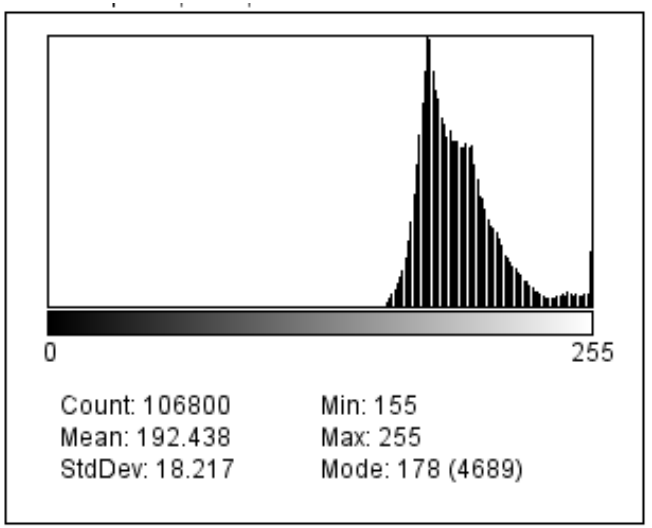
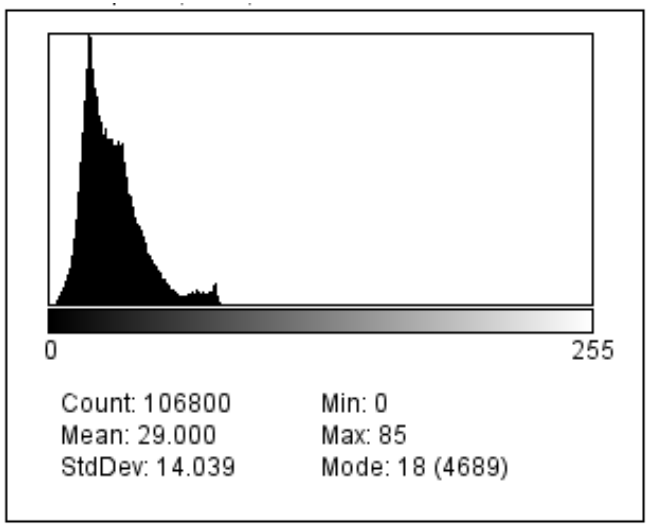


Image enhancement
Histogram manipulations: shift and stretch



$$I' = 3 \cdot (I - 119)$$

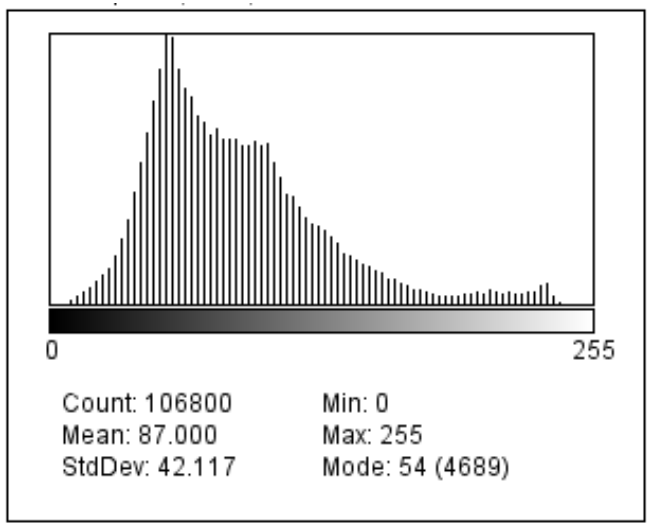
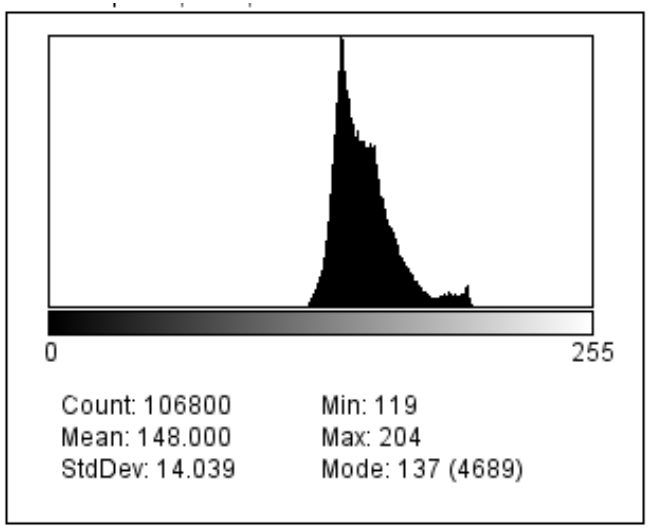


Image enhancement
Histogram manipulations: equalisation

- The effect on the image: visually enhancing dynamic range, e.g. lightening underexposed areas, darkening overexposed areas.
- The effect on the histogram: image values distributed across the whole range, spaced in proportion to the number of pixels with a given value in the original.
- The operation: applying the inverse of the cumulative histogram (histogram's probability distribution function, pdf).
- Mathematical notation:
  - See *Histogram equalization* in the list of further readings

Image enhancement
Histogram manipulations: equalisation



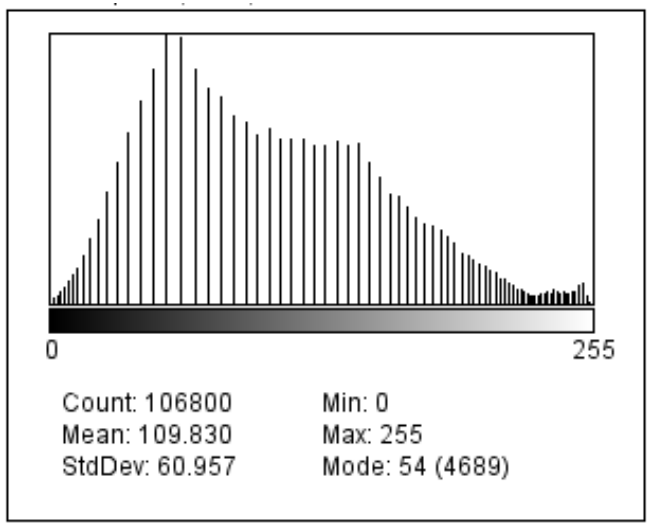


Image enhancement
LUT operations

- Indexed colour (see previous lecture)
  - A pixel value (or a value of a pixel component) is an index (a pointer) to a table containing colour definitions

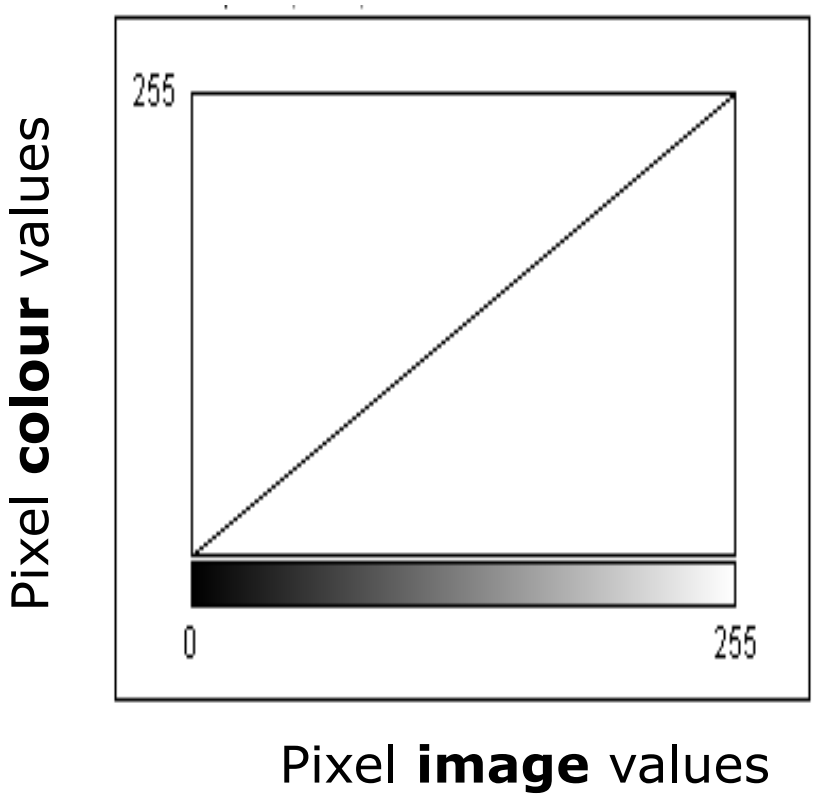


Image enhancement
LUT operations

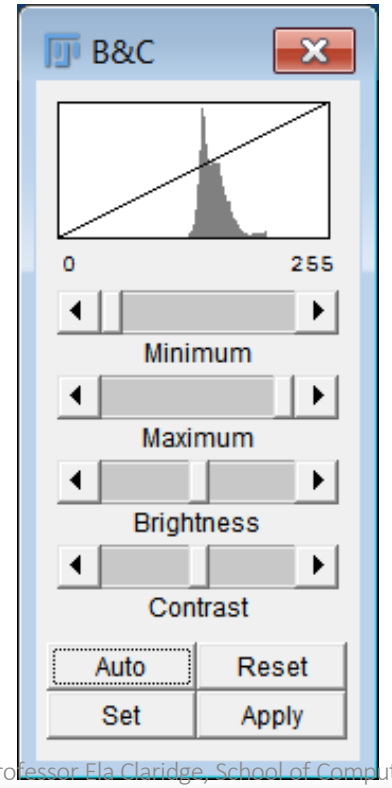
- Instead of manipulating pixel values, we can manipulate the contents of the LUT.
- The same results can be achieved but much faster.
- On a 1,000x1,000 image (1,000,000 pixels) with 256 grey levels
  - Using operations on pixel values: million operations
  - Using operations on LUT: 256 operations

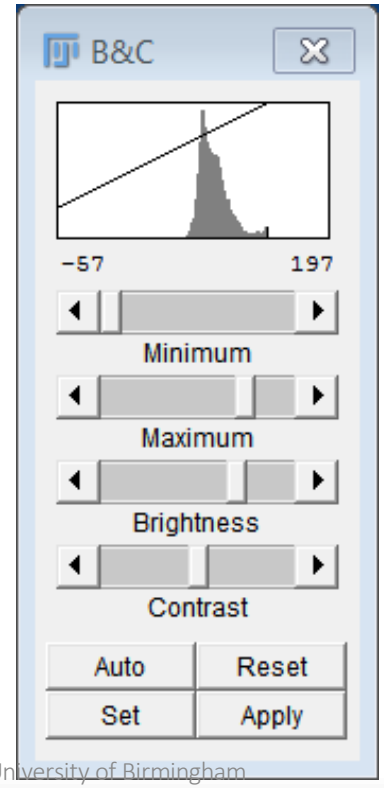
Image enhancement
LUT operations (equivalent to histogram shift)

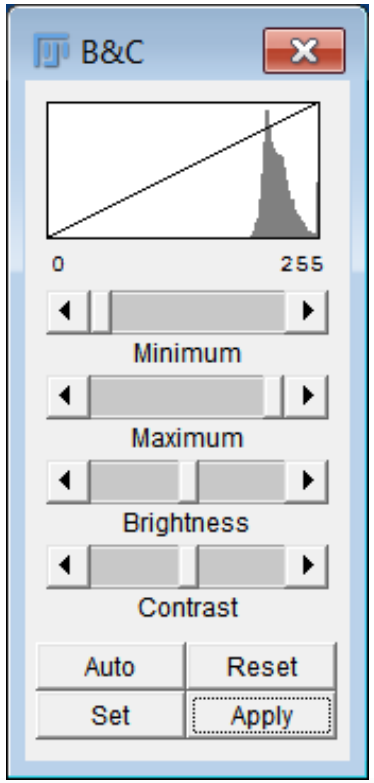
Original mapping

Change LUT

Apply LUT







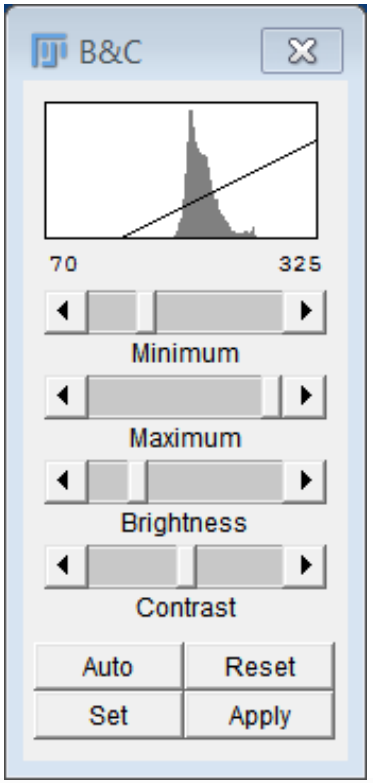
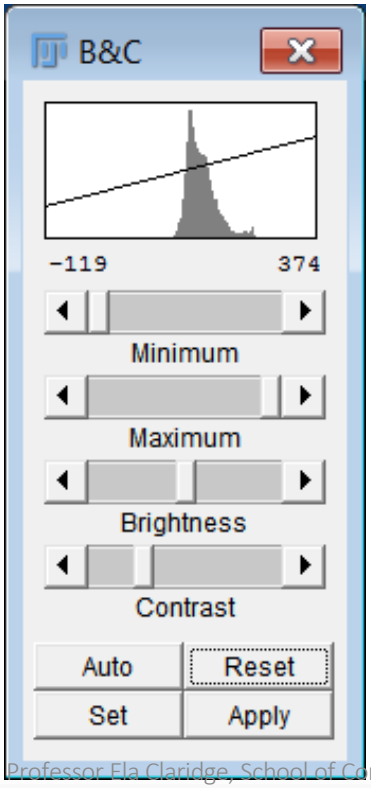


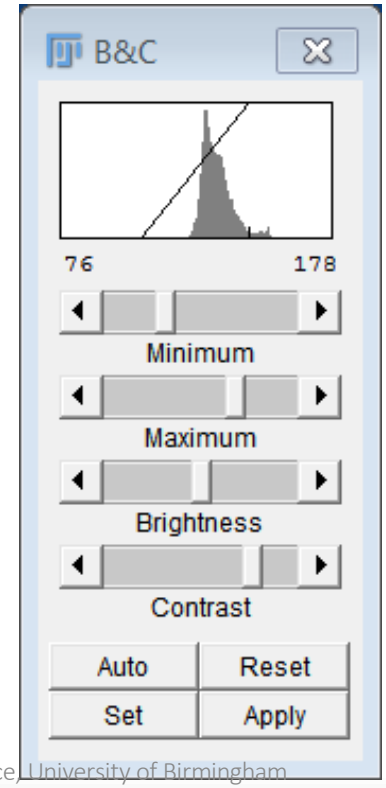
Image enhancement

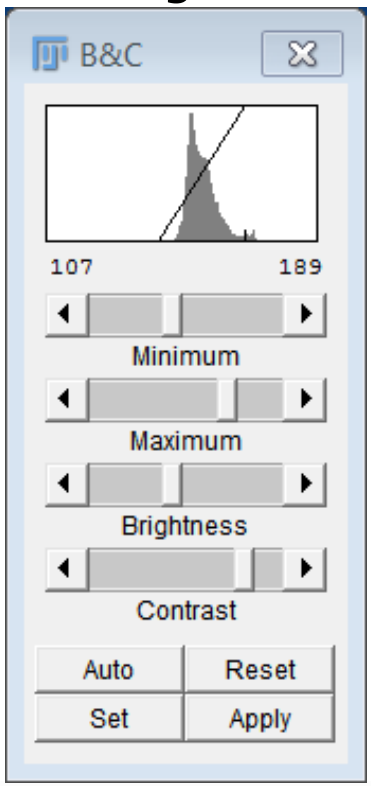
LUT operations (equivalent to histogram stretch)

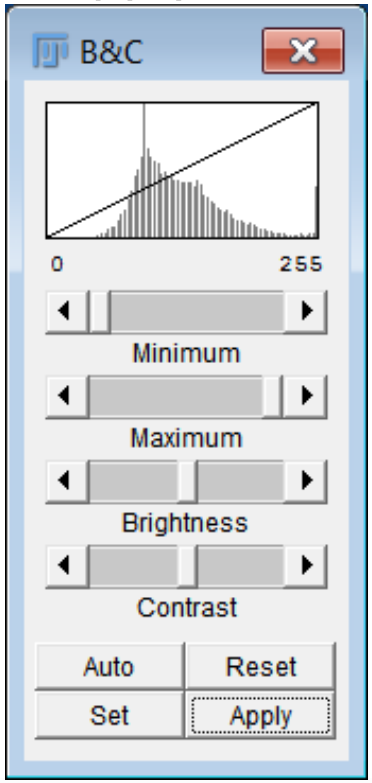
Change LUT

Apply LUT









In this lecture we have covered:

- Improving image quality
  - Manipulating image brightness
  - Contrast enhancement
  - Image histogram
  - LUT operations

Next lecture:

- Common types of image corruption
  - Noise
  - Blur
- Image frequencies
- Tools and methods for noise removal
  - Image profile
  - Image filtering operations
  - Convolution
  - Low-pass (smoothing) filters

Further reading and experimentation

- **Book chapters**
- Sonka, M. Hlavac, V. Boyle, R. (various editions) Image Processing, Analysis and Machine Vision, Chapman & Hall Computing, 4.1
- Gonzalez, R.C. & Woods, R.E. (various editions) Digital Image Processing, Addison-Wesley, Ch. 4.
- **Contrast enhancement**
- http://micro.magnet.fsu.edu/primer/digitalimaging/russ/expandingcontrast.html
- http://micro.magnet.fsu.edu/primer/digitalimaging/imageprocessingintro.html
- **Histogram equalization**
  www.math.uci.edu/icamp/courses/math77c/demos/hist_eq.pdf
- **Gamma correction**:
  http://www.cambridgeincolour.com/tutorials/gamma-correction.htm
- https://ledshield.wordpress.com/2012/11/13/led-brightness-to-your-eye-gamma-correction-no/
- http://www.dfstudios.co.uk/articles/programming/image-programming-algorithms/image-processing-algorithms-part-6-gamma-correction/