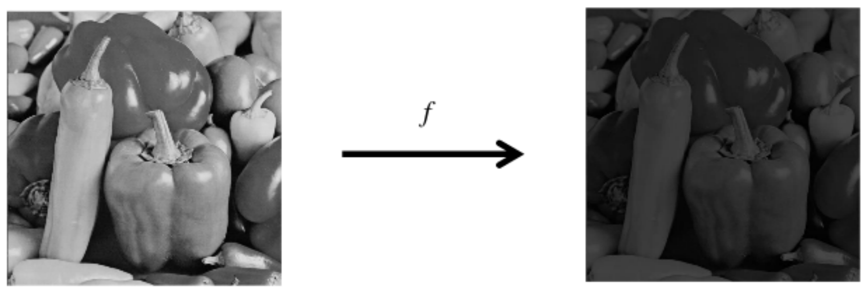
Point intensity transforms for contrast enhancement

1 Functional point transforms

Processing each pixel value, p, individually using a mathematical function

$$p' = f(p)$$

as a point transform operator transforms the image from one state to another



Also known as intensity transform functions

2 Image enhancement

Goal: make the image look better so we can view and process the visual information with greater clarity

Image enhancement is subjective. It depends on

- The information required by the visual task
- The physical characteristics of the image
- The user's prior knowledge/experience
- The user's intuition and judgement

Evaluation methodology: perceived quality of results

Common poor image characteristics: poor lighting and noise

3 Dynamic range

Definition: Range of a sensor

The set of all possible intensity values of the images it captures

A good image should utilise the full (or most of the) sensor's range

Definition: Dynamic range of a sensor

The largest (possible) signal value divided by the smallest (possible) signal value

Increasing the dynamic range improves contrast

4 Conventions

Pixels can either be represented as:

- Floats from 0 to 1
- Integers from 0 to 255

5 Logarithmic transform

The logarithmic transform replaces each pixel value with its logarithm

$$I_{\text{output}}(i, j) = \log I_{\text{input}}(i, j)$$

In practice, we control the range using the function:

$$I_{\text{output}}(i, j) = c \cdot \log \left[1 + (e^{\sigma} - 1)\, I_{\text{input}}(i, j)\right]$$

with scaling parameters σ and c σ controls the range of values onto which the logarithmic function is applied

c normalises the output to the range [0,255]. That is,

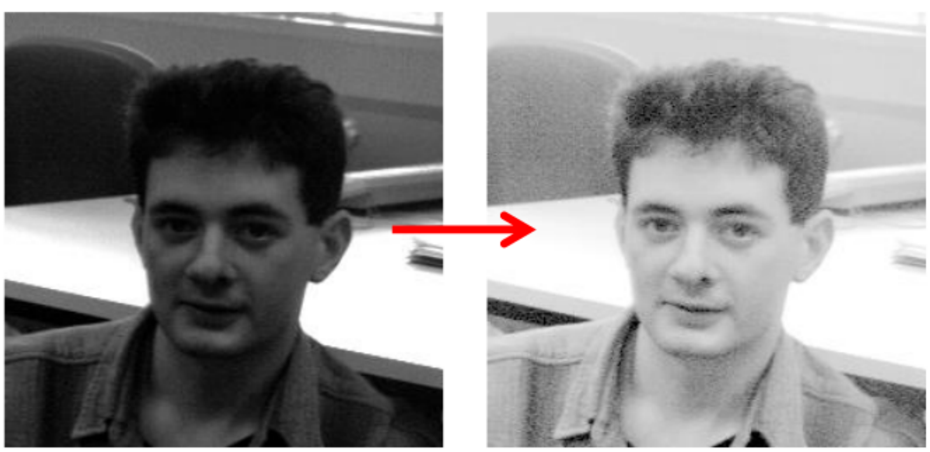
$$c = \frac{255}{R}$$

Where R is the maximum of

$$\log \left[1 + (e^{\sigma} - 1)\, I_{\text{input}}(i, j)\right]$$

The dynamic range of this scene exceeded that of the sensor/camera (dark foreground - bright background)

As a result of a (usually automatic) decision on the camera exposure, the dynamic range of the dark parts was compressed



The logarithmic transform in this example:

- brightens the foreground (which consists of dark pixels) spreading low pixel values over a wider range
- compresses the background pixel range (the bright high values)

Applying the logarithmic transform yields poor results: information loss and worse visualisation

6 Application: X-ray images

X-ray sensors return values given by an exponential function

$$I(i, j) = I_o \cdot \exp(-f(i, j))$$

I_o is the X-ray source intensity
f = material attenuating properties (object thickness and material density)

The logarithmic transform cancels the exponent

$$\log I_{out} = \log \left[I_o \cdot (\exp(-f(i, j))\right]$$

As a result, the image gives a linear mapping of the material properties

7 Exponential transform

The exponential transform is the inverse of the logarithmic transform

It replaces each pixel value with its exponent

$$I_{\text{output}}(i, j) = \exp\left(I_{\text{input}}(i, j)\right)$$

In practice, we use a variable basis and scaling

$$I_{\text{output}}(i, j) = \mathrm{c} \cdot \left[(1 + \alpha)^{I_{\text{input}}(i,j)} - 1\right]$$

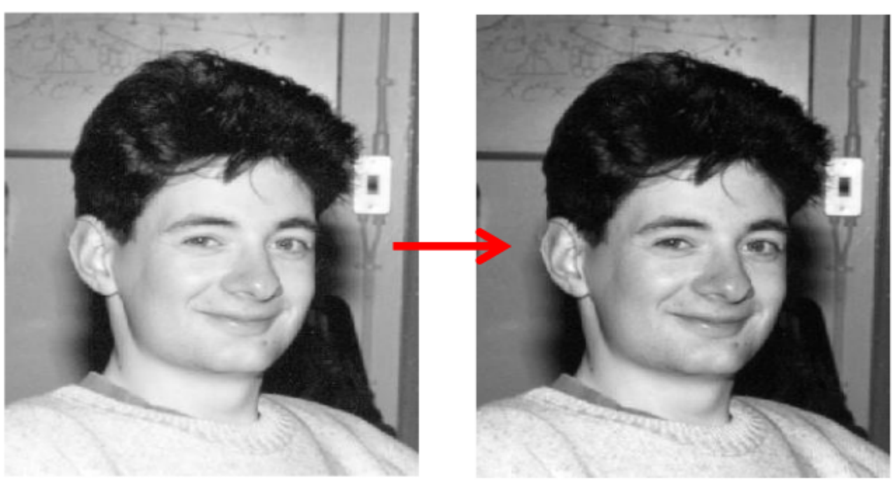
where $1 + \alpha$ is the basis and c the scaling factor

$I_{input}(i, j) = 0$ gives

$$I_{\text{output}}(i, j) = \mathrm{c} \cdot \left[(1 + \alpha)^{I_{\text{input}}(i,j)}\right] = c$$

We subtract 1 to prevent offset in output

Basis > 1 is required for functions suitable for out purpose (decrease the dynamic range of dark regions - increase the dynamic range of bight regions)



The exponential transform decreases the dynamic range of dark regions whilst increasing the dynamic range in light regions
Enhances detail in high value (bright) areas

8 Power-law ('raise to power') transform

Raise each pixel value to a fixed power

$$I_{\text{output}}(i, j) = c \cdot \left(I_{\text{input}}(i, j)\right)^{r}$$

for $r > 1$ it enhances (spreads) high value intensities whilst compressing low value intensities

For $r < 1$ it enhances (spreads) low value intensities whilst compressing high value intensities

The 'power-law' transform has similar effect the logarithmic (when $r < 1$) or to the exponential (when $r > 1$)

9 Application: gamma correction

The power-law transform is used in digital photography to correct the tonality of an image

r is traditionally called the gamma value, and the process gamma correction

The transform $f(x) = x^{\gamma}$ with $\gamma < 1$ weights the intensities towards higher (brighter) values

- an underexposed photo can be corrected using gamma correction with $\gamma < 1$

The transform $f(x) = x^{y}$ with $\gamma > 1$ weights the intensities toward lower(darker) values

- An overexposed photo can be corrected using gamma correction with $\gamma > 1$