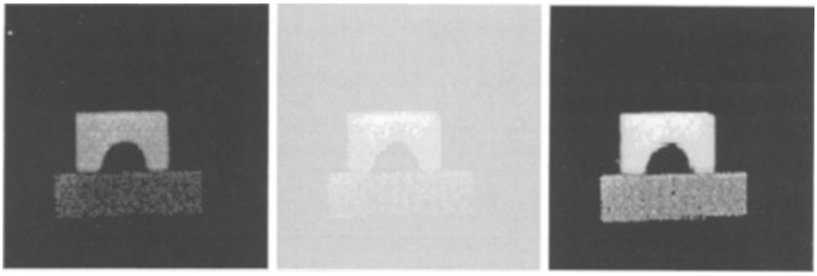

Fig. 5. From left to right: Original image, histogram equalized, λ-enhanced.

In Fig. 5 a result of λ-enhancement is illustrated.

In fuzzy systems we generally endeavor to reduce the amount of fuzziness because it produces uncertainties and makes decisions more difficult. But in image processing, and especially for human brightness perception, it can be sometimes useful to increase the grayness ambiguity by increasing the number of gray levels. The initialization of membership values plays an important role in the achievement of satisfactory results. Any kind of membership function can be applied regarding to the specific requirements of the application. One can also interpret the cumulative histogram (normalized in $[0, 1]$) as a membership function representing the fuzziness of a bright image:

$$\mu(g) = \begin{cases} \dfrac{h(g)}{\max_g h(g)} & \text{if} \quad g = 0, \\[2ex] \dfrac{h(g) + h(g-1)}{\max_g h(g)} & \text{otherwise.} \end{cases} \tag{39}$$

In this case, the results of λ-enhancement are similar to those of histogram equalization.

3.5 Rule-based contrast enhancement

The fuzzy rule-based approach is a powerful and universal method for many tasks in the image processing. In [44] a simple inference system is proposed to increase the contrast of medical image data (see also [53,22,6,7]). The algorithm can be given as follows:

- Initialization of the parameters of the inference system (number of input and output membership functions, their shapes and locations with respect to first order statistics etc.)
- Fuzzification of gray levels (e.g. membership values to the *dark*, *gray* and *bright* sets of gray levels (Fig. 6))
- Inference procedure evaluating appropriate rules (e.g. if *dark* then *black*, if *gray* then *gray*, if *bright* then *white*)

- Defuzzification of the output using three singletons (e.g. $S_1 = g_{min}, S_2 = g_{mid}, S_3 = g_{max}$):

$$g' = \frac{\mu_{dark}(g) \times S_1 + \mu_{gray}(g) \times S_2 + \mu_{bright}(g) \times S_3}{\mu_{dark}(g) + \mu_{gray}(g) + \mu_{bright}(g)}. \tag{40}$$

Fig. 7 shows an example of rule-based enhancement.

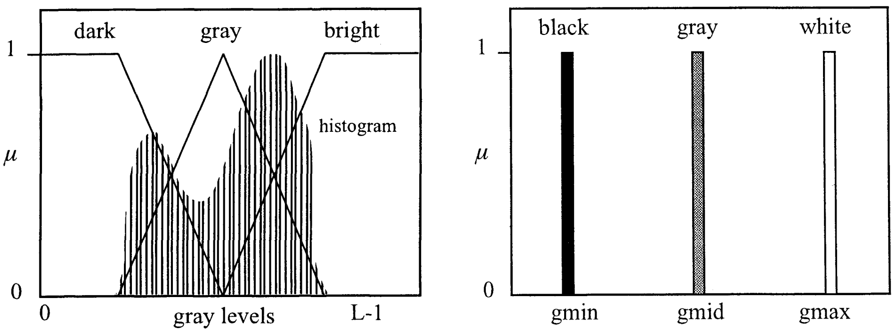

Fig. 6. Rule-based contrast enhancement. Left: input membership functions for gray-level fuzzification; right: output singletons for generation of modified gray-levels

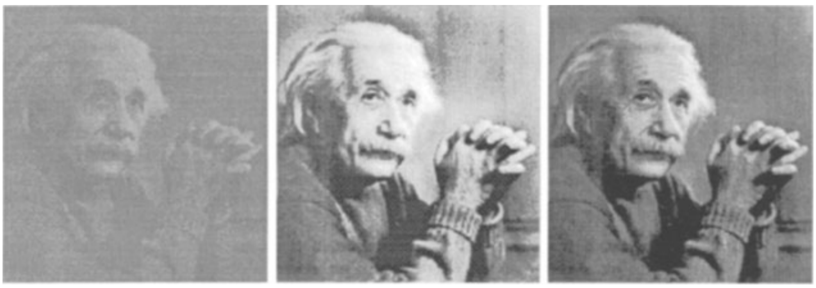

Fig. 7. Left to right: Original image, histogram equalized, rule-based enhanced

3.6 Enhancement based on fuzzy relations

Bhutani and Battou [3] used fuzzy relations to develop a new enhancement technique. Considering an image with M rows and N columns, one can view the image as a weighted relation from a set X with M elements into a set Y