

# Fast Fourier Transform-Based Retinex and Alpha-Rooting Color Image Enhancement

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DR. ARTYOM GRIGORYAN

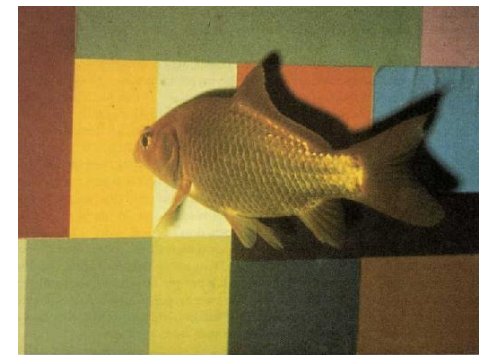
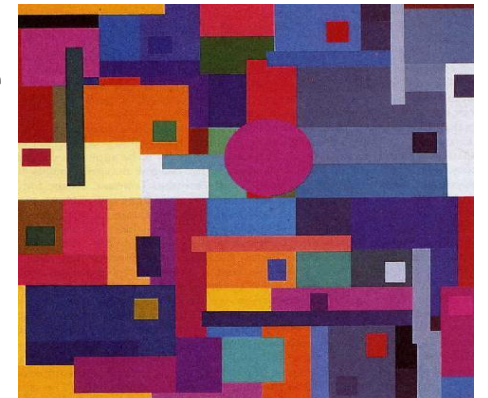
DR. SOS AGAIAN

ANALYSA GONZALES

# Color Constancy

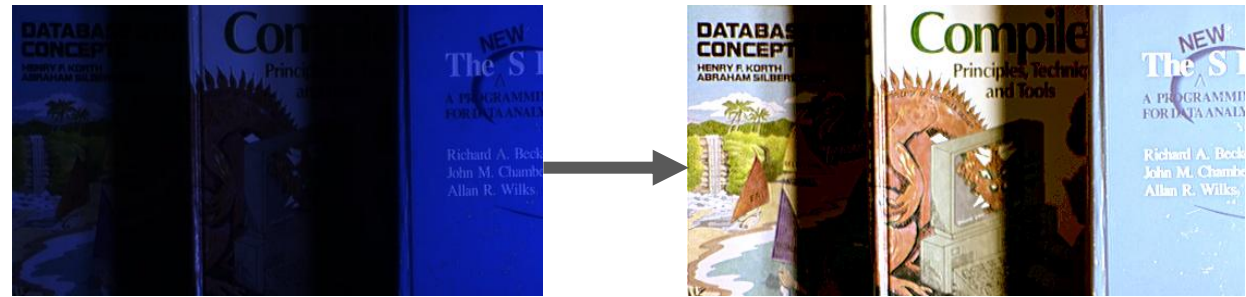
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- Edwin Lands' experiments were designed to prove that despite variations (both large and small) in relative intensities of red, green, and blue illuminations upon a patchwork, the colors of each patch remain constant.
- David Ingle's Experiment: Despite changes in projector intensities used in to illuminate the patchwork, a goldfish was found to swim to the green patch every time regardless of the color of illumination being used, a behavior akin to the perceptual results in human found by Edwin Lands' experiments.



<http://hubel.med.harvard.edu/book/b45.htm>

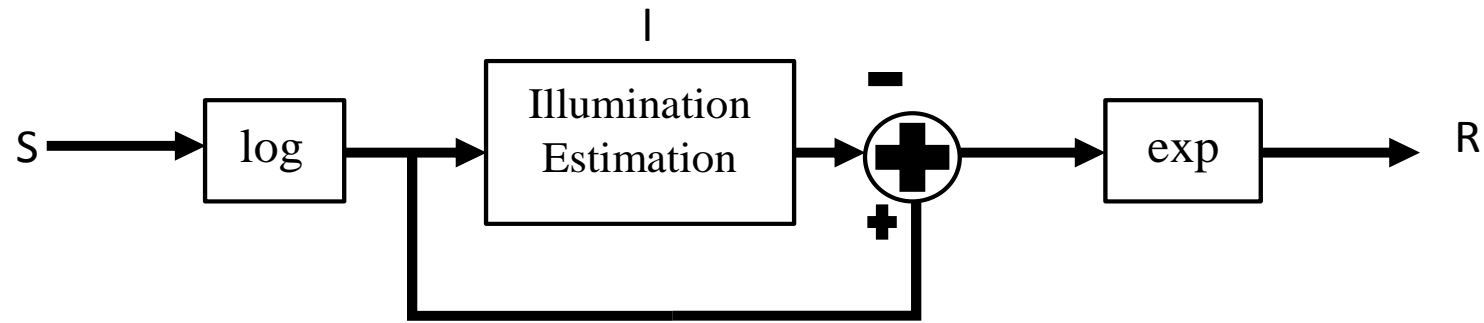
# RETINEX



- Proposed by Edwin Land in 1986 and based upon his experimentation involving color constancy.
- A model of human perception of lightness and color which describes a method of image enhancement seeking to bridge the gap between digital images and those images observed by the human eyes.
- Offers a means of sharpening an image, improving its color consistency regardless of variations in illumination, and the means to achieve dynamic range compression.

# General RETINEX Form

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In this figure,  $S(x, y)$  is the input color image to be enhanced, which is presented in the multiplicative form

$$S(x,y): \log(S(x,y)) = s \quad \log(R(x,y)) = r \quad \log(L(x,y)) = l$$

$$S(x,y) = R(x,y) \cdot L(x,y)$$

$$\log(S(x,y)) = \log(R(x,y)) + \log(L(x,y)) \rightarrow R(x,y) = \exp[ \log S(x,y) - \log L(x,y) ]$$

(where  $S(x,y)$  = original image,  $R(x,y)$  = reflectance and  $L(x,y)$  = illumination)

# Single Scale RETINEX (SSR)

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$$R_i(x, y) = \log(I_i(x, y) - \log[F(x, y) * I_i(x, y)])$$

$$R_i(x, y) = \log\left(\frac{I_i(x, y)}{F(x, y) * I_i(x, y)}\right) = \log\left(\frac{I_i(x, y)}{\bar{I}_i(x, y)}\right)$$

$I_i(x, y)$ : the image distribution in the  $i^{\text{th}}$  spectral band

$R_i(x, y)$ : Retinex output

$C$ : Gaussian surround space constant

$F(x, y)$ : Gaussian function  $F(x, y) = K e^{-(x^2 + y^2)/C^2}$

- Serious tradeoff: while both color/lightness rendition (using a large scale or large  $C$  value) and dynamic range compression (using a small scale or small  $C$ ) can both be achieved, SSR cannot do both simultaneously.

# Multi-Scale RETINEX (MSR)

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$$R_{MSRi} = \sum_{n=1}^N \omega_n \{ \log[I_i(x, y)] - \log[F_n(x, y) * I_i(x, y)] \}$$

$N$ : number of scales

$\omega_n$ : the weight associated with the  $n$ th scale

empirical values:  $N = 3$ ,  $\omega_n = 1/3$ ,  $C = 15, 80$  and  $250$  correspondingly for each scale in  $F_n$ .

- Notably better than SSR in terms of dynamic compression and color rendition in that both can be done simultaneously
- Method does not always do well with colored images due to tendency of MSR to desaturate colors in a given image.

# Multi-Scale RETINEX with Color Restoration (MSRCR)

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$$R_i(x_1, x_2) = \sum_{k=1}^K W_k (\log I_i(x_1, x_2) - \log [F_k(x_1, x_2) * I_i(x_1, x_2)]) \quad i = 1, \dots, N,$$

$$F_k(x_1, x_2) = k \exp[-(x_1^2, x_2^2) / \sigma_k^2]$$

*N*: number of spectral bands

*F<sub>k</sub>*: *k*<sup>th</sup> surround function

*W<sub>k</sub>*: the weights

- To avoid desaturation problem of MSR, a post-processing technique for color restoration (CR) is applied in order to enhance local contrast.

# Flaws of original RETINEX Algorithm

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(D.J. Jobson, Z. Rahman, and G.A. Woodell)

- Processing extremely slow (due to using “imfilter”)
- Enhanced output image itself had an embossed mask that made it 3-dimensional, giving the image properties the image itself did not have (having to do with centering of the image).



# RETINEX using Fast Fourier Transform (FFT)

$$\mathcal{F}[x(t) * y(t)] = X(j\omega) Y(j\omega)$$

- Convolution of Gaussian filter to original image in time domain mapped to multiplication in frequency domain [imfilter → fft]
- Expected to achieve faster processing time since generally, *fft* is considered the fastest enhancement method in comparison to “*conv*” and “*imfilter*” operations.

# New Measure: EMEC

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To calculate the color image enhancement, we can use the measure CEME (color image enhancement measure) introduced by Grigoryan and Aghaian which generalizes the concept of the known EME concept for the gray-scale images.

The quantitative measure of enhancement of the color image processed:

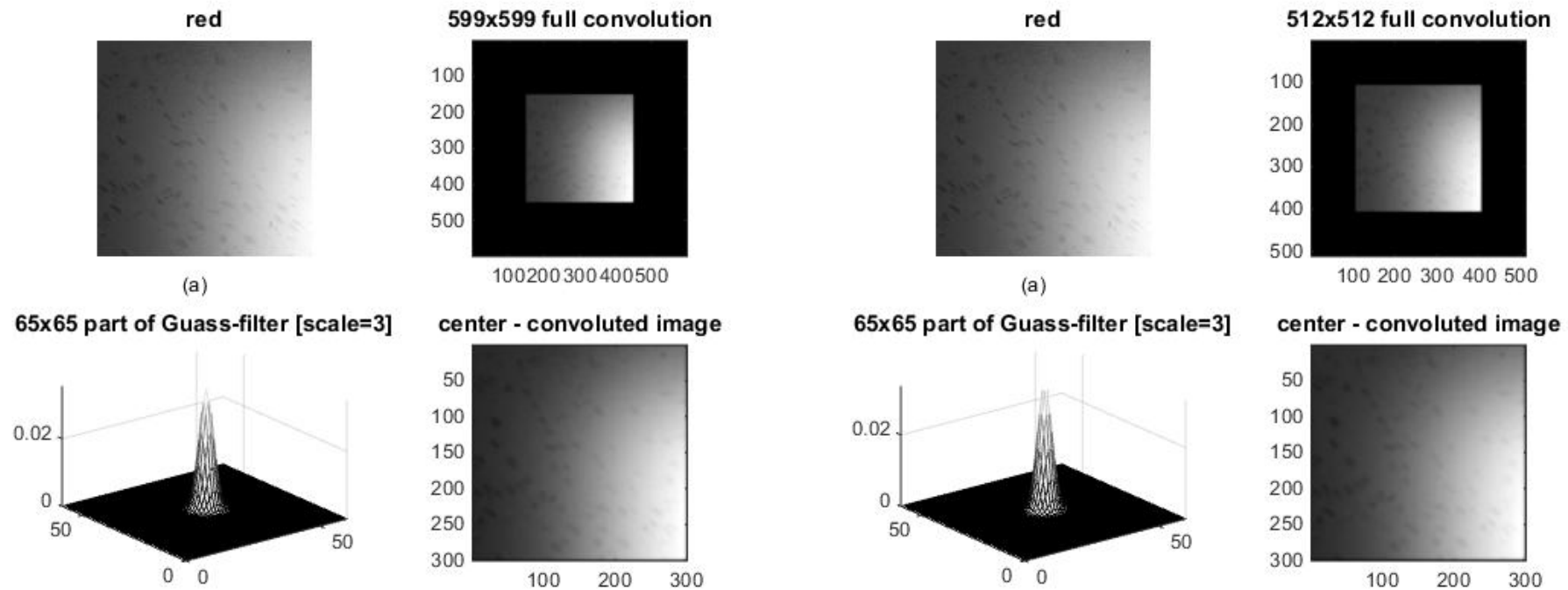
$$E_q(\alpha) = CEME_\alpha(\hat{f}) = \frac{1}{k_1 k_2} \sum_{k=1}^{k_1} \sum_{l=1}^{k_2} 20 \log_{10} \left[ \frac{\max_{k,l}(\hat{f}_R, \hat{f}_G, \hat{f}_B)}{\min_{k,l}(\hat{f}_R, \hat{f}_G, \hat{f}_B)} \right]$$

$CEME_\alpha(\hat{f})$  is called a *measure of enhancement*, or *measure of improvement of the image*  $f_{n,m}$ . The "best" image enhancement parameter  $\alpha$  is considered to be the one which maximizes the value of the  $CEME$ .

For color image, we can apply the following measure of enhancement calculated on the image gradients:

$$CEME(\hat{f}) = \frac{1}{k_1 k_2} \sum_{k=1}^{k_1} \sum_{l=1}^{k_2} 20 \log_{10} \left[ \frac{\max_{k,l} G_{x+y}(\hat{f})}{\min_{k,l} G_{x+y}(\hat{f})} \right]$$

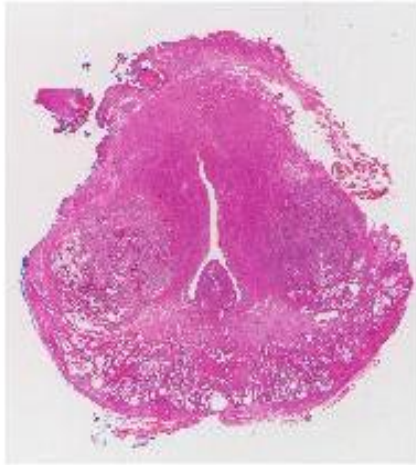
# Experimental Results: Original vs Fast



EMEC: (original) 5.6808  
(RETINEX) 8.5392

EMEC: (original) 5.6808  
(Fast RETINEX) 8.5392

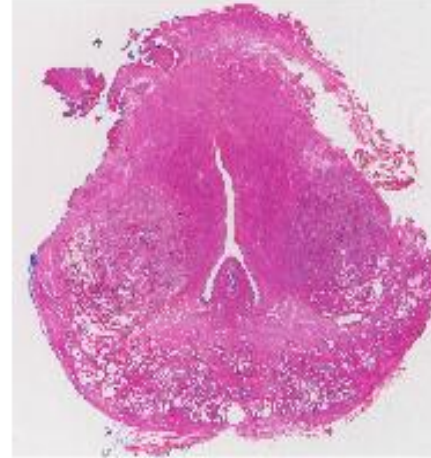
# Experimental Results: Original vs Fast



Original



RETINEX



Original



Fast RETINEX

Imfilter : Processing time: 35.6371s  
(11.0224s)\* (once edited)

EMEC: (original) 15.1640  
(RETINEX) 21.7974

FFT : Processing time: 1.7852s

EMEC: (original) 15.1640  
(RETINEX) 21.7974

# Alpha Rooting (Post Processing)

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$\alpha$ -Rooting is a “Genetic Algorithm” which has the objective of finding the best parameter  $\alpha$  to maximize the EME function and is thus considered a powerful solution to optimization.

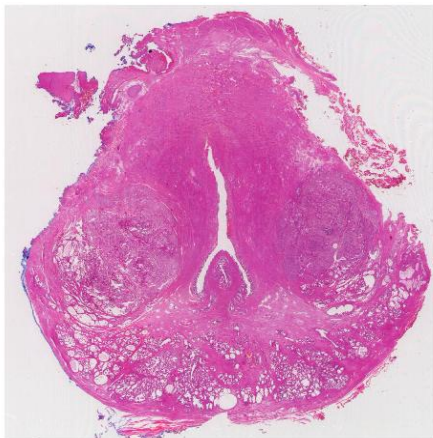
A Fourier based image enhancement method which:

- Transfers image to frequency domain
- Performs a function which modifies the magnitude  $M$
- Transfers back to time domain

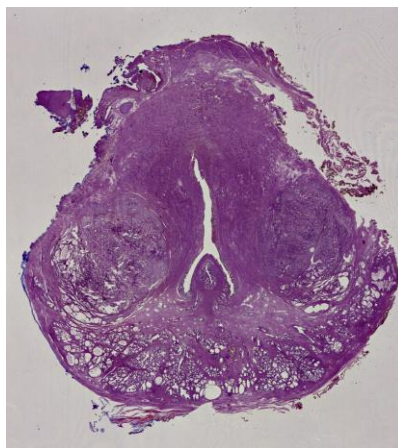




original image

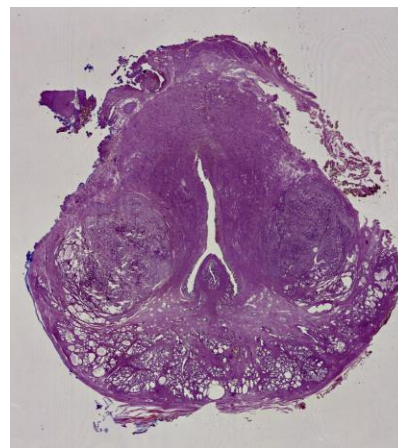


$\alpha$ -rooting by DQFT



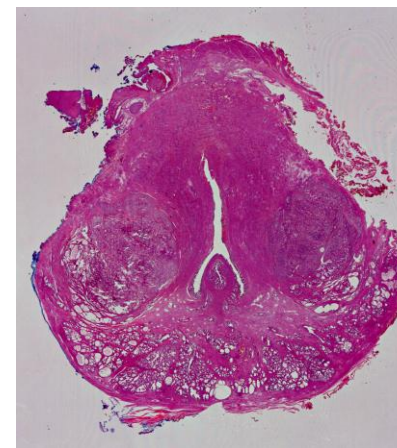
(a)  $\alpha=0.90$

$\alpha$ -rooting by DQFT



(b)  $\alpha=0.92$

rgb-space

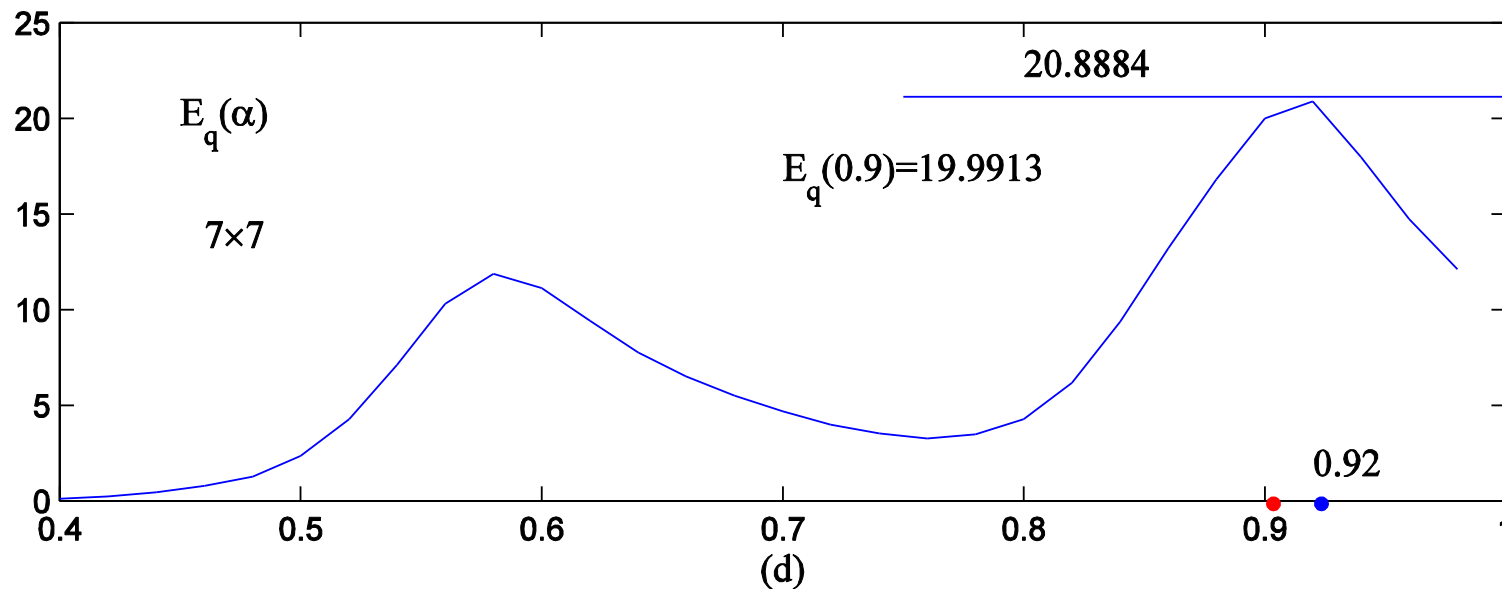


(c) EMEC=20.97

RETINEX using FFT



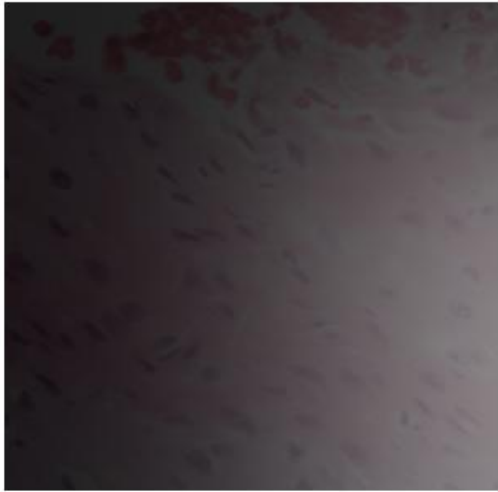
EMEC: (original) 15.1640  
(RETINEX) 21.7974



# Results: RETINEX and Alpha Rooting

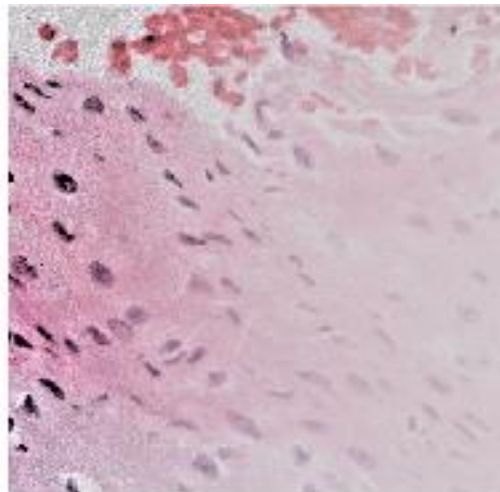
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original image



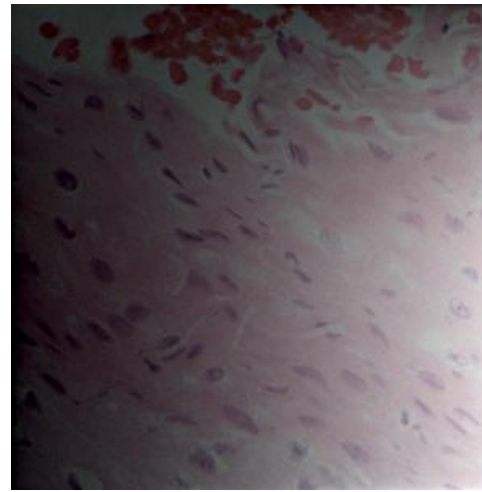
EMEC: 6.0458

RETINEX using FFT



EMEC: 8.2218

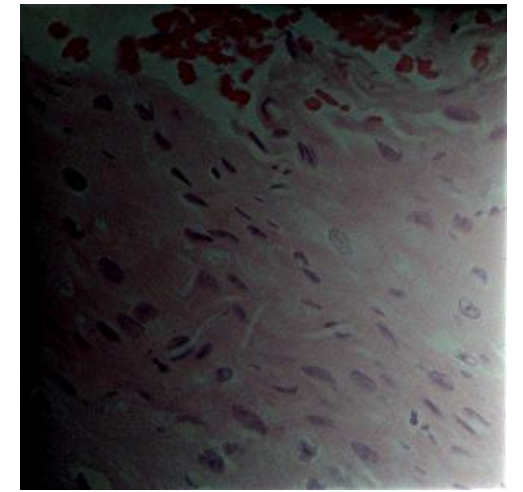
$\alpha$ -rooting by the DQFT



(b)  $\alpha=0.90$

EMEC=10.7507

$\alpha$ -rooting by the DQFT



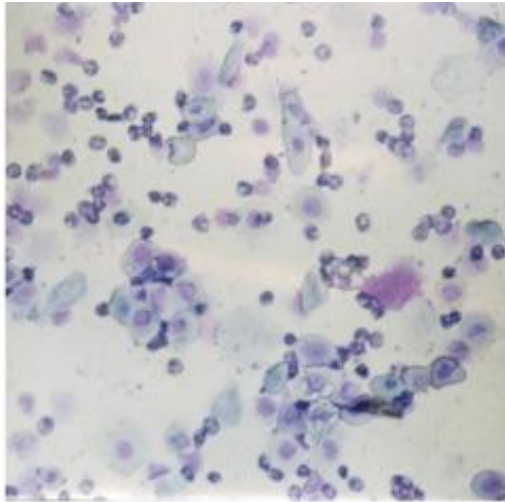
(c)  $\alpha=0.80$

EMEC=12.9091

# Results: RETINEX and Alpha Rooting

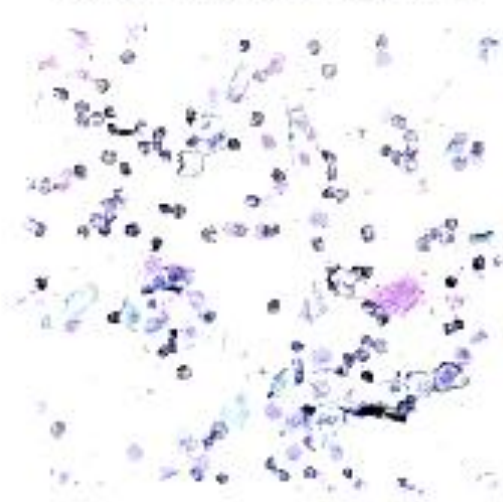
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original image



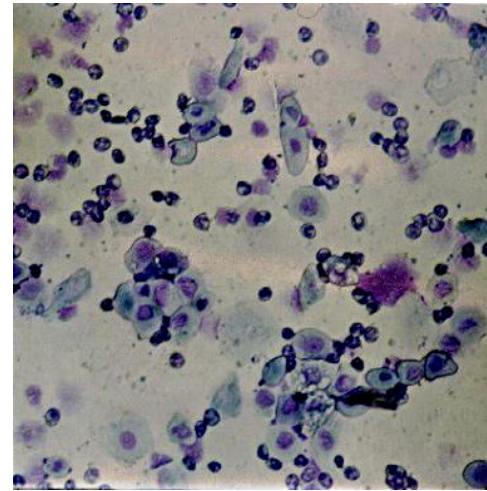
EMEC: 5.6808

RETINEX using FFT



EMEC: 8.5392

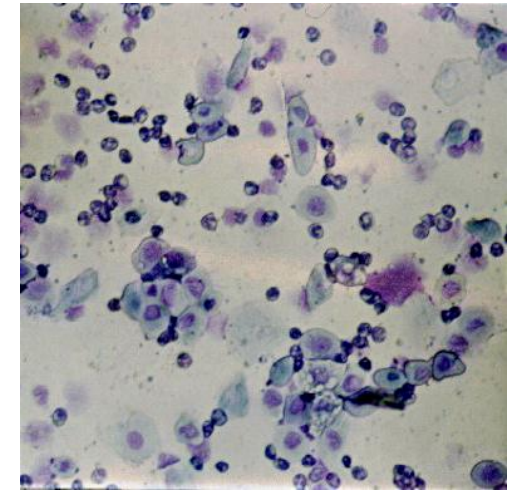
$\alpha$ -rooting by the DQFT



(b)  $a=0.85$

EMEC=10.7507

$\alpha$ -rooting by the DQFT



(c)  $a=0.90$

EMEC=12.9091



# Fusion of Retinex and Alpha Rooting

original image



EMEC: 39.9520

[retinex by H]+SV



EMEC: 34.9638

$\alpha$ -rooting by the DQFT



(b)  $a=0.80$

EMEC=8.9223

$\alpha$ -rooting by the DQFT



(c)  $a=0.90$

EMEC=8.8182

# Conclusion

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- The new measure (EMEC) shows that the result of the original RETINEX algorithm (with center point fixing) and the fast RETINEX algorithm produce identical images.
- Thus the only difference between the two algorithms lies in the processing speed: The fast RETINEX algorithm taking advantage of the fft proved much faster and more efficient than the original RETINEX algorithm using “imfilter” (over 20 second difference)! \*(10s difference with loop-enhanced)
- The effectiveness of alpha rooting output being fused with the result of the RETINEX algorithm may be shown using the EMEC calculation to decide what type of fusion would be best. Individually speaking, both RETINEX and alpha-rooting enhance images in terms of sharpness so further testing to figure out the best combinations is still necessary.

# References

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- [1] W.K. Pratt, Digital Image Processing, New York: Wiley, 2000.
- [2] R.C. Gonzalez and R.E. Woods, Digital Image Processing, 2nd Edition, Prentice Hall, 2002.
- [3] H. J. Trussell, E. Saber, and M. Vrhel, "Color image processing," IEEE Signal Processing Magazine, vol. 22, no.1, pp.14– 22, 2005.
- [4] A.M. Grigoryan and S.S. Aгаian, Multidimensional Discrete Unitary Transforms: Representation, Partitioning, and Algorithms, New York: Marcel Dekker, 2003
- [5] A.M. Grigoryan and S.S. Aгаian, "Transform-based image enhancement algorithms with performance measure," Advances in Imaging and Electron Physics, Academic Press, vol. 130, pp. 165-242, May 2004.
- [6] S.S. Aгаian, K. Panetta, and A.M. Grigoryan, "Transform-based image enhancement algorithms," IEEE Trans. on Image Processing, vol. 10, pp. 367-382, 2001.
- [7] A.M. Grigoryan and S.S. Aгаian, "Retooling of color imaging in the quaternion algebra," Applied Mathematics and Sciences: An International Journal (MathSJ), vol. 1, no. 3, pp. 23-39, December 2014.