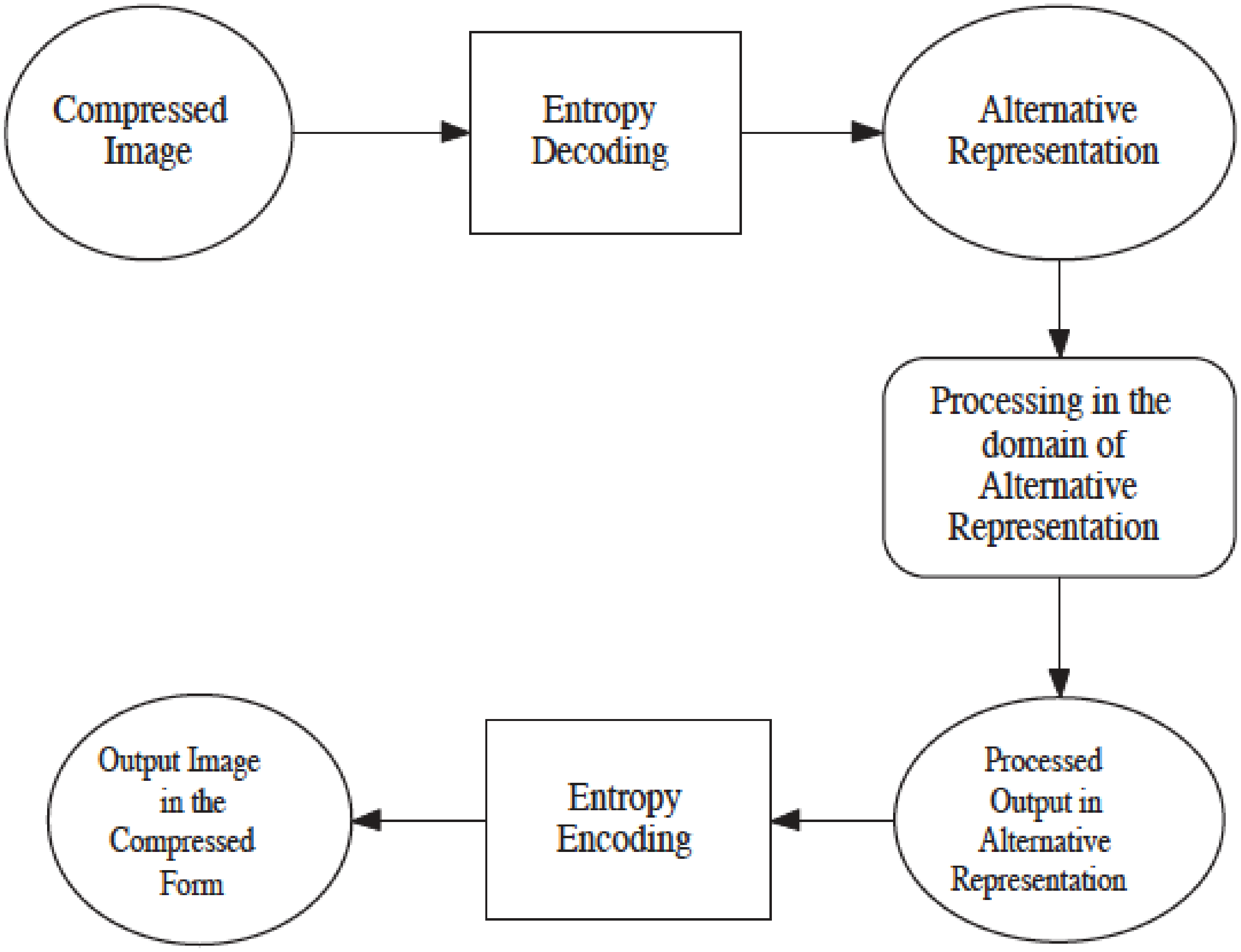
Color image processing in the compressed domain

Jayanta Mukhopadhyay
Dept. of Computer Science and Engg.
Indian Institute of Technology, Kharagpur

Processing with compressed image: Compresed domain approach

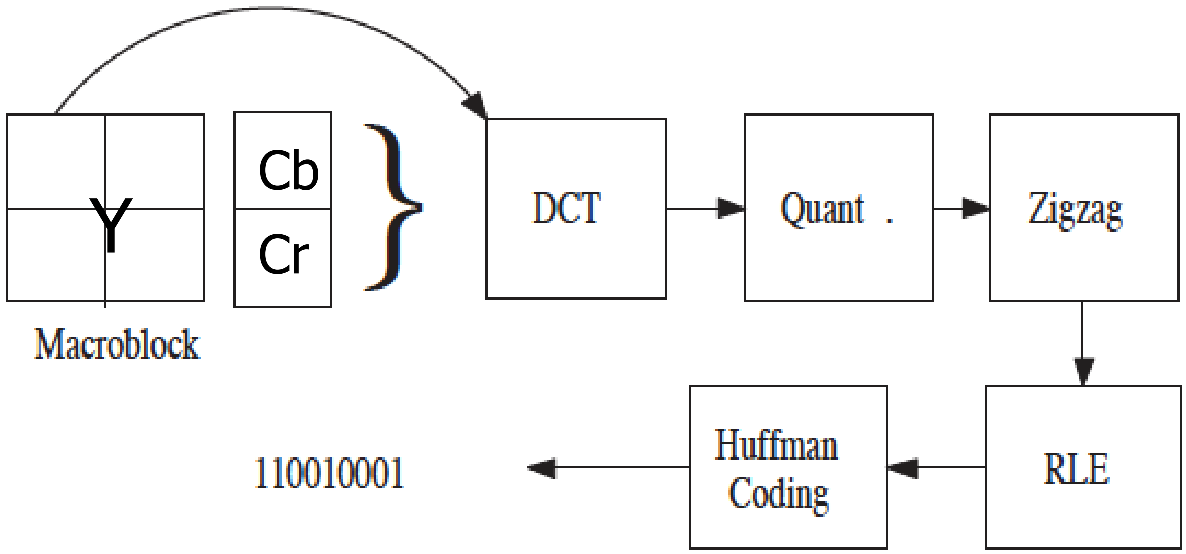


J. Mukhopadhyay, "Image and video processing in the compressed domain", CRC Press, 2011.

Color encoding in JPEG

- Y-Cb-Cr color space:

$$\begin{aligned} Y &= 0.502G + 0.098B + 0.256R, \\ Cb &= -0.290G + 0.438B - 0.148R + 128, \\ Cr &= -0.366G - 0.071B + 0.438R + 128. \end{aligned}$$



Motivations

- Computation with reduced storage.
- Avoid overhead of forward and reverse transform.
- Exploit spectral factorization for improving the quality of result and speed of computation.
- Color Image Processing in DCT domain.
  - Filtering
  - Enhancement
  - Color constancy
  - Resizing

2D DCT

$$\alpha(k) = \begin{cases} \sqrt{\frac{1}{2}} & k = 0 \\ 1 & otherwise \end{cases} \qquad \beta(k) = \begin{cases} \frac{1}{2} & k = 0, N \\ 1 & Otherwise \end{cases}$$

- Type-I Even: $$C_N^I = \left[\sqrt{\frac{2}{N}} \beta(k) \cos\left(\frac{\pi k n}{N}\right) \right]_{0 \le (k,n) \le N}$$
- Type-II Even: $$C_N^{II} = \left[\sqrt{\frac{2}{N}} \alpha(k) \cos\left(\frac{\pi k (2n+1)}{2N}\right) \right]_{0 \le (k,n) \le N-1}$$
- Type-I DCT of $h(m,n)$: $$H = C_M^I h C_N^{I^T}$$
- Type-II DCT of $x(m,n)$: $$X = C_M^{II} x C_N^{II^T}$$

Useful properties of DCT blocks

2D DCT: Sub-band relation

$$x_{LL}(m,n) = \frac{1}{4}\{x(2m,2n)+x(2m+1,2n) +x(2m,2n+1)+x(2m+1,2n+1)\},\ 0 \le m,n \le \frac{N}{2}-1.$$

Sub-band approximation:

2D DCT of $x_{LL}(m,n)$

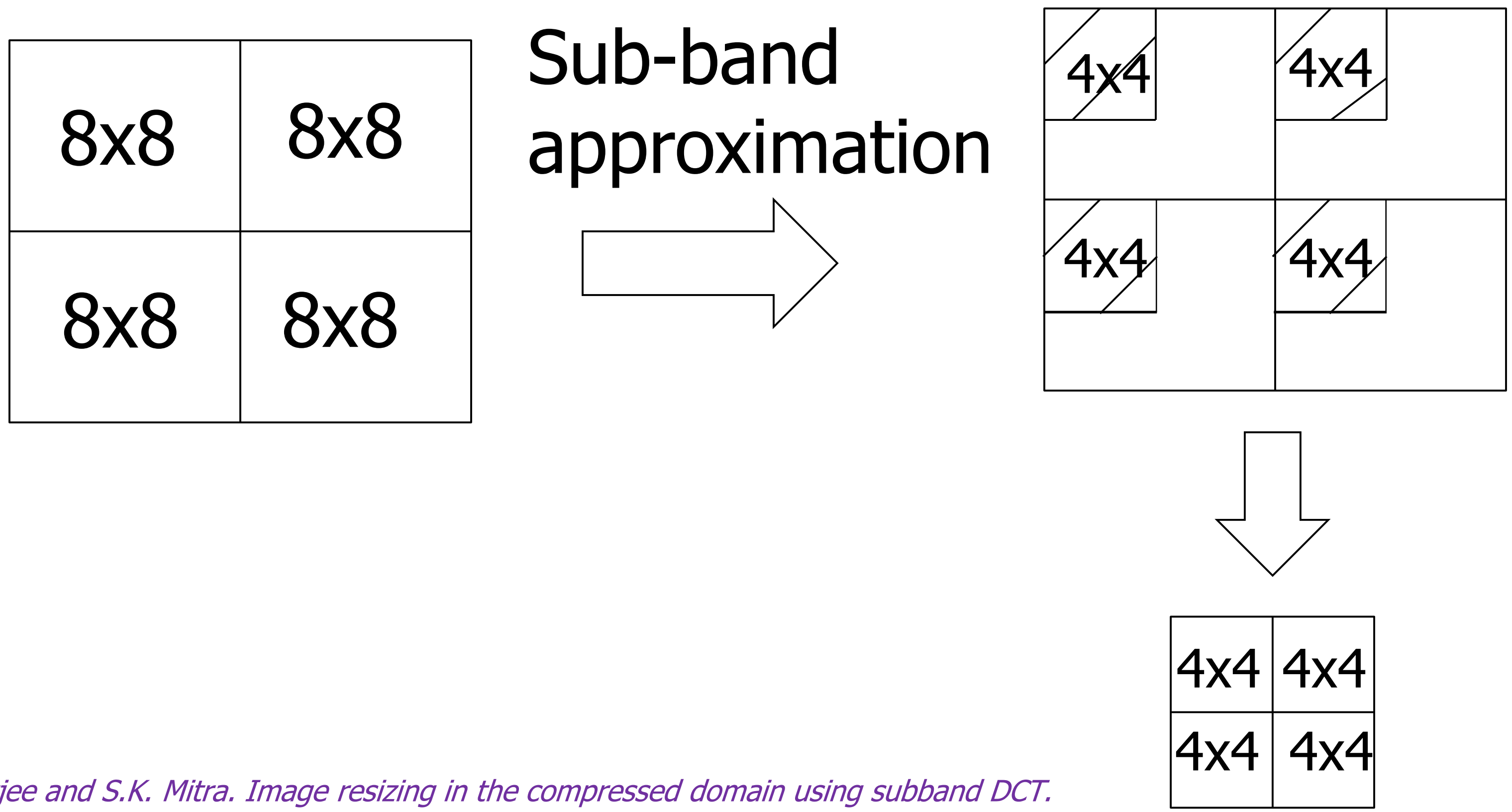
$$X(k,l) = \begin{cases} 2cos(\frac{\pi k}{2N})\cos(\frac{\pi l}{2N})\overline{X_{LL}}(k,l), & k,l = 0,1,......,\frac{N}{2}-1 \\ 0, & \text{otherwise.} \end{cases}$$

Low-pass truncated approximation:

$$X(k,l) = \begin{cases} 2\overline{X_{LL}}(k,l), & k,l = 0,1,......,\frac{N}{2}-1 \\ 0, & \text{otherwise.} \end{cases}$$

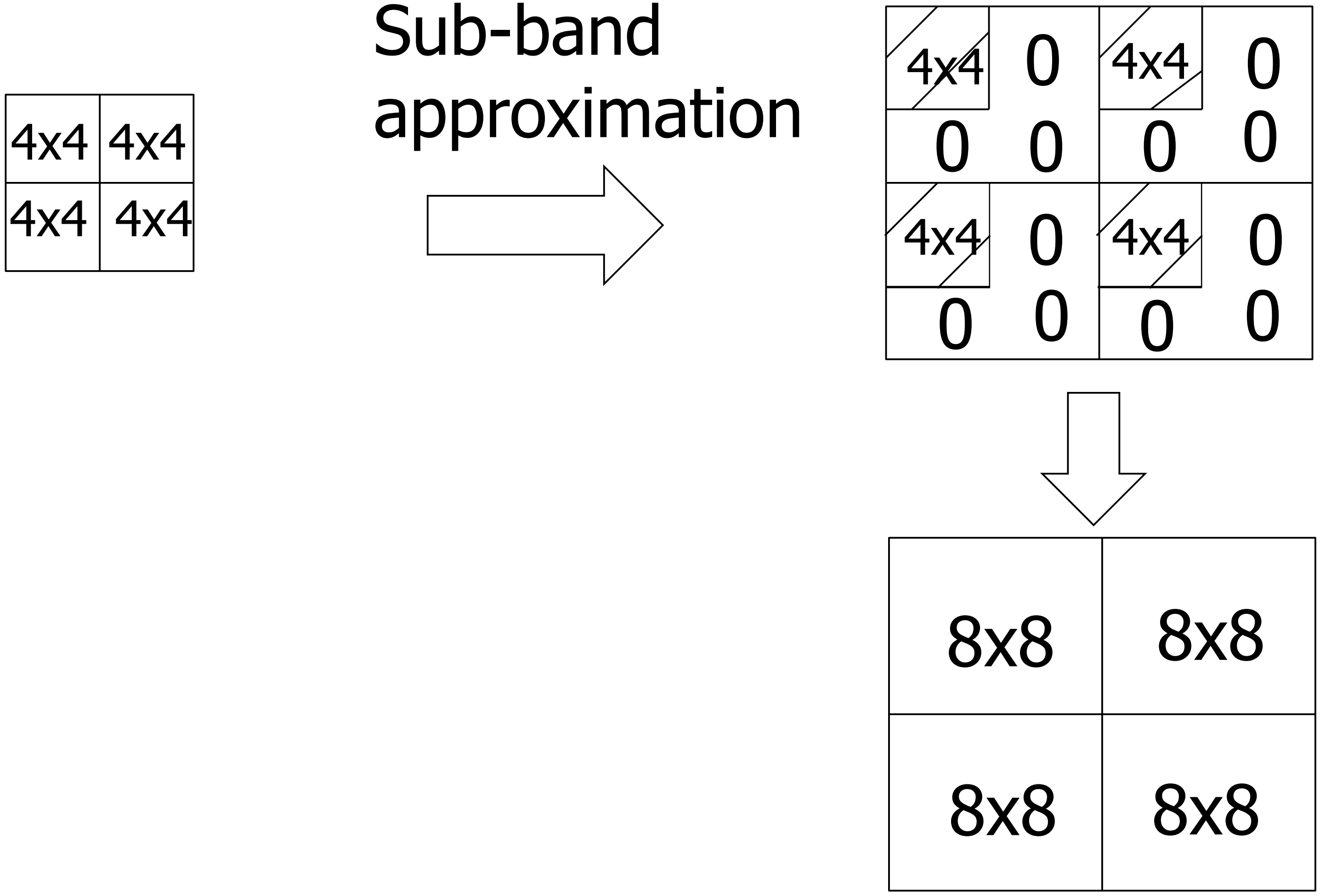
S.-H. Jung, S.K. Mitra, and D. Mukherjee, Subband DCT: Definition, analysis and applications. IEEE Trans. on Circuits and systems for VideoTechnology, 6(3):273–286, June 1996.

Image downsampling



J. Mukherjee and S.K. Mitra. Image resizing in the compressed domain using subband DCT. IEEE Transactions on Circuits and systems for Video Technology, 12(7):620–627, July 2002.

Image upsampling



2D DCT: Block composition and decomposition

$$X^{(LN\times MN)} = A_{(L,N)} \begin{bmatrix} X_{0,0}^{(N\times N)} & X_{0,1}^{(N\times N)} & \cdots & X_{0,M-1}^{(N\times N)} \\ X_{1,0}^{(N\times N)} & X_{1,1}^{(N\times N)} & \cdots & X_{1,M-1}^{(N\times N)} \\ \vdots & \vdots & \ddots & \vdots \\ X_{L-1,0}^{(N\times N)} & X_{L-1,1}^{(N\times N)} & \cdots & X_{L-1,M-1}^{(N\times N)} \end{bmatrix} A_{(M,N)}^{T}$$

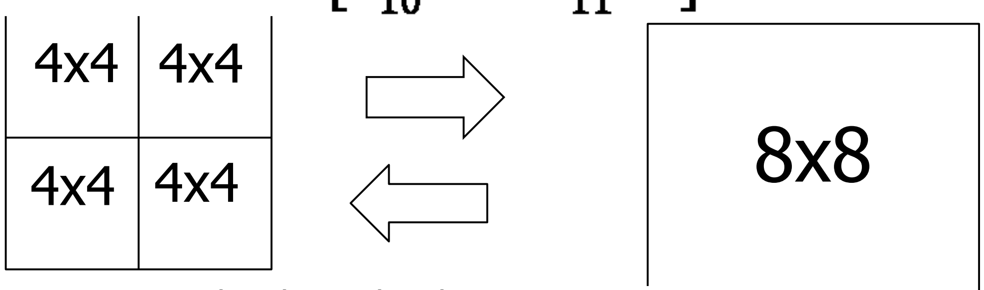
$$\begin{bmatrix} X_{0,0}^{(N\times N)} & X_{0,1}^{(N\times N)} & \cdots & X_{0,M-1}^{(N\times N)} \\ X_{1,0}^{(N\times N)} & X_{1,1}^{(N\times N)} & \cdots & X_{1,M-1}^{(N\times N)} \\ \vdots & \vdots & \ddots & \vdots \\ X_{L-1,0}^{(N\times N)} & X_{L-1,1}^{(N\times N)} & \cdots & X_{L-1,M-1}^{(N\times N)} \end{bmatrix} = A_{(L,N)}^{-1} X^{(LN\times MN)} A_{(M,N)}^{-1^{T}}$$

J. Jiang and G. Feng. The spatial relationships of DCT coefficients between a block and its sub-blocks. IEEE Trans. on Signal Processing, 50(5):1160–1169, May 2002.

Block composition and decomposition

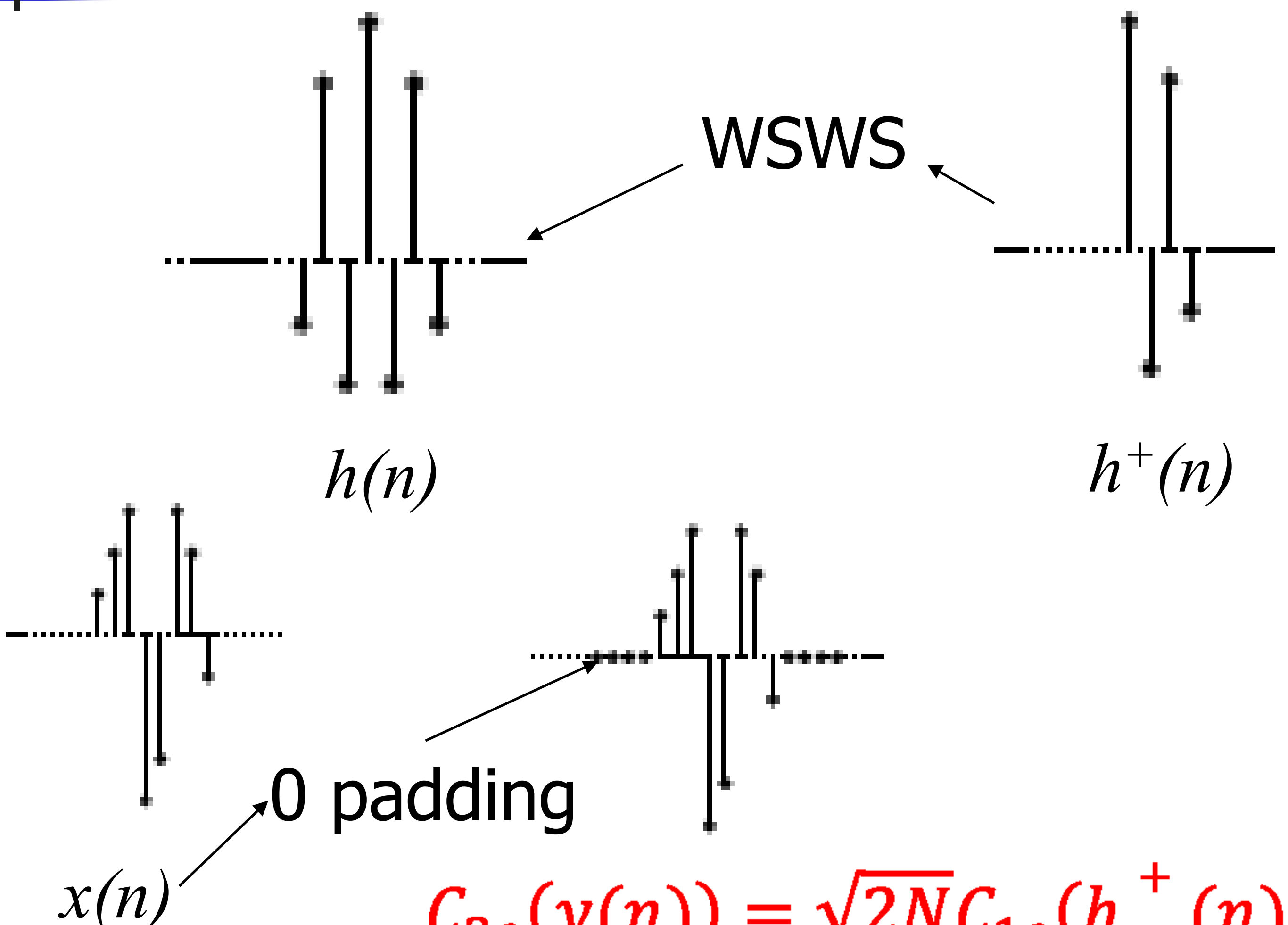
$$
\begin{aligned}
A_{(2,4)} &= C_8.\begin{bmatrix} C_4^{-1} & 0_4 \\ 0_4 & C_4^{-1} \end{bmatrix} \\
&= \begin{bmatrix}
0.7071 & 0 & 0 & 0 & 0.7071 & 0 & 0 & 0 \\
0.6407 & 0.294 & -0.0528 & 0.0162 & -0.6407 & 0.294 & 0.0528 & 0.0162 \\
0 & 0.7071 & 0 & 0 & 0 & 0.7071 & 0 & 0 \\
-0.225 & 0.5594 & 0.3629 & -0.0690 & 0.225 & 0.5594 & -0.3629 & -0.069 \\
0 & 0 & 0.7071 & 0 & 0 & 0 & 0.7071 & 0 \\
0.1503 & -0.2492 & 0.5432 & 0.3468 & -0.1503 & -0.2492 & -0.5432 & 0.3468 \\
0 & 0 & 0 & 0.7071 & 0 & 0 & 0 & -0.7071 \\
-0.1274 & 0.1964 & -0.2654 & 0.6122 & 0.1274 & 0.1964 & 0.2654 & 0.6122
\end{bmatrix}.
\end{aligned}
$$

$$X^{(8\times8)} = A_{(2,4)} \begin{bmatrix} X_{00}^{(4\times4)} & X_{01}^{(4\times4)} \\ X_{10}^{(4\times4)} & X_{11}^{(4\times4)} \end{bmatrix} A_{(2,4)}^T$$



$$\begin{bmatrix} X_{00}^{(4\times4)} & X_{01}^{(4\times4)} \\ X_{10}^{(4\times4)} & X_{11}^{(4\times4)} \end{bmatrix} = A_{(2,4)}^{-1} X^{(8\times8)} A_{(2,4)}^{-T}$$

Symmetric convolution and CMP for type II DCT



$$C_{2e}(y(n)) = \sqrt{2N}\,C_{1e}(h^{+}(n))\,C_{2e}(x(n))$$

CONVOLUTION-MULTIPLICATION PROPERTY

$x(n) \longrightarrow \boxed{h(n)} \longrightarrow y(n) = h(n) * x(n)$

$\Updownarrow$ **•Symmetric convolution operation**

$X_{II}(k) \longrightarrow \boxed{H_I(k)} \longrightarrow Y_{II}(k) = H_I(k).X_{II}(k)$

$$Y_{II}^{(N)} = \begin{bmatrix} H_{I,0} & 0 & 0 & 0 \\ 0 & H_{I,1} & 0 & 0 \\ 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & H_{I,N-1} \end{bmatrix} X_{II}^{(N)}$$

$diag(H_I)$

Diagonal matrix formed by $H_I(k)$

2D DCT: CMPs

Circular convolution with respective symmetric extensions.

$$C_{2e}\{x(m,n) \maltese h(m,n)\} = C_{2e}\{x(m,n)\}C_{1e}\{h(m,n)\}$$

$$C_{1e}\{x(m,n) \maltese h(m,n)\} = C_{2e}\{x(m,n)\}C_{2e}\{h(m,n)\}$$

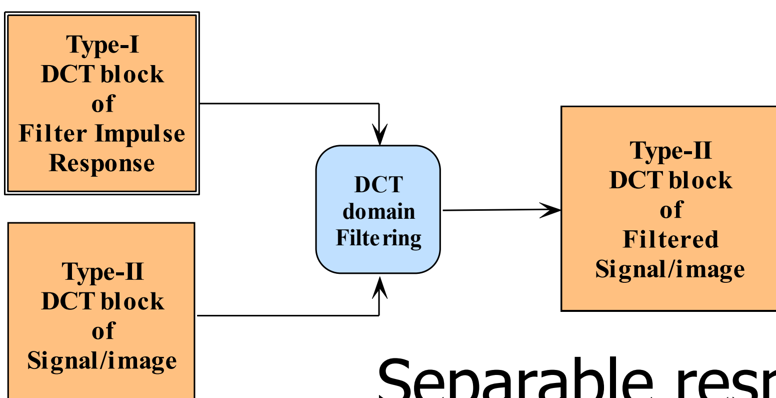
S.A. Martucci. Symmetric convolution and the discrete sine and cosine transforms. IEEE Trans. on Signal Processing, 42(5):1038–1051, May, 1994.

DCT Domain Filtering

Filtering in 2-D block DCT space

Given, **type-I DCT** of the impulse response of a filter and an input in **type-II DCT space**, filtered output can be transformed in the same space (i.e. type-II DCT space).

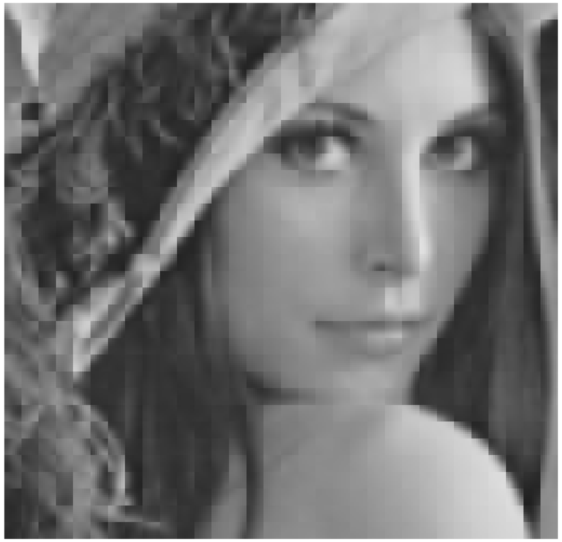
$$
\begin{aligned}
Y_{II}^{(N\times N)} &= \left(diag(H_I)\left(diag(H_I)X_{II}^{(N\times N)}\right)^T\right)^T \\
&= diag(H_I)X_{II}^{(N\times N)}diag(H_I)^T \\
&= diag(H_I)X_{II}^{(N\times N)}diag(H_I)
\end{aligned}
$$



Separable response: $h(x,y)=h(x)h(y)$

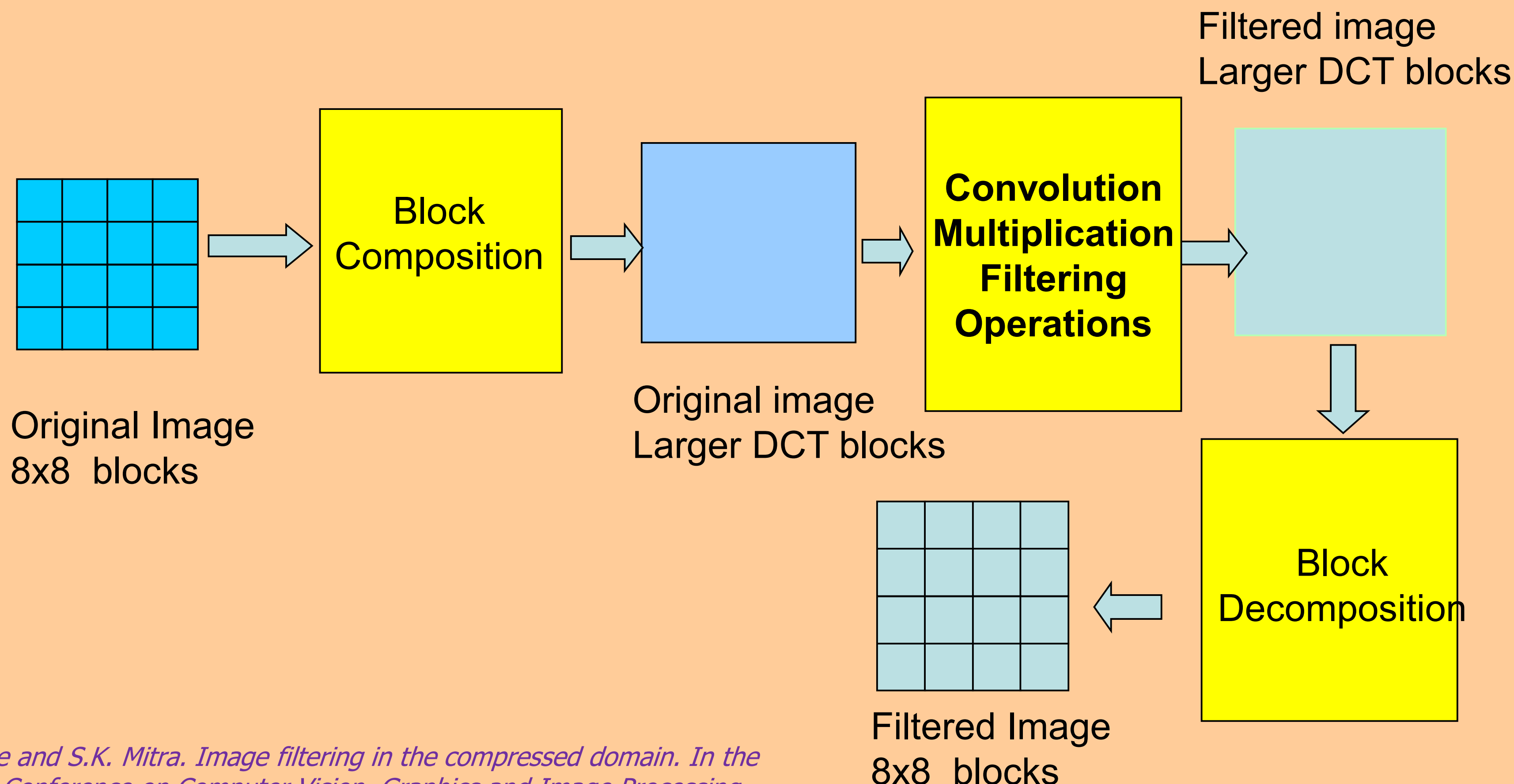
BOUNDARY EFFECT IN BLOCK DCT DOMAIN

Linear Convolution



Block Symmetric Convolution

Computation with larger blocks: The BFCD filtering Algorithm



J. Mukherjee and S.K. Mitra. Image filtering in the compressed domain. In the Fifth Indian Conference on Computer Vision, Graphics and Image Processing, pages 194–205, Madurai, India, Dec. 14-16 2006. LNCS- 4338.

Composite operation

- Block composition + Multiplication with filter coefficients + Block decomposition can be expressed by a composite matrix for the linear operation.

In 1-D: For filtering 3 NxN adjacent DCT blocks:

$$U^{(3N\text{x}3N)} = A^T_{(3,N)}\,\mathbb{D}(\{\sqrt{6N}\,C^I_{3N}\,\mathbf{h}^+\}_0^{3N-1})\,A_{(3,N)}$$

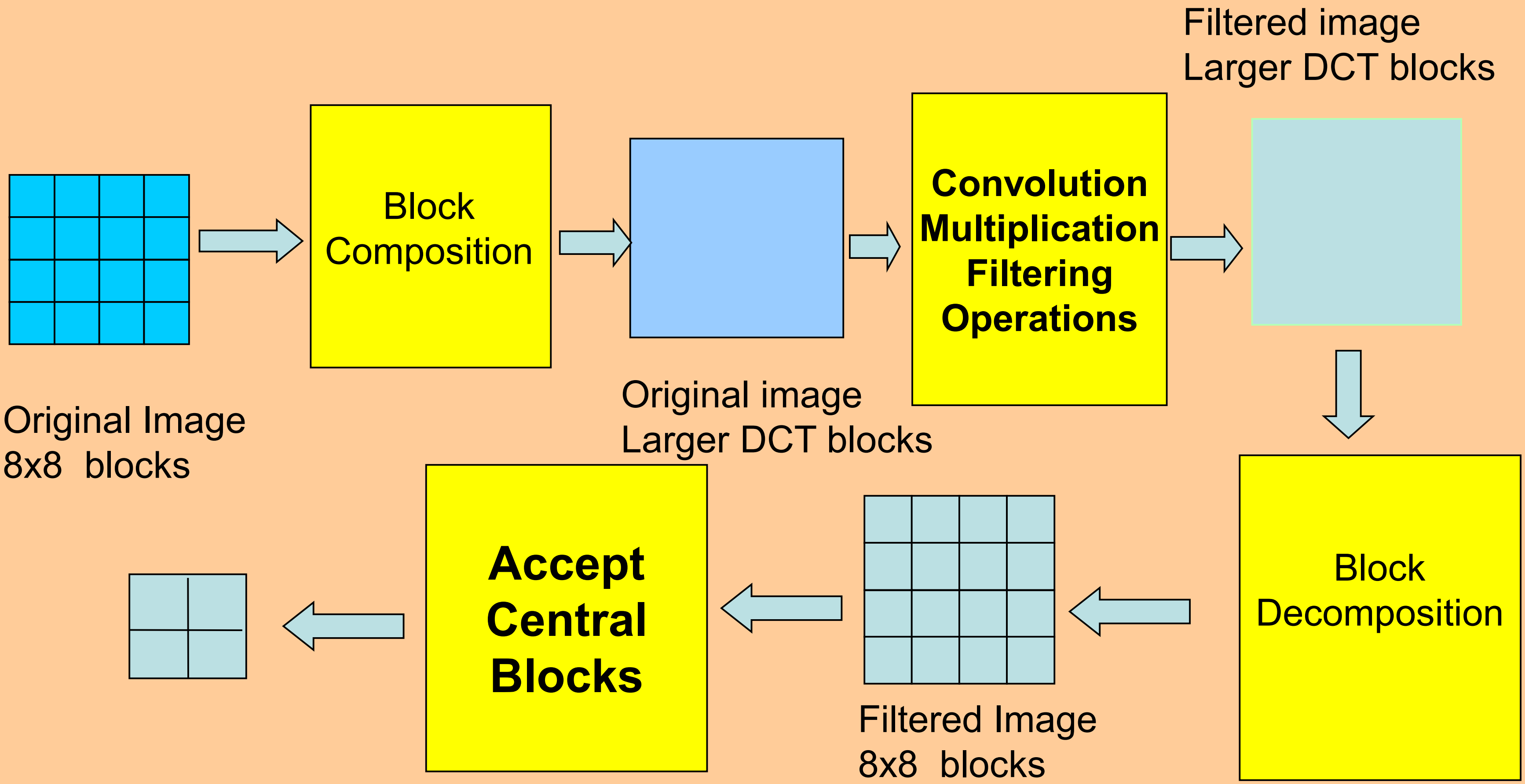
Decomp. Multiplication Composition

$$\begin{bmatrix} Y_1^{(N)} \\ Y_2^{(N)} \\ Y_3^{(N)} \end{bmatrix} = U \begin{bmatrix} X_1^{(N)} \\ X_2^{(N)} \\ X_3^{(N)} \end{bmatrix}$$

In 2-D

$$\begin{bmatrix} Y_{11}^{(N\times N)} & Y_{12}^{(N\times N)} & Y_{13}^{(N\times N)} \\ Y_{21}^{(N\times N)} & Y_{22}^{(N\times N)} & Y_{23}^{(N\times N)} \\ Y_{31}^{(N\times N)} & Y_{32}^{(N\times N)} & Y_{33}^{(N\times N)} \end{bmatrix} = U \begin{bmatrix} X_{11}^{(N\times N)} & X_{12}^{(N\times N)} & X_{13}^{(N\times N)} \\ X_{21}^{(N\times N)} & X_{22}^{(N\times N)} & X_{23}^{(N\times N)} \\ X_{31}^{(N\times N)} & X_{32}^{(N\times N)} & X_{33}^{(N\times N)} \end{bmatrix} U^T$$

Exact Computation: The Overlapping and Save (OBFCD) filtering Algorithm



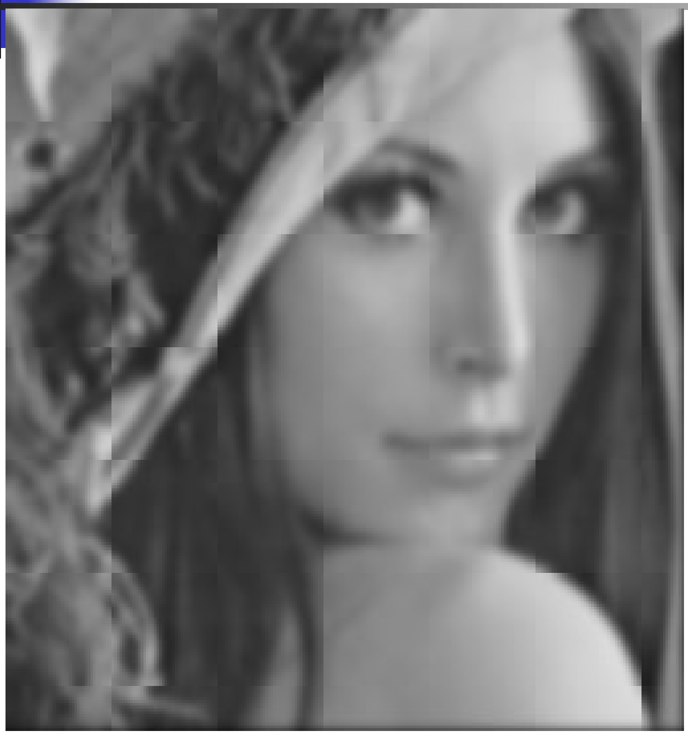
J. Mukherjee and S.K. Mitra. Image filtering in the compressed domain. In Fifth Indian Conference on Computer Vision, Graphics and Image Processing, pages 194–205, Madurai, India, Dec. 14-16 2006. LNCS- 4338.

Overlap and Save Strategy

$$\begin{bmatrix} Y_{11}^{(N\times N)} & Y_{12}^{(N\times N)} & Y_{13}^{(N\times N)} \\ Y_{21}^{(N\times N)} & \color{red}{Y_{22}^{(N\times N)}} & Y_{23}^{(N\times N)} \\ Y_{31}^{(N\times N)} & Y_{32}^{(N\times N)} & Y_{33}^{(N\times N)} \end{bmatrix} = U \begin{bmatrix} X_{11}^{(N\times N)} & X_{12}^{(N\times N)} & X_{13}^{(N\times N)} \\ X_{21}^{(N\times N)} & X_{22}^{(N\times N)} & X_{23}^{(N\times N)} \\ X_{31}^{(N\times N)} & X_{32}^{(N\times N)} & X_{33}^{(N\times N)} \end{bmatrix} U^T$$

Save only the central block.

Filtered Images



BFCD Algorithm (5x5)

OBFCD Algorithm

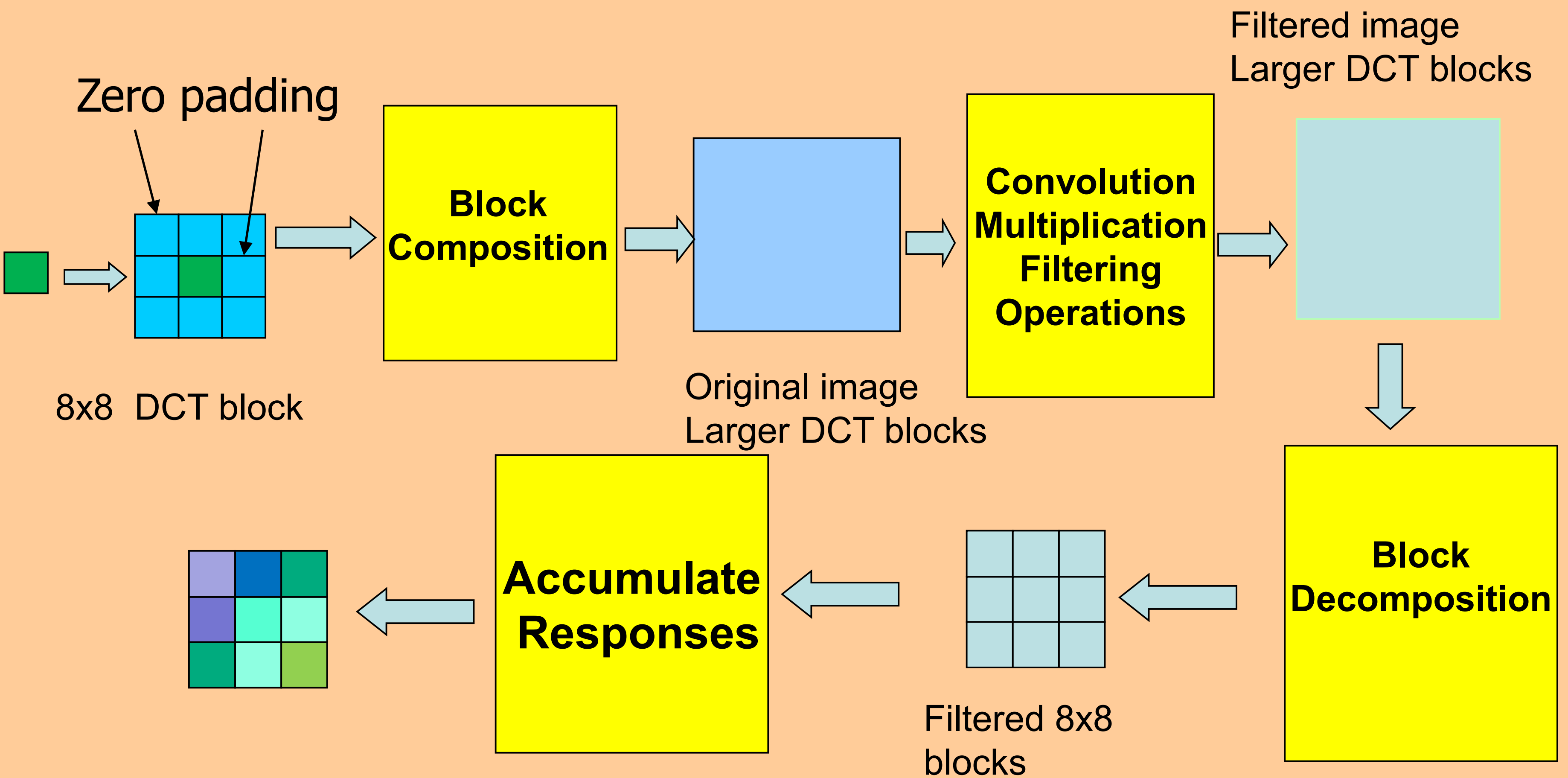
J. Mukherjee and S.K. Mitra. Image filtering in the compressed domain. In Fifth Indian Conference on Computer Vision, Graphics and Image Processing, pages 194–205, Madurai, India, Dec. 14-16 2006. LNCS- 4338.

Overlap and add strategy

$$\begin{bmatrix} Y_{11}^{(N\times N)} & Y_{12}^{(N\times N)} & Y_{13}^{(N\times N)} \\ Y_{21}^{(N\times N)} & Y_{22}^{(N\times N)} & Y_{23}^{(N\times N)} \\ Y_{31}^{(N\times N)} & Y_{32}^{(N\times N)} & Y_{33}^{(N\times N)} \end{bmatrix} = U \begin{bmatrix} X_{11}^{(N\times N)} & X_{12}^{(N\times N)} & X_{13}^{(N\times N)} \\ X_{21}^{(N\times N)} & X_{22}^{(N\times N)} & X_{23}^{(N\times N)} \\ X_{31}^{(N\times N)} & X_{32}^{(N\times N)} & X_{33}^{(N\times N)} \end{bmatrix} U^T$$

- For computing contribution of the central block X_{22} to neighboring blocks all other blocks in the input set to zeros.
- Add accumulated contribution at every block.

Exact Computation: The Overlapping and Add filtering Algorithm



J. Mukhopadhyay. Isolating neighbor's contribution towards image filtering in the block DCT space. In IEEE Int. Conf. on Image Processing (ICIP), Hong Kong, Sept. 25-30 2010. IEEE.

Removal of Blocking Artifacts

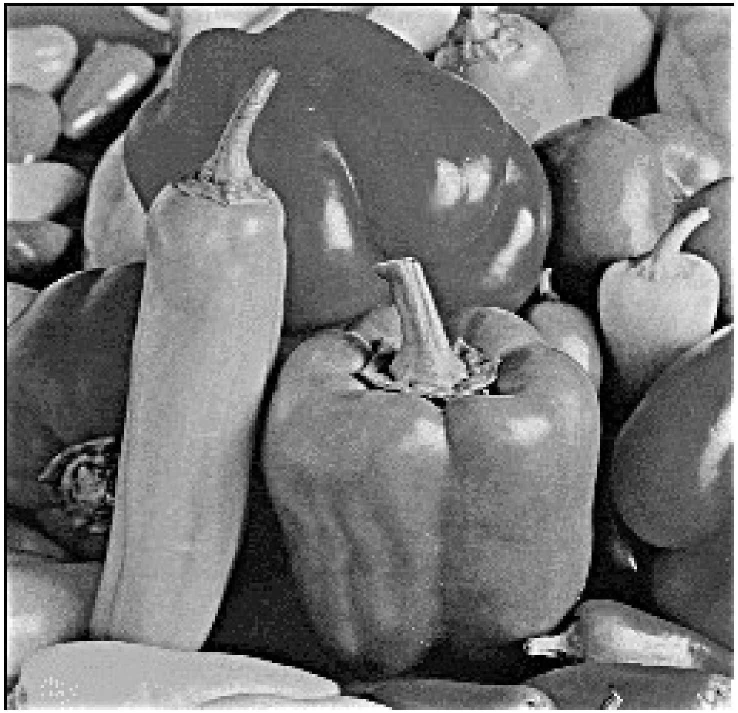
Blocking artifacts Compressed with quality factor 10

Artifacts removed By filtering in DCT domain

Image Sharpening in DCT domain

$$X_s = X + k.\,(X - X_{lpf})$$

Lena



Peppers

J. Mukhopadhyay, "Image and video processing in the compressed domain", CRC Press, 2011.

Color preservation in the compressed domain

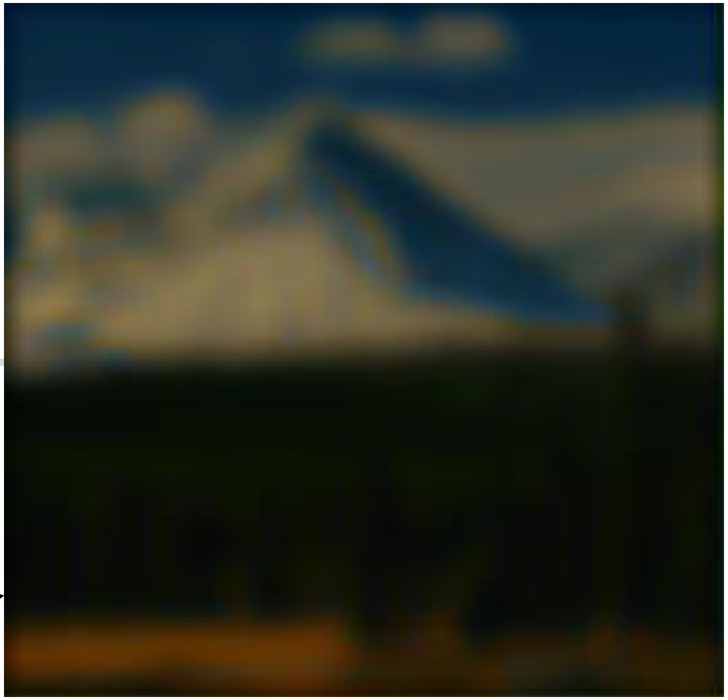
$$
\begin{aligned}
Y &= 0.502G + 0.098B + 0.256R, \\
Cb &= -0.290G + 0.438B - 0.148R + 128, \\
Cr &= -0.366G - 0.071B + 0.438R + 128.
\end{aligned}
$$

- R-G-B to Y-Cb-Cr : Affine
- R-G-B to Y-Cb'-Cr', where Cb'=Cb-128 & Cr'=Cr-128: Linear
- DC of a Y-block (Y_{dc}) scaled by a factor k.
- Corresponding Cb'_{dc} and Cr'_{dc} should also be scaled by a factor k for color preservation.
- Transform Cb'_{dc} and Cr'_{dc} to Cb_{dc} and Cr_{dc} then by simple addition.
  - $Cb_{dc} = Cb'_{dc} + 128N$ $Cr_{dc} = Cr'_{dc} + 128N$

Color Sharpening

Original

Filtered



Sharpened

Color Saturation and Desaturation

CIE chromaticity chart

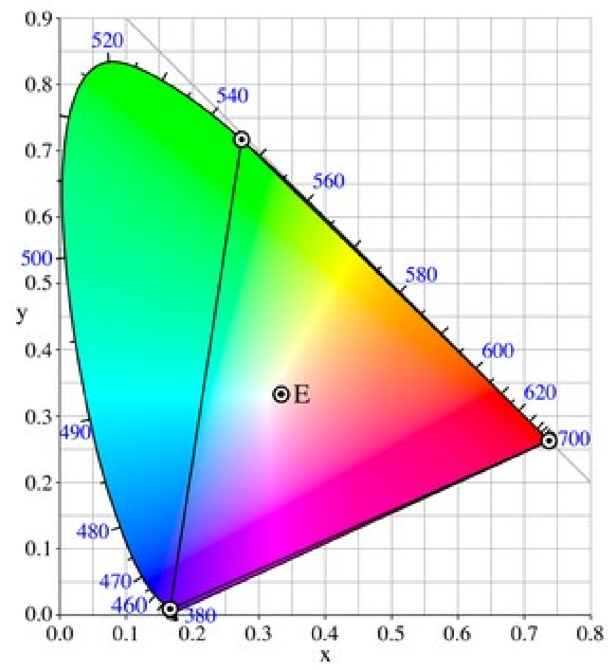
- The Commission Internationale de l'Eclairage (estd. 1931) defined 3 hypothetical additive primaries: X, Y, Z

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.6067 & 0.1736 & 0.2001 \\ 0.2988 & 0.5868 & 0.1143 \\ 0.0000 & 0.0661 & 1.1149 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

- Normalized x-y space:

$$x = X/(X+Y+Z)$$

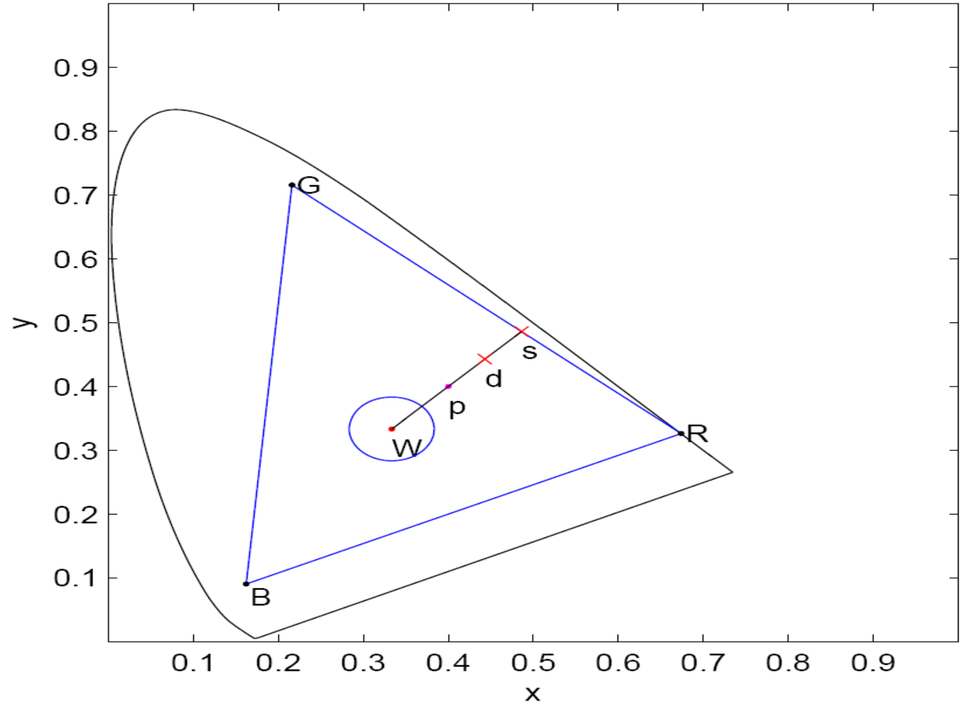
$$y = Y/(X+Y+Z)$$



http://en.wikipedia.org/wiki/CIE_1931_color_space

Saturation and De-saturation Operation

- Move radially to the gamut edge → Maximum Saturation given a hue.
- Move inward using center of gravity law of color mixing.



Luca Lucchese, SK Mitra, J Mukherjee, A new algorithm based on saturation and desaturation in the xy chromaticity diagram for enhancement and re-rendition of color images, ICIP 2001.

Desaturation using Center of Gravity Law

The *Center of Gravity Law* provides the resulting color $C_2 = (x_2, y_2, Y_2)$ of the mixture of the two colors $W = (x_W, y_W, |Y_W|)$ and $S = (x_S, y_S, Y_1)$ where

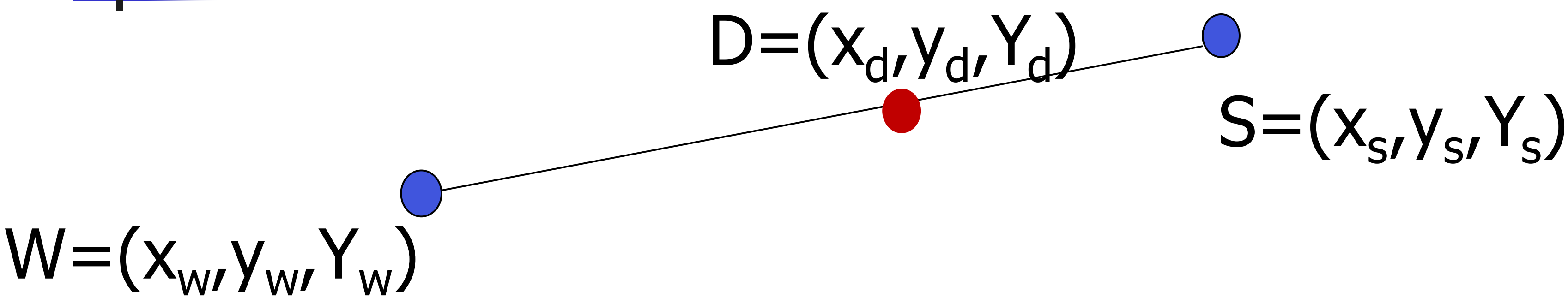
$$x_2 = \frac{x_W \frac{|Y_W|}{y_W} + x_S \frac{Y_1}{y_S}}{\frac{|Y_W|}{y_W} + \frac{Y_1}{y_S}}, \quad y_2 = \frac{|Y_W| + Y_1}{\frac{|Y_W|}{y_W} + \frac{Y_1}{y_S}}, \quad \text{and} \quad Y_2 = Y_W + Y_1. \tag{3}$$

$$Y_W = \kappa Y_{avg}$$

Apparent masses for chromatic mixture: Y_W/y_W and Y_1/y_S.

Hunt, R.: Measuring Colour, 2nd Ed. Ellis Horwood Ltd. Publ., Chichester, UK (1987)

Desaturation using Center of Gravity Law



$$x_d = \frac{x_w \frac{|Y_w|}{y_w} + x_s \frac{|Y_s|}{y_s}}{\frac{|Y_w|}{y_w} + \frac{|Y_s|}{y_s}}$$

$$y_d = \frac{|Y_w| + Y_s}{\frac{|Y_w|}{y_w} + \frac{|Y_s|}{y_s}}$$

$$Y_d = |Y_w| + Y_s$$

$$Y_w = kY_{avg}$$

Hunt, R.: Measuring Colour, 2nd Ed. Ellis Horwood Ltd. Publ., Chichester, UK (1987)

nCb-nCr color space

$$nCb = \frac{Cb - 128}{aY + b(Cb - 128) + c(Cr - 128)}$$

$$nCr = \frac{Cr - 128}{aY + b(Cb - 128) + c(Cr - 128)}$$

a=3.51
b=1.99
c=0.14

$$\begin{bmatrix} nCb \\ nCr \end{bmatrix} = \begin{bmatrix} -0.6823 & -0.7724 \\ 1.532 & -0.6047 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} 0.4849 \\ -0.3091 \end{bmatrix}$$

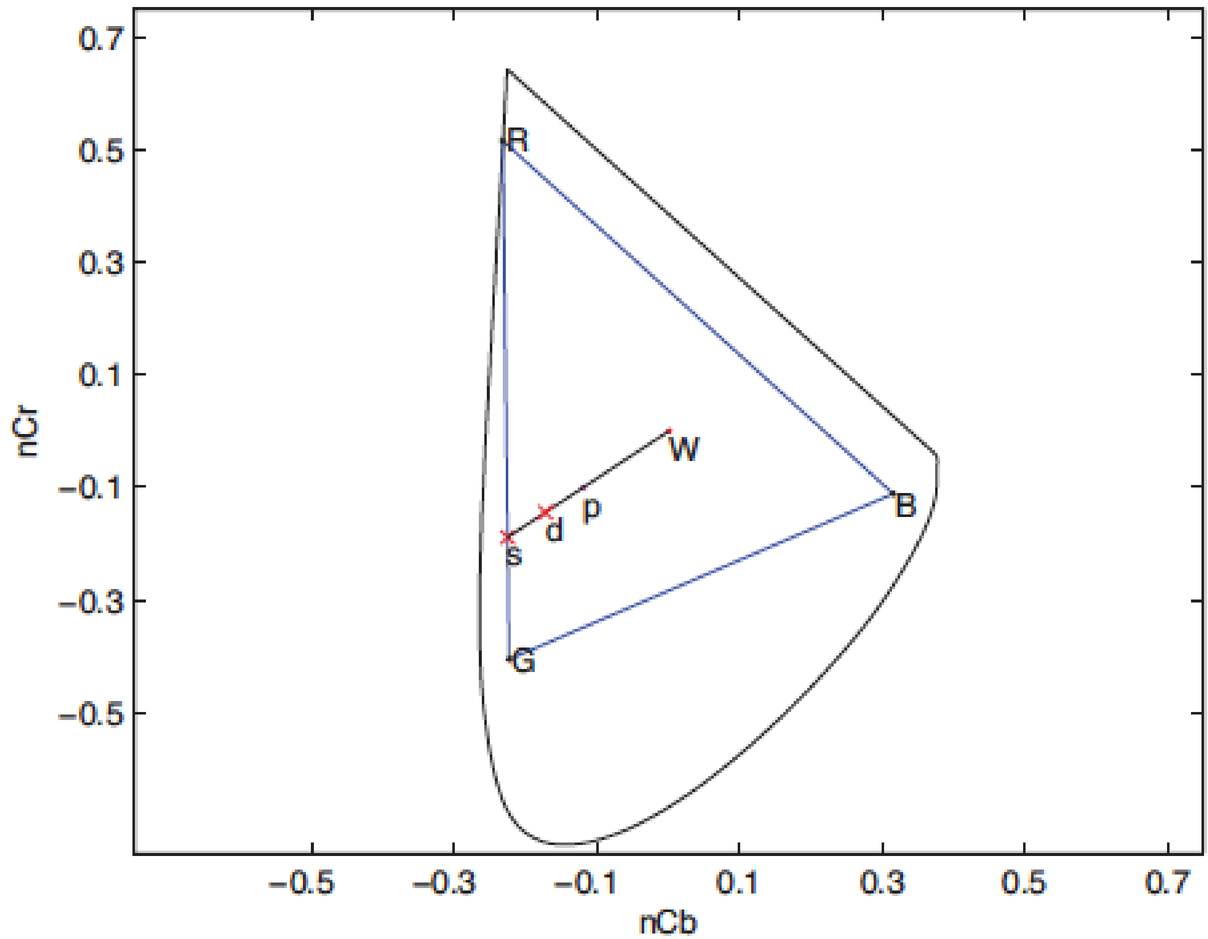
$$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} -0.3789 & 0.484 \\ -0.96 & -0.4275 \end{bmatrix} \begin{bmatrix} nCb \\ nCr \end{bmatrix} + \begin{bmatrix} \frac{1}{3} \\ \frac{1}{3} \end{bmatrix}$$

J. Mukhopadhyay, "Image and video processing in the compressed domain", CRC Press, 2011.

Cb-Cr from nCb-nCr given Y

$$\begin{bmatrix} Cb_s \\ Cr_s \end{bmatrix} = a.Y \begin{bmatrix} 1 - b.nCb & -c.nCb \\ -b.nCr & 1 - c.nCr \end{bmatrix}^{-1} \begin{bmatrix} nCb \\ nCr \end{bmatrix} + \begin{bmatrix} 128 \\ 128 \end{bmatrix}.$$

Saturation and De-saturation Operation in nCbCr space



J. Mukhopadhyay, "Image and video processing in the compressed domain", CRC Press, 2011.

Chromatic Shift in Cb-Cr space

- The ratio of (Cb-128) and (Cr-128) preserves the hue.
- Shift the (Cb,Cr) point along the line joining from (128,128) to it.
- Equivalent to saturation and desaturation operation.

original

Max-sat

Sat-desat

Chromatic-shift

original

Max-sat

Sat-desat

Chromatic-shift

Color Enhancement

Contrast : Definition

Weber Law: $\zeta = \frac{\Delta L}{L}$

where ΔL is the difference in luminance between a stimulus and its surround, and L is the luminance of the surround

μ: mean of a block ← DC coefficient of the block

σ: standard deviation of a block ← Sum of AC coefficients

Contrast ζ of an image is defined here as: .

$$\zeta = \frac{\sigma}{\mu}$$

Theorem on Contrast Preservation in the DCT Domain

κ_d: the scale factor for the DC coefficient
κ_a : the scale factor for the AC coefficients

$$Y_e(i,j) = \begin{cases} \kappa_d Y(i,j), & i=j=0 \\ \kappa_a Y(i,j), & otherwise \end{cases}$$

The contrast of the processed image : κ_a / κ_d times of the contrast of the original image.

$\kappa_d = \kappa_a = \kappa$ preserves the contrast.

J. Mukherjee and S.K. Mitra. Enhancement of color images by scaling the DCT coefficients. IEEE Trans. on Image Processing, 17(10):1783–1794, 2008.

Preservation of Colors in the DCT Domain

U, V: Blocks of DCT coefficients of C_b and C_r

κ :Scale factor for the luminance component Y

$$U_e(i,j) = \begin{cases} N\left(\kappa\left(\frac{U(i,j)}{N} - 128\right)\right) + 128, & i=j=0 \\ \kappa U(i,j), & otherwise \end{cases}$$

$$V_e(i,j) = \begin{cases} N\left(\kappa\left(\frac{V(i,j)}{N} - 128\right)\right) + 128, & i=j=0 \\ \kappa V(i,j), & otherwise \end{cases}$$

Color Enhancement by Scaling Coefficients (CES)

- Find the scale factor by mapping the DC coefficient with a monotonically increasing function.

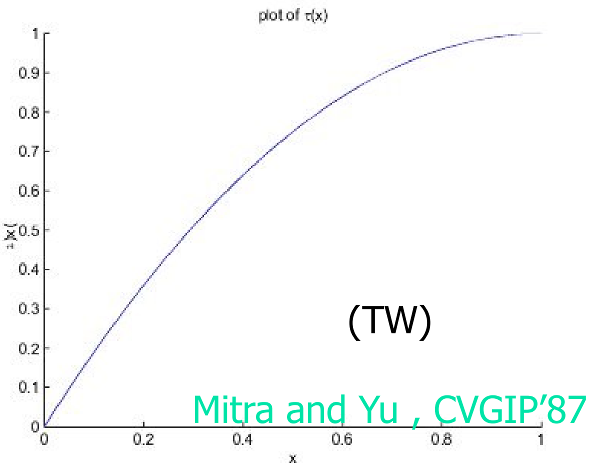
$$1 \leq \kappa \leq \frac{B_{max}}{\mu + \lambda.\sigma}$$

Max. intensity

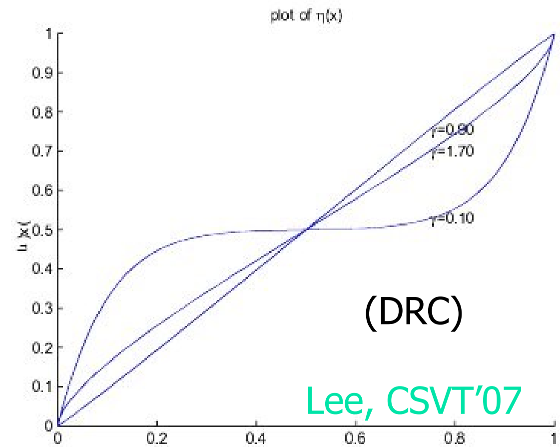
Scale factor

- Apply scaling to all other coefficients in all the components.
- For blocks having greater details judged by s.d., apply block decomposition and re-composition strategy.

Mapping functions for adjusting the local background illumination

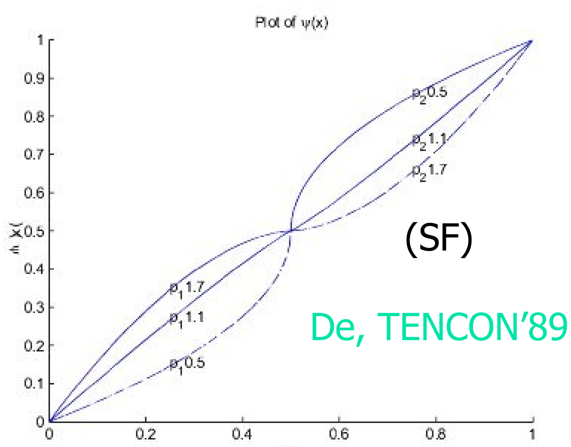


$$\kappa = \frac{f(Y(0,0))}{Y(0,0)}$$

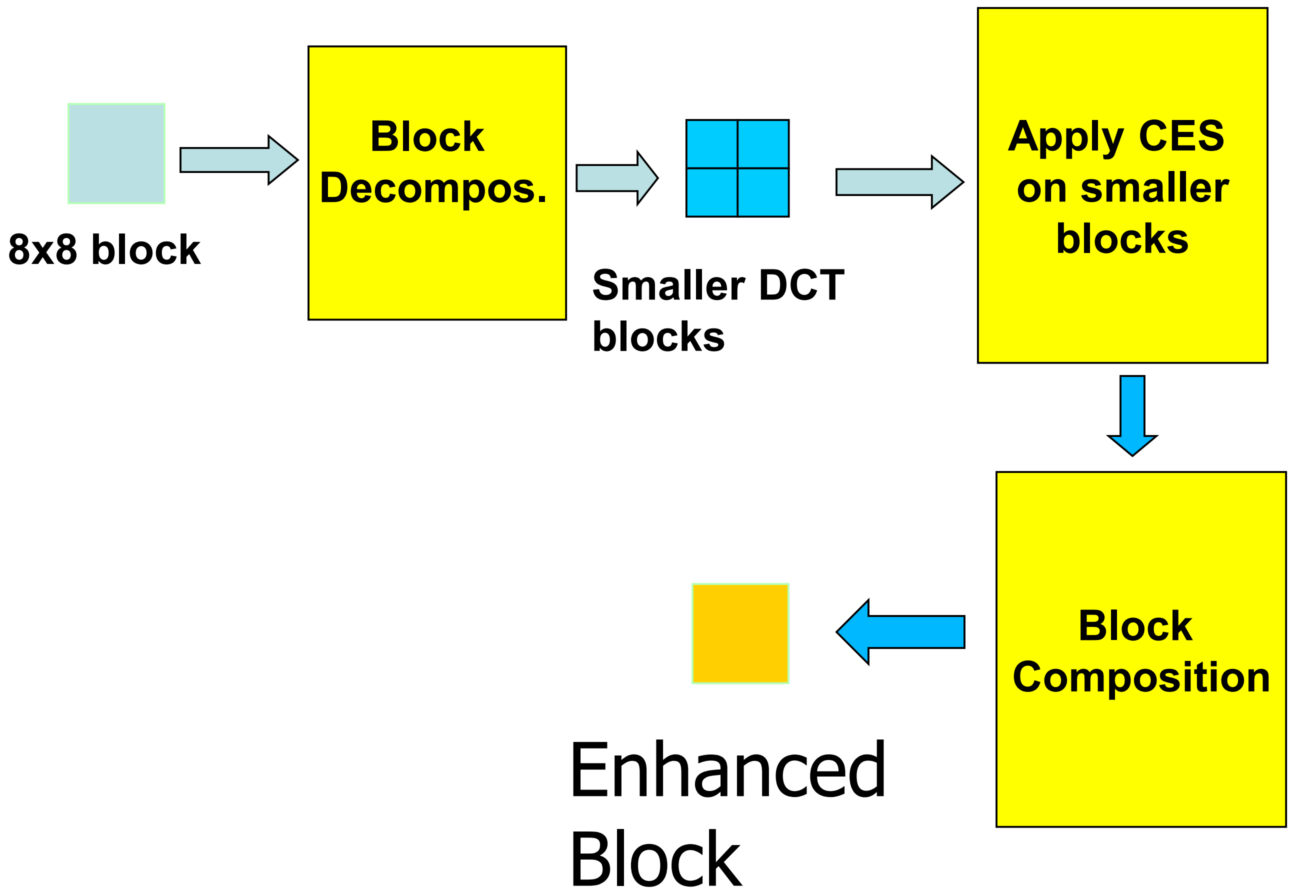


$$\eta(x) = \frac{(x^{\frac{1}{\gamma}} + (1-(1-x)^{\frac{1}{\gamma}}))}{2}, \quad 0 \le x \le 1.$$

$$\tau(x) = x(2-x)$$



Enhancement of Blocks with more details



MCE

MCEDRC

CES

Some Results

original

AR

MCE

MCEDRC

TW-CES-BLK

MSR

Iterative Enhancement

Iteration no.=1

Run CES iteratively.

Iteration no.=3

original

Iteration no.=2

Iteration no.=4

0

1

2

3

Color Constancy

Color constancy

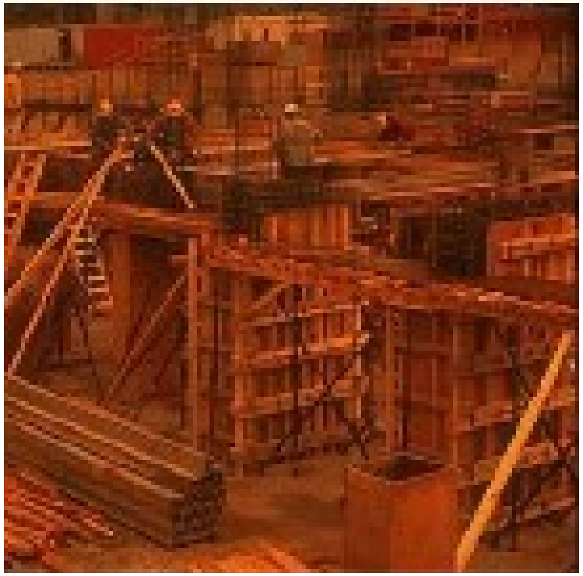
- Computation of color of illuminant
  - Avg. of colors (Gray world)
  - Maximum of each channel (White world)
  - Use of DC coefficient of DCT blocks in compressed domain.
- Diagonal Color correction: $(R_s, G_s, B_s) \rightarrow (R_d, G_d, B_d)$

$$
\begin{aligned}
k_r &= \frac{R_d}{R_s}, & k_g &= \frac{G_d}{G_s}, & k_b &= \frac{B_d}{B_s}, \\
& & f &= \frac{R+G+B}{k_r R + k_g G + k_b B}, & & \\
R_u &= f k_r R, & G_u &= f k_g G, & B_u &= f k_b B.
\end{aligned}
$$

- Chromatic Shift in Y-Cb-Cr:

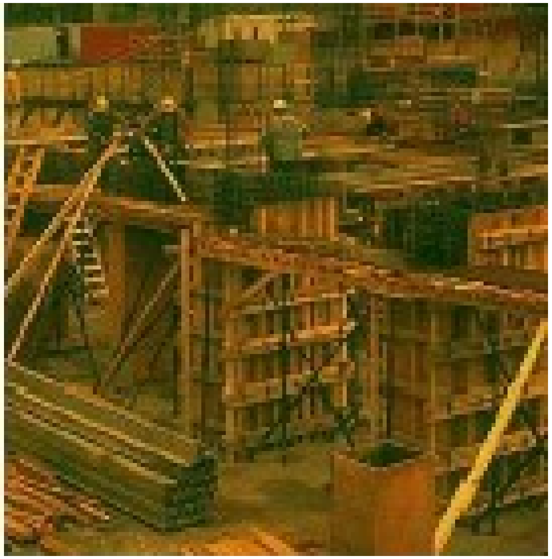
$$
\begin{aligned}
Y_u &= Y, \\
C_{bu} &= C_b + C_{bd} - C_{bs}, \\
C_{ru} &= C_r + C_{rd} - C_{rs}
\end{aligned}
$$

Color correction: Example



Original

Diagonal Correction

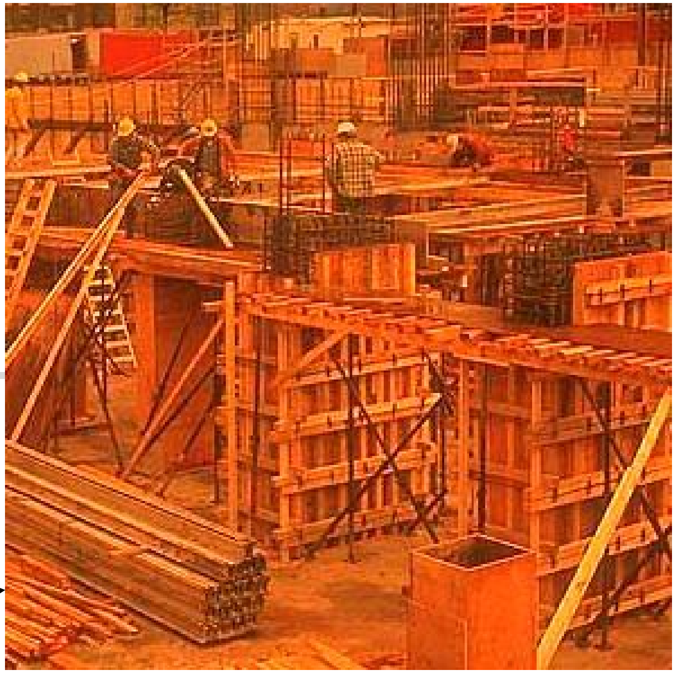


Chromatic Shift

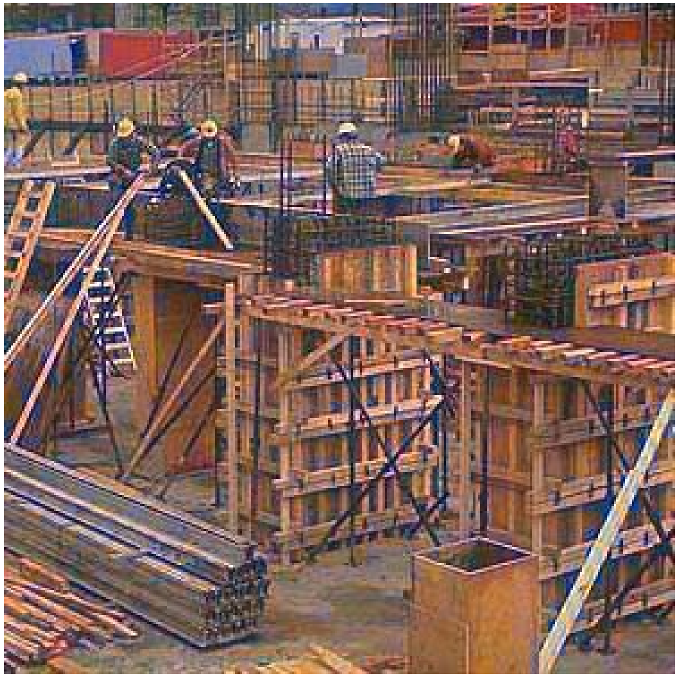
J. Mukhopadhyay and S.K. Mitra. Color constancy in the compressed domain. In IEEE Int. Conf. on Image Proc. (ICIP-2009), pp. 705-708, Cairo, Egypt, Nov. 7-11 2009. IEEE.

Color constancy coupled enhancement

- Perform color correction
- Perform color enhancement



Enhancement without color correction



Color Image Resizing

Resizing with integral factors

To convert NxN block to LNxMN block.

LN x MN block

NxN DCT block

$$X(k,l) = \begin{cases} \sqrt{LM} X_{LL}(k,l), & k,l = 0,1,\ldots,N-1, \\ 0, & otherwise. \end{cases}$$

LxM D/S (LMDS)

1. Merge LxM adjacent DCT blocks.

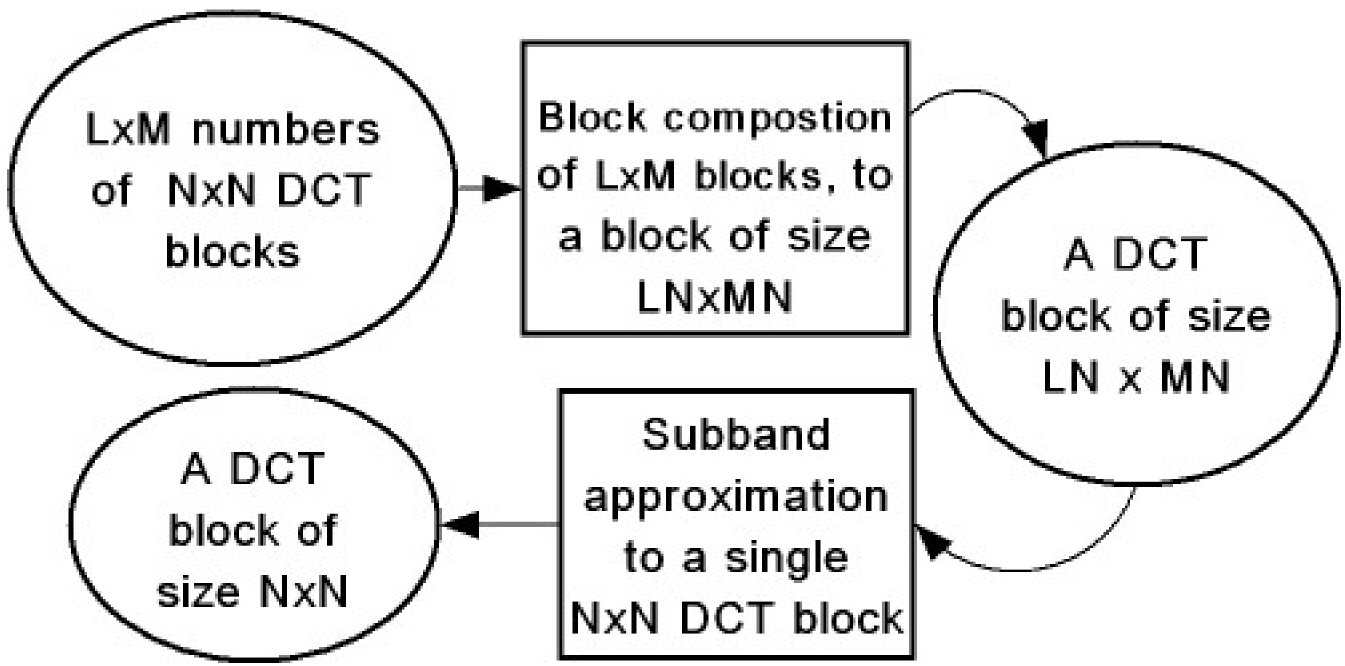
$$Z = A_{(L,N)} \begin{bmatrix} X_{0,0} & X_{0,1} & \cdots & X_{0,(M-1)} \\ X_{1,0} & X_{1,1} & \cdots & X_{1,(M-1)} \\ \cdot & \cdot & \cdots & \cdot \\ X_{(L-1),0} & X_{(L-1),1} & \cdots & X_{(L-1),(M-1)} \end{bmatrix} A^T_{(M,N)}$$

2. Sub-band approximation to a NxN DCT block.

$$Y = \sqrt{\frac{1}{LM}} \left[Z(k,l) \right]_{0 \le k,l \le N-1}$$

J. Mukherjee and S.K. Mitra. Arbitrary resizing of images in the DCT space. IEE Proc. Vision, Image & Signal Processing, 152(2):155–164, 2005.

LMDS



J. Mukherjee and S.K. Mitra. Arbitrary resizing of images in the DCT space. IEE Proc. Vision, Image & Signal Processing, 152(2):155–164, 2005.

LxM U/S (LMUS)

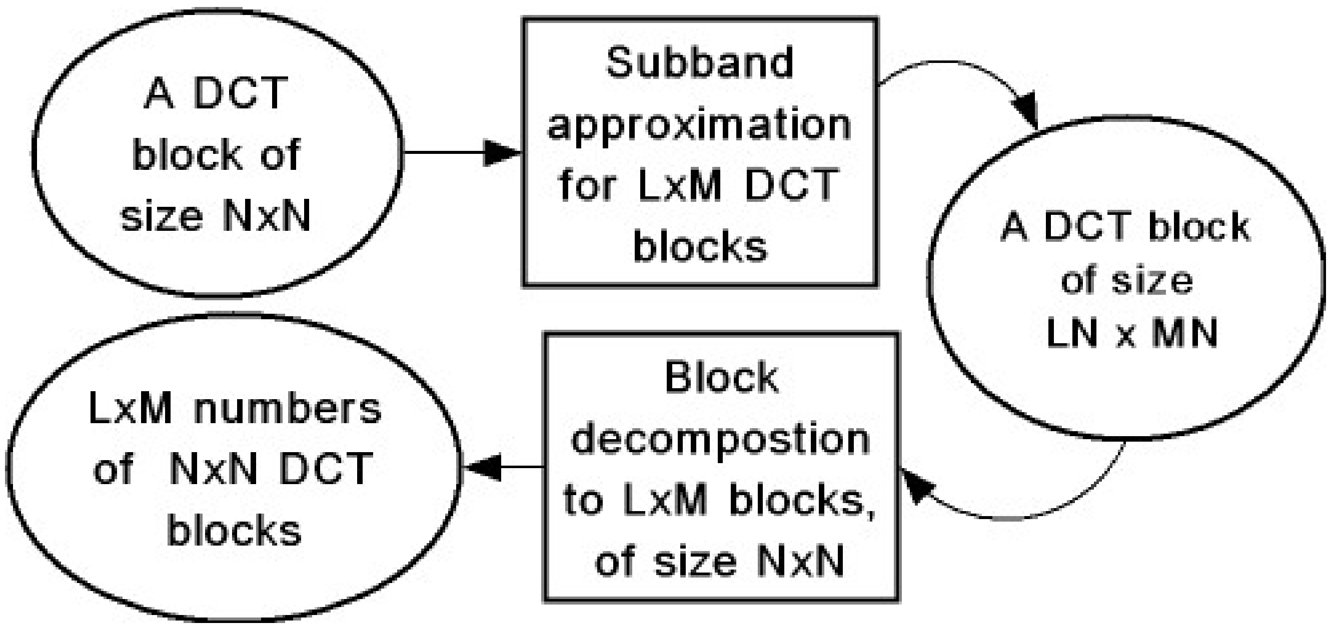
1. Convert NxN to LNxMN block

$$\hat{B} = \begin{bmatrix} \sqrt{LM}B & 0_{(N,(M-1)N)} \\ 0_{((L-1)N,N)} & 0_{((L-1)N,(M-1)N)} \end{bmatrix}$$

Efficiently compute exploiting large blocks of zeroes.

2. Decompose into LxM NxN blocks.

LMUS



J. Mukherjee and S.K. Mitra. Arbitrary resizing of images in the DCT space. IEE Proc. Vision, Image & Signal Processing, 152(2):155–164, 2005.

An example: 3x2 D/S and U/S

Arbitrary Resizing (P/R x Q/S)

- U/S-D/S Resizing Algorithm (UDRA)
  - U/S by PxQ
  - D/S by RxS
- D/S-U/S Resizing Algorithm (DURA)
  - D/S by RxS
  - U/S PxQ

HDTV (1080x920) to NTSC (480x640)

UDRA

DURA

Issues involved in color resizing

- Baseline JPEG Compression:
  Usually the chromatic components Cb and Cr are at lower resolution than the Y component.
- Cascaded stages of down-sampling and up-sampling(the DURA algorithm) faces a problem of dimensionality mismatch.
- Appearance of color artifacts in boundary.

Lighthouse (original)

3/4 x 4/3 Resizing

DURA

UDRA

Conclusion (contd.)

- Useful properties of DCT exploited in developing algorithms.
  - Linear and distributive property.
  - Sub-band relationship
  - Spatial relationship
  - Convolution-Multiplication properties.
- Processing of DC coefficients adapts spatial domain algorithm in the DCT domain.
- Processing of AC coefficients also required to handle details, etc.

Conclusion

- Color space in compressed domain Y-Cb-Cr
  - Affine transformation from R-G-B space.
  - Usually Cb and Cr blocks are down-sampled.
- Processing in chromatic space required to preserve color vector, if luminance component (Y) is modified.

Thank you!