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VON KARMAN INSTITUTE FOR FLUID DYNAMICS

LECTURE SERIES 1984-03

DIGITAL IMAGE PROCESSING IN FLUID DYNAMICS

MARCH 5-9, 1984

DIGITAL IMAGE PROCESSING AND ANALYSIS

WILLIAM K. PRATT - VICOM SYSTEMS INC., USA

DIGITAL IMAGE PROCESSING AND ANALYSIS

COURSE NOTES

IMAGE ASSOCIATES

DIGITAL IMAGE PROCESSING AND ANALYSIS	COURSE CONTENTS

1. IMAGE PROCESSING

   1.1 IMAGE REPRESENTATION

   1.2 PSYCHOPHYSICAL PROPERTIES OF VISION

   1.3 IMAGE PROCESSING TECHNIQUES

   1.4 IMAGE ENHANCEMENT

   1.5 IMAGE RESTORATION

2. IMAGE ANALYSIS

   2.1 IMAGE DETECTION

   2.2 IMAGE FEATURE EXTRACTION

   2.3 MORPHOLOGICAL IMAGE PROCESSING

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DIGITAL IMAGE PROCESSING

IMAGE REPRESENTATION

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DIGITAL IMAGE PROCESSING	PERCEPTUAL DESCRIPTORS

BRIGHTNESS - ATTRIBUTE THAT CHARACTERIZES PERCEPTUAL AMPLITUDE OF A LIGHT AN OBJECT OF UNIFORM INTENSITY MAY NOT APPEAR TO BE OF UNIFORM BRIGHTNESS

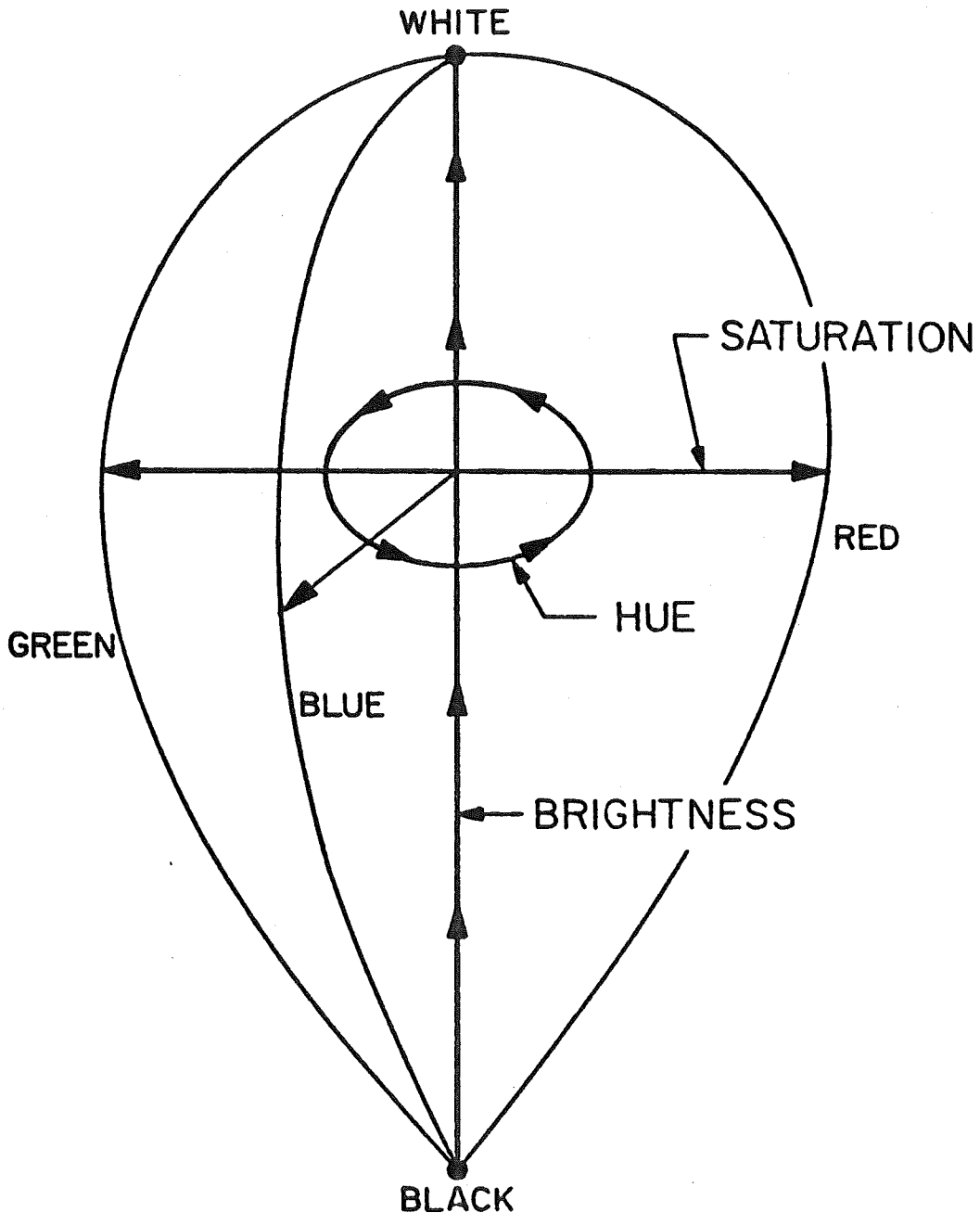
HUE - ATTRIBUTE THAT DISTINGUISHES A RED LIGHT FROM A GREEN LIGHT

TWO LIGHT SOURCES WITH DIFFERENT SPECTRAL ENERGY DISTRIBUTIONS CAN BE PERCEIVED IDENTICALLY. SUCH LIGHTS ARE CALLED METAMERIC PAIRS.

SATURATION - ATTRIBUTE THAT DISTINGUISHES A PURE SPECTRAL LIGHT FROM A PASTEL LIGHT OF THE SAME HUE.

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DIGITAL IMAGE PROCESSING	PERCEPTUAL REPRESENTATION OF LIGHT



F-2

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DIGITAL IMAGE PROCESSING	CONTINUOUS IMAGE REPRESENTATION

$C(x, y, t, \lambda)$ - SPECTRAL ENERGY DISTRIBUTION OF LIGHT SOURCE AS A FUNCTION OF SPACE (x, y), TIME (t), AND WAVELENGTH (λ).

LUMINANCE:

$$Y(x, y, t) = \int_0^\infty C(x, y, t, \lambda)\, V_s(\lambda)\, d\lambda$$

$V_s(\lambda)$ - RELATIVE LUMINOUS EFFICIENTY (SPECTRAL RESPONSE OF HUMAN VISION)

TRISTIMULUS VALUES:

$$R(x, y, t) = \int_0^\infty C(x, y, t, \lambda)\, R_s(\lambda)\, d\lambda$$

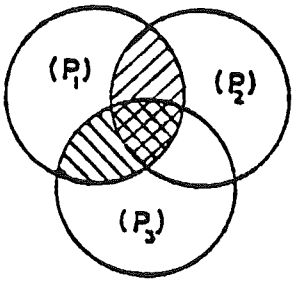
$$G(x, y, t) = \int_0^\infty C(x, y, t, \lambda)\, G_s(\lambda)\, d\lambda$$

$$B(x, y, t) = \int_0^\infty C(x, y, t, \lambda)\, B_s(\lambda)\, d\lambda$$

$R_s(\lambda)$, $G_s(\lambda)$, $B_s(\lambda)$ - SPECTRAL TRISTIMULUS VALUES FOR RED, GREEN, AND BLUE PRIMARIES

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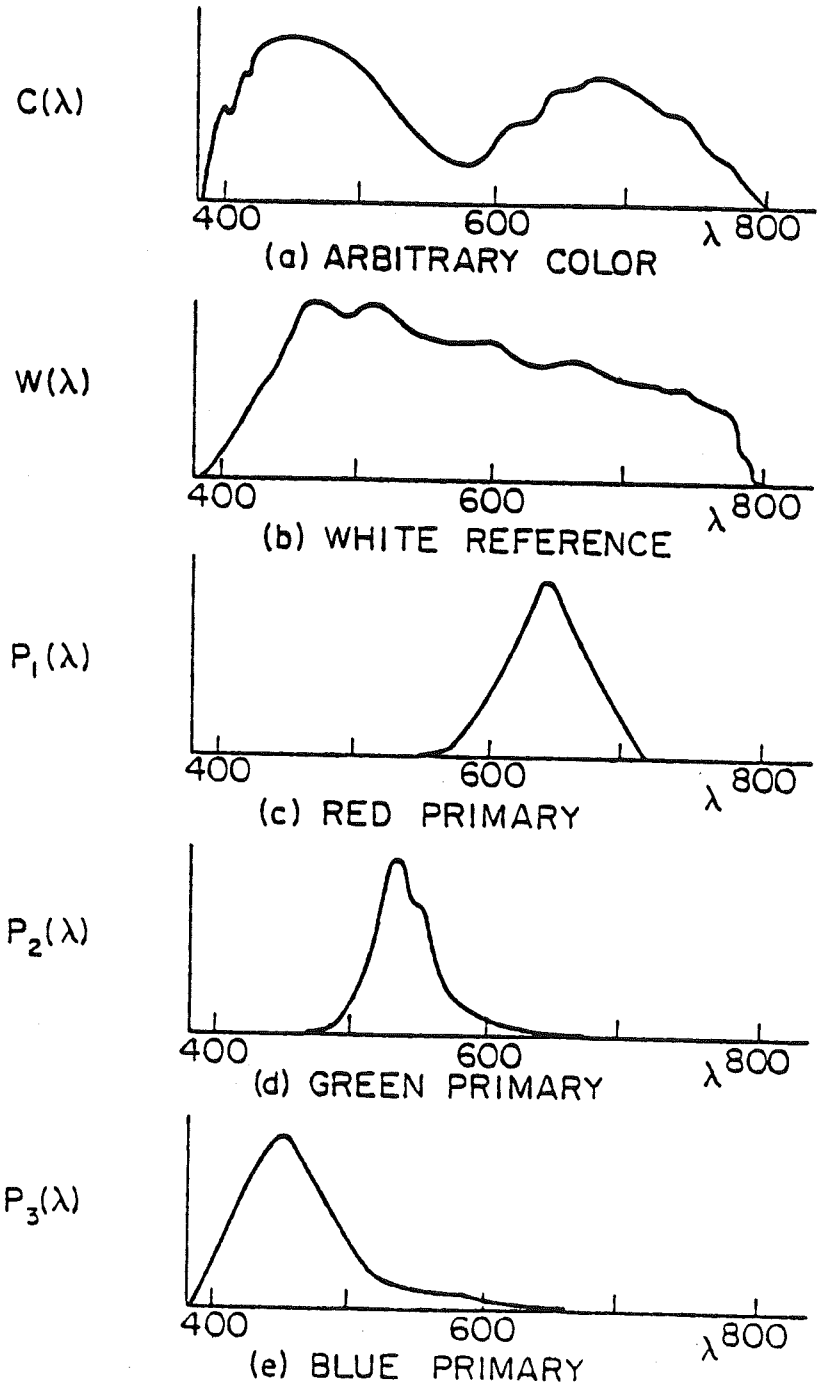
DIGITAL IMAGE PROCESSING AND ANALYSIS	COLOR MATCHING - I





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DIGITAL IMAGE PROCESSING	COLOR MATCHING - II



SPECTRAL ENERGY DISTRIBUTIONS

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COLOR IMAGE COORDINATES

RED, GREEN, BLUE TRISIMULUS VALUES:

R, G, B

LUMINANCE:

$$Y = aR + bG + cB$$

WHERE a, b, c ARE CONSTANTS DEPENDENT ON SPECTRAL PROPERTIES OF PRIMARIES

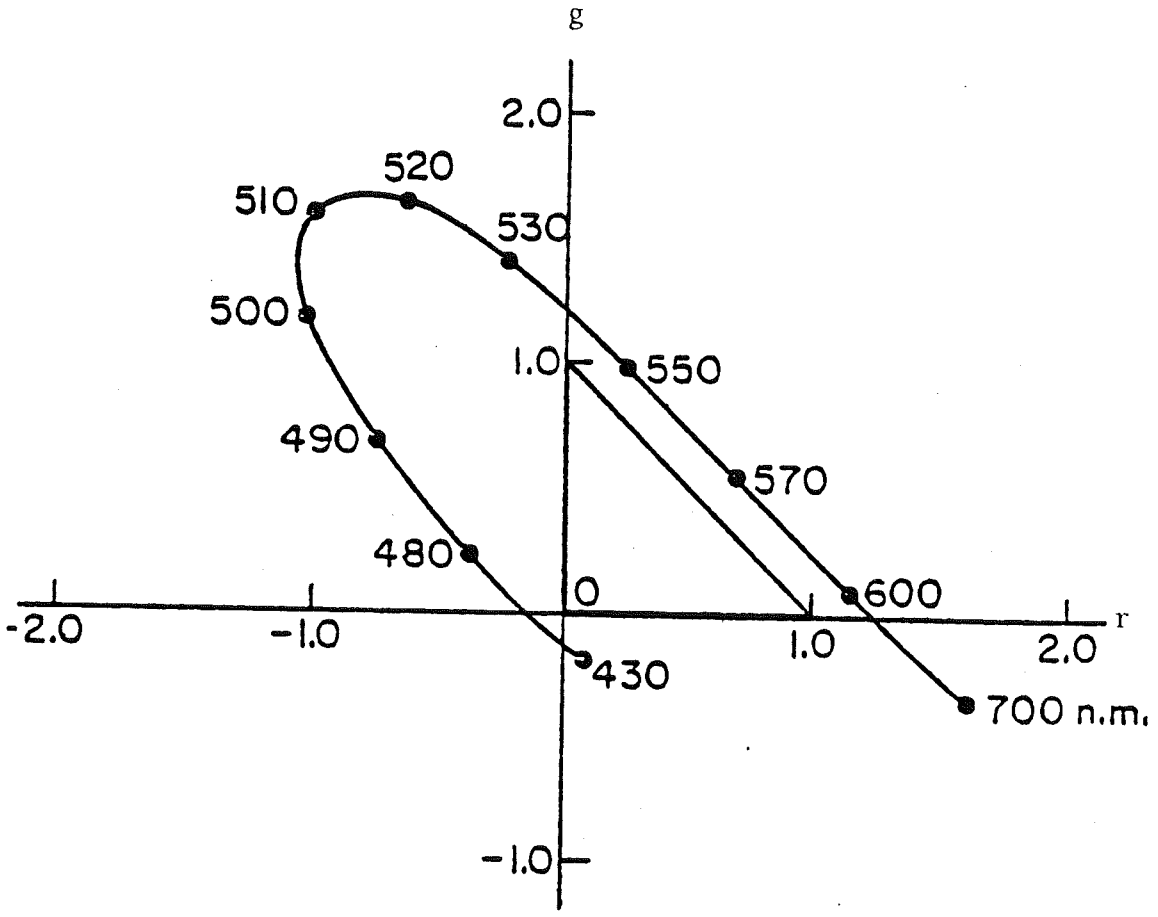
CHROMATICITY COORDINATES:

$$r = \frac{R}{R + G + B}$$

$$g = \frac{G}{R + G + B}$$

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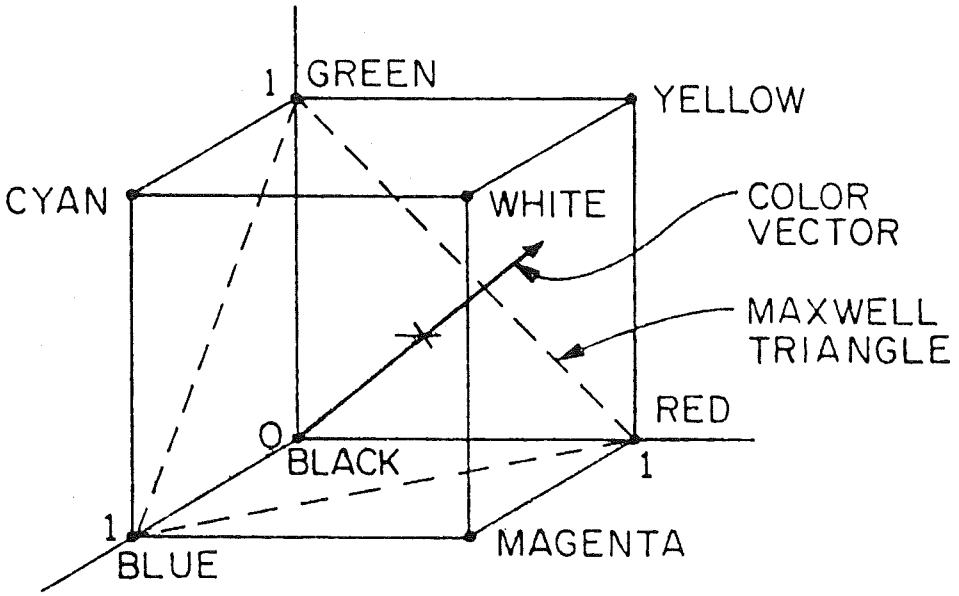
DIGITAL IMAGE PROCESSING	CHROMATICITY SPACE



CHROMATICITY DIAGRAM FOR TYPICAL RED, GREEN, AND BLUE PRIMARIES.

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DIGITAL IMAGE PROCESSING	TRISTIMULUS SPACE



COLOR SPACE FOR TYPICAL RED, GREEN, AND BLUE PRIMARIES .

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DIGITAL IMAGE PROCESSING	COLOR COORDINATE SYSTEMS

COLOR COORDINATE SYSTEMS

N.T.S.C. TRANSMISSION SYSTEM:

R_N, G_N, B_N

C.I.E. X - Y - Z SYSTEM:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.607 & 0.174 & 0.201 \\ 0.299 & 0.587 & 0.114 \\ 0.000 & 0.066 & 1.117 \end{bmatrix}$$

L - A - B SYSTEM:

$$L = 25 \left[100 \frac{Y}{Y_0} \right]^{1/3} - 16$$

$$A = 500 \left[\left(\frac{X}{X_0}\right)^{1/3} - \left(\frac{Y}{Y_0}\right)^{1/3} \right]$$

$$B = 200 \left[\left(\frac{Y}{Y_0}\right)^{1/3} - \left(\frac{Z}{Z_0}\right)^{1/3} \right]$$

WHERE X_0, Y_0, Z_0 ARE TRISIMULUS VALUES OF REFERENCE WHITE

$X_0 = 0.982$

$Y_0 = 1.000$

$Z_0 = 1.183$

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DIGITAL IMAGE PROCESSING	DISCRETE IMAGE CHARACTERIZATION

IMAGE MATRIX:

$$\underline{F} = \begin{bmatrix} F(1,1) & F(1,2) & \cdots & F(1,K) \\ F(2,1) & F(2,2) & \cdots & F(2,K) \\ \vdots & \vdots & & \vdots \\ F(J,1) & F(J,2) & \cdots & F(J,K) \end{bmatrix}$$

IMAGE VECTOR:

$$N = J \cdot K$$

$$\underline{f} = \begin{bmatrix} f(1) \\ f(2) \\ \vdots \\ f(j) \\ \vdots \\ f(N) \end{bmatrix}$$

PURPOSE: VECTOR SPACE REPRESENTATION OF IMAGES PERMITS UTILIZATION OF ONE-DIMENSIONAL SIGNAL PROCESSING ALGORITHMS.

$\underline{g} = \underline{M}\ \underline{f}$

$\underline{M}$ = OPERATOR MATRIX

$\underline{f}$ = INPUT IMAGE VECTOR

$\underline{g}$ = OUTPUT IMAGE VECTOR

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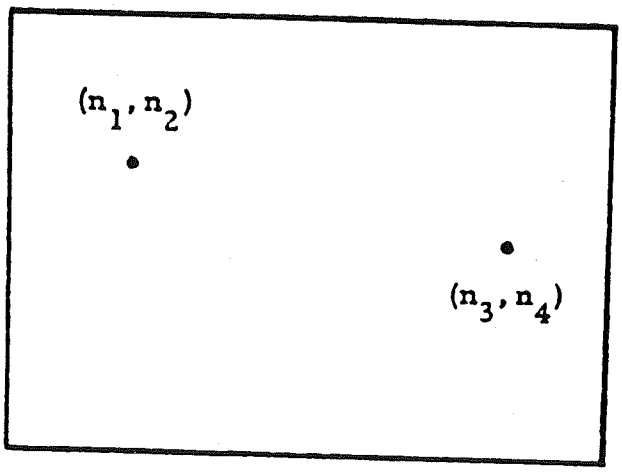
DIGITAL IMAGE PROCESSING	STATISTICAL CHARACTERIZATION OF DISCRETE IMAGES

MEAN:

$$E\{\underline{F}\} = [E\{F(n_1, n_2)\}]$$

CORRELATION:

$$R_F(n_1, n_2; n_3, n_4) = E\{F(n_1, n_2)F^*(n_3, n_4)\}$$



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DIGITAL IMAGE PROCESSING	PROBABILITY DENSITY MODEL

MATRIX FORM:

$$p(\underline{F}) = p\left\{F(1, 1), F(2, 1), \ldots, F(J, K)\right\}$$

ONE-DIMENSIONAL MODELS:

- UNIFORM
- GAUSSIAN
- LAPLACIAN
- LOG NORMAL

MULTI-DIMENSIONAL MODELS:

- HUNT - GAUSSIAN, SPACE VARIANT MEAN
- HUINS - CORRELATED MARGINALS

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DIGITAL IMAGE PROCESSING	IMAGE HISTOGRAM

ONE DIMENSIONAL:

$$\underline{h} = \begin{bmatrix} C_1 \\ C_2 \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ C_L \end{bmatrix}$$

WHERE

C_i = NUMBER OF PIXELS FOR WHICH F(j,k) = i

L - NUMBER OF LUMINANCE LEVELS

TWO DIMENSIONAL:

$$\underline{H} = \begin{bmatrix} C_{11} & C_{12} & \cdots & C_{1L} \\ C_{21} & C_{22} & \cdots & C_{2L} \\ \cdot & \cdot & & \\ \cdot & \cdot & & \\ \cdot & \cdot & & \\ C_{L1} & C_{L2} & \cdots & C_{LL} \end{bmatrix}$$

WHERE

C_{ij} = NUMBER OF PIXEL PAIRS FOR WHICH F(j,k) = i AND F(m,n) = j

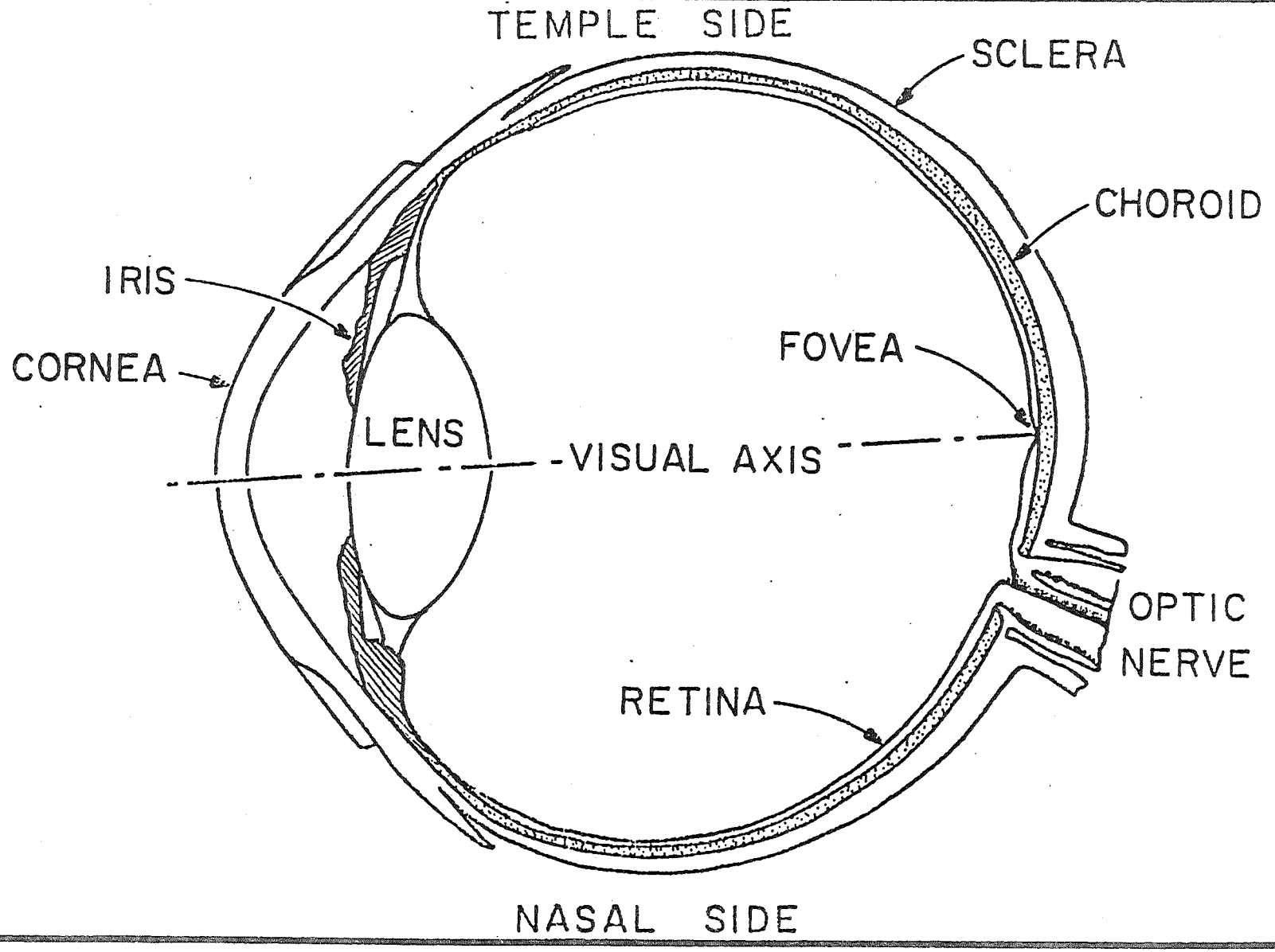
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PSYCHOPHYSICAL PROPERTIES OF VISION

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DIGITAL IMAGE PROCESSING

HUMAN EYE ELEMENTS



V-1

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DIGITAL IMAGE PROCESSING	PHYSIOLOGY OF THE EYE

- RECEPTORS ARE LOCATED IN THE RETINA
- RODS (100,000,000) ARE RESPONSIBLE FOR MONOCHROME VISION
- CONES (6,500,000) ARE RESPONSIBLE FOR COLOR VISION
- THREE DIFFERENT TYPES OF CONES BASED UPON SPECTRAL ABSORPTION CHARACTERISTICS
- 800,000 NERVE FIBERS CONNECTING RODS AND CONES TO BRAIN

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VISUAL PHENOMENA

CONTRAST SENSITIVITY

MACH BAND

SIMULTANEOUS CONTRAST

CHROMATIC ADAPTION

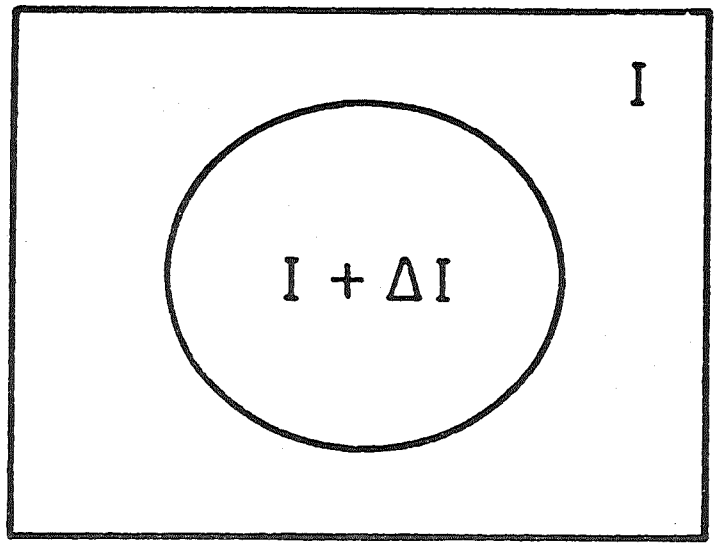
COLOR BLINDNESS

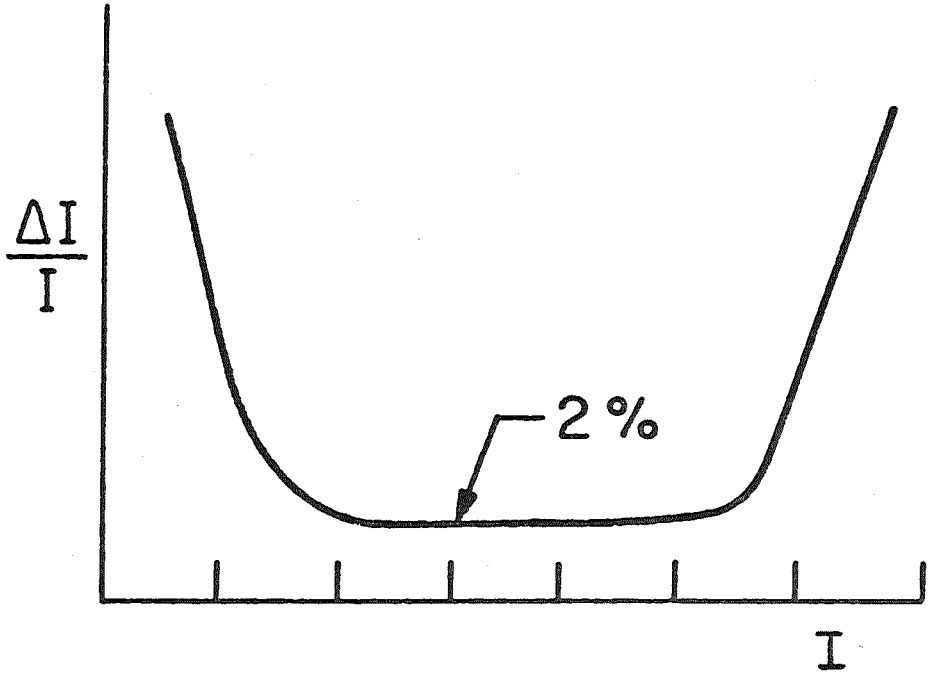
SUBJECTIVE COLOR

LAND'S EXPERIMENTS

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CONTRAST SENSITIVITY MEASUREMENTS

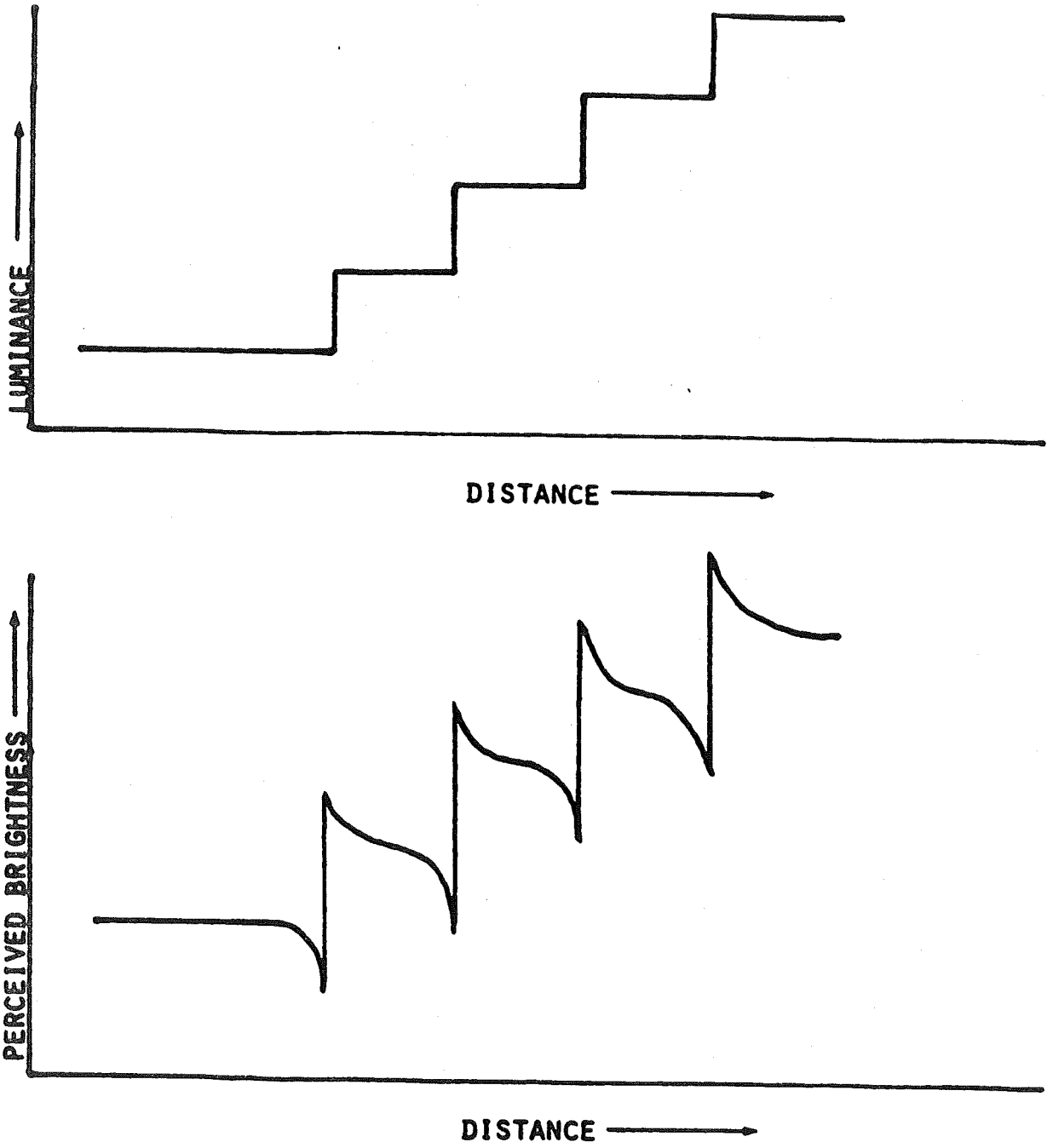




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DIGITAL IMAGE PROCESSING

MACH BAND EFFECT

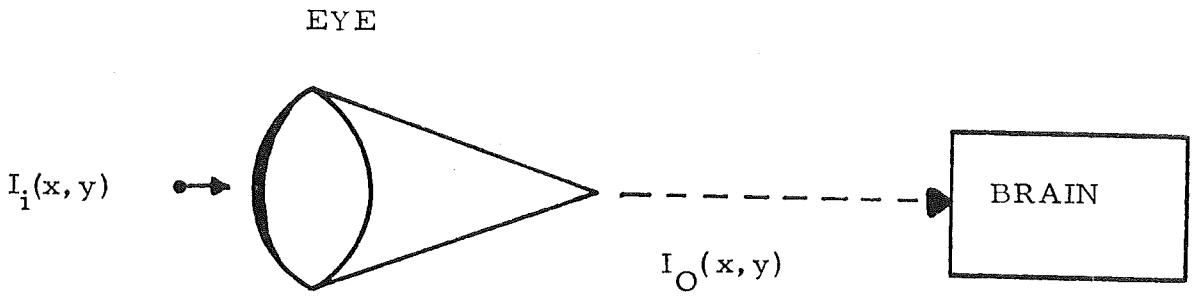


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DIGITAL IMAGE PROCESSING	MONOCHROME VISION MODEL

PHYSICAL SYSTEM:

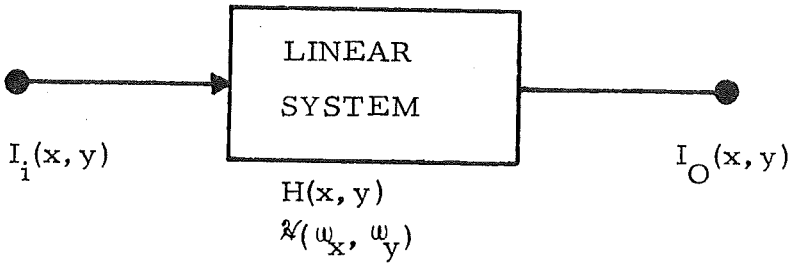


WHERE

$I_i(x,y)$ = INPUT INTENSITY SPATIAL DISTRIBUTION

$I_O(x,y)$ = PERCEIVED INTENSITY SPATIAL DISTRIBUTION

LINEAR MODEL:

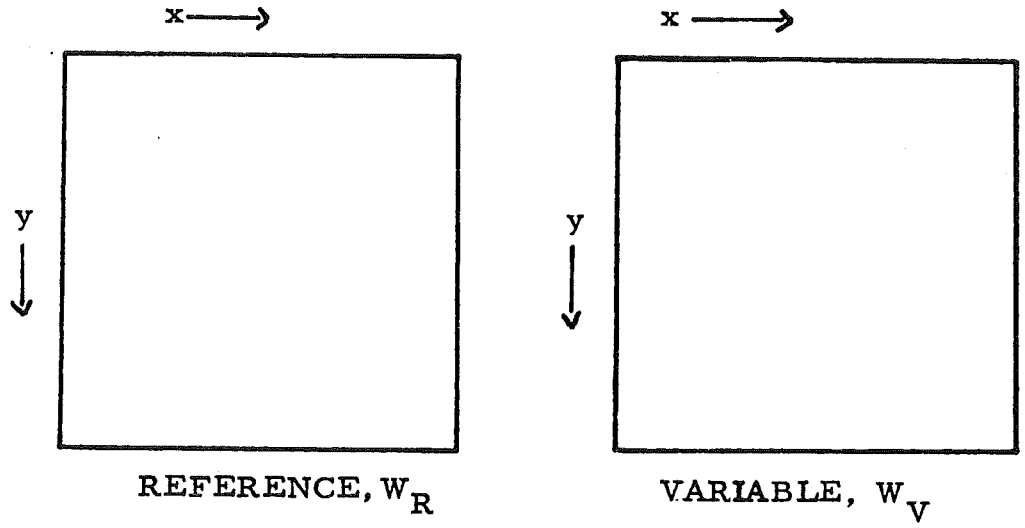


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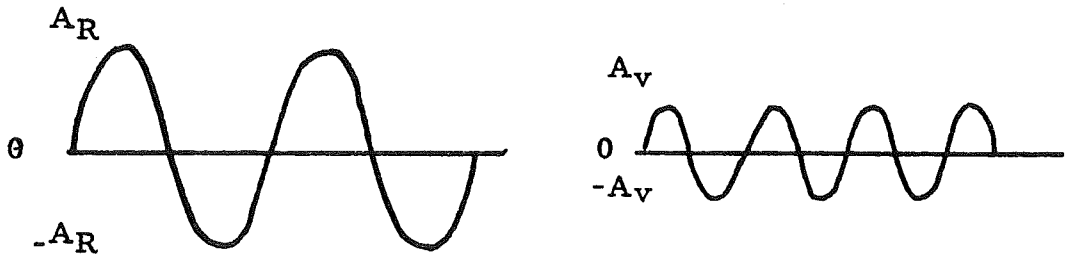
DIGITAL IMAGE PROCESSING	MONOCHROME VISION MODEL - II

MEASUREMENT METHODOLOGY

1. SUBJECT VIEWS TWO LIGHT PATTERNS CONTAINING ONE DIMENSIONAL SINE WAVE LIGHT DISTRIBUTIONS



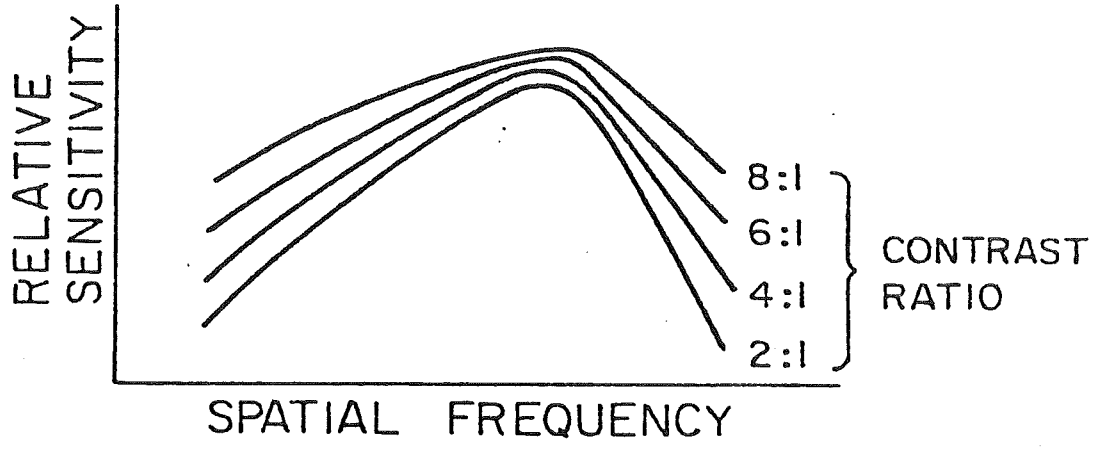
REFERENCE, W_R VARIABLE, W_V



2. CONTRAST OF VARIABLE PATTERN IS ADJUSTED UNTIL SINE WAVE PATTERNS ARE EQUALLY PERCEPTIBLE

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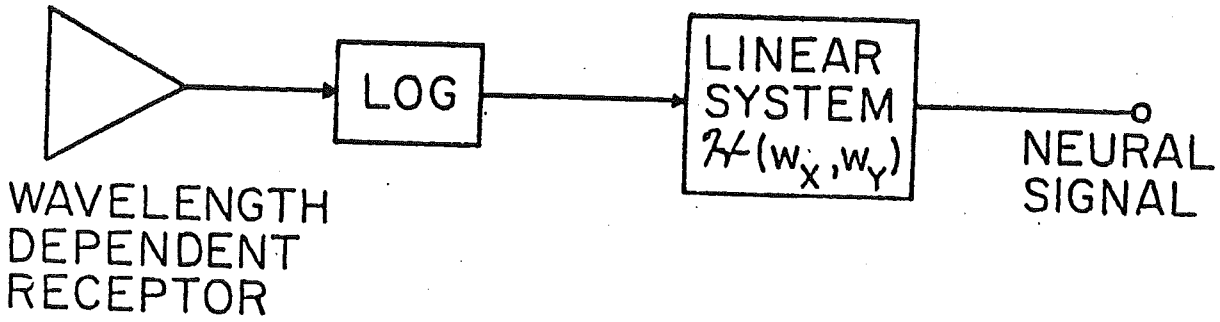
DIGITAL IMAGE PROCESSING	HYPOTHETICAL FREQUENCY RESPONSE OF HUMAN VISUAL SYSTEM FOR SINE WAVE PATTERN



(a) SINE WAVE GRATING

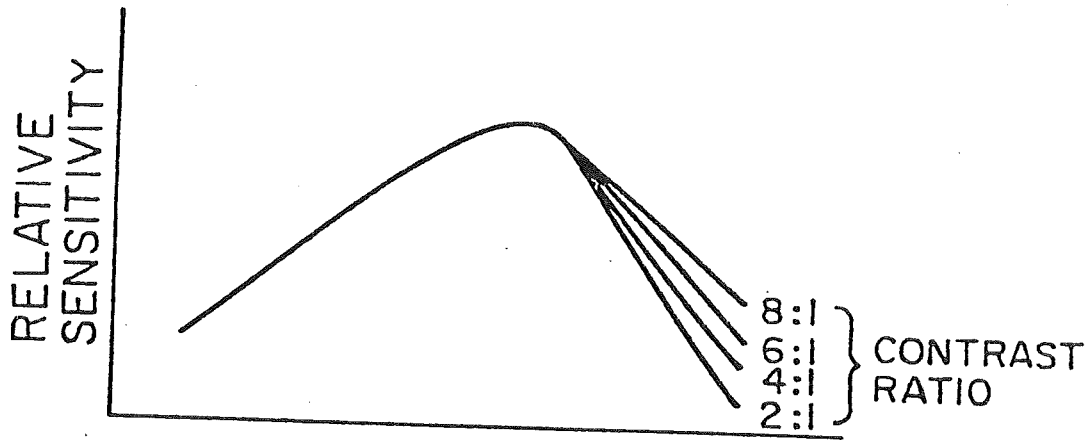
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DIGITAL IMAGE PROCESSING	LOGARITHMIC MODEL FOR MONOCHROME VISION



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DIGITAL IMAGE PROCESSING	HYPOTHETICAL FREQUENCY RESPONSE OF HUMAN VISUAL SYSTEM FOR EXPONENTIAL SINE WAVE PATTERN



(b) EXPONENTIAL SINE WAVE GRATING

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DIGITAL IMAGE PROCESSING | POINT RESPONSE MODELS

NONLINEAR INTENSITY RESPONSE RESULTS FROM PHOTOCHEMICAL EXCITATION OF RODS AND CONES

LOGARITHMIC MODEL:

$$I_0(x, y) = K_1 \log[K_2 + K_3 I_i(x, y)]$$

FRACTIONAL MODEL:

$$I_0(x, y) = \frac{K_1 I_i(x, y)}{K_2 + I_i(x, y)}$$

POWER LAW MODEL:

$$I_0(x, y) = [I_i(x, y)]^{\nu}$$

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DIGITAL IMAGE PROCESSING	SPATIAL FREQUENCY RESPONSE MODELS

OPTICAL EFFECTS:

FINITE SIZE OF LENS APERTURE

LENS ABERRATIONS

FINITE DIMENSIONS OF RODS AND CONES

LATERAL INHIBITION EFFECT:

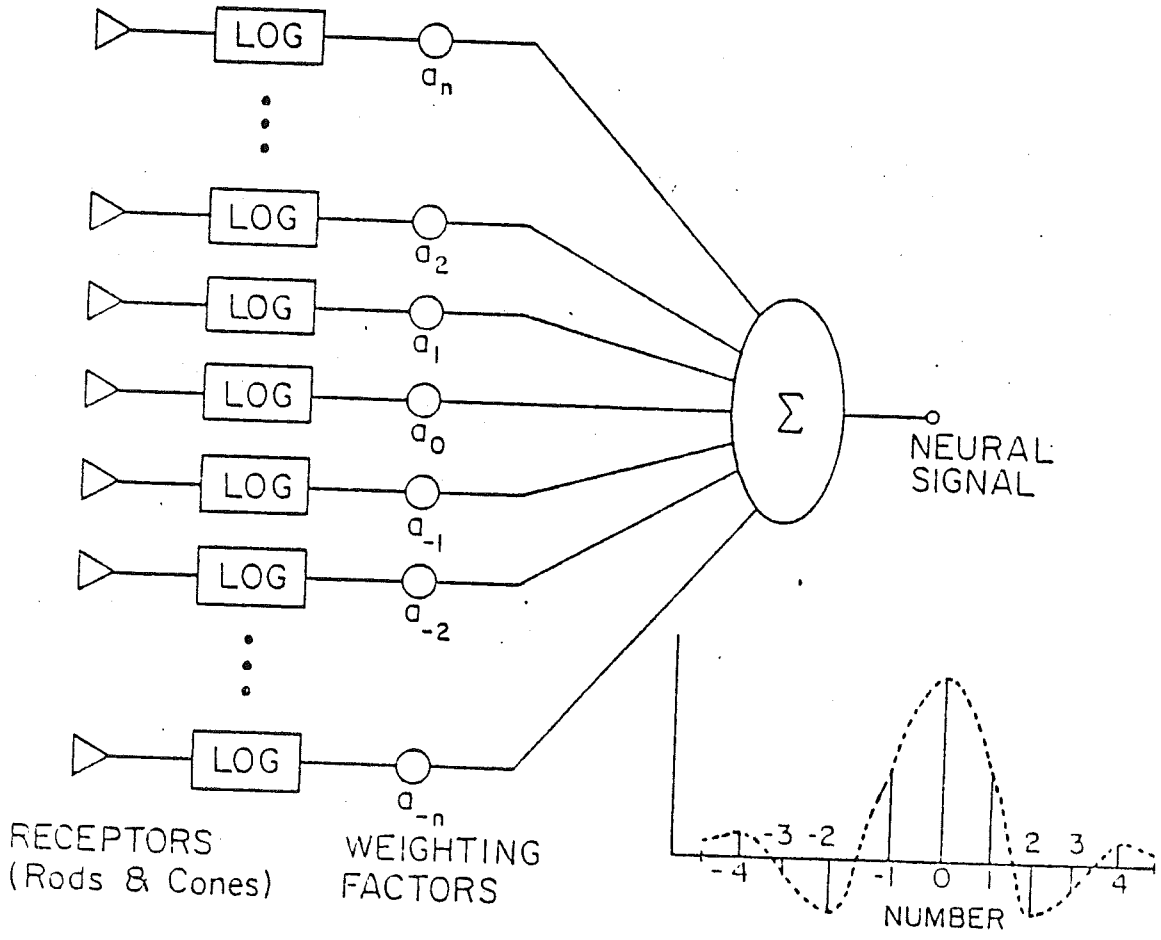
A NEURAL SIGNAL IS GENERATED BY A WEIGHTED CONTRIBUTION OF ADJACENT RODS AND CONES

SOME RECEPTORS EXERT AN INHIBITORY EFFECT ON ADJACENT RECEPTORS

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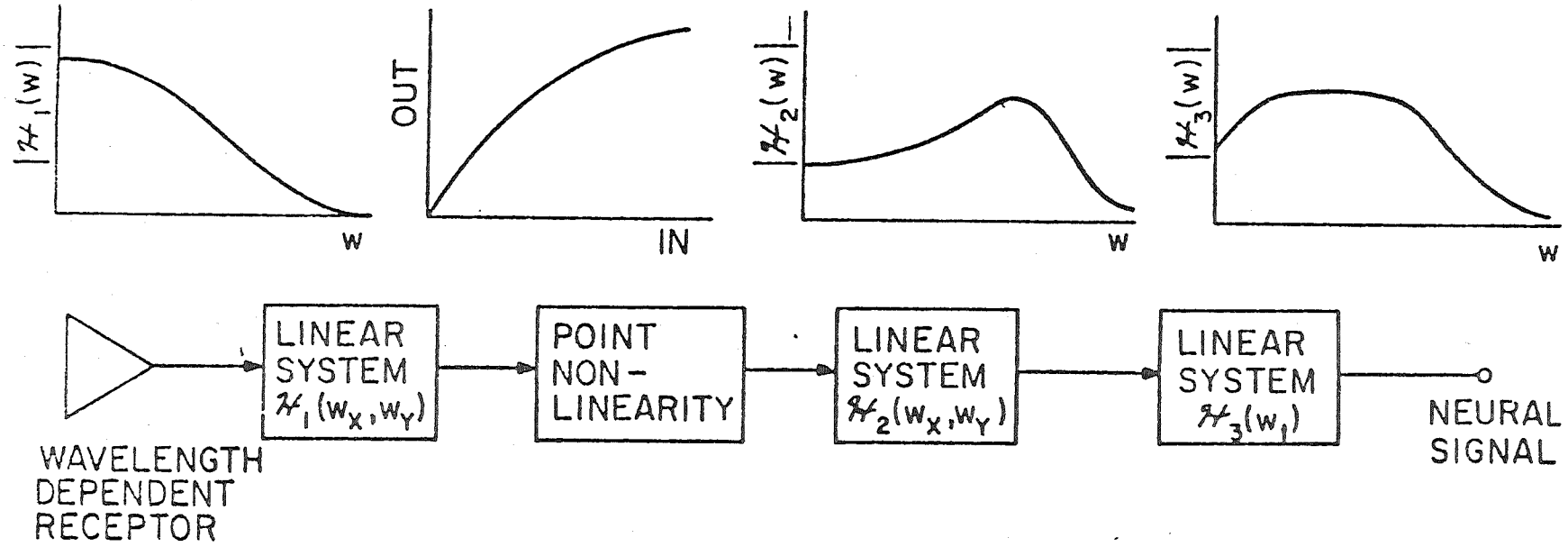
DIGITAL IMAGE PROCESSING

LATERAL INHIBITION



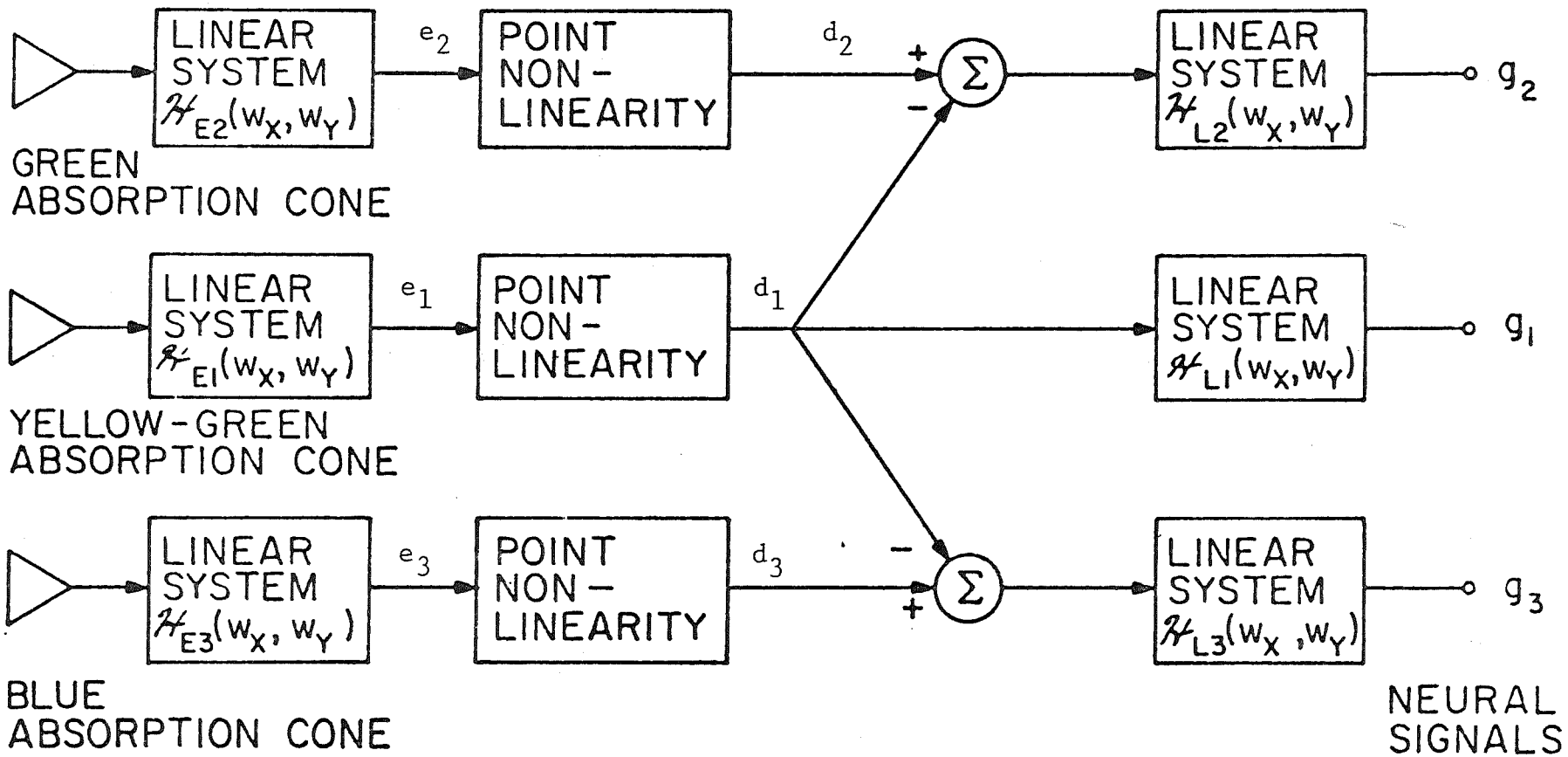
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EXTENDED MODEL FOR MONOCHROME VISION



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EXTENDED MODEL FOR COLOR VISION



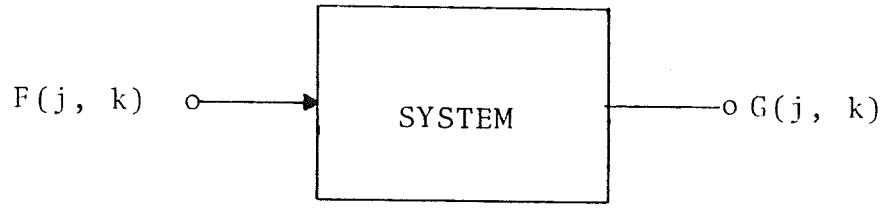
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IMAGE PROCESSING TECHNIQUES

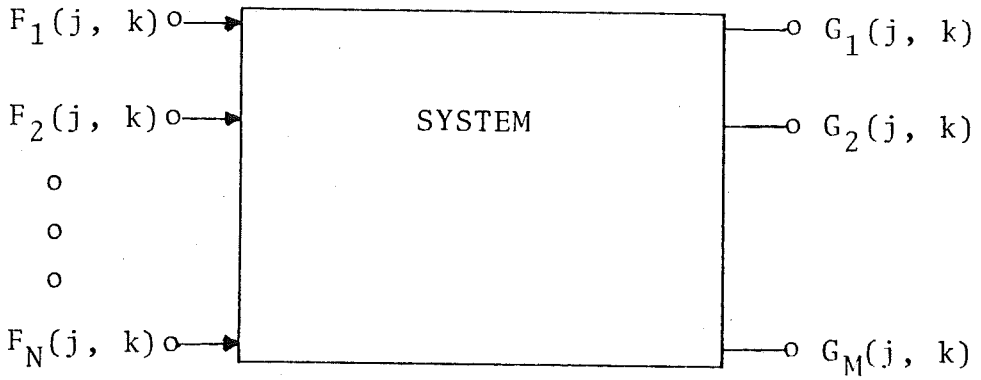
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DIGITAL IMAGE PROCESSING	TWO DIMENSIONAL SYSTEMS

ONE-TO-ONE SYSTEM:



MANY-TO-MANY SYSTEM:



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DIGITAL IMAGE PROCESSING AND ANALYSIS	DISCRETE DIRAC DELTA FUNCTION

DISCRETE DIRAC DELTA FUNCTION:

$$\delta(j - m + 1, k - n + 1) = \begin{cases} 1 & j = m \text{ and } k = n \\ 0 & \text{otherwise} \end{cases}$$

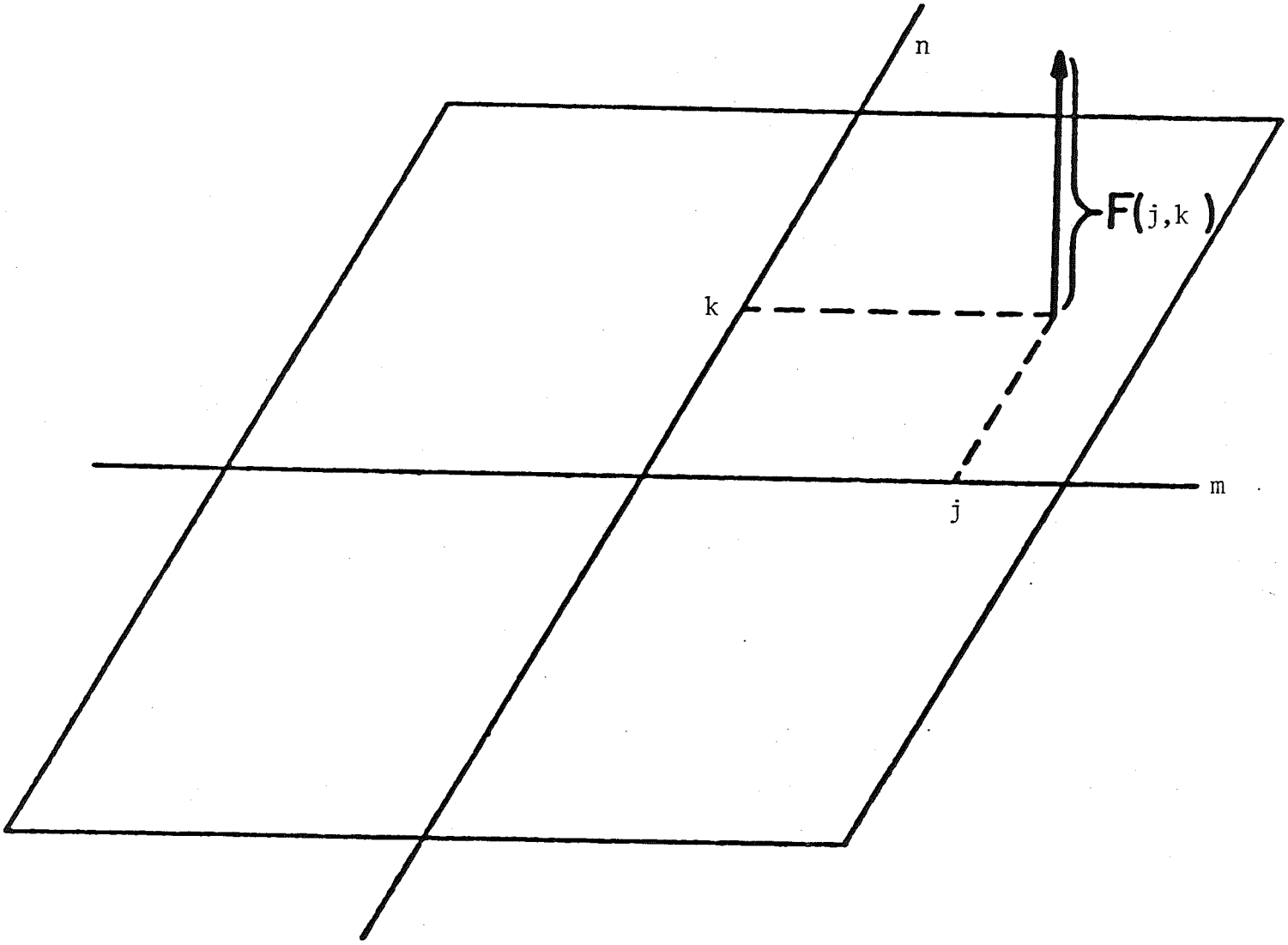
SIFTING SUMMATION:

$$\sum_{m=1}^{M} \sum_{n=1}^{N} F(m, n)\, \delta(j - m + 1, k - n + 1) = F(j, k)$$

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DIGITAL IMAGE PROCESSING

DECOMPOSITION OF IMAGE FUNCTION



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DIGITAL IMAGE PROCESSING AND ANALYSIS	SUPERPOSITION PROPERTY

SUPERPOSITION PROPERTY:

$$\mathcal{O}\left\{a_1 F_1(j,k) + a_2 F_2(j,k)\right\} = a_1 \mathcal{O}\left\{F_1(j,k)\right\} + a_2 \mathcal{O}\left\{F_2(j,k)\right\}$$

LET

$$G(j,k) = \mathcal{O}\left\{F(j,k)\right\}$$

AND REPRESENT F(j,k) BY SIFTING SUMMATION

$$G(j,k) = \mathcal{O}\left\{\sum_{m=1}^{M}\sum_{n=1}^{N} F(m,n)\,\delta(j - m + 1, k - n + 1)\right\}$$

OR

$$G(j,k) = \sum_{m=1}^{M}\sum_{n=1}^{N} F(m,n)\,\mathcal{O}\left\{\delta(j - m + 1, k - n + 1)\right\}$$

IMPULSE RESPONSE:

$$H(m, n; j, k) = \begin{cases} \mathcal{O}\left\{\delta(u, v)\right\} & 1 \le u, v \le L \\ 0 & \text{otherwise} \end{cases}$$

WHERE $u = j - m + 1$

$v = k - n + 1$

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DIGITAL IMAGE PROCESSING AND ANALYSIS	SUPERPOSITION OPERATOR

SUPERPOSITION OPERATOR:

$$G(j,k) = \sum_{m=1}^{M} \sum_{n=1}^{N} F(m,n)\, H(m,n;\, j,k)$$

IF IMPULSE RESPONSE IS SPACE INVARIANT

$$H(m,n;\, j,k) = H(j - m + 1,\, k - n + 1)$$

AND RESULT IS THE CONVOLUTION OPERATOR:

$$G(j,k) = \sum_{m=1}^{M} \sum_{n=1}^{N} F(m,n)\, H(j - m + 1,\, k - n + 1)$$

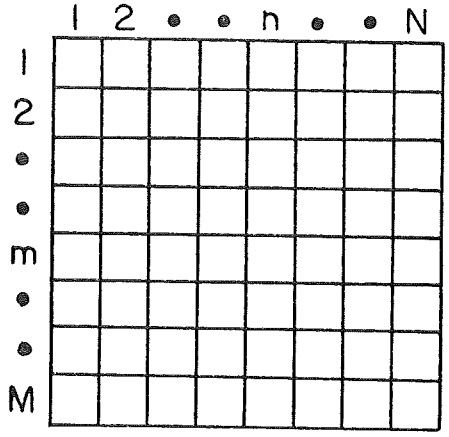
SYMBOLICALLY

$$G(j,k) = F(j,k) \circledast H(j,k)$$

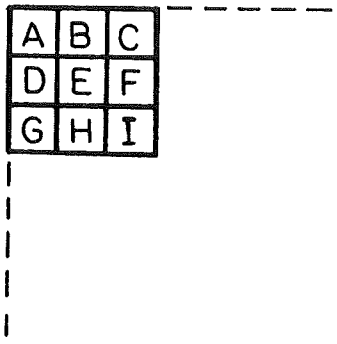
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DIGITAL IMAGE PROCESSING

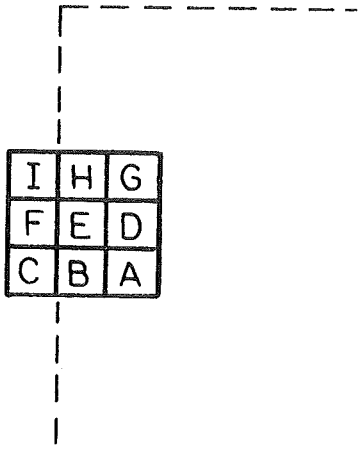
GRAPHIC EXAMPLE OF TWO-DIMENSIONAL CONVOLUTION



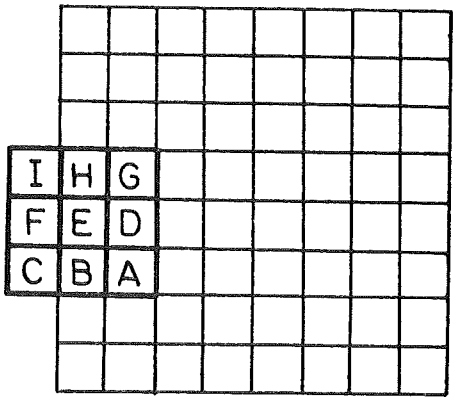
F (m, n)



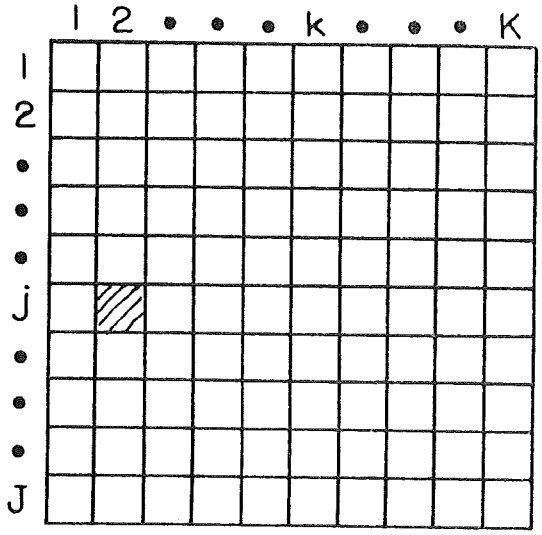
H(m,n)



H(j-m+1, k-n+1)



F(m,n) H(j-m+1, k-n+1)

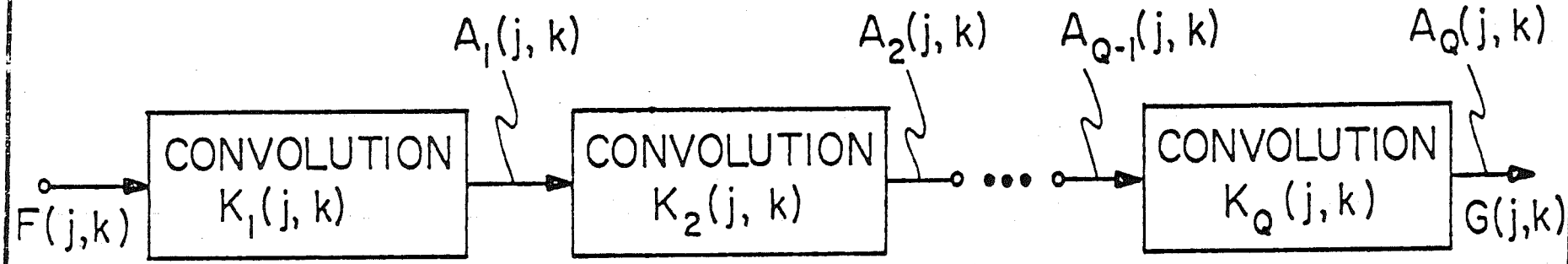


G (j, k)

T-6

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SMALL GENERATING KERNEL CONVOLUTION



BASIC SMALL GENERATING KERNEL CONVOLUTION SYSTEM

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DIGITAL IMAGE PROCESSING	SVD/SGK CONVOLUTION

SVD/SGK CONVOLUTION

SVD IMPULSE RESPONSE DECOMPOSITION:

$$H(j, k) = H_1(j, k) + H_2(j, k) + \ldots + H_R(j, k)$$

WHERE

$$H_i(j, k) = S_i \underline{a}_i \underline{b}_i^T$$

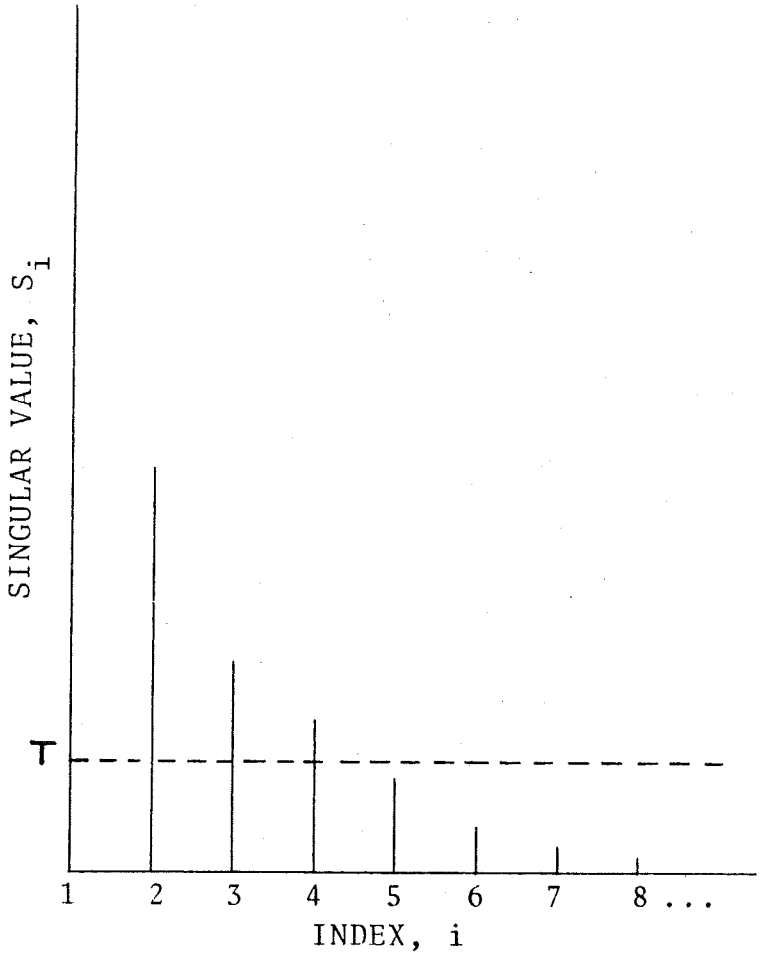
S_i = i - th SINGULAR VALUE

SGK DECOMPOSITION:

$$H_i(j, k) = K_{i1}(j, k) \circledast K_{i2}(j, k) \circledast \ldots \circledast K_{iQ}(j, k)$$

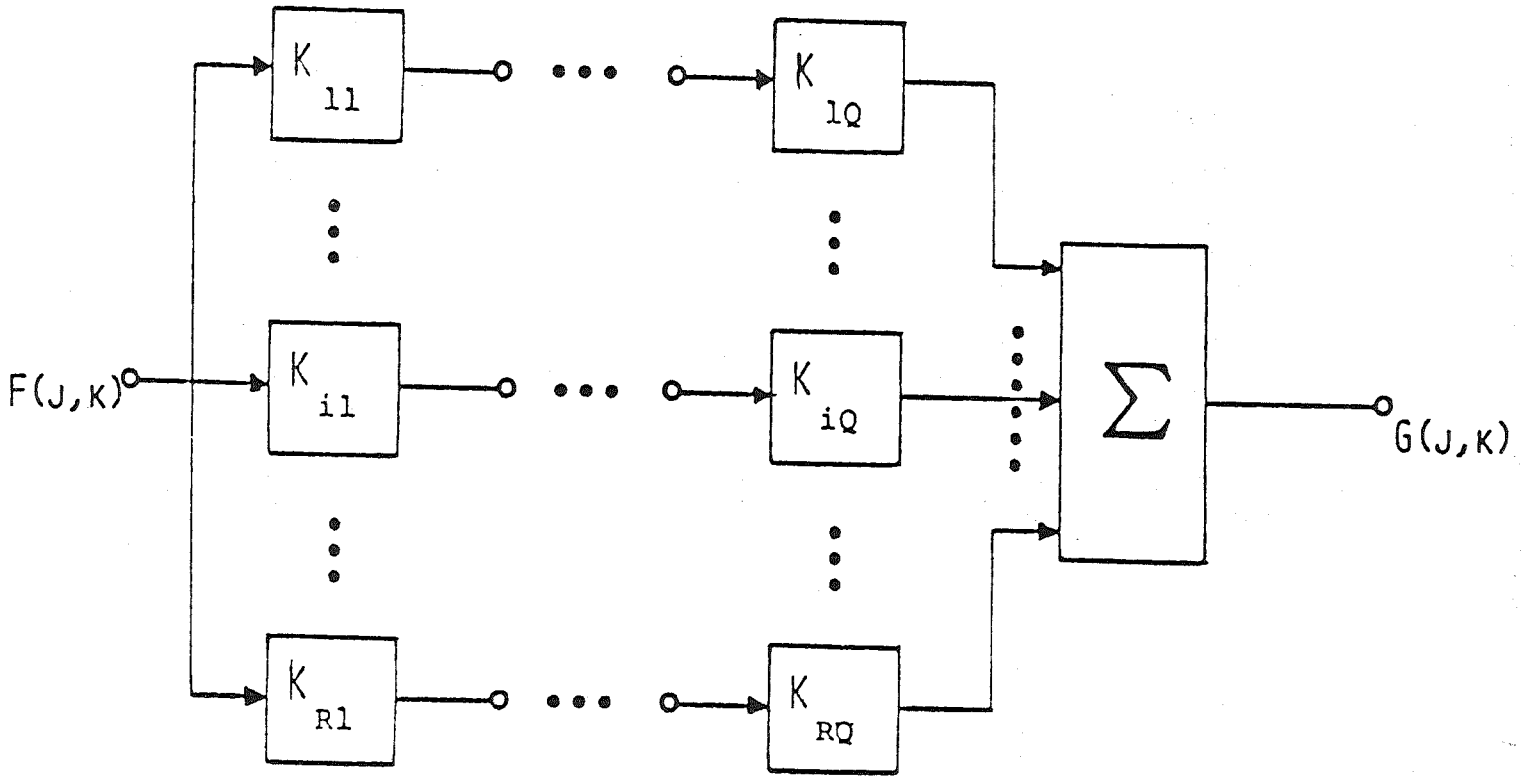
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DIGITAL IMAGE PROCESSING	SINGULAR VALUE, S_i



T-18

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NON-SEPARABLE SVD/SGK EXPANSION.

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DIGITAL IMAGE PROCESSING	FOURIER TRANSFORM

FOURIER TRANSFORM

$$\mathcal{F}(u,v) = \frac{1}{N} \sum_{j=0}^{N-1} \sum_{k=0}^{N-1} F(j,k) \exp\left\{ -\frac{2\pi i}{N}(uj + vk) \right\}$$

$$F(j,k) = \frac{1}{N} \sum_{u=0}^{N-1} \sum_{v=0}^{N-1} \mathcal{F}(u,v) \exp\left\{ \frac{2\pi i}{N}(uj + vk) \right\}$$

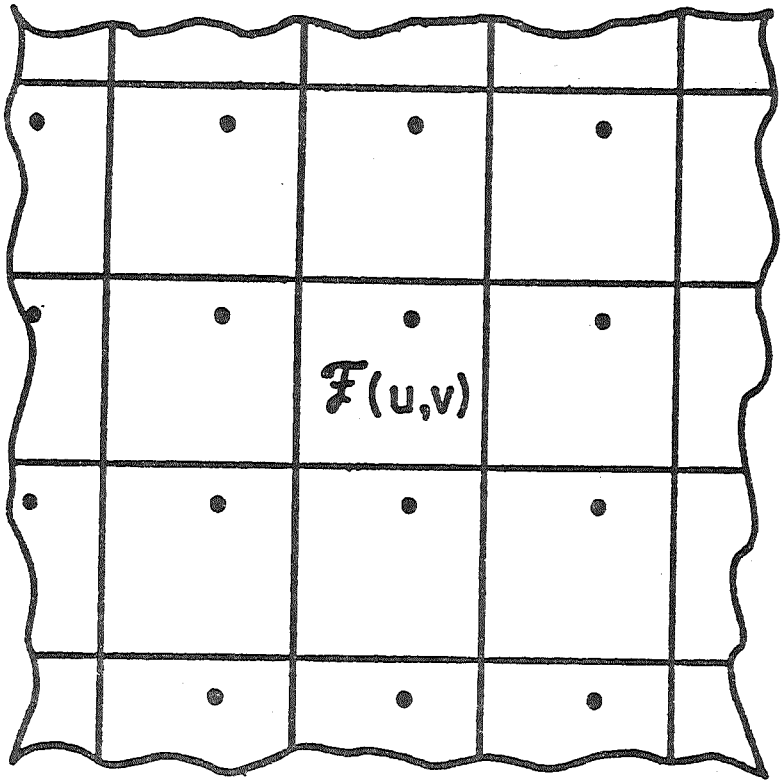
PROPERTIES:

- ORTHOGONALLY SEPARABLE
- $\mathcal{F}(0,0) = \frac{1}{N} \sum_{j=0}^{N-1} \sum_{k=0}^{N-1} F(j,k)$
- $\mathcal{F}(u + mN, v + nN) = \mathcal{F}(u,v)$

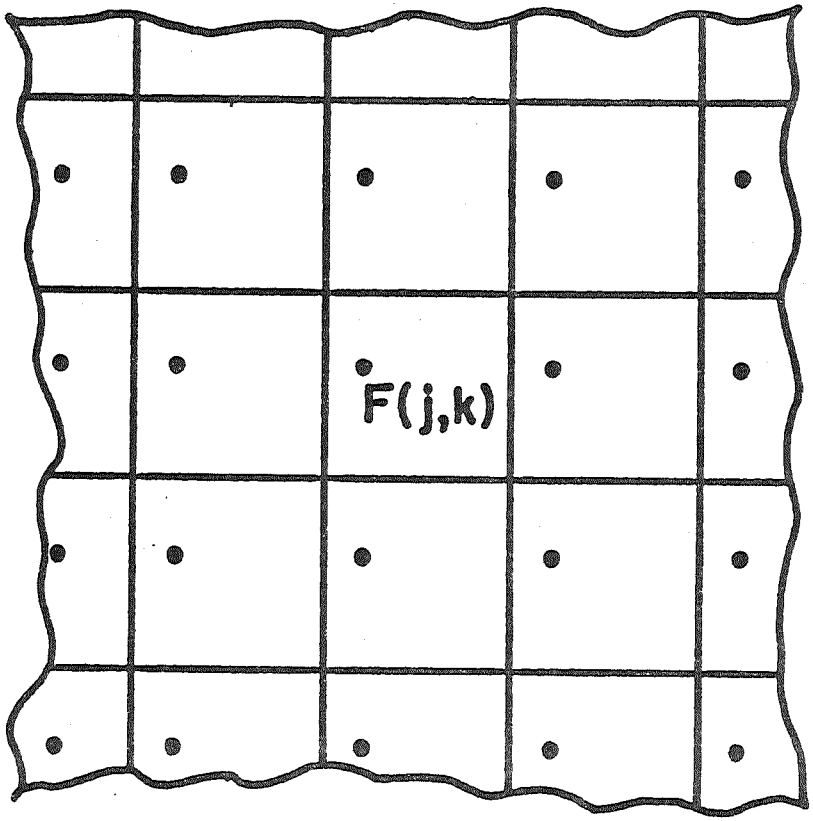
  for $m, n = 0, \pm 1, \pm 2, \ldots$
- SLOW CONVERGENCE
- FAST ALGORITHM
- CONVOLUTION THEOREM
- TRANSLATION THEOREM

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PERIODIC IMAGE AND FOURIER TRANSFORM ARRAYS



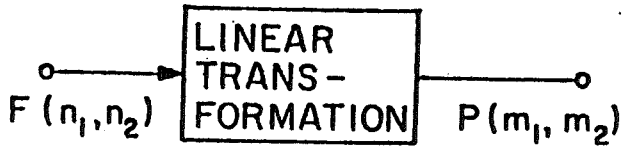
(a) FOURIER DOMAIN



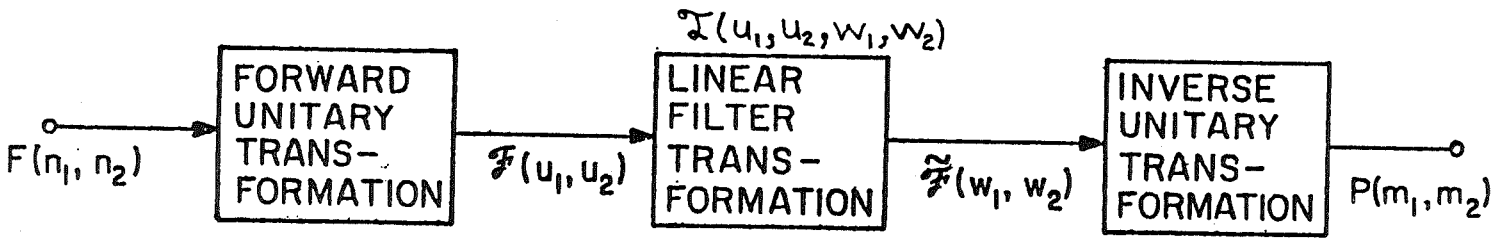
(b) SPATIAL DOMAIN

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DIRECT PROCESSING AND GENERALIZED LINEAR FILTERING - SERIES FORMULATION



(a) DIRECT PROCESSING



(b) GENERALIZED LINEAR FILTERING

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DIGITAL IMAGE PROCESSING	COMPUTATIONAL COMPARISON

FORWARD TRANSFORM: $2N^2\log_2 N$

FILTER MULTIPLICATION: $k_g M^2 N^2$

INVERSE TRANSFORM: $2M^2\log_2 M$

k_g IS SPARSENESS INDEX $(0 \leq k_g \leq 1)$

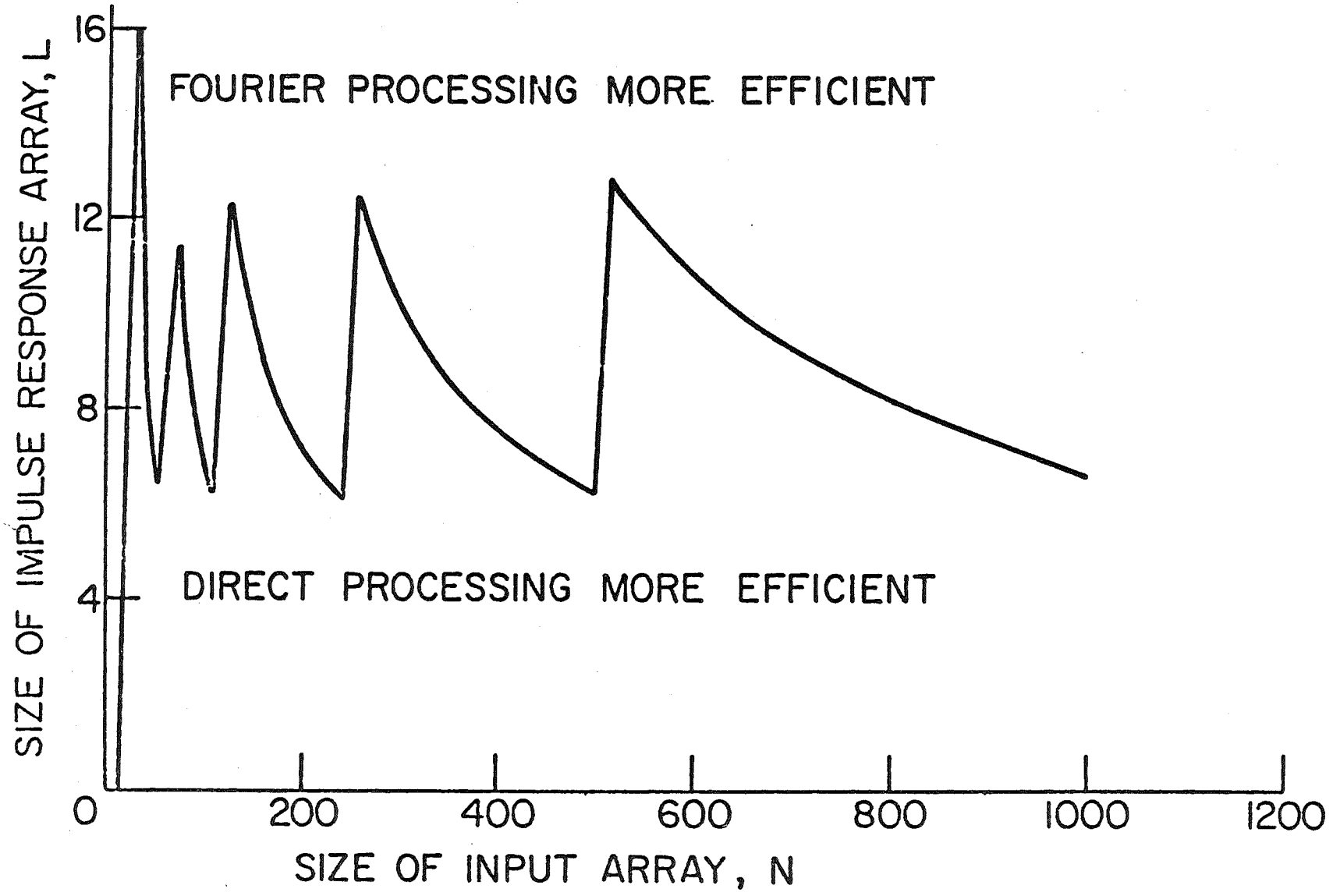
IF $\mathcal{T}$ IS SUFFICIENTLY SPARSE, TRANSFORM DOMAIN PROCESSING WILL BE MORE EFFICIENT THAN DIRECT DOMAIN PROCESSING

FOR CONVOLUTION USING A FOURIER TRANSFORM, $\mathcal{T}$ BECOMES A DIAGONAL MATRIX OPERATOR

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DIGITAL IMAGE PROCESSING

COMPARISON OF DIRECT AND FOURIER DOMAIN PROCESSING FOR FINITE AREA CONVOLUTION



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DIGITAL IMAGE PROCESSING

IMAGE ENHANCEMENT

E-0

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IMAGE ENCHANCEMENT DEFINITIONS

IMAGE ENHANCEMENT TECHNIQUES

- IMPROVE VISUAL APPEARANCE
- CONVERT IMAGE TO A FORM BETTER SUITED FOR HUMAN OR MACHINE ANALYSIS

TECHNIQUES MOTIVATED BY GENERAL KNOWLEDGE OF MACHINE AND HUMAN OBSERVER CHARACTERISTICS

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DIGITAL IMAGE PROCESSING AND ANALYSIS	IMAGE ENHANCEMENT TECHNIQUES

CONTRAST ENHANCEMENT

- CONTRAST STRETCHING
- HISTOGRAM MODIFICATION
- STATISTICAL DIFFERENCING

NOISE CLEANING

- LOW PASS CONVOLUTION MASK
- NONLINEAR SMOOTHING
- MEDIAN FILTERING

EDGE CRISPENING

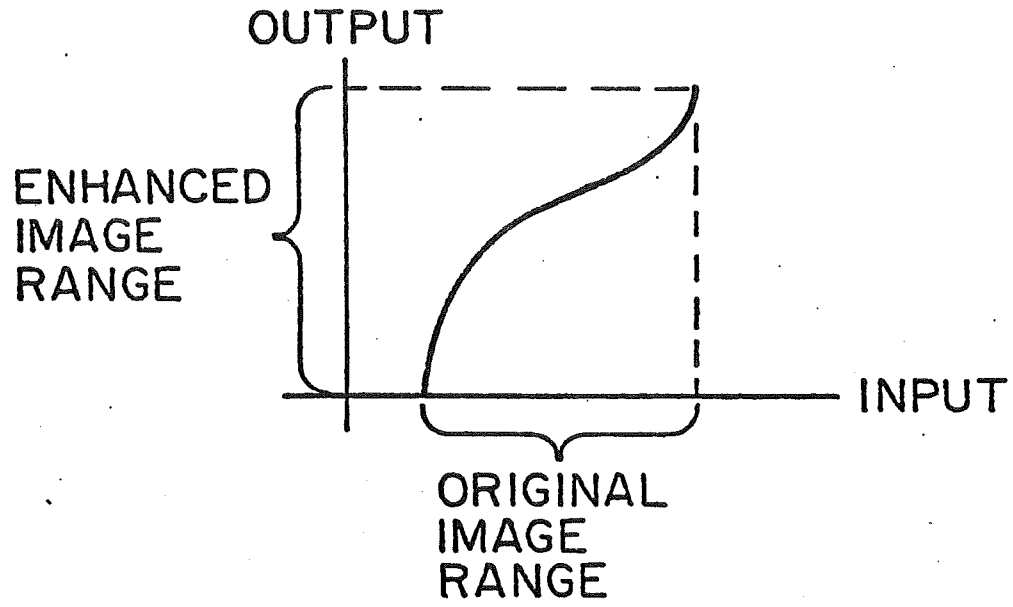
- UNSHARP MASKING
- HIGH PASS CONVOLUTION MASK

COLOR ENHANCEMENT

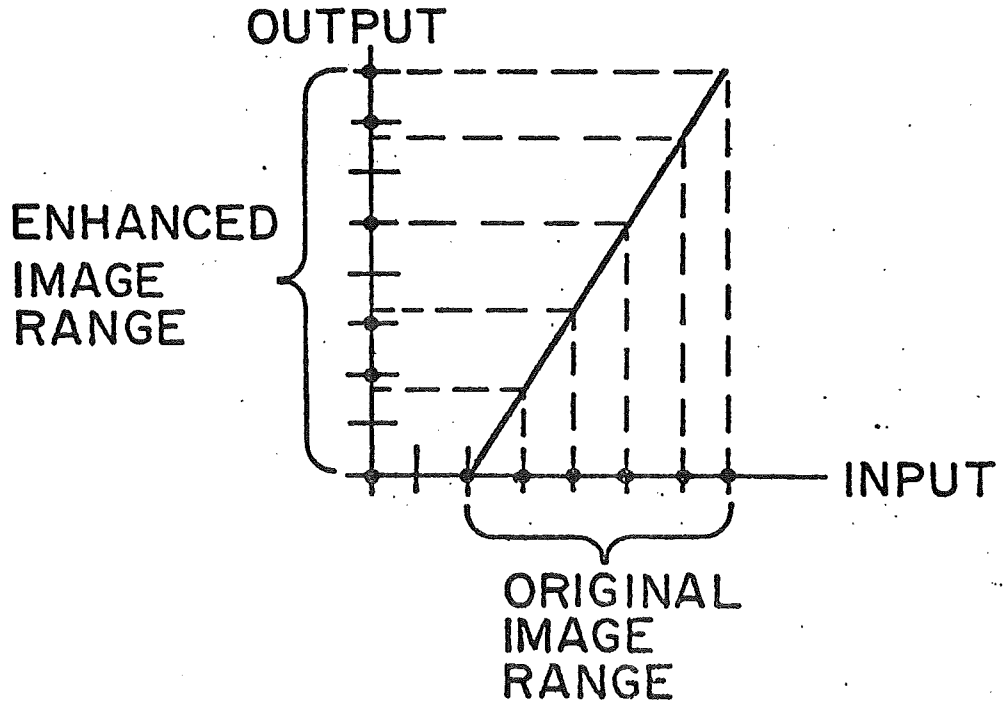
- FALSE COLOR
- PSEUDOCOLOR

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DIGITAL IMAGE PROCESSING	CONTINUOUS AND DIGITAL CONTRAST STRETCHING



(a) CONTINUOUS IMAGE CONTRAST ENHANCEMENT

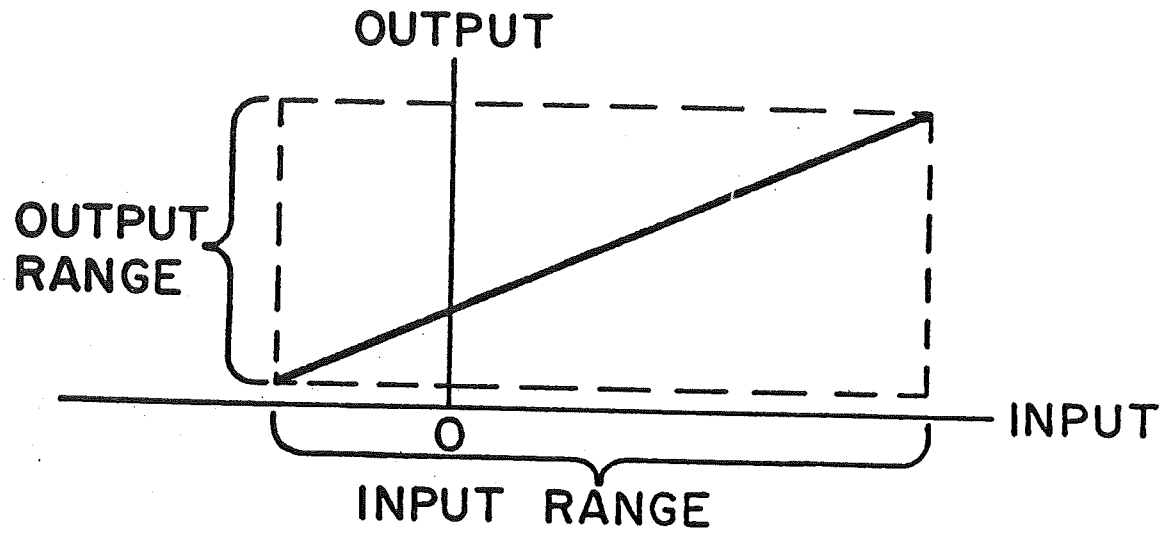


(b) DIGITAL IMAGE CONTRAST ENHANCEMENT

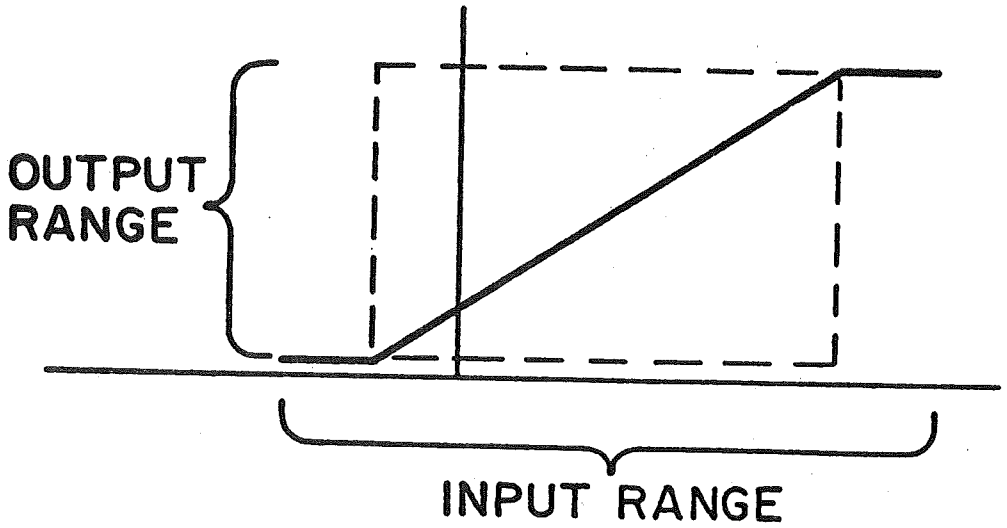
E-3

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DIGITAL IMAGE PROCESSING	EXAMPLE OF IMAGE SCALING



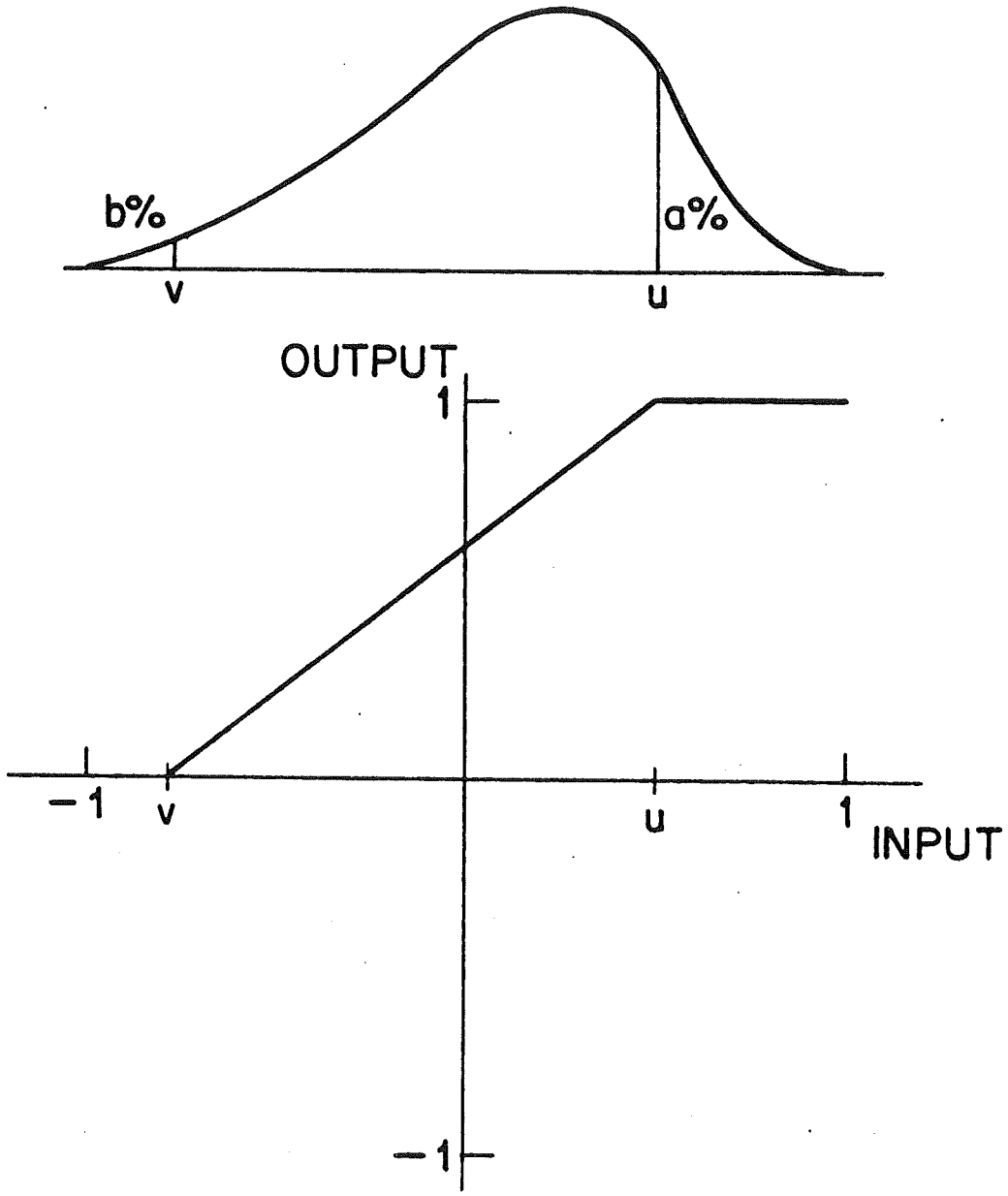
(a) LINEAR IMAGE SCALING



(b) LINEAR IMAGE SCALING WITH CLIPPING

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DIGITAL IMAGE PROCESSING	HISTOGRAM SCALING FUNCTION

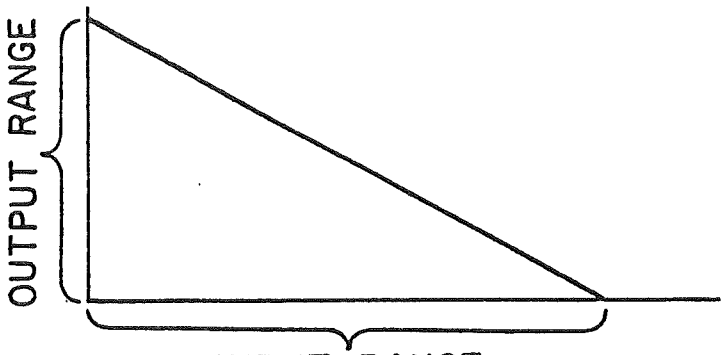


HISTOGRAM SCALING FUNCTION

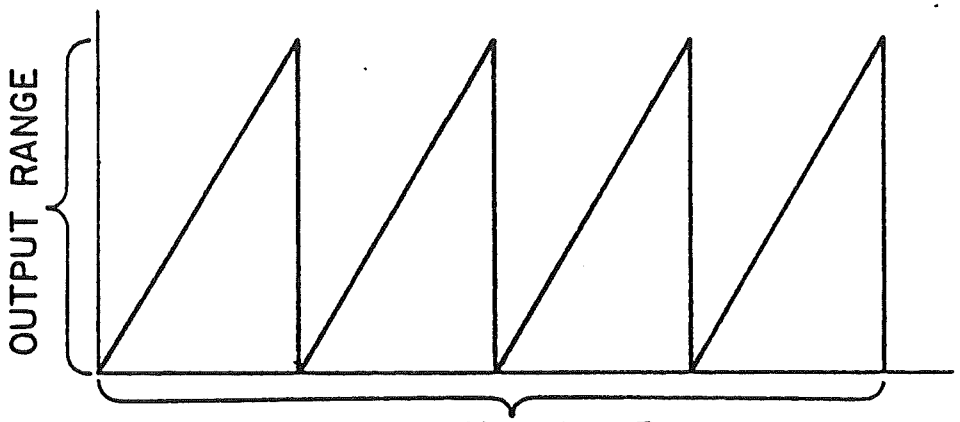
E-5

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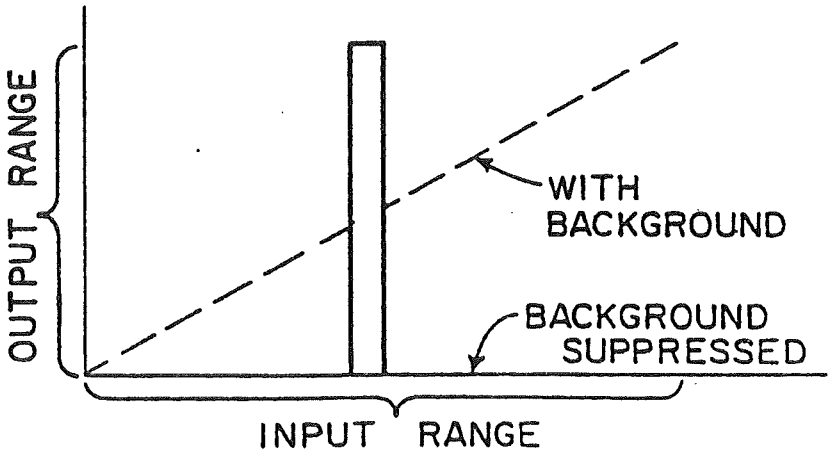
DIGITAL IMAGE PROCESSING	REVERSE SCALING, SAWTOOTH SCALING, AND LEVEL SLICING



(a) REVERSE SCALING



(b) SAWTOOTH SCALING



(c) LEVEL SLICING

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HISTOGRAM MODIFICATION - I

HISTOGRAM GRAY LEVEL DISTRIBUTION IS USUALLY

SKEWED TO DARK LEVELS

RESCALE IMAGE TO A DESIRED HISTOGRAM

UNIFORM
EXPONENTIAL
HYPERBOLIC

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DIGITAL IMAGE PROCESSING	HISTOGRAM MODIFICATION - II

MONOTONIC NONLINEAR TRANSFORMATION

$$g_k = T\{f_j\}$$

g_k = OUTPUT

f_j = INPUT

OUTPUT PROBABILITY DISTRIBUTION $P_R\{g_k = b_k\}$

INPUT PROBABILITY DISTRIBUTION $P_R\{f_j = a_j\}$

$$\sum_{n=0}^{k} P_R\{g_n = b_n\} = \sum_{m=0}^{j} P_R\{f_m = a_m\} = \sum_{m=0}^{j} H_F(m)$$

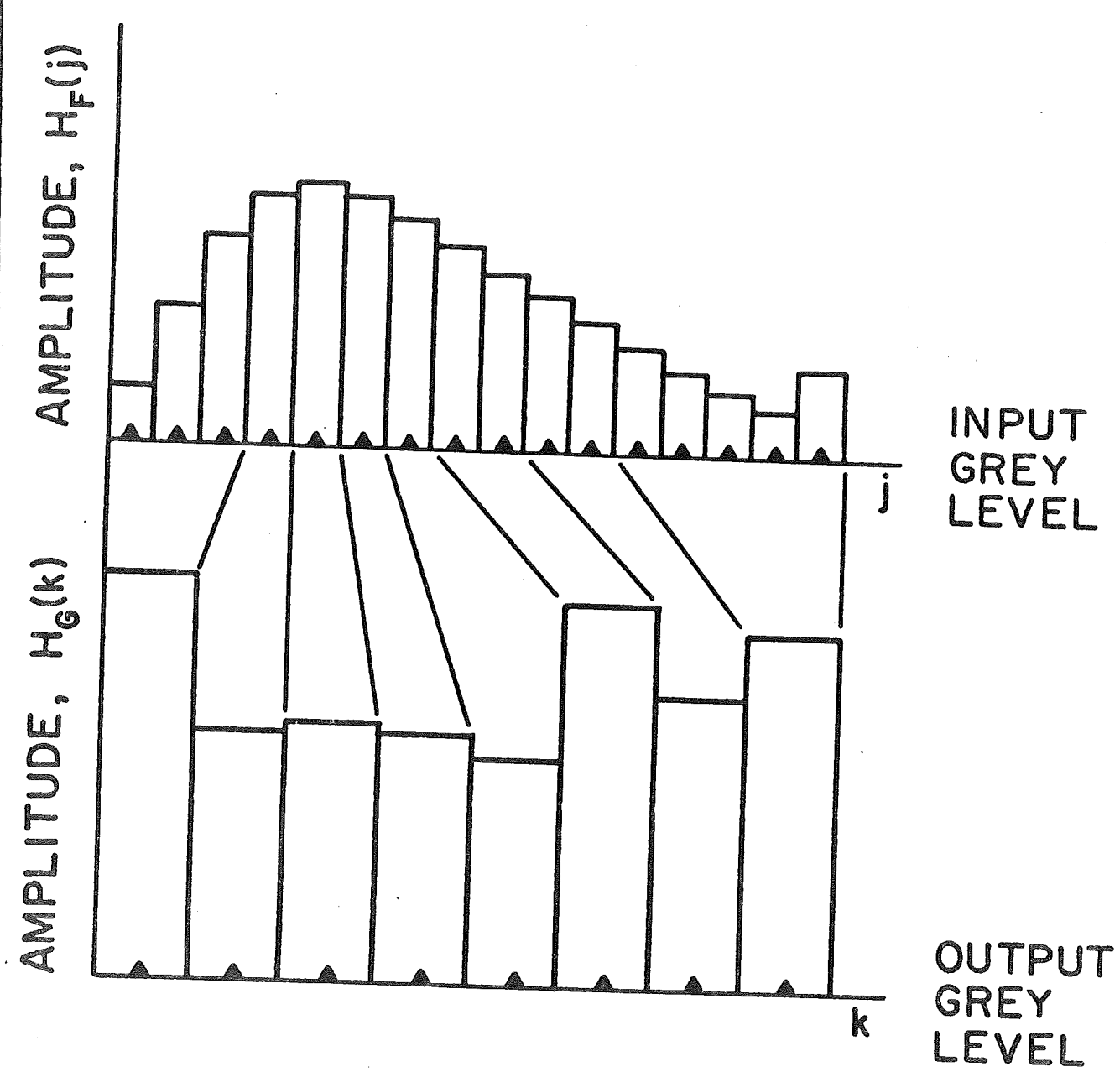
= CUMULATIVE HISTOGRAM

SOLVE TO FIND g_k IN TERMS OF f_j

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DIGITAL IMAGE PROCESSING

EXAMPLE OF APPROXIMATE GREY LEVEL HISTOGRAM EQUALIZATION



E-9

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DIGITAL IMAGE PROCESSING	STATISTICAL DIFFERENCING

STATISTICAL DIFFERENCING

BASIC ALGORITHM:

$$G(j,k) = \frac{F(j,k)}{\sigma(j,k)}$$

GENERALIZED ALGORITHM:

$$G(j,k)=[F(j,k)-\bar{F}(j,k)]\left[\frac{A\sigma_D}{A\sigma(j,k)+\sigma_D}\right]+[\alpha m_D+(1-\alpha)\bar{F}(j,k)]$$

WHERE

$$\bar{F}(j,k) = \frac{1}{W}\sum_j\sum_k F(j,k)$$

$$\sigma^2(j,k) = \frac{1}{W}\sum_j\sum_k [F(j,k)-\bar{F}(j,k)]^2$$

W = PIXEL AREA OF WINDOW

EFFECT IS TO ACCENTUATE SMALL CONTRAST CHANGES

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NOISE CLEANING
LOW PASS
CONVOLUTION MASK

$$Q(m,n) = \sum_j \sum_k F(j,k)H(m-j+1,n-k+1)$$

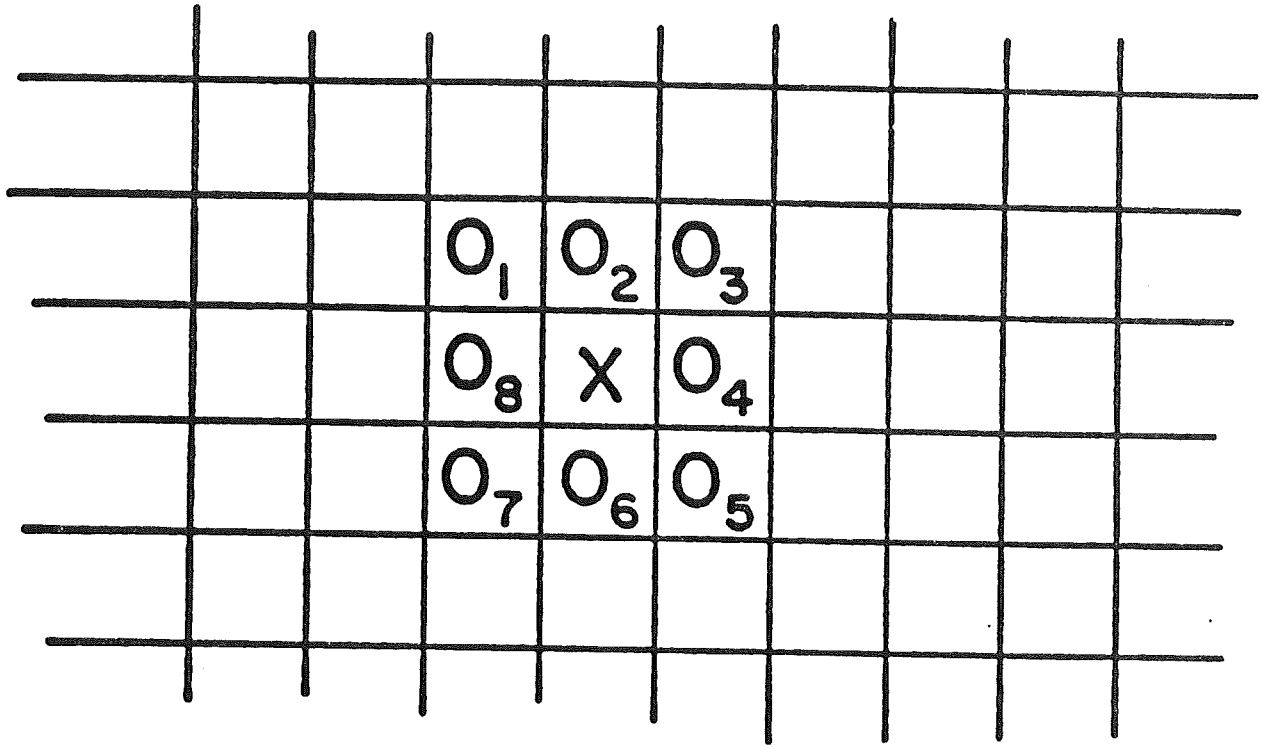
$$\underline{H} = \frac{1}{9}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

$$\underline{H} = \frac{1}{10}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 2 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

$$\underline{H} = \frac{1}{16}\begin{bmatrix} 1 & 2 & 1 \\ 2 & 4 & 2 \\ 1 & 2 & 1 \end{bmatrix}$$

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DIGITAL IMAGE PROCESSING	EXAMPLE OF NONLINEAR NOISE CLEANING ALGORITHM



IF $\left| X - \frac{1}{8}\sum_{i=1}^{8} O_i \right| > \epsilon$ THEN

$$X = \frac{1}{8}\sum_{i=1}^{8} O_i$$

WHERE

$$X = F(j,k) \circledast \frac{1}{8}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 0 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

E-5

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DIGITAL IMAGE PROCESSING	MEDIAN FILTERING

INTRODUCED BY TUKEY

OUTPUT IS THE MEDIAN OF AN ODD NUMBER OF SAMPLES IN A MOVING WINDOW

PULSES LESS THAN HALF THE WINDOW SIZE ARE SUPRESSED

EXAMPLES: 80, 90, 200, 110, 120

REPLACE BY 110 = MEDIAN [80,90,110,120,200]

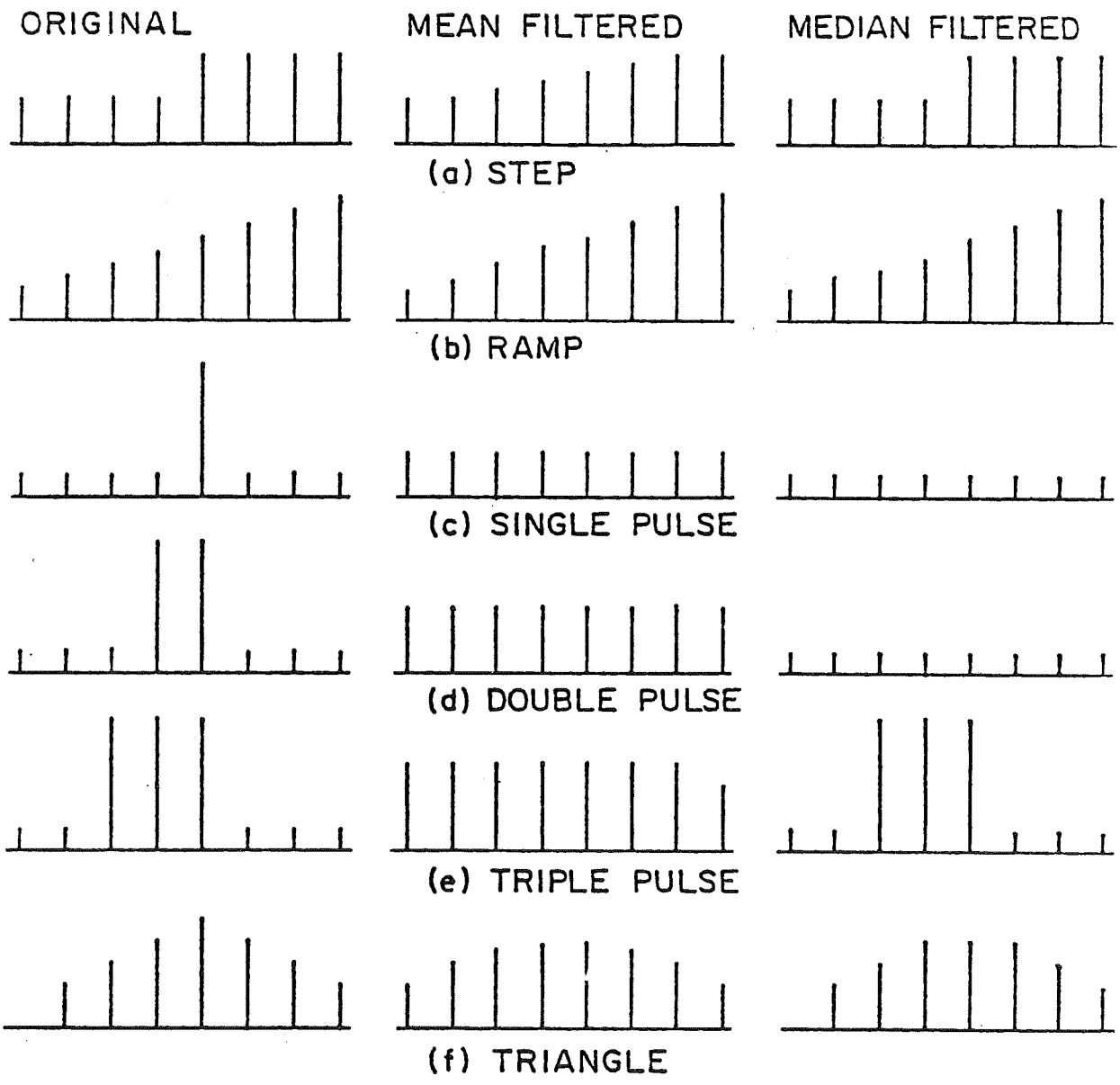
NONLINEAR FILTER SINCE

$$\text{med}\{f(j)+g(j)\} \neq \text{med}\{f(j)\} + \text{med}\{g(j)\}$$

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DIGITAL IMAGE PROCESSING

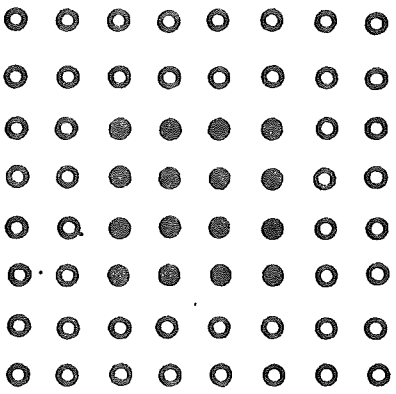
EXAMPLES OF MEDIAN FILTERING ON PRIMITIVE SIGNALS - L = 5



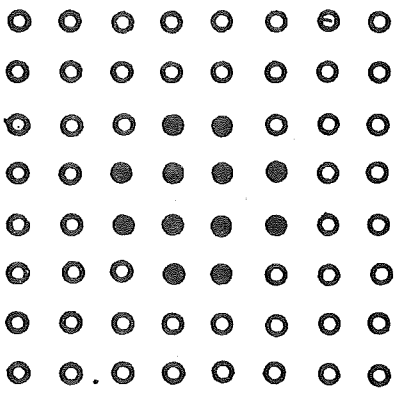
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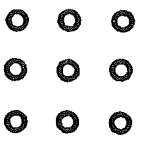
DIGITAL IMAGE PROCESSING

EXAMPLE OF TWO-DIMENSIONAL MEDIAN FILTERING



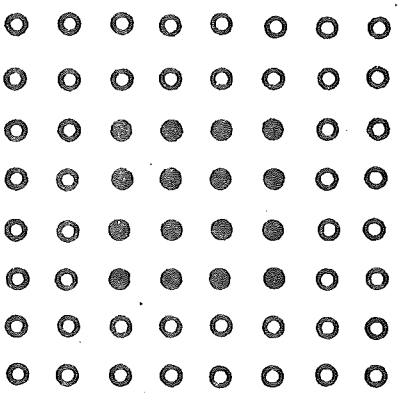
ORIGINAL IMAGE

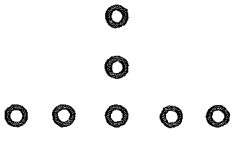




FILTER

FILTERED IMAGE





FILTER

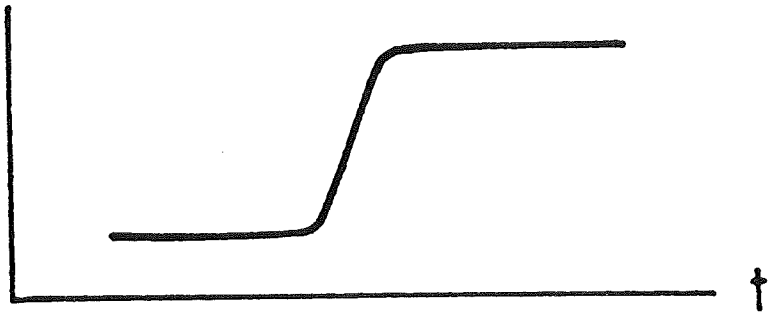
FILTERED IMAGE

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DIGITAL IMAGE PROCESSING

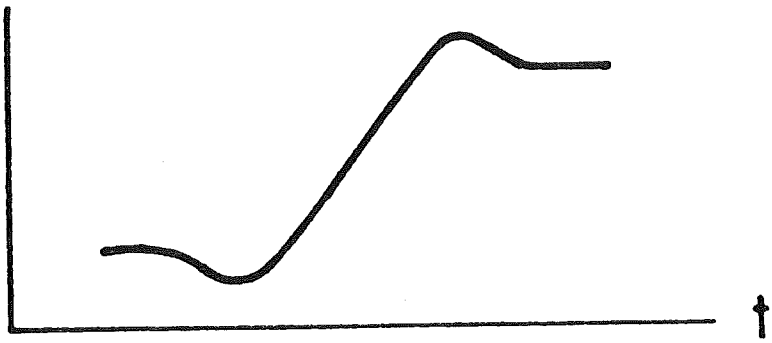
WAVEFORMS IN AN UNSHARP MASKING IMAGE ENHANCEMENT SYSTEM



(a) HIGH RESOLUTION



(b) LOW RESOLUTION



(c) UNSHARP MASKED SIGNAL

E-16

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EDGE CRISPENING HIGH PASS CONVOLUTION MASK

$$Q(m,n) = \sum_j \sum_k F(j,k)\, H(m-j+1,\ n-k+1)$$

$$\underline{H}_1 = \begin{bmatrix} 0 & -1 & 0 \\ -1 & 5 & -1 \\ 0 & -1 & 0 \end{bmatrix}$$

$$\underline{H}_2 = \begin{bmatrix} -1 & -1 & -1 \\ -1 & 9 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

$$\underline{H}_3 = \begin{bmatrix} 1 & -2 & 1 \\ -2 & 5 & -2 \\ 1 & -2 & 1 \end{bmatrix}$$

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DIGITAL IMAGE PROCESSING	FALSE COLOR

MAP IMAGES IN DIFFERENT SPECTRAL BANDS (3 PRIMARY COLORS, INFRARED OR ULTRAVIOLET) TO DIFFERENT TRISTIMULUS INPUTS FOR HUMAN OBSERVER. LINEAR OR NONLINEAR MAPPING.

INCREASE HUMAN OBSERVER ATTENTION BY NON-NATURAL COLORS.

MAP INPUTS TO SPECTRAL REGIONS OF MAXIMUM SENSITIVITY - YELLOW-GREEN FOR HUMANS.

$F_1, F_2, \ldots$ = MULTISPECTRAL IMAGE PLANES

$$R_D = \mathcal{O}_R\{F_1, F_2, \ldots\}$$

$$G_D = \mathcal{O}_G\{F_1, F_2, \ldots\}$$

$$B_D = \mathcal{O}_B\{F_1, F_2, \ldots\}$$

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DIGITAL IMAGE PROCESSING	PSEUDOCOLOR

ORIGINAL IMAGE MONOCHROME (BLACK AND WHITE).

HUMAN OBSERVER MORE SENSITIVE TO SMALL COLOR CHANGES THAN GRAY LEVEL CHANGES.

$$R(j,k) = \mathcal{O}_R\{F(j,k)\}$$

$$G(j,k) = \mathcal{O}_G\{F(j,k)\}$$

$$B(j,k) = \mathcal{O}_B\{F(j,k).$$

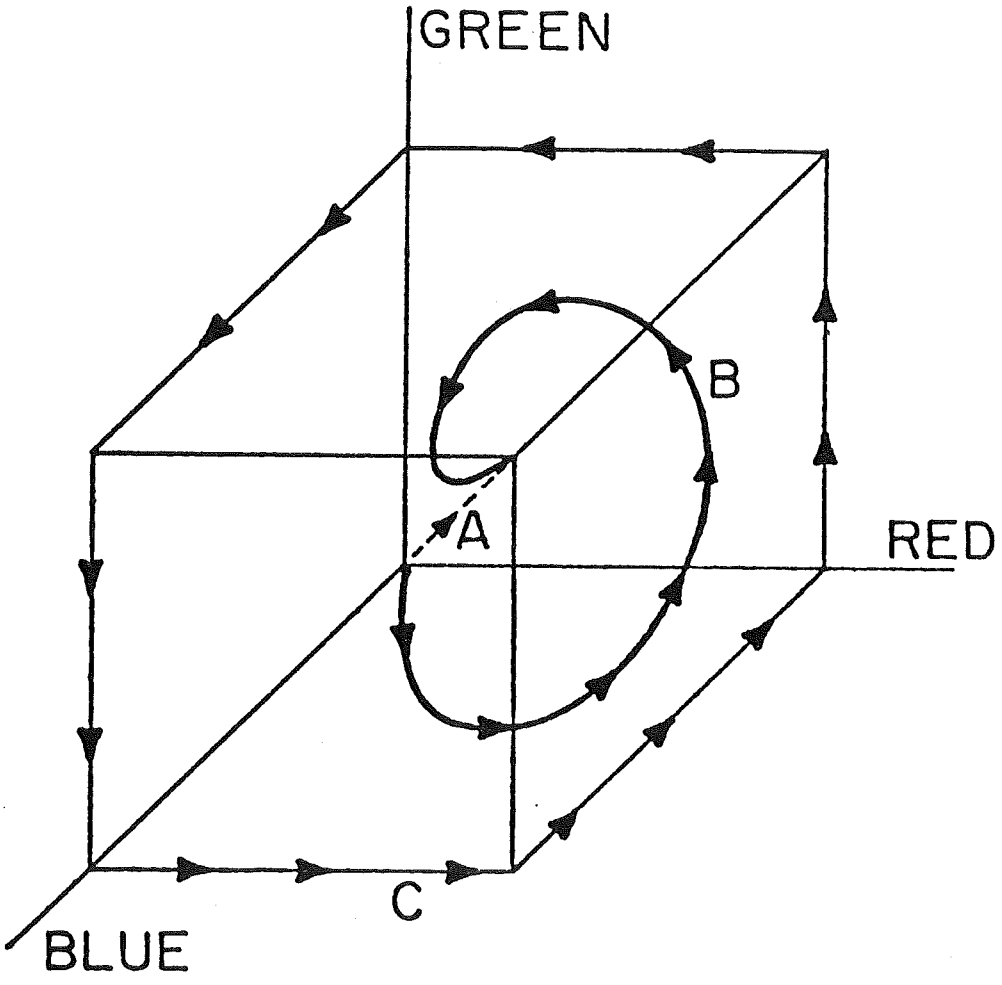
MAPPINGS ALSO ON COLOR SCALES

CONSTANT LUMINANCE - DISCRIMINATION BY HUE AND SATURATION

CONSTANT SATURATION - DISCRIMINATION BY HUE AND LUMINANCE

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DIGITAL IMAGE PROCESSING	BLACK TO WHITE PSEUDOCOLOR MAPPINGS AND RGB PERIMETER MAPPING



E-20

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IMAGE RESTORATION

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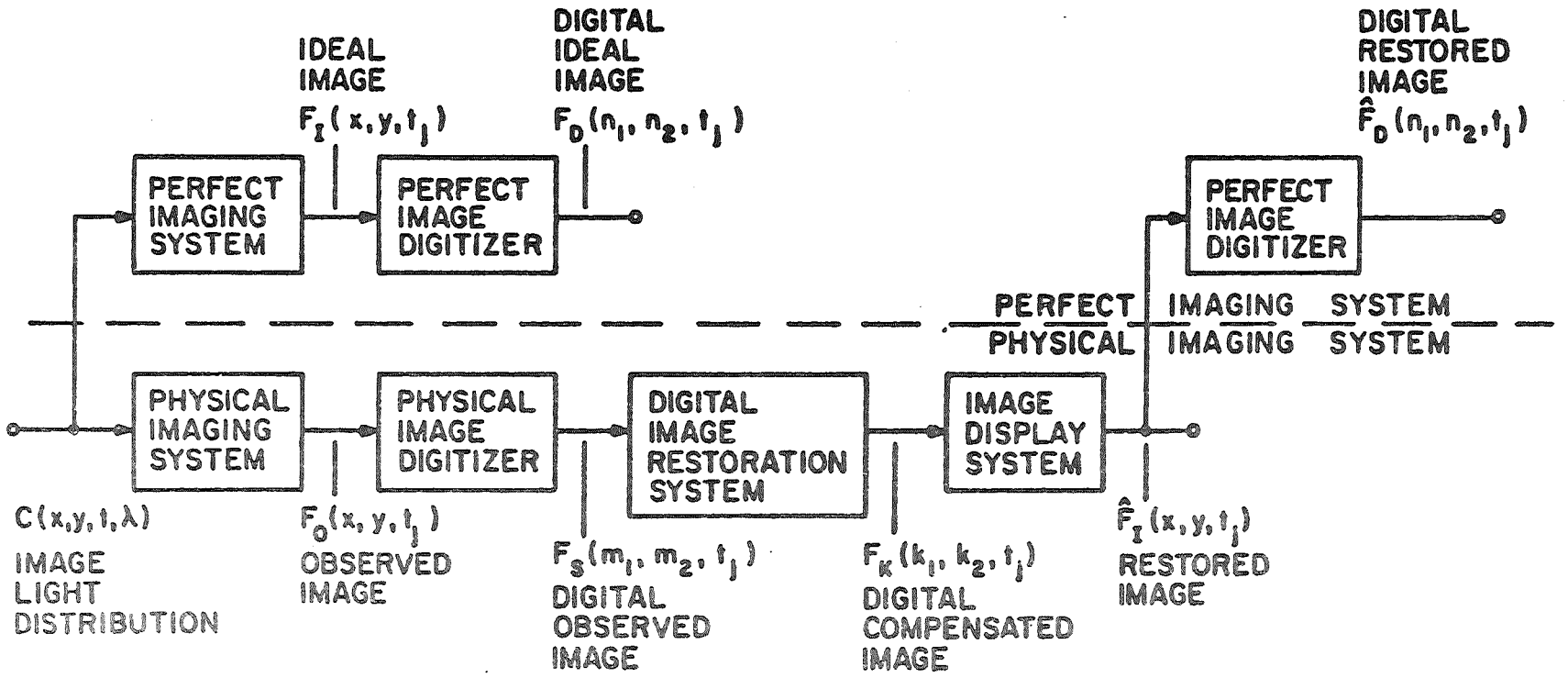
DIGITAL IMAGE PROCESSING	IMAGE RESTORATION MODELING

RESTORATION - ESTIMATE AN IDEAL IMAGE FIELD GIVEN AN OBSERVED OR MEASURED FIELD CONTAINING DEGRADATIONS.

MODELING AND UNDERSTANDING OF IMAGE FORMATION AND DEGRADATION EFFECTS - KEY TO EFFECTIVE RESTORATION.

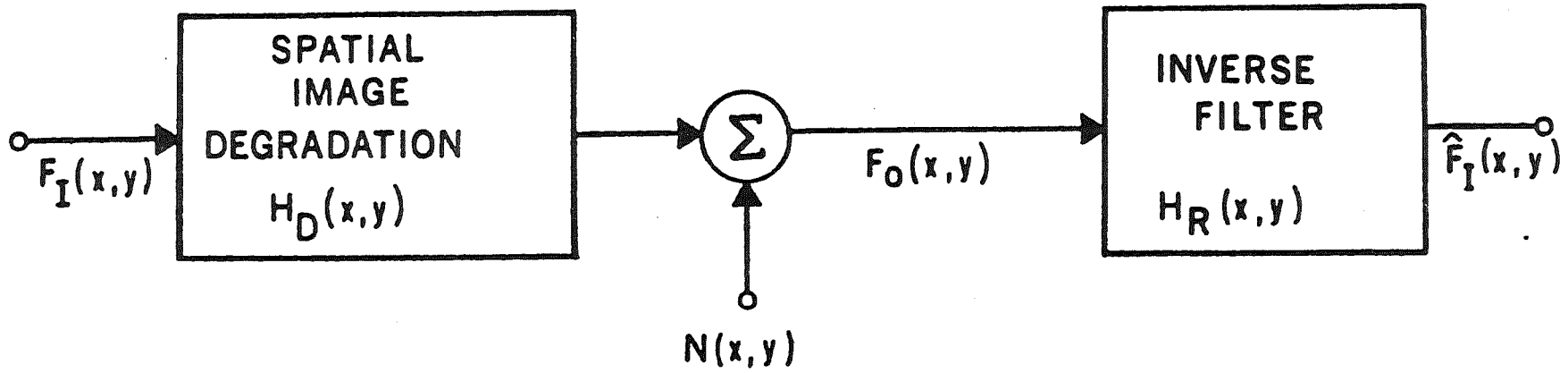
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DIGITAL IMAGE RESTORATION MODEL



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INVERSE FILTERING IMAGE RESTORATION



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DIGITAL IMAGE PROCESSING

CONTINUOUS INVERSE FILTERING RESTORATION

FOURIER TRANSFORM OF OBSERVED IMAGE:

$$\mathcal{F}_O(\omega_x, \omega_y) = \mathcal{F}_I(\omega_x, \omega_y)\mathcal{K}_D(\omega_x, \omega_y) + \mathcal{N}(\omega_x, \omega_y)$$

WHERE $\mathcal{K}_D$ IS TRANSFER FUNCTION OF DEGRADATION.

FOURIER TRANSFORM OF RESTORED IMAGE:

$$\hat{\mathcal{F}}_I(\omega_x, \omega_y) = \mathcal{F}_O(\omega_x, \omega_y)\mathcal{K}_R(\omega_x, \omega_y)$$

WHERE $\mathcal{K}_R$ IS TRANSFER FUNCTION OF RESTORATION FILTER.

LET

$$\mathcal{K}_R(\omega_x, \omega_y) = \frac{1}{\mathcal{K}_D(\omega_x, \omega_y)}$$

THEN

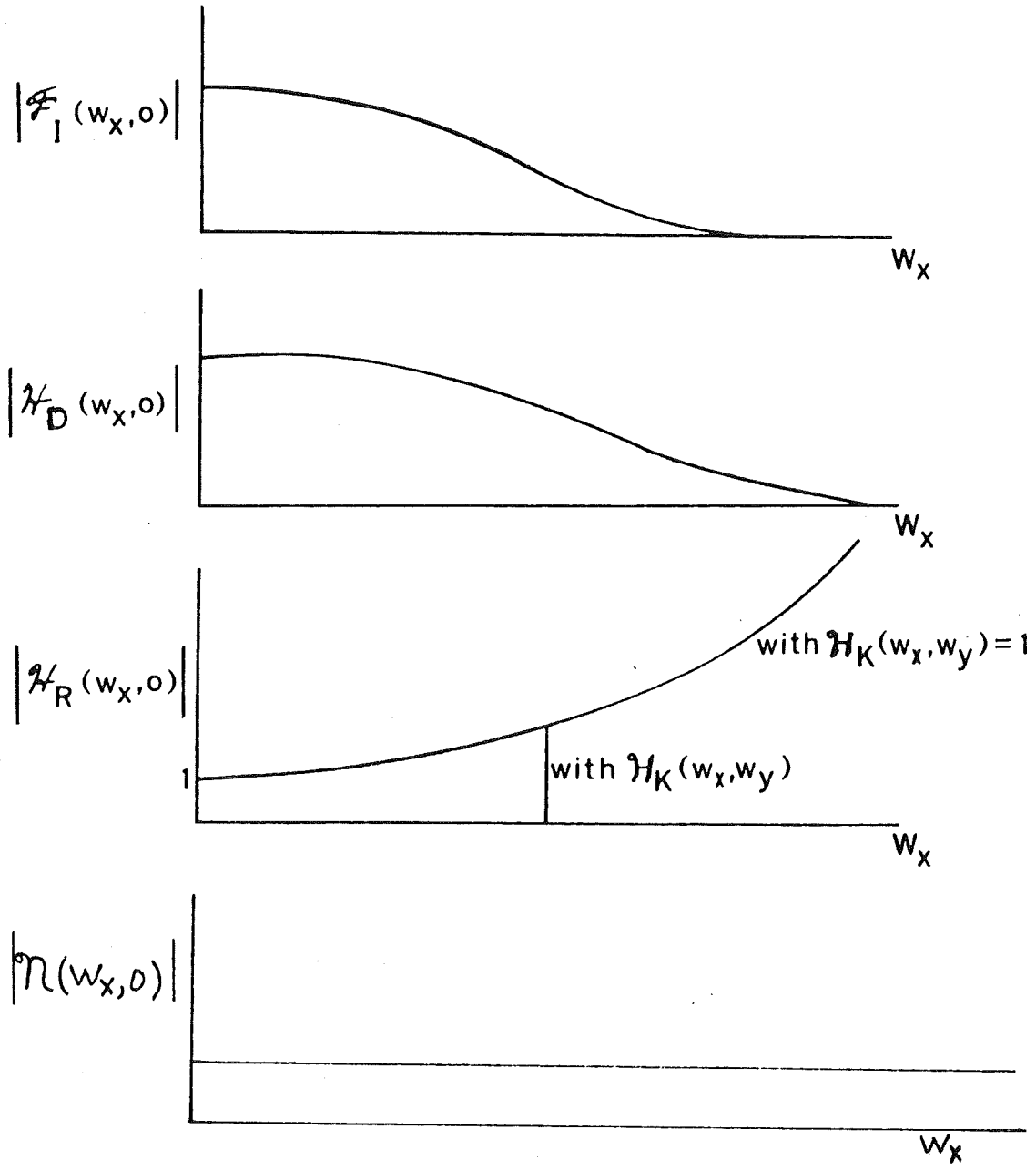
$$\hat{\mathcal{F}}_I(\omega_x, \omega_y) = \mathcal{F}_I(\omega_x, \omega_y) + \frac{\mathcal{N}(\omega_x, \omega_y)}{\mathcal{K}_D(\omega_x, \omega_y)}$$

INVERSE FILTER IS A HIGH EMPHASIS FILTER. NOISE WILL BE EXCESSIVELY AMPLIFIED AT HIGHER FREQUENCIES AND AT ZEROS OF $\mathcal{K}_D$.

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DIGITAL IMAGE PROCESSING

TYPICAL SPECTRA OF INVERSE FILTERING IMAGE RESTORATION SYSTEM



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DIGITAL IMAGE PROCESSING

CONTINUOUS WIENER FILTERING RESTORATION

ADDITIVE NOISE - KNOWN SIGNAL AND NOISE STATISTICS

LET

$\mathscr{W}_{F_I}(\omega_x, \omega_y)$ = SIGNAL POWER SPECTRAL DENSITY

$\mathscr{W}_N(\omega_x, \omega_y)$ = NOISE POWER SPECTRAL DENSITY

MINIMUM MEAN SQUARE ERROR:

$$\mathcal{E} = E\{[F_I(x,y) - \hat{F}_I(x,y)]^2\}$$

OPTIMAL RECONSTRUCTION FILTER:

$$\mathscr{H}_R = \frac{\mathscr{H}_D^*}{|\mathscr{H}_D|^2 + \frac{\mathscr{W}_N}{\mathscr{W}_{F_I}}} \qquad \text{SNR} = \frac{\mathscr{W}_{F_I}}{\mathscr{W}_N}$$

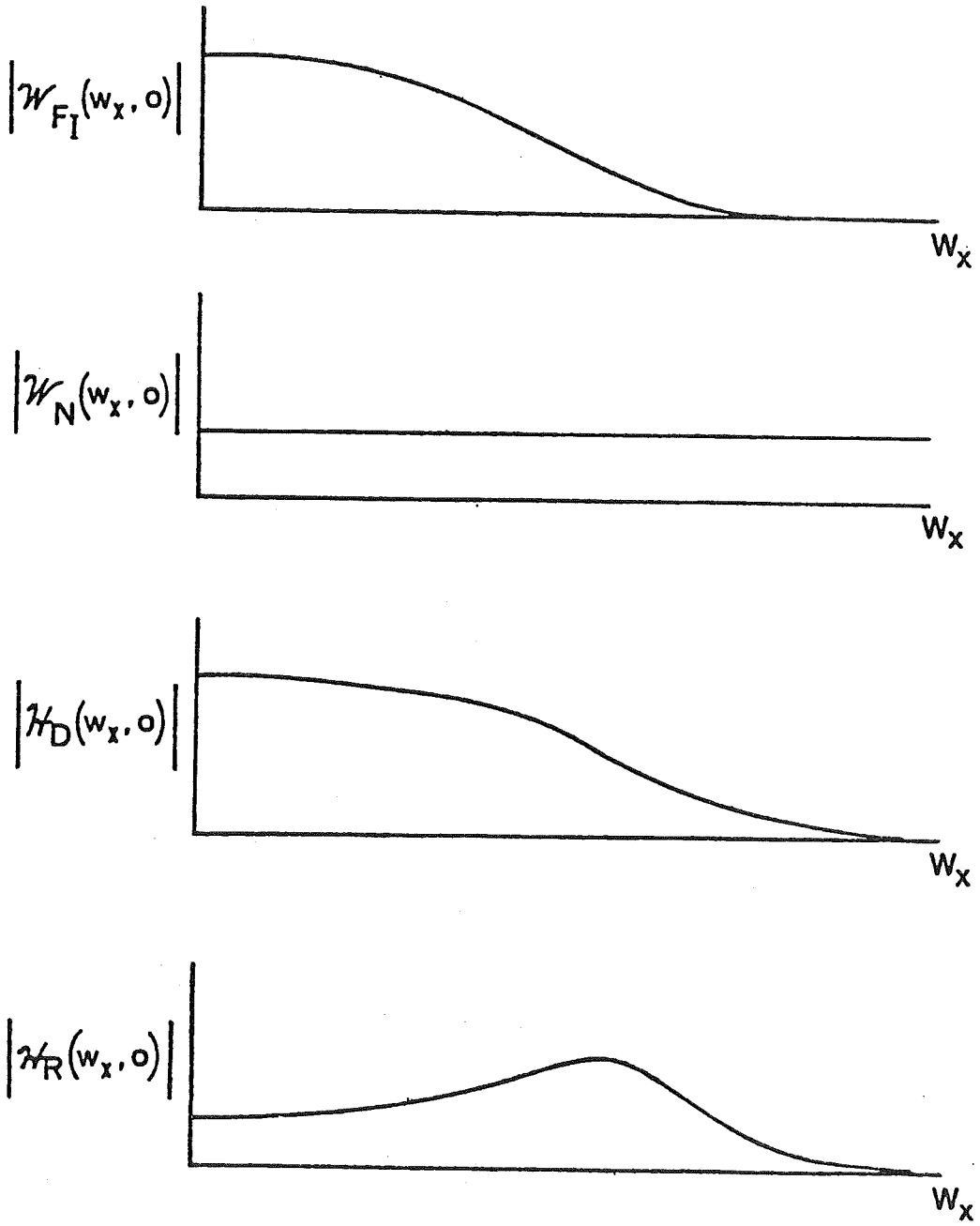
REDUCES TO INVERSE FILTER FOR INFINITE SNR

IF $\mathscr{W}_{F_I} = 1$, NO IMAGE CORRELATION,

$$\mathscr{H}_R = \frac{\mathscr{H}_D^*}{|\mathscr{H}_D|^2 + \mathscr{W}_N}$$

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DIGITAL IMAGE PROCESSING	TYPICAL SPECTRA OF WIENER FILTERING IMAGE RESTORATION SYSTEM



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DIGITAL IMAGE PROCESSING	POWER SPECTRUM FILTER

$$|\mathcal{K}_R| = \left[\frac{\mathcal{W}_{F_I}}{\mathcal{W}_{F_I} |\mathcal{K}_D|^2 + \mathcal{W}_N} \right]^{\frac{1}{2}}$$

POWER SPECTRUM OF OUTPUT IS

$$\mathcal{W}_{\hat{F}_I} = |\mathcal{K}_R|^2 \mathcal{W}_{F_O}$$

WHERE

$$\mathcal{W}_{F_O} = |\mathcal{K}_D|^2 \mathcal{W}_{F_I} + \mathcal{W}_N$$

SO

$$\mathcal{W}_{\hat{F}_I} = \mathcal{W}_{F_I}$$

AND ESTIMATE POWER SPECTRUM = IDEAL IMAGE POWER SPECTRUM

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DIGITAL IMAGE PROCESSING	GEOMETRIC MEAN FILTER & LEAST SQUARES FILTER

GEOMETRIC MEAN FILTER:

$$\mathcal{H}_R = \mathcal{H}_D^{-S} \left[\frac{\mathcal{H}_D^* \mathcal{W}_{F_I}}{|\mathcal{H}_D|^2 \mathcal{W}_{F_I} + \mathcal{W}_N} \right]^{1-S}$$

FOR $S = \frac{1}{2}$ AND $\mathcal{H}_D(\omega_x, \omega_y) = \mathcal{H}_D^*(\omega_x, \omega_y)$

REDUCES TO PREVIOUS FILTER

$$\mathcal{H}_R = \frac{\mathcal{H}_D^*}{|\mathcal{H}_D|^2 + \gamma |\mathcal{C}|^2}$$

$\mathcal{C}(\omega_x, \omega_y)$ ASSUMED SPECTRAL VARIATION

SAMPLED MATRIX VERSIONS OF THESE FILTERS EXIST FOR SPATIAL DOMAIN PROCESSING.

SAMPLED FILTERS NOT RESTRICTED TO FOURIER (SPACE-INVARIANT) DOMAIN.

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DIGITAL IMAGE PROCESSING AND ANALYSIS	PSEUDOINVERSE RESTORATION

MODEL:

$$\underline{g} = \underline{B}\,\underline{f} + \underline{n}$$

ESTIMATE:

$$\hat{\underline{f}} = \underline{B}^{-}\underline{g}$$

FULL RANK GENERALIZED INVERSE:

$$\underline{B}^{-} = \underline{B}^{T}(\underline{B}\,\underline{B}^{T})^{-1}$$

ESTIMATE:

$$\hat{\underline{f}} = \underline{B}^{-}\underline{g} = \underline{B}^{-}\underline{B}\,\underline{f} + \underline{B}^{-}\underline{n}$$

FUNDAMENTAL PROBLEMS:

$\underline{B}^{-}\underline{B} \neq \underline{I}$ FOR UNDERDETERMINED SYSTEM

$\underline{\Delta f} \equiv \underline{B}^{-}\underline{n}$ IS OFTEN QUITE LARGE (ILL-CONDITIONED PROBLEM)

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DIGITAL IMAGE PROCESSING	SVD PSEUDOINVERSE RESTORATION - I

MODEL:

$$\underline{g} = \underline{B}\,\underline{f} + \underline{n}$$

DECOMPOSITION:

$$\underline{B} = \underline{U}\,\underline{\Lambda}^{\frac{1}{2}}\,\underline{V}^{T}$$

WHERE:

$\underline{U}$ - EIGENVECTORS OF $\underline{B}\,\underline{B}^{T}$

$\underline{V}$ - EIGENVECTORS OF $\underline{B}^{T}\,\underline{B}$

} UNITARY MATRICES

$\underline{\Lambda}$ - EIGENVALUES OF $\underline{B}\,\underline{B}^{T}$ & $\underline{B}^{T}\,\underline{B}$ } DIAGONAL MATRIX

$$\underline{U}^{T}(\underline{B}\,\underline{B}^{T})\,\underline{U} = \underline{\Lambda}$$

$$\underline{V}^{T}(\underline{B}^{T}\,\underline{B})\,\underline{V} = \underline{\Lambda}$$

SERIES FORMULATION:

$$\underline{B} = \sum_{i=1}^{R} \lambda^{\frac{1}{2}}(i)\,\underline{u}_i\,\underline{v}_i^{T}$$

WHERE R = RANK OF $\underline{B}$

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DIGITAL IMAGE PROCESSING | SVD PSEUDOINVERSE RESTORATION - II

ESTIMATE:

$$\underline{\hat{f}} = \underline{B}^{-} \underline{g}$$

WHERE:

$$\underline{B}^{-} = \underline{V} \underline{\Lambda}^{-\frac{1}{2}} \underline{U}^{T}$$

SERIES FORMULATION:

$$\underline{B}^{-} = \sum_{i=1}^{R} [\lambda(i)]^{-\frac{1}{2}} \underline{v}_i \underline{u}_i^{T}$$

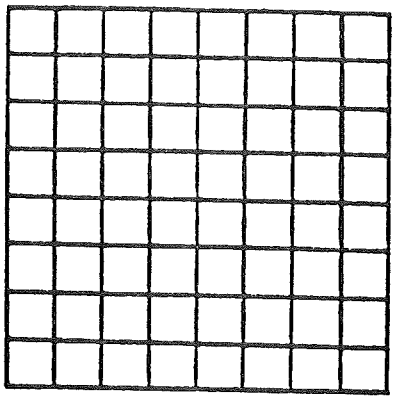
SEQUENTIAL ESTIMATE:

$$\underline{\hat{f}}_k = \underline{\hat{f}}_{k-1} + [\lambda(k)]^{-\frac{1}{2}} (\underline{u}_k^{T} \underline{g}) \underline{v}_k$$

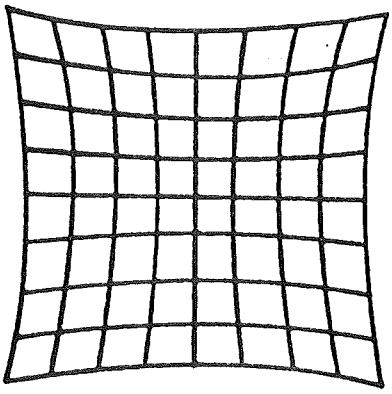
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DIGITAL IMAGE PROCESSING

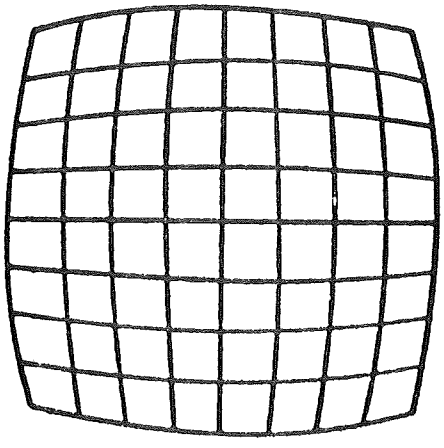
EXAMPLE OF GEOMETRIC DISTORTION



a) ORIGINAL



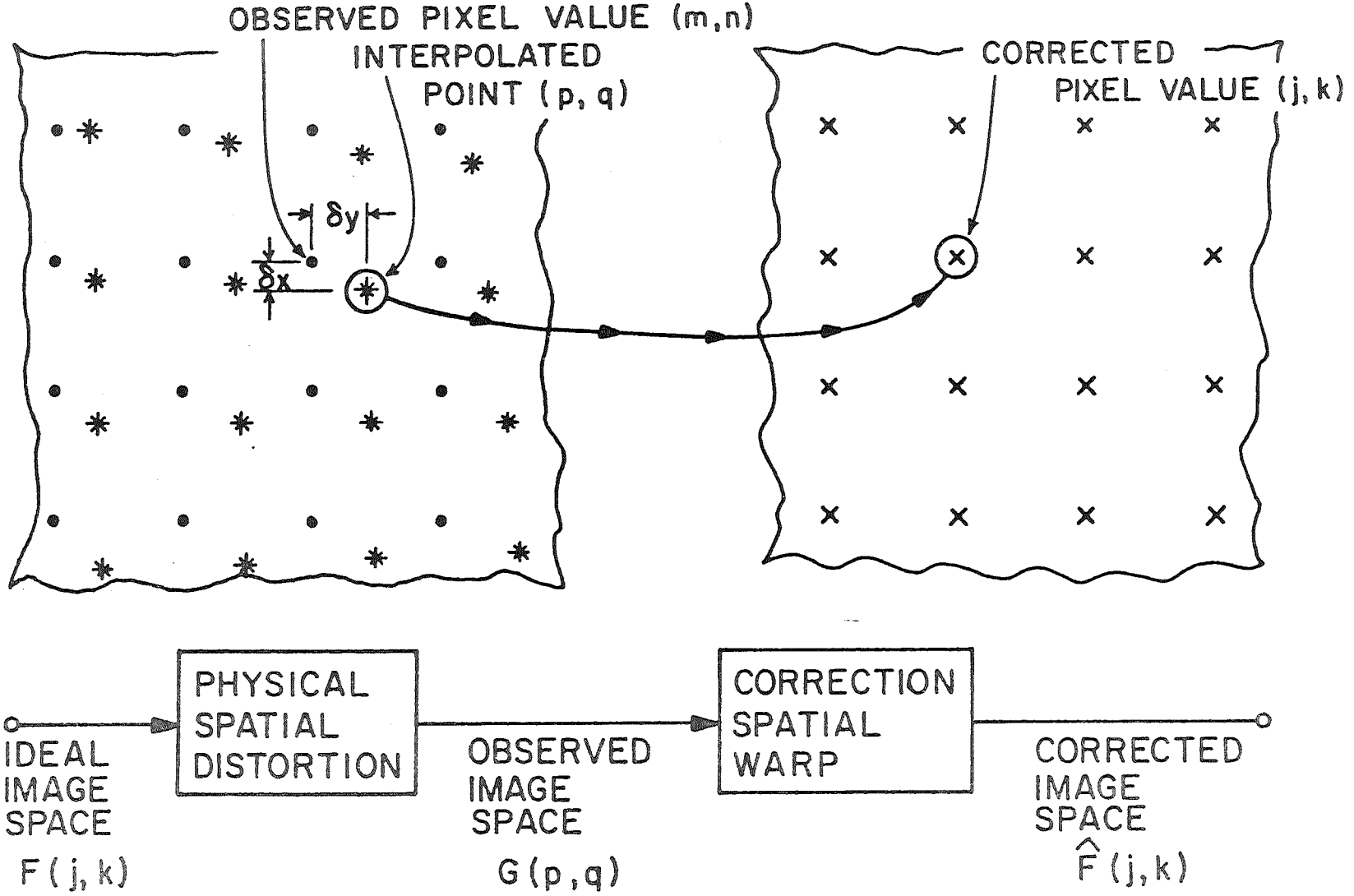
b) PINCUSHION DISTORTION



c) BARREL DISTORTION

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SPATIAL WARP CORRECTION



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DIGITAL IMAGE PROCESSING	GEOMETRIC DISTORTION CORRECTION - I

PHYSICAL SPATIAL DISTORTION:

$$p = \mathcal{O}_p\{j,k\}$$

$$q = \mathcal{O}_q\{j,k\}$$

WHERE (j,k) = INPUT POINT

(p,q) = WARPED POINT

IF $\mathcal{O}_p\{\cdot\}$ AND $\mathcal{O}_q\{\cdot\}$ ARE KNOWN, THEN IT IS SOMETIMES POSSIBLE TO FORM ESTIMATES $(\hat{j},\hat{k})$ FROM (p,q).

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DIGITAL IMAGE PROCESSING	IMAGE ROTATION

IMAGE ROTATION

PHYSICAL SPATIAL DISTORTION:

$$p = j \cos \theta - k \sin \theta$$

$$q = j \sin \theta + k \cos \theta$$

CORRECTION SPATIAL WARP:

$$j = p \cos \theta + q \sin \theta$$

$$k = -p \sin \theta + q \cos \theta$$

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DIGITAL IMAGE PROCESSING	GEOMETRIC DISTORTION CORRECTION - II

IF WARP DISTORTION FUNCTIONS ARE NOT KNOWN, STANDARD APPROACH IS TO USE POLYNOMIAL APPROXIMATION.

SECOND ORDER POLYNOMIAL APPROXIMATION:

$$\hat{p} = a_0 + a_1 j + a_2 k + a_3 j^2 + a_4 jk + a_5 k^2$$

$$\hat{q} = b_0 + b_1 j + b_2 k + b_3 j^2 + b_4 jk + b_5 k^2$$

CONSTANTS ARE DETERMINED BY MINIMIZING APPROXIMATION ERROR FOR A SET OF M CONTROL POINTS WHOSE COORDINATES ARE KNOWN IN ORIGINAL DOMAIN (j_m, k_m) AND WARPED DOMAIN (p_m, q_m)

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DIGITAL IMAGE PROCESSING

GEOMETRIC DISTORTION CORRECTION - III

VECTOR FORMULATION:

$$\underline{p}^T = [p_1, p_2, \ldots, p_M]$$
$$\underline{q}^T = [q_1, q_2, \ldots, q_M]$$
$$\underline{a}^T = [a_0, a_1, a_2, a_3, a_4, a_5]$$
$$\underline{b}^T = [b_0, b_1, b_2, b_3, b_4, b_5]$$

APPROXIMATION ERROR:

$$\delta = \underbrace{(\underline{p}-\underline{A}\,\underline{a})}_{p}^T(\underline{p}-\underline{A}\,\underline{a}) + \underbrace{(\underline{q}-\underline{A}\,\underline{b})}_{q}^T(\underline{q}-\underline{A}\,\underline{b})$$

WHERE

$$\underline{A} = \begin{bmatrix} 1 & j_1 & k_1 & j_1^2 & j_1k_1 & k_1^2 \\ 1 & j_2 & k_2 & j_2^2 & j_2k_2 & k_2^2 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ 1 & j_M & k_M & j_M^2 & j_Mk_M & k_M^2 \end{bmatrix}$$

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DIGITAL IMAGE PROCESSING	GEOMETRIC DISTORTION CORRECTION - IV

ERROR IS MINIMIZED IF

$$\underline{a} = \underline{A}^{-}\underline{p}$$

$$\underline{b} = \underline{A}^{-}\underline{q}$$

WHERE $\underline{A}^{-}$ IS THE GENERALIZED INVERSE OF $\underline{A}$

IF NUMBER OF CONTROL POINTS IS GREATER THAN NUMBER OF COEFFICIENTS

$$\underline{A}^{-} = (\underline{A}^{T}\underline{A})^{-1}\underline{A}^{T}$$

AFTER COEFFICIENTS ARE DETERMINED, POLYNOMIAL GIVES ESTIMATE $(\hat{p}, \hat{q})$ CORRESPONDING TO EACH INTEGER POINT (j, k) IN CORRECTION ARRAY.

INTERPOLATION MUST BE PERFORMED TO OBTAIN LUMINANCE ESTIMATE $\hat{F}(\hat{j}, \hat{k})$ FROM $G(p, q)$

INTERPOLATION METHODS:

- SPLINE FUNCTION
- BILINEAR
- NEAREST NEIGHBOR

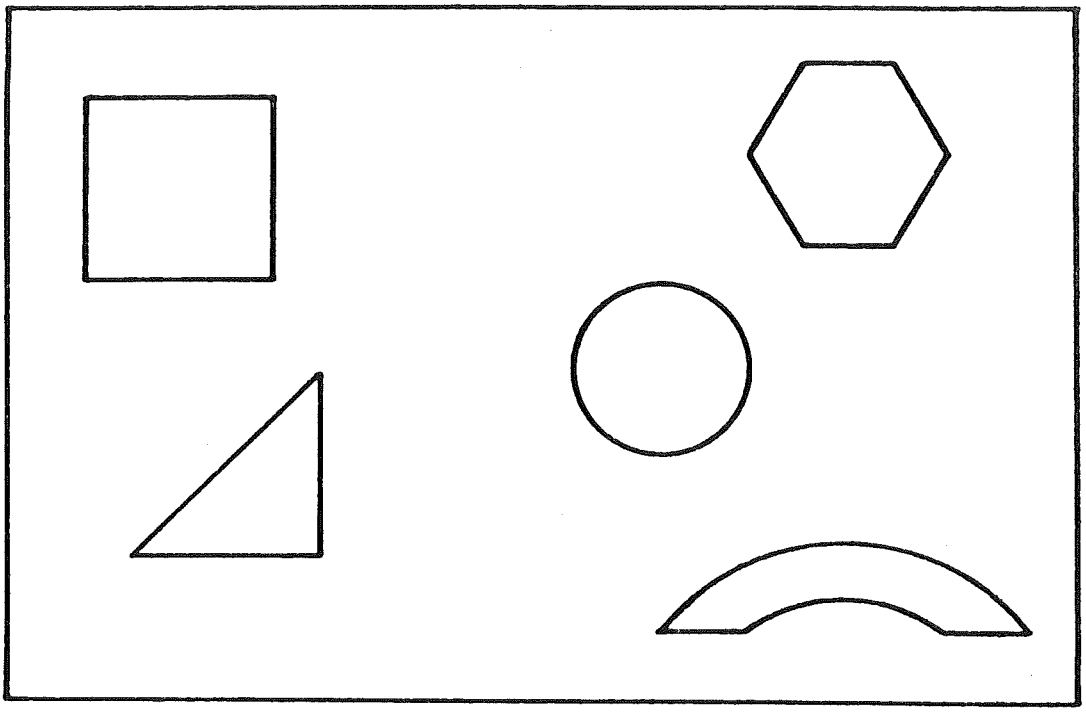
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COMPUTER TECHNIQUES IN
IMAGE PATTERN RECOGNITION
AND ANALYSIS

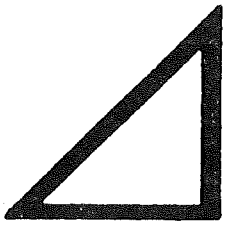
IMAGE DETECTION

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COMPUTER TECHNIQUES IN IMAGE PATTERN RECOGNITION AND ANALYSIS	TEMPLATE MATCHING -II



(a) ARRAY OF OBJECTS



(b) TRIANGLE TEMPLATE

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DIGITAL IMAGE PROCESSING	TEMPLATE MATCHING - II

NORMALIZED CROSS-CORRELATION:

$$R(j,k) = \frac{\sum_m \sum_n F(m,n)T(m-j,n-k)}{\sum_m \sum_n [F(m,n)]^2}$$

MATCH IF

$$R(j,k) \geq L(j,k)$$

WHERE $L(j,k)$ IS A THRESHOLD VALUE

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COMPUTER TECHNIQUES IN IMAGE PATTERN RECOGNITION AND ANALYSIS	IMAGE REGISTRATION

TYPES OF MIS-REGISTRATION

- TRANSLATION
- ROTATION
- DILATION

TRANSLATION DETECTION

- CROSS CORRELATION OF IMAGE PAIRS OVER SEARCH AREA

ROTATION DETECTION

- CONVERT TO TRANSLATION DETECTION PROBLEM BY TRANSFORMATION TO POLAR COORDINATES

DILATION DETECTION

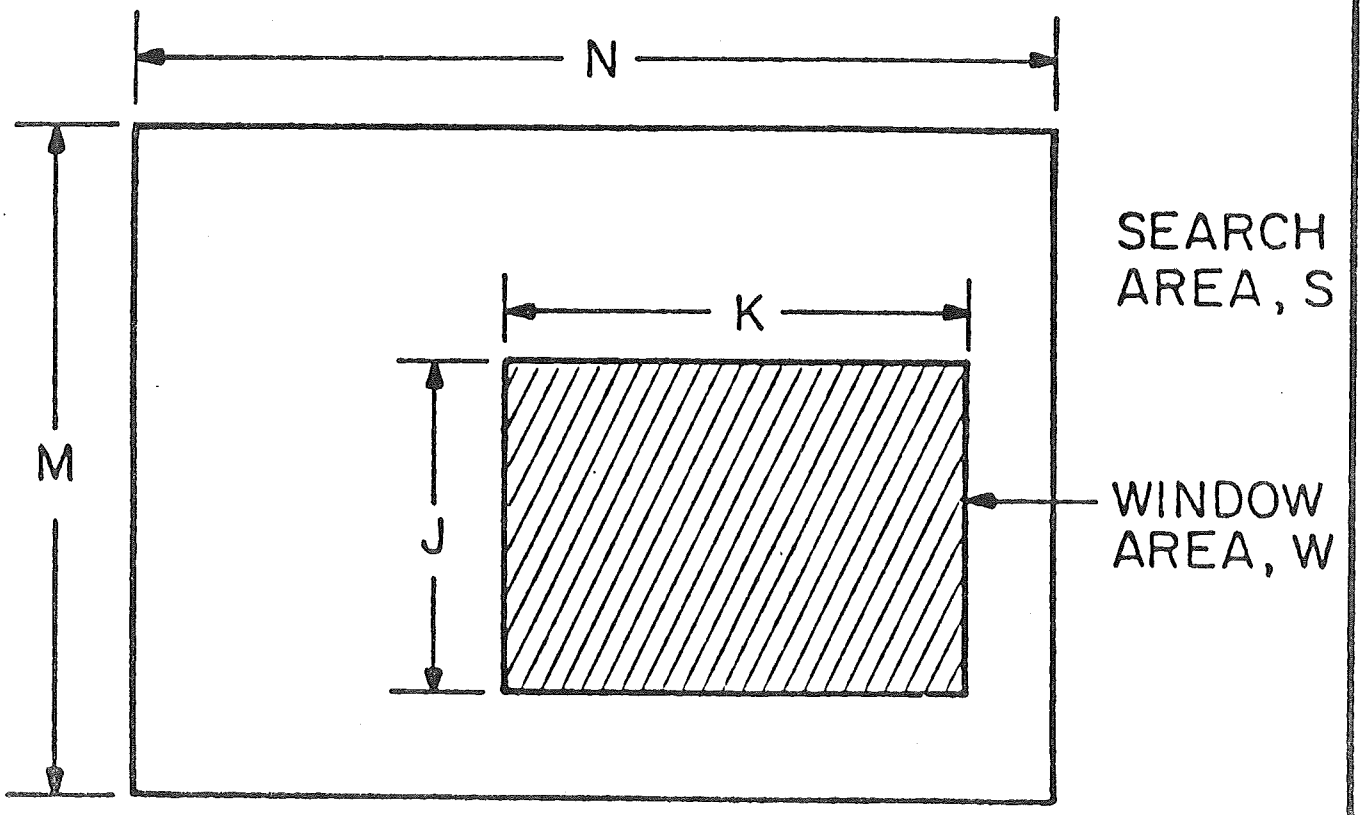
- CONVERT TO TRANSLATION DETECTION PROBLEM BY MELLIN TRANSFORMATION

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COMPUTER TECHNIQUES IN IMAGE PATTERN RECOGNITION AND ANALYSIS	TRANSLATION DETECTION - I

BASIC CORRELATION:

$$R(m,n)=\frac{\sum_{j=1}^{J}\sum_{k=1}^{K} F_1(j,k)\,F_2(j-m,\,k-n)}{\left[\sum_j\sum_k F_1^2(j,k)\right]^{\frac{1}{2}}\left[\sum_j\sum_k F_2^2(j-m,\,k-n)\right]^{\frac{1}{2}}}$$



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TRANSLATION DETECTION - II

STATISTICAL CORRELATION:

$$R(m,n) = \frac{\sum_{j=1}^{J}\sum_{k=1}^{K} G_1(j,k)\, G_2(j-m,k-n)}{\left[\sum_j\sum_k G_1^2(j,k)\right]^{\frac{1}{2}}\left[\sum_j\sum_k G_2^2(j-m,k-n)\right]^{\frac{1}{2}}}$$

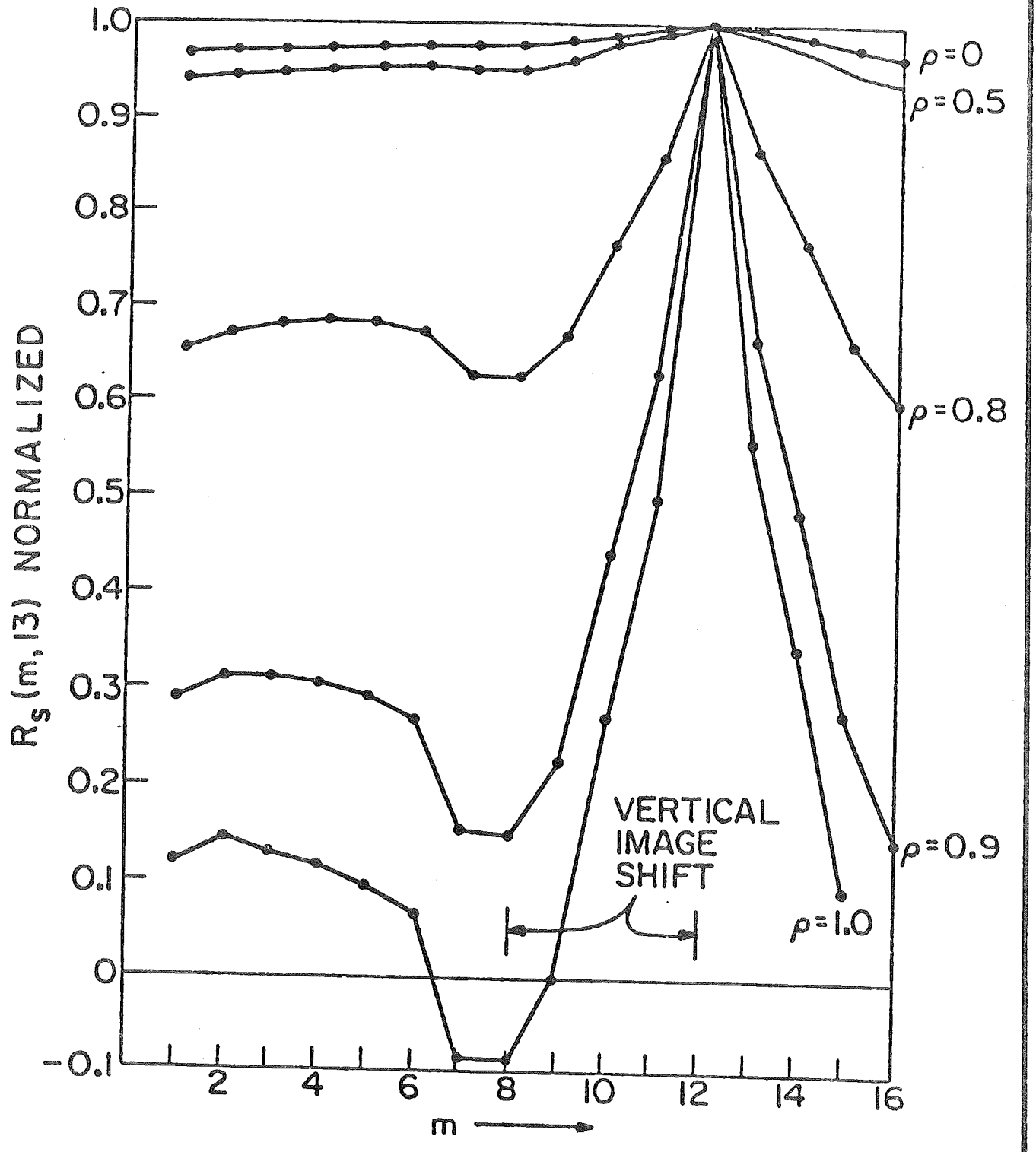
WHERE $G_i(j,k) = F_i(j,k) \circledast D_i(j,k)$

$$D_i(j,k) = \begin{bmatrix} \rho_i^2 & -\rho_i(1+\rho_i^2) & \rho_i^2 \\ -\rho_i(1+\rho_i^2) & (1+\rho_i)^2 & -\rho_i(1+\rho_i^2) \\ \rho_i^2 & -\rho_i(1+\rho_i^2) & \rho_i^2 \end{bmatrix}$$

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COMPUTER TECHNIQUES IN IMAGE PATTERN RECOGNITION AND ANALYSIS

TRANSLATION DETECTION - III



M-8

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COMPUTER TECHNIQUES IN
IMAGE PATTERN RECOGNITION
AND ANALYSIS

FEATURE EXTRACTION

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DIGITAL IMAGE PROCESSING AND ANALYSIS	IMAGE FEATURE EXTRACTION

FEATURE EXTRACTION - ISOLATE PRIMITIVE CHARACTERISTICS

NATURAL - BRIGHTNESS, EDGE OUTLINES, TEXTURE

ARTIFICIAL - HISTOGRAMS, MOMENTS, FREQUENCY

AMPLITUDE FEATURES

HISTOGRAM FEATURES

EDGE FEATURES

SPOT AND LINE FEATURES

TEXTURE FEATURES

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DIGITAL IMAGE PROCESSING AND ANALYSIS	IMAGE AMPLITUDE FEATURES

AMPLITUDE FEATURES

POINT LUMINANCE

POINT TRISTIMULUS VALUE

POINT MULTISPECTRAL VALUE

WINDOW MEAN

WINDOW STANDARD DEVIATION

WINDOW MEDIAN

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COMPUTER TECHNIQUES IN IMAGE PATTERN RECOGNITION AND ANALYSIS	HISTOGRAM FEATURES - I

FIRST ORDER PROBABILITY DISTRIBUTION:

$$P(b) = P_R\{F(j,k) = b\}$$

FIRST ORDER HISTOGRAM:

$$P(b) \approx \frac{N(b)}{M}$$

WHERE

M = NUMBER OF PIXELS IN WINDOW

$N(b)$ = NUMBER OF PIXELS IN WINDOW OF AMPLITUDE b

SHAPE CHARACTERISTICS

NARROW HISTOGRAM - LOW CONTRAST

BIMODEL HISTOGRAM - TWO BRIGHT REGIONS

SHAPE MEASURES:

MEAN

VARIANCE

SKEWNESS (3RD MOMENT)

KURTOSIS (4TH MOMENT)

ENERGY

ENTROPY

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DIGITAL IMAGE PROCESSING AND ANALYSIS

Mean

$$\bar{b} = \sum_{b=0}^{L-1} bP(b)$$

Variance

$$\sigma_b^2 = \sum_{b=0}^{L-1} (b - \bar{b})^2 P(b)$$

Skewness

$$b_S = \frac{1}{\sigma_b^3} \sum_{b=0}^{L-1} (b - \bar{b})^3 P(b)$$

Kurtosis

$$b_K = \frac{1}{\sigma_b^4} \sum_{b=0}^{L-1} (b - \bar{b})^4 P(b) - 3$$

Energy

$$b_N = \sum_{b=0}^{L-1} [P(b)]^2$$

Entropy

$$b_E = -\sum_{b=0}^{L-1} P(b) \log_2 [P(b)]$$

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COMPUTER TECHNIQUES IN IMAGE PATTERN RECOGNITION AND ANALYSIS

HISTOGRAM FEATURES - II

SECOND ORDER PROBABILITY DISTRIBUTION:

$$P(a,b) = P_R\{F(j,k) = a, \quad F(m,n) = b\}$$

SECOND ORDER HISTOGRAM:

$$P(a,b) \approx \frac{N(a,b)}{M}$$

WHERE M = NUMBER OF PIXEL PAIRS IN WINDOW

N(a, b) = NUMBER OF PIXEL PAIRS IN WINDOW FOR WHICH ONE IS AMPLITUDE a AND THE OTHER IS AMPLITUDE b

SHAPE CHARACTERISTICS

UNIFORM HISTOGRAM - UNCORRELATED PIXELS

DIAGONAL HISTOGRAM - CORRELATED PIXELS

SHAPE MEASURES:

AUTOCORRELATION

COVARIANCE

INERTIA

ABSOLUTE VALUE

INVERSE DIFFERENCE

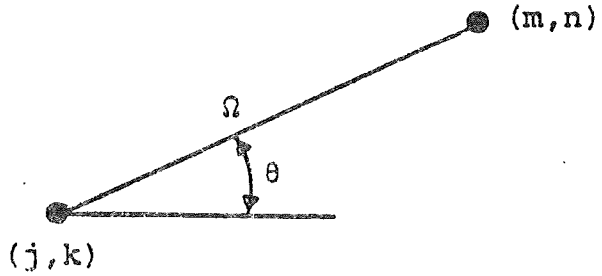
ENERGY

ENTROPY

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COMPUTER TECHNIQUES IN IMAGE PATTERN RECOGNITION AND ANALYSIS	HISTOGRAM FEATURES - III

SECOND ORDER HISTOGRAM:



a \ b	0	1	. . . .	L-1
0				
1				
. . .				
L-1				

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DIGITAL IMAGE PROCESSING AND ANALYSIS

Autocorrelation

$$B_A = \sum_{a=0}^{L-1} \sum_{b=0}^{L-1} abP(a,b)$$

Covariance

$$B_C = \sum_{a=0}^{L-1} \sum_{b=0}^{L-1} (a-\bar{a})(b-\bar{b})P(a,b)$$

Inertia

$$B_I = \sum_{a=0}^{L-1} \sum_{b=0}^{L-1} (a-b)^2 P(a,b)$$

Absolute Value

$$B_V = \sum_{a=0}^{L-1} \sum_{b=0}^{L-1} |a-b| P(a,b)$$

Inverse Difference

$$B_D = \sum_{a=0}^{L-1} \sum_{b=0}^{L-1} \frac{P(a,b)}{1+(a-b)^2}$$

Energy

$$B_N = \sum_{a=0}^{L-1} \sum_{b=0}^{L-1} [P(a,b)]^2$$

Entropy

$$B_E = -\sum_{a=0}^{L-1} \sum_{b=0}^{L-1} P(a,b) \log_2 [P(a,b)]$$

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COMPUTER TECHNIQUES IN IMAGE PATTERN RECOGNITION AND ANALYSIS	EDGE FEATURES

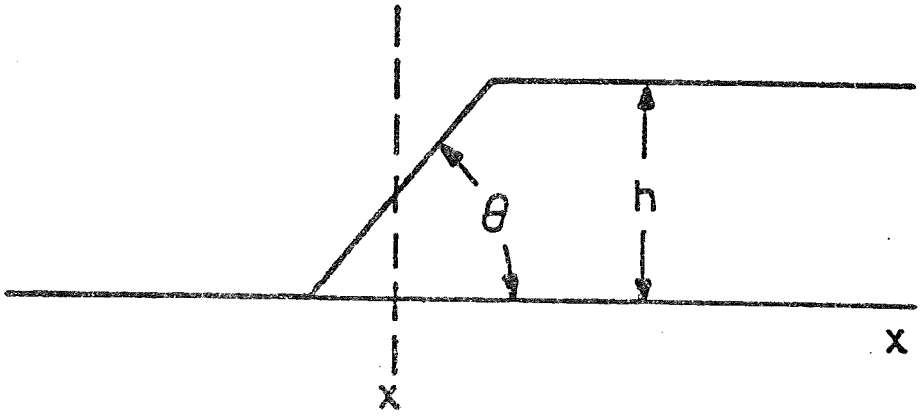
EDGE - CHANGE IN IMAGE AMPLITUDE OVER A SPECIFIED REGION

PARAMETERS: HEIGHT, SLOPE ANGLE, POSITION ORIENTATION

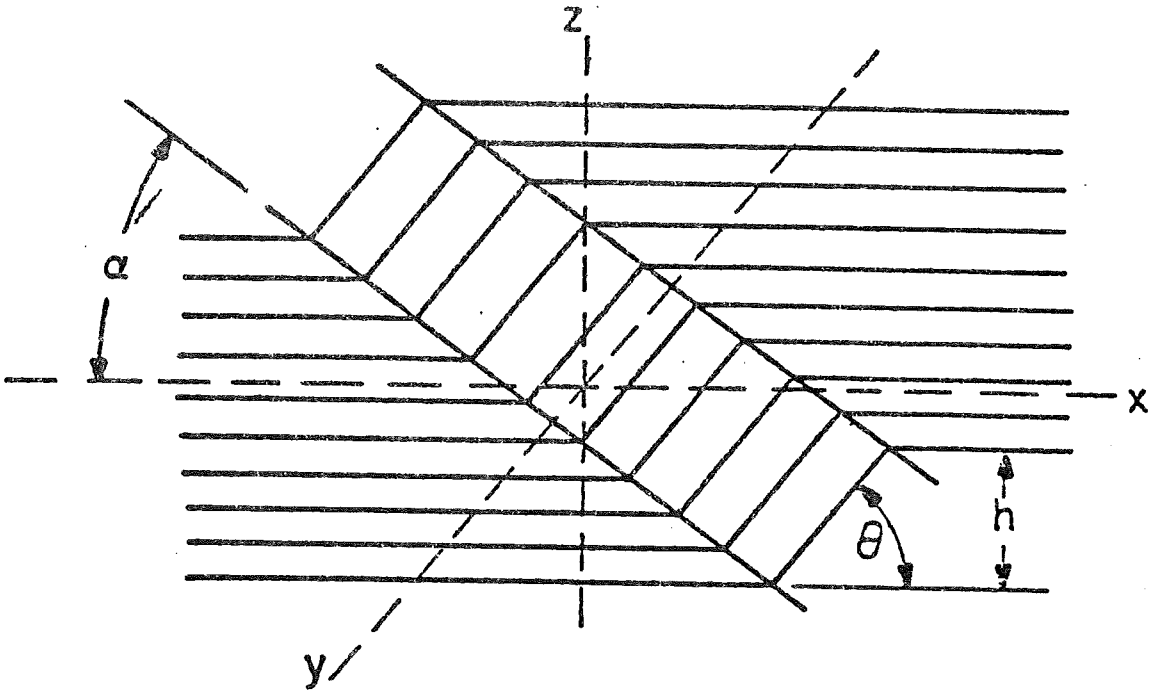
LOCAL DISCONTINUITY - GLOBAL DISCONTINUITIES ARE BOUNDARIES

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COMPUTER TECHNIQUES IN IMAGE PATTERN RECOGNITION AND ANALYSIS	ONE AND TWO DIMENSIONAL EDGES



(a) ONE DIMENSIONAL EDGE

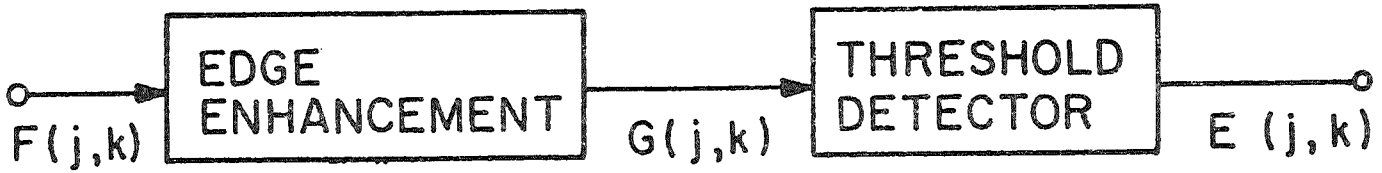


(b) TWO DIMENSIONAL EDGE

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EDGE ENHANCEMENT/THRESHOLDING

EDGE DETECTION METHOD



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DIFFERENTIAL EDGE ENHANCEMENT OPERATORS

HORIZONTAL GRADIENT:

$$A_H(j,k) = F(j,k) \circledast H_H(j,k)$$

VERTICAL GRADIENT:

$$A_V(j,k) = F(j,k) \circledast H_V(j,k)$$

SQUARE ROOT:

$$G(j,k) = \left[\left[A_H(j,k) \right]^2 + \left[A_V(j,k) \right]^2 \right]^{\frac{1}{2}}$$

MAGNITUDE:

$$G(j,k) = \left| A_H(j,k) \right| + \left| A_V(j,k) \right|$$

ANGLE:

$$\theta(j,k) = \text{ARCTAN} \left[\frac{A_V(j,k)}{A_H(j,k)} \right]$$

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COMPUTER TECHNIQUES IN IMAGE PATTERN RECOGNITION AND ANALYSIS	ROBERTS MASK

ROBERTS CROSS OPERATORS

A	B
D	C

SQUARE ROOT

$$G_S(j,k) = \sqrt{(A-C)^2 + (B-D)^2}$$

MAGNITUDE

$$G_M(j,k) = |A-C| + |B-D|$$

$$G_S(j,k) \leq G_M(j,k) \leq \sqrt{2}\, G_S(j,k)$$

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DIGITAL IMAGE PROCESSING	PREWITT OPERATOR

PREWITT OPERATOR

A	B	C
H	F(J,K)	D
G	F	E

$$S(J,K) = \sqrt{X^2 + Y^2}$$

$$X = C + D + E - G - H - A$$

$$Y = C + B + A - E - F - G$$

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DIGITAL IMAGE PROCESSING	PREWITT MASKS

PREWITT MASKS

HORIZONTAL MASK:

$$\underline{H} = \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix}$$

VERTICAL MASK:

$$\underline{V} = \begin{bmatrix} 1 & 1 & 1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{bmatrix}$$

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COMPUTER TECHNIQUES IN IMAGE PATTERN RECOGNITION AND ANALYSIS	SOBEL MASKS

SOBEL OPERATOR

A	B	C
H	F(j, k)	D
G	F	E

$$S(j,k) = \sqrt{X^2 + Y^2}$$

$$X = C + 2D + E - G - 2H - A$$

$$Y = C + 2B + A - E - 2F - G$$

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DIGITAL IMAGE PROCESSING	SOBEL MASKS

SOBEL MASKS

HORIZONTAL MASK:

$$\underline{H} = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}$$

VERTICAL MASK:

$$\underline{V} = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$$

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LINE - U SHAPED AMPLITUDE CROSS-SECTION

LINE MASKS:

$$\underline{H} = \begin{bmatrix} -1 & 2 & -1 \\ -1 & 2 & -1 \\ -1 & 2 & -1 \end{bmatrix} \qquad \underline{H} = \begin{bmatrix} -1 & -1 & 2 \\ -1 & 2 & -1 \\ 2 & -1 & -1 \end{bmatrix}$$

$$\underline{H} = \begin{bmatrix} -1 & -1 & -1 \\ 2 & 2 & 2 \\ -1 & -1 & -1 \end{bmatrix} \qquad \underline{H} = \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix}$$

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DIGITAL IMAGE PROCESSING | SPOT FEATURES

SPOT - SMALL REGION OF BRIGHTNESS DIFFERENCE

SPOT MASKS:

$$H = \begin{bmatrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{bmatrix} \qquad H = \begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

$$H = \begin{bmatrix} 1 & -2 & 1 \\ -2 & 4 & -2 \\ 1 & -2 & 1 \end{bmatrix}$$

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IMAGE TEXTURE

TEXTURE - SPATIAL IMAGE STRUCTURE CHARACTERIZED BY QUASI-REPETITIVE PLACEMENT OF BASIC PATTERN

TYPES OF TEXTURE:

- DETERMINISTIC - LINES, TILINGS
- NATURAL - GRASS, WATER, WHEAT
- STOCHASTIC - RANDOM NUMBER ARRAYS

QUALITATIVE MEASURES:

- COARSENESS
- HOMOGENEITY
- AVERAGE VALUE
- CONTRAST

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VISUAL DISCRIMINATION OF STOCHASTIC TEXTURE FIELDS

ASSUMPTION:

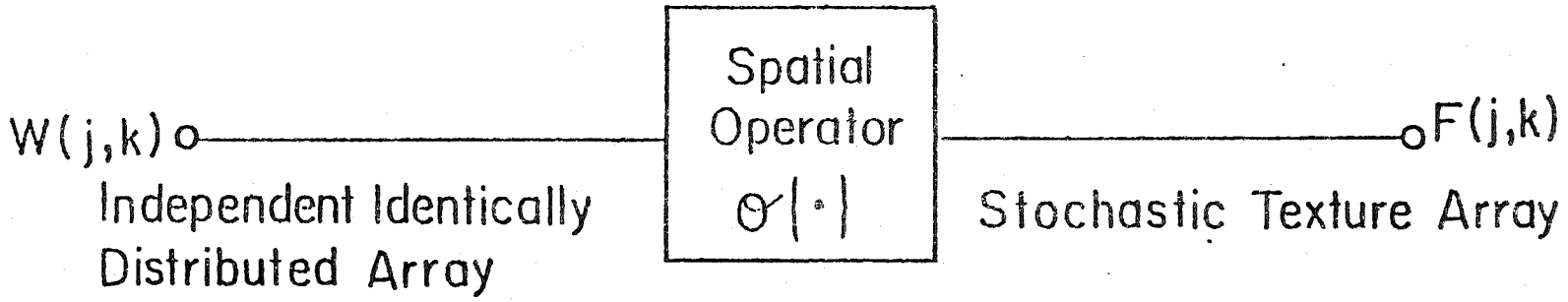
STOCHASTIC TEXTURE FIELDS POSSESS SAME VISUAL PROPERTIES AS NATURAL TEXTURE FIELDS.

OBJECTIVE:

DETERMINE PARAMETERS OF STOCHASTIC TEXTURE FIELDS IMPORTANT FOR HUMAN PERCEPTION AS BASIS FOR TEXTURE MEASURE.

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STOCHASTIC TEXTURE FIELD GENERATION - I



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VISUAL TEXTURE DISCRIMINATION EXPERIMENTS

1. OBSERVERS ARE SENSITIVE TO DIFFERENCES IN FIRST ORDER DENSITIES OF TEXTURE FIELD PAIRS.
2. OBSERVERS ARE SENSITIVE TO DIFFERENCES IN SECOND ORDER DENSITIES OF CORRELATED TEXTURE FIELD PAIRS THAT POSSESS THE SAME FIRST ORDER DENSITIES.
3. OBSERVERS ARE NOT SENSITIVE TO DIFFERENCES IN THIRD ORDER DENSITIES OF UNCORRELATED OR CORRELATED TEXTURE FIELD PAIRS THAT POSSESS THE SAME PAIRWISE FIRST AND SECOND ORDER DENSITIES.
4. OBSERVERS ARE SENSITIVE TO DIFFERENCES IN THE AUTOCORRELATION OF CORRELATED GAUSSIAN TEXTURE FIELD PAIRS WITH COMMON MEAN AND VARIANCE.
5. DISCRIMINABLE TEXTURE FIELD PAIRS CAN BE PRODUCED THAT POSSESS THE SAME MEAN, VARIANCE, AND AUTOCORRELATION FUNCTION.

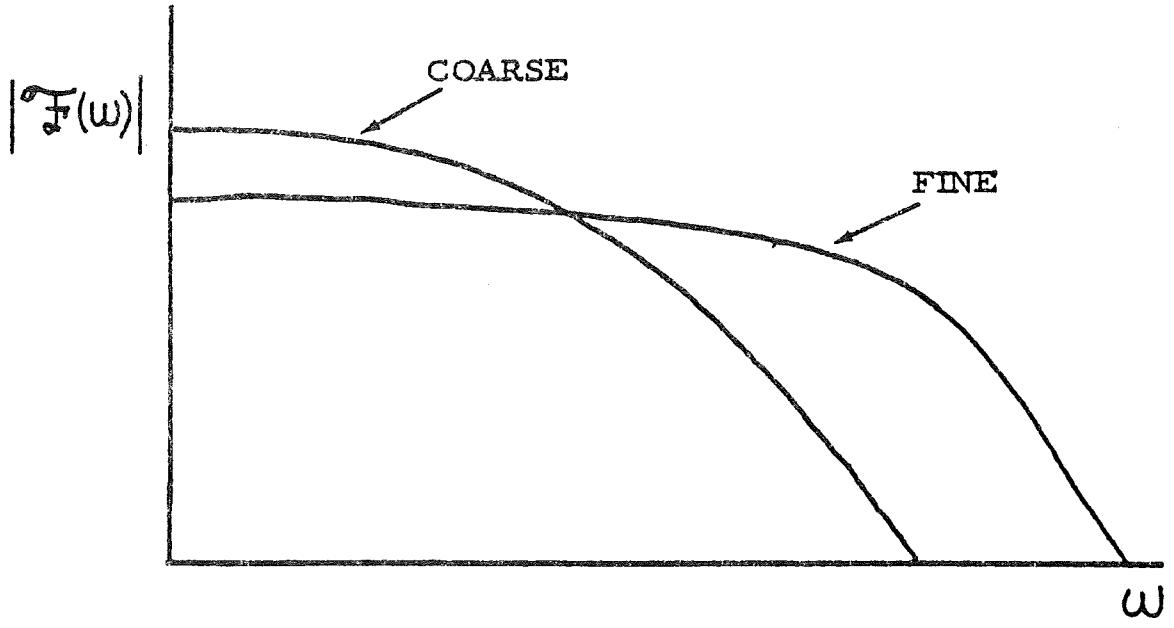
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COMPUTER TECHNIQUES IN IMAGE PATTERN RECOGNITION AND ANALYSIS	FOURIER SPECTRUM TEXTURE FEATURES

FOURIER SPECTRUM MEASURE

HIGH SPATIAL FREQUENCY - FINE TEXTURE

LOW SPATIAL FREQUENCY - COARSE TEXTURE



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COMPUTER TECHNIQUES IN IMAGE PATTERN RECOGNITION AND ANALYSIS	2-D HISTOGRAM TEXTURE FEATURES

TWO-DIMENSIONAL GREY LEVEL HISTOGRAMS

COMPUTE 2D HISTOGRAM APPROXIMATION TO 2D PROBABILITY DISTRIBUTION

$$P(a, b; j, k, r, \theta) = P_R\{F(j, k) = a,\ F(m, n) = b\}$$

WHERE

r = SEPARATION DISTANCE

θ = SEPARATION ANGLE

UNIFORM HISTOGRAM - COARSE TEXTURE

SKEWED HISTOGRAM - FINE TEXTURE

INERTIA MEASURE:

$$T(j, k, r, \theta) = \sum_{a=0}^{L-1} \sum_{b=0}^{L-1} (a-b)^2 P(a, b; j, k, r, \theta)$$

ANGULAR INVARIANCE MEAN MEASURE:

$$M_T(j, k, r) = \frac{1}{N_\theta} \sum_{\theta} T(j, k, r, \theta)$$

ANGULAR INDEPENDENT VARIANCE MEASURE:

$$V_T(j, k, r) = \frac{1}{N_\theta} \sum_{\theta} [T(j, k, r, \theta) - M_T(j, k, r)]^2$$

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COMPUTER TECHNIQUES IN IMAGE PATTERN RECOGNITION AND ANALYSIS	EDGE DENSITY TEXTURE FEATURES

EDGE DENSITY

TEXTURE PROPORTIONAL TO NUMBER OF EDGES PER UNIT AREA

$$T(j,k) = \frac{1}{(2w+1)^2} \sum_{m=j-w}^{j+w} \sum_{n=k-w}^{k+w} E(m,n)$$

WHERE

$E(m,n)$ = BINARY EDGE MAP

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COMPUTER TECHNIQUES IN IMAGE PATTERN RECOGNITION AND ANALYSIS	AUTOCORRELATION TEXTURE FEATURES

TEXTURE-SPATIAL AUTOCORRELATION

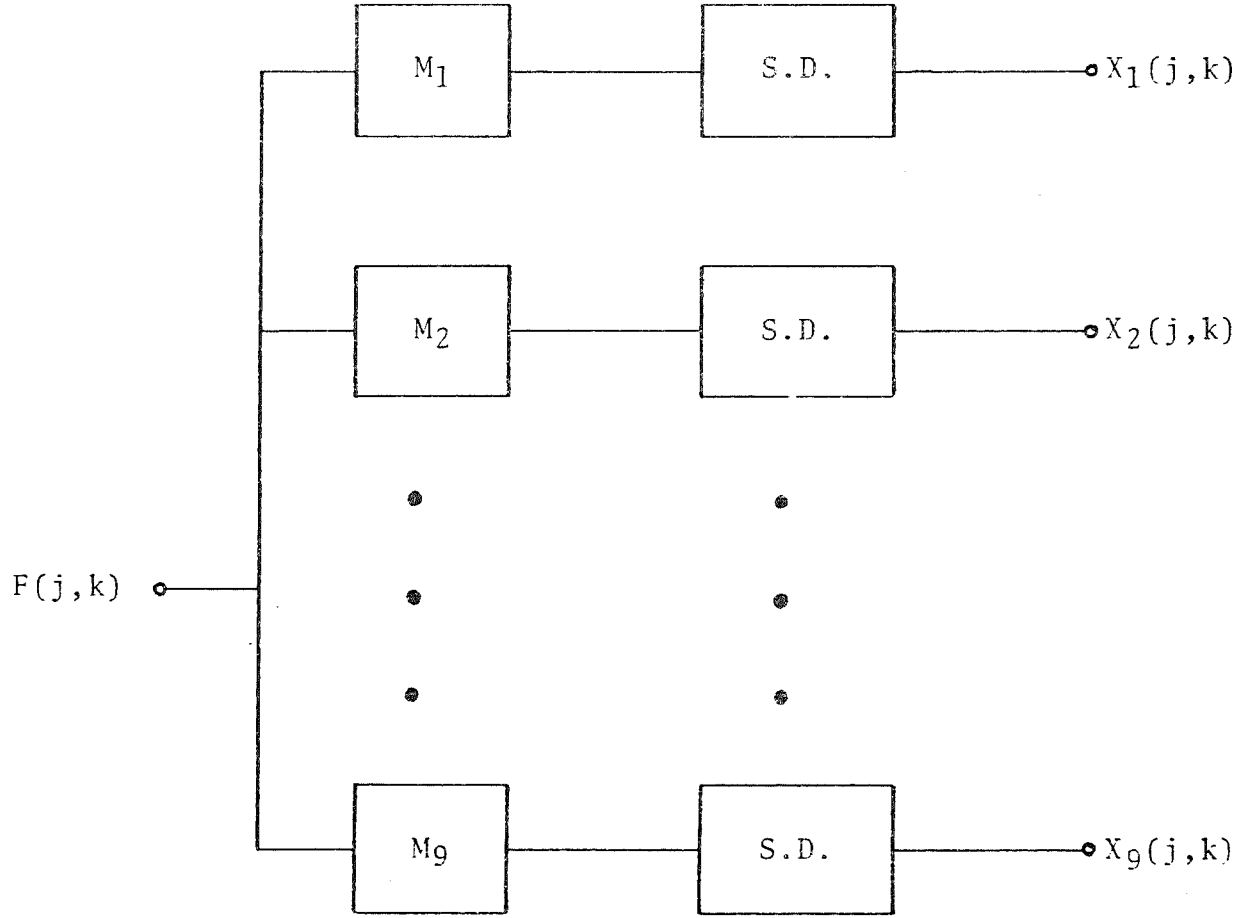
$$A(\epsilon, \eta; j, k) = \frac{\sum_{m=j-w}^{j+k} \sum_{n=k-w}^{k+w} F(m,n)F(m-\epsilon, n-\eta)}{\sum_{m=j-w}^{j+w} \sum_{n=k-w}^{k+w} [F(m,n)]^2}$$

COARSENESS PROPORTIONAL TO SPREAD OF AUTOCORRELATION FUNCTION

$$T(j,k) = \sum_{\epsilon=-T}^{T} \sum_{n=-T}^{T} \epsilon^2 n^2 A(\epsilon, n; j, k)$$

OVER T BY T WINDOW

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DIGITAL IMAGE PROCESSING	LAWS TEXTURE MASKS

LAWS TEXTURE MASKS

1	2	1	-1	0	1	-1	2	-1
2	4	2	-2	0	2	-2	4	-2
1	2	1	-1	0	1	-1	2	-1

-1	-2	-1	1	0	-1	1	-2	1
0	0	0	0	0	0	0	0	0
1	2	1	-1	0	1	-1	2	-1

-1	-2	-1	1	0	-1	1	-2	1
2	4	2	-2	0	2	-2	4	-2
-1	-2	-1	1	0	-1	1	-2	1

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MORPHOLOGICAL IMAGE PROCESSING

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DIGITAL IMAGE PROCESSING AND ANALYSIS	MORPHOLOGICAL IMAGE PROCESSING

MORPHOLOGICAL IMAGE PROCESSING

DEFINITION

MORPHOLOGICAL IMAGE PROCESSING OPERATORS MODIFY THE SPATIAL FORM AND STRUCTURE OF A BINARY OR GREY SCALE IMAGE.

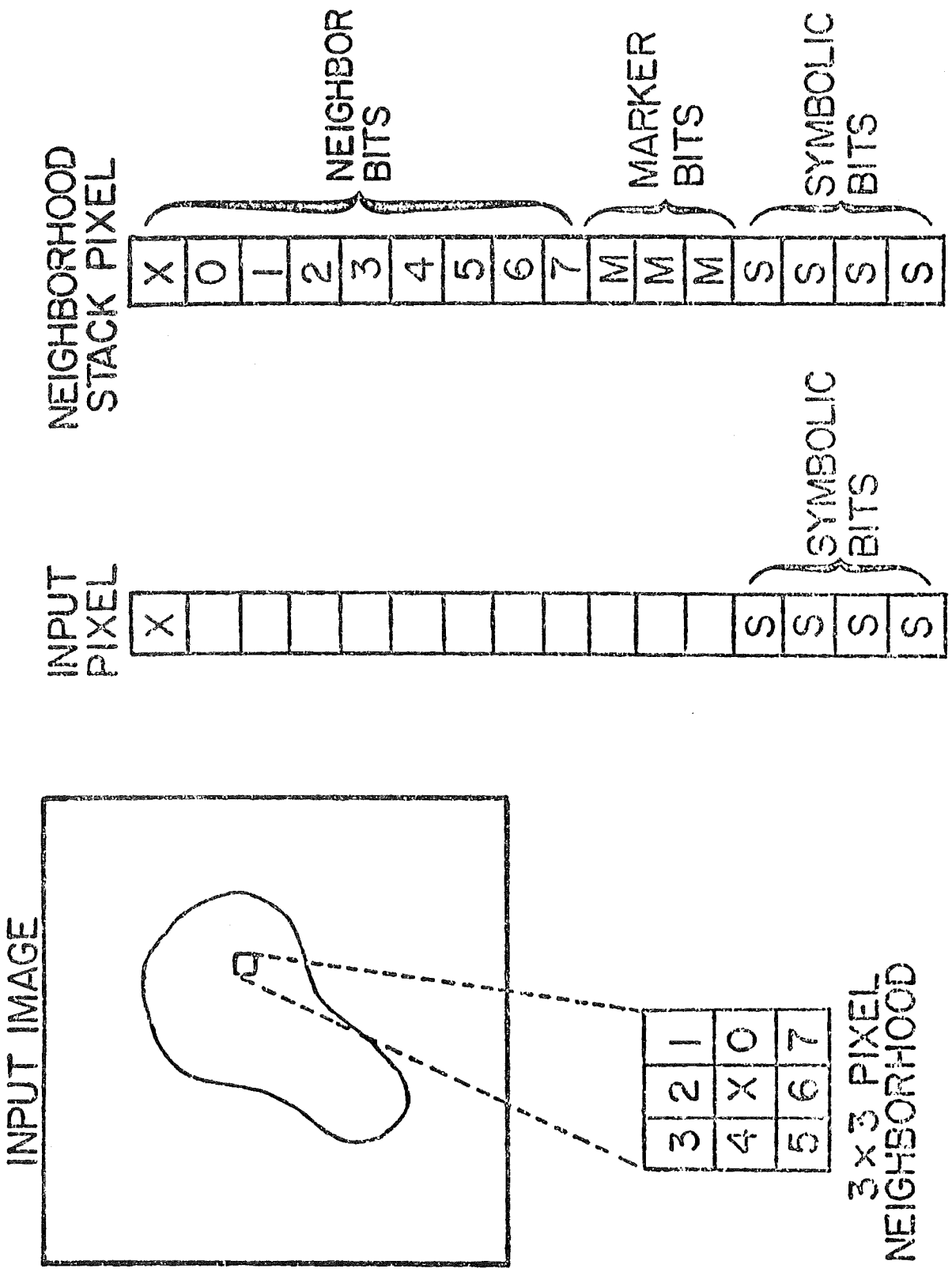
USES

OBJECT OUTLINES
SHAPE ANALYSIS

APPLICATIONS

INDUSTRIAL INSPECTION
MEDICAL IMAGE ANALYSIS
FINGERPRINT ANALYSIS

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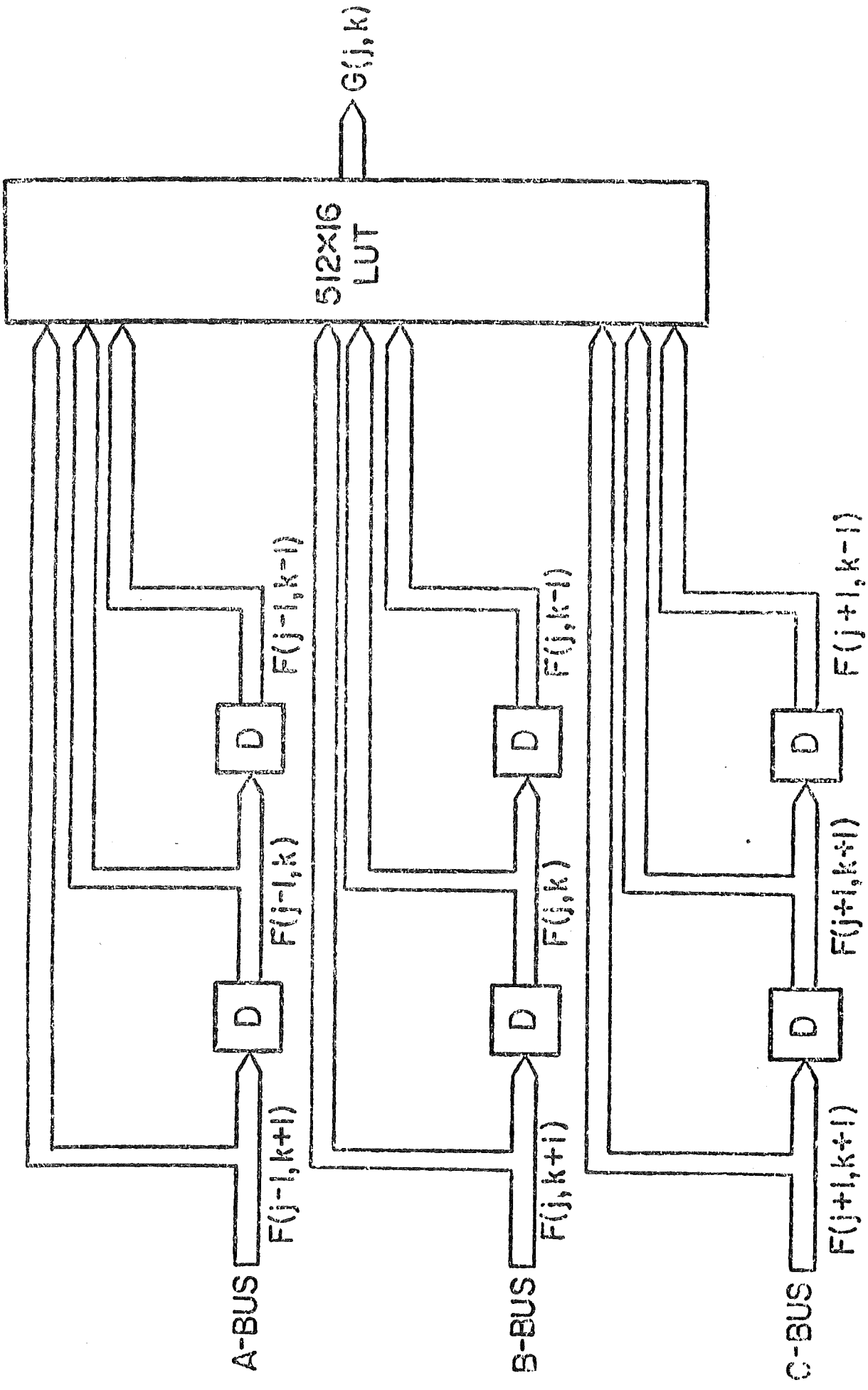

INPUT IMAGE
Q
3 2 1
4 X 0
5 6 7
3 X 3 PIXEL NEIGHBORHOOD
INPUT PIXEL
X
S S S S
SYMBOLIC BITS
NEIGHBORHOOD STACK PIXEL
X 0 1 2 3 4 5 6 7 M M M S S S S
NEIGHBOR BITS
MARKER BITS
SYMBOLIC BITS

DIGITAL IMAGE PROCESSING AND ANALYSIS	MORPHOLOGICAL PIPELINE IMAGE PROCESSOR

MORPHOLOGICAL PIPELINE IMAGE PROCESSOR

MORPHOLOGICAL IMAGE PROCESSING OPERATORS CAN BE IMPLEMENTED BY SEQUENTIAL MODIFICATION OF A BINARY OR GREY SCALE IMAGE WITH 3 x 3 PIXEL MASKS.

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MORPHIC PROCESSOR

DIGITAL IMAGE PROCESSING AND ANALYSIS	BINARY MORPHOLOGICAL DEFINITIONS

BINARY MORPHOLOGICAL DEFINITIONS

0 0 0 0 Y X 0 X 0 4-CONNECTED	0 0 0 0 Y X 0 0 X 8-CONNECTED	0 0 0 0 Y 0 0 0 0 ISOLATED
0 0 0 0 Y 0 0 0 X SPUR	X 0 0 X Y X X 0 X BRIDGE	X X X 0 Y 0 X X X H-CONNECTED
0 0 0 0 Y X 0 X X CORNER	0 X X X Y X X X X INTERIOR	0 X X 0 Y X 0 X X EXTERIOR

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BINARY LOGICAL MORPHOLOGICAL OPERATORS

NEIGHBOR AND SET - Creates black pixel if all pixels in neighborhood are black.

NEIGHBOR OR SET - Creates black pixel if center pixel is black and at least one 8-connected neighbor is black.

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DIGITAL IMAGE PROCESSING AND ANALYSIS	BINARY DENSIOMETRIC MORPHOLOGICAL OPERATOR

BINARY DENSIOMETRIC MORPHOLOGICAL OPERATOR

MAJORITY BLACK SET - Creates black pixel if majority of pixels in neighborhood are black.

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DIGITAL IMAGE PROCESSING AND ANALYSIS	BINARY ADDITIVE MORPHOLOGICAL OPERATORS

BINARY ADDITIVE MORPHOLOGICAL OPERATORS

INTERIOR FILL - Creates black pixel if 4-connected neighbor pixels are all black.

DILATE - Creates black pixel if at least one 8-connected neighbor pixel is black.

FATTEN - Creates black pixel if at least one 8-connected neighbor pixel is black provided creation does not result in a bridge between previously unconnected neighboring black pixels.

BRIDGE - Creates black pixel if creation results in connectivity of previously unconnected neighboring black pixels.

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DIGITAL IMAGE PROCESSING AND ANALYSIS	PIXEL BONDS

PIXEL BONDS

WEIGHT = 2	WEIGHT = 1
NORTH	NORTHEAST
SOUTH	NORTHWEST
EAST	SOUTHEAST
WEST	SOUTHWEST

EXAMPLE

```
0 0 X
0 X X      B = 7
X X X
```

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DIGITAL IMAGE PROCESSING AND ANALYSIS	EXAMPLES OF DILATION PATTERNS

EXAMPLES OF DILATION PATTERNS

0 0 0 0 0 0 0 0 1	0 0 0 0 0 0 0 1 0	0 0 0 0 0 0 1 1 0
W = 1	W = 2	W = 3
0 0 0 0 0 0 1 1 1	0 0 0 1 0 0 1 1 0	0 0 0 1 0 0 1 1 1
W = 4	W = 5	W = 6
0 0 1 0 0 1 1 1 1	0 0 0 1 0 1 1 1 1	0 0 1 1 0 1 1 1 1
W = 7	W = 8	W = 9

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DIGITAL IMAGE PROCESSING AND ANALYSIS	BINARY SUBTRACTIVE MORPHOLOGICAL OPERATORS

BINARY SUBTRACTIVE MORPHOLOGICAL OPERATORS

ISOLATED PIXEL REMOVE - Eliminates black pixel with eight white neighbors.

DOT REMOVE - Eliminates isolated clusters of black pixels within a 2 x 2 pixel region.

SPUR REMOVE - Eliminates black pixel with a single 8-connected neighbor.

INTERIOR PIXEL REMOVE - Eliminates black pixel with 4-connected black pixel neighbors.

BREAK - Eliminates black pixel which is H-connected.

ERODE - Eliminates black pixel with black pixel bond of 9 or less. NOTE: Repeated use will eliminate all pixels of objects without interior pixels.

SHRINK - Eliminates black pixel with black pixel bond of 9 or less, which does not break 4-connectivity of neighbors.

THIN - Eliminates black pixel with black pixel bond of 9 or less, which does not break 4-connectivity of neighbors, nor shorten minimally connected strokes.

SKELETONIZE - Creates medial axis transform.

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DIGITAL IMAGE PROCESSING AND ANALYSIS	EXAMPLES OF EROSION PATTERNS

EXAMPLES OF EROSION PATTERNS

0 0 0 0 1 0 0 0 1 W = 1	0 0 0 0 1 0 0 1 0 W = 2	0 0 0 0 1 0 1 1 0 W = 3
0 0 0 0 1 0 1 1 1 W = 4	0 0 0 1 1 0 1 1 0 W = 5	0 0 0 1 1 0 1 1 1 W = 6
0 0 1 0 1 1 1 1 1 W = 7	0 0 0 1 1 1 1 1 1 W = 8	0 0 1 1 1 1 1 1 1 W = 9

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DIGITAL IMAGE PROCESSING AND ANALYSIS	BINARY HIERARCHICAL MORPHOLOGICAL OPERATORS

BINARY HIERARCHICAL MORPHOLOGICAL OPERATORS

OPEN - Performs erode then dilate operations successively.

CLOSE - Performs dilate then erode operations successively.

DELINEATE - Performs dot remove, interior fill, thin and bridge operations successively.

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