PART II.
DIGITAL HALFTONING FUNDAMENTALS

Outline

- Halftone quality

- Origins of halftoning

- Perception of graylevels from halftones

- Printer properties

- Introduction to digital halftoning

- Conventional digital halftoning methods
    - Block replacement
    - Screening (dithering)
        + clustered-dot
        + dispersed-dot
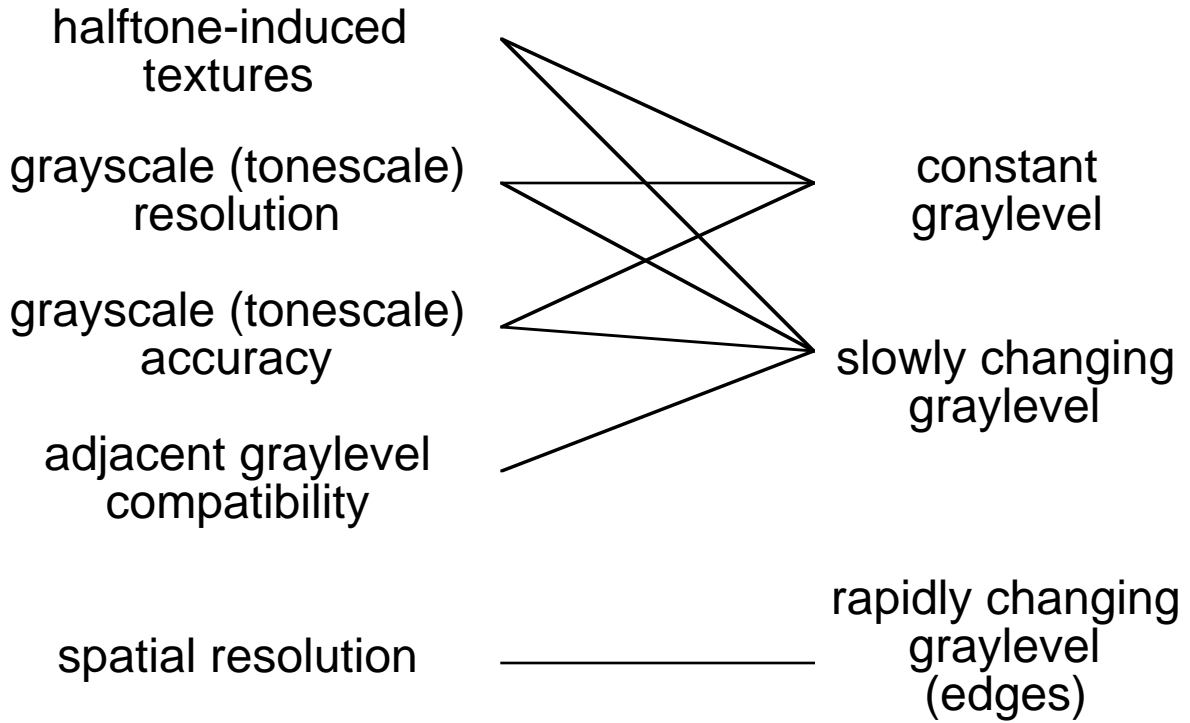   - Error diffusion (briefly mentioned)

REFERENCES ON
FUNDAMENTALS OF DIGITAL HALFTONING

[1] J.P. Allebach, "Visual model-based algorithms for halftoning images," in *Image Quality*, Proc. SPIE 310, 151-158, 1981.

[2] J.P. Allebach, editor, *Selected Papers on Digital Halftoning*, SPIE Milestone Series, vol. MS 154, 1999.

[3] J.F. Jarvis, C.N. Judice and W.H. Ninke, "A survey of techniques for the display of continuous tone pictures on blievel displays," *Computer Graphics & Image Proc.*, 5, 1-40, Mar. 1976.

[4] P.R. Jones, "Evolution of halftoning technology in the United States patent literature," *J. Electronic Imaging*, 3, 257-275, July 1994.

[5] K. Knowlton and L. Harmon, "Computer-produced grey scales," *Computer Graphics & Image Proc.*, 1, 1-20, 1972.

[6] F. Nilsson, "Halftoning and objective quality measures for halftoned images," Linkoping Studies in Science and Technology Thesis No. 671, 1998.

[7] W.F. Schreiber, *Fundamentals of Electronic Imaging Systems*, Springer-Verlag, 1986.

[8] J.C. Stoffel and J.F. Moreland, "A survey of electronic techniques for pictorial image reproduction," *IEEE Trans. Commun.*, 29, 1898-1925, Dec. 1981.

[9] R. Ulichney, *Digital Halftoning*, MIT Press, 1987.

HALFTONE QUALITY

<u>HALFTONE FEATURES</u>   <u>IMAGE REGIONS</u>

halftone-induced
textures

grayscale (tonescale)
resolution   constant
                                                          graylevel

grayscale (tonescale)
accuracy

                                                          slowly changing
                                                          graylevel

adjacent graylevel
compatibility

                                                          rapidly changing
                                                          graylevel
spatial resolution   (edges)

HALFTONE-INDUCED TEXTURES

- Examine halftoning of constant graylevel patches.

- Good halftone-induced textures, i.e. pleasing patterns:
    - Avoid large white gaps and large black clusters.

      pp. I-5, II-5: rand. thresh. halftoning $\Rightarrow$ large gaps & clusters
    - Avoid low frequency energy.

      pp. II-6 through II-8: examples of halftone-induced
      textures and their spectra:
    - Have their energy in high frequencies, i.e. "blue noise".

      p. II-9: Ulichney's ideal bluenoise spectra
    - Have less energy in horizontal and vertical than in diagonal.

      p. II-10: left column -- diagonal screening (4×8 classical)
      right column -- rectangular screening (6×6 Bayer)
    - Lack unusual or annoying artifacts.

      pp. I-8, I-10 and p. II-11: ramp halftoned with four
      methods: from left -- 4x8 classical screening, 6x6 Bayer
      screening, bluenoise screening, Fl.-St. error diffusion

- In some cases, induced texture quality varies with graylevel.
    - Low frequency energy varies with graylevel because dot
      spacing varies.

      p. II-12: halftone-induced textures for two different gray
      levels, with error diffusion
    - Artifacts may vary with graylevel.

      p. II-11: ramps halftoned with four methods
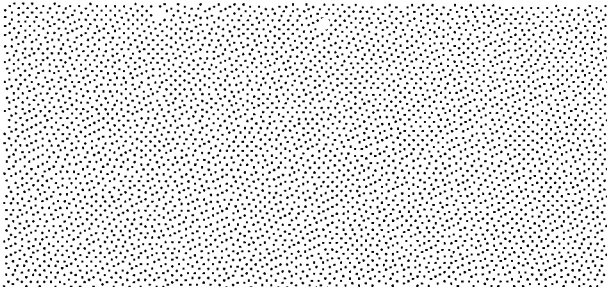
RANDOM THRESHOLD SCREENING
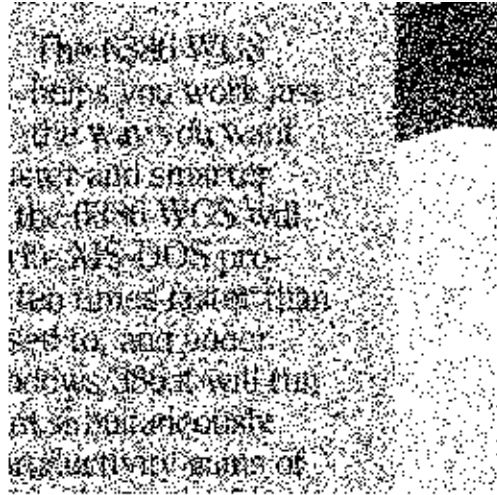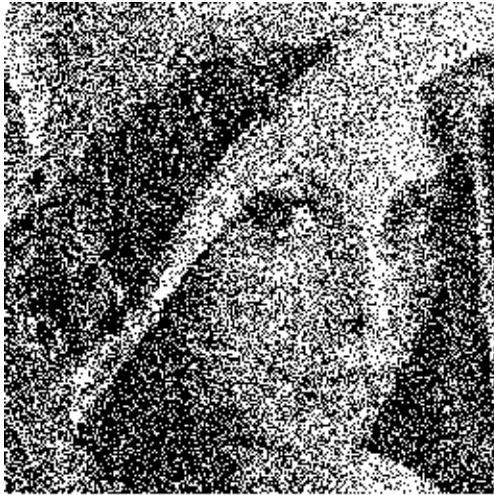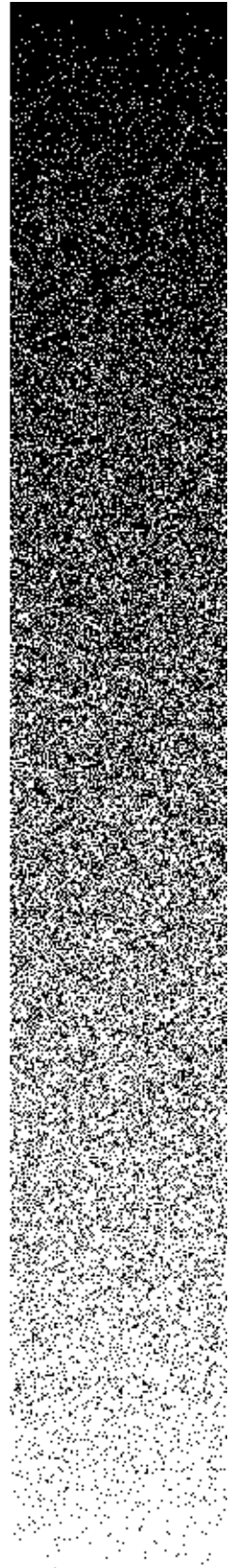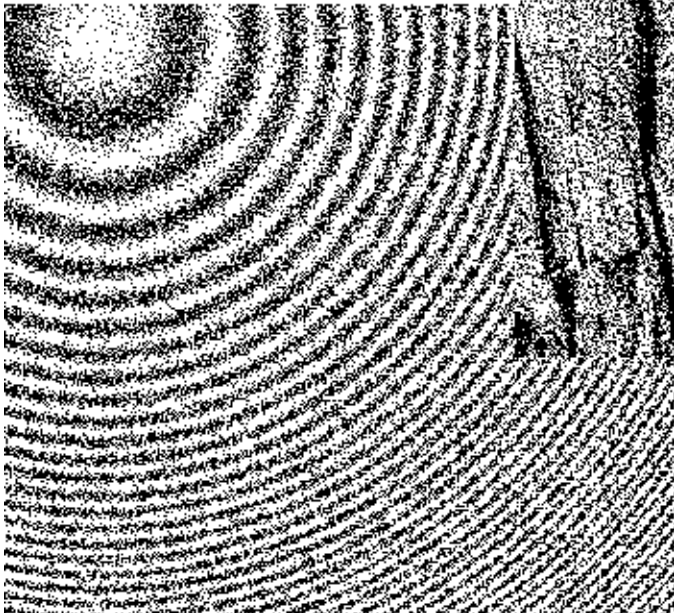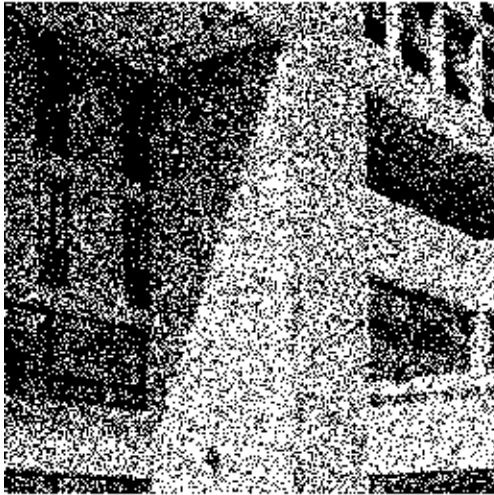
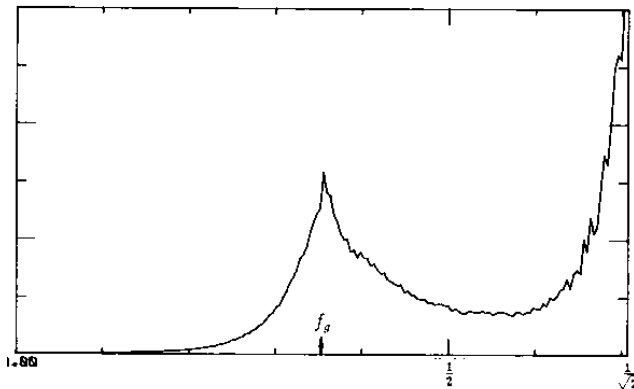# HALFTONE-INDUCED TEXTURES

- Graylevel = 1/8 on 0 to 1 scale, 0 = black, 1 = white.

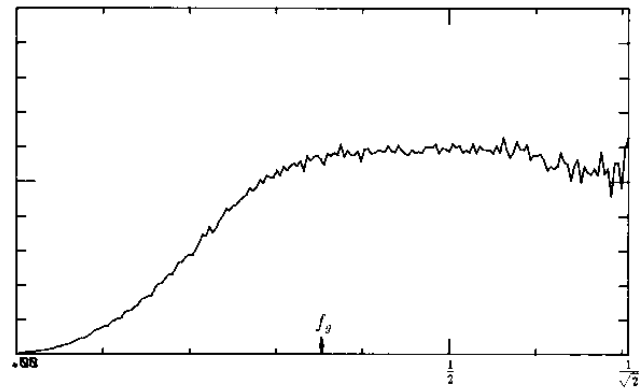- Halftoning by "error diffusion" with two different filters.

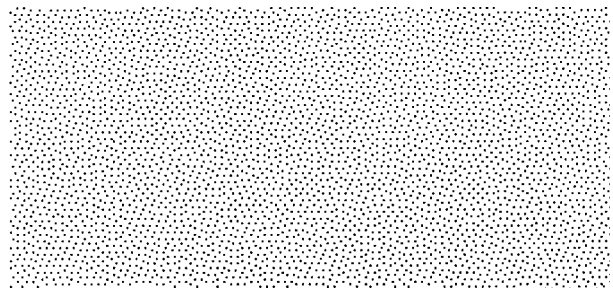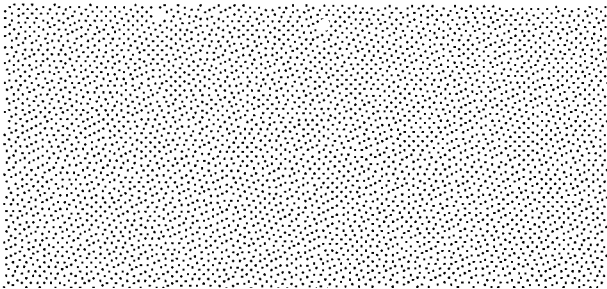## Induced Textures
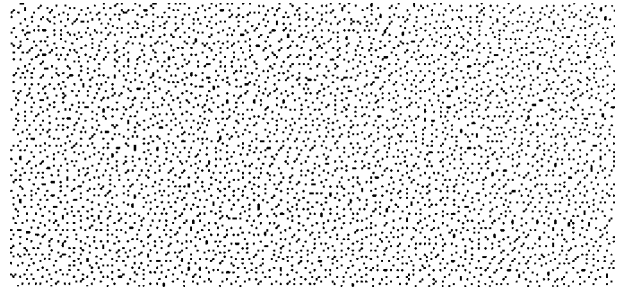
Radial Spectra

(radial freq)/ρ_θ (radial freq)/ρ_θ

- Plotted are 2-dimensional spatial frequency spectrum averaged around a circle with radius equal to frequency.

- ρ_θ = printer resolution in dots per degree

- From R. Ulichney, *Digital Halftoning,* MIT Press, 1987

SPECTRA OF
HALFTONE-INDUCED TEXTURES

- Graylevel = 1/8.
- Halftoning by "error diffusion" with two different filters.

Induced Textures

Radial Spectra

(radial freq)/f_0 (radial freq)/f_0
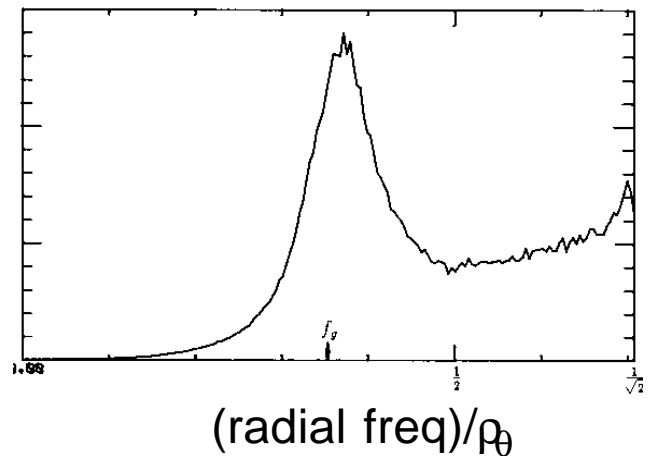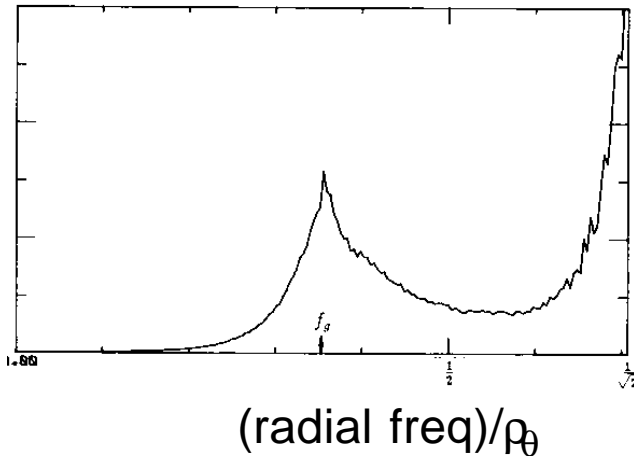
- From R. Ulichney, *Digital Halftoning,* MIT Press, 1987

SPECTRA OF
HALFTONE-INDUCED TEXTURES

- Graylevel = 1/8.
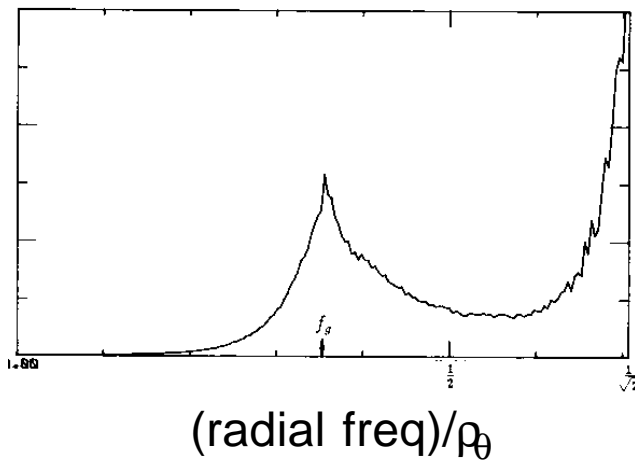
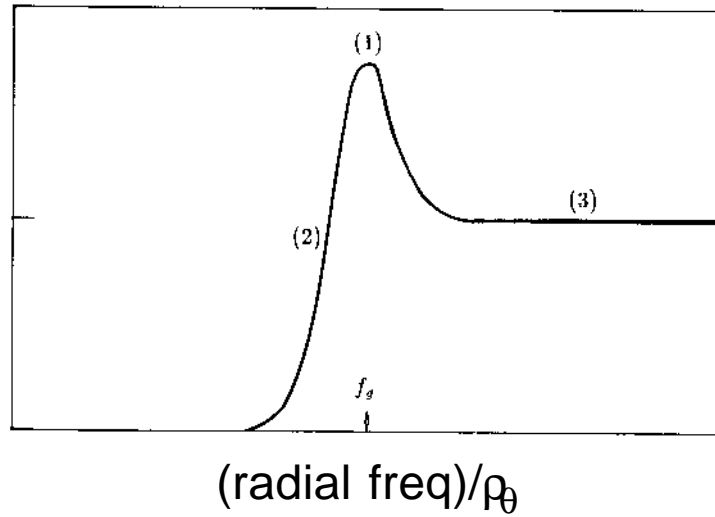   Error Diffusion   Random Threshold Screening
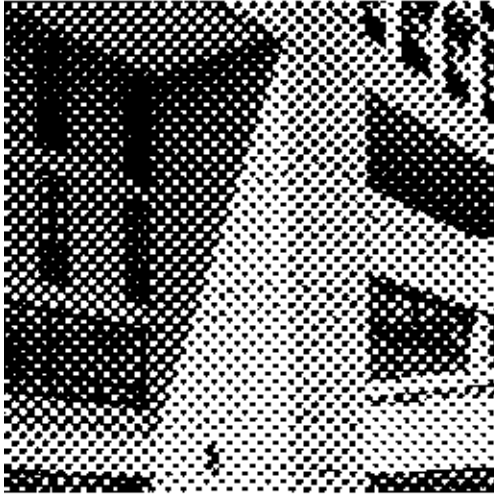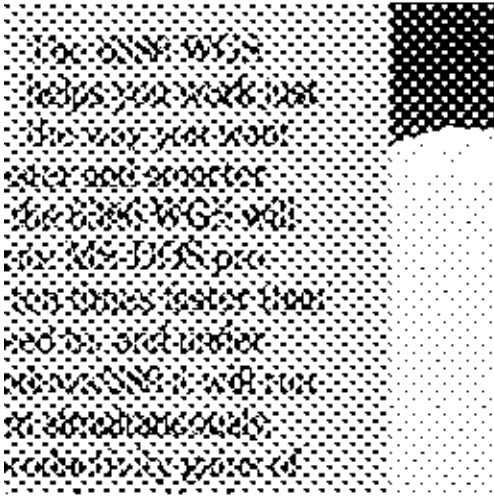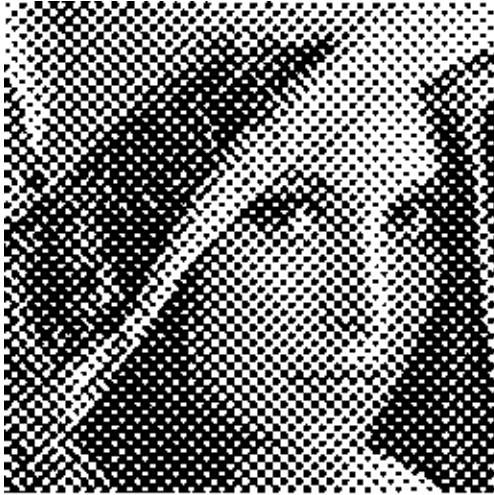
Induced Textures

Radial Spectra

(radial freq)/ρ_θ (radial freq)/ρ_θ
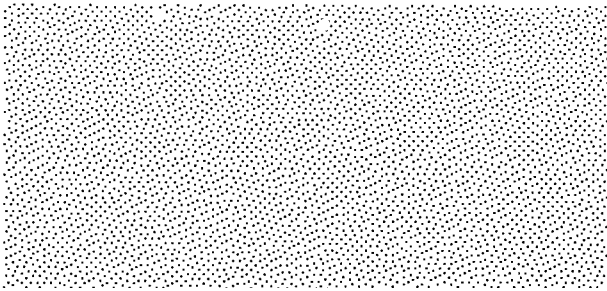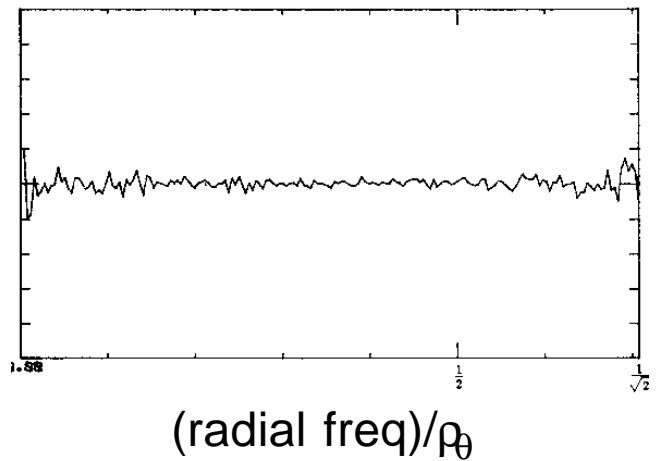
- From R. Ulichney, *Digital Halftoning,* MIT Press 1987
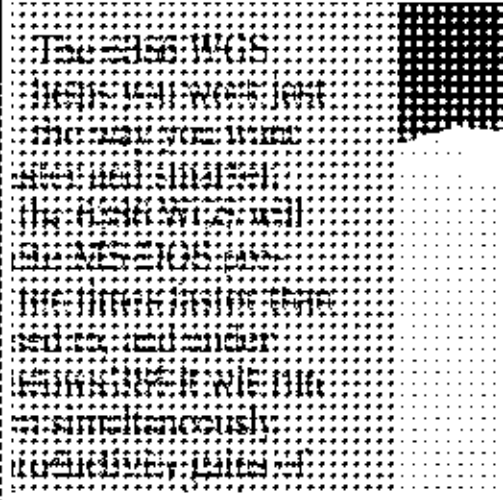
ULICHNEY'S IDEAL BLUENOISE SPECTRUM

(radial freq)/ρ_0

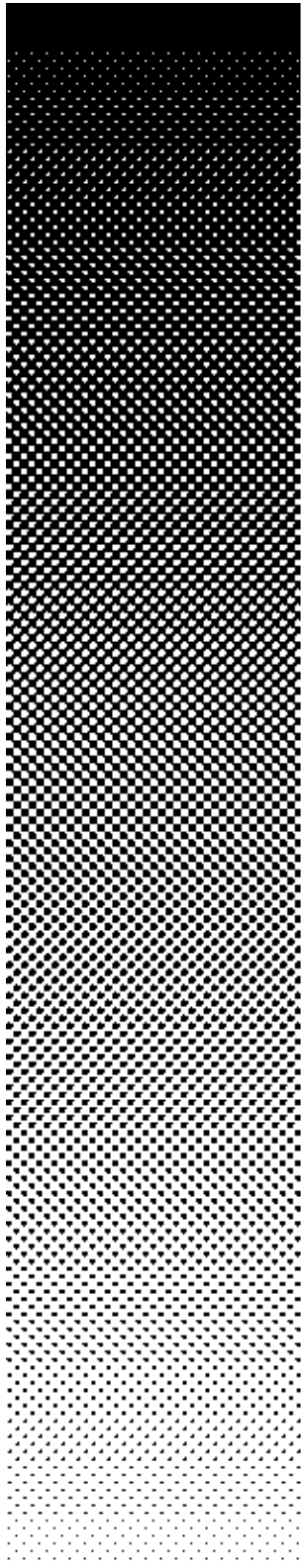- From R. Ulichney, *Digital Halftoning,* MIT Press 1987

Diagonal Screening
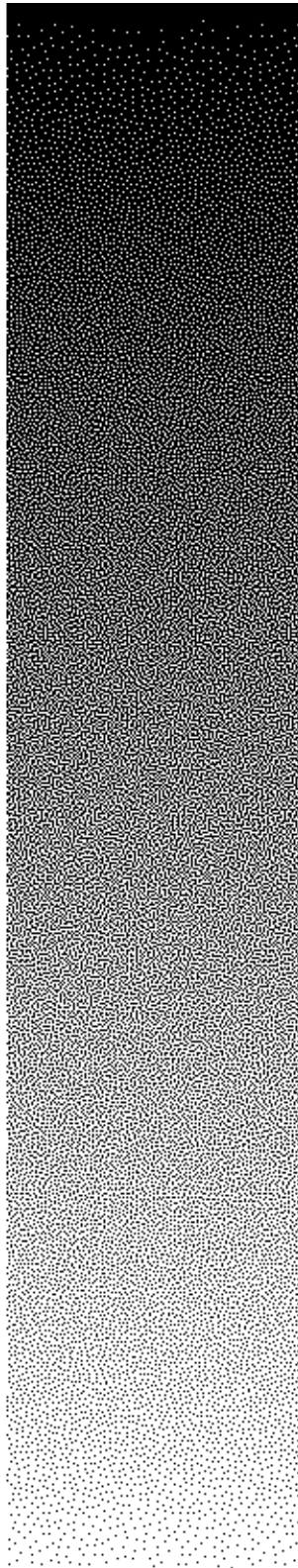## (8x8 classical)

Rectangular Screening
(6x6)

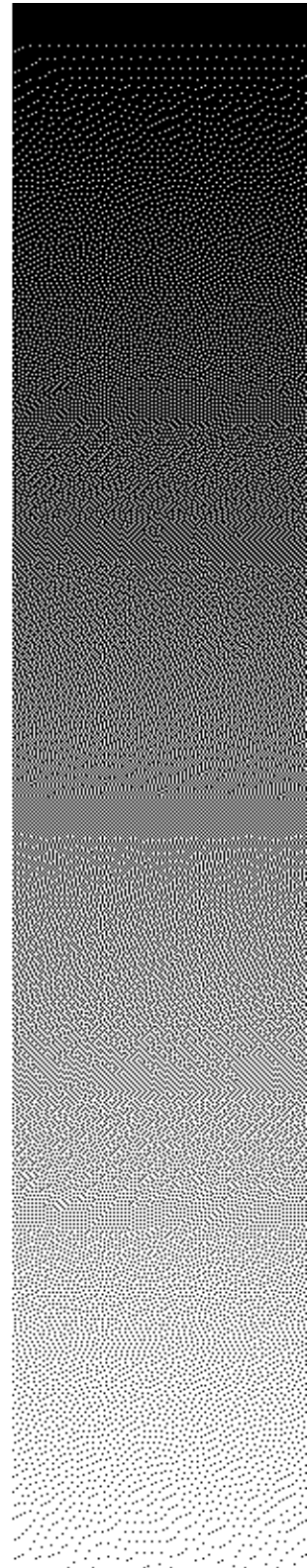# Classic screen
(8x8)

Bayer screen
(6x6)
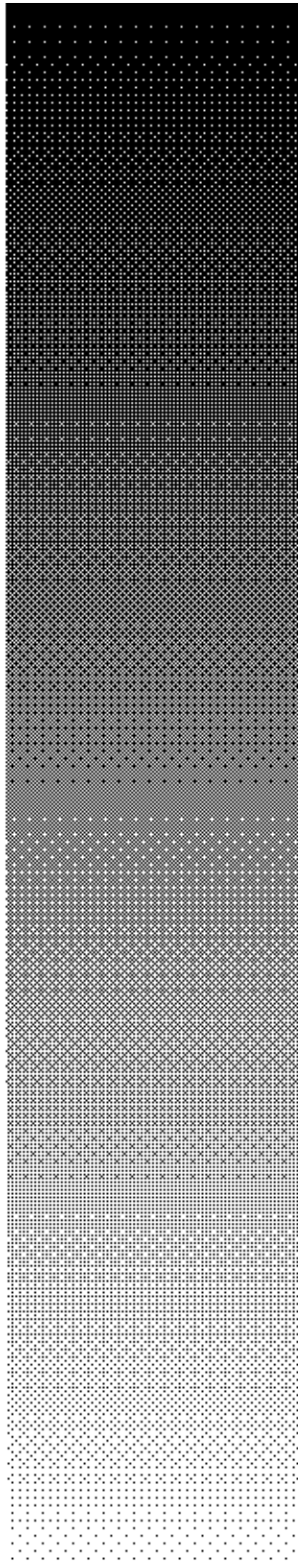
Bluenoise scrn
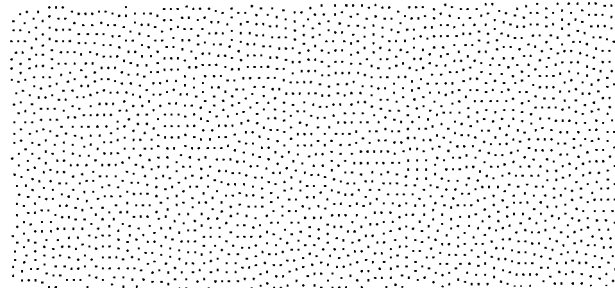
Error diff'n
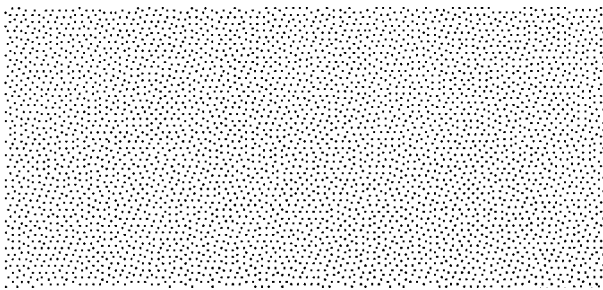### (F-S)

HALFTONE-INDUCED TEXTURE
MAY VARY WITH GRAYLEVEL
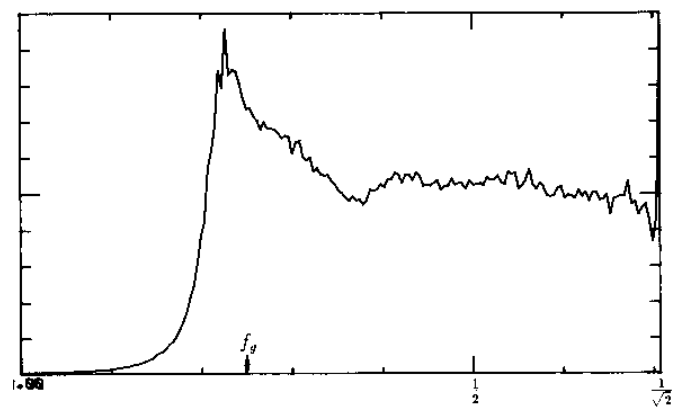
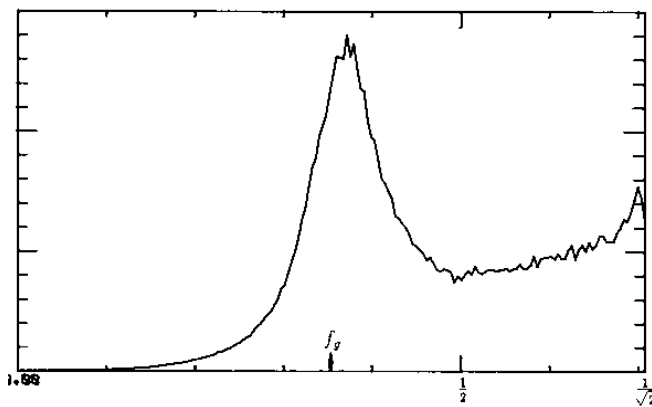- Error diffusion applied to two different graylevels

graylevel = 1/8   gray level = 1/16

Induced Textures

Radial Spectra

(radial freq)/ρ_θ (radial freq)/ρ_θ

- Very light patterns and very dark patterns will necessarily have more low frequency energy

- From R. Ulichney, *Digital Halftoning,* MIT Press, 1987