EMBEDDED HALFTONING AND INVERSE HALFTONING FOR JBIG2 CODING

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OUTLINE

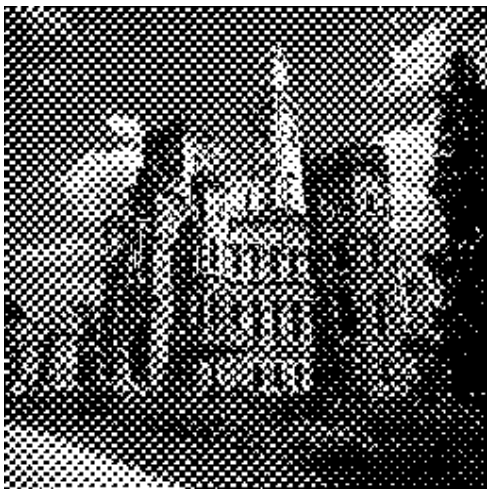
- Introduction to halftoning
- Common halftoning techniques
- JBIG2 text/halftone compression
- Inverse halftoning algorithms
- Fast inverse halftoning
  - Adaptive smoothing
  - Non-linear denoising
- Rehalftoning for JBIG2
- Conclusion

INTRODUCTION: HALFTONING

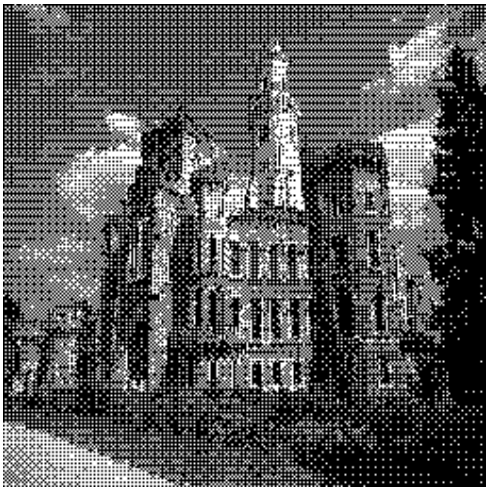
- Was analog, now digital image processing
- Wordlength reduction for images
  - 8-bit to 1-bit for grayscale
  - 24-bit Red-Green-Blue (RGB) to 8-bit for color displays
  - 24-bit RGB to Cyan-Magenta-Yellow (CMY) for color printers
- Applications
  - Printers
  - Digital copiers
  - Liquid crystal displays
  - Video cards
  - Fax machines
- Halftoning methods
  - Screening
  - Error diffusion
  - Hybrids

EXAMPLE HALFTONES

Original image



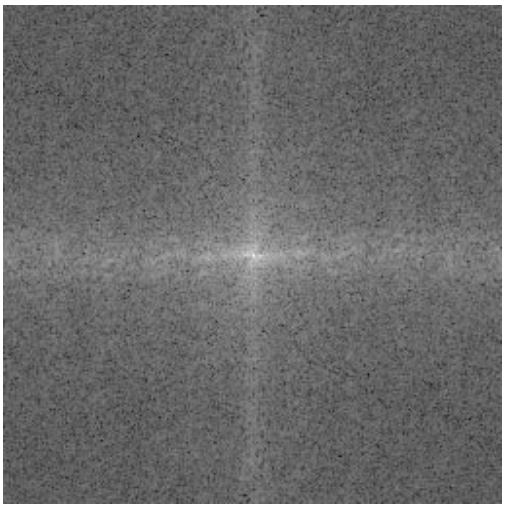
Clustered dot screen



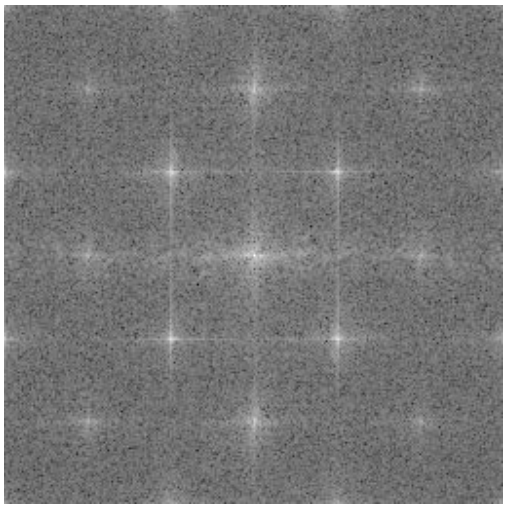
Dispersed dot screen

Error diffusion

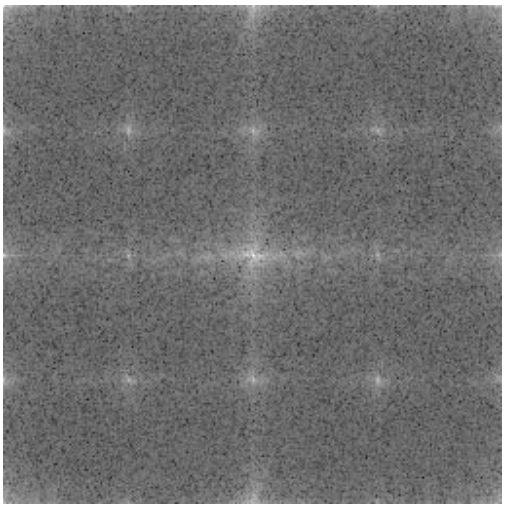
FOURIER TRANSFORMS



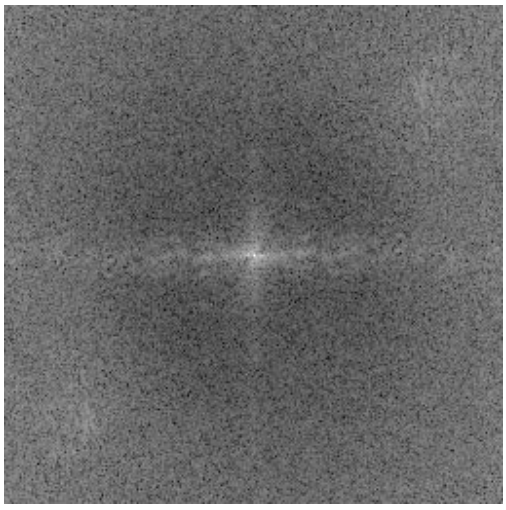
Original image



Clustered dot screen



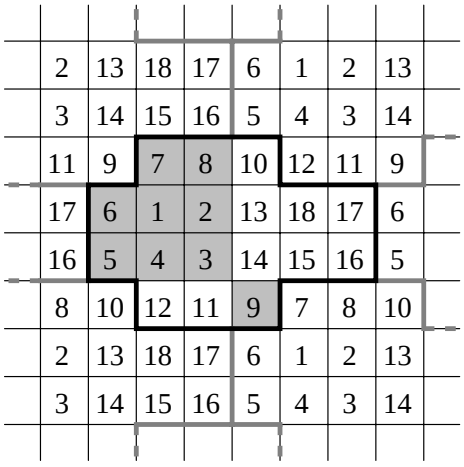
Dispersed dot screen



Error diffusion

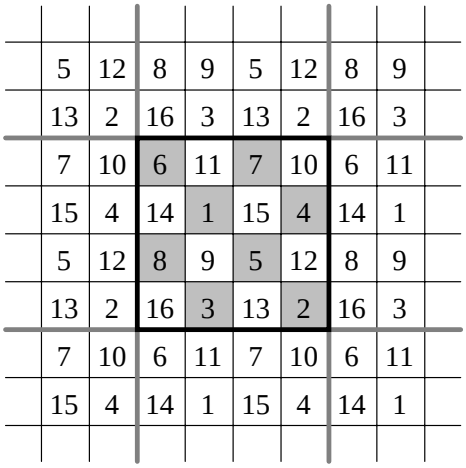
SCREENING

- Threshold with periodic screen
  - Clustered-dot dither
  - Dispersed-dot dither
  - Stochastic screen
- Point operations (pixel parallel)
- Lower quality than error diffusion



2	13	18	17	6	1	2	13	
3	14	15	16	5	4	3	14	
11	9	7	8	10	12	11	9	
17	6	1	2	13	18	17	6	
16	5	4	3	14	15	16	5	
8	10	12	11	9	7	8	10	
2	13	18	17	6	1	2	13	
3	14	15	16	5	4	3	14	

Clustered-dot screen

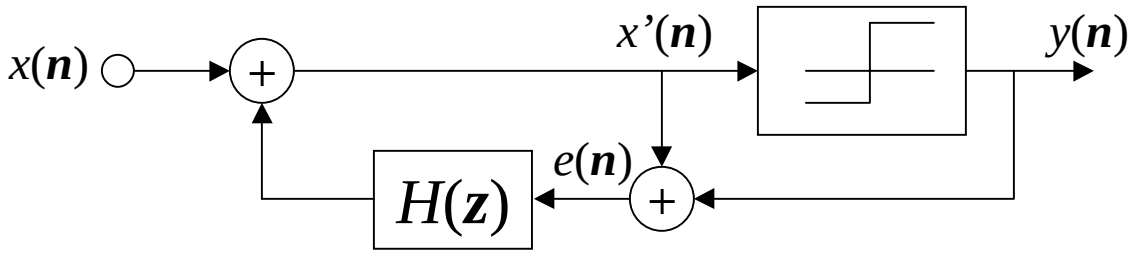


5	12	8	9	5	12	8	9	
13	2	16	3	13	2	16	3	
7	10	6	11	7	10	6	11	
15	4	14	1	15	4	14	1	
5	12	8	9	5	12	8	9	
13	2	16	3	13	2	16	3	
7	10	6	11	7	10	6	11	
15	4	14	1	15	4	14	1	

Dispersed-dot screen

ERROR DIFFUSION

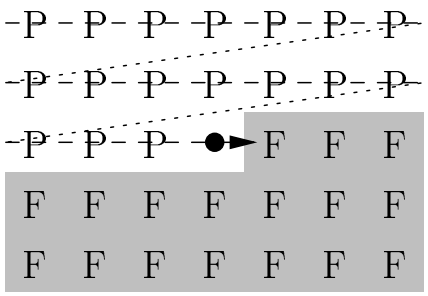
- 2-D delta-sigma modulator
- Noise shaping feedback coder



- Error filter

	○	7/16
3/16	5/16	1/16

- Raster scan order

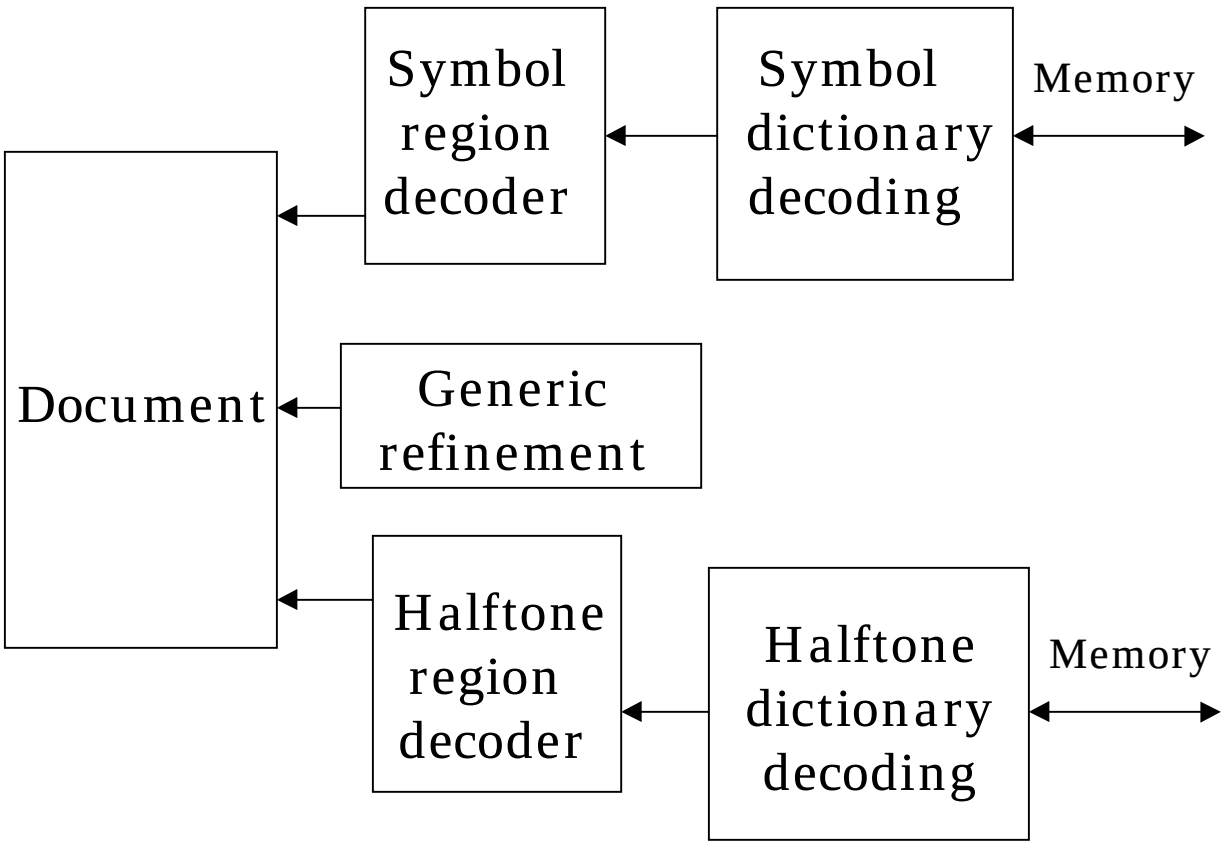


P = Past
F = Future

- Serpentine scan also used

THE JBIG2 STANDARD

- Lossy/lossless coding of bi-level text and halftone data



- Scan vs. random mode

THE JBIG2 STANDARD (cont.)

- Bi-level text coding
  - Hard pattern matching (lossy)
  - Soft pattern matching (lossless or near lossless) may be context based
- Halftone coding
  - Direct halftone compression
  - Context based halftone coding
  - Inverse halftoning and compression of grayscale image
- Implications
  - Printers, fax machines, scanners, etc. will need to decode JBIG2
  - Fast decoding may require dedicated hardware and embedded software
  - Need for low complexity, low memory solutions

PROBLEMS TO BE SOLVED

- JBIG2 compression of halftones
  - Compress halftone directly, using a dictionary of patterns
  - Convert halftone to grayscale (inverse halftoning) and compress the grayscale image
- Efficient coding of halftone data
  - Important in fax machines and digital archiving, scanning, and copying
- Fast algorithms for the encoding-decoding problem
  - JBIG2 defines the decoder behavior
  - Need for fast decoding and rehalftoning algorithms

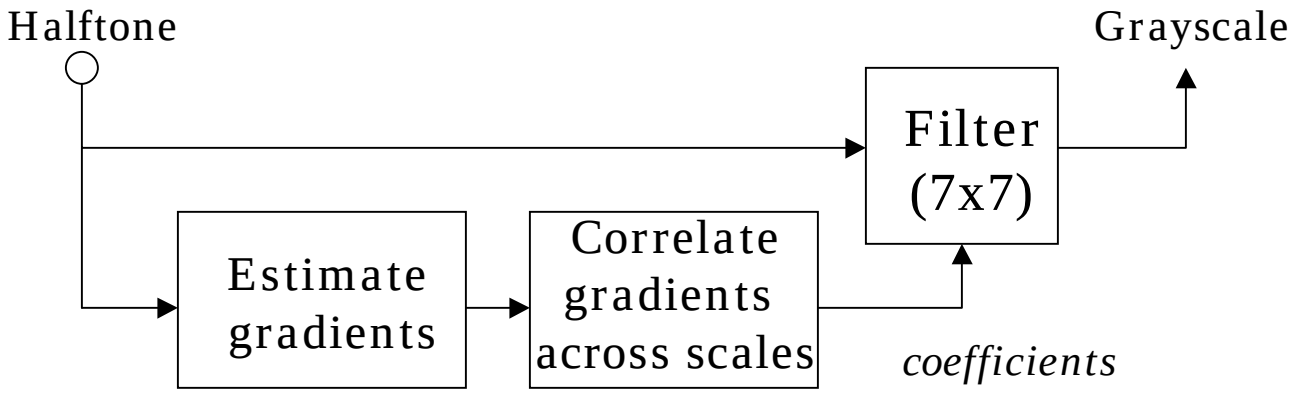
INVERSE HALFTONING

- Attempt to recover grayscale images from halftones
- Applications
  - Digital copiers (could support JBIG2)
  - Scanner software (could support JBIG2)
  - Embedded JBIG2 decoders
- Frame-based approaches
  - Bayesian estimation
  - Projection onto convex sets
  - Iterative lowpass smoothing and nonlinear filtering
  - Wavelet denoising
- Scan-based approaches
  - Adaptive smoothing
  - Non-linear denoising
- Frame-based methods are slow, memory-hungry, and often iterative

ADAPTIVE SMOOTHING

- Problems in inverse halftoning
  - Preserve edges
  - Reduce noise
  - Reduce implementation cost
- Solution for preserving edges
  - Specialized gradient estimator
  - Smooth image parallel to edges
- Solution for noise reduction
  - Correlate gradient estimate across scales
  - Smooth more where edges are absent
- Solution for low implementation cost
  - Low memory usage
  - Low computational complexity
  - Local operations only

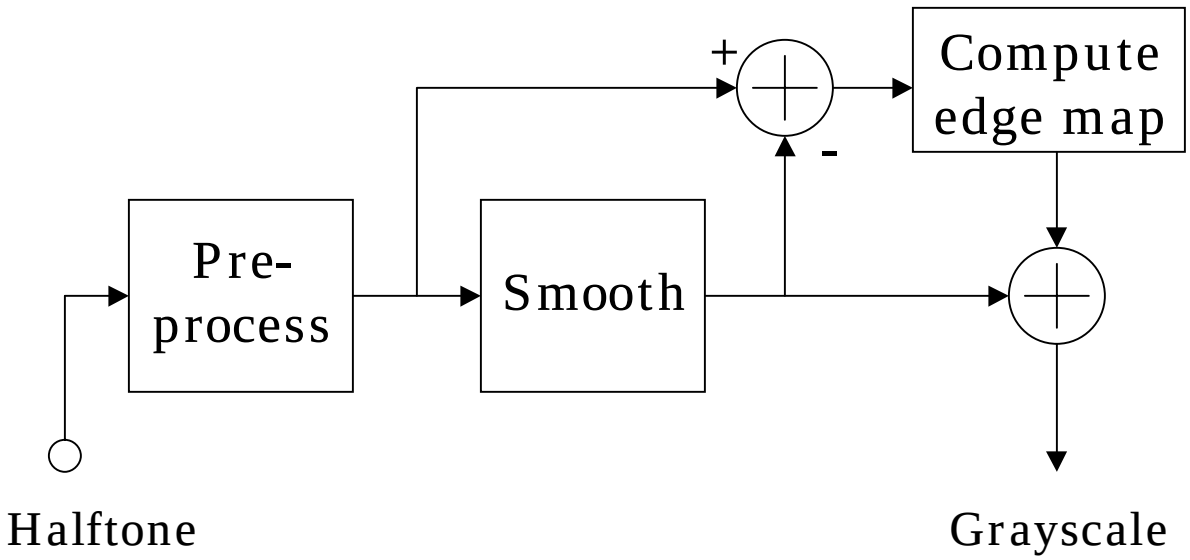
ADAPTIVE SMOOTHING (cont.)



- Linear, spatially varying system
- Estimate and refine gradients
- Construct parametric smoother
  - Separable 7 x 7 FIR filter
  - Quantized integer coefficients
- Implementation cost
  - Store 7 x 7 neighborhood (7 image rows)
  - 600 operations per pixel
- For a 512 x 512 image
  - 150 RISC MIPS and 3.5 kbytes
  - 2.9 s on a 167 MHz Ultra-2 workstation

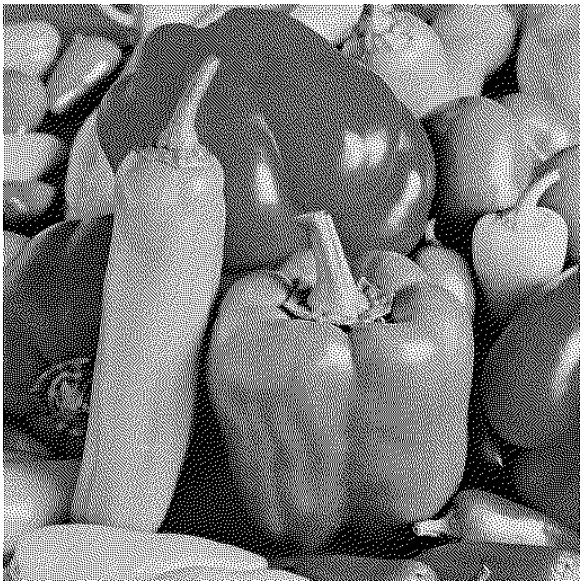
NON-LINEAR DENOISING

- Extract highpass noise and edges
  - Estimate noisy edge map by thresholding
  - Remove noise using fast binary operations
  - Enhance edge locations in grayscale image
- Increase memory for faster speed
  - Store 28 x 28 neighborhood (28 rows)
  - 300 operations per pixel
- For a 512 x 512 image
  - 100 RISC MIPS and 14 kbytes
  - 2.0 s on a 167 MHz Ultra-2 workstation



INVERSE HALFTONE RESULTS

Original image



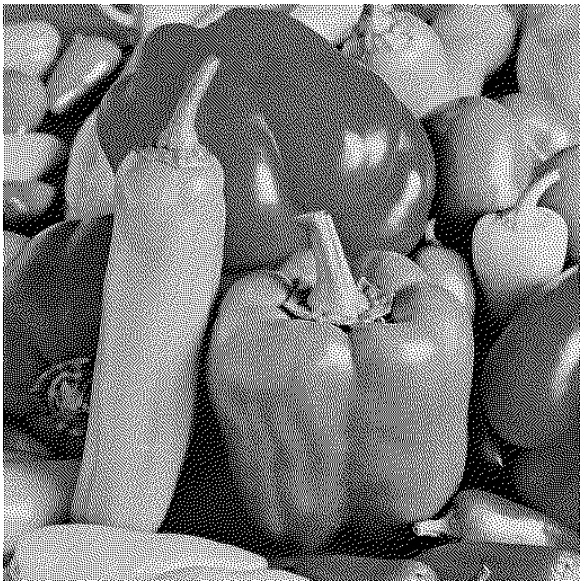
Halftone

Adaptive smoothing, 2.9 s

Wavelet, 1200 s

INVERSE HALFTONE RESULTS

Original image



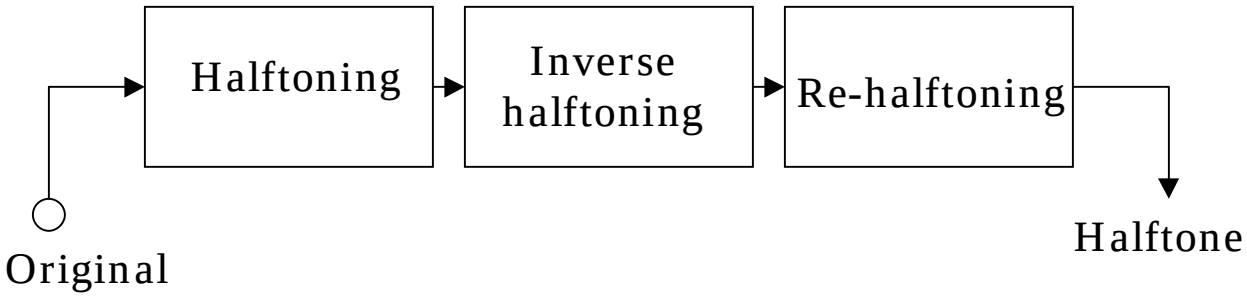
Halftone

Non-linear denoising, 2.0 s

Wavelet, 1200 s

REHALFTONING

- Halftone conversion, manipulation
- Embedded JBIG2 encoder uses inverse halftoning algorithm
- May be implemented by decoder
- Assume input and output are error diffused halftones
  - Blurring corrected by modified error diffusion
  - Noise leakage masked by halftoning
  - 64 operations per pixel
- For a 512 x 512 image
  - 16 RISC MIPS
  - 0.4 s on a 167 MHz Ultra-2 workstation



REHALFTONING RESULTS

Original 512 x 512 image

512 x 512 Rehalftone

CONCLUSIONS

- JBIG2 embedded decoders
  - Low memory requirements
  - Low computational complexity
  - High parallelism
- Inverse halftoning: a robust solution for lossy coding of halftones
  - Rendering device can use a different halftoning scheme than encoder
  - Multiresolution halftone rendering (archive browsing)
  - High halftone compression ratios (9-16:1)
  - Quality enhancement if the encoder halftoning method is transmitted
- Low-cost DSP solutions
- Web site for software and papers
  - `http://www.ece.utexas.edu/~bevans/projects/inverseHalftoning.html`