

Halftoning via Direct Binary Search using a Hard Circular Dot Overlap Model*

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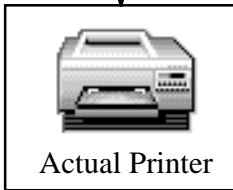
*Research supported by the Hewlett-Packard Company.

The Problem



Original image

Halftoning
without dot
overlap model

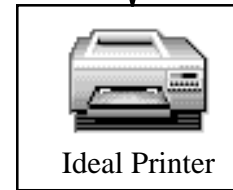


Actual Printer



Halftoned image
(Darkened tone)

Halftoning
without dot
overlap model



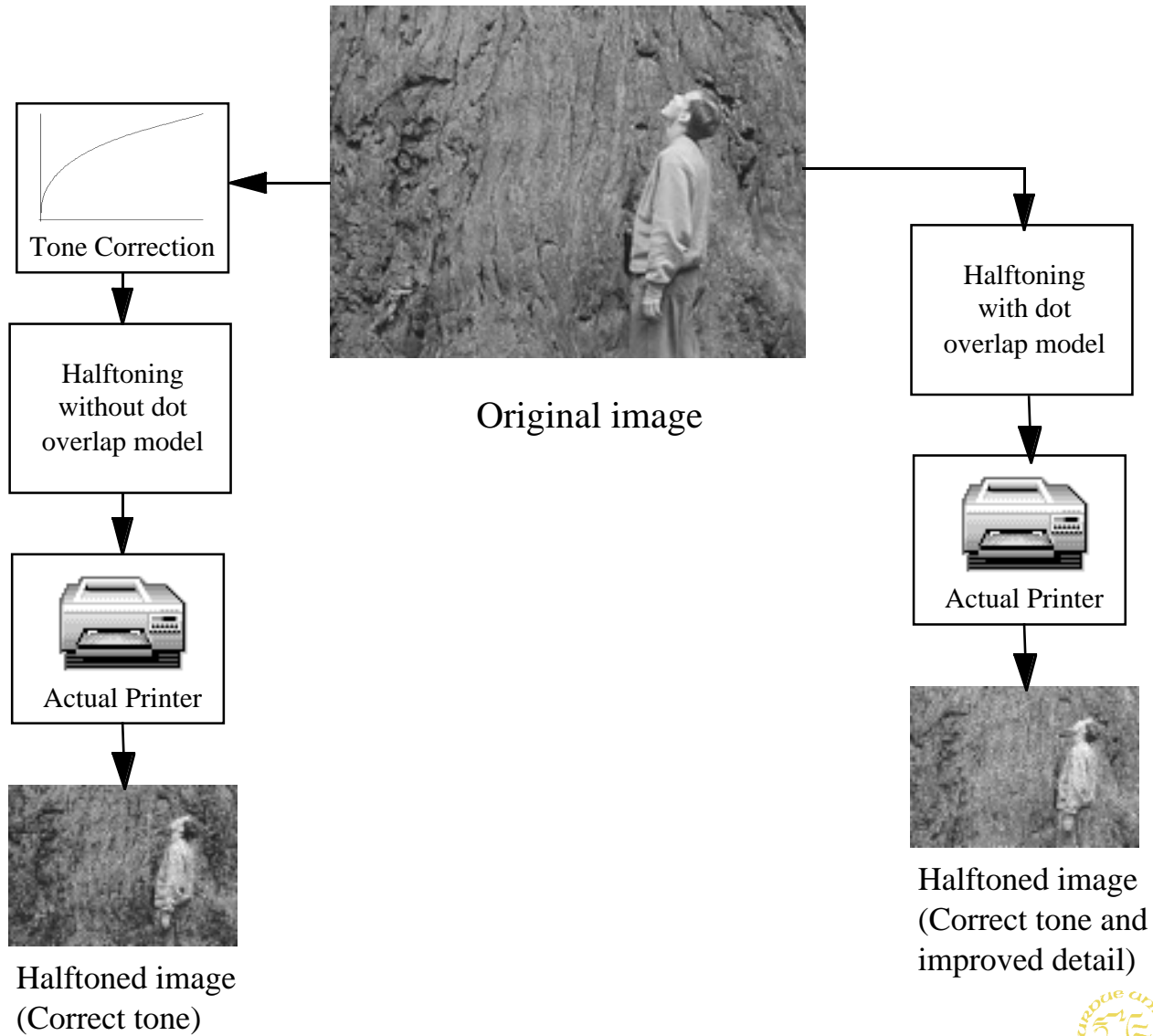
Ideal Printer



Halftoned image



Possible Remedies



Prior Work with Printer Models

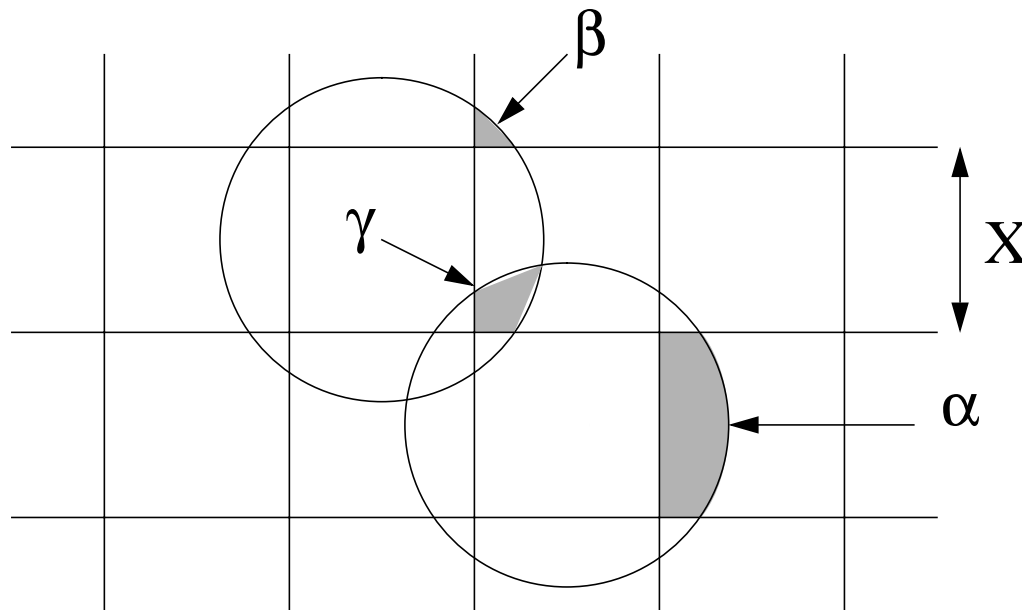
- 1 **Tone correction before halftoning**
 - u **Rosenberg [1993]**
- 1 **Error diffusion**
 - u **Stucki [1981], Stevenson and Arce [1985],
Pappas and Neuhoff [1991, 1995]**
- 1 **Iterative Methods**
 - u **Pappas and Neuhoff [1992]**
- 1 **Screen Design**
 - u **Schulze and Pappas [1994], Lin [1994]**



Hard Circular Dot Overlap Model

w Pappas and Neuhoff, 1991

w Dot overlap characterized by three parameters



Hard Circular Dot Overlap Model

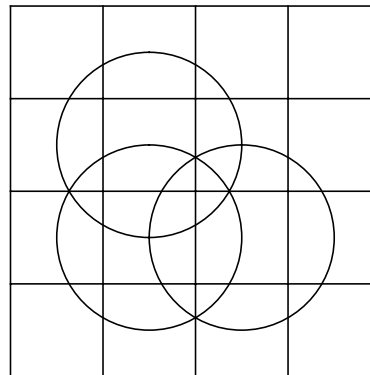
Equivalent Grayscale Image

Digital Halftone

| | | | |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 0 |
| 0 | 1 | 1 | 0 |
| 0 | 0 | 0 | 0 |

$g[m,n]$

Printer Model
Output



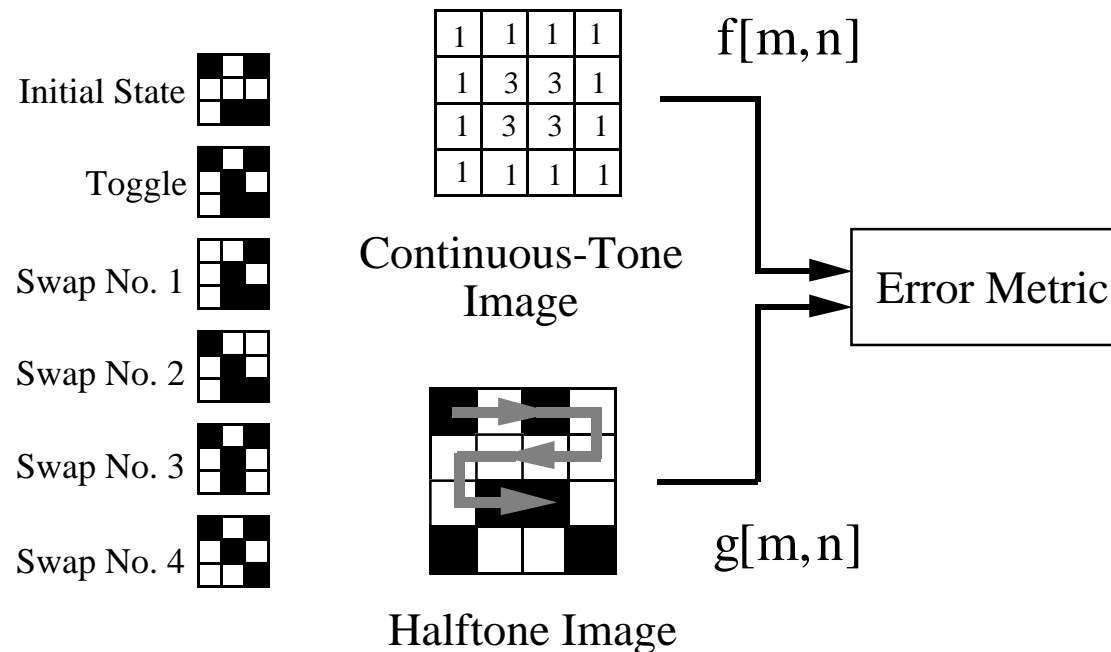
Equiv. Grayscale
Image

| | | | |
|------|------|------|------|
| 0.03 | 0.33 | 0.03 | 0.00 |
| 0.33 | 1.00 | 0.56 | 0.03 |
| 0.33 | 1.00 | 1.00 | 0.33 |
| 0.03 | 0.33 | 0.33 | 0.03 |

$\hat{g}[m,n]$

What is DBS?

- 1 Iterative search heuristic
- 1 Minimizes error metric between halftone and continuous-tone original images



Error Metric

1 Equivalent Grayscale Image

$$\hat{g}[m, n] = \text{HCD}(g[m, n])$$

1 Perceived Halftone Image

$$\tilde{g}[m, n] = \tilde{p}[m, n] * \hat{g}[m, n]$$

↑ PSF of HVS

1 Mean-Squared Error

$$\varepsilon = \sum_m \sum_n \left| \tilde{f}[m, n] - \tilde{g}[m, n] \right|^2$$

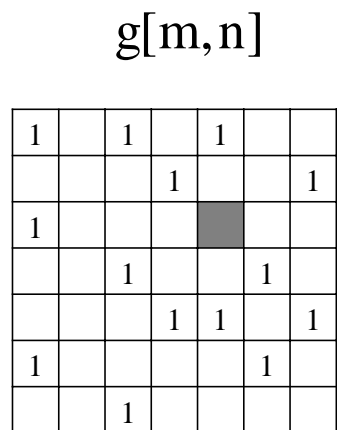
3x3 Region for Evaluating Toggle at (m_0, n_0)

| | | |
|---------------------------|-------------------------|---------------------------|
| a_1 (m_0-1, n_0-1) | a_4 (m_0, n_0-1) | a_7 (m_0+1, n_0-1) |
| a_2 (m_0-1, n_0) | a_5 (m_0, n_0) | a_8 (m_0+1, n_0) |
| a_3 (m_0-1, n_0+1) | a_6 (m_0, n_0+1) | a_9 (m_0+1, n_0+1) |

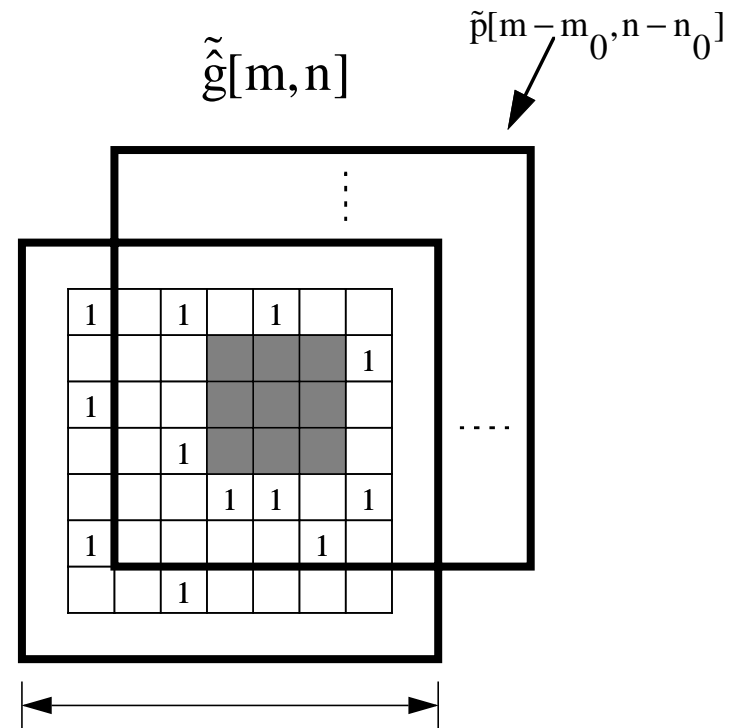
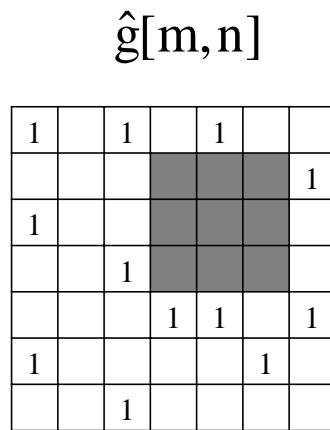
- 1 a_1, a_2, \dots, a_9 represent change in grayscale

Direct Evaluation of Change in Error

$$\tilde{g}'[m,n] = \tilde{g}[m,n] + \sum_{i=1}^9 a_i \tilde{p}[m - m_0 + \Delta m_i, n - n_0 + \Delta n_i]$$



■ Toggled pixel



Support of \tilde{p}

Efficient Evaluation of Change in Error

$$\Delta\varepsilon = K + \sum_{j=1}^9 a_j^c \tilde{p}^e [m_0 + \Delta m_j, n_0 + \Delta n_j] + \sum_{k=1}^{12} \left(\sum_{l=1}^{L_k} b_{kl} \right)^c \tilde{p}^p [m_k, n_k]$$

$$L_k \leq 6$$

- 1 The correlations are pre-computed and stored in Look up Tables (LUTs)

Cost of Evaluating a Trial Toggle

1 Direct Implementation

- u If $P \times P$ is the region of support of $\tilde{p}[m,n]$, then $9P^2 + 2(P+1)^2$ operations are required.
For $P=13$, the number of operations are 1913

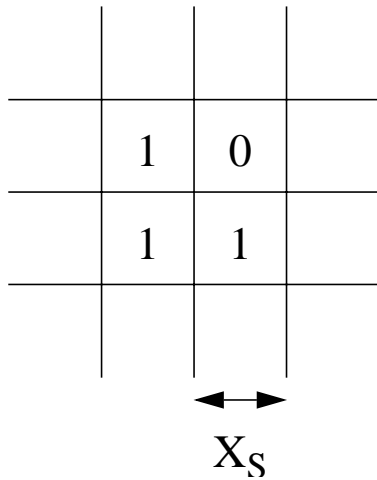
1 Efficient Implementation

- u 47 operations

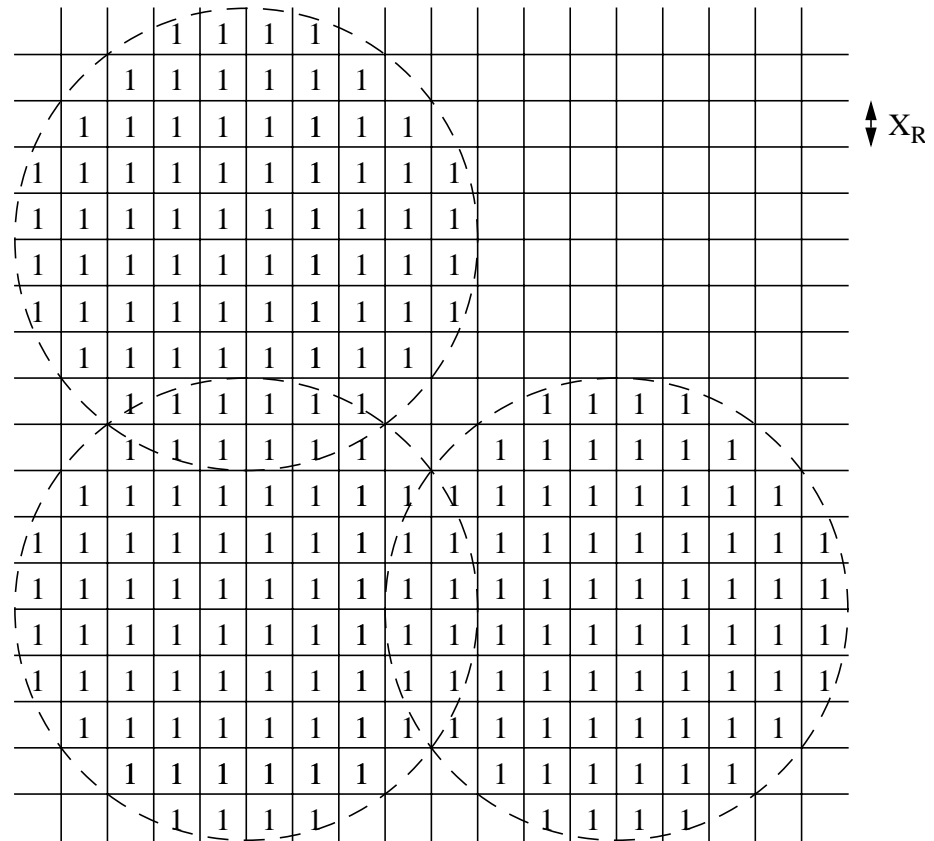
*Operation = 1 real addition + 1 real multiplication

Printer Simulation

Bit Map sent to Simulated Printer



Bit Map sent to Actual Printer



Conclusions

DBS with dot overlap model

- 1 **Yields accurate tone rendition**
- 1 **Exploits intermediate gray levels caused by dot overlap**
- 1 **Has fewer artifacts**
- 1 **Results in enhanced detail rendition**
- 1 **Can be implemented efficiently by LUTs.**