FM Halftoning Via Block Error Diffusion

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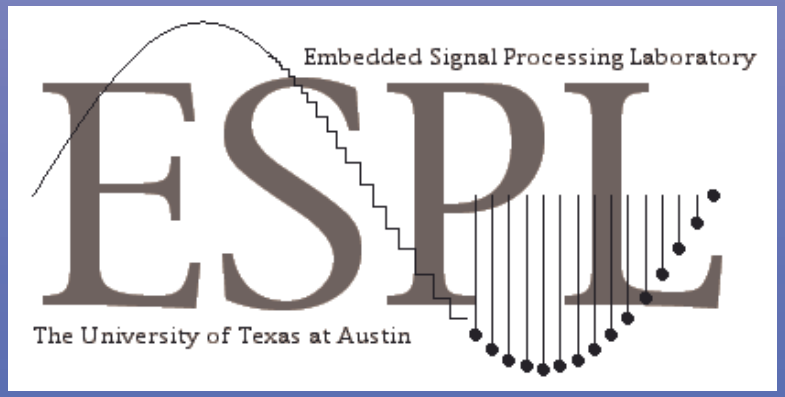
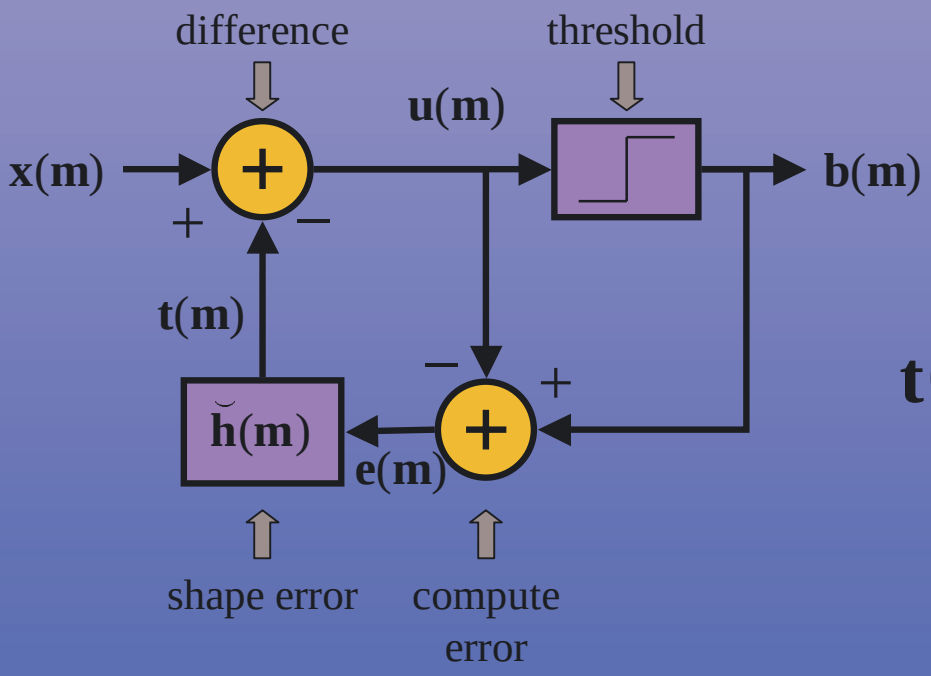


Block Error Diffusion Concept

- **Standard Error diffusion**
  - Operates on single pixels
  - Scalar error diffusion
- **Block error diffusion**
  - Operates on pixel blocks
  - Vector ‘block’ error could be diffused
  - Fast parallel implementation
- **Application**
  - FM halftoning with clustered dots
  - Artistic halftoning with defined dot shapes
  - Multiresolution halftone embedding

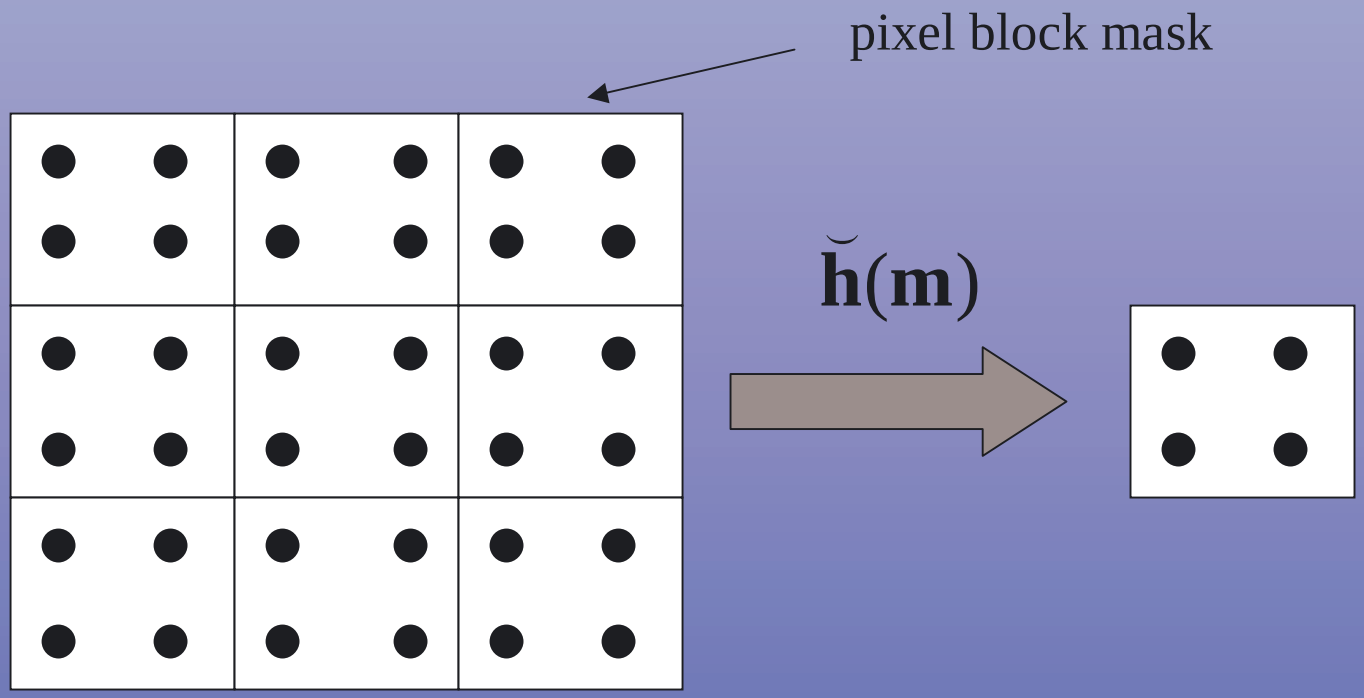
Block Error Diffusion

- **Input grayscale image is “blocked”**
- **Error filter diffuses error to all samples of neighboring blocks**



$$t(m) = \sum_{k \in S} \breve{h}(k)\, e(m-k)$$

Block Interpretation of Vector Error Diffusion



- **Four linear combinations of the 36 pixels are required to compute the output pixel block**

Block FM Halftoning

- **Why not "block" standard error diffusion output?**
  - Spatial aliasing problem
  - Blurred appearance due to prefiltering
- **Solution**
  - Control dot shape using block error diffusion
  - Extend conventional error diffusion in a natural way
- **Extensions to block error diffusion**
  - AM-FM halftoning
  - Sharpness control
  - Multiresolution halftone embedding

Block FM Halftoning Error Filter Design

- **Start with conventional error filter prototype**

$$\gamma = \left[\frac{1}{16} \quad \frac{5}{16} \quad \frac{3}{16} \quad \frac{7}{16} \right]$$

- **Form block error filter as Kronecker product**

$$\breve{\Gamma} = \gamma \otimes \breve{\mathbf{D}} \qquad \breve{\mathbf{D}} \text{ diffusion matrix}$$

- **Satisfies "lossless" diffusion constraint**

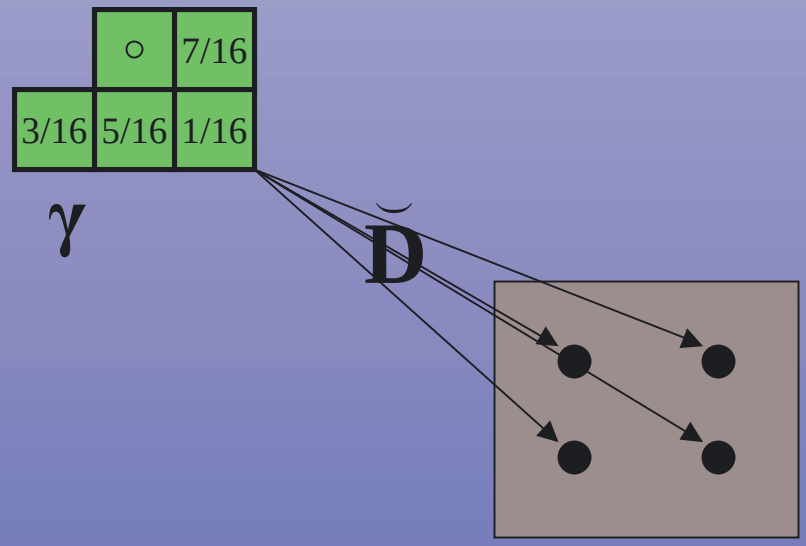
$$\breve{\Gamma}\mathbf{1} = \mathbf{1} \qquad \breve{\Gamma} \geq \breve{\mathbf{0}}$$

- **Diffusion matrix satisfies**

$$\breve{\mathbf{D}}\mathbf{1} = \mathbf{1} \qquad \breve{\mathbf{D}} \geq \breve{\mathbf{0}}$$

Block FM Halftoning Error Filter Design

- **FM nature of algorithm controlled by scalar filter prototype**
- **Diffusion matrix decides distribution of error within a block**
- **In-block diffusions are constant for all blocks to preserve isotropy**



Block FM Halftoning Results

- **Vector error diffusion with diffusion matrix**

$$\breve{\mathbf{D}} = \frac{1}{N^2}\left[\breve{\mathbf{1}}\right]$$

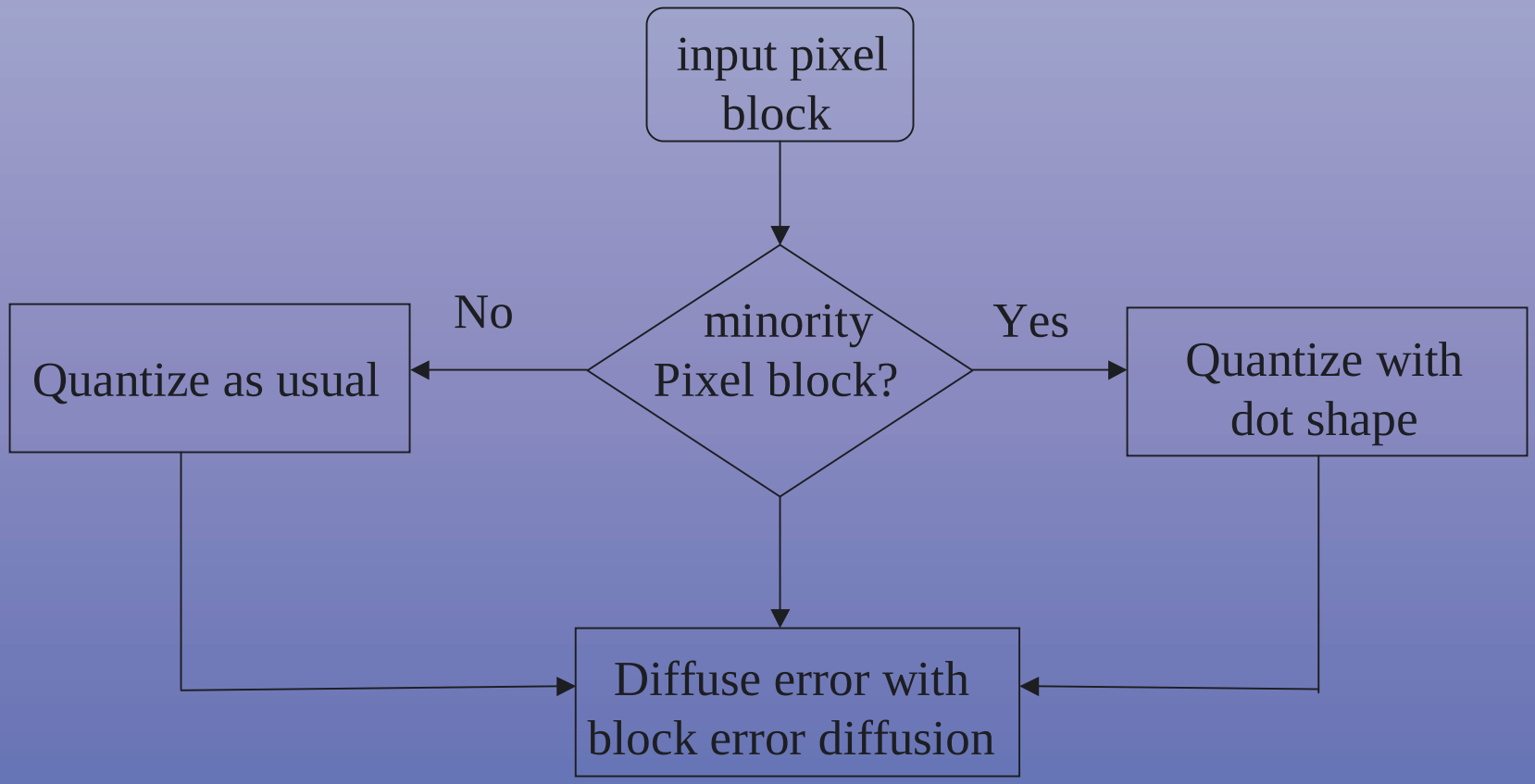
N is the block size

Pixel replication

Floyd-Steinberg

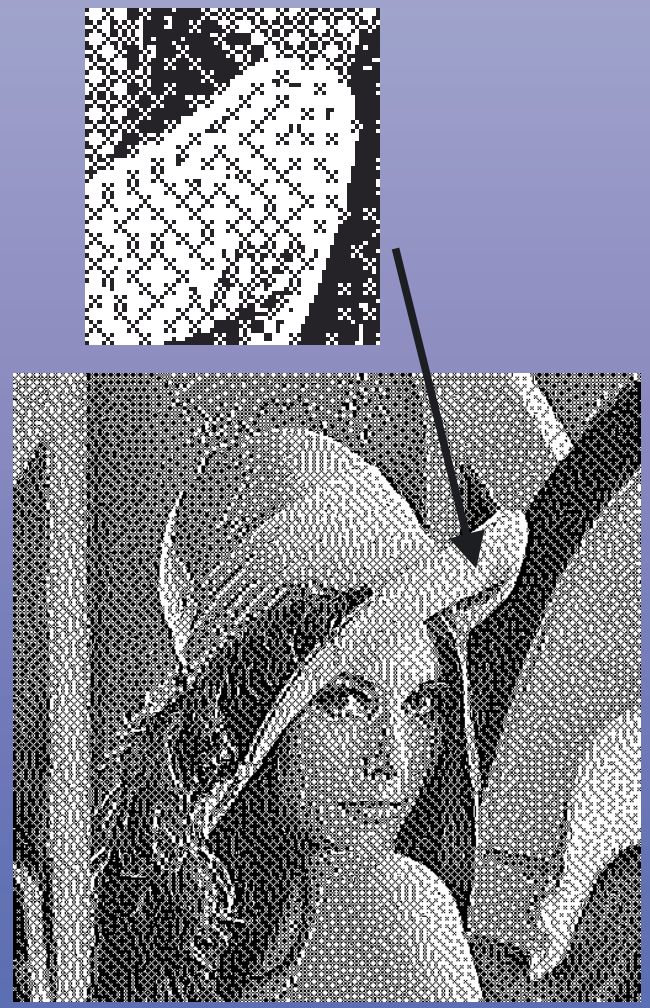
Jarvis

FM Halftoning with Arbitrary Dot Shape



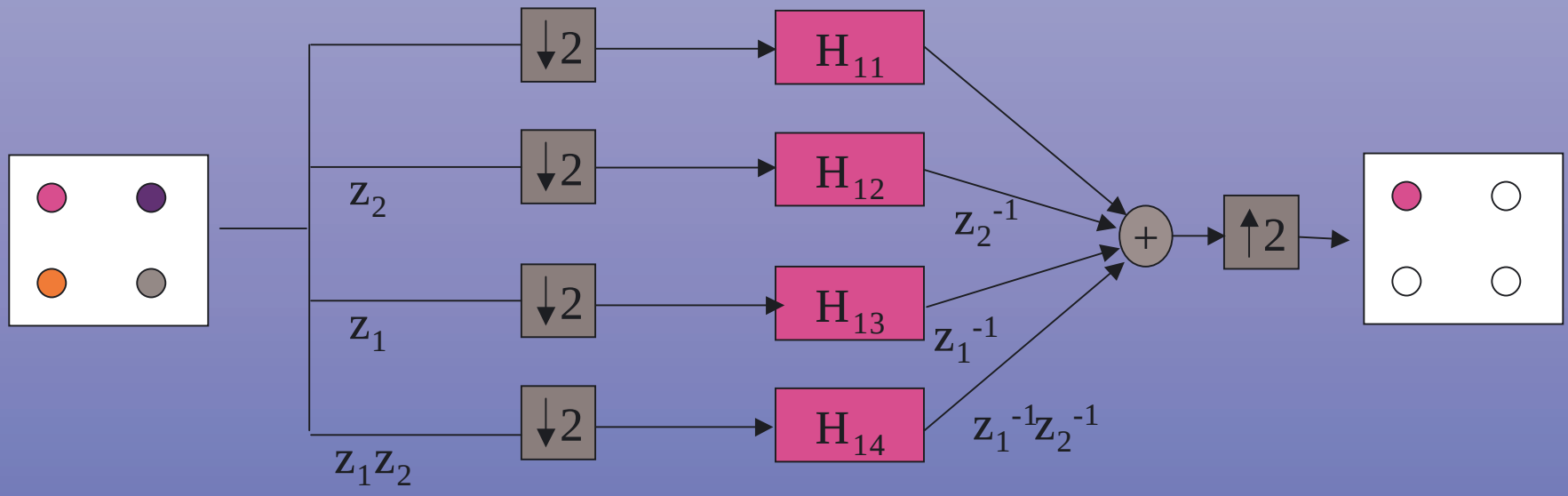
Block FM Halftoning with Arbitrary Shapes

Plus dots



Cross dots

Implementation of Block Error Diffusion



- **All the scalar filters have the same coefficients**
- **Up to 4 times faster than conventional error diffusion**

Conclusions

- **Block error diffusion**
  - Operates on pixel blocks
  - Vector ‘block’ error could be diffused
  - Arbitrary dot shapes possible
  - Fast parallel implementation

- **Future work**
  - Investigate more general error filters/diffusion matrices
  - Investigate color extension