Stochastic Floyd-Steinberg dithering on GPU: image quality and processing time improved

Giorgia Franchini, Roberto Cavicchioli, Jia Cheng Hu

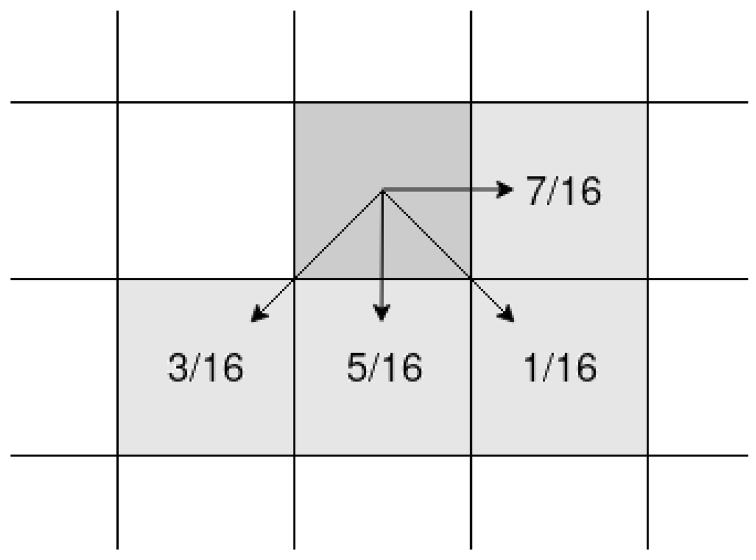
Department of Physics, Informatics and Mathematics, University of Modena and Reggio Emilia, Modena (Italy)

Dithering: Floyd-Steinberg Algorithm

- ▷ **Dithering** is a type of half-tone thresholding where grey-scale intensity is converted into a local density of binary pixels;
- ▷ many methods have been developed to obtain a higher degree of image quality;
- ▷ **Floyd-Steinberg** [2] (FS) dithering algorithm is based on error diffusion.

Algorithm 1 Floyd-Steinberg algorithm

1: **for all** rows $\in$ image **do**
2:   **for all** pixels $p \in$ row **do**
3:     find closest color τ to p
4:     $err = p - \tau$
5:     diffuse err to pixels around accordingly to $weights$
6:   **end for**
7: **end for**



The problem of Artifacts and the Stochastic Version

- The performance from different halftoning algorithms must be quantified to allow comparison;
- another way to describe the problem of digital halftoning is searching for the quantized image that minimizes the visibility of **artifacts**;
- we use a class of measurement methods that considers human visual system (HVS) characteristics, which attempts to predict perceptual visual quality;
- the HVS is based on the psychophysical process that relates psychological phenomena (contrast, brightness, etc.) to physical phenomena (light intensity, spatial frequency, wavelength, etc.);

- Weighted Signal to Noise Ratio (WSNR) [3]:

$$WSNR(dB) = 101\log_{10}\left(\frac{\sum_{u,v}|X(u,v)C(u,v)|^2}{\sum_{u,v}|(X(u,v)-Y(u,v))\,C(u,v)|^2}\right)$$

where $X(u,v)$, $Y(u,v)$ and $C(u,v)$ represent the DFT of the input image, output image and CSF (Contrast Sensitivity Function), respectively.

- To avoid the problem of artifacts the idea is to transform the FS algorithm, that is a deterministic algorithm, in a Stochastic version (SFS) inspired from [1]. In particular we choose a real number p and, for each pixel, we generate 2 random number:

$$r_1 \in [-5/16, 5/16] \text{ and } r_2 \in [-1/16, 1/16]$$

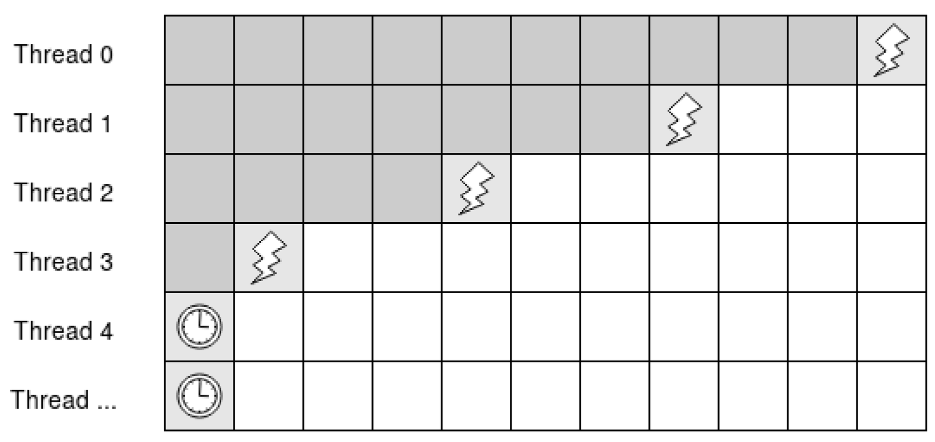
and we compute

$$\frac{7}{16} + p \cdot r_1, \frac{5}{16} - p \cdot r_1, \frac{3}{16} + p \cdot r_2 \text{ and } \frac{1}{16} - p \cdot r_2 \qquad (1)$$

as error diffusion coefficients.

GPU implementation

- In our implementation given an entire image or a chunk, each thread is assigned a row;
- In order to avoid atomic operations on the error buffer, each thread waits for the previous one to be three pixels ahead in his row instead of two, double buffering technique is applied.



- Considering an image of N rows and M columns. In the serial version: $T = N \times M$ where T is the time for the whole process.
In the parallel version, with the same image dimension, we have

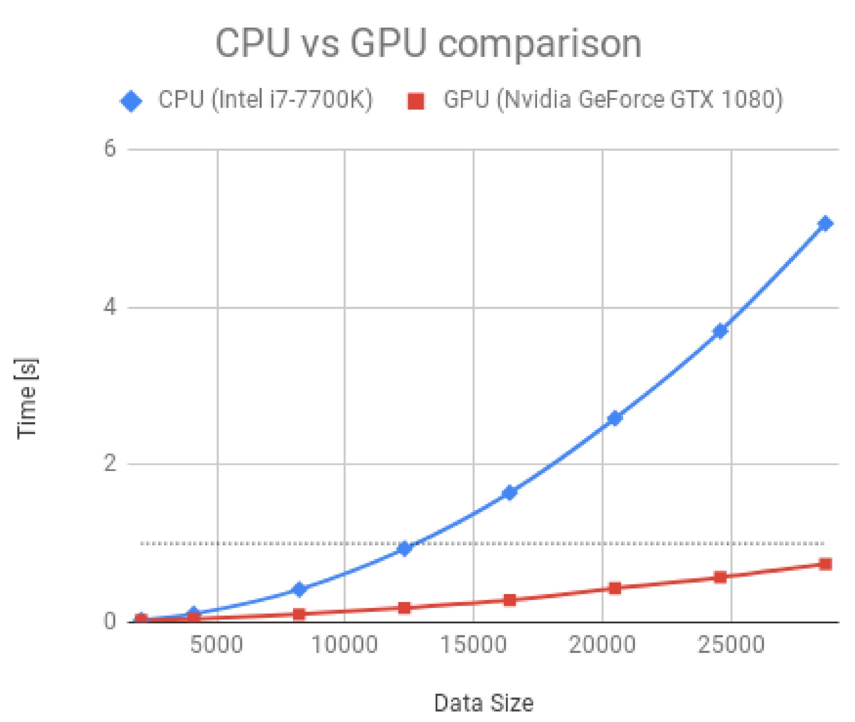
$$T = 3N + M - 3 \text{ with } M > N$$

and

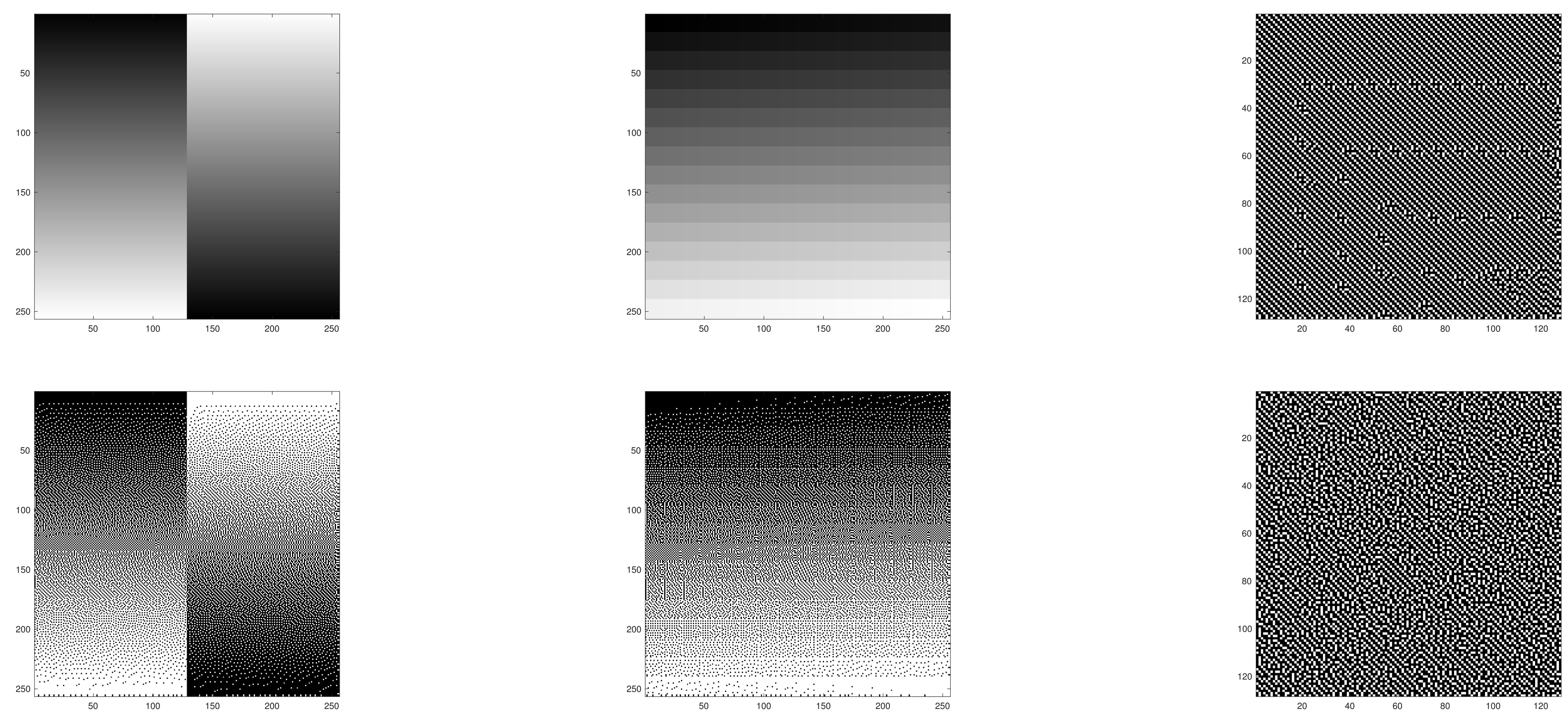
$$T = 3M + N - 3 \text{ with } N > M.$$

CPU vs GPU: speed-up

We ran the stochastic algorithm in both serial and parallel versions, obtaining very good speed-ups: as we expected the serial execution time increases quadratically w.r.t the input size while the parallel increases linearly.



Numerical experiment: synthetic images



Double gradient, original (top-left) and dithered with traditional two-tones FS (bottom-left), artifacts are clearly recognizable. In the center row, 256 different toned squares (top-center) ant their half-toned version (bottom-center) On the right particular of a single tone (128): on the top artifacts are clearly arising with traditional FS, while on the bottom there is no emerging pattern thanks to the stochastic nature of the method.

Numerical experiment: realistic images

PNGs of dithered images with $p = 0$ on the top and p corresponding to the best WSNR value on the bottom.

References

[1] MIT course: Digital hard copy, *http://web.media.mit.edu/ vmb/mas814/*
[2] Floyd, R.W., Steinberg, L.S., *An adaptive algorithm for spatial gray scale* , (1975)
[3] Nasanen, R., *Visibility of halftone dot textures*, IEEE transactions on systems, man, and cybernetics (6), 920-924 (1984)