SURGE Project
Report

Binary Image Recombination after Bit-wise Operations of Cellular Automaton

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Binary Image Recombination after Bitwise Operations of Cellular Automaton

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Abstract

A **weighed summation method** to recombine binary images for better performance of Cellular Automaton(CA) based Image Processing algorithms is developed. Generally, Cellular Automaton operates on cells having a small number of states because of *exponential dependence of search space on number of possible states*. So,any application of CA on gray scale images involves transforming the image to many new images with fewer states such as binary images using methods like thresholding and then their recombination to produce the originally transformed gray scale image.
We have developed a **regression based weight** evaluation algorithm to yield a better gray-scale image from binaries.The algorithm is extended to include images with more states(Ternary) with a corresponding increase in the computational requirements.The algorithm is implemented in **MATLAB R2016b** in the specific case of denoising **Salt and Pepper Noise** to test against standard benchmark algorithms such as Median Filter for various images, noise levels and segmentation factors.

Acknowledgments

Prima facea, I am grateful to the God for the good health and well being that were necessary to complete this project.

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1 Introduction

A cellular automaton (pl. cellular automata, abbrev. CA) is a discrete model studied in computability theory, mathematics, physics, complexity science, theoretical biology and microstructure modeling. Cellular automata are also called cellular spaces, tessellation automata, homogeneous structures, cellular structures, tessellation structures, and iterative arrays [1]

The concept of Cellular Automaton (CA) was initiated in the early 1950's by J. Von Neumann and Stan Ulam. Cellular Automaton consists of a regular grid of cells (Generally two dimensional) each of which can be in only one of a finite number of possible states. The state of a cell is determined by the previous states of a surrounding neighborhood of cells and is updated synchronously in discrete time steps. The identical rule contained in each cell is essentially a finite state machine, usually specified in the form of a rule table with an entry for every possible neighborhood configuration of states.

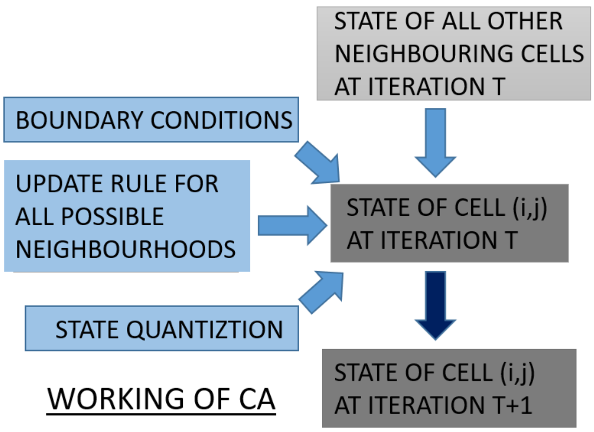

Figure 1: Flowchart for Working Of a Cellular Automaton

Complex Image processing algorithms require huge computational resources to be performed in real time. Parallel algorithms for solving any image processing task is the most promising way to achieve computationally heavy tasks in real time.Also,Cellular Automaton are the most common and simple models of parallel computation. Consequently, CA has been utilized heavily in the recent literature for image processing tasks. An image can be viewed as a two dimensional CA where each cell represents a pixel in the image and the intensity of the pixel is represented by the state of that cell. Considerable effort has been expended in developing special purpose hardware (e.g., Cellular Logic Image Processor, CLIP)[CITE] alongside developing rules for the application of the Cellular Automaton to image analysis.

2 Motivation

There are various kind of applications in many scientific fields involving image processing.For instance, image enhancement is the processing of images to improve their appearance to human viewers or to enhance the performance of other image processing system. In most applications involving images or image processing one of the most common problems is the presence of noise. [1]
CAs have been applied to perform a range of computer vision tasks, such as

- Calculating distances to features [5]
- Calculating properties of binary regions such as area, perimeter, and convexity [3]
- Performing medium level processing such as gap filling and template matching [2]

Denoising of images is an extensively studied field.Various kind of noises such as Gaussian noise, Salt and pepper Noise,Shot Noise, Quantization Noise,Film grain etc. have [4] have been studied in great detail. The problem of applying Cellular Automaton to Image processing has been studied by [6] and [7] . Its extension to grayscale images as proposed is to transform the image to many new images with fewer states such as binary images using methods like thresholding and then their recombination to produce the originally transformed gray scale image.The recombination method proposed was to sum up the binary images.**The aim of the project is to find a better recombination method using weights for binary images during summation.**

3 Related Work

The recent work “Training Cellular Automata from Image Processing”[6] is aimed at learning Two-dimensional rectangular grid binary state CA rules for performing specific tasks such as Convex Hull and denoising Salt and Pepper noise.The algorithm developed uses **Sequential Forward Floating Search**.For example, in case of Salt and Pepper noise the rule set learned for low noise level (around 0.01) is:

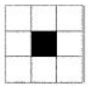

Figure 2: Single rule learnt in case of 1 percent SPN noise

And on raising the noise levels the rule sets are:

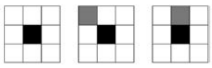

Figure 3: Three rules learnt in case of 10 percent SPN noise

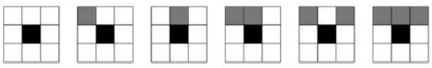

Figure 4: Five rules learnt in case of 30 percent SPN noise

All these rules are applied on binary images of corresponding noise level and the results were recombined using appropriate methods.

4 Our Algorithm and Simulation

4.1 Problem Description

In general, the inverse problem of finding the rules of CA to achieve a desired end is hard and involves a lot of intuition and guesswork. Also, various other researchers have tackled this problem using approaches such as Sequential Floating Forward Search (SFFS), Genetic Algorithms, Particle Swarm Optimization etc. However, all of such Cellular Automaton rule can be applied fundamentally only on Image with only a few intensity states.Formally, the problem can be described in THREE parts:

STEP 1 : <u>THRESHOLDING THE GRAYSCALE IMAGE</u>

$$T_k : \{ [X]_{m\times n} | \, X(i,j) \in (0,L) \} \rightarrow \{ [I]_{m\times n} \, | \, I(i,j) \in \{0,1\} \}$$

$$\{ \, [\mathrm{A}_X]_{m\times n\times(l+1)} \, | \, A_X(i,j,k) = T_k \, \forall \, k \in (0,L) \}$$

STEP 2 : <u>APPLYING CELLULAR AUTOMATON BIT-WISE</u>

$$\mathrm{CA} : \{ \quad [\mathrm{A}_X]_{m\times n\times(l+1)} \rightarrow [B'_X]_{m\times n\times(l+1)} \}$$

STEP 3 : <u>RECOMBINING BINARIES TO OUTPUT IMAGE</u>

$$\mathrm{T'}_k : \{ [B'_X]_{m\times n\times(l+1)} | \, B(i,j,k) \in 0,1 \} \rightarrow \{ [X']_{m\times n} \, | \, I(i,j) \in \{0,1\} \}$$

4.2 Approaches for Recombination of Images

4.2.1 Frequency Based Weight Evaluation

For recombination a frequency based weighed approach for combining the different binary images was carried out.Each binary images has weight W_k defined as:

$$\mathrm{W}_k = \frac{\sum_{j=1}^{N} \sum_{i=1}^{M} \delta(X(i,j)-k)}{m\times n}$$

and then getting the transformed image back using weighed summation approach:

$$[\text{X'}]_{M\times N} = \sum_{k=0}^{L} W_k * \{B(i,j,k')|(i,j,k') \in (m \times n, k' = k\}$$

However,this did not produce a good desired output because most of the intensity values were mapped to 0 at lower intensities due to less occurrence. This distorted the shape of histogram envelope and gave a **'Dimmed Down'** look to the output image. To cope with this drawback, an **offset** was applied choosing it among the 'L' intensity choices available to maximize similarity between the desired and actual output. This resulted in images that were **90 percent** similar improving the result from **50-55 percent** measured using SSIM as metric.The results obtained from this method performed worse than setting all W_k to 1 as utilized in [6].

IMAGE	Frequency based	With Offset
Lenna	~53%	~91%
Cameraman	~51%	~87%
Baboon	~55%	~92%

4.2.2 Regression Based Weights

In this method the **Peak Signal to Noise Ratio** (PSNR) was considered to measure the effectiveness of recombination based on the initialized weights. Then, **Linear regression** was applied considering the PSNR value to be a function of the chosen weights (BASED ON FREQUENCY APPROACH) and the weights were adjusted to maximize the PSNR value. 'TRUST-REGION' algorithm is used to maximize the function.
This method was found to be computationally intensive and to reduce the time only a certain percentage of the total uncorrupted pixels were used to learn the weights.Below are the results fo reconstruction from noised image using All the three methods: Learning using all pixels, Learning using randomly segmented uncorrupted pixels and using all te weights as 1 for Lenna and barbara images.The images used are **128*128 pixels** in size and all the simulation is performed in **MATLAB 2016**.

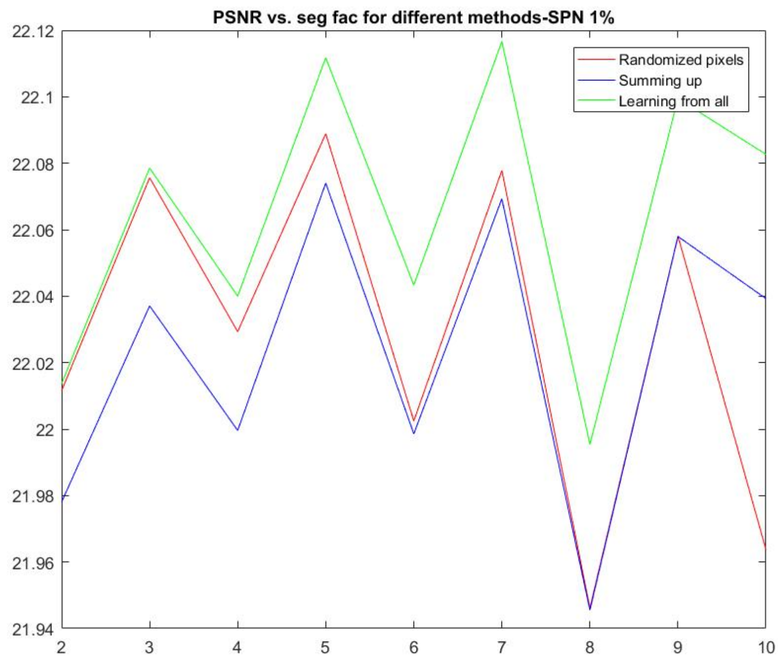

Figure 5: PSNR vs. segmentation factor for Lenna Image.

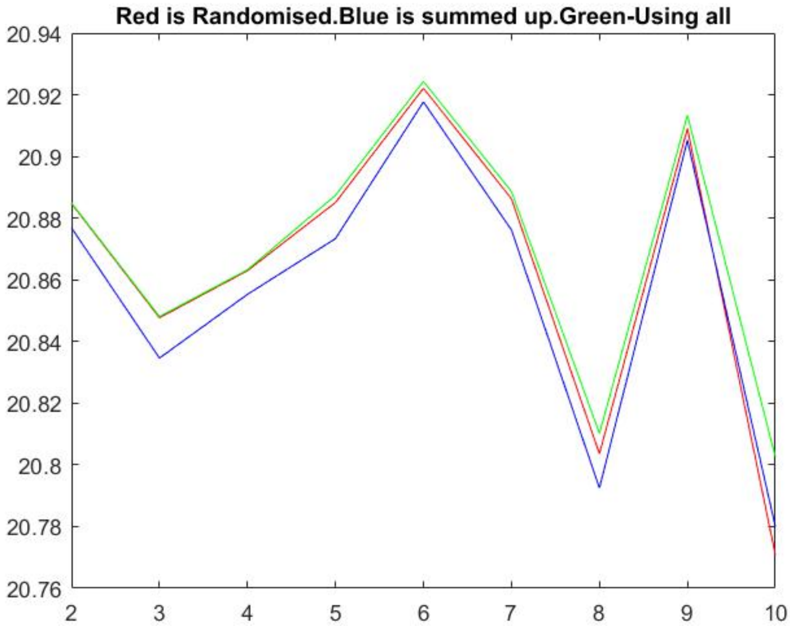

Figure 6: PSNR vs. segmentation factor for Barbara Image.

5 Conclusion

- Frequency Based Weight Evaluation method produces worse results.However, the time and memory overloads are minimal.
- Using offset in frequency based weight scheme can increase th performance drastically with little footprint on time and memory.
- Using Regression based weights produces superior results compared to naive summing up algorithm.The memory requirements can be reduced by efficient use of buffers and swapping pointers.Time requirements are cut down to 10 percent by using only randomly selected uncorrupted pixels for weight training.
- The overall results are 1-2 percent better than the currently used method.The time requirements are 10-15 times higher but can be further reduced using quantization of weights.

The proposed algorithm successfully improves the performance of the currently used method and consistently performs better over all the test images.The higher time requirements are compensated by calculating the required weights just ONCE and then providing them with the image itself in its meta data and so effectively reducing the time to the conventional algorithm on a large user set.

6 Future Work

- There is much scope to optimize the Linear regression model used.Quantization of weights,Clustering based on frequency and thresholding in groups need to be implemented and experimented with.
- The method can be extended to tasks other than denoising such as Convex Hull recognition and Edge Detection as well.The corresponding change in the Linear regression method needs to be experimented with.
- A lot of experimentation with the method of thresholding used to breakdown gray-scale images to binary images needs to be done.
- There is scope to improve the performance further by using tenary state CA as suggested in [7].

  Overall, this project has cleared a roadblock to effectively using Cellular Automaton in Image Processing but the path ahead is uncharted and much can be explored.

References

[1] Dan Popovici Adriana Popovici. ”cellular automata in image processing”. *Fifteenth International Symposium on Mathematical Theory of Networks and Systems University of Notre Dame*, 2002.

[2] T. de Saint Pierre and M. Milgram. “new and efficient cellular algorithms for image processing”. *CVGIP: Image Understand., vol. 55, no. 3, pp. 261–274*, 1992.

[3] C. Dyer and A. Rosenfeld. “parallel image processing by memory-augmented cellular automata”. *IEEE Trans. Pattern Anal. Mach. Intell., vol. PAMI-3, no. 1, pp. 29–41*, Jan. 1981.

[4] Mohd Awais Farooque and Jayant S.Rohankar. Survey on various noises and techniques for denoising the color image. *International Journal of Application or Innovation in Engineering Management (IJAIEM)*, 2013.

[5] A. Rosenfeld and J. Pfaltz. “digital distance functions on digital pictures”. *Pattern Recognition vol. 1, no. 1, pp. 33–61*, 1968.

[6] Paul L. Rosin. Training cellular automata for image processing. *IEEE Transactions on Image Processing, VOL. 15, NO. 7*, 2006.

[7] Paul L. Rosin. Image processing using 3-state cellular automata. *Computer Vision and Image Understanding,114 790–802*, 2010.