Binary Image Recombination after bitwise operations of Cellular Automaton

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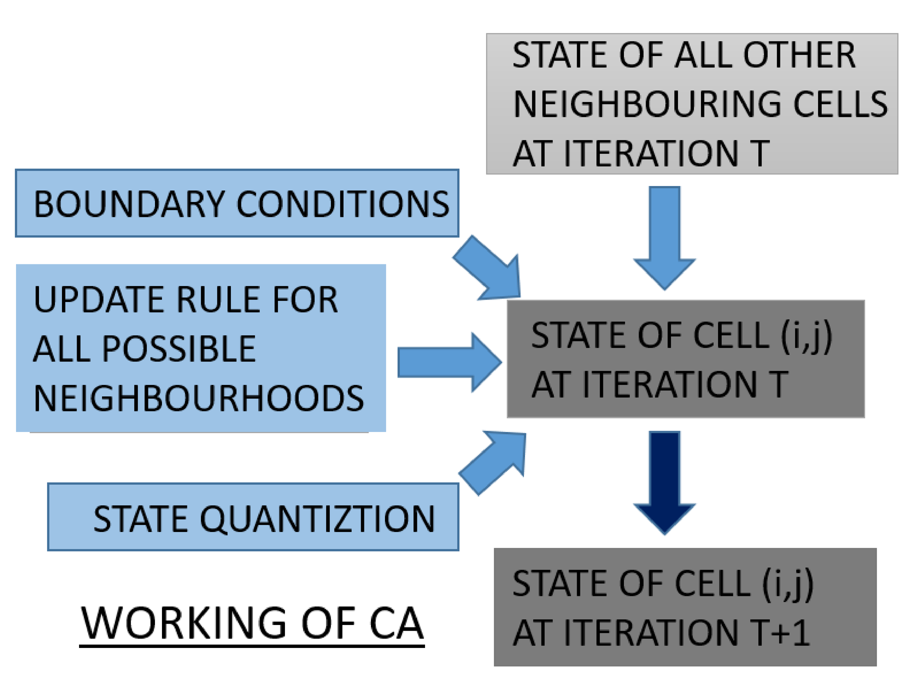
Objectives

Find a method for recombination of binary images obtained after thresholding the original Grayscale image and applying bit-wise Cellular Automaton Operations on it.

Introduction

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.

Any Cellular Automaton can be characterized by:



WORKING OF CA

1. Grid/Map (size/shape/folded/semi-open etc.)
2. Number of states (>=2 mostly)
3. Neighborhood to be considered (Radial ,Moore Neighborhood,Von Neumann neighbourhood etc.)
4. Initial Conditions/Terminal Conditions.
5. Rules for evolution.

Application In Image Processing

The Cellular Automaton used is a 2-dimensional Binary CA with closed boundary and a search space of 256 rules considering Moore's neighbourhood.

Applying CA to Gray-scale images

Learning CA rules

Sequential Forward Floating Search[1][2]

- The inverse problem of finding CA rules to perform Image processing tasks requires a lot of intuition and guesswork
- SFFS minimizes a user specified function of CA rules as a linear descent algorithm.
- At each step a rule is greedily selected and the rules already selected are greedily removed.
- It is applied to various operations such as Convex Hull, Edge Detection and denoising Salt and Pepper Noise.

Application to denoising][1]

- Application to denoising is done primarily on Binary images to reduce the search space for CA rules,drastically.
- The rules learnt are effective at denoising binary images more than the standard methods.
- This poses the problem of recombination of binary images to produce the originally transformed gray-scale image.

Binary Image Recombination

Formally, the problem is described as:

STEP 1 :
THRESHOLDING THE GRAYSCALE IMAGE

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

STEP 2 :
APPLYING CELLULAR AUTOMATON BIT-WISE

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

STEP 3 :
RECOMBINING BINARIES TO OUTPUT IMAGE

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

Improving the last step is a roadblock in application of CA to gray-scale images.A **weighed summation method** using regression is proposed to employ at the last step rather than inverting the thresholding step.

Weighed Summation Method

Methodology

- **Regression based weights**: The weights are initialized based on the occurence of instensity level in the original gray-scale image.

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

- An output image is reconstructed as:

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

- The Structrual Similarity index is minimized by regressing the weights W_k :

$$\min_{\{W_k | k \in (0,L)\}} \mathrm{SSIM}([\mathrm{X'}]_{m\times n}, [X]_{m\times n})$$

- A method to cut down on the time requirement of the last step is to use only 10 percent of the total number of uncorrupted pixels for learning the rules.Thus, reducing the time to one-tenth.
- Further, reduction is achieved by using parallel implementation of CA like Cellular Logic Image Processor(CLIP).

Results

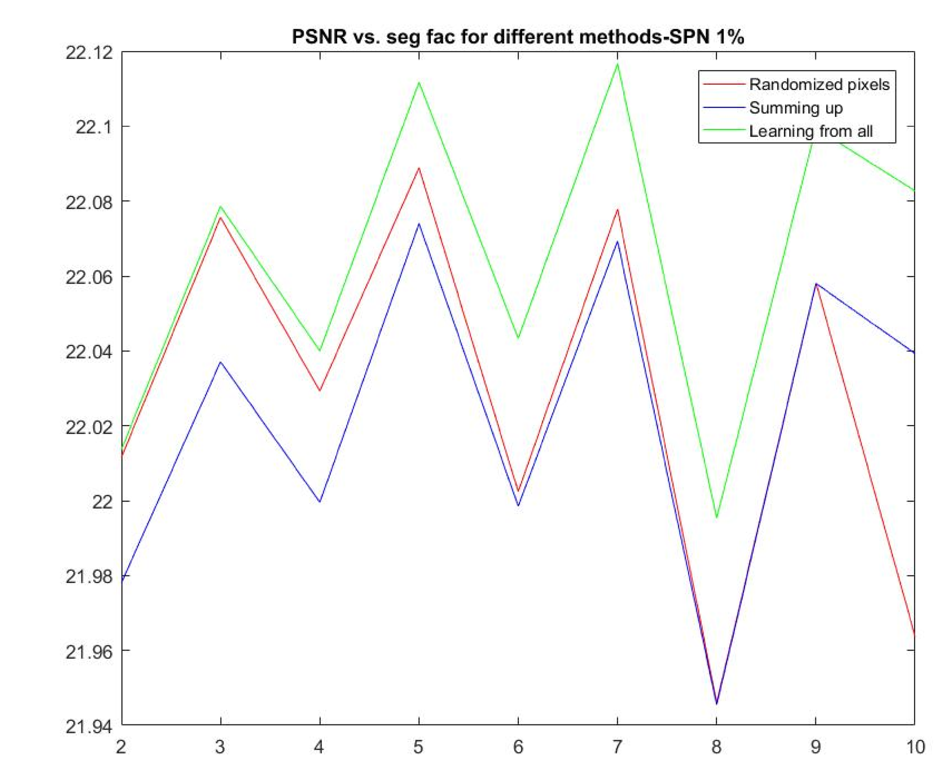


Figure 1: PSNR vs. segmentation factor for Lenna Image using three different methods

Conclusion

The proposed algorithm using regression 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.

References

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

[2] Paul L. Rosin.
Image processing using 3-state cellular automata.
Computer Vision and Image Understanding, 2010.

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