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Implementation of Gray-Level Image Restoration with Annealing Machine on CAM^2

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Abstract— Restoration of gray-level degraded image is demonstrated. The restored image is obtained by maximum likelihood estimation with annealing on CAM^2. The annealing algorithm was implemented on CAM^2 emulator and the processing speed was evaluated. Estimated from the number of instruction steps, it can be processed in 272 seconds with a clock cycle of 100 MHz.

1. Introduction

In recent years, an annealing machine utilizing the quantum effect has been realized and is expected to be applied to optimization problems. However, quantum annealing machines have many problems to overcome due to problems such as noise, and their potential has not yet been fully demonstrated.

In this research trend, we have studied the possibility of CAM^2 as an annealing machine. CAM^2 is CAM-based cellular hardware implemented in CMOS technology. We proposed binary image restoration using probabilistic information processing on CAM^2, and showed implementation method of annealing. In this research, we extend this and propose implementation method for the restoration of gray-level images.

2. Gray-level image restoration with probabilistic information processing

We consider channel transmission of q-level gray-scale images. The original image is $\boldsymbol{X} = \{x_{i,j} | 1 \le i \le M, 1 \le j \le N\}$. Each pixel has a pixel value of $0, \cdots, q-1$. This image is affected by noise in the channel, and $x_{i,j}$ becomes $y_{i,j}$.

Annealing is used for maximum likelihood estimation [1], and the following algorithm is applied. For a certain pixel (k,l), a next-state candidate $x_{k,l}$ is randomly generated. Furthermore, the random number α within $[0,1]$ is generated and the following expression is evaluated.

$$\rho(x_{k,l}|\boldsymbol{x}_{\overline{k,l}}, \boldsymbol{y}^*, T, \boldsymbol{J}^*) = \frac{\exp\left(-H_{kl}(x_{k,l}|\boldsymbol{x}_{\overline{k,l}}, \boldsymbol{y}^*, \boldsymbol{J}^*)/T\right)}{\sum_{x_{k,l}=1}^{q} \exp\left(-H_{kl}(x_{k,l}|\boldsymbol{x}_{\overline{k,l}}, \boldsymbol{y}^*, \boldsymbol{J}^*)/T\right)} > \alpha, \tag{1}$$

where T and J^* is annealing temperature and hyperparameter, respectively. When Eq. (1) is valid, the value of the pixel (k,l) changes to $x_{k,l}$. In left-hand side of Eq. (1), $H_{kl}(x_{k,l}|\boldsymbol{x}_{\overline{k,l}}, \boldsymbol{y}^*, \boldsymbol{J}^*)$ is obtained by the following expression.

$$H_{kl}(x_{k,l}|\boldsymbol{x}_{\overline{k,l}}, \boldsymbol{y}^*, \boldsymbol{J}^*) = -\delta(x_{k,l}, y^*_{k,l}) + \sum_{x_{\mathrm{N}} \in \mathbb{N}} \phi_{k,l}(x_{\mathrm{N}}|\boldsymbol{J}^*), \tag{2}$$

where $\phi_{k,l}(x_{\mathrm{N}}|\boldsymbol{J}^*)$ is a function determined by the difference between two pixel values $|x_{k,l} - x_{\mathrm{N}}|$. $\mathbb{N}$ is a set of 4 neighbor cells (up, down, right and left) of $x_{k,l}$.

3. Implementation

CAM^2 is a SIMD processor based on associative memory. It has an architecture suitable for processing two-dimensional cellular structures.

Here, we only describe the implementation of Eq. (1). The calculation of Eq. (1) is complicated on CAM^2. Therefore, it is calculated by an external processor and sent to CAM^2. Corresponding to $x_{k,l}$ and the four pixel values of the neighboring cells, the external processor sends the values of $\rho(x_{k,l}|\boldsymbol{x}_{\overline{k,l}}, \boldsymbol{y}^*, T, \boldsymbol{J}^*)$. Since it is necessary to send a value for q^6 states, this method becomes impractical when q becomes large.

4. Experiment

The standard image 'Lenna' is chosen as a test image. The image is quantized with 4 levels ($q = 4$). The annealing process is implemented on a CAM^2 emulator. The CAM^2 emulator emulates cell-level behavior of CAM^2, and it also outputs an executable instruction set on CAM^2 hardware. We estimated processing time with a generated instruction set. The estimated processing time is 272 seconds with a clock cycle of 100 MHz. In case of $q = 4$, one state update requires 4096 (q^6) communications between CAM^2 and the external processor. Depending on the application, this result indicates a practical processing time.

5. Conclusion

In order to verify the potential of CAM^2 as an annealing machine, we examined an image restoration method for gray-level images. The experimental result shows that the processing time is 272 seconds for a 4-level grayscale image. In our method, the computational cost increases by q^6, so the method is not practical when q is large. Improvement by revising the probabilistic model is a future issue.

References

[1] K. Tanaka and T. Horiguchi, "Probabilistic, iterated and quantum-iterated computational methods in gray-level image restoration," *Interdisciplinary Information Sciences*, vol. 8, 01 2002.

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