Neural Networks

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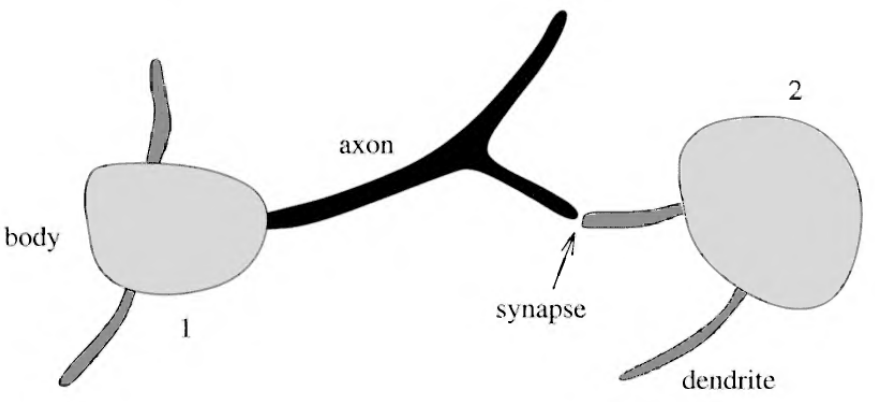
Background

An Ising model will be used to simulate how neurons interact to store memories

Neurons will influence each other by being in a “firing” or “not firing state”



Assumptions

1. Neurons are modeled as an on/off device, firing or not firing.

2. The firing rate has no importance

3. The interactions matrix and therefore the interactions between neurons are symmetric

Objectives

1. To develop a simulation for neurons in the brain

2. To determine how, if at all, the code can be optimized to produce better results

3. To analyze the ability of the simulation to store and recall images

Code Overview

1. Written in C++ for better performance

2. An Ising Model was used to simulate the interaction of neurons

3. A Monte Carlo algorithm was used to determine when a spin should be flipped.

    A. The temperature was set to 0, meaning the nearest stable configuration would be found.

    B. Temperatures greater than 0 were used for annealing the system to determine the lowest energy configuration.

4. Bitmap images were used to input and output configurations.

Code Alterations

1. Iterative J Matrix Calculations

   After beginning to implement the code, it became apparent that the iterative method, in the best case, would settle on the calculation we already implemented.

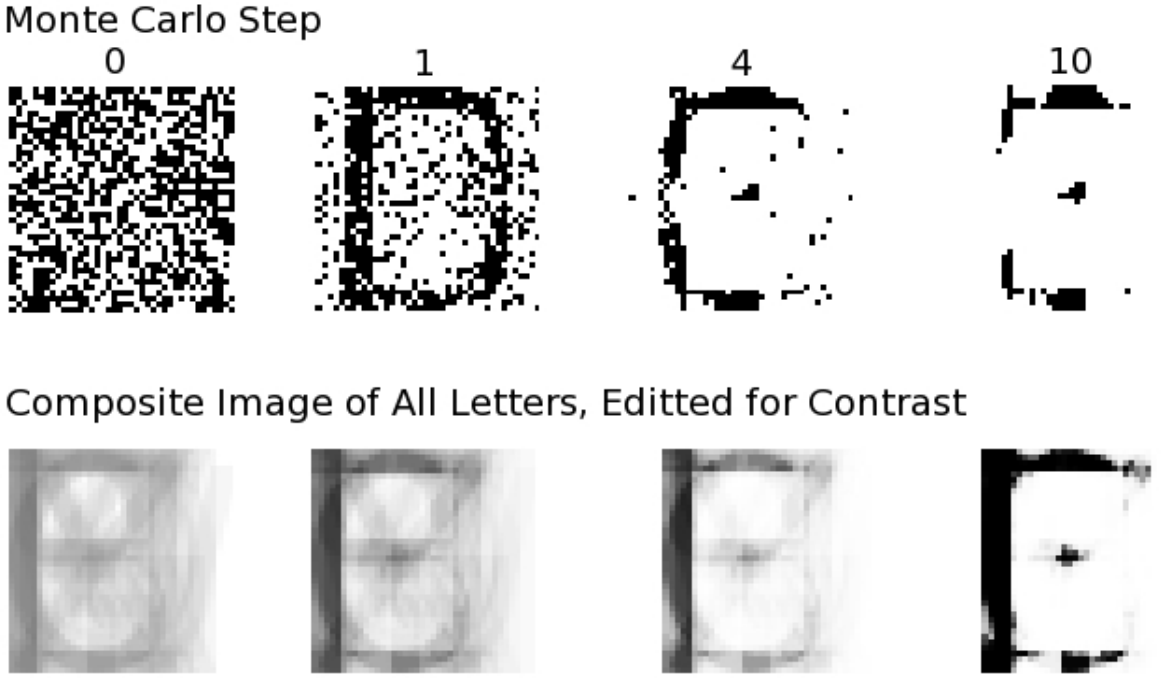
2. Continuous Spin Spectrum

   Having a continuous spin spectrum allowed for less rapid changes between configurations, but ultimately appeared to settle on the same final configuration.

   It was concluded that our time would be better invested in analyzing the discrete spin model.

Spin Glass

Spin Glass – The point at which enough configurations have been stored, that no single, unique configuration is identifiable.



An extreme case of *spin glass*, once all letters of the alphabet have been stored in the J Matrix. The spin glass configuration is representative of a weighted sum of all letters.

Letter Identification

Results

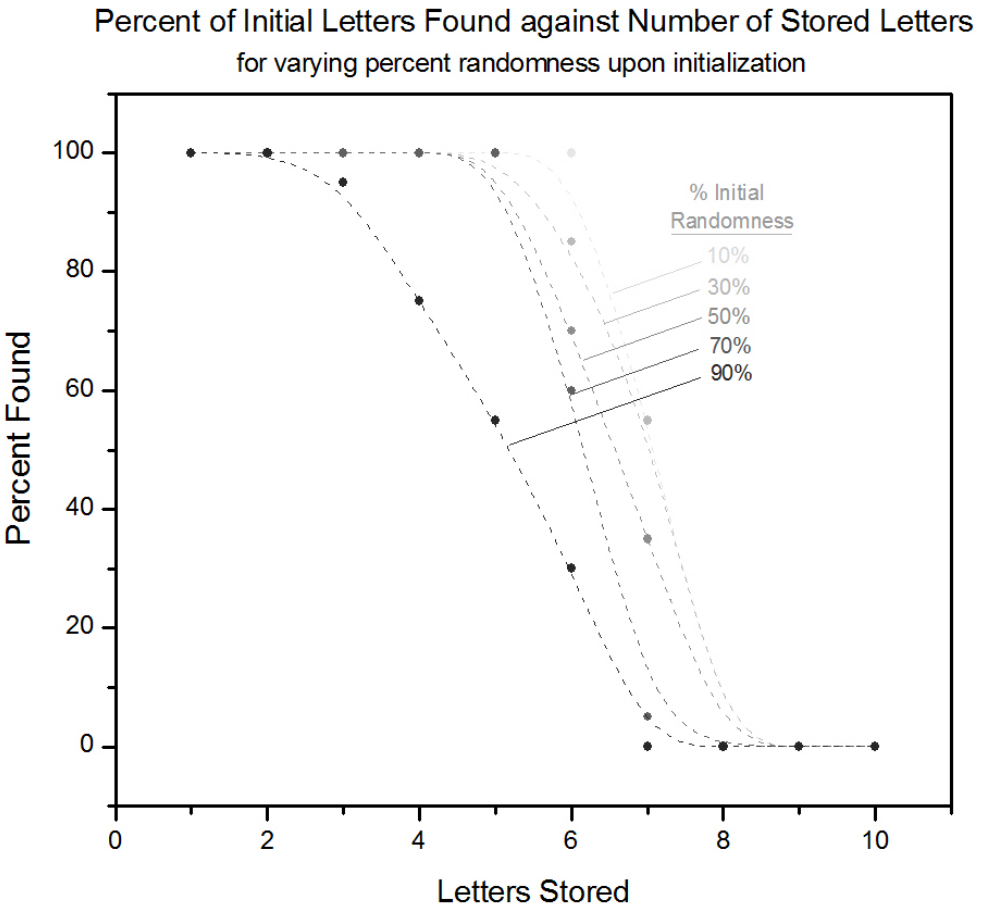
- The chances of finding the desired configuration are affected by:

  1. The percent of spin damage (percent of randomization in the initial configuration)

  2. The total number of stored letters

- At low initial randomization, the chances of identifying the initial configuration are limited by *spin glass*

- At high initial randomization (> 80%), the chances of identifying the initial configuration are limited by the stability of the configuration's energy minimum.



Initial Randomness and Brain Damage

Results

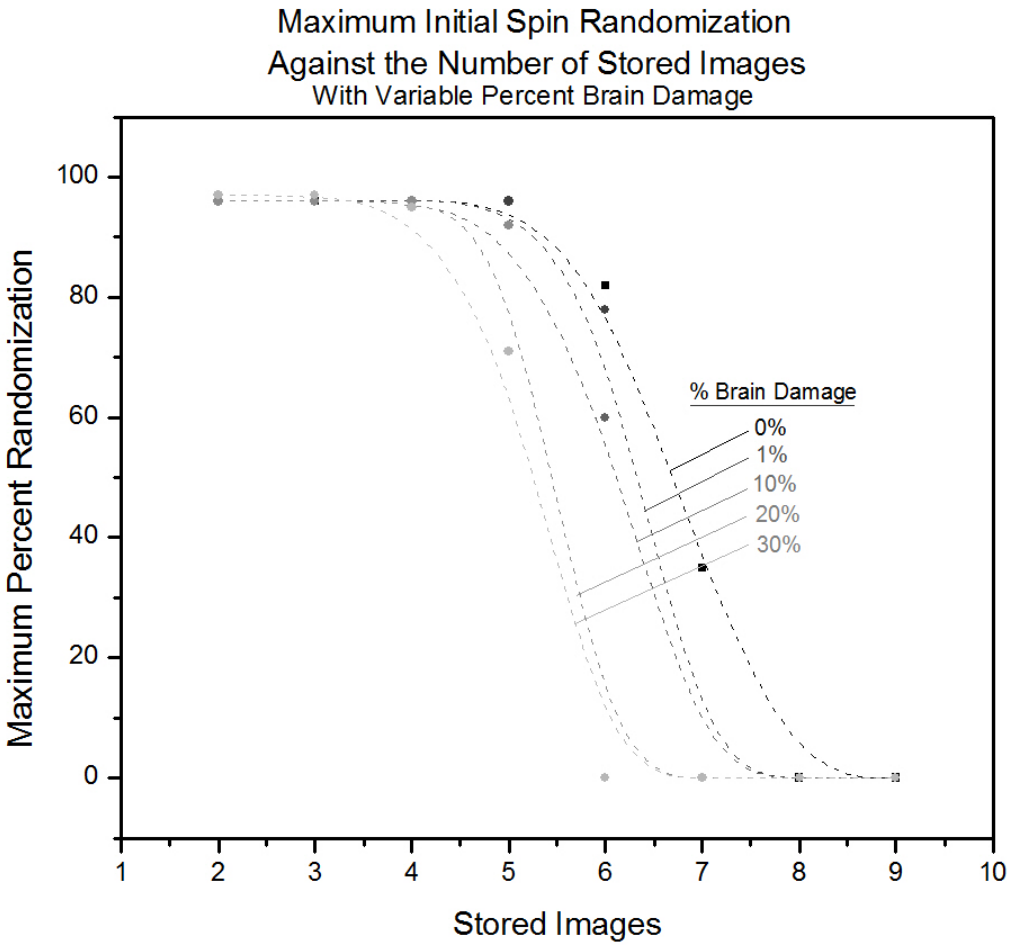
- Maximum Initial Randomization Limited By

  1. The percent of brain damage (percent of J Matrix set to 0)

  2. The total number of stored letters

- Small percents of damage in the J Matrix are responsible for notable decreases in the maximum number of stored images.

- An approximate linear trend between the maximum number of stored images and the percent damage to the J Matrix



Initial Randomness and Image Size

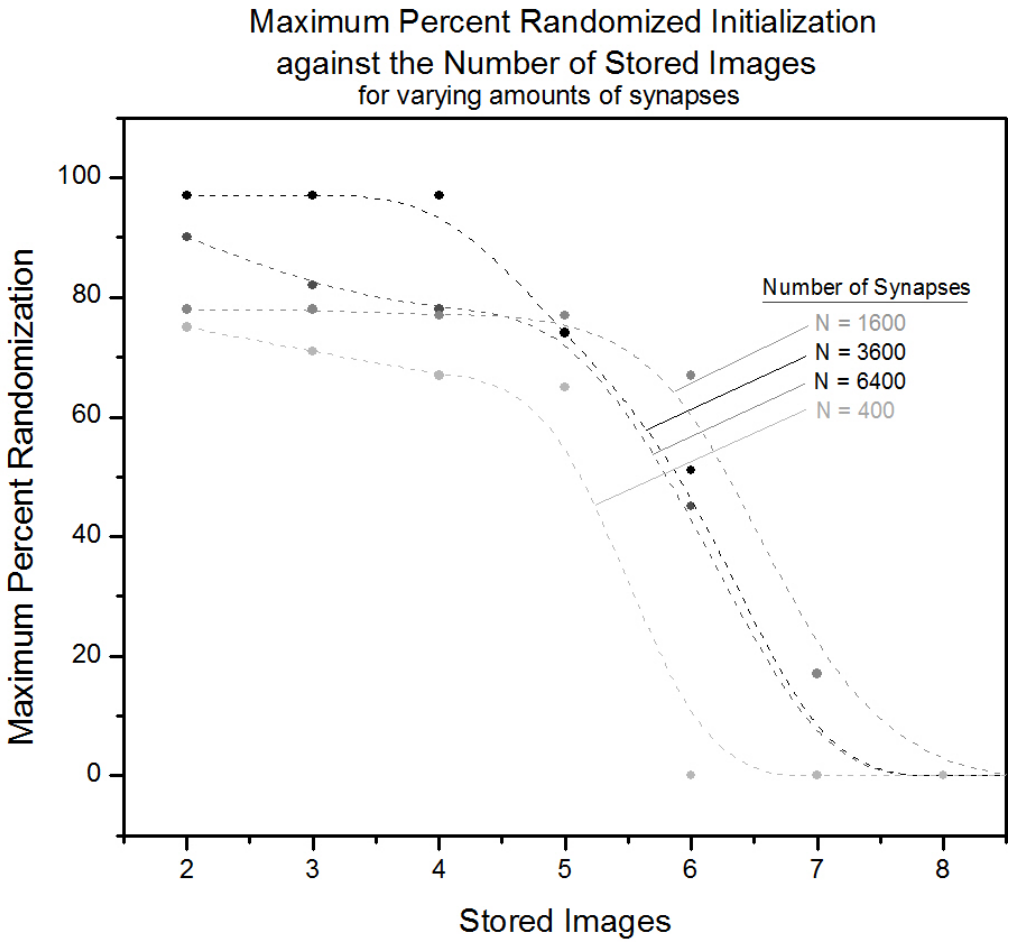
Results

- Inconclusive dependence on the number of synapses
- Orthogonality between images has a drastic effect on the maximum number of stored images

  This means that any change in letter positioning could be the source for error in measurements.

Proposed Solutions

- Scale large images down to respective image size instead of producing new images from scratch at each size.

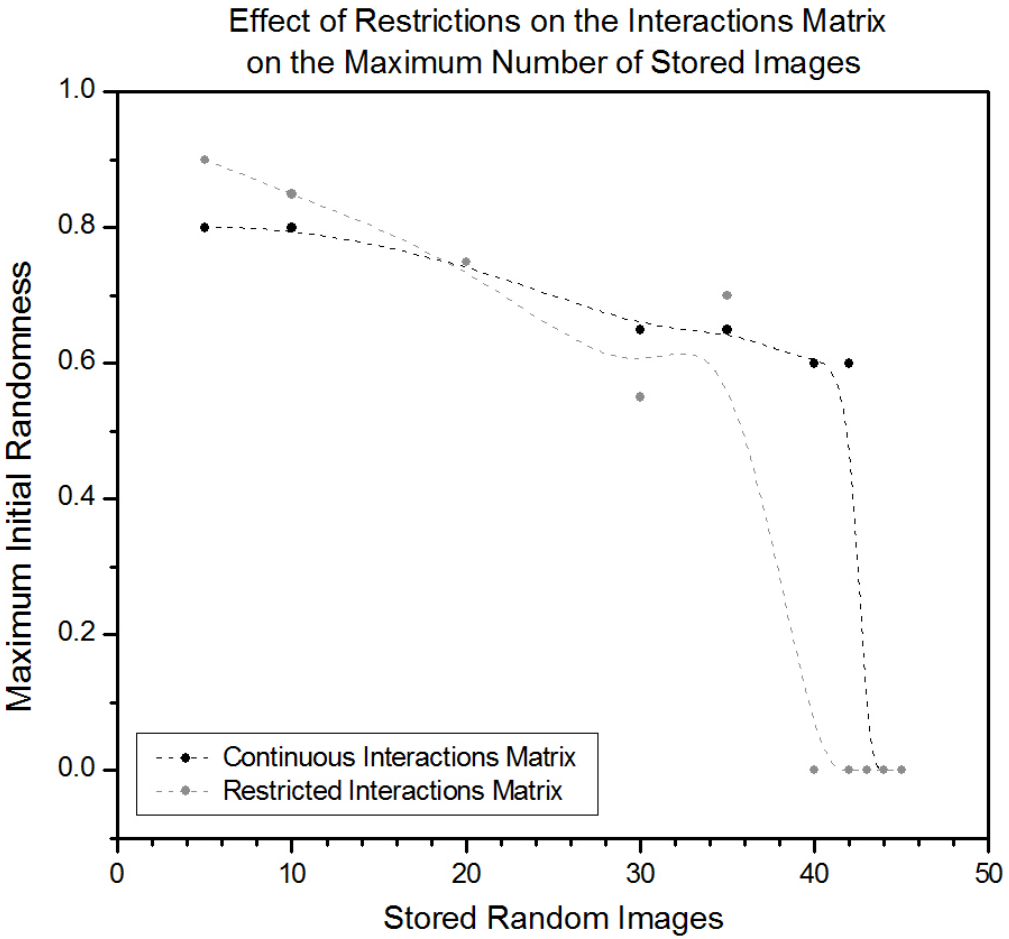


Initial Spin Damage using Orthogonal Images

Results

- Many times more orthogonal images are able to be stored than non-orthogonal images (letters)
- In some cases, the simulation appears to benefit from having a J Matrix restricted to only +1 or -1.

  This trend is likely within the uncertainty of the simulation and is dependent on the random number seed.



Spin Glass Analysis using Orthogonal Images

Results

- Using pseudo-orthogonal images (images with each spin equally likely to be up or down), the theoretical limit of maximum stored images was approached

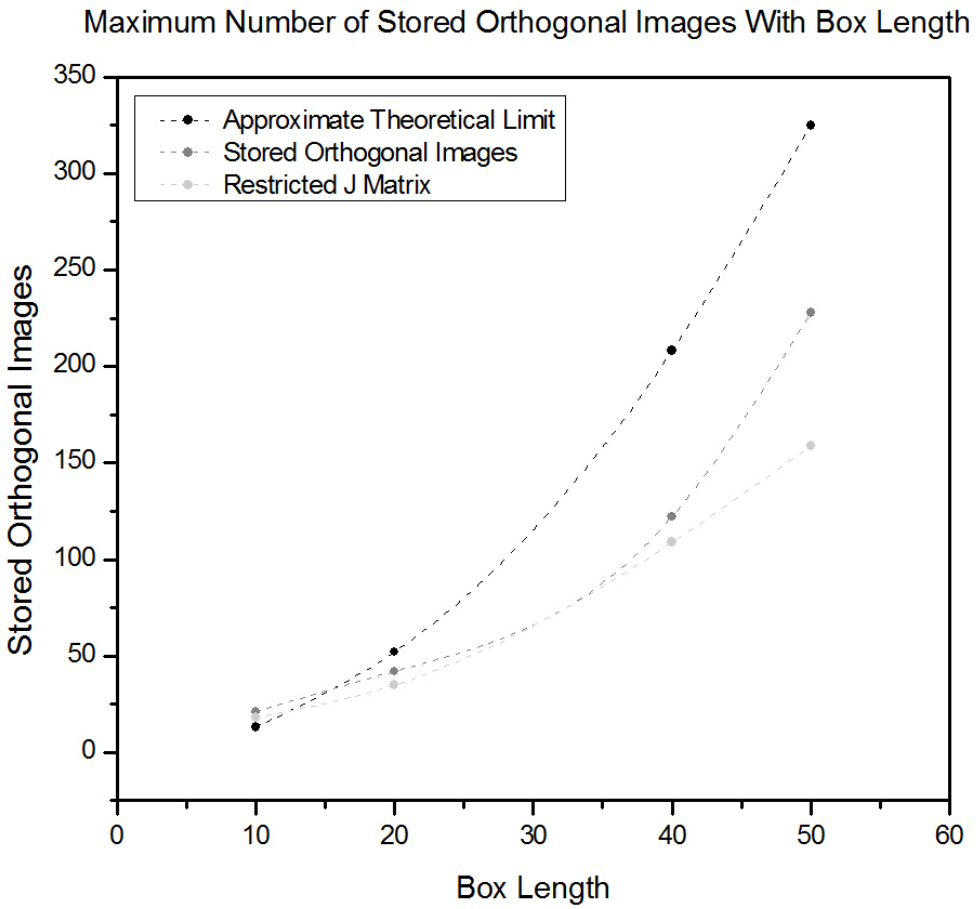
$$\sum_i S_i(m)\, S_j(n) \sim 0$$

- The maximum number of orthogonal images increases with box length according to the equation for the theoretical limit

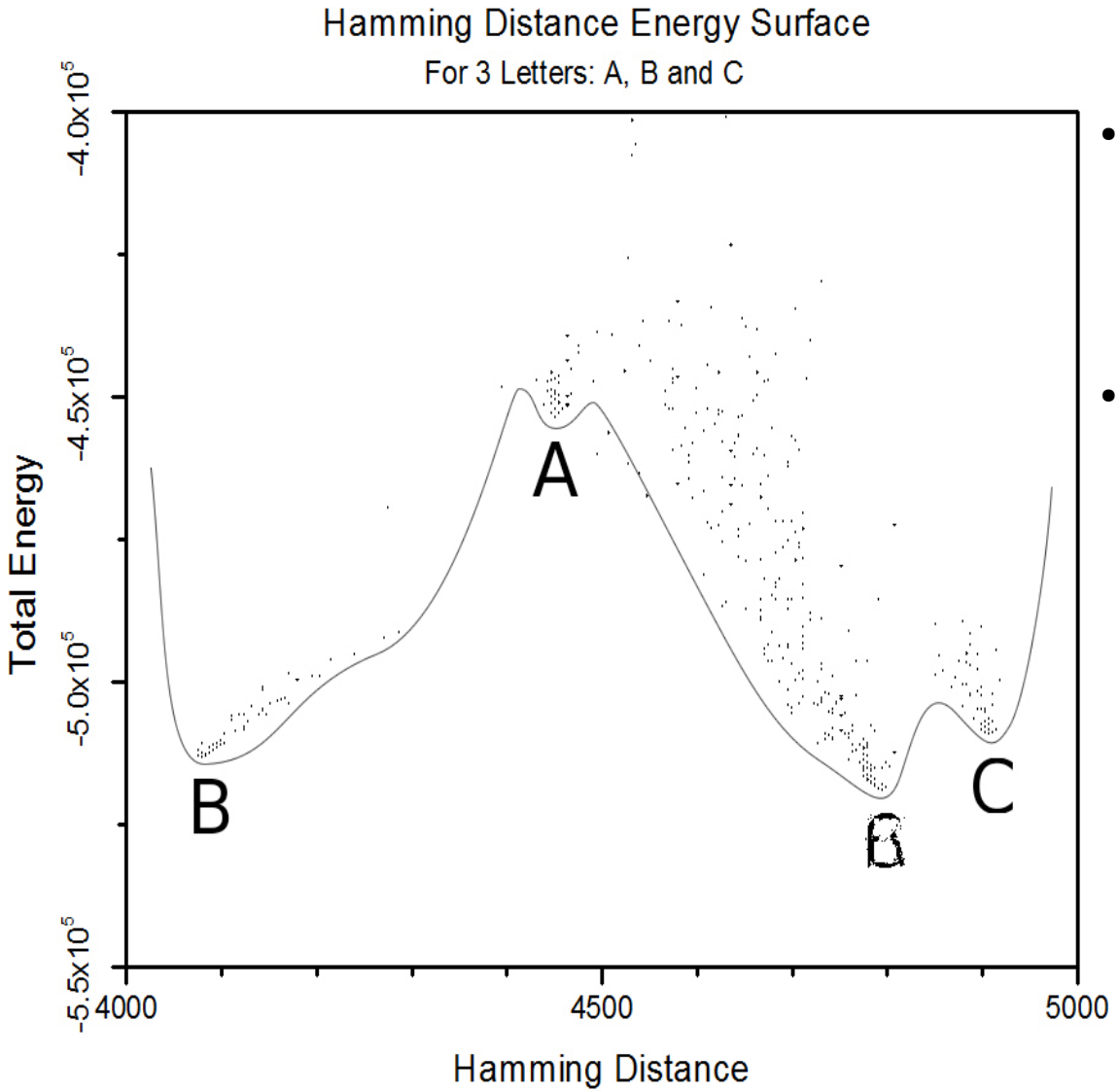
$$N = 0.13\, L^2$$

- The maximum number of stored orthogonal images vastly exceeds the maximum number of stored letters

- With a restricted J Matrix, the maximum number of stored images is reduced



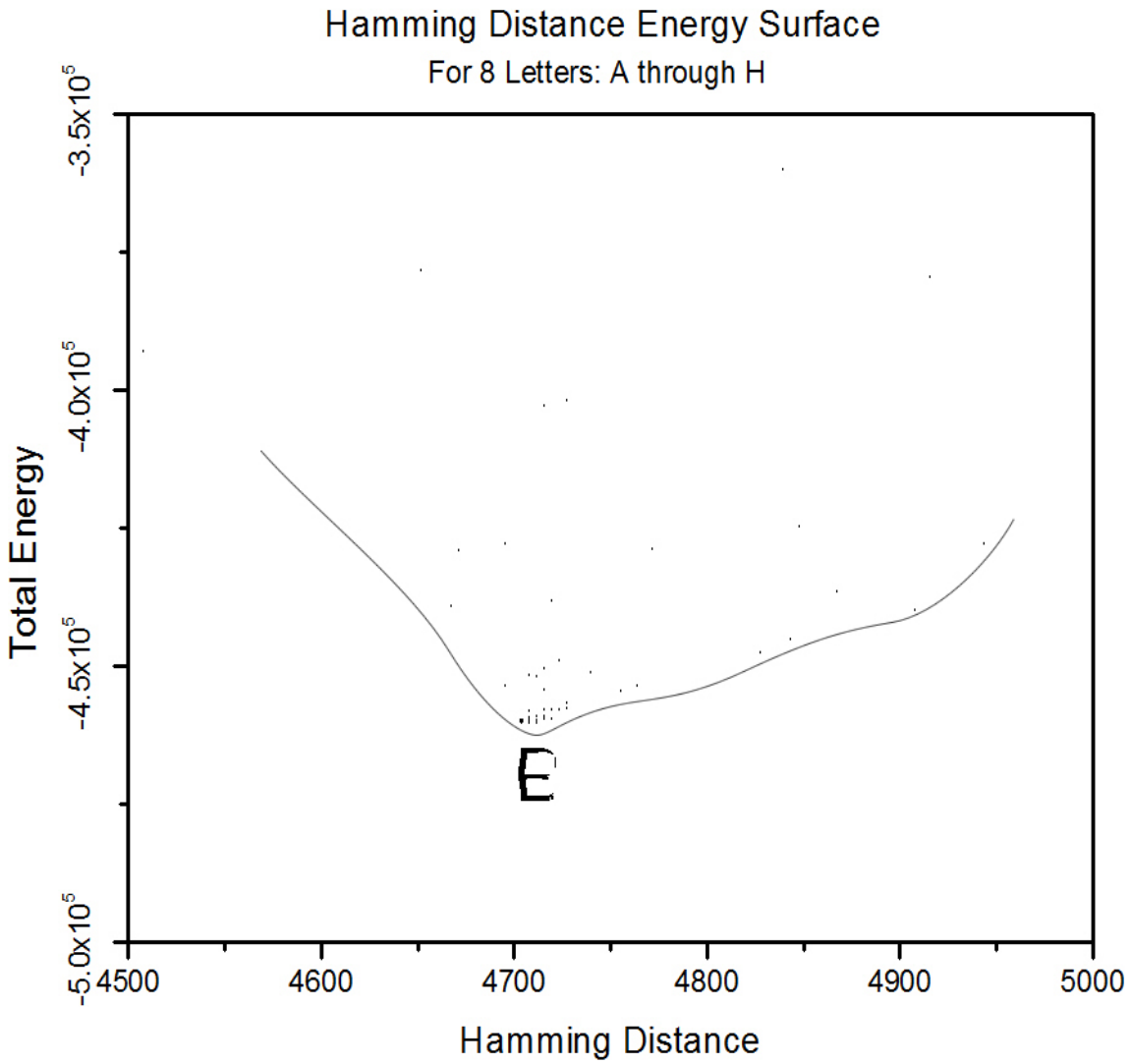
Hamming Plots



- The Hamming Distance is a measure of the total number of opposite spins between two images, and is not unique to a given configuration.
- In this plot, the configuration A rests in a local minimum

  This means that, if the system is initialized around A, it is likely it will identify the A

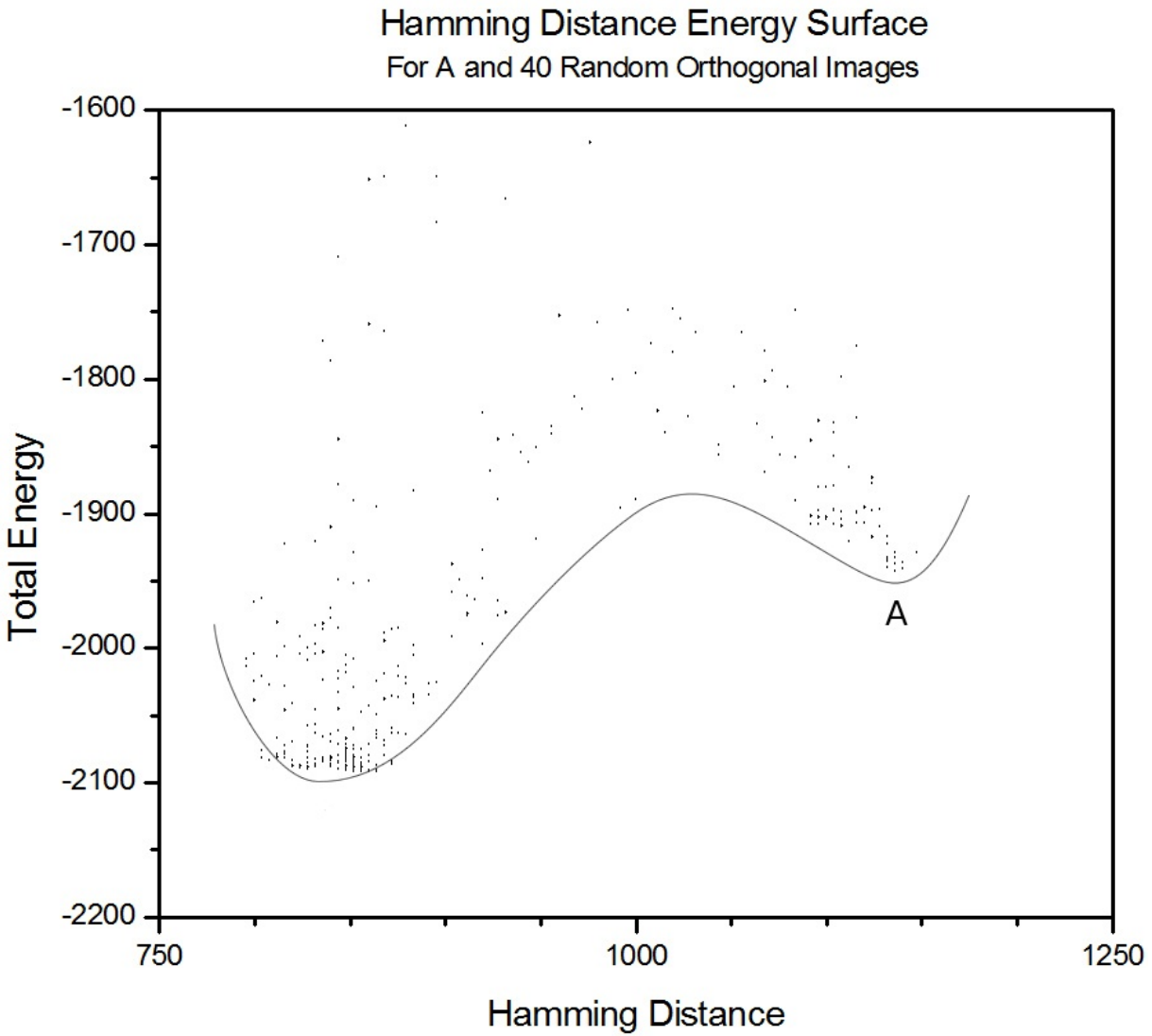
Hamming Plots



- In this plot, the configuration A energy minimum is unidentifiable

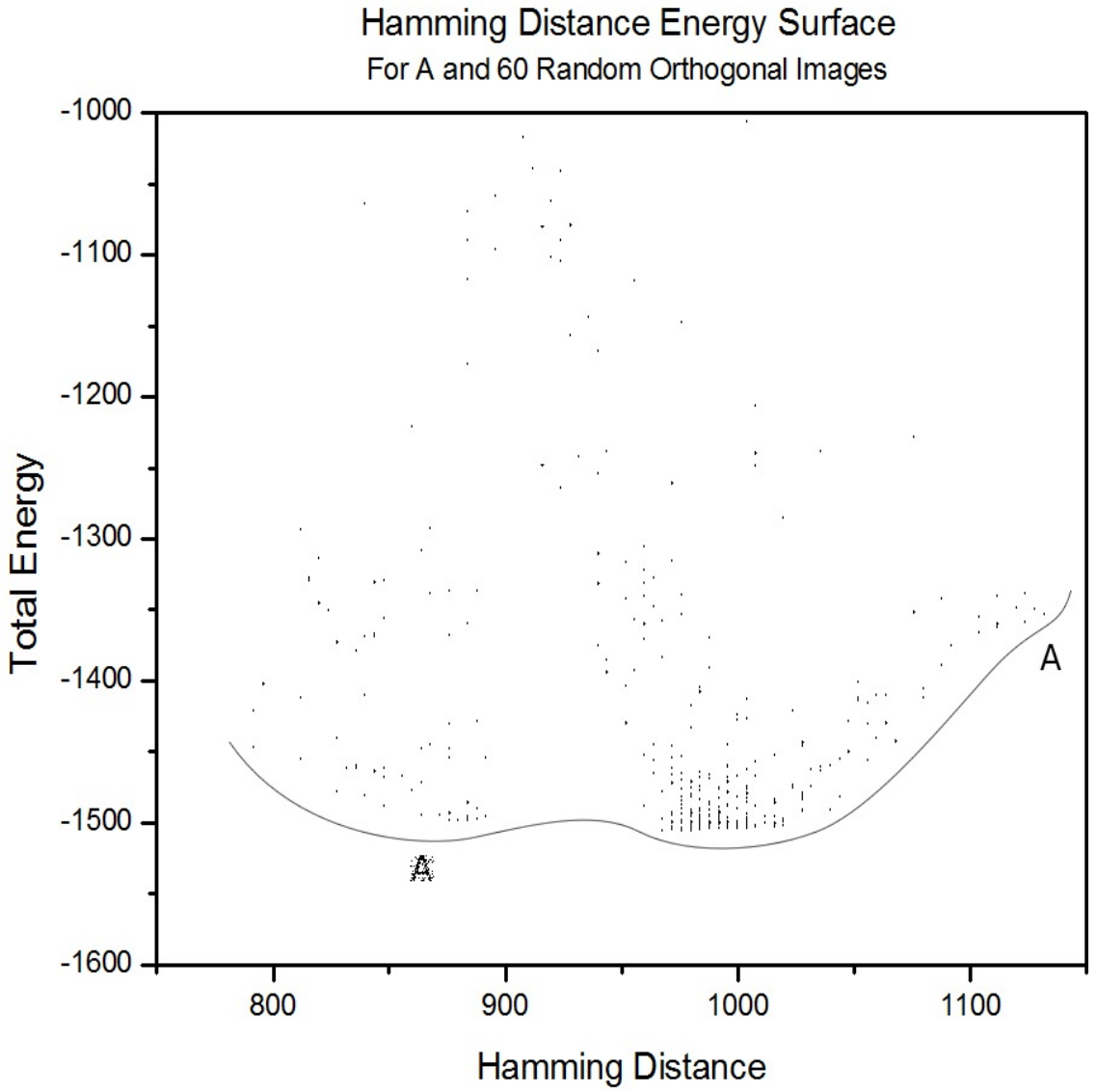
  This means that, if the system is initialized an any point, it will always reach the *spin glass* energy minimum

Hamming Plots



- In this plot, the configuration A is at a local energy minimum
- The collection of orthogonal images have produced an absolute energy minimum below configuration A's energy.

Hamming Plots



- In this plot, the configuration A is unstable, and the system will always find one of the two lower energy configurations.
- In this case, a *spin glass* configuration is at an energy higher than the hybrid orthogonal image mixture.

  Starting from A, the system always found the *spin glass* configuration, even though the hybrid orthogonal image appears to have a lower energy.

  This implies that there is a large energy barrier between the *spin glass* configuration and the hybrid orthogonal image configuration.

Conclusions

1. The simulation was able to successfully learn and store spin configurations
2. The simulation was optimized by using orthogonal images.
3. Alterations to the J Matrix had only an inconclusive positive impact on the storage of images

Possible Future Alterations

1. The Maximum Entropy Method for shape recognition
2. Further alterations to how the J Matrix is computed

Works Cited

(1.) Giordano, Nicholas J. "11.3 Neural Networks and the Brain." Computional Physics. Upper Saddle River, NJ: Prentice-Hall, 1997. 328-45. Print.

(2.) *Maximum Entropy Image Reconstruction* - General Algorithm. Authors: Skilling, J.; Bryan, R. K.. Publication: R.A.S. MONTHLY NOTICES V.211, NO.1, P. 111, 1984