# Neural networks are good at classifying different types of magnetic materials

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## Classifying Quantum States of Matter with Machine Learning

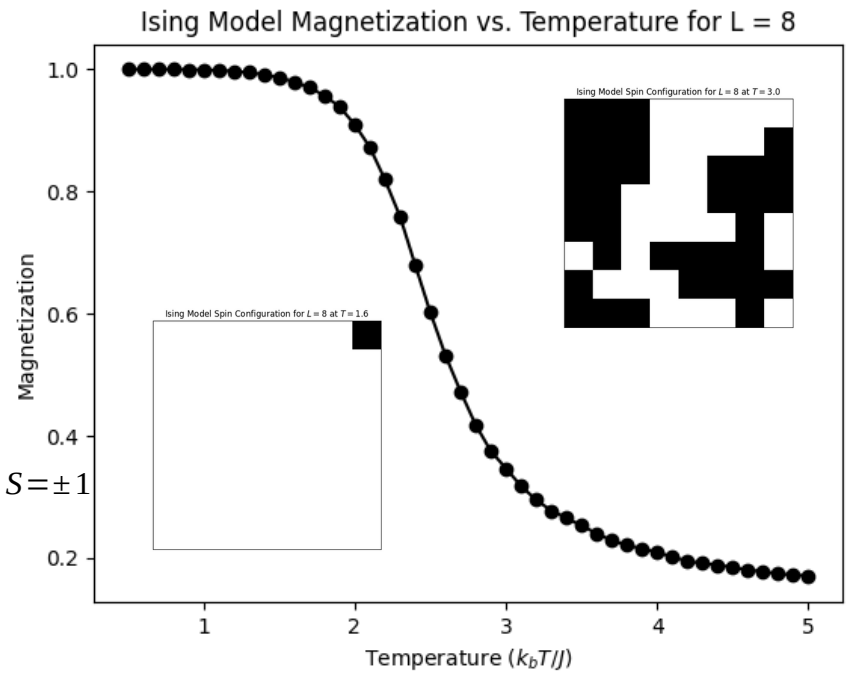
## Introduction

Magnetic phase is an important characteristic by which matter can be classified. As with the differences between solids, liquids and gases, there also exist different magnetic phases which depend on the spin orientation of individual particles within the material. When the spin of most of the particles within a material are aligned, it is said to be in the ferromagnetic phase. When there is no clear pattern to the spin configuration, the material is said to be paramagnetic.

The Ising model provides a simple model for a magnetic material in which particles can be either spin up or spin down. The total energy of our system using the Ising model is given by the following equation,

$$E = -J \sum_{i,j} S_i S_j$$

Where S = ±1 is the spin configuration of a particle and J is a constant with units of energy relating the strength of the interaction between neighboring particles.

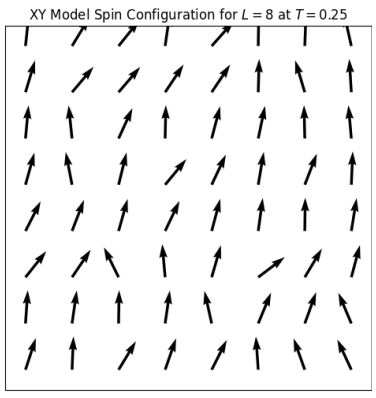


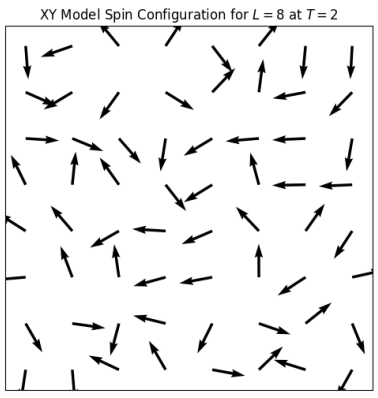

$$M = \frac{1}{N} \sum_i S_i$$

The magnetization of a material is simply the average of all of the spin values across the total number of particles N.

## XY Model

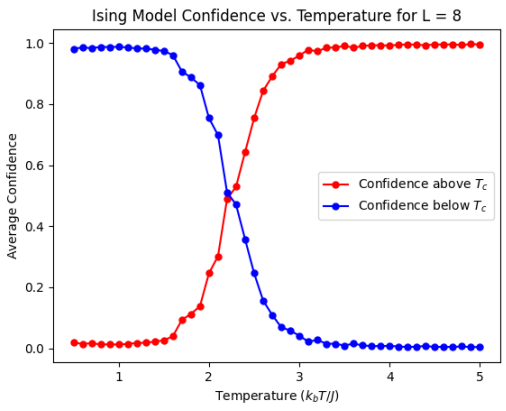
The XY model provides a more complex representation of a magnetic material in which spins can be oriented anywhere in a 2D plane. As with the Ising model, there is a well-defined $T_c$ at which the magnetic phase transitions from paramagnetic to ferromagnetic.

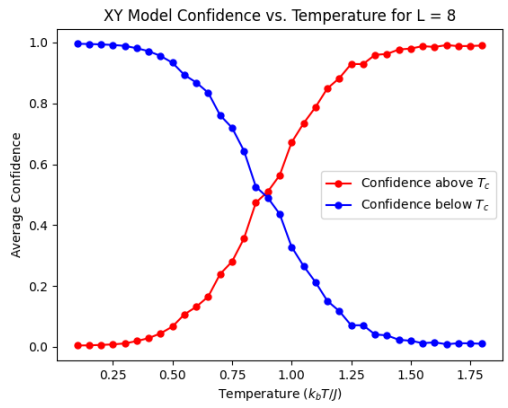



## Neural Network

A TensorFlow neural network can be used to classify different lattice spin configurations as either above or below the critical temperature, thus indicating whether a material is paramagnetic or ferromagnetic.

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