ND*nano* Undergraduate Research Fellowship (NURF)
2015 Project Summary

1. Student name: Emily Song

2. Faculty mentor name: Prof. Gyorgy Csaba and Prof. Wolfgang Porod

3. Project title: Non-Boolean Computing Using Nanodevices

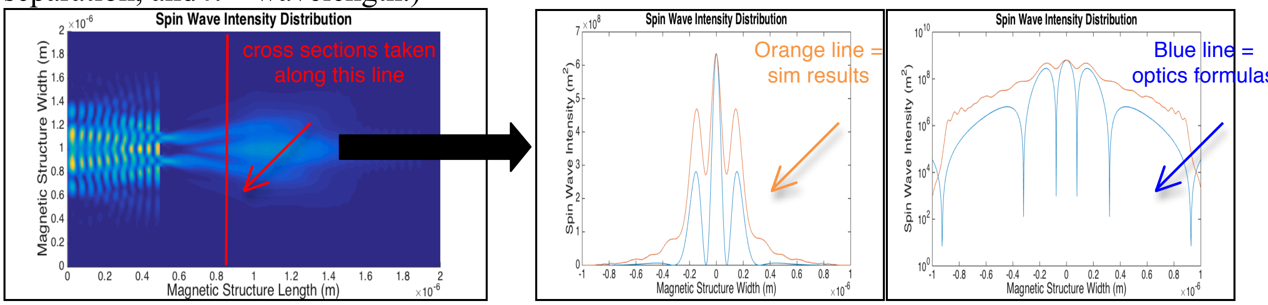
4. Briefly describe any new skills you acquired during your summer research:
I gained a strong understanding of micromagnetics over the summer. In particular, I became familiar with OOMMF (Object Oriented Micromagnetic Framework), a simulation software used to analyze spin wave interference in different micromagnetic structures. Furthermore, I learned how to use GIMP to create and export complex designs; I developed greater proficiency in MATLAB by writing code that generated figures and processed data; and in order to run large simulations, I interacted with the CRC, sending batch files to the central computing cluster and ultimately gaining a strong command of the Unix operating system. Finally, I gained valuable experience with various means of communicating experimental results, such as writing research abstracts and creating research posters.

5. Briefly share a practical application/end use of your research:
Non-Boolean, spin-wave devices inspired by optical computing algorithms are promising because they could potentially replicate the function of optical computers. These devices could possibly perform Fourier transforms, take the form of Fresnel lenses, perform matrix operations, carry out image processing, be used for shape recognition, and so on.

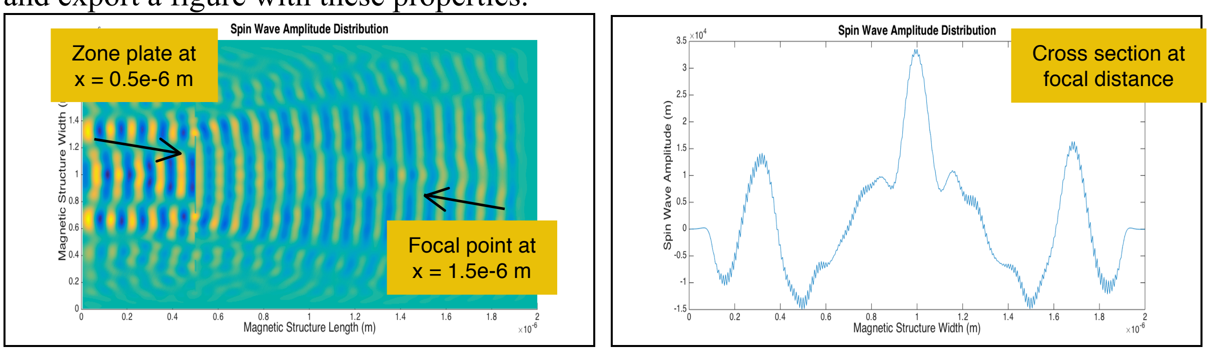
Project summary (problem/goal and activities/results):
CMOS-based digital devices are notably inefficient for many analog processing tasks, such as image recognition. In the past, optical computing was used to perform highly complicated analog signal processing tasks using wave interference. It is now believed that by using spin waves, it is possible to replicate the function of optical computers, but with much more practical hardware. This research aims to further explore this idea.

Much of this research is carried out with a micromagnetic simulation software called OOMMF (Object Oriented Micromagnetic Framework). OOMMF is a popular and powerful software that simulates magnetism by solving the equations of micromagnetics. Setting up and carrying out a simulation in OOMMF requires the following: (1) Designing the structure (usually with GIMP), (2) Launching the software using command prompts, (3) Opening the solver and the display windows, (4) Loading the file specifying the simulation parameters, (5) Running the simulation and saving the results, (6) Processing the data (usually with MATLAB).

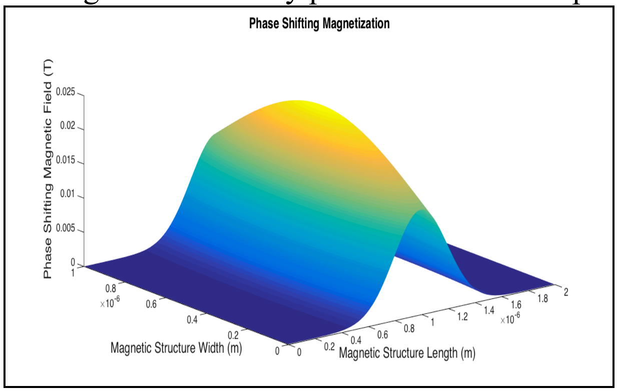
Using this method, it was found that for double slit structures, the spin wave interference pattern could be similar to the interference pattern predicted by textbook optics formulas. In a 2.0e-6 m x 2.0e-6 m structure with slits 100e-9 m wide and 200e-9 m apart, the intensity distribution 350e-9 m from the slits was comparable to the intensity distribution given by the equation: $I(\theta) = I_m(\cos^2 \beta)(\sin \alpha/\alpha)^2$ (where $\alpha = (\pi a/\lambda)\sin\theta$, $\beta = (\pi d/\lambda)\sin\theta$, I_m = max intensity, a = slit width, d = slit separation, and λ = wavelength.)

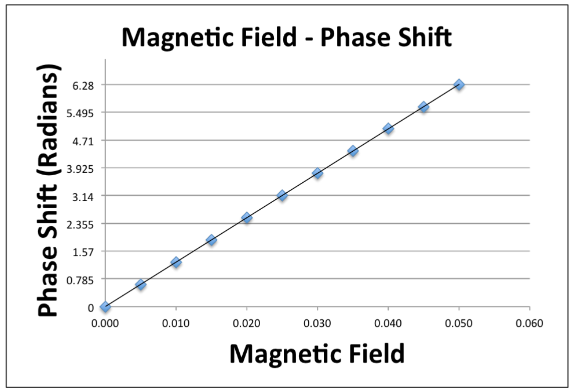


It was found that for zone plate structures, using textbook optics formulas to design the figure could ultimately produce the desired spin wave interference pattern. The following formula was used: $y = \sin(\omega t+(2\pi/\lambda)(f^2+r^2)^{1/2})$ (where ω = angular frequency, λ = wavelength, f = focal distance, r = radius, and t = time). Spin waves produce constructive interference if y > 0 and destructive interference if y < 0, so in order to produce the greatest intensity possible at the focal point, the desired figure must have slits wherever the spin waves meet in phase (y > 0) and barriers wherever the spin waves meet out of phase (y < 0). MATLAB code was used to create and export a figure with these properties.



It was also discovered that a time constant but spatially varying magnetic field near the center of the structure could produce phase shifts in the spin waves. This knowledge can be used to phase shift the spin waves in such a manner that they all meet at the focal point in phase. The relationship between the strength of the applied magnetic field and the resulting phase shift is essentially linear. Using this relationship and some MATLAB code, the file containing the magnetization parameters can be altered so that the magnetic field at each point corresponds to the magnetic field necessary for phase shifting the spin wave so that all the spin waves contribute to the greatest intensity possible at the focal point.





These aforementioned simulations all use OOMMF as a means of designing and testing simple micromagnetic structures. These preliminary results show considerable potential and lend hope for creating more complex spin wave devices.

Publications (papers/posters/presentations):
Poster at the Summer Undergraduate Research Symposium
"Non-Boolean Computing Using Spin-Wave Devices"