ND*nano* Undergraduate Research Fellowship (NURF)
2012 Project Summary

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Faculty mentors' names: György Csaba and Wolfgang Porod

Project title: Design of Nanomagnet Logic Devices

Briefly describe any new skills you acquired during your summer research:
Firstly, I learned to read and write scientific papers. Through the reading of these papers, and with lots of help from Dr. Csaba, I also learned lots about nanomagnetic logic and how a research team works to find the application that will bring their technology to industry. I also learned to use Matlab, which will certainly prove very useful.

Please briefly share a practical application/end use of your research:
During my stay, I designed 4 nanomagnetic circuits and wrote a simulation tool in Matlab for Co/Pt nanomagnets. If anyone in Notre Dame pursues this line of research, my simulation tool may help in the design of new circuits. I designed a circuit for wire crossing and three nanomagnetic implementations of cellular automata rules. These circuits will mainly serve as a starting point for future work in this field.

Summary of work:
Nanomagnetic logic (NML) is currently one of the front runners in the race to succeed CMOS in micro-electronic circuits. Thanks to the non-volatility provided by the magnetic representation of states**,** the low power dissipation due to lack of current flow**,** the relatively high clock speeds and the nanoscale sizes, NML has plenty of ingredients for success. The shortcomings of NML are that wire crossings are not yet possible, and that it is not fast enough to act as a direct swap for CMOS. The main challenge that remains is to find an application of nanomagnetic logic that will propel it onto the global radar. The objective of my research was to investigate whether NML could be used to create cellular automata (CA) cells – the high parallelism of these circuits along with the ultra-low power characteristics of nanomagnetic logic means that there is the potential to design very attractive and highly efficient systems.

During the first few weeks, I learned about nanomagnetic logic, and then about cellular automata, and finally wrote a simulation tool that would allow me to test the circuits that I would ultimately design. The first circuit that I designed is based on elementary CA rule 30, which can serve as a random number generator and therefore has applications in cryptography. The circuit and the results that it produces are shown in figure 1. The second useful circuit that was explored has applications in the noise reduction of binary images. Once again, the circuit and the results achieved from the NML circuit are illustrated in figure 2. Although neither of these circuits is going to be the next generation CPU, they will serve as a foundation for further research into NML based CA, which will hopefully lead us towards finding the "killer" application that the team is seeking.

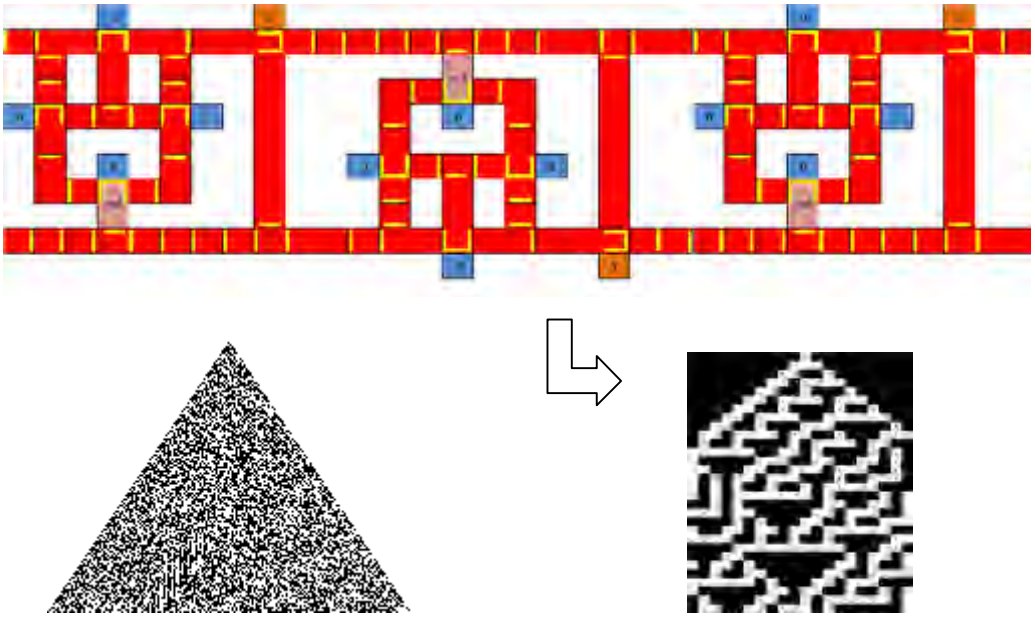

Figure 1. Top: 3 cells of the nanomagnetic circuit that performs the logic for Rule 30. **Left:** the theoretical pattern produced by Rule 30. **Right:** the pattern produced by simulating the circuit expanded to 20 cells and extracting the values from the "out" magnets at every time step (matches theoretical pattern, proving that the system works).

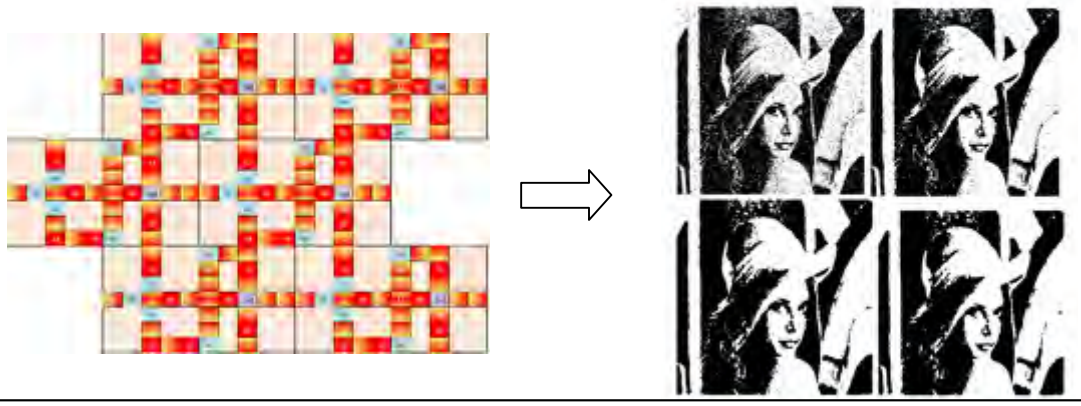

Figure 2. Left: 6 cells of the NML circuit that performs the noise reduction illustrated in the **right hand** image. The top left girl is the original noisy image, and its pixels serve as the input to the CA system. The top right, is the output after 4 time steps, bottom left is the out after 8 time steps, and finally, bottom right, 12 time steps – by this time the noise has been fully removed.

Publications:

- Poster: attached.
- Paper: contact Dr. Csaba for the paper based on my research. I wrote the first draft before leaving, but he is going to polish it up for potential submission.