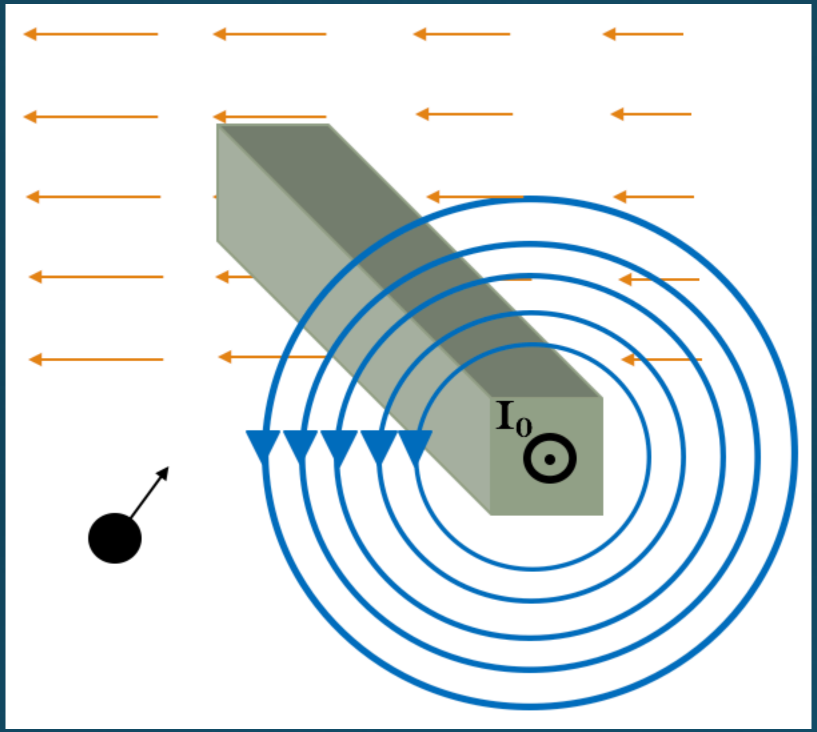
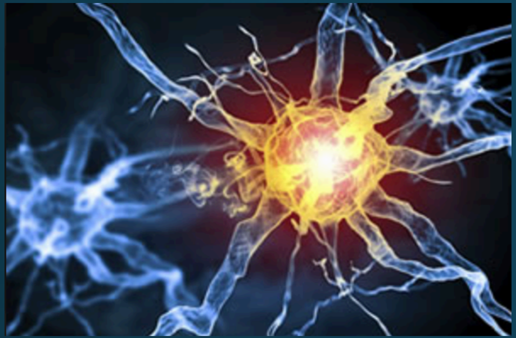


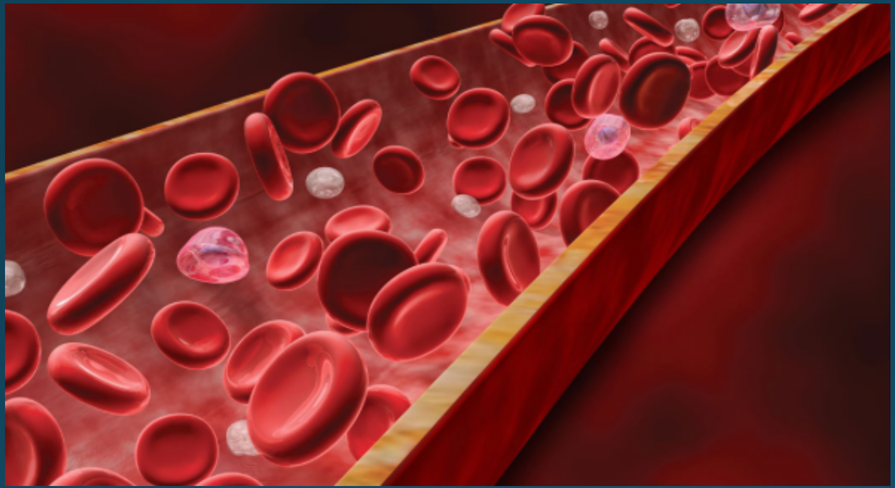
Localized Manipulation of Multiple Magnetic Robots

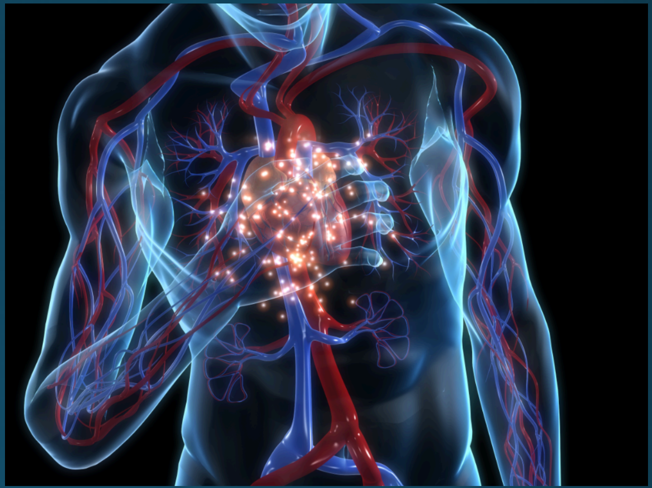
Simran Arora, 2016

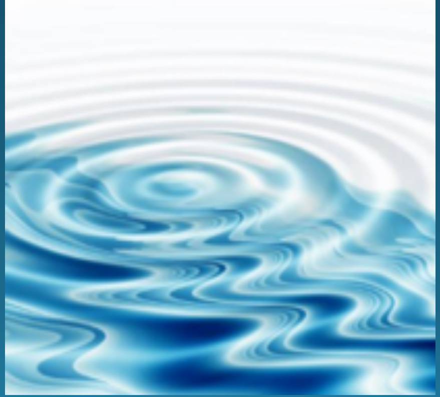
Advised by: Denise Wong, Ed Steager, Vijay Kumar

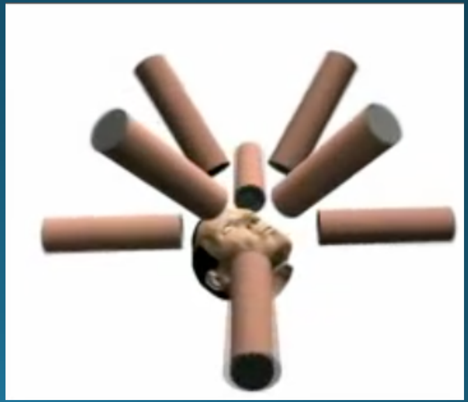
Motivations for Magnetic Micro-robots







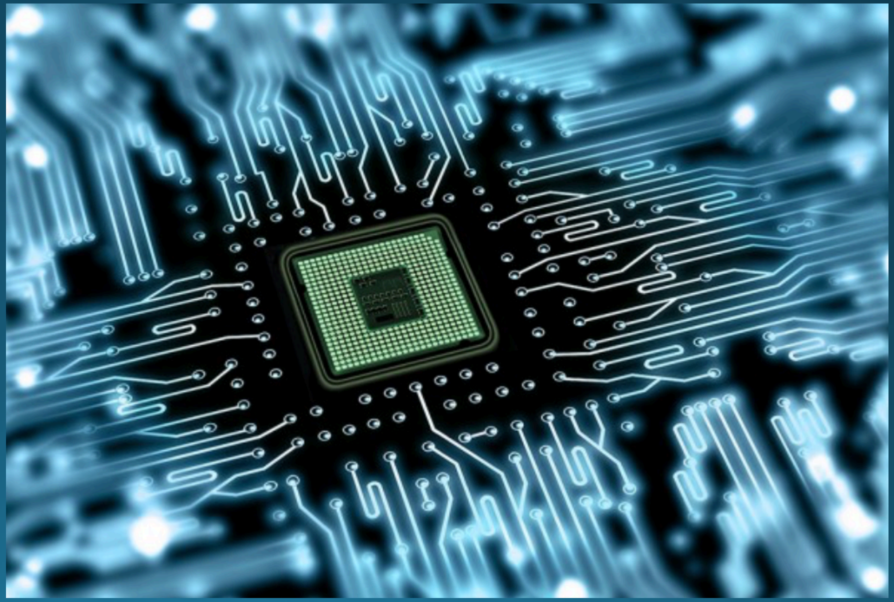




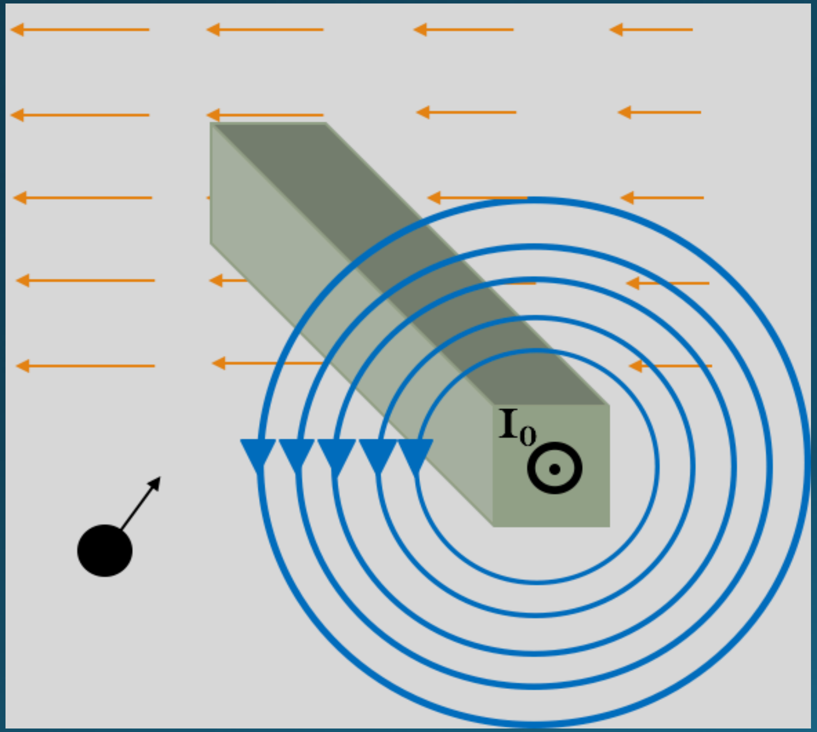
Existing Efforts

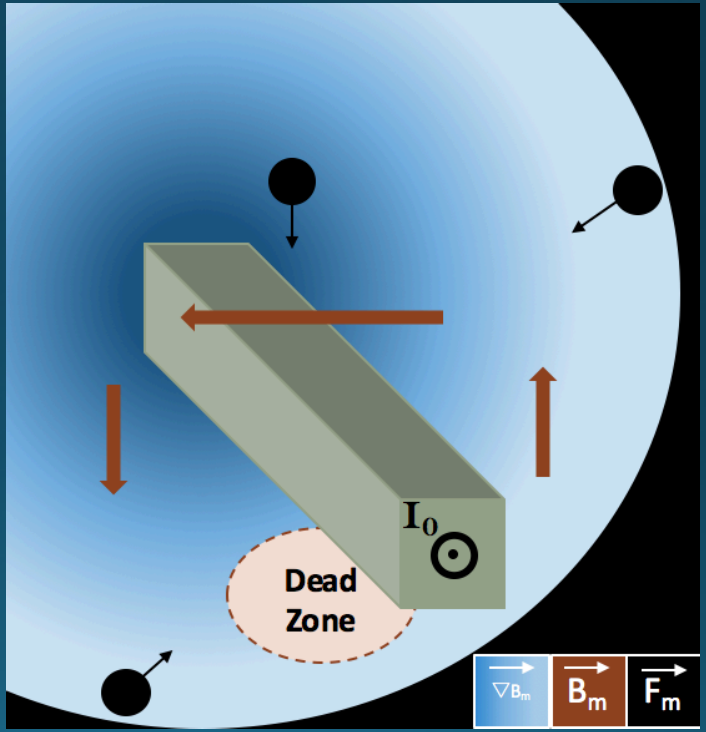
- Global Magnetic fields (electromagnets, permanent magnets)
  - One robot
- Local Magnetic fields (microscale wires)
  - Printed Circuit Boards

Goal: We want to manipulate multiple magnets in all workspaces and characterize how these localized processes function in the presence of global magnetic fields.



Local *and* Global Fields

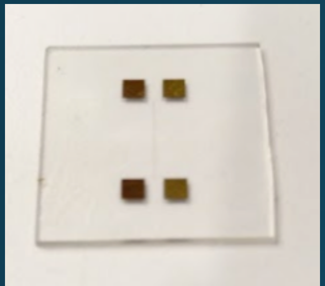


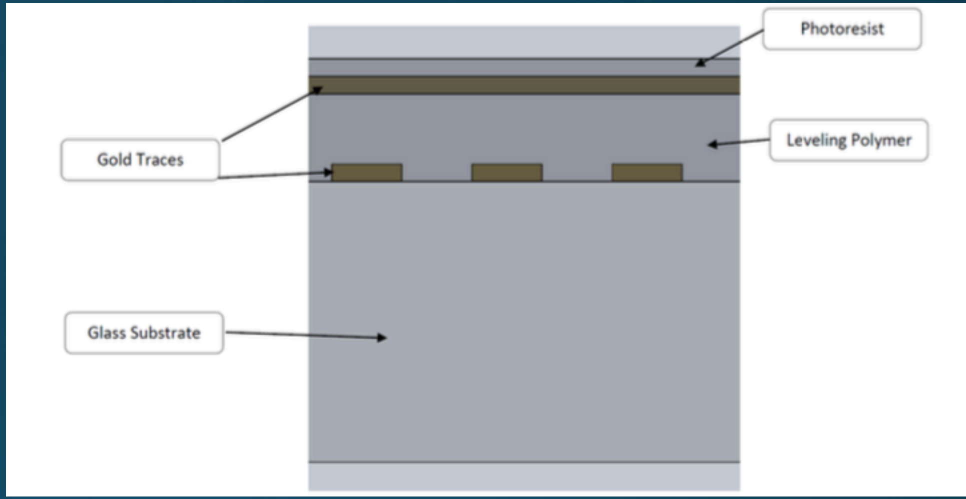


10 µm

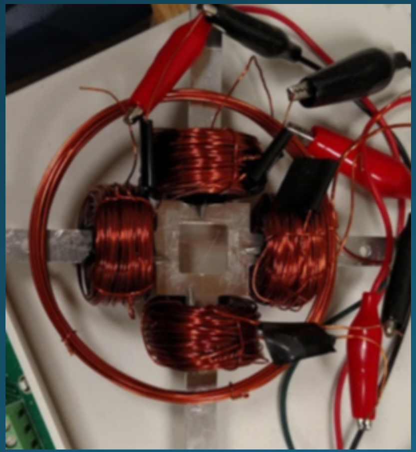
Microfabrication, Experimentation, and Simulation

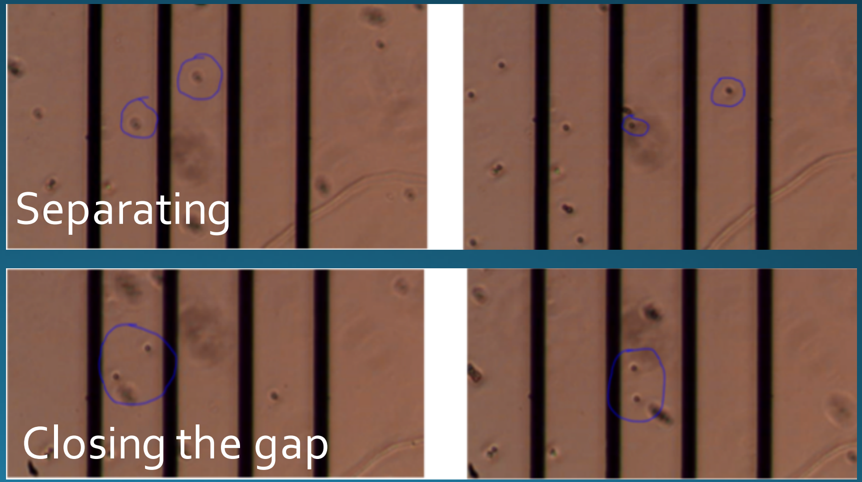
- Microfabrication





- Experimentation



Theory

- Low Reynolds number

$$0 = F_m + F_s$$

$$F_s = -6\pi\eta R v$$

- Magnetic Fields and Gradients

$$B = \frac{\mu_0 I}{2\pi r}$$

Above: Trace
Right: Electromagnet

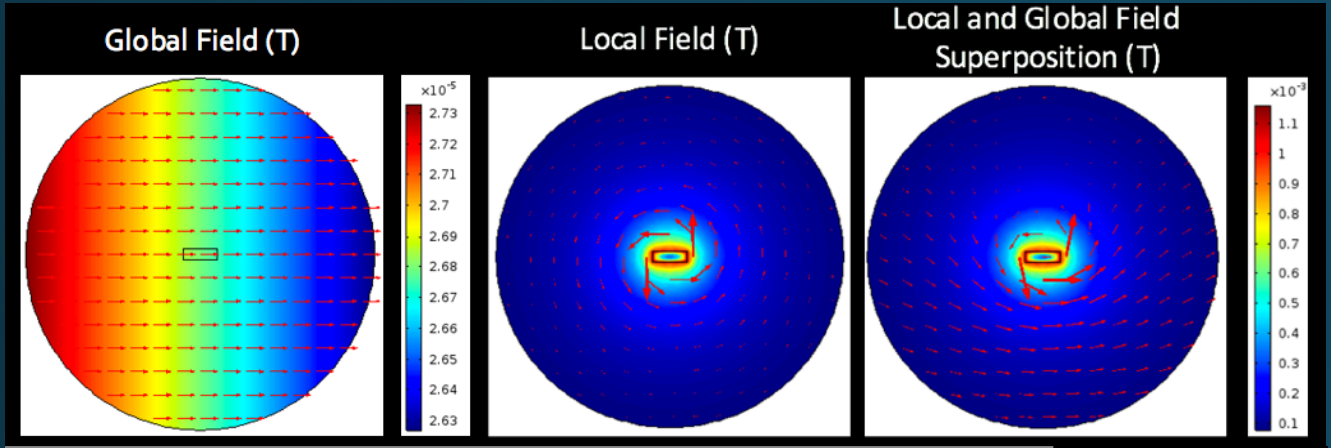
$$B = \frac{\mu_0 I n R^2}{2\pi(x^2 + R^2)^{\frac{3}{2}}}$$

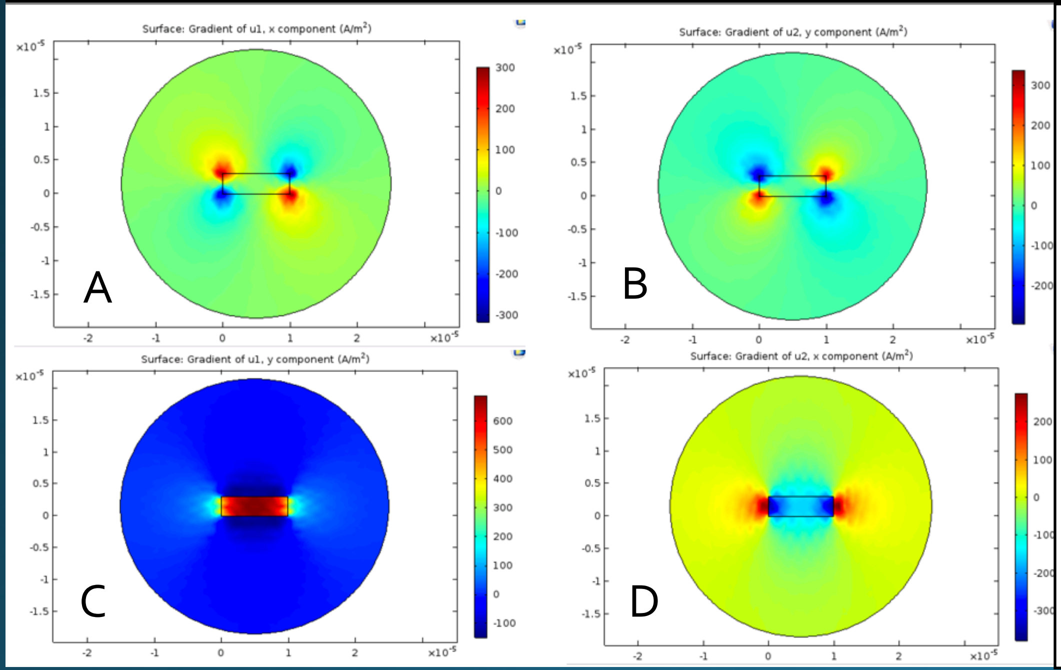
$$\frac{\partial B_x}{\partial x} = \frac{\mu_0 I n R^2 (2x)(\frac{-3}{2})}{2\pi(x^2 + R^2)^{\frac{5}{2}}}$$

- Force Magnetic

$$F_m = -pV \begin{pmatrix} M_{0x}\frac{\partial B_x}{\partial x} + M_{0y}\frac{\partial B_x}{\partial y} + M_{0z}\frac{\partial B_x}{\partial z} \\ M_{0x}\frac{\partial B_y}{\partial x} + M_{0y}\frac{\partial B_y}{\partial y} + M_{0z}\frac{\partial B_y}{\partial z} \\ M_{0x}\frac{\partial B_z}{\partial x} + M_{0y}\frac{\partial B_z}{\partial y} + M_{0z}\frac{\partial B_z}{\partial z} \end{pmatrix} - \frac{V\chi_{bead}}{\mu_0} \begin{pmatrix} B_x\frac{\partial B_x}{\partial x} + B_y\frac{\partial B_x}{\partial y} + B_z\frac{\partial B_x}{\partial z} \\ B_x\frac{\partial B_y}{\partial x} + B_y\frac{\partial B_y}{\partial y} + B_z\frac{\partial B_y}{\partial z} \\ B_x\frac{\partial B_z}{\partial x} + B_y\frac{\partial B_z}{\partial y} + B_z\frac{\partial B_z}{\partial z} \end{pmatrix}$$

COMSOL Physics – Theoretical Simulation



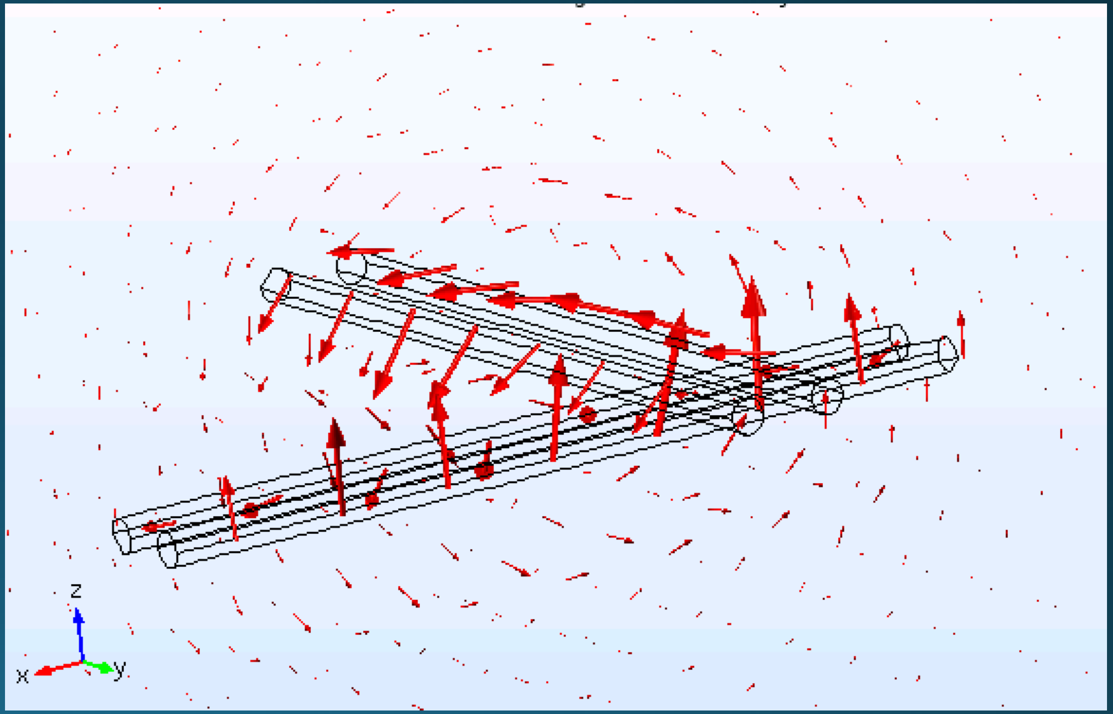


A: dBx/dx

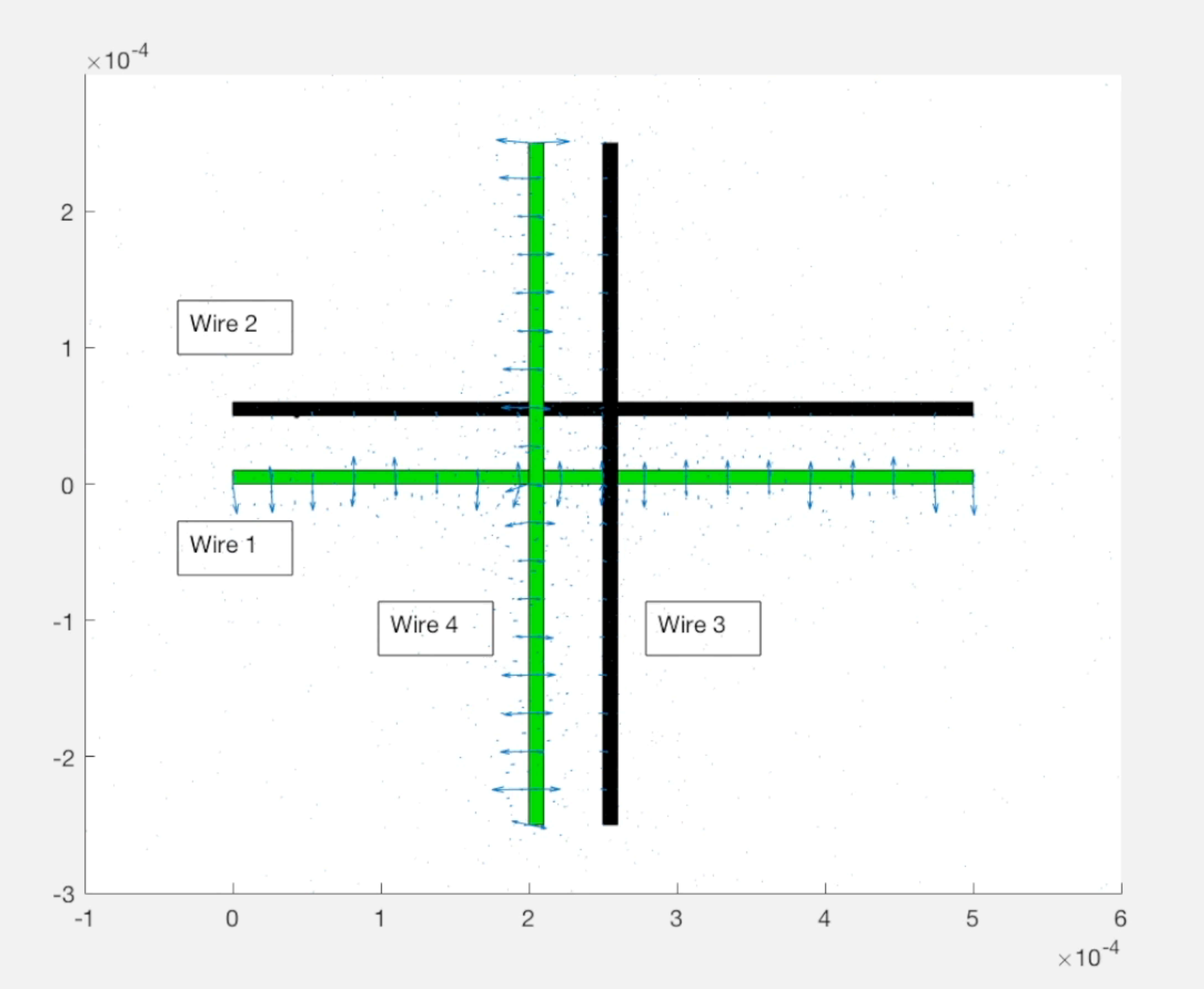
B: dBy/dy

C: dBx/dy

D: dBy/dy



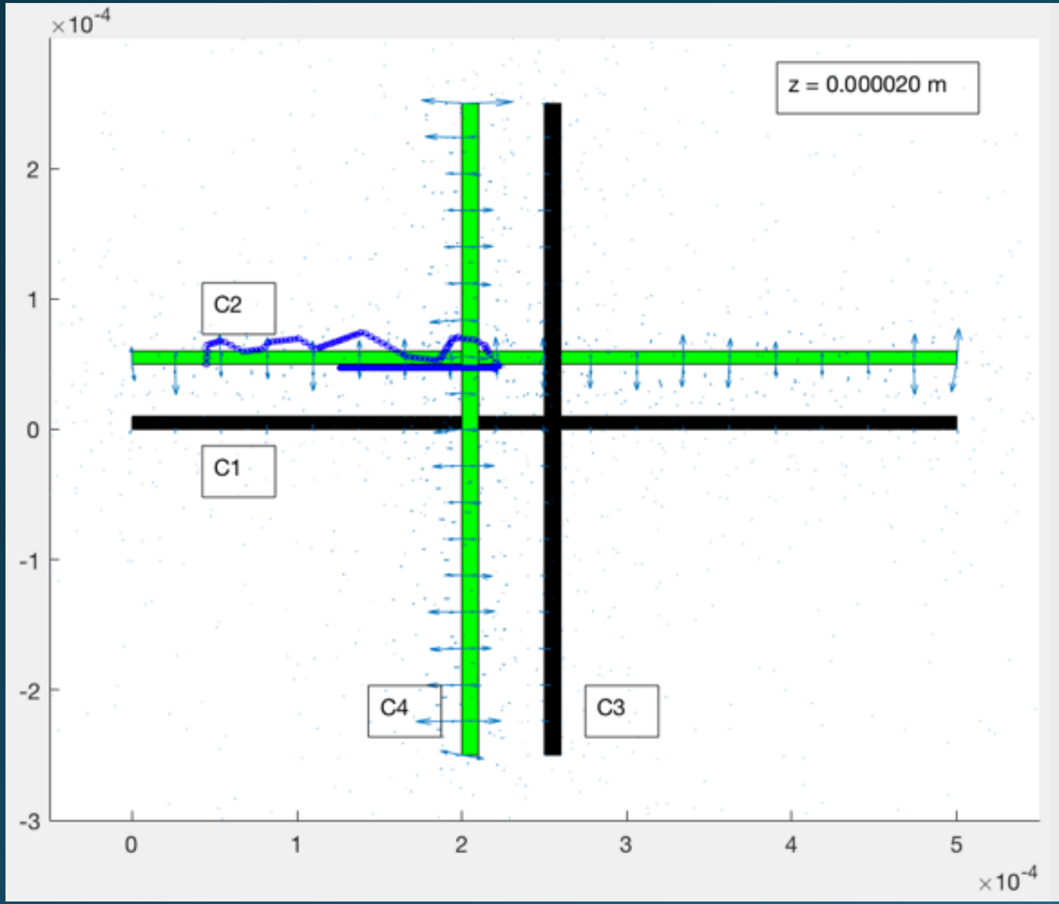
Assemble Magnets – Theoretical Simulation



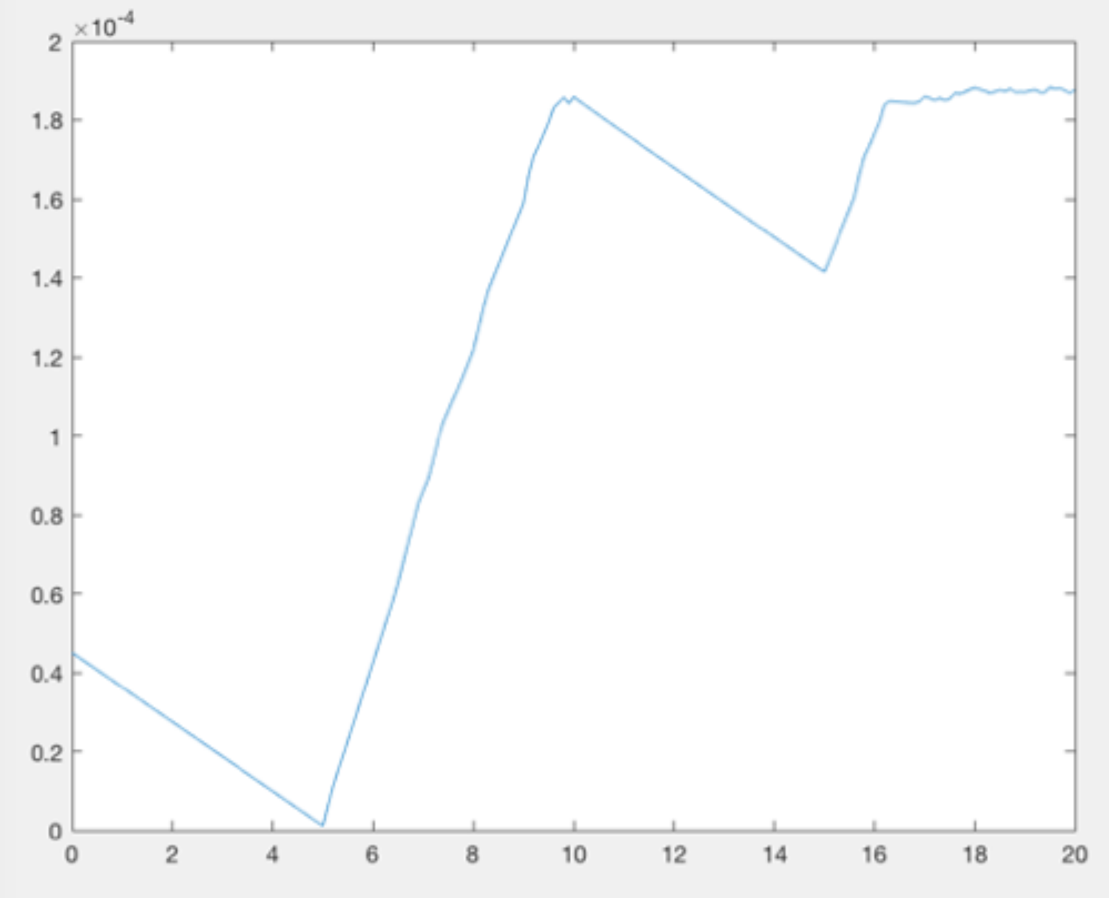
Time (s)	Wire 1	Wire 2	Wire 3	Wire 4
0	0	0	0	0
0	0	0	0	0
5	1	0	0	1
10	0	0	0	0
15	1	0	0	1

Magnets travel at z = 20μm above the plane in a photoresist layer

Assemble Magnets – Theoretical Simulation



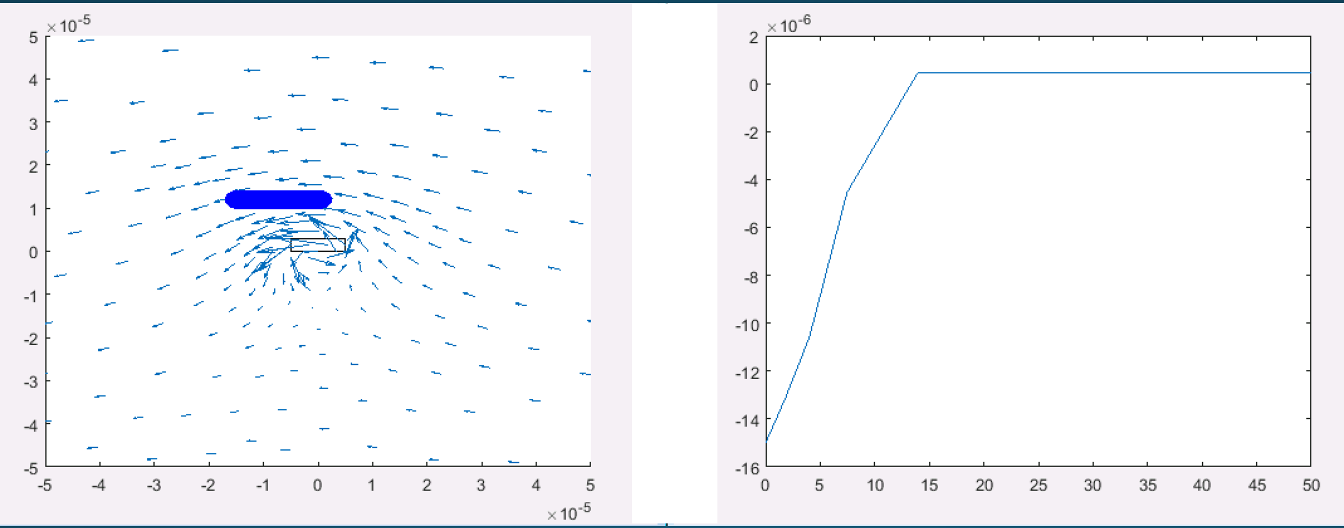
Trajectory of one Magnet



X position (m) versus t (s)

MATLAB – Theoretical Simulation

- Characterize stopping location as a function of time and start location



- Efficiently scale for larger number of wires and magnets
  - Took 5+ minutes to run program at one point
- Visualize gradients at magnet location, applied forces, and other metrics through output plots

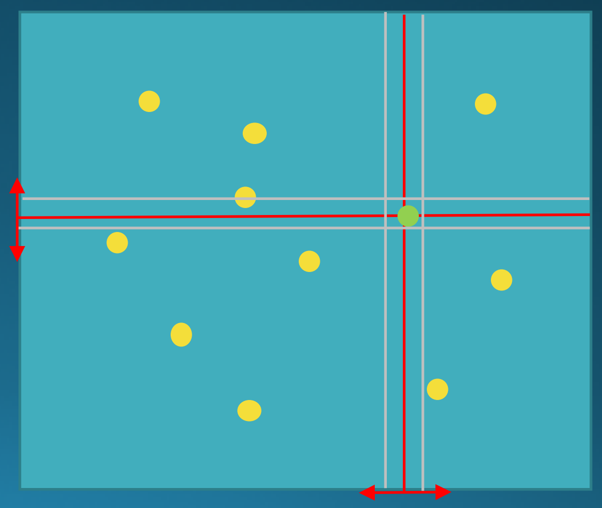
Next Steps

Project

- Finalize grid microfabrication and pair with simulations

Additional Thoughts

- Mobilizing traces or particle plane in x-y directions
- Switching current flow
- Z-axis
  - Mobilizing entire grid layers
  - Mobilizing in-between photoresist layer



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Questions?