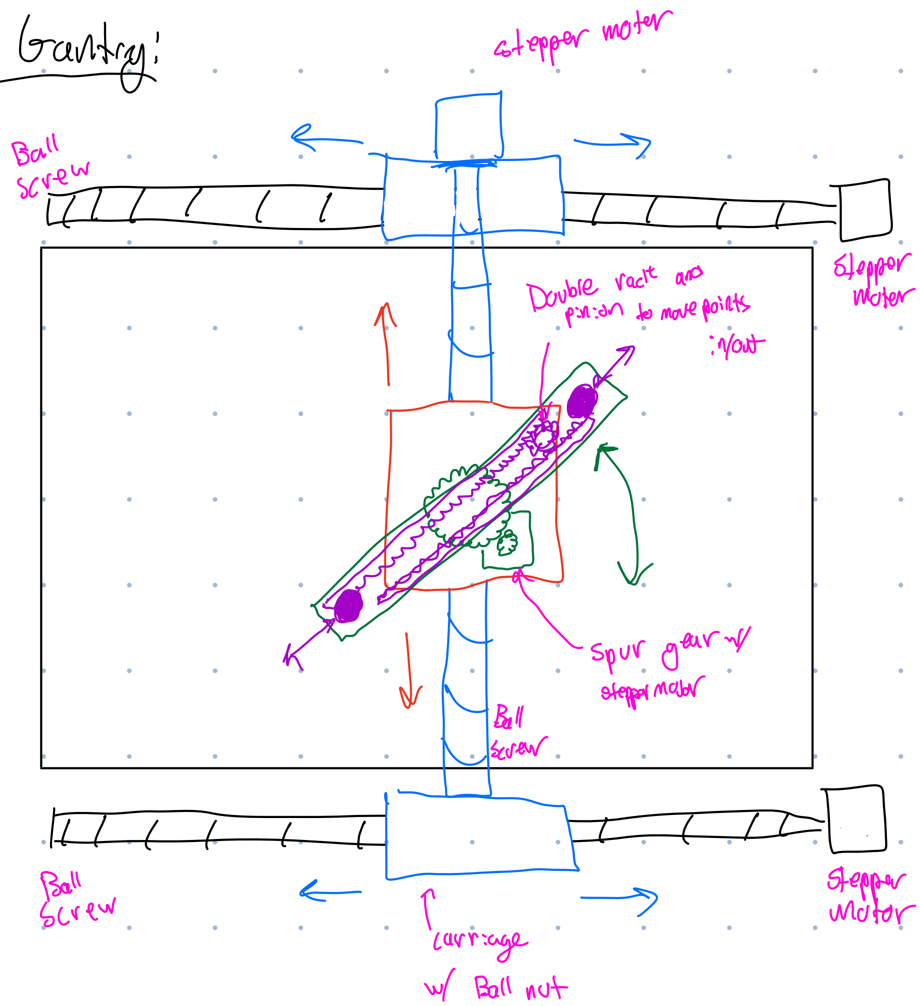
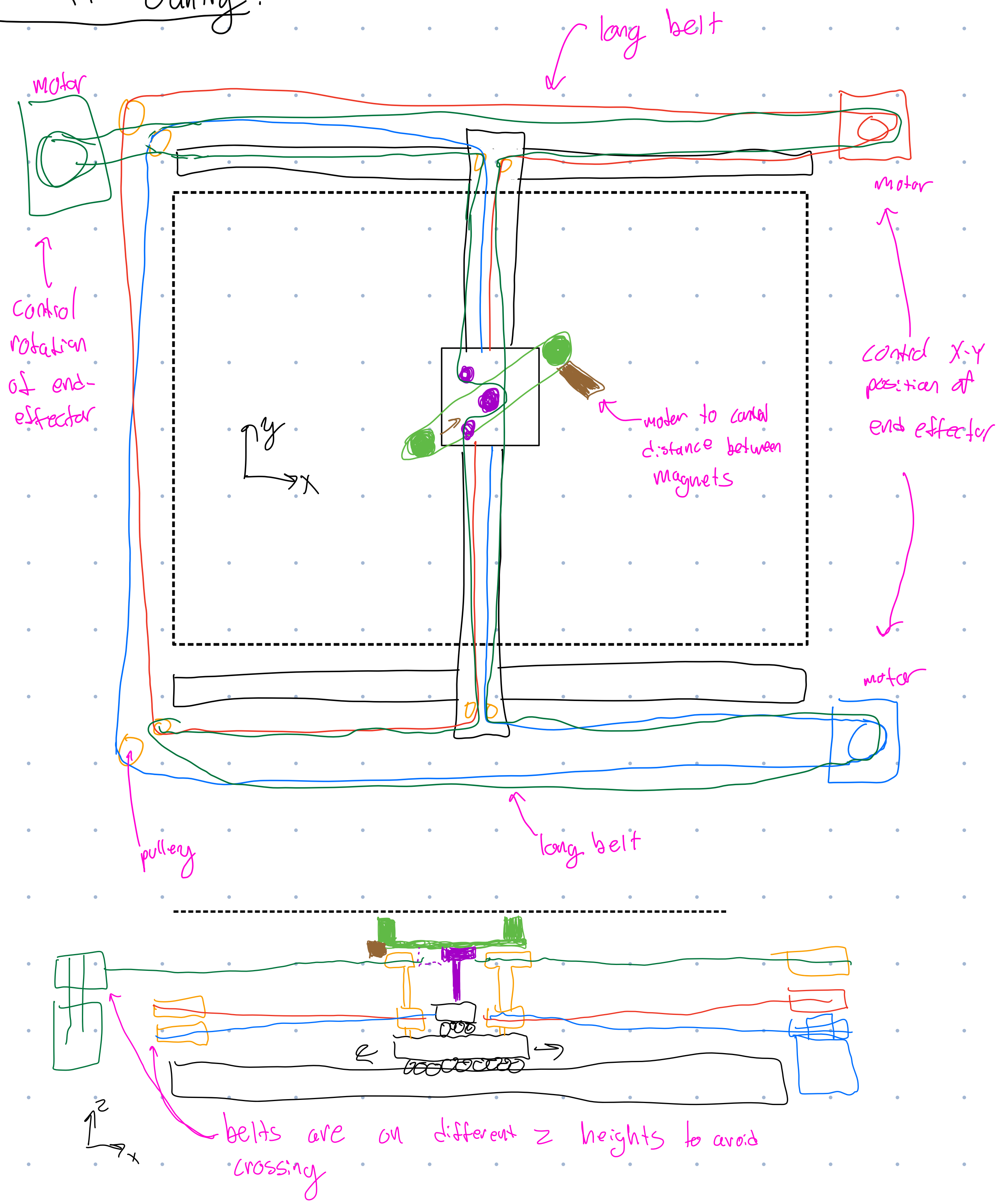
Ball-Screw Gantry:



Pros:
- Ball screws are relatively easy to use, have good mechanical advantages with low inertias, and have little backlash (making them ‘feel’ good for haptics)
- Ball screws with decent stepper motors can achieve positional accuracy less than 0.1mm (0.004”)
- Don’t need additional degrees of freedom to achieve all necessary configurations
- Won’t need to machine a lot of custom parts, ball screws and ball nuts are very common parts on McMaster-Carr

Cons:
- Motors can’t be displaced from the parts they are actuating, in other words, they need to be directly attached to their system, which adds inertia to the gantry
    - End effector will likely have a high inertia that could be hard to compensate for in controls
- Ball screws and ball nuts can be relatively expensive, on the order of $100-$300
- Use of spur gears and rack and pinion for final two degrees of freedom will likely diminish the haptics of the device, as these have backlash that would be noticeable

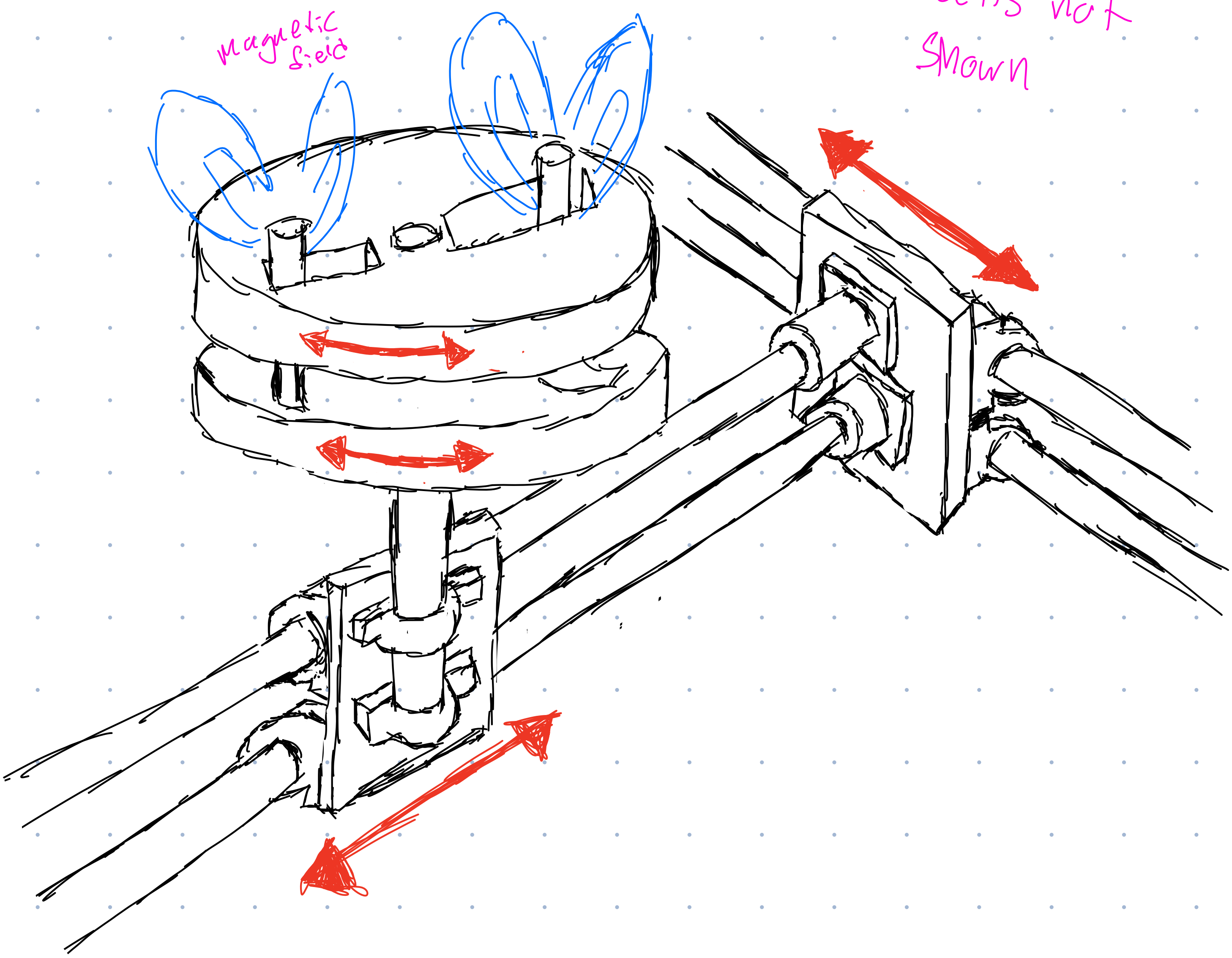
Core-XY Gantry:



Pros:
- 3 DOF are remotized, which reducers the inertia of the gantry and end effector
- Belt system is very back-driveable, good for impedance control
- Can replace motors with cable drives ideally for smoothest haptic experience

Cons:
- Belt system could become mechanically complex (i.e. lots of pulleys, belt heights, etc.)
- Requires some space outside of the display, doesn't package as nicely
- Still requires an actuator for the final DOF which adds inertia

Double Disc End Effector:



Pros:

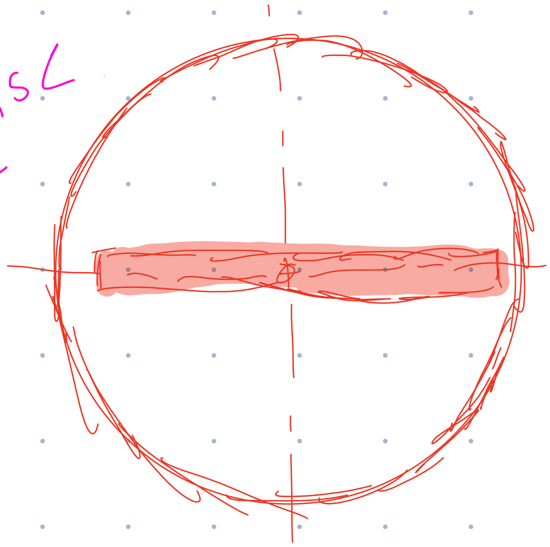
- Achieve full 4DOF with the ability to remotely actuate all bodies through belts
- Discs can be engineered to have minimal inertia
- Minimize inertia of moving parts for smoothest possible free motion
- Gantry is not a novel solution, lots of examples and systems have already been engineered, parts can be achieved easily and aren't super example

Cons:

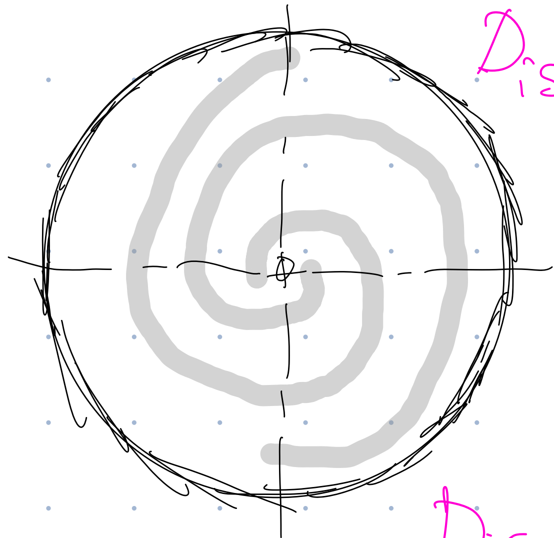
- Adds complexity to control since actuators won't map 1-to-1 with cartesian space
    - i.e. to move in a straight line all 4 actuators will have to be active
- Belt routing could become finicky, belts on at least 3 planes, possibly 4

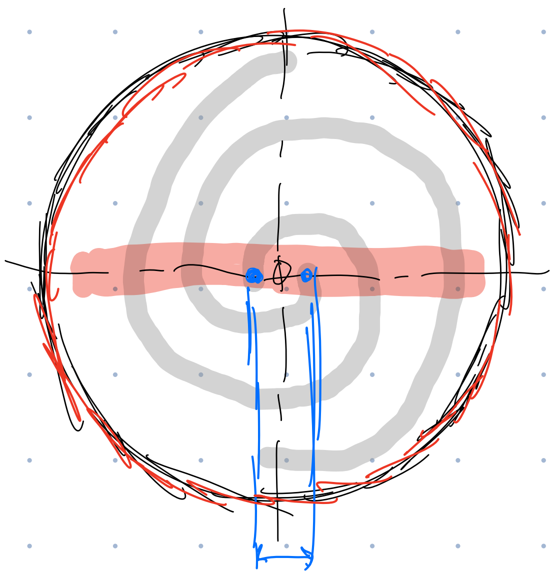
Double Disc contd:

Disc A



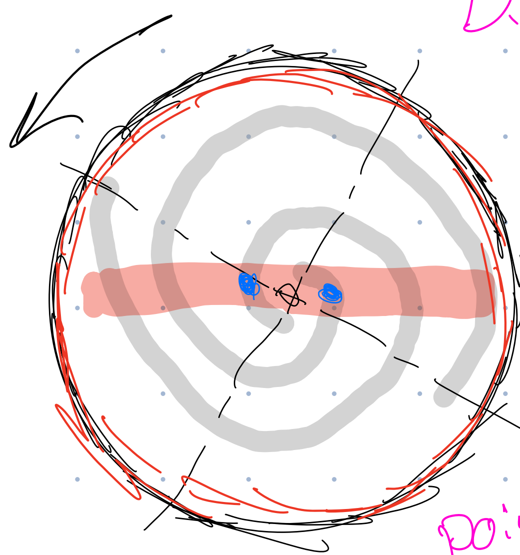
Disc B



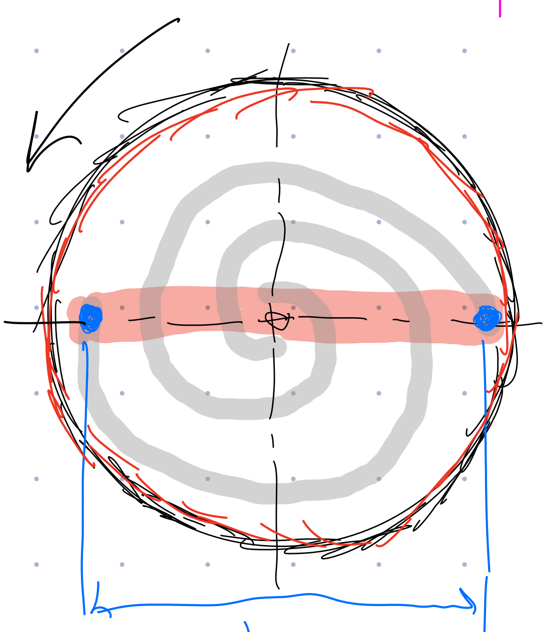


dmin

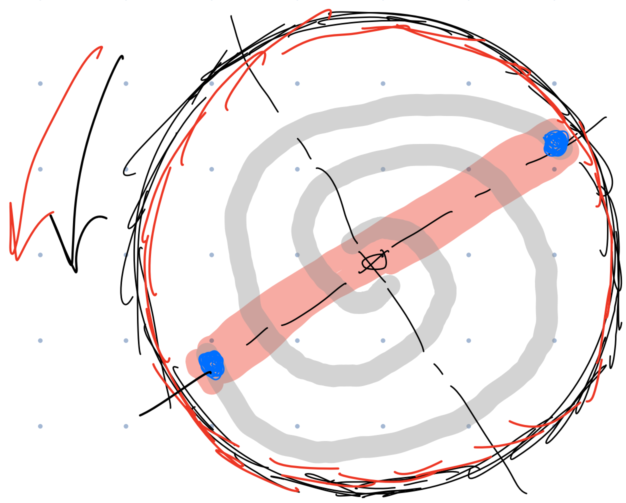
Disc B rotates ccw



points slowly move apart

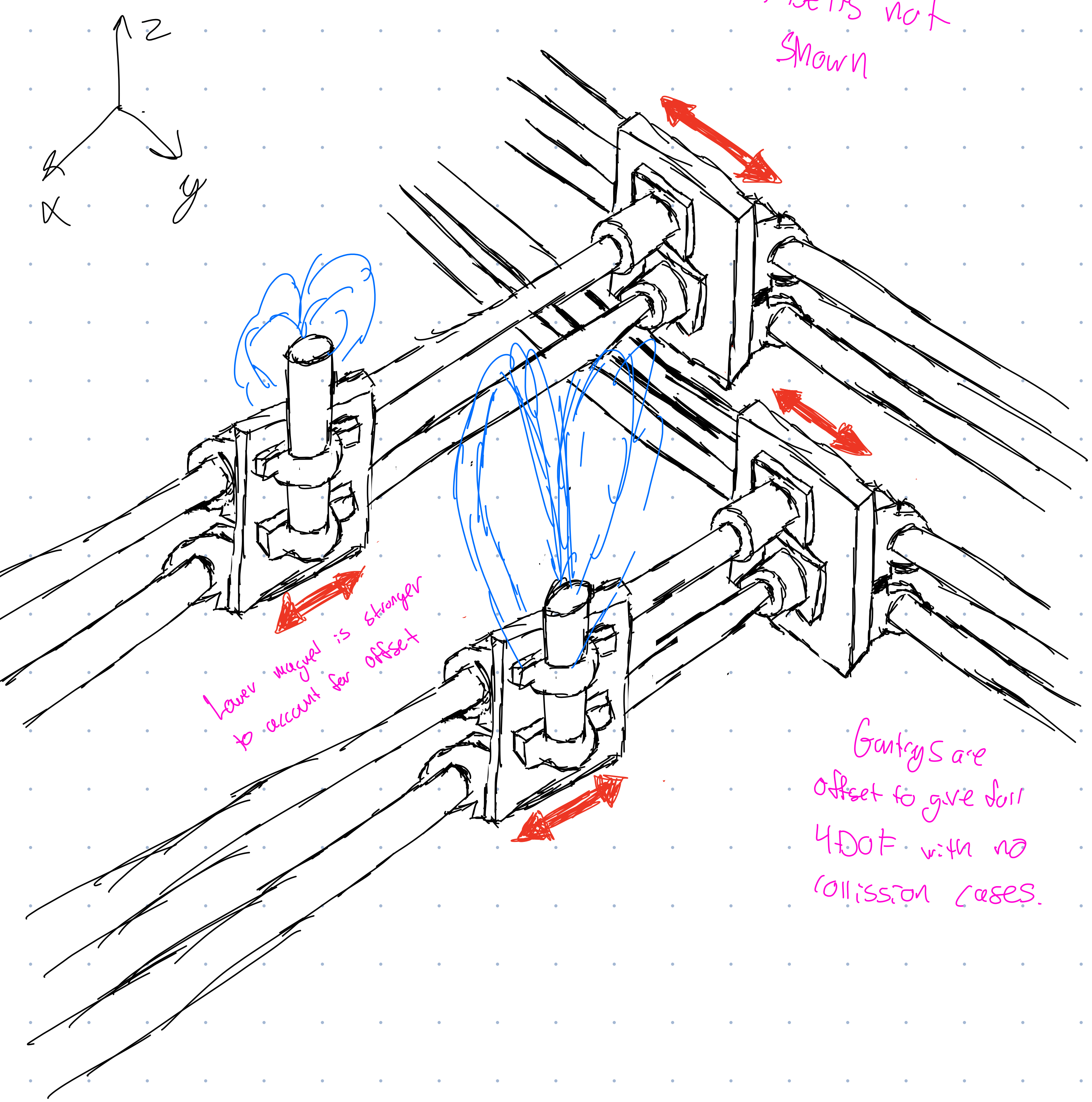


dmax

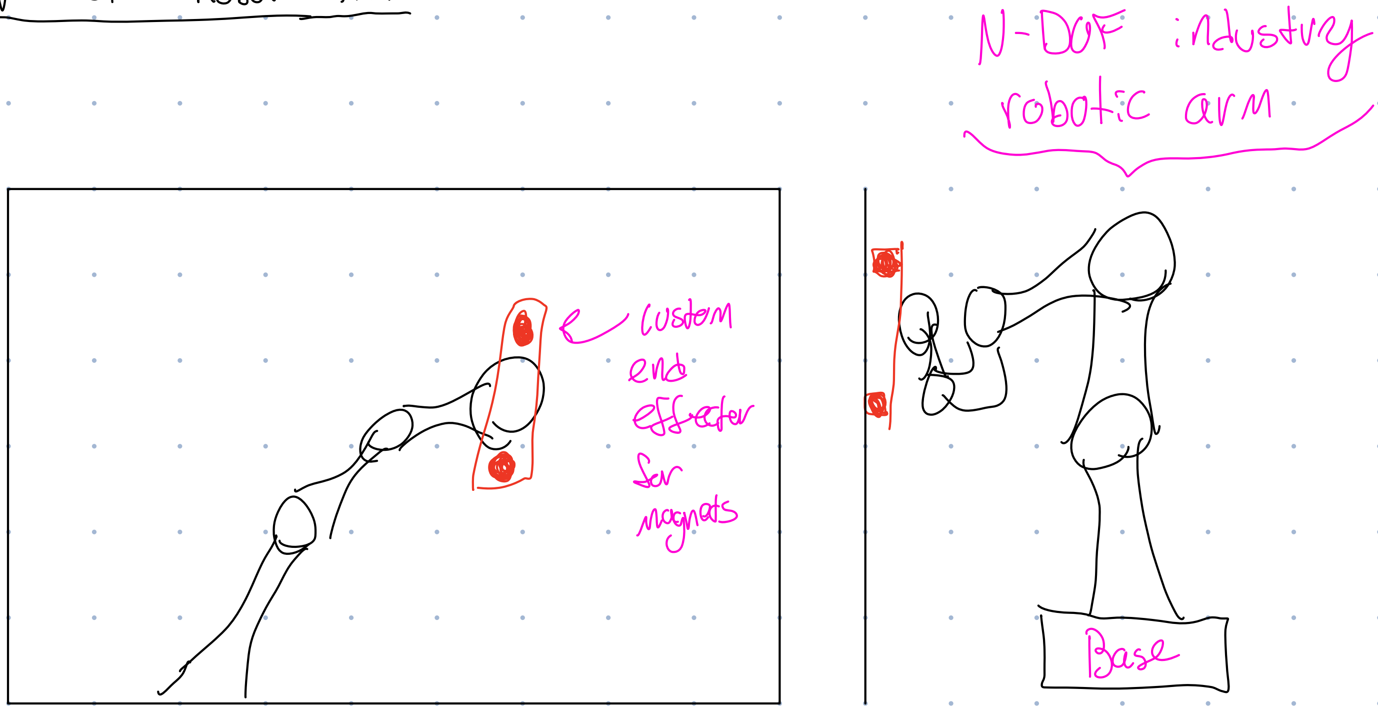


rotate both Discs to rotate points w/ constant width

Offset CoreXY Gantry:



N-DOF Robotic Arm:



Pros:

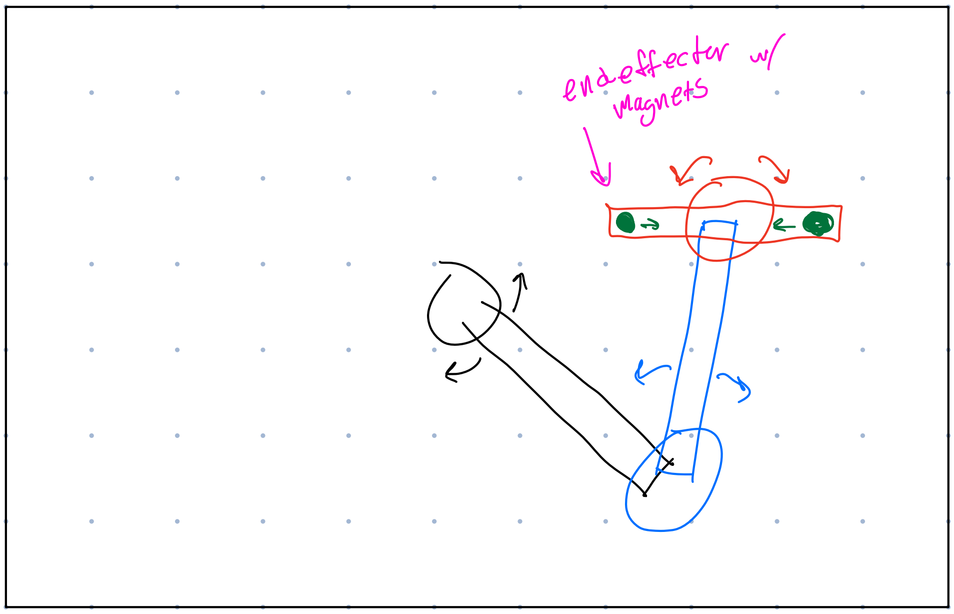
- Industry standard robotic arms are very good at what they do, they have sub-millimeter accuracy, wide ranges of motions, and the control algorithms/loops are already engineered for us
    - Saves us a lot of engineering work
    - Would likely handle the inertia of the end-effector well
- Provides extra degrees of freedom into/out of the display to control magnitude of magnetic forces with finer tuning

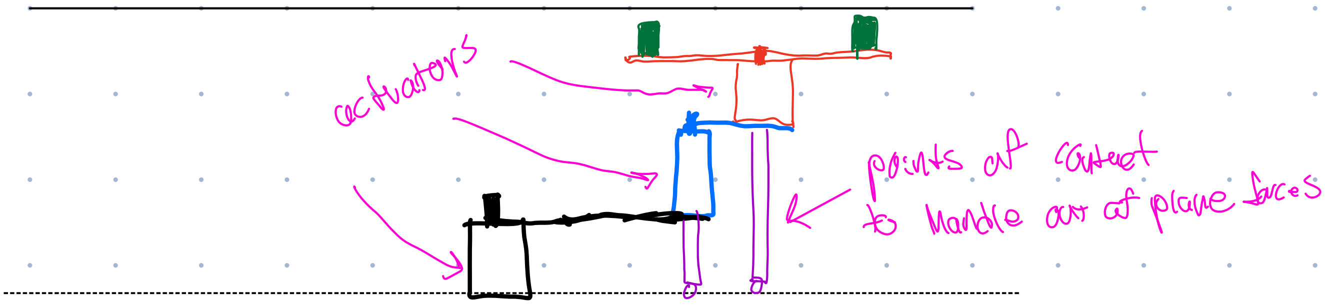
Cons:

- Expensive, a new one likely exceeds budget on its own

- Large and bulky, might not package well with a smaller display
- Still requires custom engineering for the end-effector; not an all-in-one solution

Open-Chain Linkage,





Pros:

- Reaches all necessary configurations with minimum number of actuators
- Likely packages well beneath the surface
- Could use belts to displace some of the motors to actuate the joints ‘remotely’ (e.g. make the actuators stationary)
- Could use cable drives (best for haptics) in place of the actuators to eliminate backlash and create the best user/haptic experience

Cons:

- Large inertia on early-stage actuators; inertia is not constant across the entire configuration space
    - User may experience different free-motion inertia, damping, stiffness etc. at different locations on the tablet
- Handling forces due to gravity becomes challenging; out of plane forces affect the actuators
- Lots of cantelevers