A Brief Exploration of Drawing Machines

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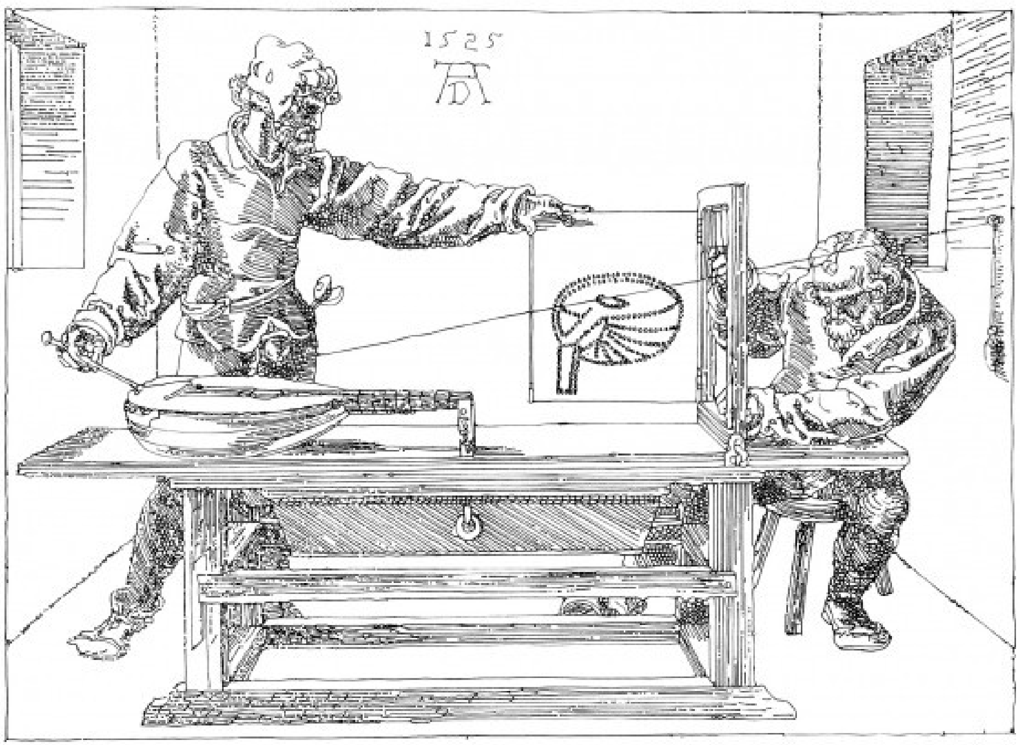
Local Maker, Hack-a-thon Winner, and General Mad Man

Older than you might think...

- **Drawing machines have been around for a very long time...**



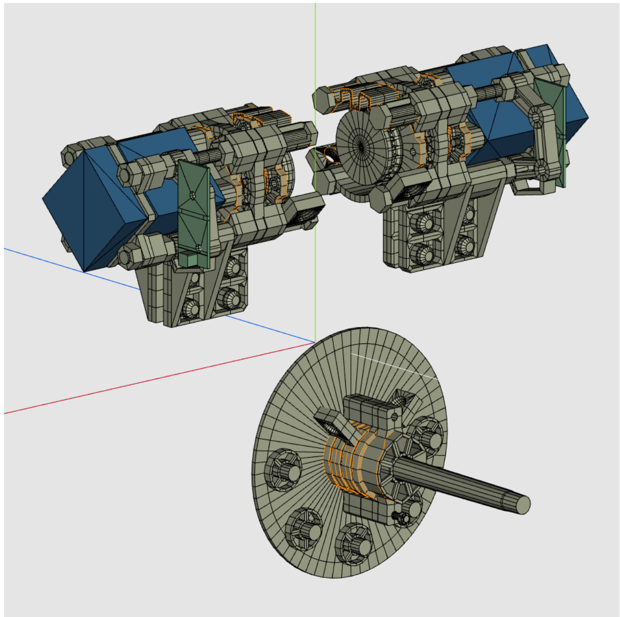
"Dürer's Door", Albrecht Dürer, 1525

Focus is not the Typical “Drawing” Machines

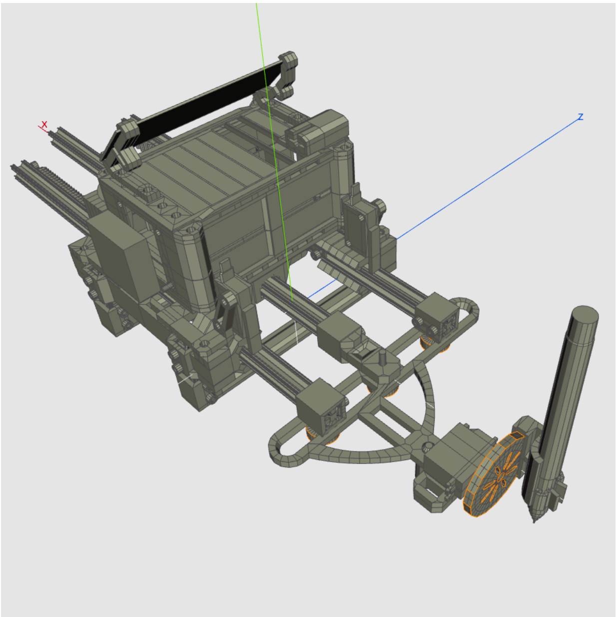
These rely on X-Y Cartesian coordinate Systems. (*Boring*...)

Of Machines More Unusual...

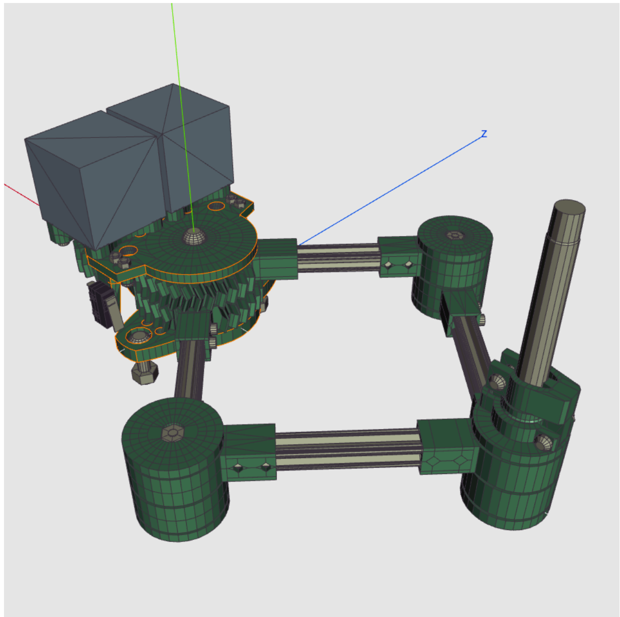
- **Discuss Three Machines in Particular:**



Alexandria



Baalbeck



Exeter

Alexandria

What is Alexandria?

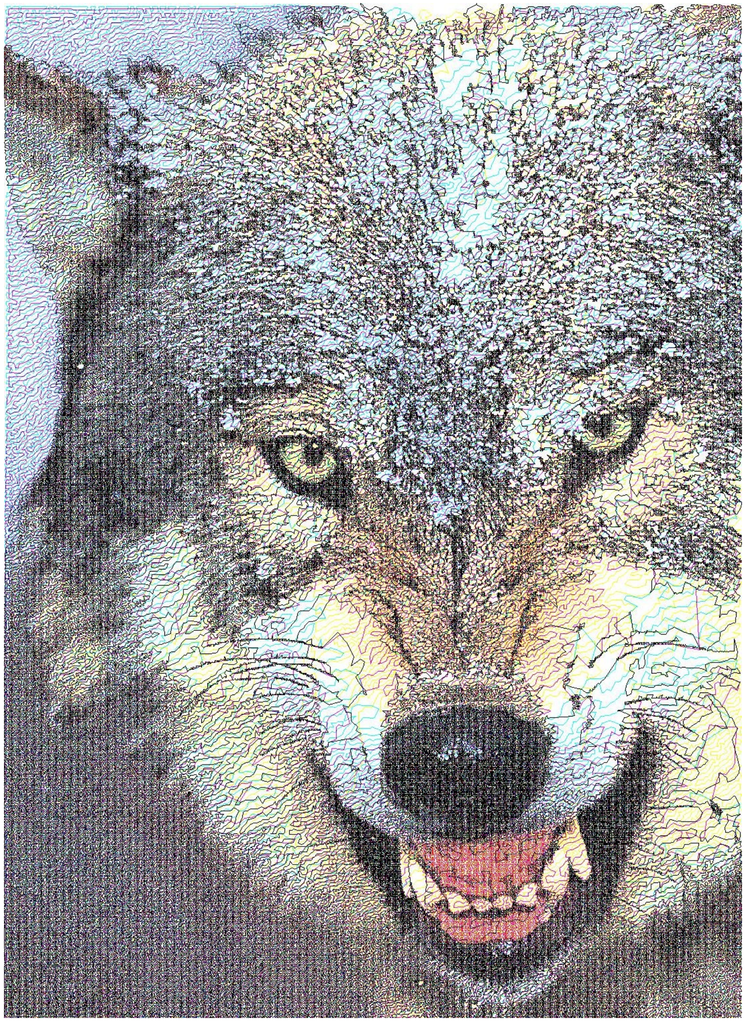
- Alexandria is a V-Plotter.
- A pen hangs from two strings.
- String length is varied to move the pen around.
- Very simple mechanical design.

A Little History

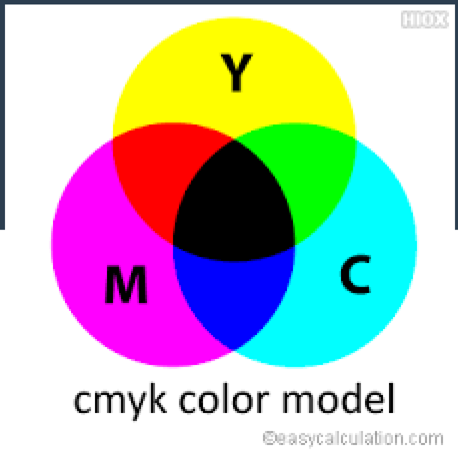
- Alexandria came about as a challenge to myself from some art students at M.I.C.A.
- I was shown a machine called the "Polargraph Drawing Machine" and asked if I could make it better.
- Alexandria was born as a result.

What Makes Alexandria Different?

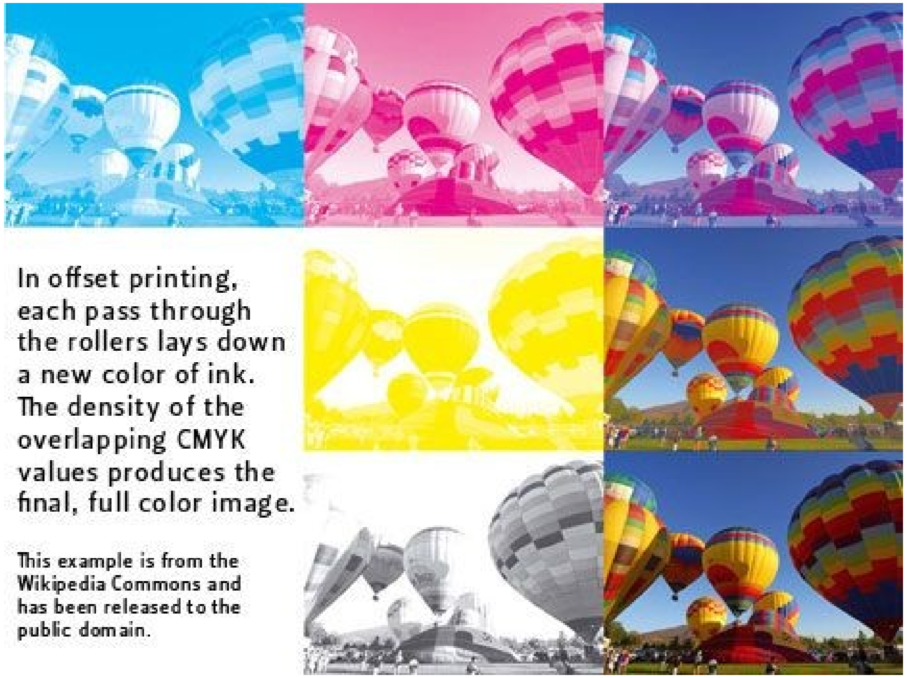
- Alexandria can do full color photographs.
- <u>No counterweights</u>!
- Very high resolution.
- Alexandria cannot lift the pen!
  - Each color is one line from beginning to end.



Photos via CMYK Color

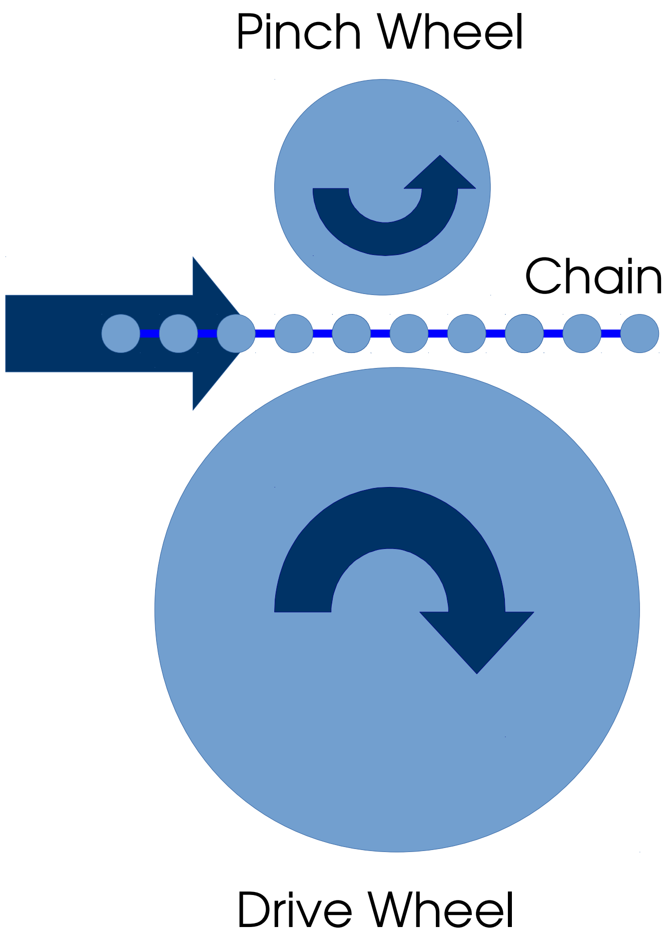


- **Break image into:**
  - Cyan
  - Magenta
  - Yellow
  - Black
- **Dither**
- **Run TSP solver**
  - Traveling Salesman Problem

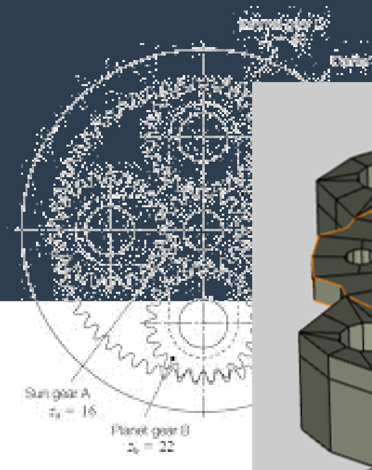


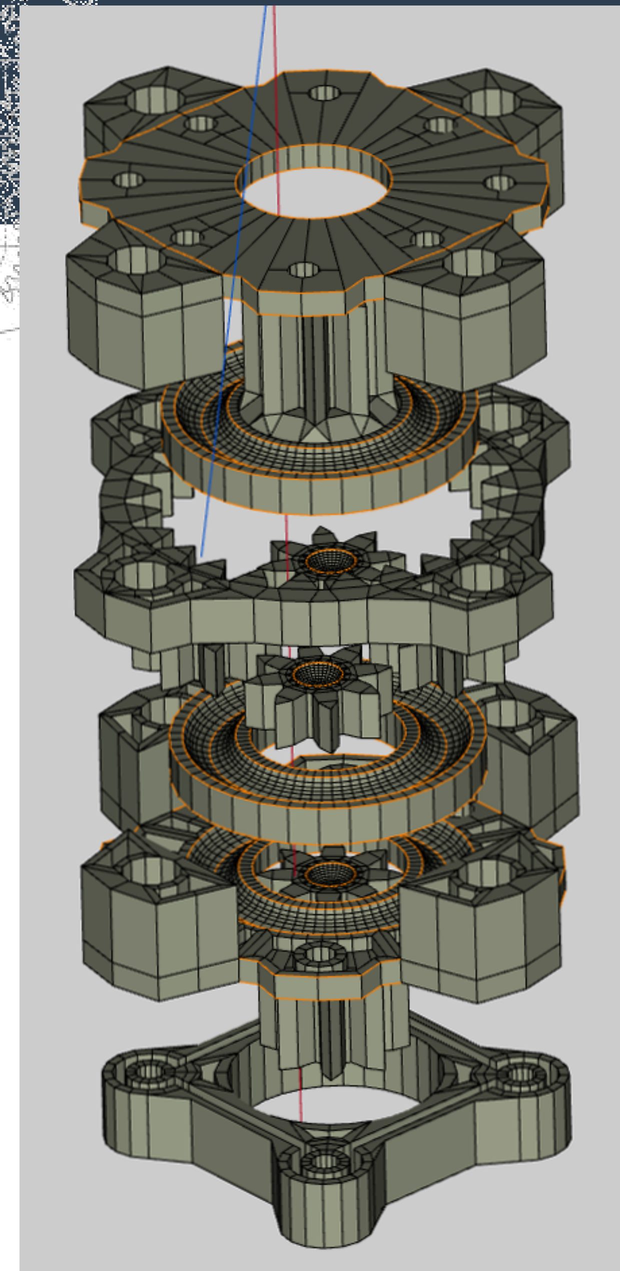
No Counterweights

- **Counterweights must be balanced to work correctly.**
  - Tension changes as a function of string length and position.
  - Very common for weights to slip on polargraph machines.
- **Alexandria works around this problem by using a pinch wheel.**



High Resolution

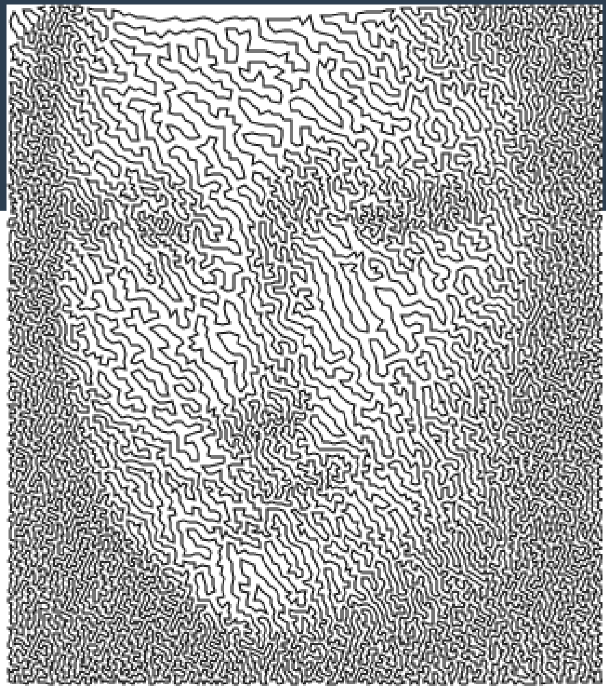


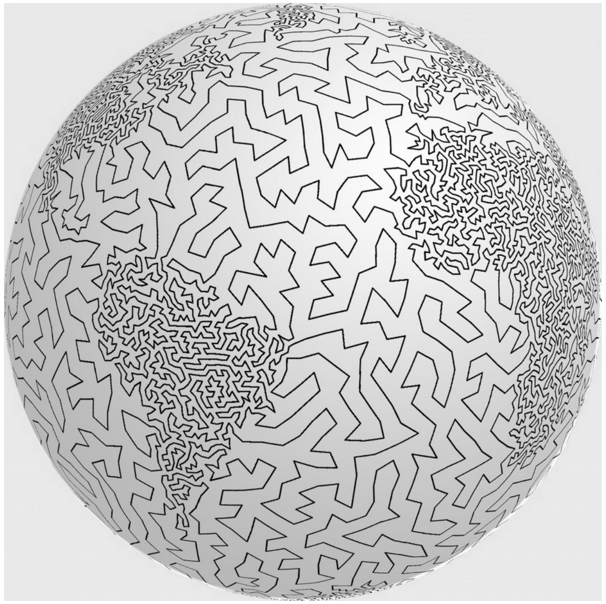


- **Alexandria uses a planetary gearbox to increase angular resolution.**
- **4X improvement over regular stepper motors.**
- **4X Torque improvement.**
  - The gondola can be heavy!

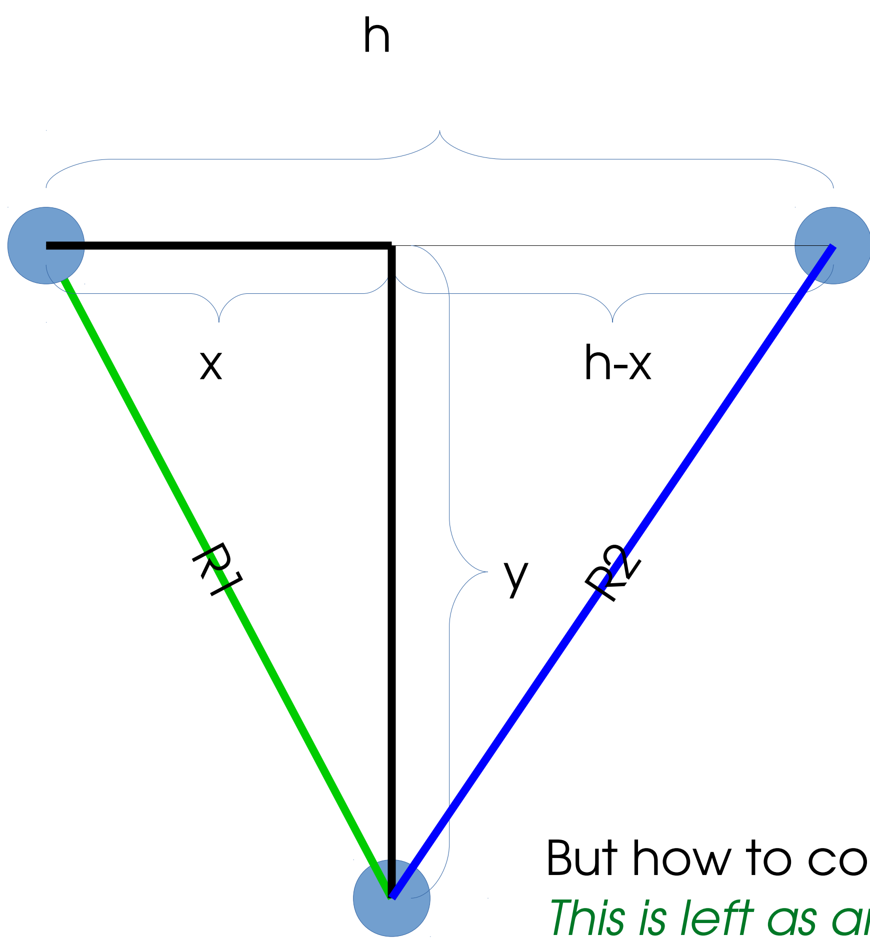
Can’t Lift the Pen?

- Just how are those drawings possible?
- TSP Art:
  - http://www.cgl.uwaterloo.ca/csk/projects/tsp/
  - https://wiki.evilmadscientist.com/TSP_art





The Math Behind Alexandria



$$R1=\sqrt{x^2 * y^2}$$

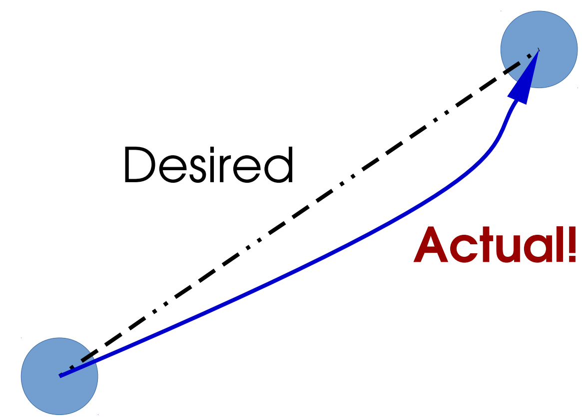
$$R2=\sqrt{(h-x)^2 * y^2}$$

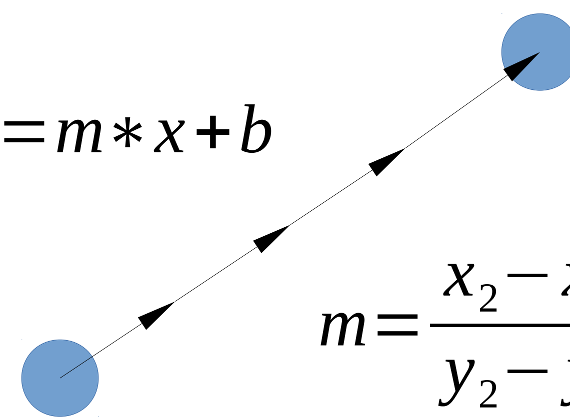
h can be measured

But how to convert motors steps to actual length R??
This is left as an exercise for the reader.

Lessons Learned… A Useful Tip

- **Drawing a single, long, straight line may not end up being straight!**
- **Break the lines into smaller segments.**
  - Bonis! The speed can vary along path.





$$y = m * x + b$$

$$m = \frac{x_2 - x_1}{y_2 - y_1}$$

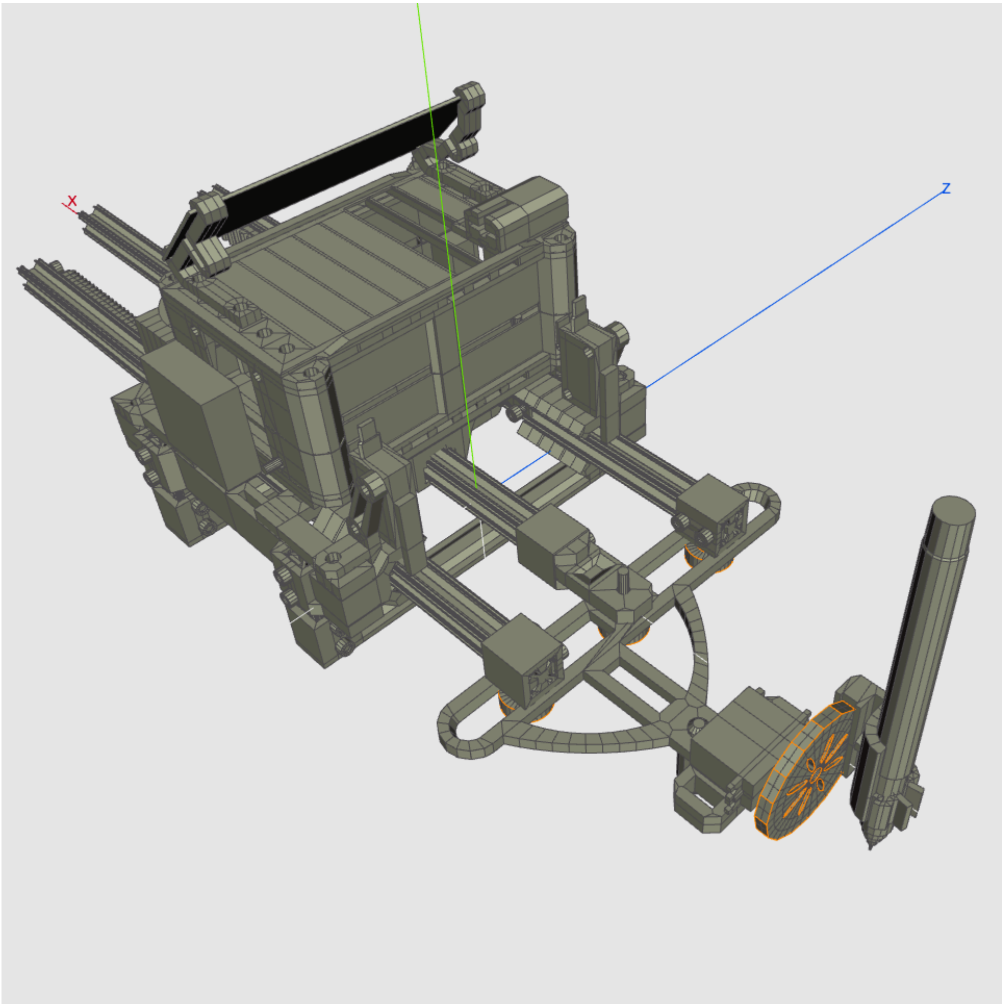
What Would I Have Done Different?

- **Improve the chain guides as the chain is slowly sawing through them…**
- **Improve the pen holder on the gondola.**
  - It needs a quick release.
- **Better computer and user interface.**
  - Display the drawing as it progresses.
- **Alexandria is hard to transport...**

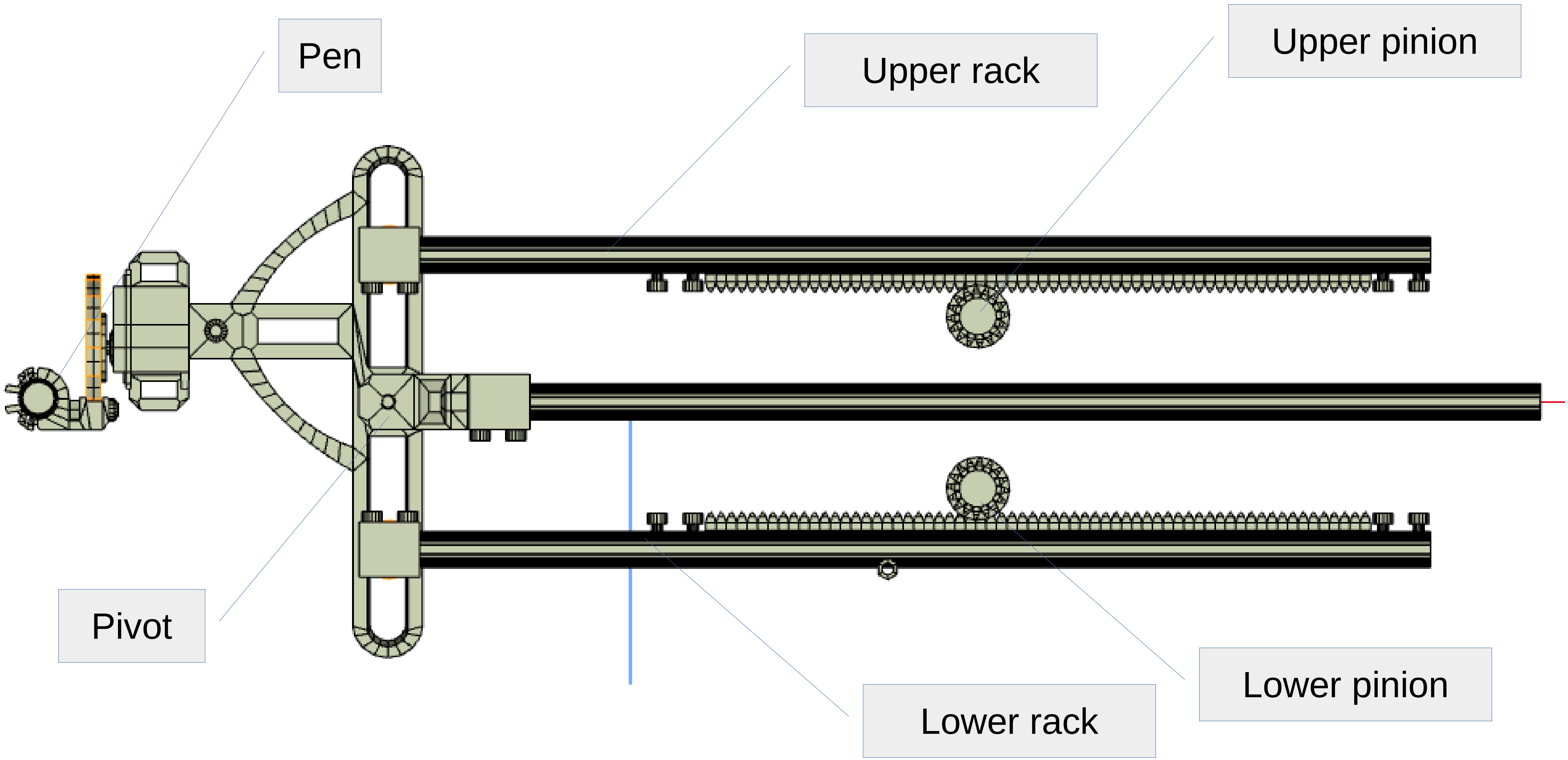
Baalbeck

What is Baalbeck?

- Baalbeck is a very unusual design.
- Baalbeck uses two racks with pinions and a pivot in the center.
- The pen can move left and right or swing about the pivot.

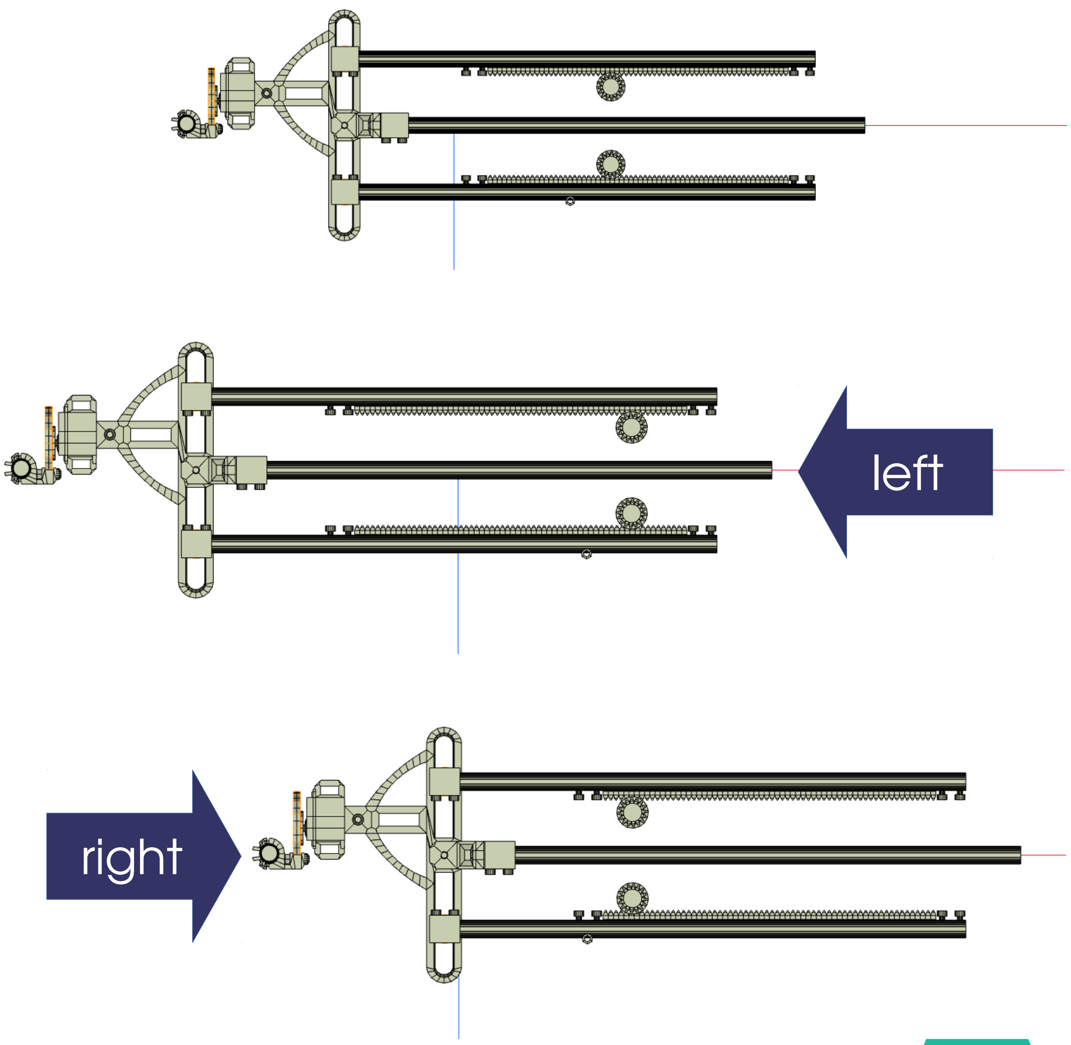


Baalbeck’s Main Mechanism



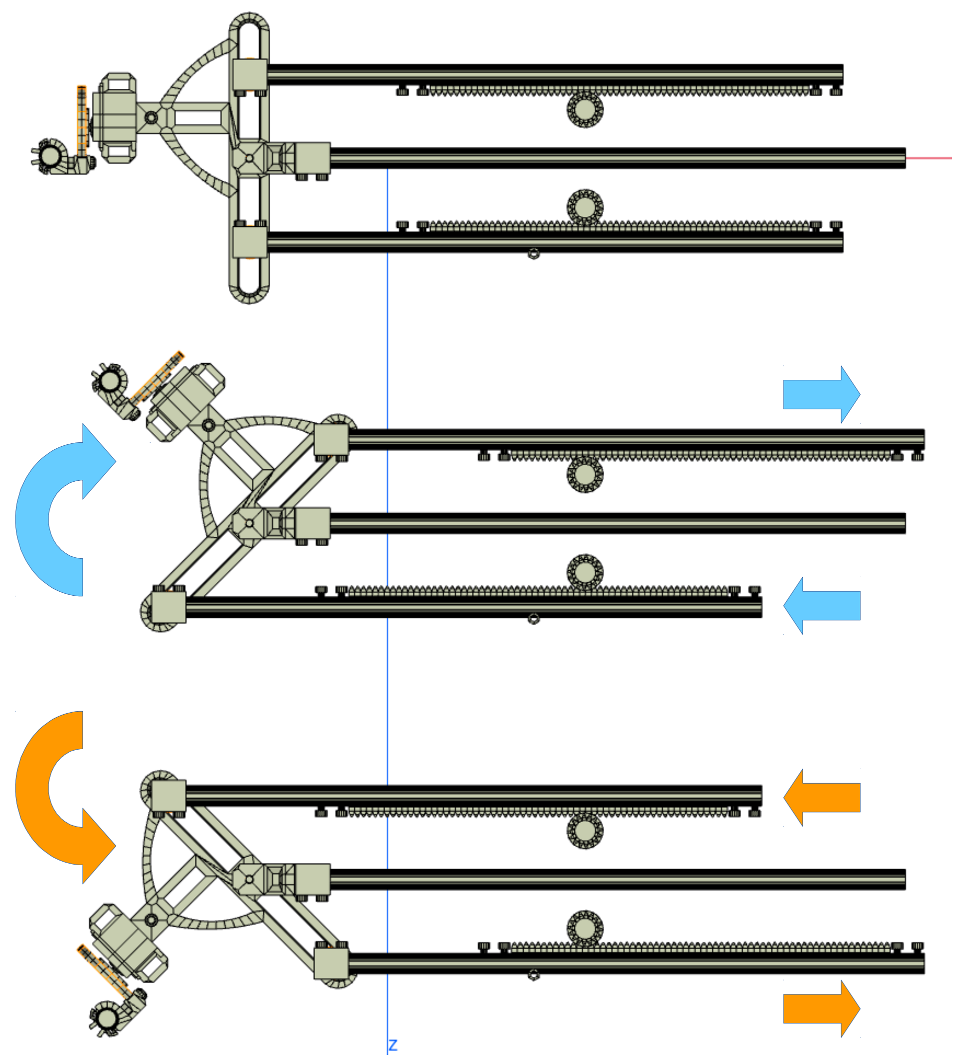
Baalbeck Horizontal Movement

- The racks both move the same direction to achieve left/right movement.
- The pinions rotate opposite directions to achieve this.



Baalbeck "Vertical" Movement

- The pen rotates up/down around a pivot.
- The rotation has a left/right movement that requires compensation.
  - More math exercises for the reader.



A New Idea?

- Nope…
- What is old is new again.
- Found the same basic design in a Navy WWII mechanical computing video.

https://www.youtube.com/watch?v=gwf5mAlI7Ug

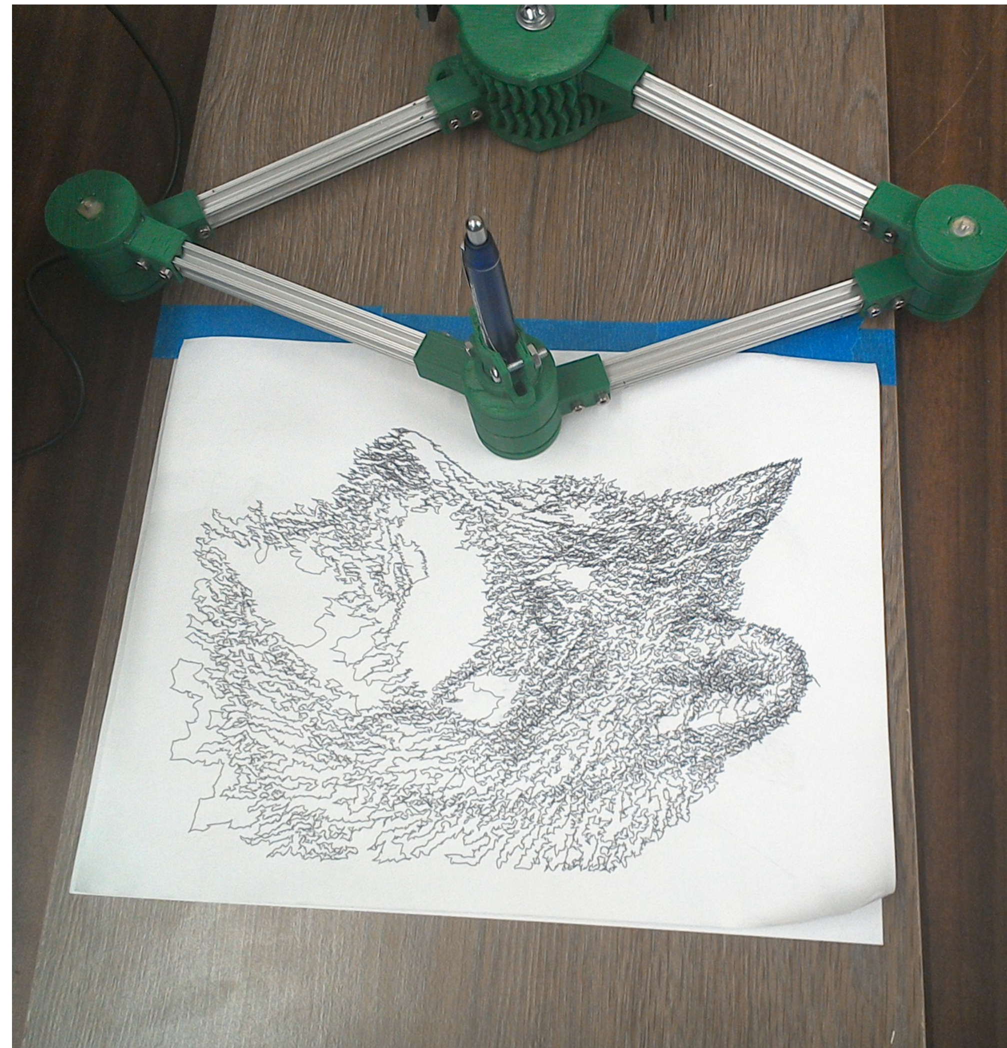
What Would I Have Done Different?

- <u>EVERYTHING</u>!
- The linear racks need smoother movement.
- Expand range of motion.
- Replace stepper motors with ones that support micro stepping.
- Replace pivot with large disc.
- Use herring-bone teeth on racks to hold disc.
- Others...

Exeter

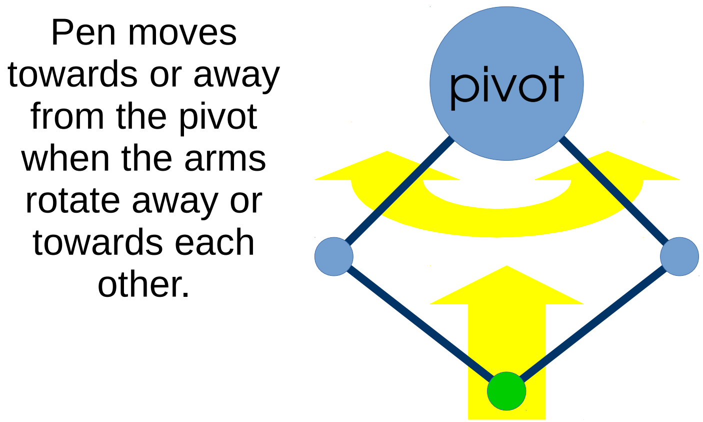
What is Exeter?

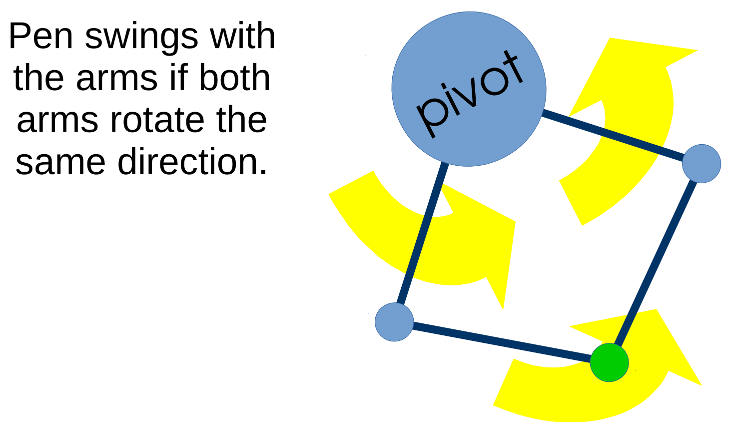
- **Exeter is a dual SCARA**
  - Selective
  - Compliance
  - Articulated
  - Robot
  - Arm



How Does Exeter Work?

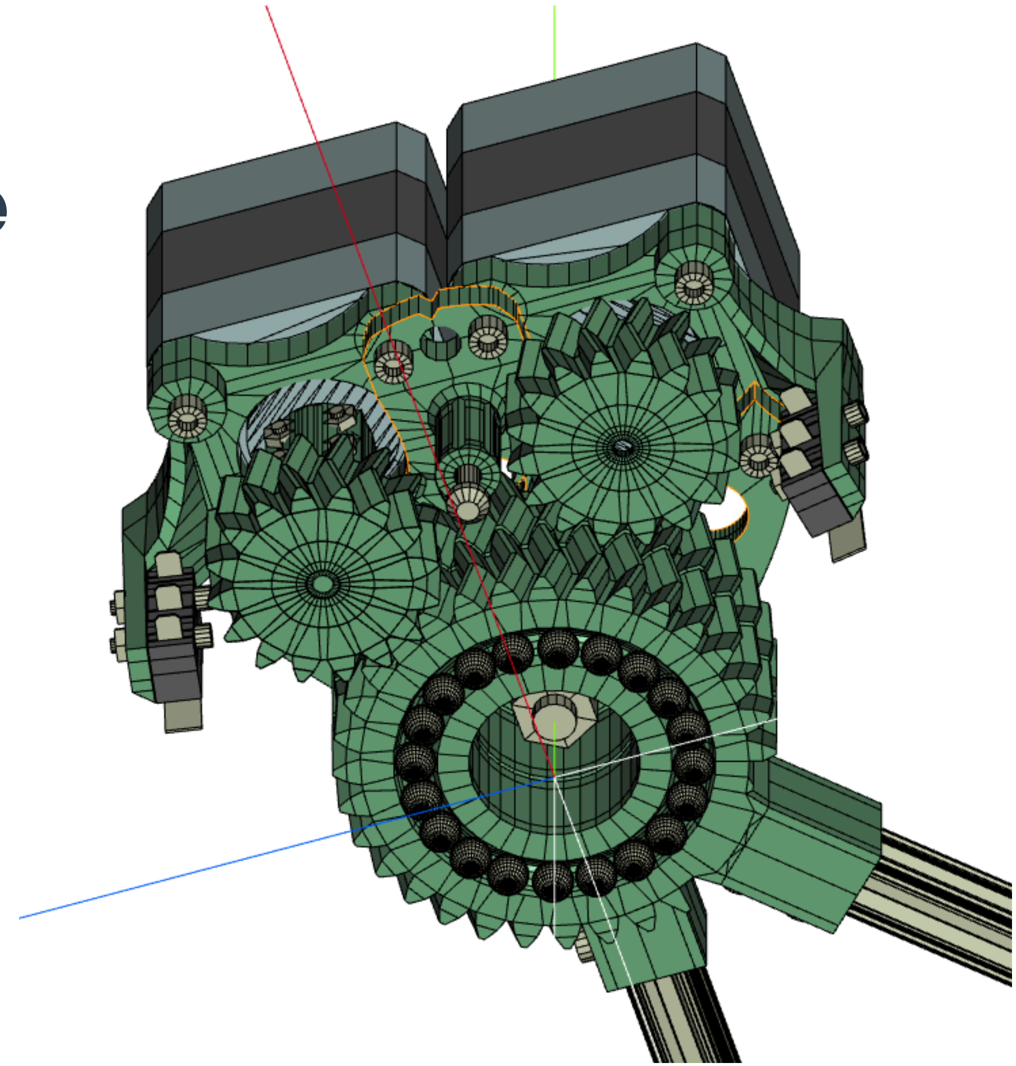
- Exeter can move a pen in/out or rotate about a pivot.
- It is very much like Baalbeck in this regard.
- It is very different from Baalbeck in how this is achieved.





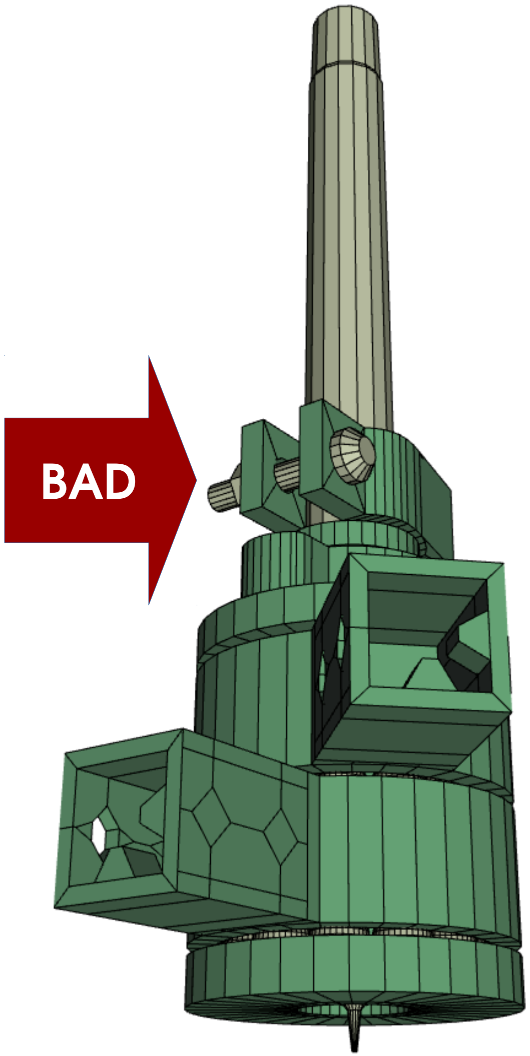
Lessons Learned… The Pivot

- **The pivot implements stacked herring-bone gears.**
- **This caused a problem…**
  - Moving one gear causes the other to move!!!
  - Caused by friction.



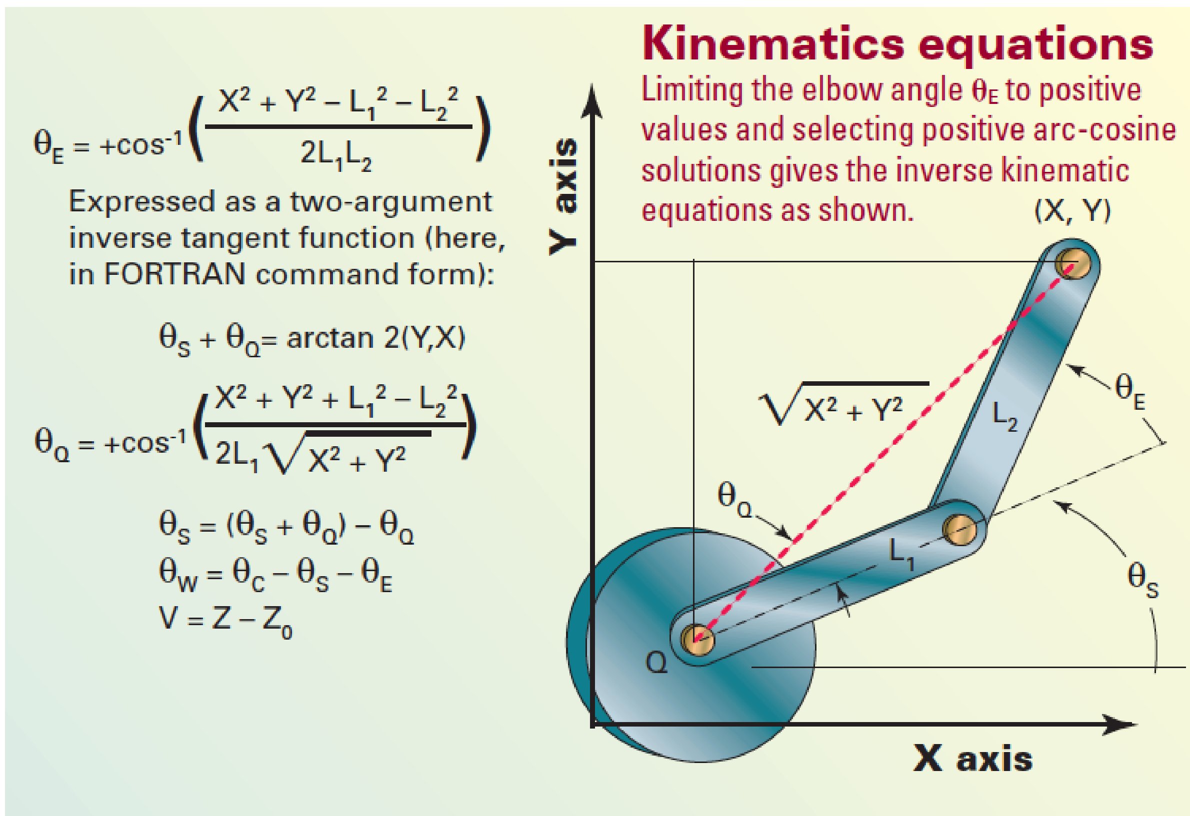
Lessons Learned… The Pen

- The pen holder proves to be a particular challenge…
- It works with any pen but is held halfway up the shaft!
- Try writing holding a pen *<u>only</u>* at its mid point to experience the problem.



SCARA Arm Math

- This is a well studied problem and it is easy to find references on-line



What Would I Have Done Different?

- **The pivot and pen holders need to be redesigned.**
- **I would replace the limit switches with optical detectors.**
- **“Homing” on this machine is scary.**
  - The arms moves very quickly.