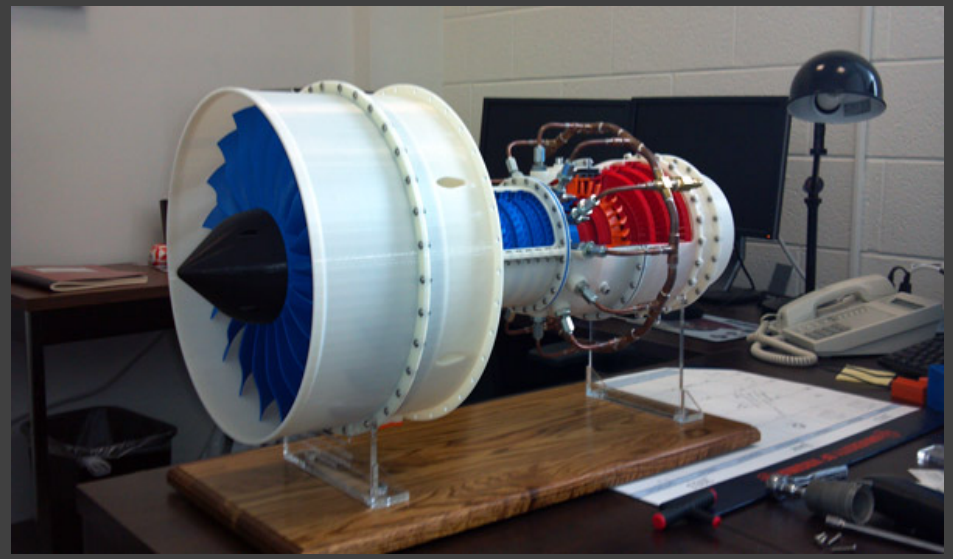
Optimization of print parameters to reduce warpage in fused deposition modeling

Pranav Addepalli

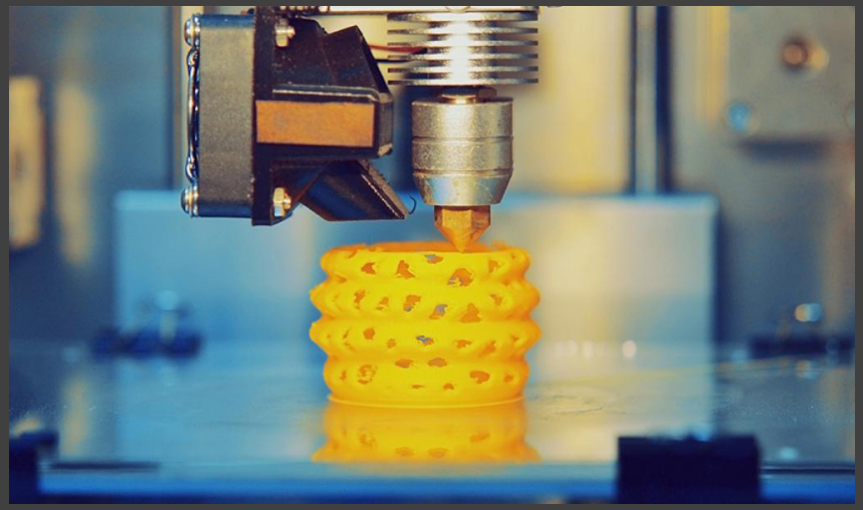
Background



http://www.3dprinterworld.com/article/3d-printing-enables-university-students-become-aerospace-manufacturers

- 3D printing is crucial for many industries
  - Construction
  - Medicine
  - Robotics
  - Aerospace
  - Defense

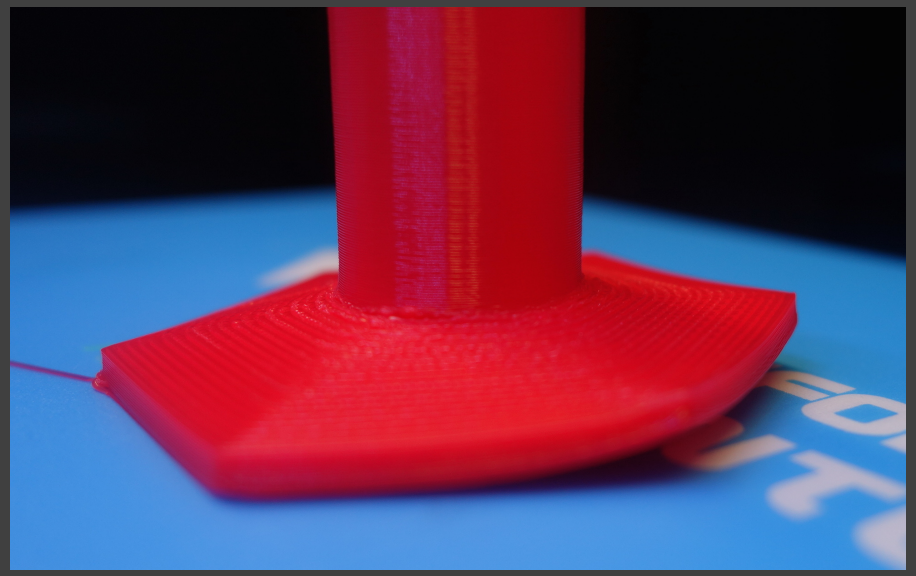
Background



https://www.3dnatives.com/en/fused-deposition-modeling100420174/

- Fused Deposition Modeling
  - Most common printing method
  - Melts a thermoplastic filament repeatedly
- Polylactic Acid
  - Most common filament
  - Made from renewable lactic acid

Background



https://www.3dhubs.com/talk/t/adhesion-and-upward-warping-problems/4334

- FDM prints layer by layer, creating thermal cycles
  - Cooling → Contraction → Mechanical stress
  - Heating → Expansion → Mechanical stress
  - Greatest stress in corners
- This is called ***warpage***

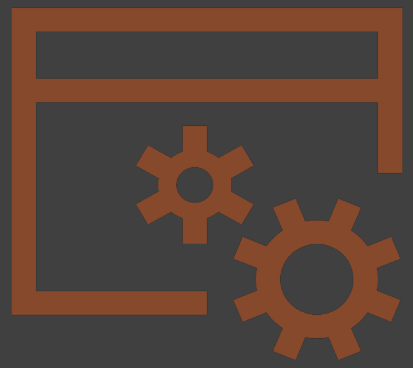
Thermal properties are important to understand!

My Project

https://www.dddrop.com/wp-content/uploads/2018/02/3D-printen-stevige-infill.jpg

- Studying multiple print parameters
  - Wall thickness
  - Layer height
  - Infill percentage
  - Infill height
- Effect on temperature distribution
- PLA discs during printing process

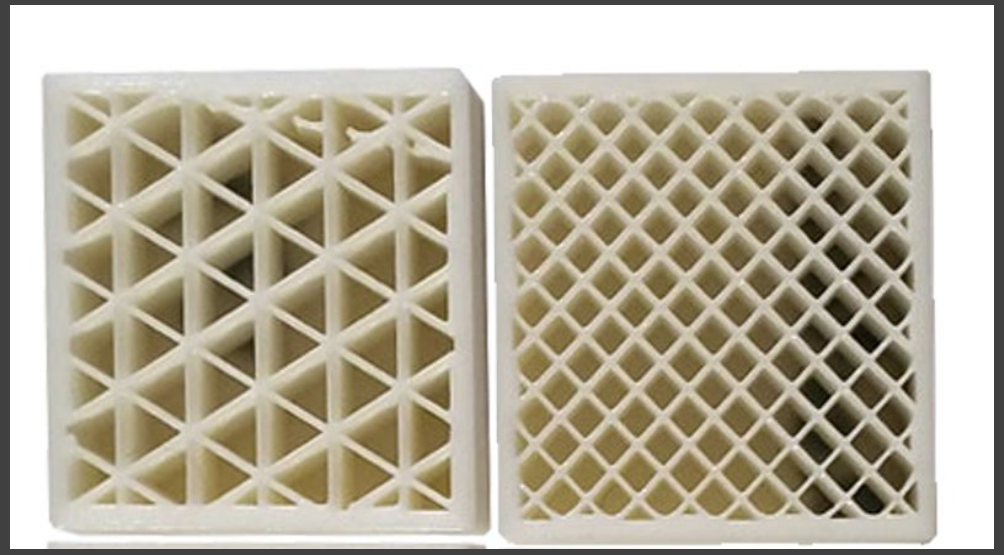
My Project



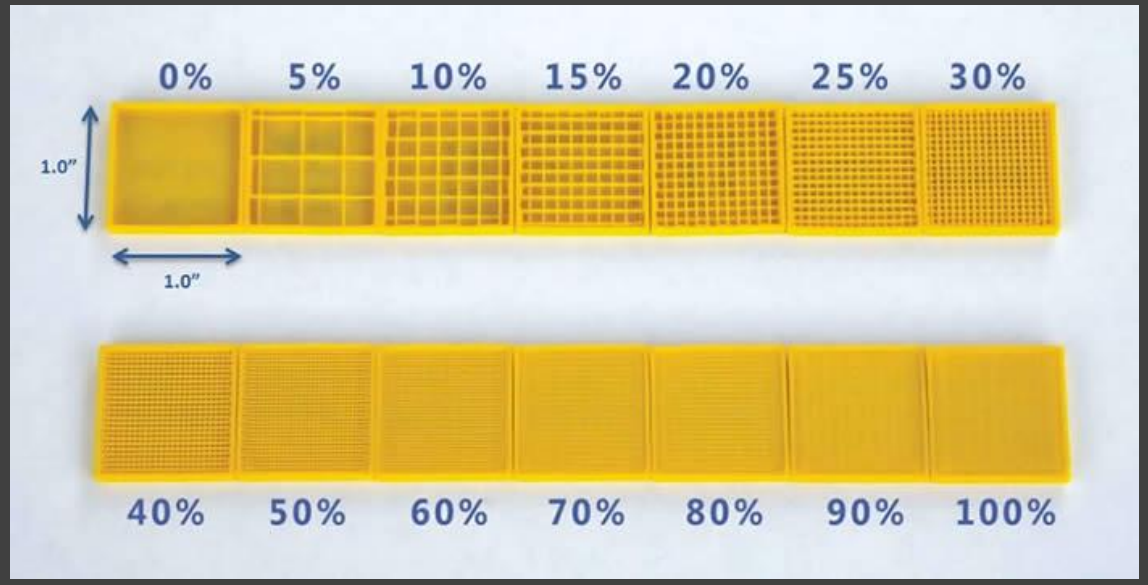
- Optimizing values for the print parameters
- Deep Learning
  - Visualize, model, find trends
  - in spatiotemporal temperature data and heat flow trajectories
- Find the best parameters and print test discs

Variables

- Infill type (grid vs. triangular)
- Infill percentage (10%, 20%, 30%)



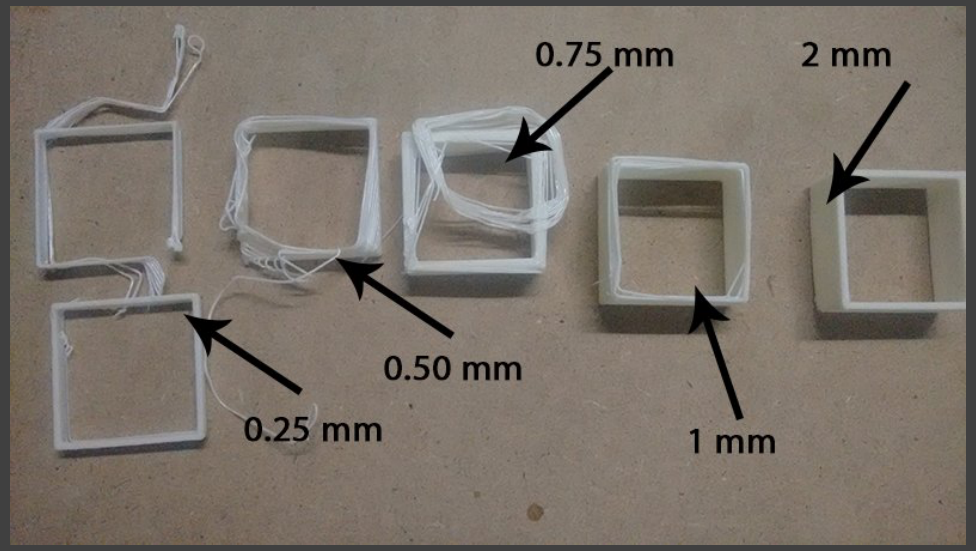
https://3dprinting.com/tips-tricks/how-to-choose-an-infill-for-your-3d-prints/



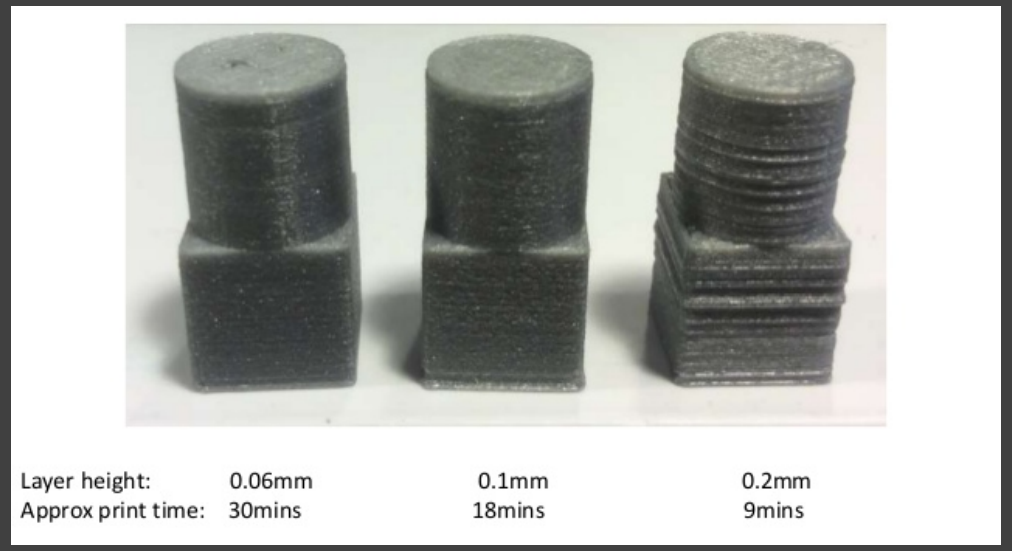
http://tcadsolutions.com/3dprinting.html

Variables

- Wall thickness (0.4mm vs. 0.8mm)
- Layer height (0.1mm vs. 0.2mm)

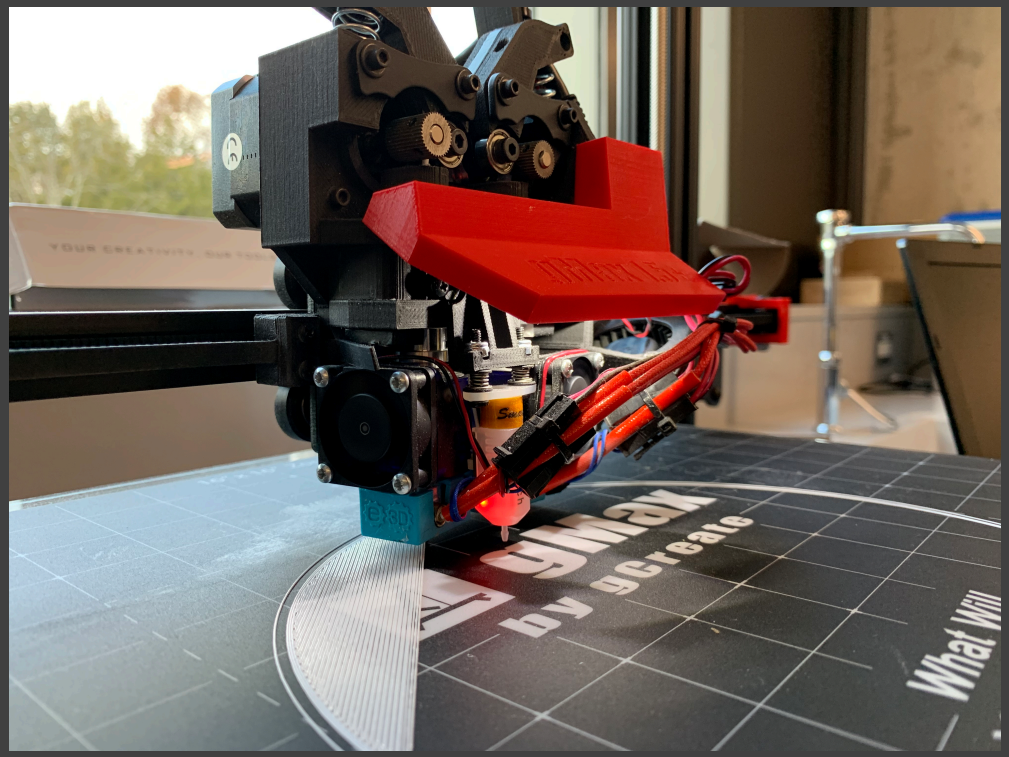


http://archive.fabacademy.org/fabacademy2017/fablabvigyanashram/students/132/assignments/assignment%205.html



https://medium.com/3d-printing-in-o-p/iv-slicing-72a9515f44bc

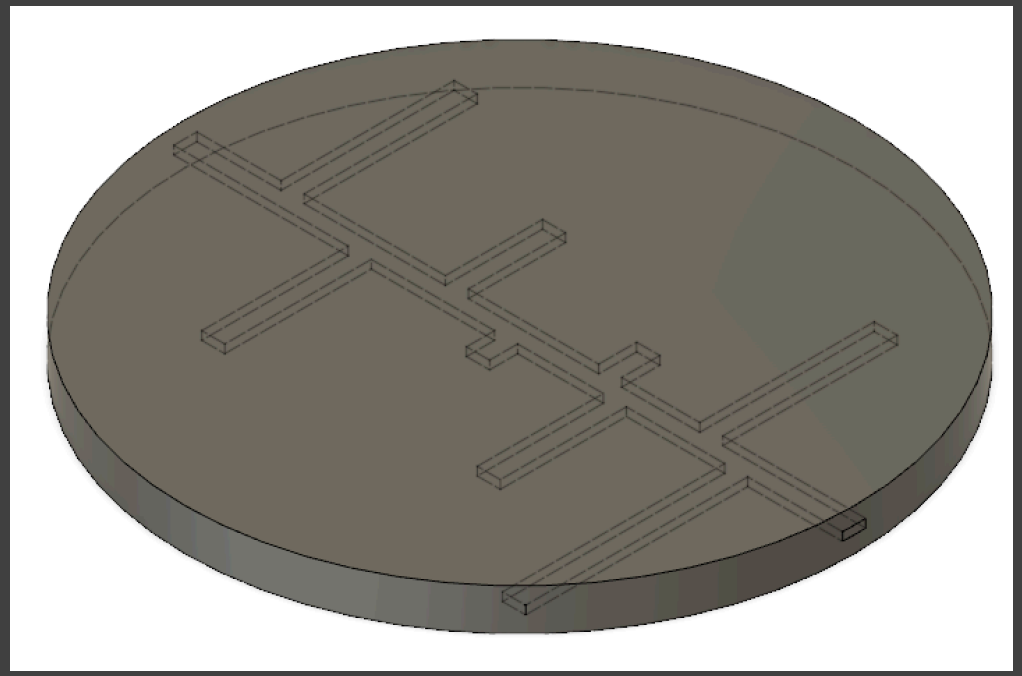
Materials



- NTC Thermistors
- Hatchbox PLA
- Arduino Uno R3 (with breadboard)
- NVIDIA Jetson Nano
- gCreate gMax 1.5 XT+

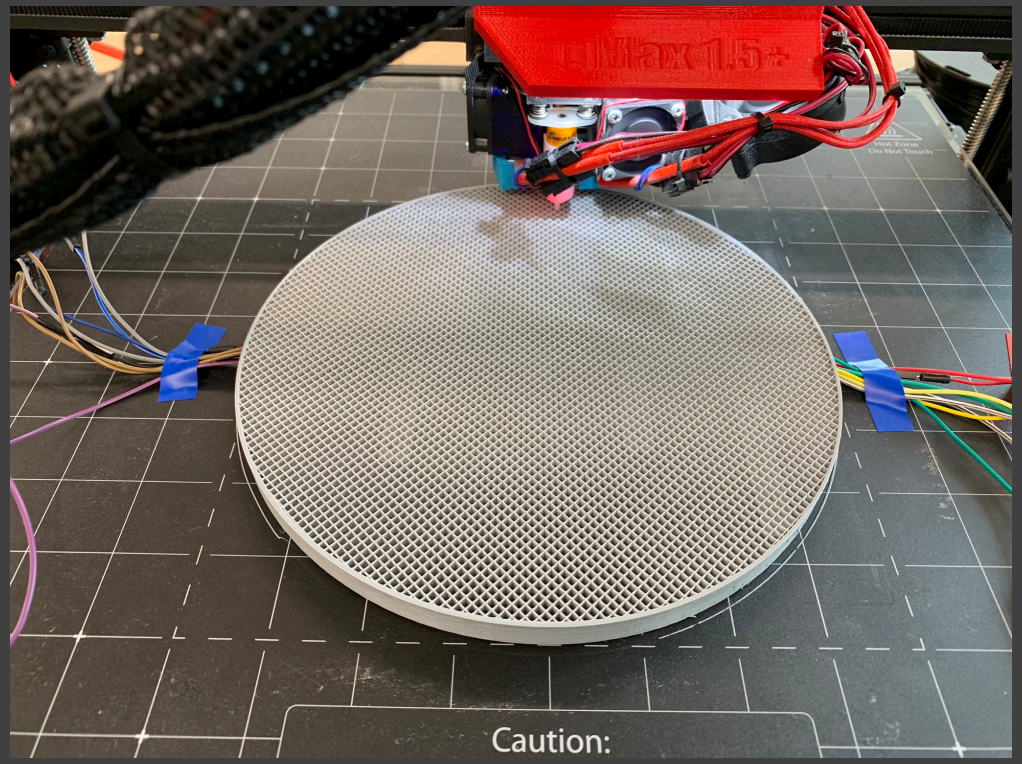
5 Phase Procedure

1) Design



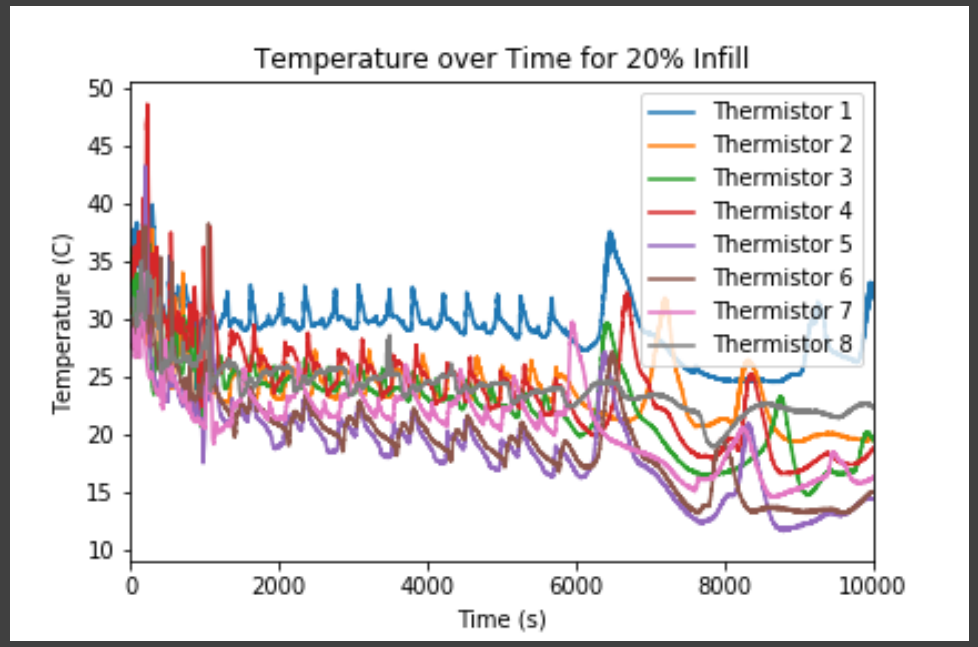
- Design CAD models in Fusion 360
  - 8 inch diameter
  - 0.5 inch thickness
  - Channels along circles for thermistors
- Slice disc with different print parameters in Ultimaker Cura

2) Data Collection

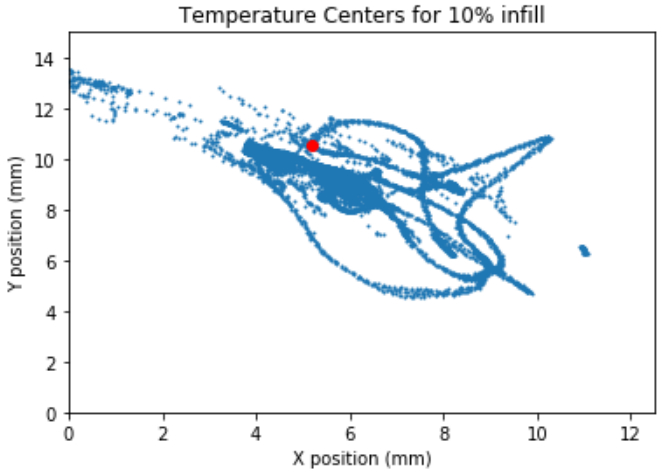


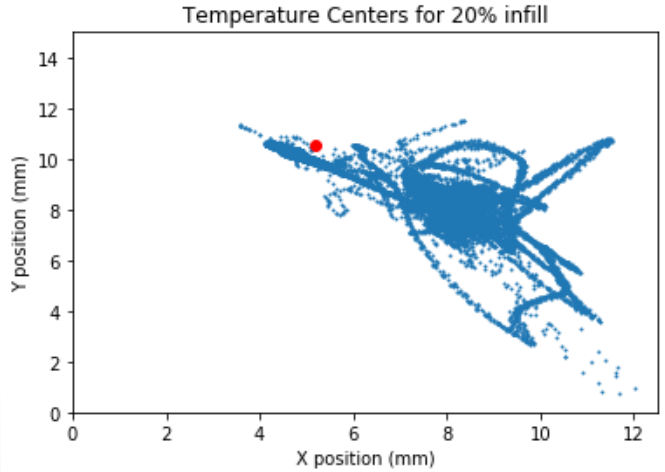
- Halfway through the printing process:
  - Embed thermistors
  - Connect to Arduino
  - Begin recording temperature

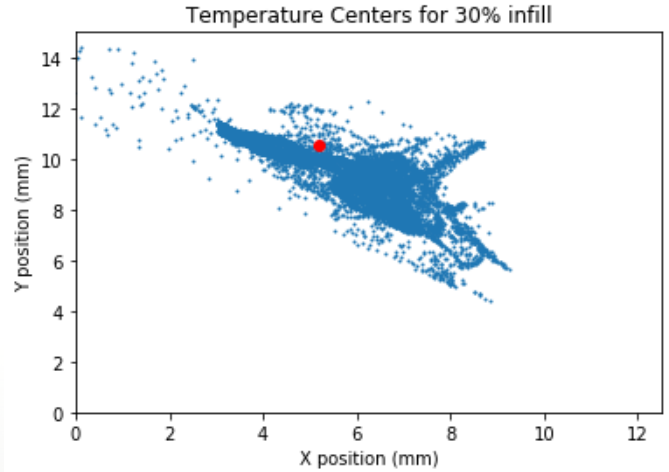
3) Modelling



- Similar to the data from junior year
- More parameters and tests → can find trends in the data
  - Deep learning (ANNs, DTW, Getis-Ord GI*, etc.)
  - Heat flow trajectory analysis

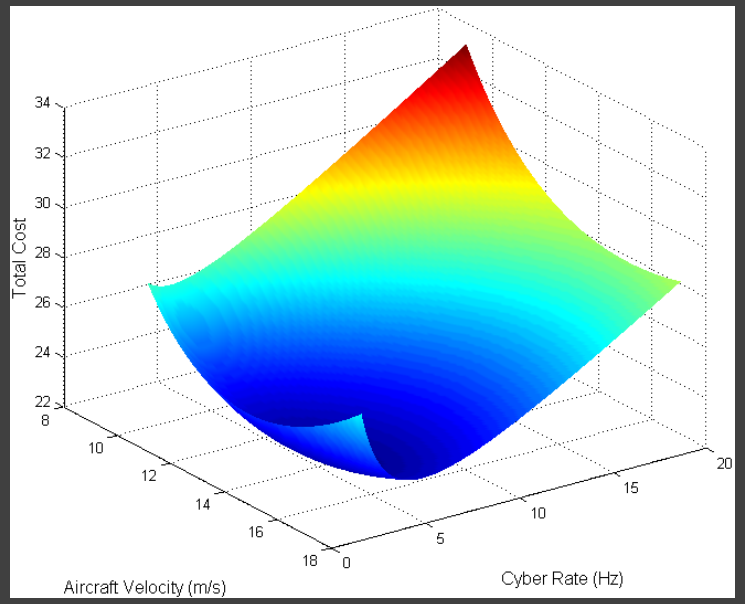

Temperature Centers for 10% infill
Y position (mm)
X position (mm)
0
2
4
6
8
10
12
14


Temperature Centers for 20% infill
Y position (mm)
X position (mm)
0
2
4
6
8
10
12
14


Temperature Centers for 30% infill
Y position (mm)
X position (mm)
0
2
4
6
8
10
12
14

4) Optimization

(a basic framework for it)



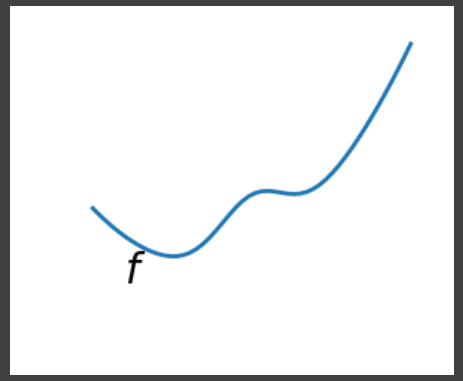
https://justinbradley.unl.edu/cps-co-optimization

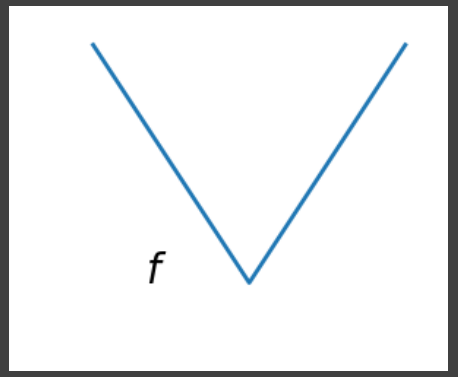
- Method will be refined later
- Optimization, simply: reducing the value of a cost function by changing some inputs

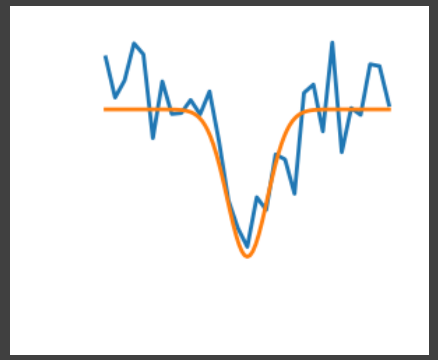
- Inputs: print parameters
- Cost function *f* : Euclidian distance from geometric center to a weighted temperature center at time *t*

4) Optimization

(a more complex framework for it)







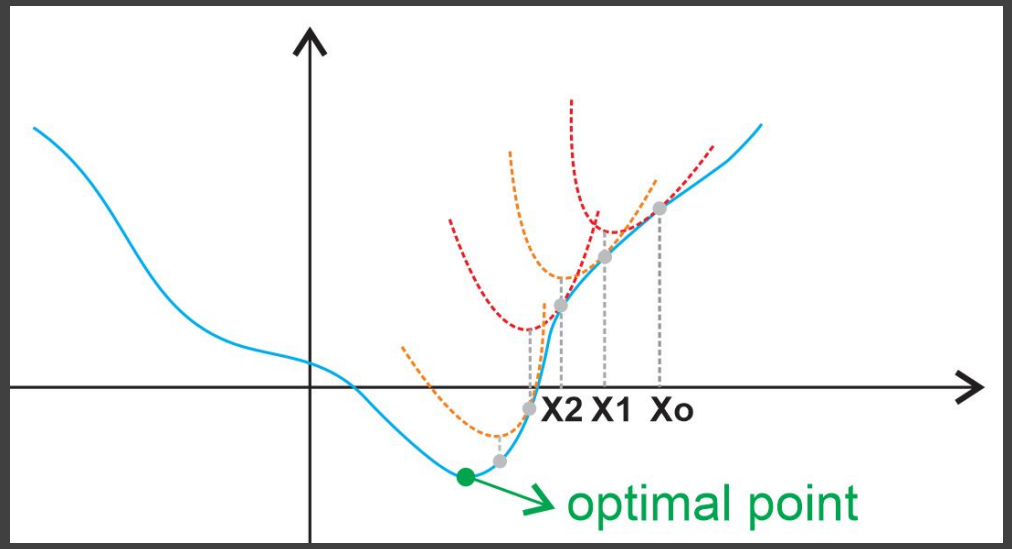
https://scipy-lectures.org/advanced/mathematical_optimization/index.html

- The full process I use depends on what the data looks like, but…
- Assuming *f* is:
  - non-convex (not always above its tangent),
  - non-smooth (gradient can be undefined at some points),
  - noisy (in blue),
  - well-conditioned (scale of input values is known)
  - and numerically unknown,

We have a very difficult problem.

4) Optimization

(a complicated framework for it)

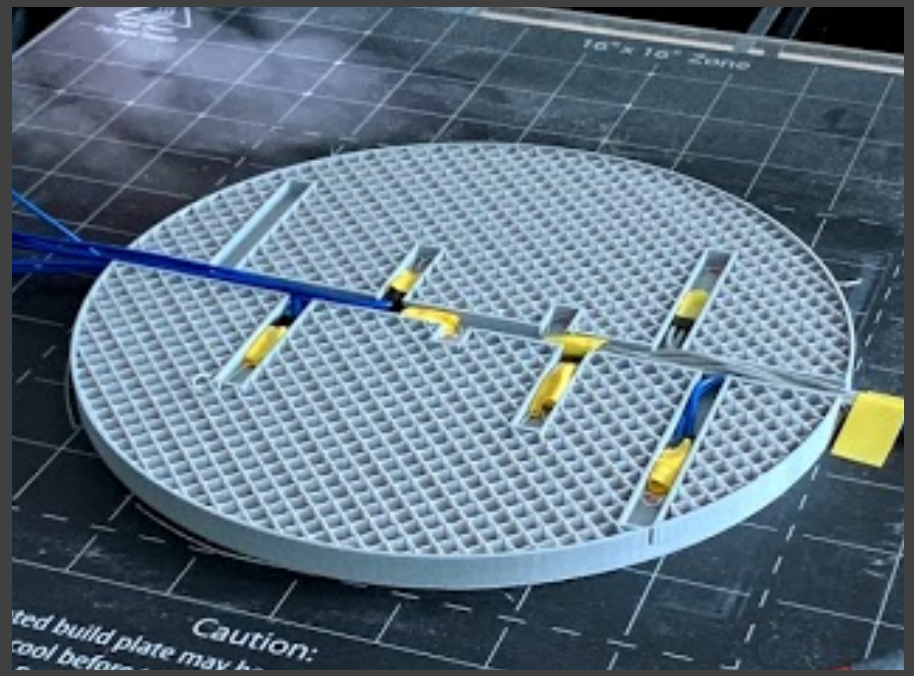


https://ardianumam.wordpress.com/2017/09/27/newtons-method-optimization-derivation-and-how-it-works/

- But we can still approach this!
- *The Newton Method:*
  - uses local quadratic approximations to find which direction to "jump" to find the minimum
  - uses the gradient and the Hessian
- *The Broyden-Fletcher-Goldfarb-Shanno algorithm* (BFGS) approximates the Hessian iteratively

This gives us a quasi-Newton method for our optimization.

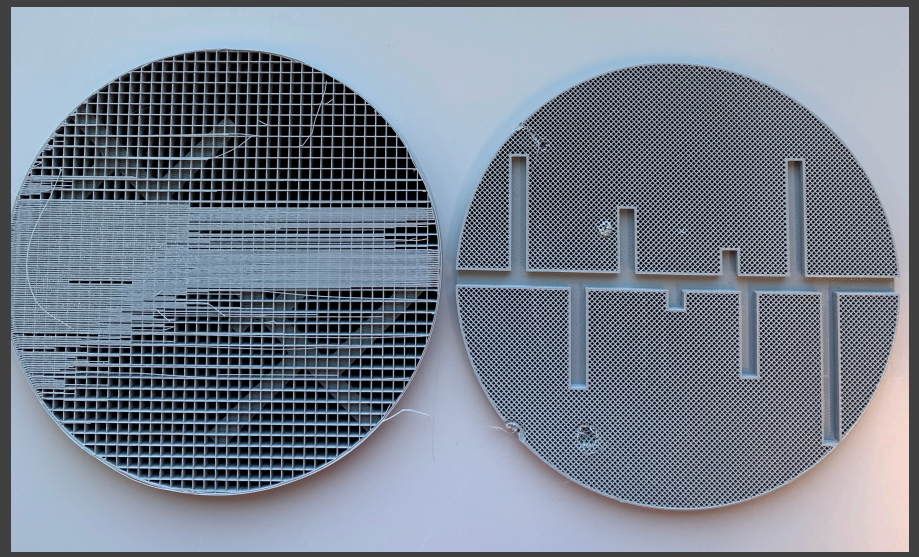
5) Final Tests



- Will print discs with the optimized parameters
- Will study the cost function and look for a statistically significant decrease

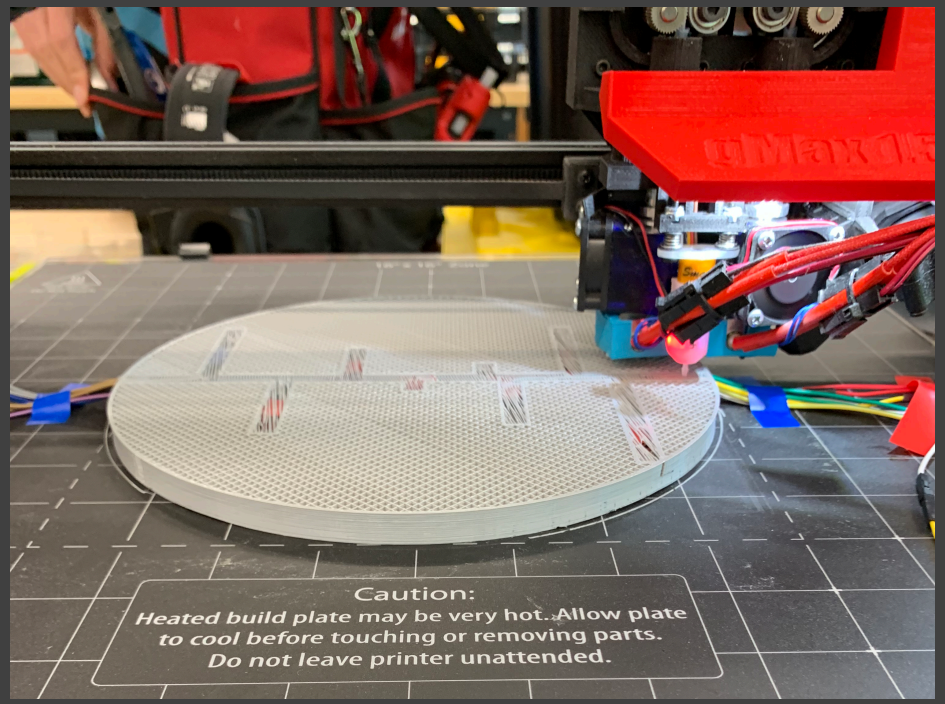
Current Progress

Junior Year Conclusions and Results



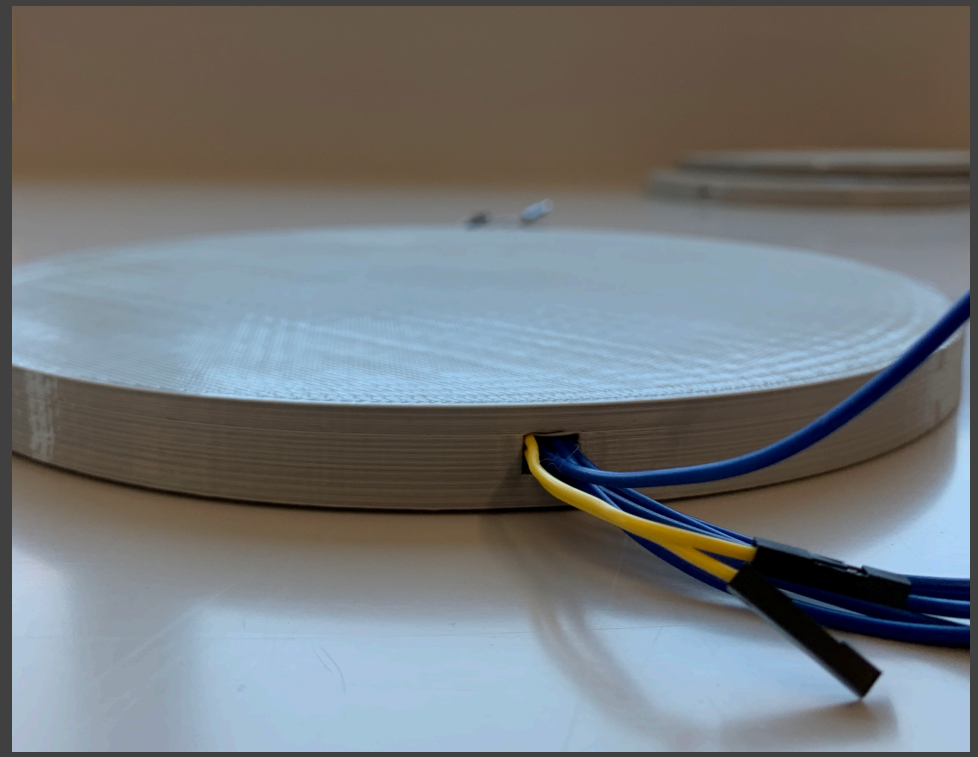
- Increasing infill percentage increases the uniformity of the temperature distribution and theoretically reduces warpage
- Designed a process to collect spatiotemporal temperature data during 3D printing
- Designed a weighted temperature centers method to analyze data

Senior Year Progress



- Completed Phase 1 (Design)
- Working on Phase 2 (Data Collection)
- Completed multiple subtasks for future phases
  - *built Arduino-thermistor circuit*
  - *explored junior year data*
  - *developed program for modelling data in Python*
  - *started setting up Jetson*
  - *fixed gCreate printer's z-axis problem*

Future Work



- Complete Phase 2 (data collection) and Phase 3 (modelling) by March 1st
  - Enough for the engineering side of the project
  - Can draw conclusions
- Complete Phase 4 (optimization) and Phase 5 (final tests) by Symposium in May
  - Computational modeling side of the project
  - Will support/oppose my conclusions

References

- Zhang, J., Wang, X. Z., Yu, W. W., Deng, Y. H. (2017). Numerical investigation of the influence of process conditions on the temperature variation in fused deposition modeling. Materials & Design, 130, 59-68. doi:10.1016/j.matdes.2017.05.040
- Deng, C., Kang, J., Shangguan, H., Hu, Y., Huang, T., Liu, Z. (2018). Effects of hollow structures in sand mold manufactured using 3D printing technology. Journal of Materials Processing Technology, 255, 516-523. doi:10.1016/j.jmatprotec.2017.12.031
- Vaughan, N. & Gabrys, B. (2016). Comparing and combining time series trajectories using Dynamic Time Warping. Procedia Computer Science, 96, 465 – 474. doi:10.1016/j.procs.2016.08.106
- Studer, M & Ehrig, F. (2014). Minimizing part warpage in injection molding by optimizing wall thickness distribution. *Advances in Polymer Technology, 33*. doi:10.1002/adv.21454