Statement of Purpose

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Who am I?

Most of my time in grad school was spent working on pure mathematics problems involving a lot of differential geometry. That was fun, but after a few years I realized that what I really loved doing wasn't math, it was, and is, using math to solve and analyze real-world problems. Once the initial excitement of being able to understand advanced mathematics wore off, I was left wanting for problems with a clear application. After grad school I decided to refocus, got a job teaching, and started using my free time to code and learn about computer vision. Actually, I started thinking about neural networks in grad school, before I knew they were a thing people actually worked on (just on paper, modeling neurons with Heaviside activation functions instead of the sigmoid functions people use – I got the idea after a neurology student gave me a talk on how brains work). A year or two later, when refocusing on CV, I learned how much success researchers were having with neural networks; I became interested, started reading papers, implementing simple networks, taking online classes, and attempting to improve on implementations of particularly cool papers/ideas (e.g. *A Neural Algorithm of Artistic Style* and *DeepDream* were my first). Over the last year I've even become a regular consumer of gpu time on Amazon AWS. In an effort to get paid to learn I've also been teaching statistics courses as often as possible – my ninth and tenth *Introduction to Probability and Statistics* classes begin this month. Ever since completing my MS in Mathematics, I've been becoming progressively more serious about machine learning, and now four years later I feel confident it's the right field for me.

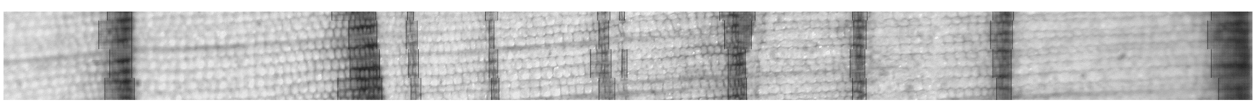
Mathematics Research (Undergraduate and Graduate Research)

My first experience with mathematical research was my Major Qualifying Project (senior thesis) at WPI. Working with the great Professor Roger Lui, myself and one other student developed a (PDE) mathematical model for fibroblast cell motility, gave an existence/uniqueness proof of a solution, and I developed and coded a numerical solver in MATLAB. We won the WPI Provost Major Qualifying Project award for Mathematical Sciences for this work. I initially intended to continue this research in graduate school, but I became interested in the field of geometry and spent a couple years doing research in pure mathematics with Professor Motohico Mulase on symplectic/complex geometry problems that came from a mathematical physics field called Eynard-Orantin theory. After about a year (sometime in my third year of graduate school) I successfully solved what Professor Mulase had originally suggested would be my PhD thesis problem: computing the Laplace transform of a generating function ("Norbury's recursion") for the number of lattice points on the the moduli space of punctured Riemann surfaces (2-surfaces that are locally isomorphic to the complex plane). I was awarded an NSF VIGRE fellowship that summer to continue my research on related problems. OK, so the thing is, I wasn't happy working on these problems. I didn't understand the underlying physics or many of the important results in the field that were based in algebraic geometry (outside my area of expertise). I wanted to work on something I could understand the motivation for. After my third year I switched my focus to mathematical physics and spent the next eight months working with a physicist on problems related to higher-spin field theory, and gauge theoretic and string theoretic electromagnetism in 5D Anti-de Sitter Space. I did find the time I spent working on these problems (and learning the basics of string theory and quantum field theory) incredibly rewarding. That said, I came to realize that the community interested in these new problems I was working on was very small. Eventually a related conversation with a senior faculty member left me with a very blunt assurance that a PhD in this area was not likely lead to a future in research. I then wrote a master's thesis[1] on a geometric topic I found interesting called Homological Mirror Symmetry and exited graduate school, confused about what I wanted to do with my career. In the following months and years, adjuncting for money, I worked on whatever I wanted. I found that I didn't ready many geometry or math physics papers. What I did with my time when given a choice was: coding, machine learning, and computer vision.

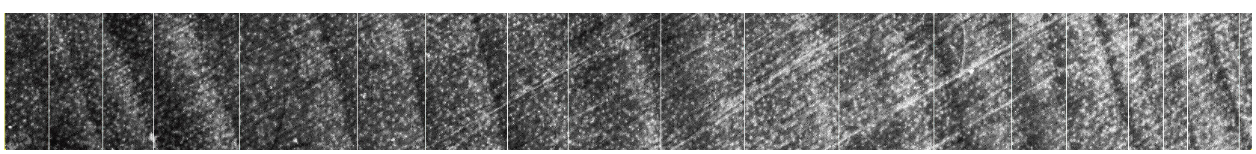
Development and Research since Graduate School

I got a job teaching math and statistics at two local community colleges and, I suppose, began a search for clarity. I spent a lot of time playing music, a lot of time coding, doing whatever piqued my interest at the time. That summer I took on a project, as the sole developer, writing software to help dendrochronologists measure/extract features of tree rings (used to predict historic rainfall) from an image of a cross-section of a tree trunk. This was an excitingly nontrivial project, involving computer vision and image analysis (I'll say more below on this), topological sorting, time-series analysis, human-error detection/correction, and required me to develop a deep understanding of Bézier curves. A graduate student, Brook Constantz, published a master's thesis, *Tree Ring Analysis of Santalum Paniculatum...* utilizing this software, which I named *SVG Dendro*[2]. Further publications pending from Brook and possibly two other groups. While working on this project I also published *svgpathtools*[3], a library of tools for performing geometric manipulations and analysis of SVG Path elements in Python. I'm proud to say this library is now actively used, and even contributed to, by other developers.

Originally I'd hoped to automatically generate a spline tracing of the tree rings. While this aspect was eventually dropped from the project. I did have some very quick initial success marking tree rings over a strip of the trunk cross-section in very nice images (e.g. figure 1a). My method was to use gradient edge detection and then eliminate of false positives by looking for an alternating pattern of changes in shading. For harder examples (e.g. figure 1b) it wasn't clear to me if even human experts could mark tree rings effectively. In fact, possibly the majority of the time spent developing SVG Dendro went towards designing code to detect, fix, and assist with fixing human error. It was a learning experience. As soon as I'd satisfied my commitment to the SVG Dendro project, I began



(a) A simple example. Markings made automatically using the gradient-based method mentioned above.



(b) A harder example. Markings made by a human expert.

working on a new project with the two goals of, firstly learning more about computer vision, secondly I wanted this project to have some potential to make money. I decided to attempt to write a VR/AR application that would allow two users to share a piece of paper (or whiteboard) in a virtual space. The users would be writing on a real/physical piece of paper/whiteboard and the virtual piece of paper/whiteboard would display any writing on either user's real piece of paper. This was a great project to motivate me to learn more about classical methods of computer vision. It inspired me to thoroughly read the O'Reilly *Learning OpenCV* book and also to take Guillermo Sapiro's online course on Image and Video Processing (I'd also already taken Andrew Ng's famous *Machine Learning* course).

[1] An Introduction to Homological Mirror Symmetry and the Case of Elliptic Curves – `https://arxiv.org/abs/1501.00730`
[2] `https://github.com/mathandy/svg-dendro`
[3] `https://pypi.python.org/pypi/svgpathtools` – if asked to pick a repository to show off my Python skills, this would be it.

As I said, this was a great learning project, but tablet-based drawing applications get better everyday while AR/VR tech is still in its infancy. I stepped away from the project about a year ago and recently open-sourced[4] the code I developed to track a piece of paper on a desk (see figure to right). The method I came up with uses OpenCV's contour finding tool on a binary thresholding of each frame (after some morphological closing) and then uses the Douglas-Peucker algorithm to approximate the convex hull with a quadrilateral. The corners are then refined. If any corners are obstructed, the unobstructed corners are used along with the previous frame's corner locations/plane to approximate the obstructed corner locations.

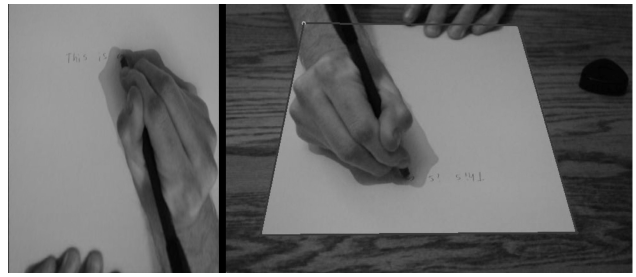


Figure 1: A detected rectangular piece of paper (with one obstructed corner) and its image after a homographic transformation.

What I want from your institution. What I can offer your institution.

I've learned a lot over the past four years about machine learning and computer vision, but more than anything, I've learned I want to learn more of it and do more with it, full-time. For the last nine years I've been employed as either a graduate student or an adjunct professor – I know that studying/working under the experts in your department will provide a much more efficient and much richer learning environment than I can achieve through my own self-guidance. In particular, I'd be ecstatic to have an opportunity to work with Professor Yong Jae Lee. I've been a fan of his work since I read his dissertation, *Visual Object Category Discovery in Images and Videos*, several years ago when I was just beginning to read machine learning literature (living in Davis, of course I checked out what CV research was happening in my town). Perhaps because his dissertation formed some of the basic ideas I have about how to go about image segmentation and unsupervised learning in computer vision, Professor Lee's research interests seem almost perfectly aligned with my own.

With that in mind I'm excitedly hoping you'll offer me admission and funding to study computer science in your department with an emphasis on computer vision and machine learning. In return for your department's funding and faculty's time, I offer a graduate student with research experience, teaching experience, firm foundation in, and comfort with, high-level mathematics.

On another note, I want to apologize for my GRE scores not being up-to-date (and, no, I don't know why my writing score was in the second percentile – I think I argued for a compromise when asked to take a position). I hope you won't judge me for admitting this, but I'm a slow test-taker. I'm not sure I'd finish the GRE without the extra 50% time I was granted previously. Unfortunately ETS is requiring me to renew my accommodation documentation and after I do will take six weeks to process my new application. If it helps my case, I received a perfect (800/800) quantitative and high (85th percentile) verbal score on the GRE when I took the exam in 2006.

To end, while I'd embrace any requirements made of me to catch-up on core undergraduate CS material, I'd like to emphasize that in addition to my strong background in mathematics and the great deal of teaching experience I possess, I also have significant coding experience – in addition to my three core undergraduate courses in CS and many undergraduate (and two graduate) courses in discrete math and numerics, I've successfully completed several large, mathematical coding projects (e.g svgpathtools, SVG Dendro, and my undergraduate thesis) and many more small CV/ML projects e.g. the tree ring tracer, rectangle/paper tracker, Classifiers2LearnWith[5].

I realize this was long for an S.o.P. – sorry about that, I'll try to make it up to you if you let me in :) Thanks for reading.

[4] `https://github.com/mathandy/rectangle_tracker`

[5] `https://github.com/mathandy/Classifiers2LearnWith` - a personal library of classification methods coded with MATLAB, scikit-learn, and TensorFlow