Skylar Artemis Sutherland

Curriculum Vitae

Education

B.Sc. — **Massachusetts Institute of Technology (MIT)** Cambridge, MA
Majors: Brain and Cognitive Sciences, Mathematics GPA: **4.7** (out of 5.0)

Publications

- **Sutherland, Skylar**; Egger, Bernhard; Tenenbaum, Joshua. "Building 3D Morphable Models from a Single Scan". In submission. Preprint available at: https://arxiv.org/abs/2011.12440
- **Sutherland, Skylar**; Egger, Bernhard; Tenenbaum, Joshua. "Learning a Generative Model of Human Faces Through Inverse Rendering". Poster presented at *Cognitive Science*, Aug. 1, 2020.

Research and Employment

Massachusetts Institute of Technology Fall 2019 – present
Research assistant at the MIT Computational Cognitive Science Group
Supervisors: Dr. Bernhard Egger (direct supervisor), Prof. Joshua Tenenbaum

- I am leading a project to computationally model the development of face perception in infants through a Gaussian process architecture similar to a wake-sleep algorithm.
- This project has involved combining many different machine learning and computer vision approaches, specifically Gaussian processes, 3D morphable models (3DMMs), Markov chain Monte Carlo (MCMC), convolutional neural networks (CNNs), and shape-from-shading.
- This project has also involved proving theorems concerning the use of Gaussian processes in novel contexts, as well as constructing software for numerical computing using these theorems.
- The software for this project was initially constructed in Scala using the Scalismo 3DMM framework. I am developing a software system for this project from scratch in Julia, Python, and C++, using the Gen library for probabilistic programming (in Julia), the Keras library for deep learning (in Python), and OpenGL for graphics programming (in C++).
- This project has heavily relied on high-performance computing, including parallel programming, GPU acceleration for both graphics and deep learning, and containerization.
- As a research assistant I have also been partially responsible for managing the Computational Cognitive Science Group. In particular, since the summer of 2020 I have been responsible for running our lab's weekly lab meetings, including scheduling research presentations.

Massachusetts Institute of Technology Spring 2019
Final project for the class: Probabilistic Programming and Artificial Intelligence
Also listed as: Advanced Topics in Computer Systems
Taught by: Dr. Vikash Mansinghka
Additional teachers: Prof. Martin Rinard, Prof. Joshua Tenenbaum

- This class was concerned with teaching probabilistic programming, a new approach to artificial intelligence and cognitive science based around the specification of generative models and associated probabilistic inference methods. Specifically, it introduced the cutting-edge probabilistic programming frameworks Gen (built on Julia) and Metaprob (built on Clojure) that Dr. Mansinghka's lab has developed.

- For my class project, I used Gen to implement a prototype probabilistic raycasting algorithm for generative voxel octrees, a novel class of generative models of 3D shapes based on sparse voxel octrees that I had earlier proposed for my class project in the course "Computational Cognitive Science" (described below).

Massachusetts Institute of Technology Fall 2018
Final project for the class: Aspects of a Computational Theory of Intelligence
Taught by: Prof. Shimon Ullman, Prof. Tomaso Poggio

- In this class project, I and my fellow student Yasmin Siahpoosh studied whether a recurrent CNN could be trained to perform mental rotation via a human-like iterative process.

- Using a dataset of wireframes that I had previously produced for my final project in the class "Machine-Motivated Human Vision", we attempted to train a CNN to perform an incremental rotation, i.e. map an image I_1 of a wireframe to an image I_2 of that wireframe rotated by a small amount in a consistent direction. We used as a loss function ℓ_2-distance in the latent space produced by a late stage of a classification CNN retrained on one of the wireframe datasets. This enabled us to train our recurrent CNN for a single iteration, avoiding the vanishing gradient problem.

- We found ambiguous results; while the resulting recurrent CNN did seem to be able to represent the 3D shape of the input wireframes to some degree, it did not produce rotated wireframes, but rather highly out-of-sample images tuned to the precise feature set of the classification CNN used in the loss function.

Massachusetts Institute of Technology Fall 2018
Final project for the class: Statistical Learning Theory and Applications
Taught by: Prof. Tomaso Poggio

- In this project I performed a mathematical analysis of what the weights in a single-layer autoencoder with ReLU activation functions represent about the input distribution, extending the existing result (see e.g. "From Principal Subspaces to Principal Components with Linear Autoencoders" (Plaut, 2018)) that a single-layer autoencoder with linear activation functions performs principal component analysis on its input.

- Based on my results, I argued that the better performance of deep neural networks with ReLU activation functions over those with sigmoidal activation functions was not purely due to the vanishing gradient problem; rather, the ReLU activation function also provides regularization, similar to the use of dropout layers.

Massachusetts Institute of Technology Summer 2018
MIT Undergraduate Research Opportunities Program
Supervisors: Prof. Ilker Yildirim (direct supervisor), Prof. Joshua Tenenbaum
Project title: Pose Perception of Humans and Animals

- This project was concerned with the problem of creating generative models of body poses in humans and animals for use in analysis-by-synthesis models of pose perception.

- This research made use of the SMPL (Skinned Multi-Person Linear Model) generative model of human body shape, and the SURREAL (Learning from Synthetic Humans) framework.

Massachusetts Institute of Technology Spring 2018
Final project for the class: Machine-Motivated Human Vision
Taught by: Prof. Pawan Sinha

- In this class project, I studied the question of whether a purely feedforward CNN (using only 2D representations) could perform mental rotation tasks, i.e. correctly determine whether two images were images of two different novel objects, or of the same novel object seen from two different viewpoints. In humans this task is performed through mental rotation, an iterative process involving the 3D rotation of a reconstruction of one of the depicted objects.
- To perform this experiment I wrote simple 3D rendering software in Matlab to generate two datasets of synthetic wireframe images. I then retrained AlexNet (using Matlab's deep learning toolkit) on one of these datasets, and classified images from the second dataset by performing k-means clustering on the latents produced by a late stage of the retrained CNN. I found that this classification model was able to perform the mental rotation task with near-perfect performance.

Massachusetts Institute of Technology Fall 2017
Final project for the class: Computational Cognitive Science
Taught by: Prof. Joshua Tenenbaum

- For this class project I outlined a novel probabilistic representation of 3D shape—generative voxel octrees—and an associated algorithm for rendering 2.5D depth maps from a generative voxel octree through raycasting.
- This research was based on sparse voxel octrees (see e.g. "Efficient Sparse Voxel Octrees – Analysis, Extensions, and Implementation" (Laine and Karras, 2010)), a type of voxel-based representation of 3D shapes. In a sparse voxel octree, only the voxels which are visible to the camera (as determined by a raycasting algorithm) are included at full resolution; invisible regions are stored using a lower resolution. In a generative voxel octree, the shape is not known ahead of time; rather, each low-resolution voxel is subdivded into higher-resolution voxels probabilistically.
- I argued that this representation could enable efficient inference of full 3D shape from a depth map through analysis-by-synthesis. This is because the specific subdivision of a generative voxel octree into high- and low-resolution voxels can be deterministically computed from a depth map, and given such a subdivision the probabilistic component of the generative voxel octree becomes simply a tree-structured Bayesian network.

Massachusetts Institute of Technology Spring 2017 & Summer 2017
Final project for the class: Laboratory in Psycholinguistics
Continued with the MIT Undergraduate Research Opportunities Program
Taught by: Prof. Edward (Ted) Gibson

- In this project I replicated and extended Prof. Gibson's paper "Memory Limitations and Structural Forgetting: The Perception of Complex Ungrammatical Sentences as Grammatical" (Gibson and Thomas, 1999)). This paper studied the parsing of sentences with nested relative clauses. I extended it to also include sentences with nested relative clauses in the object rather than the subject.
- To gather data for this experiment I used Amazon Mechanical Turk, and performed a statistical analysis of the resulting data using R. The lists of questions shown to participants were ordered using a Latin square, with the total number of participants determined using a power analysis, and data was analyzed (after z-scoring) with linear mixed-effects regression.
- Since the results obtained were surprising in light of previous hypotheses about structural forgetting, I briefly continued this project in the summer of 2017 through the MIT Undergraduate Research Opportunities Program.

Massachusetts Institute of Technology Summer 2016
MIT Undergraduate Research Opportunities Program
Supervisors: Dr. Jeremy Kepner (direct supervisor), Prof. Alan Edelman
Project title: Mathematical Solutions for Canonical Neural Network Problems

- This project sought to mathematically model of the learning process (as opposed to the runtime behavior) of simple neural networks as dynamical systems with differential equations.
- The larger goal of this research was the creation of benchmarks with mathematically-described learning rates for canonical learning problems, such as MNIST digit classification.

Massachusetts Institute of Technology Summer 2015
MIT Undergraduate Research Opportunities Program
Supervisors: Dr. Jeremy Kepner (direct supervisor), Prof. Alan Edelman
Project title: The Mathematics of Big Data

- I assisted Dr. Jeremy Kepner and Hayden Jananthan with their book *Mathematics of Big Data*, published by the MIT press in 2018. This book presented a novel mathematical framework for combining matrices, graphics, databases and spreadsheets based around associative arrays.
- I proved several basic lemmas (mainly concerned with abstract algebra) for this book, and wrote a draft of one of its chapters laying out my contributions. I additionally created several of this book's figures and assisted in editing it.