CaCTüS Internship Projects 2024

The projects are thematically sorted by their main focus on:

- Data Analysis
- Human Experiments
- Machine Learning
- Neuroscience

However, most projects span several methods and areas of research, so you are advised to read through all projects and their specific requirements.

Data Analysis

Project: Modeling brain-wide communication at cellular resolution
Project ID: DA-01
Lab: Systems Neuroscience & Neuroengineering
Area: Data Analysis, Machine Learning, Neuroscience

In the RoLi lab we are interested in how animals' internal state influences behavior. For example, why does the response to a stimulus change when an animal is asleep vs. when they are awake? How does the brain implement this type of state- dependent, flexible computation? To study this, we record brain-wide neural activity at cellular resolution in freely behaving zebrafish and use computational methods to relate neural activity to behavior.
As an intern, you will analyze large-scale neural imaging data. Specifically, you will determine how well various models are able to describe communication between neural populations, which is critical for generating behavior. You will explore extensions of these models that incorporate internal state variables in order to study how state modulates communication between neurons. Models will be evaluated not only by their prediction accuracy, but also by their biological interpretability. For more background on these methods and topics, please see this review: Semedo et al., *Current Opinions in Neurobiology*, 2020.

Required skills:

- familiarity with basic machine learning methods (e.g., regression)
- strong foundation in math/statistics, particularly linear algebra
- experience programming in Python, Julia, or similar

Project: Understanding the properties of natural scenes: Image registration, data augmentation, dimensionality reduction and visualization
Project ID: DA-02
Lab: Sensory and Circadian Neuroscience
Area: Machine Learning, Data Analysis

In our lab, the Max Planck Research Group Translational Sensory & Circadian Neuroscience (https://-tscnlab.org), we focus on understanding how light impacts human physiology and behaviour. We combine experimental methods where we examine physiological responses to light using physiological, psychophysical and neuroendocrine methods, with characterizing and modelling environmental light exposure. Our special focus is on a set of cells in the back of the eye that express the blue-sensitive photopigment melanopsin, which signals light intensity independent of the cones and rods.

As an intern, you will be working on a data set we have been collecting across the globe that captures what the world looks like to the human photoreceptors (https://www.scenes-dataset.org/). You will be developing novel techniques to align and compare data from different imaging techniques, augment RGB images with

multispectral information, use dimensionality reduction techniques, and generate visualizations of large-scale data.

Required skills:

- good coding skills in Python
- experience in image processing and/or computer vision
- experience in version control with git
- ability to communicate complex technical results

Human Experiments

Project: Human-AI symbiosis for ethical decision-making: Insights from neurophysiological studies
Project ID: HE-01
Lab: Organizational Leadership & Diversity and Bioinspired Autonomous Miniature Robots
Area: Human Experiments, Data Analysis (Neurophysiological Data)

In our lab, we focus on exploring the nature of leadership in the artificial intelligence (AI) age and on how to develop ways to mitigate bias in human-machine collaboration. The overarching goal of the project you will be part of is to explore cognitive and neurophysiological mechanisms that shape and potentially enhance ethical decision-making within human-AI collaboration. The project encompasses three key areas: (I) leveraging explainable AI (XAI) from the user perspective; (II) the application of the dual-process theory of cognition to the field of human-AI interactions; and (III) neurophysiological studies in the domain of XAI.

As an intern, you will participate in the execution of human experiments and conduct data analysis resulting from these (pilot) experiments aimed to explore brain activation and eye-movement patterns of AI users when supported by AI explanations in AI-assisted decision making. You will learn to conduct neurophysiological data preparation (cleaning) and analysis. On the side, you will have the opportunity to learn how to formulate theory-based hypotheses, and how to prepare human experiments to test such hypotheses.

Required skills:

- good coding skills in Matlab, and Python or R
- good knowledge of statistics
- major in cognitive neuroscience, knowledge of brain imaging techniques and/or eye-tracking data analysis is preferable but not a must

Project: Investigating human neocortical memory formation
Project ID: HE-02
Lab: Brain States for Plasticity
Area: Human Experiments

The Brain States for Plasticity Group aims to understand how information is encoded and stored in the human brain from a systems level perspective and how different brain states like wakefulness, sleep and transitional states shape this process. To answer these questions, we combine behavioral paradigms with multimodal neuroimaging methods (fMRI, dwMRI, sMRI, EEG) and multivariate analysis techniques.

As an intern, you will be working on a research project that investigates how repeated reactivation of information (e.g. rehearsal during wakefulness, spontaneous reactivation during sleep) contributes to the rapid build-up of memory traces in the human neocortex and how these memory traces are distributed across the neocortical network. As part of your internship, you will be involved in optimizing the experimental paradigm, collecting behavioral and MRI data and analyzing the behavioral data. You will gain insight into the main preprocessing and analysis steps of fMRI data and learn about different MR biomarkers that can detect the

formation of a memory trace. Depending on your motivation and expertise, you will have the opportunity to also conduct (multivariate) MR data analysis.

Required skills:

- background in Neuroscience, Psychology, Cognitive Science or similar
- good coding skills in Matlab, R or Python (preferably the first)
- good foundation in statistics

Project: Ocular accommodation and retinal image quality under polychromatic illumination
Project ID: HE-03
Lab: Sensory and Circadian Neuroscience
Area: Human Experiments

In our lab we study the effects of light on human physiology and behaviour. We aim to understand how light is processed by non-image-forming visual pathways in the brain and how this impacts the human circadian clock and other physiological processes.

As an intern, you will be working on a project studying the effects of the optical aberrations of the human eye on ocular accommodation and retinal image quality under polychromatic illumination. This will involve mainly experimental work, but possibly also simulation of retinal images and computation of image quality metrics using existing toolboxes. You will learn to develop and run an experimental procedure, use relevant instrumentation in the lab (refractometers, eye-trackers, spectroradiometers), collect data with human subjects, and analyse time series data.

Required skills:

- basic coding skills in Matlab or Python

Machine Learning

Project: Evaluating The Promise of Language Model Watermarking for Real-World Usecases
Project ID: ML-01
Labs: Deep Models and Optimization and Safety- and Efficiency-aligned Learning
Area: Machine Learning

Our labs are interested broadly in both efficiency considerations (DMO group, Antonio Orvieto) and safety considerations (SEAL group, Jonas Geiping) in modern machine learning, and we hence are interested not only in understanding and improving state-of-the art deep learning models, such as large language model, but also in methods to reduce harm arising from the use of these models.
A first strategy to reduce harm through large language models (LLMs) is to detect machine-generated text. This task of detection is made tractable through methods like watermarking of generated text. However, most comparisons of watermarking algorithms focus on simple text completion scenarios that are quite far from real-world usecases in which one might want to detect machine-generated text, such as Amazon reviews or Twitter posts.

As an intern, you would prompt LLMs to generate watermarked text in real-world usecases. Then, you would analyze the quality and reliability of watermarking schemes in benign and malicious threat models, to clarify the question to what extent watermarks are a tool for harm reduction.

Required skills:

- good coding skills in Python
- great command of the English language, necessary to improve and analyze text model outputs
- interest in Nature Language Processing with Large Language Models

Project: Surface recognition with an ML-enabled audio-based tactile sensor
Project ID: ML-02
Labs: Haptic Intelligence and Autonomous Learning
Area: Machine Learning

The Autonomous Learning Group focuses on developing autonomous systems that learn about their environment in a data-efficient and self-motivated way. We believe that an elaborate sense of touch is essential for this goal, to efficiently collect information about the physical interactions a robot has with its environment. For this purpose, we develop our own robotic touch sensors [1,2] in collaboration with the Haptic Intelligence Department.

As an intern, you will be working on extending our existing miniature vision-based tactile sensor [2] into the high-frequency vibration domain. The current sensor delivers accurate information about static normal and shear forces with a frame rate of 60 Hz. However, detecting and recognizing the texture of surfaces the sensor slides along requires faster haptic measurements. We developed an extension to [2], which captures high-frequency information via a MEMS microphone. During the internship you will validate this new sensor design by collecting contact data for different object surfaces and developing a processing pipeline to recognize the surface being touched. You will learn about tactile sensing in robotics and machine learning for time-series analysis, as well as get into contact with real robots and meet many fun people.
[1] A soft thumb-sized vision-based sensor with accurate all-round force perception
[2] Minsight: a fingertip-sized vision-based tactile sensor for robotic manipulation

Required skills:

- basic coding skills in Python (preferred) or Matlab
- willingness to conduct physical experiments
- data analysis knowledge

Project: Training Dynamics in Language Models
Project ID: ML-03
Labs: Deep Models and Optimization and Safety- and Efficiency-aligned Learning
Area: Deep Learning, Optimization

In our lab (Antonio Orvieto, Deep Models and Optimization Group), we focus on theoretical insights addressing the challenges of training modern deep learning models, using tools from optimization theory and statistics. An important topic in AI today is language models (ChatGPT, Llama, etc.): neural networks based on the transformer architecture, pre-trained on massive text data, and capable of performing a diverse set of tasks after fine-tuning. Training transformers is known for its difficulty, requiring numerous techniques, extensive hyperparameter adjustments, and significant computational resources. *Developing improved optimization methods is crucial to make the training process more accessible to scientists and engineers with limited resources.*
We are joining forces with the Safety- and Efficiency-aligned Learning Group (Jonas Geiping), focusing on safe and effective training of transformer-based models, to provide advances in this direction.

As an intern, you will be working on designing and testing optimizers on transformer models, gathering insights on training dynamics, interesting phenomena, and best practices. In particular, starting on a setup that allows for easy experimentations, you will have the opportunity to develop a clear understanding of the challenges

behind training state-of-the-art language models and to design improved solutions with safety and speed as top priorities. An exciting initial direction is to benchmark a few new adaptive or second-order optimizers for transformers proposed in the last year, e.g., Lion and Sophia – testing their limitations and providing an in-depth analysis of their behavior.

Required skills:

- good coding skills in Python and knowledge of libraries such as Torch or Jax
- basic knowledge of machine learning concepts
- working knowledge of the structure of transformer models
- interest in sequential data (e.g., text)
- experience in training language models is a plus

Neuroscience

Project: Data-driven discovery of functional subnetworks in the brain of freely moving zebrafish involved in social behaviors
Project ID: NE-01
Lab: Systems Neuroscience & Neuroengineering
Area: Neuroscience, Machine Learning, Data Analysis

Our lab focuses on recording large scale brain activity in freely moving zebrafish. We use this data to understand how the brain controls behavior.

As an intern, you will be working on discovering dynamical subsystems in whole brain activity data, using unsupervised methods such as dynamic mode decomposition, Koopman analysis, and reduced order models (see work and teaching from S. Brunton and N. Kutz). You will then interpret these results using zebrafish anatomy, and correlate activity in these networks with behavior, with a particular focus on social behaviors such as aggression. This will help develop testable models of neuronal interactions.

Required skills:

- good coding skills in Python
- good notions of dynamical systems modeling