CaCTüS Internship Projects 2023

The projects are thematically sorted by their main focus on:

- Machine Learning
- Theoretical Neuroscience
- Cognitive Computational Science
- Human Experiments

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

Machine Learning

Project: Understanding the composition of obsessive-compulsive disorder (OCD) symptoms
Project ID: ML-01
Labs: Computational Psychiatry Lab & Computational Neuroscience
The computational psychiatry lab, led by Tobias Hauser is interested in understanding the cognitive and neural mechanisms underlying psychiatric disorders. We combine human experiments with neuroimaging methods and computational modeling to understand how and when mental disorders emerge.

As an intern, you will spearhead our efforts into understanding symptom organization in OCD, a common but understudied mental health disorder. You will address this question by analyzing large questionnaire datasets, interrogating OCD forum discussions using large language models, and analyzing interview transcripts. Using supervised and unsupervised machine learning methods and cutting-edge large language models, you will learn to interrogate complex data to derive clinically relevant answers in psychiatry.
Required skills:

- excellent coding skills in Python
- experience with machine learning methods
- experience with large language models (e.g., NLPs)
- interest in psychiatric disorders and relevant topics in computational psychiatry

Project: Characterizing behavioural dynamics in larval zebrafish
Project ID: ML-02
Labs: Systems Neuroscience & Neuroengineering & Computational Neuroscience
Behavior is dynamic and complex, showing organization at multiple spatiotemporal scales. How can we best characterize behavior quantitatively? In this project, you will work on a collaborative project with Jennifer Li and Drew Robson (RoLi lab), who use imaging methods to record and manipulate neural activity in freely swimming larval zebrafish, and Kevin Lloyd (Dayan lab), who uses computational models to study decision-making.

As an intern, you will be working on modeling how the behavior of zebrafish changes as they forage for food, and will learn about quantitative methods for characterizing these behavioral dynamics, including latent state space analysis and dimensionality reduction techniques.
Required skills:

- good foundation in math/statistics
- good coding skills in Python, Julia, or C/C++

Project: Reinforcement learning for object manipulation
Project ID: ML-03
Lab: Autonomous Learning

In our lab we focus on developing reinforcement learning methods for data-efficient and self-motivated learning. Our aim is to create learning robots that can become dexterous and quickly learn new skills, such that they can be valuable assistants to humans,

As an intern, you will be working on applying our latest reinforcement learning methods, e.g. [1] on different robotic systems, both in simulation and on real robots. For instance, we have a battery of manipulation platforms here at the institute, as used in our real-robot challenge [2]. These are highly agile and high-performance robots that are easy to use and do not require extensive hardware experience. You will be learning about reinforcement learning methods and supervised learning methods for dynamics prediction as well as get into contact with real robots and meet many fun people.

Required skills:

- computer science background
- good coding skills in Python
- machine learning knowledge

[1] Curious Exploration via Structured World Models Yields Zero-Shot Object Manipulation: https://al.is.mpg.de/publications/sancaktaretal22
[2] https://real-robot-challenge.com/

Project: Physics-based methods for efficient transport network design
Project ID: ML-04
Lab: Physics for Inference and Optimization

Optimal transport of resources in complex networks is a central issue in many real-world problems. These range from the compelling design of smart urban transportation systems for cities of the future, which have to meet efficiency, sustainability, and economical requirements, to the study of natural selection mechanisms shaping ecosystems systems, e.g., venation of leaves, deltas of rivers.
In the Physics for Inference and Optimization group we address such application-oriented problems by developing models derived from statistical physics principles. In particular, we combine Optimal Transport theory, routing algorithms, and network science, to simulate path-selection mechanisms, and we study the emerging patterns deriving from our models.

As an intern, you will learn about Optimal Transport theory and its connection to transportation networks. Furthermore, you will work with real datasets from domain-specific applications, and study them with numerical simulations and analytical derivations.

Required skills:

- familiarity with mathematics at STEM undergrad level (e.g., notions of differential calculus, basic concept of statistics and probability)
- programming experience with one (or more) between: Python, C++, Julia, or similar
- good English communication and team work skills, adequate to a collaborative work environment

Project: Latent network models to unravel the hidden structure of social network datasets
Project ID: ML-05
Lab: Physics for Inference and Optimization

Networks are flexible tools to study complex systems, i.e., systems that consist of many individual elements with intricate interactions among them. Notably, the increasing production and availability of data have significantly promoted the development of models in this area.

A popular approach to model networks is that of generative models, namely, probabilistic models where latent variables are introduced to incorporate domain knowledge and capture complex interactions. Specifically, the structural information is included in the model through latent variables. In particular, these models enable us to incorporate different types of interactions and attributes of the individual elements, to infer the unobserved structures; in addition, they predict the existence of unobserved interactions.

In this project, we develop network generative models that incorporate domain information, such as community membership and reciprocity, to increase their predictive power, to overcome the limitations of the standard algorithms. To this end, we need to relax some of the restrictive assumptions behind the widely-used models. The aim is to develop principled theoretical models, and simultaneously, provide efficient algorithmic implementations to tackle concrete applications like reciprocity and multiplexity.

Required skills:

- a good background in probability and statistics
- programming experience with one (or more) of: Python, R, C++, or similar
- a good written and oral command of English and excellent team working skills are essential

Theoretical Neuroscience

Project: A hidden dimension of the visual world: Analysis of melanopsin signals in natural scenes
Project ID: TN-01
Lab: Translational Sensory & Circadian Neuroscience

In our lab, the Max Planck Research Group Translational Sensory & Circadian Neuroscience, we focus on understanding how light impacts on human physiology and behaviour. We combine experimental methods where we examine physiological responses to light using physiological, psychophysical and neuroendocrine methods, with characterizing and modeling 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 novel data set capturing the spectral, temporal and spatial dimensions of the visual world that surrounds us. You will be learning techniques for processing and handling different data sets, linking environmental light data with human physiological responses, and developing summary statistics and other analytic strategies for capturing the complexity of the visual environment.

Required skills:

- good skills in Python
- understanding of image processing techniques
- experience in version control with git

Project: Reinforcement Learning (RL) models for spatial navigation
Project ID: TN-02
Lab: Computational Neuroscience

In our lab we focus on computational neuroscience with a strong RL emphasis. We determine equations that govern behaviors, in particular ones that are reinforced or shaped according to the interaction with a rewarding environment. Knowing where we are and being able to successfully navigate in any environment are crucial abilities for survival, therefore spatial navigation behaviors are well suited to be modelled within an RL framework. In particular, it enables to understand how spatial information can be linked to action selection in order to generate a trajectory.

As an intern, you will be working on implementing and/or fitting an RL model for spatial navigation in Python. You will learn to link equation and behavior, discretize it in a way that can be implemented, and compare the behaviors of the agents to the ones of rodents in spatial navigation tasks.

Required skills:

- Python from 'beginner' level

Cognitive Computational Science

Project: Leader Emergence and Intersectional Identities
Project ID: CC-01
Labs: Human and Machine Cognition Lab & Organizational Leadership & Diversity

Recent economic, technological, and societal changes require organizations to adapt to the transforming nature of work by challenging assumptions, changing corporate cultures, and altering the way work is performed. In order to understand why and how people emerge as leaders in teams and organizations, we need to have a deeper understanding of human behavior. Therefore, in collaboration with the Human and Machine Cognition lab, we are investigating how computational models can be effectively used to develop and test theories from leadership and organizational behavior. The research is highly interdisciplinary and combines theory, agent-based simulations, and human behavioral experiments. Specifically, we aim to investigate how diverse leaders can benefit organizations, and which organizational principles can select the best leaders and avoid marginalizing persons from underrepresented backgrounds with intersectional identities (i.e., looking beyond one diversity dimension).

As an intern, you will be working on the expansion and improvement of the computational model for agent-based simulations as well as having the possibility to work on human behavioral experiments. You will learn how to work with real world data and help to implement computational modeling to the field of organizational behavior, as this is an exciting and newly emerging area of research.

Required skills:

- strong coding skills in R
- interests in computational modeling and/or human experiments
- good communication and team work skill

Project: Measuring the level of compositionality in sequences
Project ID: CC-02
Lab: Computational Principles of Intelligence

This interdisciplinary research group of cognitive scientists, neuroscientists, and computer scientists develops computational models of human intelligence. The goal is to build formal theories of how people learn, generalize, explore, and find approximate solutions in complex and richly-structured environments.

In this project, you will study the question: how to measure the level of compositionality in an environment. Perceptual sequences contain repeated patterns. Humans are good at identifying those patterns, extrapolate them as perceptual units, and construct a compositional structure to understand those structures, thereby leveraging unbeknown tasks and novel environments. You will conduct literature search and review in this topic, formulate a measure of compositionality, and compare and measure the performance of pre-existing learning algorithms on environments with various levels of compositionality measures.

Required skills:

- good coding skills in Python
- communication and team work

Human Experiments

Project: Forward and Backward models of confidence in hybrid decision-making
Project ID: HE-01
Lab: Computational Neuroscience

In every-day decisions which involve multiple systems of decision-making, people monitor their mistakes and can report how confident they are about their choices. These metacognitive assessments of decision quality are important for the guidance of behavior, particularly when people are learning the values of options at the same time as they are making their decisions. However, we currently lack a computational framework that accounts for meta-cognitive sensitivity in multiple-system decision-making. The currently available methods are limited to the cases with deterministic and stationary reward. We will build and fit extended computational models of metacognition to human data in decision-making tasks with dynamic rewards that engage multiple decision-making systems.

As an intern, you will work with human data, learn to simulate basic reinforcement learning models and fit the models to human data. You would also have the experience of thinking about cognitive aspects of human behavior and explaining them via computational modeling.

Required skills:

- good coding skills in R, Matlab or Python (the first is preferred)
- primary experience or knowledge of working with data and computational modeling

Project: Assessing team dynamics in stressful situations
Project ID: HE-02
Lab: Haptic Intelligence

Our lab is renowned for research on haptic interfaces, robotic touch perception, and human-robot interaction, frequently with applications in health. We draw inspiration from the amazing capabilities of humans and seek to understand and support them through technology. Recently, we have become fascinated with human-human interactions, especially in the context of stressful collaborative situations, and we want to gain a better understanding of team dynamics.

As an intern, you will design and run a collaborative experiment to test team behavior hypotheses of your own, supported by the literature and input from your mentors. For example, you could design an escape game to evaluate how different levels of stress affect problem-solving skills, looking for characteristic patterns of collaboration and communication. We have created a platform in C# that will help you collect real-time audio, video, position, orientation, and physiological data during your experiment. You are welcome to extend it with new sensors (e.g., eye tracking, electrodermal activity), visualization methods, and algorithms. You will test your hypotheses by analyzing your collected data set. Then hopefully you will co-author a conference or journal paper about your methods and results.

Required skills:

- creativity and interest in conducting experiments with human participants
- good computer programming skills in C#
- experience with data analysis in Python, R, or MATLAB, ideally including basics of digital signal processing and statistics
- good communication and team work skills

Project: Psychophysiological measurements of alertness
Project ID: HE-03
Lab: Translational Sensory & Circadian Neuroscience

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.

As an intern, you will be working on a project studying different psychophysiological measurements of alertness, which is a crucial variable when assessing potential delays to the human sleep-wake cycle. One of the main tests we use in the lab for this purpose is the psychomotor vigilance test (PVT), which is a reaction time test that can come in different modalities (e.g., visual, auditory). While this is among the most widely used assessment methods of behavioral alertness in the field, it can often be lacking in standardization and measurements of accuracy for specific hardware. For this project, you will learn to implement this test in different modalities, and to collect and analyse data with human participants. Other methodologies that might be included in the project are eye-tracking and pupillometry, wrist-worn actigraphy, measurements of core body temperature, and other psychophysical tasks.

Required skills:

- basic coding skills (e.g., Python, MATLAB, R)
- basic experience on data analysis