Portfolio

MSc Projects

Bayesian Intelligent Autonomous Systems lab

March 12, 2023

1 Cocktail party problem

Problem description

You are challenged to design an agent that learns to solve the cocktail party problem through on-the-spot interactions with a (human) listener. The cocktail party problem refers to the issue of not being able to understand your conversation partner in the presence of many simultaneously competing voices (Fig.1). The learning protocol is displayed in Fig.2. A listener wears earbuds that are capable to process audio signals in real-time (like hearing aids). In response to a detected problem, the agent proposes the most promising alternative parameter settings for the audio algorithm (the TRY step). Next, the new audio algorithm is executed in the ear buds and evaluated by the listener (EXECUTE and EVALUATE steps). Based on the listener's appraisal, the agent should now update its model of the world (LEARN step). This design loop repeats in real-time until the listener indicates that the problem has been solved.

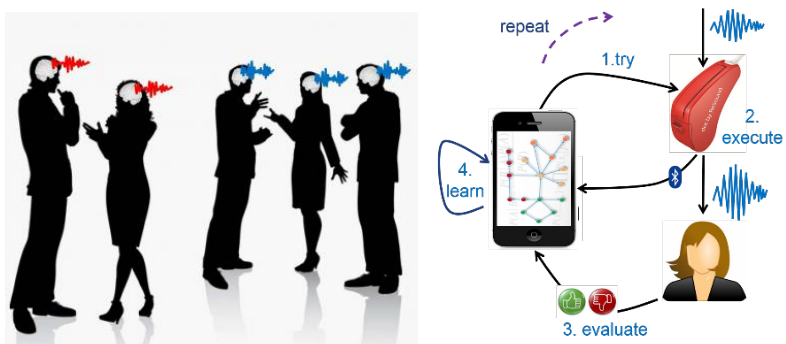

Figure 1: (Left) Cocktail party. (Right) Hearing aid.

Student task description

This project will get you involved with the latest artificial intelligence methods, since the agent needs to (1) learn from each interaction and (2) be smart about selecting the most promising algorithm candidates. It will also give you an opportunity to learn about how biological brains solve real-time design issues.

Concrete tasks:

- Familiarize yourself with the literature on Active inference.
- Discuss problem and solution proposal with researchers at BIASlab.
- Implement solution proposal using BIASlab resources.
- Experiment with the implementation and compare to current solutions.

- Analyze results and reflect on what has been achieved.
- Write a report detailing the advantages and limitations of this approach.

Project positioning

The Bayesian Intelligent Autonomous Systems lab BIASlab (http://biaslab.org, FLUX-7.060) is a subgroup of the Signal Processing Systems (SPS) that aims to develop Intelligent Autonomous Agents. These agents interact with their environment through their sensors and actuators in order to learn purposeful behavior, e.g., to navigate, play soccer or they may learn to decode speech signals under bad acoustic conditions. Our research projects are inspired by the latest insights from machine learning, computational neuroscience and signal processing.

Supervision:

- Weekly progress meetings with Bert de Vries.
- Periodic progress meetings with contacts at GN Resound.
- The student should prepare update meetings, preferably with derivations or visualizations in interactive notebooks.

Timeline

The project is available from September 2017 onwards. The total duration will be 32 weeks. Halfway through, there will be a ”midterm” evaluation where the student must report on their activities and indicate how they will proceed for the remainder of the project. At the end, the student will write a thesis in 10-page double-column IEEE Transactions style summarizing their work, their findings and possible future steps. The thesis will be presented in an official ”defense” ceremony and a committee of experts will grade the student’s work.

2 Active inference for quadrupedal robot locomotion

Problem description

The goal is to develop an intelligent autonomous system (agent) for a quadrupedal robot (see example in Fig. 2). The agent must learn to walk: it will have to gradually build a locomotion model from interaction with its environment. You will use *Active Inference* (AIF), a probabilistic machine learning framework from the computational neuroscience community, to design and train the agent.

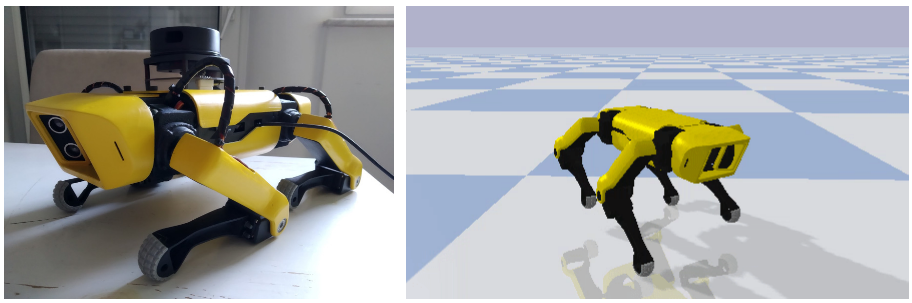

Figure 2: (Left) A physical SpotMicro. (Right) A SpotMicro in simulation. Figures courtesy of `https://spotmicroai.readthedocs.io/en/latest/`.

Please note that this is a software project; it does not involve hardware. You will write code to control a simulated robot that interacts with a simulated environment (see Fig. 2 right), generated using the open-source physics engine Bullet. The challenge will be to adapt an existing active inference agent to a specific walker.

Project positioning

This project does not involve a company. You will be working in the Bayesian Intelligent Autonomous Systems lab (BIASlab) at TU Eindhoven. BIASlab develops probabilistic models and inference algorithms for signal processing and control problems. This graduation project is a part of a larger research initiative towards AIF agents for robot locomotion.

Student assignment

You will initially be spending time familiarizing yourself with the tools and techniques that BIASlab develops (RxInfer.jl). Once familiar, you will write your own active inference agent based off of existing AIF agent implementations within BIASlab. Note that you'll be supported by BIASlab researchers that are working on other robot locomotion projects. Concretely, tasks include:

- Review literature on AIF agents for robotics.
- Familiarize yourself with the challenges of quadrupedal locomotion.

- Learn to use the probabilistic machine learning toolbox RxInfer.jl.
- Familiarize yourself with the simulation environment Bullet.
- Develop an active inference agent for a quadrupedal robot system.
- Reflect on what has been achieved and discuss with BIASlab's researchers.
- Write a report detailing your agent's properties and behaviour.

Supervision

- Weekly progress meetings with dr. Wouter Kouw.
- Periodic progress meetings with BIASlab researchers.
- The student should prepare for meetings in advance, e.g. with notebooks.
- All software that has been developed should be accessible online through BIASlab's github organization and should be legible / usable for future students.

Timeline

The project is available from September 2022 onwards. The total duration will be 32 weeks. Halfway through, there will be a ”midterm” evaluation where the student must report on their activities and indicate how they will proceed for the remainder of the project. At the end, the student will write a thesis summarizing their work, their findings and possible future steps. The thesis will be presented in an official ”defense” ceremony and a committee of experts will grade the student's work.

3 Parallel reactive computing

Problem description

In this project you are challenged to setup factor graph-based agents that operate simultaneously on multiple CPU cores. You will investigate the feasibility of splitting a factor graph model into multiple parts and how to run message passing-based inference in parallel using multiple CPU cores (see Figure 3). Since graph models can become quite large (e.g., millions of nodes) and data may arrive at different graph locations at different time scales, it is practically important to run these kinds of models in parallel.

In the second part of the project, you will evaluate the performance of parallel message passing-based inference on factor graphs. In principle, parallel inference on multiple CPU's should lead to more efficient use of computational resources and provide the same results in less time.

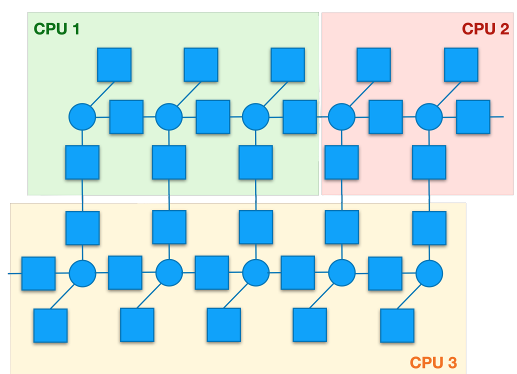

Figure 3: Forney-style factor graph distributed over multiple CPU cores.

Student task description

- Literature search: he student needs to be able to obtain a working understanding of Bayesian Inference, probabilistic methods, probabilistic graphical models, Forney-style factor graphs and message passing.
- Learning programming: this project is best suited for a student with a strong computer science background. The student should get familiar with relevant software tools (Julia programming language, RxInfer.jl) and understand how to setup parallel computation infrastructures.
- Develop an efficient **parallel implementation** of message passing-based inference in factor graph models.

- Depending on progress, the student may extend the system to more complex benchmark tasks.
- Iterate steps 3 and 4 until satisfaction and/or time runs out.
- Write a MSc-thesis detailing performance benchmarks, results and findings, including positioning of the work within the broader field.

Project positioning

BIASlab (FLUX-7.060) is a subgroup of the Signal Processing Systems (SPS) group that aims to develop **Intelligent Autonomous Agents**. These agents interact with their environment through their sensors and actuators in order to learn purposeful behavior without any supervision ("autonomously"), e.g., to navigate, play soccer or they may learn to decode speech signals under bad acoustic conditions. Our research projects are inspired by the latest insights from machine learning, computational neuroscience and signal processing.

Intelligent agents process information through Bayesian inference. In our lab, we realize these agents as (Forney-style) **Factor Graphs** that execute Bayesian inference in complex models through message passing in a graph. In our team, we are developing a toolbox that supports message passing-based inference in factor graphs, see RxInfer.

Supervision:

- Weekly progress meetings with Dmitry Bagaev.
- Periodic progress meetings with larger software development team.
- The student should prepare update meetings, preferably with derivations or visualizations in interactive notebooks.
- All developed code should be accessible (e.g., on BIASlab's Github organization).

Timeline

The project is available from September 2022 onwards. The total duration will be 32 weeks. Halfway through, there will be a "midterm" evaluation where the student must report on their activities and indicate how they will proceed for the remainder of the project. At the end, the student will write a thesis in 10-page double-column IEEE Transactions style summarizing their work, their findings and possible future steps. The thesis will be presented in an official "defense" ceremony and a committee of experts will grade the student's work.

4 Bayesian identification of convection in thermal systems

Problem description

Convection systems, for instance cooling fans, can have a complex effect on heat transfer in machines. Modelling this effect often requires incorporating flow terms in large state-space models which makes system identification a computational challenge. In this project, a data-driven component (black-box) is added to a thermodynamical model (white-box) to form a hybrid model (grey-box); the normal thermal dynamics may be captured by the white-box while the black-box looks for structure in the noise. Estimation will be performed using Bayesian inference algorithms. Recent work has shown that such models can identify the overall effects of unmodelled factors [1]. Here, we aim to recover a convection source on a demonstrator system of increasing complexity. The performance of the model must be evaluated on those devices. The model may need to be optimized automatically and/or manually to be able to run as a digital twin on less capable devices.

Figure 4: Cooling fans in a electromechanical system.

Project positioning

This project involves an internship at the Mathware department of Sioux Technologies B.V., located at the Esp campus (Google Maps). Sioux aims to explore new probabilistic models and probabilistic programming tools, specifically Gaussian Process state-space models. The student is not expected to understand these techniques in complete detail but will get a chance to familiarize themselves through project work and with the aid of dedicated software. An important part of this project is to assess how rapid these techniques may produce approximate results, which would allow for optimizing the location of cooling systems in high-precision mechatronic systems.

The prospective student should have an interest in probability and statistics, and their application to engineering. She/he should have some experience with software development, preferably in Julia, Python or Matlab. Sioux Technologies offers a paid internship position in a collaborative, inspiring and fun working environment, with highly trained and supportive professionals.

Student assignment

The student will apply a specific probabilistic model and statistical inference technique to a proprietary thermomechanical system. She/he is expected to familiarize themselves with the model, to write software to do Bayesian inference on a dynamical system, to design experiments, to analyze results and to present their findings.

Supervision

- Weekly progress meetings with TU/e supervisor Wouter Kouw.
- Regular progress meetings with Sioux supervisor Caspar Gruithuijsen.
- The student should prepare work summaries for update meetings, either in slideddeck or interactive notebook form.

Timeline

The project may be started anywhere from January to June 2023. The total duration will be 32 weeks. Halfway through, there will be a ”midterm” evaluation where the student must report on their activities and indicate how they will proceed for the remainder of the project. At the end, the student will write a thesis summarizing their work, their findings and possible future steps. The thesis will be presented in an official ”defense” ceremony and a committee of experts will grade the student’s work.

References

1. Rogers & Friis (2022). A Latent Restoring Force Approach to Nonlinear System Identification. *Mechanical Systems and Signal Processing*, *vol. 180*.

5 Forecasting student counts using hierarchical Bayes

Problem description

Forecasting how many students sign up for an educational program is an important challenge for many schools and universities. This project is about developing a probabilistic model for student arrival rate, fitting the data day-by-day and using cutting-edge mathematical techniques to forecast final student counts. A key component will be exploring ways to introduce hierarchical dependencies to the mathematical model. For example, the arrival rate might depend on the time of the year, due to high school schedules and registration deadlines. We may also want to account for one-off external factors such as school policy changes. Ultimately, the model should predict, with uncertainty, how many students will sign up for a specific university program. Such a model will assist education coordinators but will also have wider applications in Operations Research.

Figure 5: DALL-E generated image of a student crowd.

Project positioning

This project is situated in the Mathware department of Sioux Technologies B.V., located at the Esp campus (Google Maps).

Students signing up for educational program is an example of an arrival process, where a counter ticks up at random time increments. These increments often follow well-behaved probability distribution functions and are described using probabilistic models. The quality of a model's predictions may be improved by including higher-order factors that affect the process. For example, adding high school schedules from other countries may help predict sudden changes in the arrival rate caused by international students. Sioux Technologies would like to explore Bayesian inference techniques for designing and fitting such models.

Sioux is looking for a student interested in applying techniques from probability and statistics to real-world problems. The prospective intern should have some experience with software development (in Python or Julia), where exposure to probabilistic programs is a big plus. In return, we offer a collaborative, inspiring and fun working environment with highly trained and supportive professionals.

Student assignment

The prospective student will iterate over a model design cycle, i.e., build, evaluate, critique, and improve their mathematical model. In each iteration, the student is expected to write probabilistic programs, run simulations, and visualize results. Finally, the student is invited to present their findings to the Mathware Competence Group(s).

Supervision:

- Weekly progress meetings with Sioux supervisor Alp Sari.
- Regular progress meetings with Sioux supervisor Tak Kaneko and TU/e supervisor Wouter Kouw.
- The student should prepare work summaries for update meetings, either in slideck or interactive notebook form.

Timeline

The project is available from March 2023 onwards. The total duration will be 32 weeks. Halfway through, there will be a ”midterm” evaluation where the student must report on their activities and indicate how they will proceed for the remainder of the project. At the end, the student will write a thesis summarizing their work, their findings and possible future steps. The thesis will be presented in an official ”defense” ceremony and a committee of experts will grade the student’s work.

6 Football player simulation for coach assistance

Problem description

This project is part of a long-term research program that aims to develop an intelligent agent (software) that provides strategic football (soccer) coaching decisions in real-time. We work together with the KNVB (Royal Dutch Football Association), and we aim to use the agent to assist coaching staffs of Dutch football teams.

As an example, consider an agent that receives the real-time coordinates of the players and the ball while the match is ongoing. The agent should be capable of analyzing the match in real-time and make coaching recommendations, e.g., switch our left-wing attacker to the right wing because the pairing with the opposing team's left-back is more advantageous.

Figure 6: Arjan Robben's big chance at the World Championship in 2010.

Intelligent decision making derives from our capacity to compare (the performance of) simulations of future scenarios. In this project, we aim to develop an agent that supports this type of "human intelligence"-inspired decision making. Technically, in this project you will explore the Free Energy Principle (FEP) as a guide on how to develop this type of agents. The FEP is a celebrated neuroscientific theory of how brains perceive and make decisions, based on a single objective, namely "Free Energy" minimization. As such, in a broader context, this project aims to develop a novel neuro-inspired approach to real-time intelligent decision making.

Clearly, developing such an agent is too difficult to accomplish in a single project. Therefore, this project is part of a larger program that encompasses multiple projects, where each project tries to accomplish intermediate milestones.

Student task description

Your main job will be to develop an agent (a software program) that is able to cast strategic coaching decisions during a football game.

Concrete tasks:

- Specify the scope of the project. A first task is to specify what ”strategic coaching decisions” means in this project. We will need to describe and unpack this problem into a concrete and limited problem statement. This stage will be executed through discussions with your coaches and the KNVB.
- Do a literature study on existing approaches to data-driven coaching agents. Do a focused literature review and a select (at least 1) data-driven coaching algorithm from the literature that you will use as your ”reference” algorithm. Implement this reference algorithm.
- Do a literature study on the Free Energy Principle. In this project, our aim is to develop a new approach to data-driven coaching that learns through Bayesian machine learning methods. This can be described as an application of the Free Energy Principle (FEP). You will need to read about the FEP in general and about some previous efforts by BIASlab members and others on how to build FEP-inspired synthetic agents. Together with the literature study on existing coaching agents, this should lead to a small review paper (which we later embed in your thesis).
- Develop a FEP-based agent that learns to cast coaching decisions. The task of designing a new agent based on Bayesian machine learning may seem daunting, but you will be able to design your first agents after a few discussions with your supervisor.
- Evaluate your FEP-based agent in comparison to the reference method(s).
- Iterate steps 4 and 5 until satisfaction and/or time runs out.
- Write and defend an awesome thesis on a new data-driven approach to developing strategic football coaching agents.

Project positioning

The Bayesian Intelligent Autonomous Systems lab (BIASlab) is a subgroup of the Signal Processing Systems (SPS) group that develops agents that interact with their environment through their sensors and actuators. The goal is to learn purposeful behavior, e.g., to navigate, play soccer or they may learn to decode speech signals under bad acoustic conditions. Our research projects are inspired by the latest insights from probabilistic machine learning, computational neuroscience and signal processing.

The KNVB is the Royal Dutch Football Association. You will be working with data scientists from the KNVB who have a tremendous amount of experience analyzing football matches and the behaviour of players. They have collected rich data sets on all matches played by the Dutch national team over the past few years. Their insights will be invaluable for the development of a useful football simulation model.

Supervision:

- Weekly progress meetings with dr. Wouter Kouw and prof. Wim Nuijten.
- Periodic progress meetings with contacts at the KNVB.
- The student should prepare update meetings, preferably with derivations or visualizations in interactive notebooks.

Timeline

The project is available from September 2021 onwards. The total duration will be 32 weeks. Halfway through, there will be a ”midterm” evaluation where the student must report on their activities and indicate how they will proceed for the remainder of the project. At the end, the student will write a thesis summarizing their work, their findings and possible future steps. The thesis will be presented in an official ”defense” ceremony and a committee of experts will grade the student’s work.

7 Modeling Sparse Acoustic Signals

Problem description

Modeling acoustic signals is vital for common tasks such as noise reduction, speech enhancement, source separation and speech recognition. Most acoustic signals have a very sparse structure: in the frequency domain often only a few frequency bins are dominant as shown in Fig. 7. Leveraging this knowledge helps us in accurately modeling acoustic sounds.

The recently introduced NUV priors enable us to explicitly model sparse processes. Furthermore they allow for efficient probabilistic inference, making them suitable for demanding applications.

The goal of this internship is to use NUV priors for modeling acoustic signals such as speech.

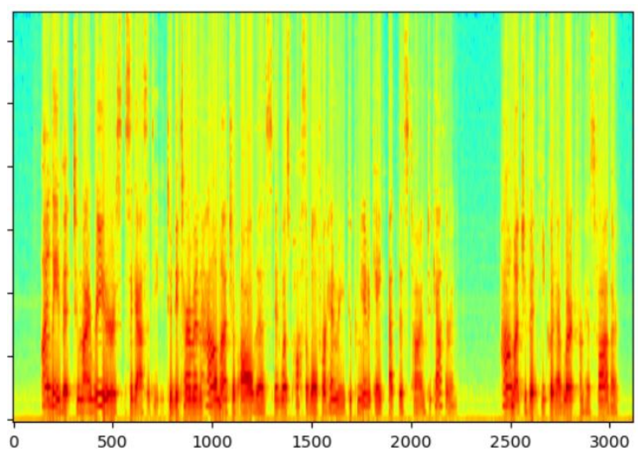

Figure 7: A spectrogram of speech. The majority of the signal power is located near the lower frequencies, making the signal very sparse over the entire frequency range.

Student task description

The student will be working on implementing the sparsity promoting priors in our state-of-the-art probabilistic programming toolbox `ReactiveMP.jl`. These priors will be used for the sparse modeling of acoustic signals, such as speech.

Concrete tasks:

- Familiarize yourself with the literature on probabilistic modeling, probabilistic inference and NUV priors.
- Implement the NUV priors in our toolbox `ReactiveMP.jl`.

- Model acoustic signals, such as speech, with these priors.
- Experiment with the implementation and compare to current solutions.
- Analyze results and reflect on what has been achieved.
- Write a report detailing the advantages and limitations of this approach.
- Defend your work.

Project positioning

The Bayesian Intelligent Autonomous Systems lab (BIASlab) is a subgroup of the Signal Processing Systems (SPS) group that develops agents that interact with their environment through their sensors and actuators. The goal is to learn purposeful behavior, e.g., to navigate, play soccer or they may learn to decode speech signals under bad acoustic conditions. Our research projects are inspired by the latest insights from probabilistic machine learning, computational neuroscience and signal processing.

Supervision:

- Weekly progress meetings with Bart van Erp.
- Weekly seminars with the BIASlab group, where we highlight our state-of-the-art research.
- The student should prepare update meetings, preferably with derivations or visualizations in interactive notebooks.
- All developed code should be accessible (e.g., on BIASlab's GitHub organization).

Timeline

The project is available from March 11, 2022 onwards. The total duration will be 11-14 weeks. At the end, the student will write a report summarizing their work, their findings and possible future steps. The student will present their work in the BIASlab research group during one of the weekly seminars.

8 Active listening

Problem description

The below excerpt is adopted from (Friston, 2021) and very nicely describes both the problem that we are tackling and the solution strategy:

Speech recognition is not a simple problem. The auditory system receives a continuous acoustic signal and, in order to understand the words that are spoken, must parse a continuous signal into discrete words. To a naïve listener, the acoustic signal provides few cues to indicate where words begin and end (Altenberg, 2005; Thiessen and Erickson, 2013). Furthermore, even when word boundaries are made clear, there exists a many-to-many mapping between lexical content and the acoustic signal. This is because speech is not 'invariant' (Liberman et al., 1967)—words are never heard out of a particular context. An example is the identical perception of the phrases "grade A" and "grey day". When considering how words are generated, there is wide variability in the pronunciation of the same word among different speakers (Hillenbrand et al., 1995; Remez 2010)—and even when spoken by the same speaker, pronunciation depends on prosody (Bänziger and Scherer, 2005). From the perspective of recognition, two signals that are acoustically identical can be perceived as different words or phonemes by human listeners, depending on their context.

In the seminal paper by Friston they describe a new approach and model to solve this speech recognition problem. They consider the task of setting the word boundaries and classifying the separated words as an active process, where they are performed simultaneously instead of sequentially. However, the model that they propose relies on an extensive set of (unnecessary) assumptions. In this project the goal is to reduce the set of assumptions, improve the model for acoustic sounds and to beat the performance of the model in (Friston, 2021). The baseline implementation has already been implemented by a previous master's student for a quick comparison.

Student task description

The student will be working on improving the current implementation of the active listening paper. A thorough review of the used preprocessing steps and modeling choices needs to performed, such that it becomes clear where performance can be gained.

Concrete tasks:

- Familiarize yourself with the literature on probabilistic modeling and model comparison.
- Discuss problem and solution proposal with researchers at BIASlab.
- Improve the current model in terms of performance, scalability and preprocessing.
- Implement solution proposal using BIASlab resources.
- Experiment with the implementation and compare to current solutions.

Figure 8: The ”carnavalsmachine” is a melodic speech synthesis device. It is capable of synthesising speech for composing Dutch music specially tailored for the annual religious festivities in the south of the Netherlands. Although its true operations are surrounded by secrecy, we have reasons to believe that a generative model is at the core of the machine. This generative model is capable of generating perceptually accurate speech and as the underlying model is probabilistic, it is also suited for recognizing speech through probabilistic inference. Researchers believe that the novel speech recognition approach of (Friston, 2021) provides key insights in the operations of this mysterious machine and that it helps improving its operations in the upcoming year. ©Lamme Frans

- Analyze results and reflect on what has been achieved.
- Write a report detailing the advantages and limitations of this approach.
- Defend your work.

Project positioning

The Bayesian Intelligent Autonomous Systems lab (BIASlab) is a subgroup of the Signal Processing Systems (SPS) group that develops agents that interact with their environment through their sensors and actuators. The goal is to learn purposeful behavior, e.g., to navigate, play soccer or they may learn to decode speech signals under bad acoustic conditions. Our research projects are inspired by the latest insights from probabilistic machine learning, computational neuroscience and signal processing.

Supervision:

- Weekly progress meetings with Bart van Erp.
- Weekly seminars with the BIASlab group, where we highlight our state-of-the-art research.

- The student should prepare update meetings, preferably with derivations or visualizations in interactive notebooks.
- All developed code should be accessible (e.g., on BIASlab's GitHub organization).

Timeline

The project is available from March 11, 2022 onwards. The total duration will be 32 weeks. Halfway through, there will be a "midterm" evaluation where the student must report on their activities and indicate how they will proceed for the remainder of the project. At the end, the student will write a thesis summarizing their work, their findings and possible future steps. The thesis will be presented in an official "defense" ceremony and a committee of experts will grade the student's work.

References

Friston, K. J., Sajid, N., Quiroga-Martinez, D. R., Parr, T., Price, C. J., Holmes, E. (2021). Active listening. Hearing Research, 399(Stimulus-specific adaptation, MMN and predicting coding), 107998. https://doi.org/10.1016/j.heares.2020.107998

9 Invertible Bayesian Neural Networks

Problem description

Probabilistic models are a class of machine learning models in which we try to retain uncertainty about the variables inside our model. In these models, which we can represent as factor graphs, we can perform efficient local computations by passing messages through the model. These messages can be thought of as summaries from the part of the graph where they are coming from. This entire approach is based on theories from the field of computational neuroscience. Although this approach is very powerful, it is somewhat limited to the individual factors (operations) that we can use in the probabilistic model.

Standard neural networks are capable of modeling highly non-linear relationships. These networks can be implemented in factor graphs, leading to structures such as the extended Kalman filter. Standard neural networks, however, do not allow for flexible inference as we cannot easily reason back from the output to the input of the network. Therefore we need to guarantee the invertibility in the network. Despite their huge expressive power, these networks are prone to overfitting, when they approximate the supplied data very well, but fail to generalize to similar data sets.

Bayesian neural networks are neural networks which allow for incorporating uncertainty over the intermediate outputs and parameters. However, Bayesian neural networks are not invertible, something which we require for performing efficient inference through this model. Therefore in this project we are interested in exploring model structures, inspired by invertible neural networks, which both allow for efficient inference and simultaneously capture uncertainty over the model parameters.

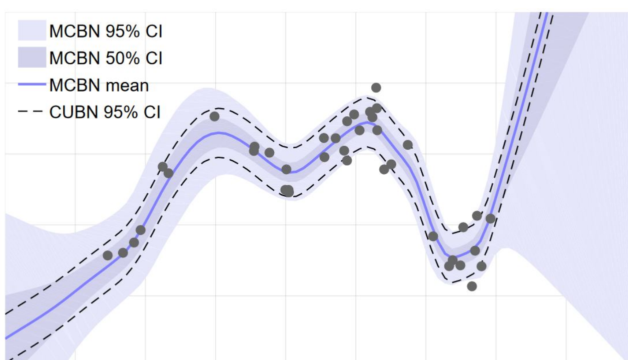

Figure 9: The output of a Bayesian neural network for a regression task. Uncertainty over its output is retained by modeling its parameters as random variables. ©`https://davidstutz.de/a-short-introduction-to-bayesian-neural-networks/`

Student task description

- Develop a good understanding of invertible neural networks, Bayesian neural networks, factor graphs and message passing.
- Learn programming in the scientific programming language Julia.
- Explore different training methods for Bayesian neural networks.
- Implement training algorithms for Bayesian neural networks.
- Combine Bayesian neural networks with invertible neural networks and describe how inference can be performed in these models.
- Write a report and present your work.

Project positioning

The Bayesian Intelligent Autonomous Systems lab (BIASlab) is a subgroup of the Signal Processing Systems (SPS) group that develops agents that interact with their environment through their sensors and actuators. The goal is to learn purposeful behavior, e.g., to navigate, play soccer or they may learn to decode speech signals under bad acoustic conditions. Our research projects are inspired by the latest insights from probabilistic machine learning, computational neuroscience and signal processing.

Besides the project activities we highly value a good collaboration with our research group (BIASlab). Besides weekly meetings with the supervisor, you will be involved in weekly update meetings with fellow master and PhD students. Furthermore you will be joining the weekly seminars in which each of us presents our state-of-the-art work.

Timeline

The project is available from September 2021 onwards. The total duration will be 32 weeks. Halfway through, there will be a ”midterm” evaluation where the student must report on their activities and indicate how they will proceed for the remainder of the project. At the end, the student will write a thesis summarizing their work, their findings and possible future steps. The thesis will be presented in an official ”defense” ceremony and a committee of experts will grade the student’s work.

10 Drift control in TwinScan lithography

Problem description

TwinScan lithography systems are used at a very high speed to produce integrated circuits which requires sub-nanometer accuracy and precision. Due to hardware imperfections, these TwinScan systems drift, which causes a negative impact on both the (sub-)nanometer scale positioning and on the system throughput, as it requires (semi-manual) maintenance actions to reduce the impact of these drift.

The current drift controller (see Figure 10) is a static event-based feedback controller which gets activated only when it is necessary by means of a human request or when the system's internal maintenance kicks in. This leads to several challenging issues, e.g.,

1. The measurements are not ideal, i.e., they are subject to measurement noise which are of time-varying and colored nature, unpredictable jumps, and time lags that are introduced while performing measurements.
2. Drifts often possess a different dynamical structure over time for each machine. As a result, using a fixed-model structure is not optimal.

In this project you are challenged to design an improved drift controller based on modern machine learning technology.

Figure 10: TWINSCAN NXE:3350B is one of ASML's nanolithography systems.

Student task description

The student will be challenged to use modern machine learning technology to develop a drift controller. The controller should learn online ("on-the-fly") from past measurements (while continuously providing feedback corrections) so as to cope with the time-varying dynamical nature of the drifts.

We expect that the proposed drift controller has several intrinsic characteristics:

- It should deal with non-uniform measurements in order to update the predictor's (internal) states.
- It should be rather general, in the sense that in principle any type of drift can be handled.
- It should possess a smart decision-making capability by learning from past measurements in order to differentiate between jumps, outliers and handle time-varying noises.
- It should not depend on a fixed-model structure (per class of drifts) as this would violate the previous requirement.

The performance of the proposed controller should be compared to the existing (non-adaptive) event-based drift controller, with both benchmark and real measurement data.

Project positioning

The Bayesian Intelligent Autonomous Systems lab (BIASlab) is a subgroup of the Signal Processing Systems (SPS) group that develops agents that interact with their environment through their sensors and actuators. The goal is to learn purposeful behavior, e.g., to navigate, play soccer or they may learn to decode speech signals under bad acoustic conditions. Our research projects are inspired by the latest insights from probabilistic machine learning, computational neuroscience and signal processing.

ASML is a market and innovation leader in the semiconductor industry. They provide chipmakers with everything they need – hardware, software and services – to mass produce patterns on silicon through lithography. Their machines are incredibly precise, even up to nanometer-scale. ASML employs a large amount of industrial researchers and is quick to incorporate new technologies into their fabrication process.

Supervision:

- Weekly progress meetings with Bert de Vries.
- Periodic progress meetings with Raaja Ganapathy Subramanian at ASML.
- The student should prepare update meetings, preferably with derivations or visualizations in interactive notebooks.

Timeline

The project is available from Augustus 2020 onwards. The total duration will be 32 weeks. Halfway through, there will be a ”midterm” evaluation where the student must report on their activities and indicate how they will proceed for the remainder of the project. At the end, the student will write a thesis summarizing their work, their findings and possible future steps. The thesis will be presented in an official ”defense” ceremony and a committee of experts will grade the student’s work.

11 Monitoring health through wearables

Problem description

This is a project in collaboration with Philips on inferring a patient's health condition from wearable sensors. In the TRICA study, patients were sent home after elective surgery with two wearable devices, a patch and a wristband - see pictures, that measured several biometric signals (including heart rate, respiration rate, activity level (acticounts) and activity type (walking, running, cycling, other)). One goal of the TRICA study is to develop algorithms that, based on the measured data streams, detect in real-time when possible post-operative complications surface. This type of analysis is hindered by the fact that the recorded data is often unreliable or missing due to movement and other artifacts.

Figure 11: The TRICA study (which stands for Transitional Care) collects data from wearables for post-operative monitoring of recovery and potential complications.

In this graduation project you are challenged to develop a robust algorithm that, based on the recorded TRICA data base, forecasts heart rate and respiratory rate from activity level and type. In particular, we are interested in personalized algorithms that improve as more data is collected. In other words, your challenge is to develop an algorithm that both executes (predicts HR and RR) and learns to improve its performance as time moves on. The predicted HR and RR can then be used for forecasting health deterioration.

Student task description

We expect the following tasks in this project:

- Specify the scope of the project.
  A first task is to specify the scope of the project. Together with you we will develop the above description into a concrete problem statement that allows you to do a focussed literature review.

- Do a literature study on available methods.
  Do a focussed literature review and a select (at least 1) prediction algorithm from the literature that you will use as your ”reference” algorithm. Implement this reference algorithm.

- Do a literature study on Bayesian machine learning-based prediction.
  At BIASlab, we develop Bayesian prediction algorithms such as advanced Kalman filters that map very nicely to the tasks in this project. You will study the literature in this field and summarize the literature and your plan in a small review paper (which you can later embed in your thesis).

- Develop an online Bayesian machine learning-based prediction algorithm for your task.

- Evaluate your algorithm in comparison to the reference method(s).

- Iterate steps 4 and 5 until satisfaction and/or time runs out.

Project positioning

The project will be carried out at Philips Research and at BIASlab (FLUX-7.060), which is a subgroup of the Signal Processing Systems (SPS) group. BIASlab’s research projects are inspired by the latest insights from machine learning, computational neuroscience and signal processing. You will get support (supervision) both from a senior Philips researcher and BIASlab researcher.

Supervision

- Weekly progress meetings with Bert de Vries.

- Periodic progress meetings with Reinder Haakma at Philips.

- The student should prepare update meetings, preferably with derivations or visualizations in interactive notebooks.

Timeline

The project is available from October 2020 onwards. The total duration will be 32 weeks. Halfway through, there will be a ”midterm” evaluation where the student must report on their activities and indicate how they will proceed for the remainder of the project. At the end, the student will write a thesis summarizing their work, their findings and possible future steps. The thesis will be presented in an official ”defense” ceremony and a committee of experts will grade the student’s work.

12 Nonlinear identification in positioning systems

Problem description

System identification is concerned with estimating a dynamical model from paired input and output data. In particular, we are considering an electro-mechanical positioning system (EMPS), where a motor drives a small platform on a track between two points (a prismatic joint). These are ubiquitous in robotics and machine tool applications, but can be challenging to control when non-linearities such as friction are involved. Our goal is to estimate the inverse dynamical model (torque/force as a function of position, velocity and acceleration), outperforming the current least-squares baseline approach. More information on the electro-mechanical positioning system, including baseline, data and code, can be found at `http://nonlinearbenchmark.org/`.

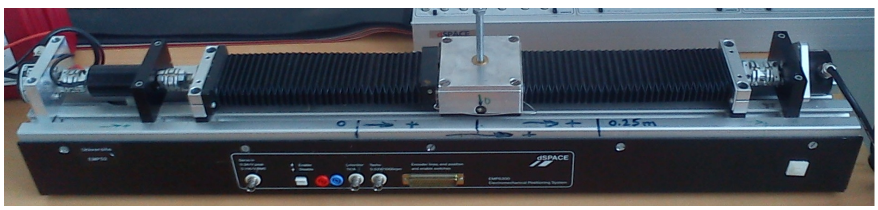

Figure 12: Electro-mechanical positioning system setup.

Student assignment

We expect the student to familiarize him/her self with variational free energy minimization and system identification. Your job will be to program an agent to infer the dynamical parameters of the system from given input-output data, and compare the agent to baseline methods. We hope to include an *optimal design / active inference* experiment as well, where the agent infers which inputs it should test to infer the dynamics as fast as possible.

- Literature search over the intersection between Bayesian machine learning and nonlinear system identification.
- Familiarize yourself with the difficulties of nonlinear system identification.
- Understand the challenges of applying variational free energy minimization to nonlinear system identification.
- Collaborate and discuss with researchers in BIASlab and the Control Systems group.
- Implement an agent that infers dynamics in the system.

- Experiment with the implementation and compare to baselines.
- Analyze results and reflect on what has been achieved.
- Write a report detailing the advantages and limitations of this approach.

Project positioning

The Bayesian Intelligent Autonomous Systems lab (BIASlab) studies intelligent agents that perceive and act through Bayesian machine learning. The lab works with a principled technique for Bayesian inference, called variational free energy minimization, which is applied to signal processing and control systems. For an introduction to this framework, see our software package RxInfer.

Outside of BIASlab, the student will also be part of the Control Systems group and will have a chance to work with PhD students under dr. Schoukens.

Supervision

- Weekly progress meetings with dr Wouter Kouw.
- Regular progress meetings with dr. Maarten Schoukens.
- The student is expected to be prepared for meetings, preferably by writing interactive notebooks.

Timeline

The project is available from August 2022 onwards. The total duration will be 32 weeks. Halfway through, there will be a ”midterm” evaluation where the student must report on their activities and indicate how they will proceed for the remainder of the project. At the end, the student will write a thesis summarizing their work, their findings and possible future steps. The thesis will be presented in an official ”defense” ceremony and a committee of experts will grade the student’s work.

13 Graphical editor for building agents

Problem description

You are challenged to develop a graphical web-based editor/debugger for developing and monitoring the dynamics of simulated agents. Please have a look at this video by Bret Victor that demonstrates the essence of the envisioned editor. Rather than developing electronic circuits, in this project we focus on developing intelligent agents that minimize a quantity known as Free Energy through message passing in a factor graph. See the 5SSD0 Bayesian Machine Learning & Information Processing lesson on intelligent agents for more information.

In the second part of the thesis work, you use the editor/debugger to analyze the internal dynamics (i.e., monitor the free energy distribution) of a few well-known (but not well-understood) intelligent agents, thus leading to an increased understanding of how Free Energy minimizing dynamics give rise to intelligent behavior (see e.g. this video for a neuroscience perspective.)

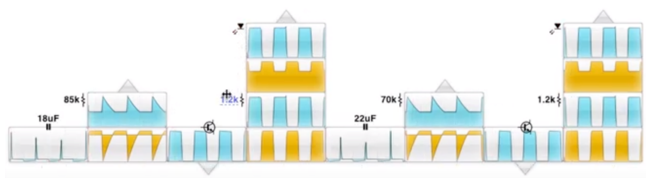

Figure 13: Visualization of (electronic circuit) dynamics (source.

Student task description

Please note that, aside from having a demonstrated interest in dynamic systems modeling and/or machine learning, for this project it is essential that you also have good programming skills, in particular related to web front-end technologies. The project is ideally suited to a good programmer with interests in visual editing and machine learning. It is also possible to do this project with 2 people.

The task is organized into the following steps:

- Scope: a first task is to narrow the scope of this project. Development of a good editor/debugger may take years, so we will focus on a few simple features that showcase proof-of-concept and allow dynamic monitoring of free energy distribution during simulations.
- Literature study of modern supporting technology for development of web-based editors.
- Literature study of free energy minimization of dynamic systems in factor graphs, finalized by an interim report and project planning.

- Develop/update a simple web-based graphical editor/debugger based on Bret Victor's principles.
- Analyze a highly performant but not well-understood intelligent agents by online monitoring and manipulation of the internal dynamics of these agents.
- Iterate steps 4 and 5 until satisfaction and/or time runs out.
- Write and defend an awesome thesis on a new approach to interpretable AI through online visualization and manipulation of the simulated system.

Project positioning

The Bayesian Intelligent Autonomous Systems lab (BIASlab) is a subgroup of the Signal Processing Systems (SPS) group that develops agents that interact with their environment through their sensors and actuators. The goal is to learn purposeful behavior, e.g., to navigate, play soccer or they may learn to decode speech signals under bad acoustic conditions. Our research projects are inspired by the latest insights from probabilistic machine learning, computational neuroscience and signal processing.

Supervision:

- Weekly progress meetings with Bert de Vries.
- The student should prepare update meetings, preferably with derivations or visualizations in interactive notebooks.
- All developed code should be accessible (e.g., on BIASlab's Github organization).

Timing

The project is available from April 26th 2020 onwards. The total duration will be 32 weeks. Halfway through, there will be a ”midterm” evaluation where the student must report on their activities and indicate how they will proceed for the remainder of the project. At the end, the student will write a thesis summarizing their work, their findings and possible future steps. The thesis will be presented in an official ”defense” ceremony and a committee of experts will grade the student's work.