AIMS
Mini-project Proposals
2016/17
Introduction

As part of the 1st year of the CDT, you have to complete two mini-projects.

These will take place between the following dates:

- Mini-project 1: 10th April 2017 – 12th June 2017
- Mini-project 2: 10th July 2017 – 11th September 2017

In this document there are proposed mini-projects by members of staff within the Departments of engineering and Computer Science. There are also proposed mini-projects by our Industry partners.

You will need to complete the registration form at the end of this document with your chosen mini-projects, and get the appropriate supervisor to sign and return to me by Friday 24th March 2017).

There will be an opportunity for you to listen to some of the projects offered on the Project Presentation Day, which will take place on Tuesday 14th and Wednesday 15th March from 2pm – 4pm.
Objectives

The objectives of the mini-projects are:

- to give each student experience in undertaking a small research project, one which could seed or turn into a substantive DPhil project;
- by undertaking two projects, with different supervisors (and normally different academic departments), to ensure that each student explores some diversity of topic, before settling on their substantive research;
- to provide a means by which the CDT and partner organisations (companies, government departments, etc.) can develop relationships – whether leading to support for a DPhil project or some other engagement;
- by providing students with a menu of projects, to shape the overall research of the CDT according to the original proposal and subsequent guidance from the Advisory Panel;
- to put potential academic supervisors from within the University in touch with the group of CDT students, giving an opportunity to explore potential research ideas of mutual interest.

A good project will:

- provide worthwhile results, leading to a written report (ideally, publishable at an academic research workshop) within the nine weeks allotted;
- be based on a realistic problem or challenge;
- be substantially an individual piece of work (collaborative work with other students or supporters etc. is possible, but the student’s contribution should be clearly defined and measurable);
- build upon, but not be constrained by, the content of and skills learned in the taught courses in the CDT;
- have an enthusiastic supporter/mentor from an external organisation and active engagement of a supervisor in the University (the first is optional; the second mandatory);
- be capable of extension into a bigger project, motivate a bigger project, or (if necessary) demonstrate the infeasibility of an intended bigger project.

Project Assessment

Projects are marked by the following assessment:

- 5 – Excellent; would need little work to be published for a conference paper
- 4 – Very good; would need slightly more work to be suitable for a conference paper;
- 3 – Good; would need more substantive work before publication
- 2 – Adequate; meets the needs for a CDT mini-project; suitable preparation for substantive research
- 1 – Borderline; has some merit, but is barely suitable
- 0 – Not adequate; no evidence of achievement at the right level

Project Assessment Submission

Project dissertations must be emailed to wendy.adams@eng.ox.ac.uk on or before the deadline unless otherwise stated. If you require an extension you must consult the Programme Administrator. Please ensure submitted projects are clearly labelled.
Format

Students are required to produce a dissertation for each project in the style of a research paper with a limit of 5,000 words. The dissertation will be assessed and marked by the project supervisor and an expert in the field.

Your submission can be submitted in either a word or pdf document.

Deadlines for submitting mini-projects

- Mini-project 1: 12 noon on 12th June 2017
- Mini-project 2: 12 noon on 11th September 2017
Title: Acoustic signal processing to battle malaria-bearing mosquitoes  
Supervisor(s): Steve Roberts + HumBug team

Abstract:
Mosquito-borne disease has a major impact on human health, income and mortality in over 100 countries affecting over half the world’s population. Control programmes rely heavily on mapping and modelling tools which are limited in that they are static in time and space. This project looks to develop acoustic monitoring sensors and embed them in handheld devices such as smartphones and wristbands, which can detect (unique, species-specific) wingbeats from mosquitoes. This level of technological sophistication has not been attempted in the past. Current efforts to deploy acoustic detection of mosquitoes often cannot differentiate between species and cannot pick up insects unless they are gathered in large swarms.

The project will look at state-of-the-art signal processing for extracting weak signals from background and develop timely, robust and power-conservative classification engines for distinguishing between known disease-bearing mosquito species. Porting approaches onto low-power portable systems, such as phones as well as bespoke devices, will also be explored. The project will eventually use such detection data in combination with ultra-high resolution (30m pixel) remote imaging to determine environmental factors such as vegetation composition and structure and distance to water bodies. This will require the development of new approaches to latent correlation analysis in sparse spatio-temporal processes.

The potential value of this app/project in the management and control of mosquito-borne disease – whether by international, governmental or NGO bodies - is huge, a fact that helped the project win funding from Google, with whom we work closely.

Additional information: www.humbug.ac.uk

Title: Acoustic event and species recognition on low-power acoustic sensors  
Supervisor: Professor Alex Rogers and Dr Davide Zilli + HumBug team

Abstract
Acoustic sensors provide a compelling way to perform long-term environmental monitoring. Small low-power sensors can continuously listen for particular events, recordings sound files and metrics to an SD card, or providing alerts via long-range radio, when particular events are detected. Such approaches find application in monitoring an area for mosquito species that are known to be vectors of malaria, or for monitoring tropical forests for illegal exploitation such as hunting and logging. A key challenge in this area is to implement effective recognition algorithms on low power microcontrollers that typically have just a few kilobytes of RAM and limited computational resource (see www.soundtrap.io). This project will explore the development of such algorithms in two settings: (i) performing mosquito species recognition (using a library currently being collected by Dr. Davide Zilli – see humbug.robots.ox.ac.uk) and tropical forest protection (using a library of gun-shot and chainsaw sounds collected in Belize in the summer of 2015 by colleagues of Prof. Alex Rogers).

Additional information: www.humbug.ac.uk

Title: Information extraction from multiple data streams using Bayesian non-parametrics  
Supervisor(s): Steve Roberts

Abstract:
Knowledge of the dependency structure between disparate data streams (such as financial assets) is crucial to many tasks. In most cases this has concentrated on the norm, i.e. measuring the typical dependency structure that captures the bulk of the data characteristics. Fewer methods exist for information fusion and extraction associated with
outlying events, such as extreme swings that occupy the tails of the distribution. Further, due consideration is frequently not given to heterogeneous temporal properties that affect asynchronous propagation events among different information sources. This project will focus on developing rich non-parametric models for multiple data streams, concentrating on the development of Bayesian non-parametric models that naturally encode information from the tails, and do not assume standard normally distributed data, nor symmetry. The application focus of the project will be in financial data, but no expertise in finance is necessary.

Further reading:

- Gaussian Processes for time-marked time-series data. John P. Cunningham Zoubin Ghahramani Carl E. Rasmussen
- Gaussian Process Volatility Model. Yue Wu, Jose Miguel Hernandez Lobato, Zoubin Ghahramani

**Title: Deep Gaussian Process models**

**Supervisor(s): Steve Roberts**

**Abstract:**

Deep Gaussian processes (DGPs) are multi-layer hierarchical generalisations of Bayesian non-parametric Gaussian processes (GPs). They are formally equivalent to neural networks with multiple, infinitely wide hidden layers. As DGPs are non-parametric probabilistic models they are arguably more flexible, have a greater capacity to generalise, and provide better calibrated uncertainty estimates than alternative deep models. This project will explore the efficient learning in DGPs, based on several approaches advocated in the literature and will extend to look at the role of depth in forming good solution spaces.

**Additional information**


**Title: The search for extra-terrestrial intelligence**

**Supervisor(s): Steve Roberts**

**Abstract:**

In the last 50 years, evidence has steadily mounted that the constituents and conditions necessary for life (as we understand it) are common. Such chemical detections offer an indication that the reactants necessary for building large complex organic structures may be formed readily in proto-planetary environs. Exoplanets themselves, while once relegated to the domain of speculation, now appear to be common and numerous, thanks in part to the science objectives met during the Kepler space telescope mission. Recent work has looked at scanning for coherent radio emissions, typical of technology in areas of rich exo-planet numbers (Siemion, 2013). The main challenge of detection is that the spectra contain a
number of human-generated radio interference (RFI) signals which take on a number of spectra forms, varying in frequency and time. This results in very non-Gaussian noise. This project will investigate the use of state of the art approaches to detect signal in heavy (coloured) noise. Beyond the detection problem there will be the challenge of efficiently processing the data. Currently there are 10's of petabytes of observation data, with that expected to only grow, so scalability as well as detection accuracy are key outcomes of any approach developed.

Further reading:

- SETI workshop on methods ([https://setiathome.berkeley.edu/~mattl/ml/](https://setiathome.berkeley.edu/~mattl/ml/)).
Title: Symmetry Declarations for SAT-solvers
Supervisor(s): Anthony W. Lin

Abstract:

Constraint programming is a programming paradigm, in which programmers write programs by specifying the problem description (in terms of constraints) and letting computers use their computational power to figure out the solution automatically. This is in contrast to typical programming paradigms, wherein programmers explicitly spell out procedures for carrying out the computation. Constraint programming has a wide range of applications (e.g. optimisation, planning, ...) and rely on powerful constraint solvers to solve computational problems. SAT-solvers --- claimed by some researchers to be among the greatest achievements in the past decade --- are one of the most powerful solvers in the constraint programming toolbox. In a nutshell, SAT-solvers are algorithms for solving satisfiability of boolean formulas, which is an NP-complete problem that can be used as a “universal language” for encoding many practical combinatorial problems. Although the problem of satisfiability of boolean formulas is difficult in theory, SAT-solvers have greatly advanced in the past two decades to the extent that large formulas (with millions of variables/clauses) can now be handled.

The aim of the project is to investigate ways in which to improve the performance of SAT-solvers by embedding “symmetry information” (e.g. variable symmetry). Boolean formulas that arise in practice (e.g. as encodings of combinatorial problems) exhibit many symmetries, which the programmers typically know. Specific questions to explore include: (1) what is a convenient (but general) way to specify symmetry information in boolean formulas? (2) given the symmetry information, how do we engineer SAT-solvers to exploit such information to speed up the search for solutions?

Additional information:
Associate Professor at Department of Computer Science
(Anthony.Lin@cs.ox.ac.uk)
Title: Various Computer Vision Projects  
Supervisor(s): Prof Philip Torr and senior RA's.

Abstract:

In the TVG we are working towards various aspect of computer vision on a human scale, i.e. for scenes that human typical see and operate on. Within that there is scope to craft the right project for an interested student. Please contact me to discuss: Philip Torr

Subjects covered in the group include:

Additional information:
Philip Torr

Title: Text spotting in the Wild to help the Partially Sighted  
Supervisor(s): Prof Philip Torr

Abstract:

Text recognition in the wild (on the streets) is still not a solved problem. We are designing a pair of smart spectacles to help the partially sighted ([http://www.smart-specs.com/](http://www.smart-specs.com/)), these spectacles, when worn will allow additional information to be passed to the partially sighted person, either by audio or image enhancement. Text recognition is of crucial importance to partially sighted people for such tasks as navigation etc.

The goal of this project would be to build on recent advances made by the group on the machine learning techniques such as random forest, and on recent new algorithms that will automatically recognize scene context in order to improve text recognition.

Additional information:
philip.torr@eng.ox.ac.uk

Title: Wholistic Semantic Segmentation of Images  
Supervisor(s): Prof Philip Torr

Abstract:

This work would involve designing an algorithm to recognize and segment objects in images following on from recent successful work within the group e.g. Shuai Zheng, Ming-Ming Cheng, Jonathan Warrell, Paul Sturgess, Vibhav Vineet, C. Rother, Philip H.S. Torr, Dense Semantic Image Segmentation with Objects and Attributes, In Proceedings of Computer Vision and Pattern Recognition (CVPR), 2014.

Recently Microsoft have released a large dataset against which to benchmark new segmentation results [http://mscoco.org/](http://mscoco.org/) the aim would be to design an algorithm which can learn from visual Big Data to solve this problem

Additional information:
philip.torr@eng.ox.ac.uk
Title: Picking up and Recognizing Objects  
Supervisor(s): Prof Philip Torr

Abstract:

As wearable camera systems, such as Google glass, become more prevalent real time recognition of objects becomes of increasing interest. The goal of this project would be to allow a user to pick up objects whilst looking at them with an augmented reality camera system, and by verbal command say what they are so that the system can recognize them if they are seen again. This work will build on recent work within the group on real time recognition and segmentation,

Some of our applications include helping the partially sighted using augmented reality spectacles, see http://www.smart-specs.com/home.

Additional information: philip.torr@eng.ox.ac.uk

Title: Learning to play games with Deep Reinforcement Learning  
Supervisor(s): Prof Philip Torr

Abstract:


Following on from this success the project would focus on applying deep learning to more complex games. The student can choose the sort of game they would like to investigate. Two suggestions: first would be 3D games (such as Quake) involving an investigation of the type of visual features learnt to enable the performance of the subtasks within the game. Second, more complex games of strategy as exemplified by Berkeley Overmind (http://overmind.cs.berkeley.edu) the Berkeley AI engine for playing Starcraft.

Additional information: philip.torr@eng.ox.ac.uk
Title: Improving SLAM for wearable devices
Supervisor(s): Prof Philip Torr, Prof David Murray

Abstract:

We are designing a pair of smart spectacles to help the partially sighted (http://www.smart-specs.com/), these spectacles, when worn will allow additional information to be passed to the partially sighted person, either by audio or image enhancement. The aim is to mount a stereo rig on the glasses from which large scale SLAM would be performed. However SLAM is far from a solved problem. This project would investigate the extension of SLAM algorithms to include more knowledge about recognition, leveraging the work of the group on wholistic semantic segmentation.

Additional information:
philip.torr@eng.ox.ac.uk
Abstract:

The goal of deductive machine learning is to provide computers with the ability to automatically learn a behaviour that provably satisfies a given high-level specification. As opposed to techniques that generalise from incomplete specifications (e.g. examples), deductive machine learning starts with a complete problem description and develops a behaviour as a particular solution.

Potential applications of deductive machine learning are:

- Game playing strategy: given the specification of the winning criteria for a two-player game, learn a winning strategy.
- Program repair: given a buggy program according to a correctness specification, learn a repair that makes the program correct.
- Lock-free data structures: learn a data structure that guarantees the progress of at least one thread when executing multi-threaded procedures, thereby helping to avoid deadlock.
- Security exploit generation: learn code that takes advantage of a security vulnerability present in a given software in order to cause unintended behaviour of that software.
- Security/cryptographic protocol: learn a protocol that performs a security-related function and potentially applies cryptographic methods.
- Compression: learn an encoding for some given data that uses fewer bits than the original representation. This can apply to both lossless and lossy compression.

Additional information: Daniel.Kroening@cs.ox.ac.uk
Title: Non-parametric probabilistic models for optimising real-time citizen science  
Supervisor: Professor Alex Rogers  

Abstract  
Citizen science provides an effective way to collect experimental data at scale. However, the resulting data is often noisy as we typically have no control over who participates in the experiment, nor how they generate the data. As such, non-parametric probabilistic models provide a principled framework for both making inferences from experimental results and also for designing the experiments in real-time. This project will explore these issues in the context of a citizen science experiment on visual perception. The experiment seeks to understand the factors that contribute to the perceived brightness of an LED indicator given the various control parameters (such as LED intensity, colour, and duty-cycle) understanding how nonlinearities in the visual perception of brightness can be exploited to save energy in a small battery powered device. The envisioned system will derive these relationships by asking volunteers to make pair-wise comparisons between two alternatives; indicating which flashing LED appears to be brighter. Since the test board is USB controlled, through the browser, we can choose these pair-wise comparisons in real-time, optimising the design of the experiment as we collect data. This project will prototype this system, using an existing test board, in readiness for a large-scale deployment.

Title: Convolution neural networks for microcontrollers and constrained hardware  
Supervisor: Professor Alex Rogers

Abstract  
Neural networks, and particularly convolution neural networks, have made dramatic advances in recent years on many image and vision processing tasks. While training such networks is computationally expensive, they can often be deployed on much simpler hardware if simplifications such as integer or even binary weights are imposed on the network. This project will explore the deployment of trained convolution networks on microcontrollers (small 32-bit processors with or without floating-point hardware support) with the intention of demonstrating useful image processing (perhaps recognising the presence of a face in the field of view of a 32x32 low pixel count camera) on low-power devices.
Abstract:

This project will speed up state-of-the-art probabilistic integration methods (Bayesian quadrature) through the use of introspective probabilistic extrapolation.

[Probabilistic Numerics](http://probabilistic-numerics.org) is a new field that aims to bring a principled Bayesian framework to the computational bottlenecks common to all AI systems: numerical optimisation, quadrature and ODE solving. This framework allows the numerical errors that emerge from the use of numerical procedures to be correctly accommodated and propagated. It also permits a finite computational budget to be optimally and automatically allocated amongst a pipeline of numerics procedures: the numerics procedures where error is most severe can be assigned more computation.

The core challenge of inference is numerical integration, so as to integrate over the many states of the world consistent with our finite information. Bayesian quadrature is the state-of-the-art for this problem, tackling many of the problems (poor convergence rate, unreliable convergence diagnostics) of MCMC. However, the computational cost of Bayesian quadrature scales cubically in the number of samples, rendering it impractical for high-dimensional domains. This project will tackle these problems through analogies with traditional extrapolation methods (e.g. Richardson extrapolation) which have been widely used as a numerical tool to speed up convergence and reduce the required number of samples. Specifically, a probabilistic numeric view will be taken to the learning curves of a Bayesian quadrature algorithm: the proposed algorithm will introspectively use the trajectory of its past estimates to probabilistically extrapolate for its future estimates. This approach offers both fascinating new views of very old numerical algorithms and powerful solutions to the practical problems of approximate integration.

Additional information:
http://www.robots.ox.ac.uk/~mosb
Title: Automated Probabilistic Numerics  
Supervisor(s): Mike Osborne, Hongseok Yang

Abstract:

This project will automate the task of picking the right numeric method for a given problem (whose source is known.)

[Probabilistic Numerics](http://probabilistic-numerics.org) is a new field that aims to bring a principled Bayesian framework to the computational bottlenecks common to all AI systems: numerical optimisation, quadrature and ODE solving. This framework allows the numerical errors that emerge from the use of numerical procedures to be correctly accommodated and propagated. It also permits a finite computational budget to be optimally and automatically allocated amongst a pipeline of numerics procedures: the numerics procedures where error is most severe can be assigned more computation.

This project will consider ways of designing a bespoke optimiser for a given objective function. Program analysis applied to the source code of this objective function will yield many details of how it might be optimised. For example, it might detect that some of the variables (inputs) are irrelevant to evaluations of the objective, or that a variable $x$ is relevant only conditional on the value of another variable $y$ (as would be the case if $x$ only appeared in an `if $y > 10$` statement). The probabilistic numeric framework allows structure to be incorporated into the design of an optimiser: for example, the conditional relevance of a variable can be built into the kernel function for Bayesian optimisation. The optimiser will then naturally ignore variables that have been detected as irrelevant. We hence have the prospect of using these automatically detected features of an objective to design an optimiser whose efficiency and robustness is guaranteed.

Additional information:  
http://www.robots.ox.ac.uk/~mosb/
Abstract:

This project will unify the diverse means of performing approximate inference that find popular use within Computational Statistics and Machine Learning.

[Probabilistic Numerics] (http://probabilistic-numerics.org) is a new field that aims to bring a principled Bayesian framework to the computational bottlenecks common to all AI systems: numerical optimisation, quadrature and ODE solving. This framework allows the numerical errors that emerge from the use of numerical procedures to be correctly accommodated and propagated. It also permits a finite computational budget to be optimally and automatically allocated amongst a pipeline of numerics procedures: the numerics procedures where error is most severe can be assigned more computation.

Another name for 'quadrature' within Machine Learning is 'approximate inference', capturing the essential role that the estimation of integrals plays in probabilistic reasoning. Under this name, we find techniques such as Variational Inference and Expectation Propagation, which make use of alternative means of observing an integral of interest. By way of example, Variational techniques rely upon a lower bound to the desired integral: these bounds can be viewed as akin to censored sensor readings. Crucially, if these approximate inference techniques give any estimates of error at all, they are poorly calibrated. In this project, we will provide Approximate Inference techniques with a Probabilistic Numerics underpinning. This will, firstly, grant a means of better understanding such methods and equip them with a native, calibrated, error estimate. Further, this unifying view will permit all forms of Approximate Inference to be commingled in a combined AI system, making best use of the strengths of each. In particular, these different means of Quadrature can be traded off against one another according to their different balances of cost and accuracy, all while retaining an overall well-calibrated error measure.

Additional information:
http://www.robots.ox.ac.uk/~mosb
Abstract:

The goal of this project is to systematically model the gestational state trajectories as a continuous-time *Hidden Markov Model (HMM)* and use this model to develop a personalized risk score for various adverse neonatal outcomes. That is, we will model the relationship between a latent gestational state (for instance, the risk of stunting and wasting or the fetal growth rate), and the observable imaging and other screening data that the mother undergoes over time. The features of our model can be summarized as follows:

1. **Learning Feature Relevance from Imaging Data.** We will extract (using deep-learning – such as convolutional neural networks) various features from image data collected from screenings performed over time. We will learn which of the extracted features are most relevant in helping understand and predict the current gestational state and state evolution. We will also evaluate how the relevancy of these features is changing over time.

2. **Model selection.** We will do model selection and discover the number of gestational state from the data; by feeding our learning algorithm with offline records for previous parents' screening tests, the algorithm will prompt a set of gestational state, their corresponding significance in terms of the fetus well-being or risk for pathological neonatal outcomes, and their corresponding screening/imaging characteristics or symptoms.

3. **Learning state transitions.** The machine learning model will be a *time-inhomogeneous HMM* that has its state transition probabilities being a function of time. That is, the probability of going from one gestational state to another will be a function of the current number of gestation months. The model will comprise an underlying *absorbing Markov chain* that correspond to the birth event, and the transition probability functions from any state will be constrained to transit to the absorbing state after 9 months. The different instantiations for state trajectories generated by the model will constitute state sequences realized over the time span [0, 9 months], and the corresponding screening/imaging test outcomes at each point of time.

4. **Risk model.** We will design an inference algorithm that can infer the gestational state based on the screening/imaging test outcomes, and can also *prognosticate the risk* of various future neonatal outcomes.

It is expected that this research, which combines state of the art imaging techniques with novel machine learning techniques, will result in a conference paper to be submitted to a top machine learning conference. More importantly, if successful, this project can help improve prenatal care and save mothers and babies lives!

The student will be supervised by Professor Mihaela van der Schaar:

http://www.oxford-man.ox.ac.uk/~mvanderschaar/;

(Past work on machine learning for medicine: http://medianetlab.ee.ucla.edu/MedAdvance)
Abstract:

Overview
In many clinical settings, such as chronic disease progression estimation and critical care prognosis, a patient experiences a hidden, evolving trajectory of severity\(^1\) that can be tracked through (noisy) observable clinical findings such as screening tests and vital signs. However, patients are \textit{heterogeneous}: different types of patients experience different disease trajectories. Modeling such heterogeneity correctly is essential in order to enable accurate diagnosis and prognosis. Existing models have overlooked this fact and have resorted to "one-size-fits-all" methodologies that fail to provide \textit{personalized} clinical assessments for individual patients. The objective of this project is to construct a novel generative model for patient's physiology through which we can discover data-driven patient "subtypes" from the electronic medical records (EMR) data.

Proposed Project

The goal of this project is to develop a generative statistical model for the patients' latent clinical states and the corresponding observable clinical findings that enables learning useful patient subtypes from the EMR data. The main components of the proposed model are summarized in what follows:

- \textbf{Clinical states}: every patient is assumed to be in a certain "clinical state" at any given point of time. Such a state can correspond to the well-being of the patient, the severity of the patient's illness or the progression stage of a chronic disease. We will adopt a realistic \textit{semi-Markovian} state transition model that takes into account the sojourn time spent in every clinical state and its impact on subsequent state transitions (see [1][2][3][4]).

- \textbf{Observations}: since the observable clinical variables are usually collected over irregularly sampled time instances, we will model the multidimensional observable variables via a \textit{multitask Gaussian process}, and we will treat the observation times as exogenous covariates that are controlled by either the patient's behavior (i.e. the times at which a chronic disease patient decides to undergo a screening or a lab test), or the clinician's behavior (i.e. the times at which clinicians gather vital signs of a hospitalized critical care patient).

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\(^1\) For instance, the progression of a disease can be modelled as transitions among different diseases stages/states.
**Censoring:** since the time series data in the EMR are usually censored via either an informative censoring procedure (e.g. patient's death, cardiac arrest, discharge, etc.) or a random censoring procedure (e.g. patient stopped showing up at the clinic for an unspecified reason), we will model right-censoring events as an absorbing state in the state evolution trajectory that could possibly convey information about the entire latent path of state evolution. An example of a state model can be found in [1] and it is called a Hidden Absorbing Semi-Markov Model (HASMM).

**Subtype:** Since the patients' population is heterogeneous, it becomes essential to incorporate and model heterogeneity in order to ensure personalized clinical assessments. We will exploit the static covariates associated with each patient, such as genetic information, as an indicator of the type of patient he/she is. We will use a Latent Dirichlet Allocation model to conceptualize the patient subtypes as "topics" that are drawn from a Dirichlet prior that is itself a function of the static covariates. The patient subtype modulates the HASMM parameters and hence controls the type of state trajectory the patient would experience. This personalized generative model is referred to as an LDA-HASMM. (The graphical model for such the novel LDA-HASMM model is provided above.)

This project will require addressing the unique technical challenges encountered in the LDA-HASMM inference and learning tasks. This may involve using a set of novel Monte Carlo EM algorithms that are based on particle filtered (sequential Monte Carlo) sampling. In addition, censoring information available in the EMR should be used to effectively learn the LDA-HASMM model parameters. The project will also investigate the possibility of using particle Gibbs ancestor sampling to enable efficient learning for large EMR datasets.

The goal of the project will be to submit a publication to a top machine learning conference based on this work. More importantly, if results are promising, this can change the way medicine is practiced, thereby changing lives!

More information about Mihaela van der Schaar's research in this area can be found at: http://medianetlab.ee.ucla.edu/MedAdvance

Title: Dynamic Survival Analysis with Competing Risks using Multi-task Gaussian Processes
Supervisor(s): Mihaela van der Schaar

Abstract:

Problem Overview

Existing survival analysis models, such as the Cox proportional hazard model and random survival forests, do not accommodate settings with multiple competing risks, and in addition, they are not well suited to deal with time series data. In various settings, such as risk prognosis for patients with comorbidities, it is important to jointly estimate the survival functions of a patient with respect to multiple clinical conditions in order to plan and prioritize treatments and interventions. Prognosis in such settings relies heavily on time series or longitudinal data comprising test outcomes, clinical findings, screening tests, or symptoms. The objective of this project is to construct a novel approach for dynamic survival analysis that can be used to estimate the patient's hazard rates with respect to multiple clinical endpoints over time.

Proposed Project

We adopt a semi-parametric approach for survival analysis that specifies a parametric baseline hazard function (e.g. Sigmoid function), and models the impact of time-varying covariates on the hazard function using a non-parametric multi-task Gaussian process that relates multiple input covariates, including time, to a set of risky events. The covariates together with the time variable are related to each other via a covariance kernel function, whereas the hazards for the different endpoints are related via a stationary covariance kernel.

In order to learn the parameters of our survival model, a new inference algorithm will need to be constructed that exploits the correlation between the different clinical conditions (comorbidities) for efficient learning. This will involve investigating different solutions to handle right and left censored data, and analyze the impact of censoring due to one clinical endpoint on the quality of hazard estimates for the other endpoints.

The goal of the project will be to submit a publication to a top machine learning conference based on this work. More importantly, if results are promising, this can change the way medicine is practiced, thereby changing lives!

More information about Mihaela van der Schaar's research in this area can be found at: http://medianetlab.ee.ucla.edu/MedAdvance

Abstract:

This project aims to use machine learning techniques such as ensemble learning, convolutional neural networks etc. to predict spot prices for a variety of industries. Machine learning is increasingly used in finance to make predictions as well as to aggregate among existing strategies for making investments over time. We will use various free as well as proprietary data sets to assess the value of our newly developed methods in terms of both profit and risk, and compare them with state of the art techniques. This will also involve developing new “lucky factors” (features) that can be extracted from the data to inform and improve existing and new investment strategies. The expectation is that the work will lead to a conference publication.
Title: Deep Learning Enabled Real-Time Localisation on Mobile Devices  
Supervisor(s): Niki Trigoni

Abstract:

Localisation in GPS-denied environments, such as indoor shopping centres, parking lots and hospitals, is a fundamental need for various services and applications. It becomes more in demand as mobile phones and smart devices are pervasive in our life. This project will fill the gap by using different sensors, e.g., camera, Inertial Measurement Unit (IMU) and magnetometer, equipped on mobile phones for real-time accurate positioning. It will build on an existing Deep Learning based visual positioning system in the Sensor Networks Group, which has achieved state-of-the-art performance in real-time. An end-to-end localisation system consisting of Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs) will be trained and tested on real-world data from mobile devices. According to its performance, it can be further developed as one of the first apps in the world to achieve accurate, robust localisation on mobile devices without relying on GPS.

Title: Autonomous Navigation of Flying Robots based on End-to-End Learning  
Supervisor(s): Niki Trigoni

Abstract:

Unmanned Aerial Vehicles (UAVs), also known as drones, are being developed to be widely used in commercial and scientific applications, e.g., product deliveries (Amazon Prime Air), aerial photography and agriculture monitoring. In order to carry out these tasks, UAVs need to navigate autonomously by using on-board GPS, cameras and Inertial Measurement Unit (IMU) sensors. Most of current autonomous navigation systems of UAVs are designed on sensor fusion and state estimation. However, to achieve fully autonomous capability in complex, real-world environments, robust perception and decision making are essential. Inspired by recent successful self-driving techniques based on Deep Learning, the project will investigate end-to-end autonomous navigation of flying robots by using large-scale real-world data. We will start from algorithm design and testing in simulators before realising and demonstrating the system on Parrot Ar.Drone flying robots.

Title: Low-Cost Deep Visual Inertial Motion Capture  
Supervisor(s): Niki Trigoni

Abstract:

Motion capture systems, such as VICON (http://www.vicon.com/), are able to record accurate movement of objects or people at high frame rates for movies, animation, virtual reality and augmented reality, etc. However, since they usually use custom-made infrared cameras and artificial reflective markers to track the object of interest, they are so expensive that they cannot be broadly used. Compact and low-cost camera and Inertial Measurement Unit (IMU) sensors enables a novel approach to recover six degrees of freedom body motion of a human in real-time. This project will explore Deep Learning based motion capture technology and next-generation motion capture systems by only using low-cost sensors. Large-scale training data can be collected from our existing VICON system and IMUs to train deep neural networks reconstructing accurate human motion without the need of infrared cameras or markers.
Title: Home monitoring of patients with early and late stages of dementia using smartwatches  
Supervisor(s): Niki Trigoni

Abstract:

The project involves the use of smartwatches to monitor motion and location information of healthy individuals and dementia patients in their home environment. The aim is to analyse the inertial and bluetooth data collected from the smartwatches that patients will wear, and analyse it to localise the user inside their home, estimate metric or topological maps of the house and infer activities or other motion patterns that could constitute warning signs of dementia.

A combination of state of the art segmentation, clustering and classification techniques may be needed to address the problem of patient monitoring. For example, the question of inferring a topological map that shows how rooms are connected, may involve several steps, including segmenting the user’s trajectory into room-only segments and room-transition segments, identifying activities within each room-only segment and clustering room-transition segments to identify room connectivity. Once connectivity is determined, a large amount of very noisy inertial data could be used to approximate a metric map of the house. Once a map is created, it can be used to estimate the location of the user within the house, at least within room level accuracy. Location information can further be improved by taking into account the correlation between location and activity data, e.g. it is more likely to be sleeping in the bedroom rather than in the kitchen.

The end goal of this work is to explore the sensor data for early signs of dementia, but the intermediate goal of the mini project will be to address the location and activity recognition problems.

Data collection will start in February 2017, and by the end of March we expect to have data from at least 10 households. By the end of the first year, we expect data from 240 households (a mixture of healthy individuals and dementia patients at different stages).

Title: Robots and people in domestic environments  
Supervisor(s): Niki Trigoni

Abstract:

This project involves the use of wearable devices, such as smartwatches, for human-robot collaboration in domestic environments.

We consider applications where an assistive robot is operating in domestic environment (up until now, almost exclusively in- habited by humans), alongside users. In such environments, concepts such as room types and user activities are important for obtaining higher level knowledge about the environment. In particular, our scenario is one in which people and assistive robots co-exist inside a home, and the objective is to combine high level information such as user activities, from a human user wearing a smart watch, and probabilistic information such as room connectivity from the mobile robot, for creating a semantic map and obtain room-level localization of the user.

The main idea is to leverage the semantic information provided by detected user activities and the accurate map created by an assistive robot. The conceptual information will be modeled as a graphical model, on which to perform semantic reasoning.

The user will be equipped with a wearable device, such as a smart watch, and complex activities will be detected using inertial data from the watch, as well as the user’s trajectory.

The assistive robot will create a map of the environment, divided into rooms. Both the user and the robot build a conceptual map composed by room categories on top of the low-level
trajectory. When the robot and the user meet, the user’s conceptual map is fused with the robot’s conceptual map.

The robot will be able to match activities with room types, learning a semantic representation of the environment over time, while the user will be able to be localized at room level by exploiting the precise map built by the robot.
Title: Innovative Sensing and Actuation for Smart Buildings  
Supervisor(s): Alessandro Abate

Abstract:

Advanced sensorisation and actuation in smart buildings and the development of smart HVAC (heat, ventilation and air-conditioning) control strategies for energy management allow for optimised energy usage, leading to the reduction in power consumption or to optimised demand/response strategies. This can further lead to optimised and predicted maintenance for the building devices.

Of course the sensorisation of buildings leads to heavy requirements on the overall infrastructure: we are interested in devising new approaches that are advanced, yet parsimonious, possibly towards the concept of using “humans as sensors”. On the actuation side, we are likewise interested in engineering noninvasive minimalistic solutions, that are robust to uncertainty and performance certified.

The project is both theoretical and experimental: it will make use of data generated from two, newly upgraded lecture rooms in the Department of Computer Science, here at Oxford, where data is currently being collected, and where we can get access to the HVAC building management system for actuation.

The project can further benefit from a visit to a number of long-term industrial partners.

In collaboration with (among others): Honeywell Labs (Prague), Trend Control (UK), Nest Labs (US).

Background: control, verification, machine learning, sensor networks.

Title: Formal Aggregation of Large Populations of Markov Models - Verification, Control, and Applications on the Power Grid  
Supervisor(s): Alessandro Abate

Abstract:

We are interested to work on problems of formal aggregation of large-scale populations of Markov models, with the goal of providing new computational algorithms for the optimal policy synthesis over such a population. The project has an applicative side: aggregating and controlling large populations of photovoltaic panels over the power grid. The project is jointly coordinated with engineers from the R&D department of RTE, the French grid operator. The end goal is the robust, reliable control of such heterogeneous and large-scale engineering systems, attaining global stability features and reliability requirements. The student can benefit from a visit to RTE R&D department, located in Versailles (France).

We are interested in using techniques from formal methods and performance analysis (such as probabilistic model checking, SMT, and other deductive approaches) from Computer Science, as well as modern approaches from control theory (correct-by-design synthesis, abstraction-based synthesis, compositional analysis) and applied probability (stochastic analysis and control).

In collaboration with: RTE R&D (France)

Background: verification and control.
Title: Integrated Model Building and Verification
Supervisor(s): Alessandro Abate

Abstract:

This project is framed within the broad goal of integrating deduction and induction over dynamical models. It deals with the development of new techniques for the formal verification of dynamical models, alongside the use of data to confidently generate such models.

Given a mathematical model, the goal is to establish some guarantees (Boolean or probabilistic, depending on the underlying nature of the model) on a property, possibly around a control architecture that is being synthesised. This can be achieved trying to smartly devise objects (certificates, Lyapunov functions, dynamical envelopes) based on the underlying dynamics and property of interest, or by abstracting both model and specification into a computable format (finite state model, property expressed as a logical formula) that can be directly fed into a software tool producing the guarantees on behalf of the modeller (hopefully, rather fast). In view of the second approach (which is preferred since it is automatic), this abstraction step has to be formal (with again guarantees on the relationship between concrete problem and abstracted one).

The deductive procedure above requires a quantitative model, and is restricted by this a-priori knowledge: moving beyond this into the realm of datadriven model inference (induction) is the goal and main topic of this project proposal. The goal is to explore new approaches to achieve model building with guarantees, in a way that can be used towards quantitative verification on such models. Further this integration should lead to a recursive procedure, where the inductive and deductive steps are fully integrated.

Background: control, verification, machine learning (RL, Bayesian inference).

Title: Automated Learning Techniques in Verification and Control, with applications in Software and Robotics
Supervisor(s): Alessandro Abate

Abstract:

We are interested in the convergence and integration of recent techniques from statistical and machine learning with successful approaches for the formal verification of reactive models. We are specifically focused in the development of innovative solutions for planning and control synthesis over models of dynamical systems, in particular of autonomous aerial robotics or of multi-agent compositions of ground vehicles. The project will investigate the verification and control of complex models in robotics, encompassing the presence of continuous physical components, as well as of discrete digital software and actuation: this naturally yields a cyber-physical modelling setup, which is challenging for both verification and control tasks.

The convergence of learning and verification techniques is key in this project. In verification, the use of machine learning to guess simple linear program invariants is promising, but complex invariants, in particular for the CPS setup mentioned above, appear to be difficult for existing statistical learning techniques.

Statistical approaches in model checking are promising in terms of scalability, but often lack providing stringent assertions that are required for safety verification tasks. On the other hand, key algorithmic ideas in verification such as efficient splitting and learning in conflict-driven clause learning and symbolic reasoning about sets have the potential to improve existing learning techniques. Further, we are interested in the integration of advanced, adaptive model learning techniques from data, with successful model-based approaches for verification, control and planning. For the verification and correct-by-design control of complex models that are relevant in the discussed robotics applications, we target the in-the-
loop coupling of such diverse perspectives, which leads to specific scalability and computational requirements.

In collaboration with: Prof. Daniel Kroening

Background: verification, control, machine learning.

**Title: Learning and Optimal Control in Finance**
**Supervisor(s): Alessandro Abate**

This project aims to use a blend of techniques from machine learning and stochastic control (such as ensemble learning, convolutional neural networks on the one hand, and approximate dynamic programming, receding-horizon control on the other) to predict spot prices for a variety of industries and to devise optimal investment strategies. Alongside more established and classical, model-based results from stochastic control, machine learning is increasingly used in finance to make predictions as well as to aggregate among existing strategies for making investments over time. We will use various free as well as proprietary data sets to assess the value of our newly developed methods in terms of both profit and risk, and compare them with state of the art techniques. This will also involve developing new “lucky factors” (features) that can be extracted from the data to inform and improve existing and new investment strategies. The expectation is that the work out of this project will lead to a conference publication.

In collaboration with: Prof. Mihaela van der Schaar

Background: learning and control.

**Title: Precise Model Reduction for Bio-Chemical Reaction Networks**
**Supervisor(s): Alessandro Abate**

**Abstract:**

Consider a chemical reaction network (CRN) and its species dynamics, which can expressed as a chemical master equation (CME) or any of its finite-state approximations: for instance, as a CTMC (exactly simulated via the SSA algorithm), or approximated as an ODE (reaction rate equation), as an SDE (Langevin equations), or as an LNA (among other options), or with the dynamics of higher-order moments.

In view of the computational complexity associated to any of these models or the introduced approximation levels, it is of interest to come up with formal approaches to provide model reductions (also known as abstractions), which allow for faster or more precise computational analysis and that are of course close to the concrete models. Key is the degree of approximation: how far is an abstracted model form the concrete one? Can we rely on the abstract model to study properties of the given CRN? This aspect is only fragmentally studied in the current literature.

Formal methods offer quantitative tools to express and compute approximation levels between a pair of (abstract and concrete) models. This can be attained, as a notable instance, by leveraging notions of exact or approximate simulations and bisimulations. On the other hand, these powerful techniques need to be adapted to models with continuous components (time, states): research in this area has shown that such extensions can be attained by leveraging notions of Lyapunov functions attainable via SOS tools. This project can have a synthetic component in the attempt to investigate the existence of ‘minimal’ networks corresponding to a given CRN.

Background: verification and control.
Title: Deep Grasping - Using Deep Reinforcement Learning to learn how to manipulate objects
Supervisor(s): Ingmar Posner and Dushyant Rao

Background: Machine Learning, Mathematics, (ideally) Reinforcement learning

Abstract:

In recent years methods based on deep neural networks have yielded state-of-the-art performance in numerous domains, including object detection, speech recognition, and image segmentation. This project is focuses on using deep learning techniques to allow a robotic manipulator to autonomously learn how to grasp objects in its workspace. This can be framed as a reinforcement learning problem, where the manipulator must learn to perform the task based on trial-and-error, given a reward or cost for its actions.

In this project, you will have the opportunity to work closely with a robotic manipulator and immerse yourself in a number of exciting research areas, including deep learning, reinforcement learning, and computer vision. Leveraging over 130 man-years of innovation in mobile robotics in the Oxford Robotics Institute, you will be developing a reinforcement learning algorithm that utilises deep neural networks to learn a control policy, which answers the question of “which actions should I take to successfully grasp the object?” given just a live camera feed. You will be developing the algorithms in C++/Python/MATLAB, and interfacing with the robotic arm software in C++ to control the arm. A successful project will result in a working system that can demonstrably learn to grasp specific objects without human intervention from just visual camera inputs - this will be measured in terms of the grasping accuracy (e.g. percentage of successful grasps) and the ease/speed at which this can be learned.

Title: A Deep Learning Approach to Estimating Visual Odometry from a Monocular Image Sequence
Supervisor(s): Ingmar Posner and Alex Bewley

Background: Machine learning and visual geometry

Abstract:

In recent years, deep neural networks (DNN) have demonstrated significant improvements over hand engineered approaches for several computer vision and robotic perception tasks, such as scene classification and object detection. In this project we are interested in evaluating the capabilities of DNNs to address the visual odometry (VO) problem, i.e. learn accurate motion trajectories when presented with an image sequence. Currently, geometric based approaches outperform early attempts of naively applying DNNs to VO, however as many perception systems on-board a robot move towards a DNN approach it is desirable to extend these networks to not only answer “What is where in an image?” (object detection) but also answer “How am I moving through the world?” (VO).

This project will expose you to deep learning techniques applied to robotic based perception problems which are typically addressed using visual geometry. In working on this project, you will access over 1000km of pre-recorded street scene videos along with odometry data for training and evaluation. You will be required to design and train a DNN (using TensorFlow in either python or C++) that takes images as input and outputs a physical transformation describing the motion of the camera. Varying architectures are to be explored
(e.g. recursive networks) with a focus on both accurate VO and extendable general purpose representations.

Success will be evaluated in the form of a working system which, when presented with a previously unseen sequence of images, would generate continuous estimates of the relative camera pose on a per frame basis. The resulting trajectory will be compared against both navigation hardware (e.g. GPS/INS) and our existing state-of-the-art geometry based VO software.

**Title: Exploiting the Urban Soundscape for Autonomous Driving**

**Supervisor(s):** Ingmar Posner, Paul Newman and Letizia Marchegiani

**Background:** Machine Learning and Signal Processing

**Abstract:**

Much attention has been devoted in robotics to object detection, using visual representations of the objects. However, humans use acoustic information as a cue to help navigate, understand and direct attention in urban environments. Indeed, some cues are explicitly designed to be auditory (think of an ambulance siren). It is surprising, then, that the use of the urban soundscape is thus far largely unexplored in autonomous driving. This project aims to change that. By leveraging state-of-the-art multimodal machine learning methods, we will monitor urban scenes fusing visual and acoustic information to detect the presence of specific sounds of interest in the presence of noise, localise the corresponding source and perform multimodal event classification for increased environmental awareness and action selection.

Multimodal learning allows to integrate information from different sensing channels and has proved to enhance the performance of robots' perception systems. Speech and speaker recognition applications, for example, have largely benefited from the use of models which take into account both utterances (auditory domain) and lip movements (visual domain). Deep neural networks have proved to be a powerful tool in this direction, able to extract complex cross-modal representations of objects. In this project, you will work on multimodal urban scene interpretation, investigating the use of different state of the art machine learning methods on data collected from microphones and cameras mounted on road vehicles such as the Oxford RobotCar. Success will be evaluated in the form of a working system which, when presented with a previously unseen sequence of simultaneous images and sounds, would correctly detect and classify specific events (e.g. overtaking, an emergency vehicle approaching, etc).

**Title: Learning to Grasp via Deep Inverse Reinforcement Learning**

**Supervisor: Ingmar Posner and Markus Wulfmeier**

**Abstract:**

Recent work in combining advances in Neural Networks with Inverse Reinforcement Learning have shown the benefits of learning cost functions for autonomous driving. While cost functions for motion planning are usually manually defined - leading to hand crafted behaviour - it was demonstrated that learning these instead has increasing performance benefits especially for corner cases situations. Refining human priors by combining the high capacity of deep function approximators and the training framework of IRL can outperform existing approaches and bring these approaches closer to application in the real world.
This project will address bringing the benefits of Deep Models for Inverse Reinforcement Learning/Inverse Optimal Control to the domain of manipulation and grasping.

You will work with Python/Tensorflow/C++ to work on the task in simulation and real world robot arm (JACO) and should have basic coding skills as well as some knowledge of machine learning and computer vision

(Knowledge in IRL is a plus but not a requirement.)
Abstract:

Set function optimization provides a unified formulation for many real-world problems. Given a ground set $S$, a set function assigns a value to each of the subsets of $S$. For example, consider the problem of binary segmentation, that is, partitioning the pixels of an image into object and background. Each element of the ground set $S$ represents a pixel. A subset $A$ of $S$ represents those pixels that have been assigned to the object class, while the remaining pixels are assigned to the background class. The set function measures the quality of the segmentation, which can take into account the appearance of the object/background, the shape of the object as well other useful information such as smoothness and contrast. Formulated in this manner, segmentation reduces to finding the subset that maximizes the appropriate set function.

A powerful framework for set function optimization is based on multilinear relaxations. Roughly speaking, we define a variable for each element of the ground set that represents the probability of choosing the element in the solution. The multilinear relaxation is the expected value of the set function in terms of the variables, which can be maximized using continuous optimization techniques such as conditional gradients. The main difficulty with this approach is that it is often computationally expensive to evaluate the multilinear relaxation or its conditional gradient (in general, exponential in the size of the ground set). In this work, we will exploit the fact that real-world set functions exhibit strong structural properties, for example, segmentations are often contiguous. To this end, we will design a deep reinforcement learning approach that allows us to obtain an efficient and accurate approximation of the multilinear relaxation and its gradients using a small number of samples.

The methodology developed as part of the project will be used for various discrete optimization tasks such as semantic segmentation and diverse subset selection, for which the basic infrastructure already exists in the group.

Related Work:

While the approximation of the multilinear relaxation has not been directly addressed in the literature, some recent papers have explored the broader idea of learning to optimize. Examples include


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Objectives:

The modernization of energy systems and the integration of increasing shares of renewable energy sources has induced an intense research activity towards this direction. However, the expected increase in the share of renewable energy sources will increase the degree of uncertainty in the system, thus posing stability and reliability challenges. To address these contemporary challenges, and to ensure a safe and uninterrupte energy systems operation, consumers’ flexibility has to be exploited. Electric vehicles, which obtain some or all of their energy from the electricity grid, will play a prominent role in this paradigm shift, since they not only contribute to pollution reduction, but also, by appropriately scheduling their charging status (e.g., charging over low demand/electricity price periods) or shifting their consumption in time, serve as virtual dynamic storage.

This project considers the problem of designing an optimal charging mechanism for a fleet of heterogeneous plug-in electric vehicles (PEVs). We treat PEVs as agents competing against each other for shared resources such as storage. Agents receive some price incentive from some central authority (aggregator) and respond to it by updating their charging schedule (see Fig. 1). This process is then repeated until convergence to a no-regret tuple of charging schedules. Several questions pertain this process, the most important of which being “Does this process converge?” and if it does, “What is the price of agents behaving like anarchists?”

Tasks:

The following tasks are anticipated:

- Familiarity with electric vehicle charging control problems.
- Familiarity with cutting-edge decentralized algorithms for non-cooperative multi-agent games.
- Application of decentralized algorithms to the electric vehicle charging control problem, appropriately extending them to account for the presence of shared resource constraints.
- Investigation of the effect of agents’ selfish behavior on the energy charging cost for the entire agent fleet.
- Simulation based analysis of the developed algorithms and comparison with cooperative charging counterparts.
Prerequisites:
Mathematical maturity and experience and/or strong interest in optimization will be greatly appreciated.

Additional information: email: kostas.margentos@eng.ox.ac.uk or antonis@eng.ox.ac.uk
Title: Optimization in multi-agent networks – Distributing the optimal power flow problem
Supervisor(s): Kostas Margellos & Antonis Papachristodolou

Objectives:
Networks involving multiple agents appear in many engineering domains, e.g., autonomous robots, wireless systems, social networks, power systems, etc. Adopting a centralized paradigm for optimizing the performance of such systems is typically hampered by the fact that not all necessary information is always available (e.g., agents may not be willing to share information due to privacy purposes), and/or the resulting solution strategy may not be scalable due to computational and communication limitations. To address these challenges and allow for highly scalable solutions that could be applied to large scale, multi-agent systems, algorithms based on distributed optimization are adopted. Under such a set-up, each agent solves a local problem, communicates its tentative decision only with neighboring agents, and then repeats this process on the basis of new information received until consensus is reached.

The project involves the application of novel algorithms for distributed optimization to the optimal power flow problem in power networks. Optimal power flow is at the backbone of power systems operation, however, it is typically treated from a centralized perspective. In this project we envision a distributed algorithmic implementation, where each generating unit is treated as an agent interacting with the other ones over the network. The objective of each unit is to minimize its local production cost, while via an iterative process units cooperate to agree on a production schedule that satisfies their generation limits, the transmission capacity constraints, and the balance between production and demand (see Fig. 1).

![Figure 1: Power network diagram.](image_url)

Tasks:
The following tasks are anticipated:

- Familiarity with recent developments on distributed optimization in multi-agent networks.
- Familiarity with state of the art optimal power flow formulations.
- Application of distributed optimization techniques to the optimal power flow problem.
- Simulation based analysis of the developed distributed optimization techniques and comparison with centralized counterparts.

Prerequisites:
Mathematical maturity and experience and/or strong interest in optimization will be greatly appreciated.

Additional information: [email: kostas.margellos@eng.ox.ac.uk](mailto:kostas.margellos@eng.ox.ac.uk) or [antonis@eng.ox.ac.uk](mailto:antonis@eng.ox.ac.uk)
Title: Probabilistic sensor fusion for terrain estimation with LIDAR and dense stereo
Supervisor(s): Maurice Fallon and Will Maddern

Abstract:

LIDAR sensors measure 3D point clouds that are precise but sparse and at low frequency. Stereo cameras can also produce point clouds. These are much more imprecise but have high resolution and operate at 30Hz. We seek the best of both worlds and to take advantage of the complementary nature of time-of-flight ranging and dense stereo reconstruction to improve 3D perception.

The project will build on previous work in ORI on stereo-lidar fusion but apply it to precise terrain reconstruction for an entirely different application. We are interested in building reliable but dense reconstructions of terrain for dynamic robots. Such methods will run online and will (eventually) be efficient enough to allow a quadruped robot to plan footsteps while trotting at 1m/s or more. Initially we will develop our approach using test structures (wooden ramps) and evaluate against 3D models built using traditional SLAM methods. In time we wish to construct terrain maps of rubble piles or rocky paths, for example.

Additional information:
This project is a part of an ongoing collaboration with the Dynamic Legged Systems Lab at the Italian Institute of Technology. The longer term goal of the collaboration is to enable the HyQ, a quadruped robot, to navigate in forests, farms, disaster sites, or industrial plants.

Title: Segment-based LIDAR localisation in unstructured natural environments
Supervisor(s): Maurice Fallon and other colleagues in ORI

Abstract:

Loop-closure detection in 3D data is a challenging task. Typical methods rely on image-based methods to detect revisits to a previously explored environment, but struggle when the scene or lighting changes. In natural environments (think pathways along dense forests or orchards) this is even more difficult. Even a human being would become unfamiliar with a forested path in different seasons. We would like to be able to localise a robot along such a path by recognising salient aspects of such a scene - major branches, distinctive terrain features and summarised descriptors of patches of 3D point clouds.

This project will develop methods to localise a mobile robot using 3D laser scanners. The scanner will produce 3D point clouds. We will explore localisation relative to a prior map using these point cloud by developing some of the methods described above. Initial sample data will be collected using a handheld sensor rig (human carried in a forest) or a ORI wheeled robot. Algorithms will be developed offline, but with good progress in the project we will move on-wards to demonstrate the approach on-board a quadruped robot in a forested environment.
Title: Ocado Technology: Machine Learning for Large Scale Product Recognition from Images  
Supervisor(s): Dr David Sharp, Joseph Zammit, 10X Technology Team

Abstract:

Sponsored by Ocado, the world’s largest online-only grocer, you are invited to apply for the opportunity to do your Project in Machine Learning for product recognition, working with the Ocado Technology 10x Team. The team creates value for Ocado in the near-term as well as the long-term by working on speculative projects that push the boundaries of what can be achieved with technology.

Our automated warehouses stock 49,000 products which we deliver to over half a million customers across the country, and the focus of the project would be to investigate deep learning methods for recognising large subsets of these products from images. This is an opportunity to deepen and enhance your experience and expertise in this field with a real-world application, using and expanding on the state-of-the-art convolutional network techniques to deal with a larger number of categories and visually similar products, considering the impact of promotional or seasonal packaging, and investigating the use of transfer learning and existing work to jump-start your investigations.

Alternative avenues and extension activities might include coupling with image segmentation to detect multiple products in an image, or integration with Ocado’s various potential applications and prototypes.

Additional information:  
Contact Joseph Zammit (joseph.zammit@ocado.com) for more information on this project and to express your interest in this opportunity. Read more about Ocado Technology at www.ocadotechnology.com

Title: Ocado Technology: Customer Simulation Engine  
Supervisor(s): Dr David Sharp, Joseph Zammit, 10X Technology Team

Abstract:

Sponsored by Ocado, the world’s largest online-only grocer, you are invited to apply for the opportunity to do your Project in simulating customer behaviours, working with the Ocado Technology 10x Team. The team creates value for Ocado in the near-term as well as the long-term by working on speculative projects that push the boundaries of what can be achieved with technology.

Our customers order from a catalogue of 49,000 products which we deliver from automated warehouses, and the focus of the project would be to investigate new statistical methods for predicting when and what a customer might order, drawing on the vast amount of historical data held in the cloud.

This is an opportunity to deepen and enhance your experience and expertise in this field with a real-world application, using and expanding on the state-of-the-art modelling techniques expanding to look at other characteristics of customers and their interactions with Ocado. You could investigate what information would it be sufficient to know from a new customer in order to predict their activity, how can your model be deployed to simulate customers, and what the implications of your simulations would be for stock demand forecasting, for example.

Additional information:  
Contact Joseph Zammit (joseph.zammit@ocado.com) for more information on this project and to express your interest in this opportunity. Read more about Ocado Technology at www.ocadotechnology.com
Abstract:

Sponsored by Ocado, the world’s largest online-only grocer, you are invited to apply for the opportunity to do your Project in Intelligent Grocery Ordering Through Interactive Talking, working with the Ocado Technology 10x Team. The team creates value for Ocado in the near-term as well as the long-term by working on speculative projects that push the boundaries of what can be achieved with technology.

The project is to prototype a component of an interactive conversational dialogue system which enables a customer to order groceries through a spoken (or typed) conversation with a machine. The focus of the project is for the machine to interact effectively with the customer as they narrow down the choice of product desired, showing filtered results on the way, for example synthesising the intent and refining search results after each of the following requests: “I want milk.”... “Do you have semi-skimmed?”... “Okay I like the organic one, but do you have a 4 pint one?”... “Yes, okay the first own brand one is great, I'll have two please.”

This is an opportunity to develop and deepen your experience and expertise in automated spoken dialogue management in a real-world scenario, using and building on state of the art computer linguistics techniques to disambiguate one of the richest catalogues of grocery items available in the world today.

Extensions could exploit the possibility of personalisation techniques based on machine learning of the preferences of individual users as they complete more orders, or involve further exploration of other Natural Language Processing challenges in Ocado’s rich domain.

Additional information:
Contact Joseph Zammit (joseph.zammit@ocado.com) for more information on this project and to express your interest in this opportunity. Read more about Ocado Technology at www.ocadotechnology.com
Title: Smart Exploration for Deep Reinforcement Learning
Supervisor(s): Shimon Whiteson

Abstract:

Deep learning has begun to demonstrate great success in reinforcement learning, as deep networks trained using Q-learning have recently shown exceptional performance on a range of Atari video games. However, this approach succeeds only on games for which the major challenge is representational, which can be overcome with deep learning. On many games, performance is still quite poor because the system has no sophisticated means for balancing exploration and exploitation, i.e., deciding when to act in a way that reduces uncertainty about the environment, and when to act in a way that maximises performance. The goal of this project is to develop smart exploration mechanisms for deep reinforcement learning, with the goal of improving the state of the art performance on at least one Atari game. The main approach is to build on existing reinforcement learning methods for smart exploration (e.g., Bayesian approaches or probably approximately correct methods) and find ways to make them scalable in a deep reinforcement learning framework.

Title: Reinforcement Learning for OpenAI
Supervisor(s): Shimon Whiteson

Abstract:

OpenAI has recently released a new web interface environment, where an agent has to learn to interact with websites, e.g., filling in forms to order plan tickets. This poses many challenges, not only for reinforcement learning, but also for transfer learning, since learning efficiently requires porting skills acquired in related tasks. The goal of this project is to design and implement a reinforcement learning agent that can learn to solve multiple OpenAI tasks.

Title: Experience Replay for Stable Sample-Efficient Multi-Agent Reinforcement Learning
Supervisor(s): Shimon Whiteson

Abstract:

Over the past few years Deep Reinforcement learning (Deep-RL) has achieved major successes in a variety of fields. Deep-Q-learning is a well known Deep-RL algorithm, in which the Q-function is parametrised by a deep Q-network (DQN). DQN was popularised by DeepMind when it was used to play Atari games in 2014. One of the core-components of DQN is the experience replay buffer which allows the agent to learn multiple times from the same experience. This replay buffer both stabilises learning, by de-correlating the gradient updates, and improves sample efficiency. One of the underlying assumptions in using a replay buffer is that the environment is stationary, and therefore past experiences remain valid samples.

Most recently adaptations of DQN of been proposed for the multi-agent domain and the ‘learning to communicate’ setting, where multiple agents have to learn how to solve a task that includes an information exchange. In these settings, as multiple agents are learning at the same time, the environment appears non-stationary from the perspective of any single agent, which so far has required disabling experience replay. The goal of this project is to develop a new form of experience replay that is robust to nonstationarity and can thus be used to stabilise multi-agent learning while improving its sample efficiency.

How the experience replay mechanism needs to be adjusted in order to allow for sample efficient and stable DQN in multi-agent environments, is an open question of great practical and theoretical importance.
Title: Oxford Robotics Institute
Supervisor(s): Will Madden, Akshay Moyre, Tom Wilcox and Paul Newman

Abstract:

The Oxford Robotics Institute looks at all aspects of mobile autonomy. We like things to move. We are currently commissioning a new autonomous vehicle - a large RangeRover sport. It’s pretty fancy. We are now quite good at localisation now, we have outstanding systems support code, and we have all the tools we would expect in terms of perception when it comes to detecting important classes of objects in images. But there is more to do.

Next on our list of things to sort out is some more advanced rules of the road. So while we can easily detect cars in images and we can sense distances in laser-light, what we would really like to do is infer the distance in meters to surrounding vehicles detected in single images. After all to make plans you need meters, not pixel coordinates. You might think it prudent for example to make a different plan in the presence of a 20 tonne lorry at 50m to a bicycle at 10. Maybe not. But whatever, we want to build a vision only system that builds a time varying locally metric model of certain object categories around the vehicle.

This project will do this by co-training a detector with both visual and lidar data and then running with pure vision. This then can feed into the vehicle’s spatial planner (where do I move) and speed profiling subsystem (when do I move) to adjust spatial and temporal trajectories.

Choose this project if you want to make something work on the road and you think combining machine learning, geometry, planning and systems sounds like fun. Indeed it is. This is not a “quickly code it in matlab” kind of project though. We’ll be leveraging some hardened system code and there is a non-trivial learning curve there, but you will be healthier for the climb.
Title: Towards Semantic Data Management for Autonomous Driving  
Supervisor(s): Ingmar Posner, Paul Newman and Lars Kunze

Background: Sensor data, Semantic Maps and Semantic Web technologies

Abstract:

Autonomous cars collect vast amounts of data. This data includes low-level sensor information about the environment as well as high-level information about the cars' own decisions. Extracting, analyzing, and reasoning about such heterogeneous data poses several challenges. However, by annotating the data semantically and by building rich semantic models in form of ontologies, the data can be accessed and queried in a uniform way. Using specialized query interfaces developers are enabled to extract data at the semantic level which allows them to analyze the behavior of autonomous systems more effectively. For example, a developer might retrieve the relevant data for a particular situation using the following query: 'select all visible pedestrians when the car slowed down in front of a green traffic light'. After the data has been extracted it can be passed on to reasoning and/or machine learning methods. Given the formal semantics of the inferred and/or learned models it is possible to apply them in novel and/or similar situations. Moreover, it is even possible to transfer knowledge between cars. Overall, semantic data management for autonomous driving can provide important functionalities with respect to data extraction, reasoning, and learning which have not been explored to their full extent.

The aim of this project is to design, to develop and to evaluate semantic data management tools in the context of autonomous driving. To this end, Semantic Web technologies will be used as they provide a scalable way to model and to reason about concepts, their relations, and particular instances. An important aspect of this work is to ground instances that might denote physical objects to low-level sensor data. Other important aspects include the provenance and the dynamicity of the data. For selected use cases, the student will build ontologies using the Web Ontology Language (OWL). Further, the student will define a set of inference/learning problems where the spatio-temporal structure of events needs to be recognized in a stream of sensor data and execution logs. He/she will use and develop dedicated reasoners to check the consistency of the overall knowledge and to infer implicit knowledge, e.g., to reason about the occurrence of particular events. Finally, the set of developed semantic data management tools will be evaluated based on previously unknown data sets.
Title: Using deep learning for inferring 3D human pose  
Supervisor(s): Andrew Zisserman and Ankush Gupta

Abstract:

The aim of this project is to estimate the 3D pose of a person from an image using deep learning. The method involves two steps: first, infer the 2D location of landmarks (such as joint positions) in the image; and second, infer the 3D position of the landmarks (up to an overall scale factor). Both steps involve training a deep convolutional neural network. The training data for the first step will be obtained from public human pose datasets, and for the second will be obtained from available kinect range data sets for videos.

The goal for the method to run at frame rate, so that human pose can be inferred from a live video stream.

Title: Deep Learning for Lip Reading  
Supervisor(s): Andrew Zisserman and Joon Son Chung

Abstract:

Recent research has shown that deep learning can be used for lip reading at the sentence level, and the performance of such systems exceeds that of professional lip readers (see "Lip Reading Sentences in the Wild", https://arxiv.org/pdf/1611.05358v1.pdf). The architecture used to achieve this is a sequence-to-sequence model, as used in machine translation, based on LSTMs. However, recent work on machine translation has shown that sequence-to-sequence models can be built directly from convolutional networks, without requiring LSTMs, and with simpler training and run-time requirements.

The aim of this project is to investigate this new generation of machine translation models for the task of lip reading.

The stages of the project would include:

- design and train a purely convolutional model at the sentence level
- apply the model to `on-line!` translation (where the sentence is read as characters are spoken, rather than once the sentence has finished).

Title: An App for text spotting  
Supervisor(s): Andrew Zisserman and Andrea Vedaldi

Abstract:

Text spotting involves detecting and recognizing text in images of natural scenes. A novel approach in the Visual Geometry Group has shown that deep convolutional neural networks can be trained on synthetic data and applied successfully for text spotting on real images - exceeding the state of the art on all public benchmark datasets (see A. Gupta, A. Vedaldi, A. Zisserman, Synthetic Data for Text Localisation in Natural Images, CVPR 2016).

The goal of this project is to reduce the memory size and number of parameters of the CNNs, so that they can run on a low power device such as a mobile phone, rather than a high end GPU. Having an application of this type on a portable device has many benefits, in particular for the visually impaired.

The stages of the project would include:

- researching current methods for distilling and decimating networks
- comparison of these for the text spotting task
- porting to a mobile app
Title: Dynamic robot locomotion: modelling and control of a hopper robot  
Supervisor(s): Ioannis Havoutis, Paul Newman(?)

Background: Robotics, modelling, control

Abstract:

Walking and running systems are often studied using lower dimensional models. Such models are approximations that capture the main dynamics of the gait in question. For example, bipedal running or quadrupedal pronking are typically modelled with a spring loaded inverted pendulum (SLIP) model, i.e. a monopod robot or a single leg hopper. Despite their simplicity, hoppers have a very rich dynamic behaviour! This project aims to introduce motivated students to the exciting area of dynamic legged locomotion.

In this project, you will work on modelling and controlling a hopper robot. You will build a physically realistic system, to model stance, flight and (switching) contact dynamics. You will begin by implementing a simple reactive controller, capable of balancing and hopping on flat terrain. Next, you will build an advanced controller based on your background and desired direction. A number of options are available, e.g. control theoretic approaches, optimal control based, learning based, etc. The difficulty of the terrain will also progressively change for evaluating the performance of the controller(s). Extra credit will be given for (shared) user control and acrobatic manoeuvres!

Title: Walk this way: motion planning for legged robots  
Supervisor(s): Ioannis Havoutis, Paul Newman(?)

Background: Robotics, machine learning

Abstract:

Path planning is equally important for legged and wheeled robots. For the latter, continuous contact with the ground greatly simplifies the problem of planning how to get from A to B. Legged systems on the other hand need to address an additional level of complexity. A legged locomotion planner must compute a sequence of footholds that reach the goal position and are subject to a variety of constraints. For example, all footholds/handholds need to be sequentially reachable, possible to make and break, kinematically reachable and dynamically feasible, etc. Naive search over the space of possible configurations quickly renders the problem intractable.

Most (kinodynamic) planners up to date make heavy use of model/robot knowledge, often in the form of hand-tuned heuristics. Nonetheless only a small number of planners can reach interactive speeds. Informative heuristics however can greatly speed up the process by biasing the search towards relevant/desirable areas. In this project you will implement a data-driven approach to learning such heuristics. You will use state of the art machine learning methods to build models for general humanoid locomotion, using examples from a motion capture database. You will evaluate your approach against a naive sapling-based method and possibly an aggressively hand-tuned planner!

Title: Dynamic mobile manipulation  
Supervisor(s): Ioannis Havoutis, Paul Newman(?)

Background: Robotics, motion planning, dynamics, control

Abstract:

Robots that can freely move around are common nowadays. Such robots have arms and legs (or wheels) and are capable of locomotion and manipulation, e.g. humanoids, quadrupeds, or any mobile manipulator. Nonetheless, often the manipulation and locomotion parts of the systems' behaviour are studied/designe separately. In contrast, whole-body
approaches result in more natural behaviour and, in most cases, more efficient performance on both parts.

A typical example is mobile manipulation. A robot needs to pick up objects from a conveyor belt and place them at another location across the room. One solution is to move to the target object, stop, grasp & pick-up, move to the goal location, stop, place & release. A better solution is to grasp & pick-up the object while the robot is moving and do the same at the target location.

In this project you will work on a simplified version of dynamic mobile manipulation. You will use tools from floating-base inverse kinematics and dynamics to plan and control a small mobile manipulator robot, performing such tasks. You will use learning approaches to compensate for the increased uncertainty that a moving base contributes and increase the robustness/efficiency of the overall system. The (locally) optimal solution will be evaluated against a naive baseline and the achieved success rate.

**Title**: Robot skill learning and failure detection  
**Supervisor(s)**: Ioannis Havoutis, Paul Newman(?)

**Background**: Robotics, machine learning

**Abstract**:  
General purpose robots constantly need to expand and refine their skill repertoire. Learning by demonstration (LbD) is an approach that aims to make teaching robots what to do easy and intuitive. This is often done using machine learning approaches that build generative models from demonstrated motions. Such motion primitives can then be used for recognition, prediction and online motion generation.

Learning by demonstration has been addressed with various approaches -- among others, Gaussian mixture models & regression (GMM/GMR), dynamical motion primitives (DMPs), probabilistic motion primitives (ProMPs) and task-parametrised hidden semi-Markov models (TPHSMM). Often such approaches do not make use of the rich sensory information that accompanies (successful) skill execution.

In this project you will work on closing the loop between control and (high-level) perception. You will build a system around a robotic arm that can learn skills with kinesthetic demonstrations, using an LbD approach of your choice. You will extend this with a state of the art machine learning approach that models 'how it feels' to perform each task successfully, by exploiting multimodal sensory information. Such predictive models will allow you to predict failures in an online manner and change the behaviour accordingly. Success will be evaluated in the form of a working system that can accurately detect stochastic failure over a small set of learnt skills.
Mini-project 1 and 2 – Registration Form

10th April – 12th June 2017
10th July – 11th September 2017

STUDENT NAME: ………………………………………………………………………………………………

MINI-PROJECT TITLE 1: ………………………………………………………………………………………………

SUPERVISOR: ………………………………………………………………………………………………
SIGNATURE OF SUPERVISOR: ……………………………………………………………………………

MINI-PROJECT TITLE 2: ………………………………………………………………………………………………

SUPERVISOR: ………………………………………………………………………………………………
SIGNATURE OF SUPERVISOR: ……………………………………………………………………………

This project *is/ *is not on the list of those already approved. (*Please delete if not applicable)
SIGNATURE OF STUDENT: ………………………………………………………………………………………………
DATE: ………………………………………………………………………………………………

Forms should be returned by 12 noon on Friday 24th March 2017 to Wendy Adams

Proposals for projects not on the list of those already approved should be accompanied by a description adequate for the committee to assess its suitability.

Confirmation of allocation will be made to the student and the supervisor.